Environment Canterbury

Kaikoura Floodplain

a strategy

for reducing the impacts of flooding and flood sediment deposition

11/07/2000

Prologue

ON THE GEOLOGY OF THE EASTERN PART OF MARLBOROUGH PROVINCIAL DISTRICT

Kaikoura Plain. - This is neither more nor less than the sloping shingle-fan of the Kowhai River, which, though not a large river, is liable to excessive floods, and, draining a mountain range whose crests reach fully 8,000 ft. not more than ten miles from the sea, it, necessarily, has an immense denuding and carrying power. The carrying power of the river is, however, employed to the full extent, as the character of the rocks forming the Looker-on Mountain is such as to supply an abundance of material, denudation proceeding at a rapid rate amongst the alternations of drossy crumbling shales and sandstones of which these mountains are built up. At the south-eastern base of Mount Fyffe the river enters on the plain, and it is certain that at no distant date it here entered the sea, Kaikoura Peninsula, at the time, forming an island a mile north-east of the promontory formed by the Lake Hills, or the low hills north-east of the lower gorge of the Kahutara River, the eastern base of Mount Fyffe being four miles off. Into the bay so bounded poured the torrent-borne debris yielded by the high ranges in the immediate background, the encroachment on, and reclamation of, the shallower parts of the bay proceeding at a rapid rate, till, eventually, the limestone island in the near distance was thus connected with the mainland. The river, from its position at the south-western corner of the bay, and also from the direction of the latter part of its rock-bound channel, has hitherto had a tendency to build up the south-western side of the fan, and, when the fan was carried so as to abut against the western end, it was thus compelled to enter the sea between the peninsula and the point of the hills to the south-west. It has now pushed reclamation to a line parallel with, or rather beyond, the southern side of the peninsula, and the greater length of course thus attained has lessened its grade and power to carry forward as formerly. Much material is therefore arrested before reaching the sea, and the river-bed is built up to the level of the north-east slope of the fan, apparently determined to alter its course and enter the sea at the north-west angle of Kaikoura Peninsula. Every effort is being made to prevent this taking place,

and, for an indefinite period, the struggles of the settlers may be successful; but in the very nature of things the river must, at the point now threatened, or higher up, break through the feeble obstacles that as yet prevent it reaching to the sea on the north-east side of the fan. The Hapuka River, six miles to the north of Kaikoura Peninsula, is a mountain torrent, which has also built up an enormous fan. This, sloping to the south, forms, where it unites with the lower north-east slope of the Kowhai fan, the lower lands between the two, east of Mount Fyffe to the sea, and opposite the deeper part of the bay north of Kaikoura. At the mouth of the Hapuka River the immense quantity of material brought down from the mountains is being carried forward into the sea with ease, piling itself to a considerable height above high-water mark, and continually encroaching thereon. Where the track crosses the river, close to the beach, the river-bed has a high grade, and is formed, not of shingle in the ordinary sense, but of angular fragments and blocks of rock, which have more the appearance of morainic matter than the ordinary contents of a river bed.

Alexander McKay,
25July, 1885.

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Introductory Comments

This report has been prepared with the help of a Community Advisory Committee and the public of Kaikoura.

At the outset, the immediacy and magnitude of the flood hazard was recognised. Also recognised were the constraints imposed in relation to the size of the rating base, and, consequently, the amount of monies that are available for mitigation measures.

It was decided, at an early stage, to examine options related to the issues on two fronts:

1. modifications and enhancements of the existing structural systems; and
2. non-structural mitigation measures.

In the event, much has been done, and is being done, with respect to (1) through the annual work programmes of the Kaikoura Rivers Rating District and the Kaikoura Drainage Rating District. Non structural matters are being addressed in the context of the Kaikoura District Council's planning processes.

This strategy is the communities response to the flooding and flood sediment deposition hazard for the short to medium term.

Purpose

The purpose of this document is to describe the Kaikoura Floodplain Management Strategy (KFMS).
The strategy has been developed by Environment Canterbury, a Community Advisory Committee, and the community who will contribute towards it.

1 Overview

1.1 Background

The fans built by the Kowhai River, the Mount Fyffe streams (Floodgate Creek, Middle Creek, Luke Creek, Waimangarara River, Harnetts Creek), and the Hapuku River, have been developed and are farmed. The commercial centre of the urban area of Kaikoura is situated on the coastal edge of the floodplain at the mouth of Lyell Creek. Frequently, it has been inundated by breakouts from this creek, many in conjunction with flood waters arriving overland from the Kowhai River.

The rivers and streams, if left to themselves, inevitably, would change course at random, and discharge damaging amounts of flood waters and sediment onto the floodplain in the process.

The flood hazard can be reduced by intervention. The Kaikoura Floodplain Management Strategy is a further medium of this intervention.

Environment Canterbury has prepared a strategy because the previous major scheme of works has proved itself impractical in many respects. The community has decided on the direction of its future activities.

Every scheme to date, the first initiated after the floods of 1868, while achieving some measure of success, has still left the area vulnerable to inundation and debris deposition.

Environment Canterbury, in partnership with the Rating Area Liason Committee, is continuing to battle these natural elements with expenditure in the order of $300,000 per annum. As history has shown, it is most difficult, if not economically impossible, to devise a protection scheme which will stand up to the extremes of weather periodically experienced on this floodplain.

This document details management options that the community considered, and sets down a single preferred option which is the Kaikoura Floodplain Management Strategy.

In its present state, the system is expected to fail from time to time. The investigations outlined in this report indicate just how vulnerable the Kaikoura floodplain is to flooding and sediment deposition, and that continuing investment in maintaining protection works is advisable and justified.

1.2 Issues and Options Report

Under the Resource Management Act 1991, Environment Canterbury, and the Kaikoura District Council, have roles to avoid or mitigate the actual, or potential, costs of loss or damage to life, property, or other parts of the environment from natural hazards. An Issues and Options report focused on mitigation of the flood hazard of the Kaikoura rivers and streams between the Kahutara River to the south and the Hapuku River to the north, with a view to minimising damages due to flooding and deposition of sediment.

Preparation of the Regional Policy Statement was the first step in this process for Environment Canterbury. It established regional objectives and policies for dealing with natural hazards within Canterbury. Another step, in relation to the Kaikoura rivers and streams, was the preparation of an Issues and Options document.

The document listed issues and options for Environment Canterbury, the Kaikoura District Council, and the affected community, to decide on a course of action for the short to medium term.

1.3 Submissions

Wide ranging submissions were received. These submissions were analysed by the Community Advisory Committee resulting in the adoption of this single preferred strategy.

2 Introduction

2.1 Physical Setting of the Catchment

INSERT Map 2.1 - Physical Setting

INSERT Photo 2.1 Kaikoura Peninsula and the floodplain fronting Mt Fyffe in the middle distance (1602 m). Beyond Mt Fyffe, the highest peaks visible along the skyline of the Seaward Kaikouras include Swyncombe (825m), Snowflake (1878m), Mt Saunders (2151 m), Manakau (2610m), and Uwerau (2212m). The sinuous bare gravel bed of the Kowhai River, flanked by protective tree cover, extends across the floodplain down towards South Beach in the left half of the photograph. Middle Ford lies at the point at which the river curves away to meet the sea on the extreme left. The Lake Hills (c.320 m) are also visible to left of the river. Photo (circa mid-1960's) V.C. Browne.

The Kowhai River is a very steep alluvial fan-building outlet river with a catchment area of some 80 square kilometres. Its headwaters drain south-facing slopes of the Seaward Kaikoura Range (Manakau 2610 m, Uwerau 2212 m, Mt Saunders 2151m) and northwest-facing slopes of the Mt Fyffe range (1602 m). A major tributary, Snowflake Stream, drains the headwaters which embrace Snowflake peak (1878 m). Downstream, the river flows entrenched through the deep gorge it has cut for itself to the east of Mt Swyncombe (825 m), to emerge onto a floodplain of gravel which it has spread seaward to cover the coast on both shoreward flanks of the Kaikoura Peninsula. The present course of the Kowhai River runs southeasterly across its floodplain, and through low hills between Middle Ford and Glen Kowhai farm, to meet the sea about midway between the Kaikoura Peninsula and Kahutara River to the south.

Ewelme Stream, known locally as "Stoney Creek", is a minor stream which drains low hills marking the south western flank of the Kowhai River floodplain. These hills are

informally identified in this document as the Lake Hills, as they are fringed by the remnants of small lakes and low-lying swampy areas which became blocked in the course of time by incoming floodplain gravel. Further south, the Kahutara is an important river which has a catchment almost as large as the Kowhai, extending up to 1700 metres in altitude back into the Seaward Kaikoura Range. It has a history of floods which have damaged coastal bridges.

Floodgate Creek, Luke Creek, and the Waimangarara River, are all vigorous fan-building streams which drain the seaward face of Mt Fyffe. The fans are steep and actively continue to grow in size as the streams flowing on top of them bring down a never-ending supply of rock debris eroded out of their unstable upper catchments. These fans have extended so far seawards that they now overtop and cover areas of the Kowhai fan surface to below Postmans Road (Map 2.2).

INSERT Map 2.2 - Geographic setting of the fans

Two other streams on the seaward face of Mt Fyffe, Middle Creek and Harnetts Creek, have smaller catchments at lower altitude. These streams are incised into their beds and flow along the interface between the fans built by their larger, and more vigorous, neighbours.

These features form the ***Kaikoura floodplain***. It has been drained and developed, resulting in fertile lands with adequate supplies of good water and broad sweeping views of the mountains and the sea.

The Kaikoura floodplain is enclosed on the north by the large fan of the Hapuku River. The present course of this river, now deeply entrenched through its own fan gravel deposits by continuing uplift of the Seaward Kaikoura Range, mirrors the setting of the Kahutara River, in that it too threatens coastal communications in times of flood.

The floodplain geomorphology and process of fan formation, together with a brief overview of the complex structural geology responsible for the floodplain's physical setting, are the subjects of a separate report published by Environment Canterbury.

2.2 Flood Protection Schemes

The community is acutely aware of the flooding and material deposition problems, because, in spite of a succession of works since 1870, the problems still exist.

The first recorded attempts at river control on the Kowhai River were undertaken in 1870, following the disastrous floods of 1868. The failures of these first attempts resulted in the formation of a "Board of Conservators for the River District of Kaikoura" in 1879, with jurisdiction limited to the left bank (looking downstream). The lower plains, at this time, were largely covered in coastal scrub, fern and forest, with extensive swamp areas at the lower levels.

During 1950, right bank properties were included in the river district. Over the next twenty years more comprehensive works were carried out, but the problems persisted.

During January 1966, the Marlborough Catchment Board was extended to cover the Kaikoura region. It prepared a “Major River Control, Drainage and Erosion Control Scheme for Kaikoura” (MCB 1969).

Scheme works began in the early 1970’s in the Kowhai River. They were aimed at containing the river on its fan crest by a series of rock armoured banks. These were to encourage the development of a single-thread channel capable of carrying flood-borne sediments to the sea (MCB 1976).

The scheme was reviewed in 1981, by which time some aspects of the scheme had proved impractical, and again in 1987, when additional scheme components were ammended (MCB 1981, 1987). In particular, the fundamental ‘single-thread’ philosophy was abandoned.

At this time, as a result of its experience in the area, the Board’s policy was to carry out a comprehensive flood hazard mapping exercise for the Kowhai and Mount Fyffe Streams, and to provide for the preparation, promotion, and implementation of a Flood Plain Management Programme for the Kaikoura Scheme Rating District.

The Major Scheme report commented -

> “Since the formation of the Kaikoura River Board and the Kaikoura County Council in 1877, a great deal of money and effort has been expended towards gaining an acceptable standard of protection against the raging rivers, and although temporary relief was obtained from time to time, no permanent solution to the problems resulted.”

The above statement remains true today.

The report also commented –

> “The River History of the Kaikoura Plains has been a turbulent one, and has been liberally sprinkled with arguments, ministerial enquiries and court costs.”

3 Planning Framework

3.1 International Context

Inundation of floodplains, with attendant loss of life and property, is a continuing and regular happening.

Floodplain management planning, of which this strategy is an example, is relatively new and involves not just looking inwards at the rivers, but also outwards onto the floodplain, incorporating, as mitigation measures, not just the traditional structural ones (such as stopbanks), but also non structural measures (for example, adjusting development recognising flood risk).

3.2 National Context

Numerous intensively developed areas of New Zealand are located on floodplains. From the earliest times of European settlement floods have frequently caused major social disruption and losses.

Flood protection schemes largely consist of structural measures , that is, physical works such as channel improvements, dams and stopbanks, designed to pass all floods up to a certain size. A common design standard was the so-called 100-year flood, selected because it was thought to have a sufficiently low likelihood of occurrence, during the life of a scheme, as to be a reasonable and acceptable choice.

Despite considerable expenditure, there is firm evidence to suggest that gross flood damage costs are rising, and this, during a period when a wide range of measures have been taken to avoid them (Eriksen 1986).

It is now recognised that growth in flood losses can be controlled only by ensuring new developments accommodate the vulnerability of land to flooding, and are designed and constructed to minimise flood damage both on, and off, site (New South Wales Government 1986). This calls for an integrated approach to land planning and floodplain management, involving non-structural measures, such as land-use zoning,

building and development controls, and flood proofing of buildings. Other measures, such as flood warning and evacuation plans, community education programmes and actuarially-based insurance can also significantly reduce flood losses (Eriksen 1986).

3.3 Regional Context

The regional context is set out in Environment Canterbury's Regional Policy Statement (26 June 1998). It includes Issues, Objectives, Policies, Methods, Environmental Results and Monitoring.

3.4 District Context

The Kaikoura District Council also has responsibilities with respect to the control, use, development or protection of land, including the implementation of rules for the avoidance or mitigation of natural hazards.

3.5 Partnership With Tangata Whenua

The Canterbury Regional Council has a partnership with Tangata Whenua in the Canterbury Region. Tangata Whenua are a treaty partner with the Crown under the Treaty of Waitangi, a partnership that is particularly relevant to natural and physical resource management because of Article 2 of the Treaty.

The partnership has been developed jointly by the CRC and Nga Rununga of the Canterbury region. This included the establishment of an Iwi Liason Unit to ensure adequate Tangata Whenua input into Council documents.

A protocol for consultation between Tangata Whenua and the Regional Council was established in 1992.

Management Plans developed by the Tangata Whenua will also guide Regional and District Councils in their service delivery.

3.6 Community

3.6.1 Scope

The Kaikoura Floodplain Management Strategy Issues and Options document set out all matters for consideration by the affected community who decided on an appropriate response to the flood and material deposition hazard for the short to medium term.

The adoption of this strategy charts a clear course of action for the immediate future.

3.6.2 Role of the Community

The commitment, knowledge, and involvement, of the community in the planning process are critical factors for achieving sustainable land management.

3.6.3 Community Advisory Committee

The committee was responsible for making recommendations to the Councils on acceptable management measures. Its involvement ensured the final methods are locally acceptable, and affordable.

3.6.4 Funding

The method of funding the implementation of the strategy is set out in the Canterbury Regional Council document "The Funding Policy", which is the support document to its "Looking Ahead - 1998-2008" document. It is by way of a mix of Private, District and Regional shares.
The Council, in its decision making, is guided by the Kaikoura Rivers Rating District Liaison Committee, which meets at least annually, to discuss funding and works programming.

4 Issues

The issues concern the potential damage to life, property, and the environment, from floods, and the deposition of flood-borne sediment over the Kaikoura floodplain, including parts of the urban settlement of Kaikoura.

5 The Flooding Problem

5.1 Introduction

The early European settlers very soon found out, that, if they were to enjoy the benefits of settling on the floodplain, they would have to solve the problems of flooding and debris inundation.

There is extensive documentation of the ravages of floodwaters during the mid to late 1800's, and throughout the twentieth century.

5.2 History of Flooding

Floods have been a part of life on the Kaikoura floodplain since records began.

Wright (1994) provides us with an historical summary of efforts at flood control, as follows:

> "The first river board was formed in 1877 to protect farm land on the left (northern) bank and the town. It was not until 1950 that right (southern) bank properties were included in the river district. Most of the river work done until 1956 was piece-meal channel clearing, rock raking, and crate and bank construction, which gave some protection against small floods, but failed to contain larger ones. In 1956 a more comprehensive approach of stopbanking the whole length of the river was tried with little success."

> "Kaikoura joined the Marlborough Catchment District in 1966. The first priority for the Catchment Board was to design and implement a major river control drainage and erosion control scheme for catchments of the Kowhai River and streams issuing from the south (seaward-facing) side of Mt Fyffe (Mt Fyffe streams). Scheme works begun in the early 1970's in the Kowhai River, were aimed at containing the river on its fan-crest by series of rock armoured banks. These were to encourage the development of a single thread channel capable of carrying flood-borne sediments to the sea. Following major flood damage to the rock-armoured banks in March 1987, the policy of single thread channel development was abandoned in favour of constructing a series of strategically-placed echelon banks on the river berms. The purpose of these banks was to intercept flood spills and return them to the main channel."

> "Mount Fyffe streams characteristically transport and deposit sediments on their fans during floods, while at other times surface flow rarely extends beyond the gorges. Like the Kowhai River, they respond rapidly to heavy rainfall. It was at first proposed to trap sediments high on the fans of the Mt Fyffe streams to prevent sediment from encroaching onto farmland below. A floodway was to have been constructed to divert flood water to the Kowhai River, but that concept was abandoned in favour of controlling each stream individually. By the end of 1991 the main body of Scheme works, including a major drainage network and erosion control works in the catchments, was completed."

No information on flooding in the Kaikoura area has been found prior to the great flood of 1868. An eye-witness account of that flood follows, written by Mrs.V.Boyd of Ramiford, Kaikoura - as told to her by her mother:

> "In 1866, a flaxmill started on the creek above what is now the Suburban School. I had been teaching the three oldest children the three 'R's' as best I could. There were some children belonging to the employees at the mill, and an old man started a little school. I sent Maria and Ted, but John had a bad foot and never got to school at all. In 1868, the flood of that time caused such havoc, that the mill had to be shifted. The Flax was all gone, and a riverbed was in its place.

There was no school available for some years, until Mrs O'Donnel, a widow, started one on Mt Fyffe Road, close to Blackguard's Corner.

In the early days, education for the children was a great problem. When the school was built in Kaikoura, some children had to walk five miles. That sounds hard, but the conditions of the tracks they had to travel made it a nightmare. Fern, flax, toi-toi, scrub and nigger-heads over their heads, and bog and springs underfoot, and with streams to negotiate, put a very high premium on education, but they just carried on until times improved.

The flood of 1868 I will never forget. The day the rain started, a man who used to come all the way to see us when his boat called here, came up. The children seemed a great pleasure to him, and he, and indeed many men, used to bring them all sorts of gifts, useful and otherwise. At different times, they brought ribbons, lace, dress material, boots, whistles, dolls, tops, and, in fact, anything they could manage to buy.

This day he had a wooden bowl and an egg beater for me. I was really delighted, for beating eggs with a spoon or fork is a slow process. It was raining when he came, and continued to rain very heavily. It seemed to come straight down. As there was no question of his boat leaving in the storm, we persuaded him to stop for the night. All next day it still rained heavily and there was water everywhere. Still it rained until I almost lost count of the days. The first few days were not really cold but then it blew up from the south, and icy rain, hail and snow took over. All the mountain and country-side were soon white. It was bitterly cold.

The men kept a roaring fire, and did their best to amuse the children - five of them. At the end of the sixth day, a north-west rain pelted down, and no pen can describe the events which followed. Almost in a flash, the snow and hailstones were gone, and water was everywhere. The noise of the rain and sea could not compete with the crashes and roars on the mountains. Whole cliffs collapsed and shingle slipped over the lower land by thousands of tons. Before this, there was no shingle on the flat land.

The Kowhai waters tore over from south of Postman's Road, down to Blackguards' Corner, where it was turned by extremely heavy swamp, then followed down what was later Mt. Fyffe Road, and took a wide spread towards Lyell Creek. The heavy swamp halted the shingle after it crossed Mill Road. Mr. David Boyd, who was later my son-in-law, had a nice spring of water. It vanished under the shingle, and he had to sink through ten feet of shingle before he got the water. There had been no shingle at all before the flood.

The Kowhai waters then turned to the other side of the country, and took a sweep towards the "Elms" and left that also a riverbed. Finally, the water took a straight course for the sea, and cut a deep gulch through what is now the Kowhai riverbed. There was a lovely native bush there, but it had no power to stop the water.

When the rain was over, the families about the Kowhai flat were delighted to have such a beautiful water supply so close. Before that, wells had to be dug, generally with indifferent success. Some families were dependent on rainwater, caught off the roof in barrels or zinc-lined tea-chests. Several women went to see the stream, and when Mrs. Burrel, wife of John Burrel, tried to jump over it, the bank gave way under her, and she fell into a swift deep stream. She was quickly rolled by the water, and the other women raced downstream until they found a place that was broken in, and pulled her out. Her clothes were in rags, and she was scratched and bruised by the sticks and stones.

The stream, later called Luke's Creek, carried down a lot of water but very little shingle. A hollow out behind our house carried a huge stream of water which spread out lower down.

The Waimangarara stream was the one that interested the two men. They were in and out all day long, coming in drenched to the skin, until the house was like a Turkish bath with the steam off clothes drying by the fire.

Before the flood, the Waimangarara gorge was, for generations, built up with leaves, twigs and shingle, until the outlet was high up between the cliffs. When the flood started the shingle, it fanned out from Mt. Fyffe Road till nearly across to Kincaid. The Hapuku was doing its share there, and the waters met. As the flood waters increased, it tore everything out of the Gorge, down to the rocks. Then the shingle really "went to town". A bank, over thirty feet high on the Mt. Fyffe side of the river, remains as proof to future generations of what the flood of 1868 did. All the stony ground round Kaikoura owes its description to it."

6 Flood Hazard Assessment

6.1 Introduction

Flood hazard is the potential for flooding to adversely affect human habitation of the floodplain. It is the potential for a community to suffer casualties, social disruption, and property loss through flooding.

This chapter describes the background studies:

- geomorphology (the physical description of the floodplain);
- population, land-use and future development;
- perception of risk and public participation;
- hydrology (the sizes of the river floods and their annual exceedance probabilities, otherwise known as return periods);
- flood forecasting;
- structural integrity of the existing system;
- sedimentation (the rise and fall of the river bed due to shingle movement);
- hydraulics (the computed river flood levels);
- physical modelling; and
- climate change.

6.2 Geomorphology

Kaikoura is centred on the only extensive low-lying land found on 70 to 80 kilometres of rugged mountainous coast. This oasis, covering 90,000 hectares of farmable land, is

built of alluvial fan sediments. The largest area of 2000 hectares of better and flatter land extends inland for 5 to 6 kilometres from the coast north of Kaikoura.

Geomorphic mapping has been a key element in the study, bringing together evidence of past flooding and fan-building. Initially, maps were constructed of the floodpath taken by the Kowhai River into Kaikoura on December 23rd, 1993, and of the residual sediment track of the same flood, still visible in January, 1994.

This mapping was followed by a detailed study of the Kowhai River and Floodgate Creek, undertaken to record changes through time to the stream beds, in terms of area of bare (mobile) river gravel, extent of riverbank vegetation, and of the development of flood protection works and flood control plantings. Protection works reached their maximum development about 1975, after which successive flood damage to inner banks and groynes led to abandonment of efforts to confine the river to a single-thread channel.

Mapping and fieldwork was then extended to cover the remainder of the Kaikoura floodplain, and includes the lower reaches of the Hapuku and Kahutara rivers. A map (Map 6.1) was prepared, titled 'Floodplain Geomorphology'. It is not included within the covers of this report because of its size, but may be examined at Environment Canterbury's offices in Christchurch and Kaikoura, and at the Kaikoura District Council office.

Over the years, a great deal has been written in scientific publications about the complex geology and geomorphology of the Kaikoura area. As part of the investigations a report was written on the floodplain and Mt Fyffe fans (McPherson 1998), aimed at helping the general public appreciate something of the complexities of the area. This is published separately, to provide a descriptive background for the large floodplain geomorphology map (referred to above).

6.3 Population and Land-Use

The Kaikoura District has been inhabited for over 1000 years. Tangata Whenua, in the Kaikoura District are the Kati Kuri Hapu of the Ngai Tahu iwi. European settlement of the District dates back to around 1840. The District has many sites, areas, and species, of heritage and cultural value.

According to the latest census information (1996), the total population of the Kaikoura District is 4035 (provisional). The majority of the District's population lives in the Kaikoura township.

The Kaikoura township, which includes the residential area of South Bay, is the District's primary residential, commercial and industrial area, and the focal point of the tourism industry. Outside the township, the District is largely rural in focus, but is scattered with smaller settlements and mixed rural residential activities. Most of the District's smaller coastal settlements function in a combination of roles, which include rural service centres for farming communities, fishing settlements, holiday and retirement settlements.

Industries within the Kaikoura District include fishing and fish proccessing, dairy farming, rural service industries, transport companies, roading contractors, timber processors and suppliers, engineering workshops, and other light industrial activities. The service and tourism industry is also a growth industry, and makes a significant contribution to the District's economy. Growth of tourism is expected to continue and, if the Tranz Rail Ferry facilities are transferred from Picton to Clifford Bay, then there could be a significant impact on the district in this regard.

6.4 Perception of Risk and Public Participation

Floodplain residents are acutely aware of their vulnerabilty with respect to flooding, erosion and deposition. The problems have been re-emphasised particularly by the events of 23 December, 1993, and 6 June, 1994. The residents are more familiar with structural than non-structural mitigation measures.

6.5 Hydrology

The relationship between the size or magnitude of flood peaks in the Kowhai River, and in streams draining the Mt Fyffe Range, and their frequency of occurrence, has been examined and summarised by Pearson and Thompson (1994), and Williman (1994). The basis for these analyses has been recorded storm rainfalls within these river catchments, recorded annual maximum river floods from similar New Zealand catchments, actual observations of these rivers in flood, and rainfall-runoff relationships developed for these catchments.

The rugged and steep nature of these river catchments, and their mobile gravel-bed river channels, has made conventional water level and flow recording virtually impossible.

Despite the complete lack of reliable river flow data for the Kaikoura river catchments, flood frequency relationships estimated by two independent methods were within 20% of each other. One method used a rainfall-runoff mathematical model and extreme storm rainfall estimates over the Kaikoura river catchments. The other utilised information from similar New Zealand catchments which had good records of river flows, based upon drainage area, topography, rainfall regime, and soil type.

6.6 Flood Forecasting

It has not been possible to develop flood forecasting for the Kaikoura floodplain to the same standards as other Canterbury catchments. This is largely because, as noted above, it is impractical to measure flood flows because of the size of the bed load that is carried. Rainfall is measured at telemetered automatic recording sites on the upper slopes of Luke Creek and Snowflake. The use of this information and Meteorological Office predictions enable some warning of flood events.

6.7 Structural Integrity of the Existing System

The objectives of the most recent Scheme of Works, the Marlborough Catchment Board's "Major River Control, Drainage and Erosion Control Scheme for Kaikoura" February 1969 were –

- the prevention of flooding;
- the prevention of gravel deposition over farmed areas;
- the control of erosion within the catchments and on the steep river fans and farmed land;
- the stabilisation of all river and stream channels within the Scheme area; and
- the provision of adequate drainage.

The thrust of these objectives is consistent with a philosophy of the imposition of absolute control on the natural systems. It could not, and did not, succeed.

The reasons were:

- the training works did not allow a wide enough river channel;
- the aggradation and degradation effects were underestimated;
- absolute control of such a system is not possible in any situation, and, particularly, with the relatively low level of expenditure available;
- the rock size combined with its method of deployment were inadequate;
- gravel retention structures in Floodgate Creek, Luke Creek and the Waimangarara River proved, at best, to be temporary;
- no consideration was given to non-structural measures in the context of a deeper understanding of the floodplain. Assets have been established in vulnerable areas of the floodplain.

An appraisal of the efficiency of flood protection works put into place as a consequence of the foregoing scheme was carried out by the Marlborough Catchment Board during 1987, and detailed in the report headed:

"Major River Control, Drainage and Erosion Control Scheme for Kaikoura -a review of Performance and Physical and Financial Progress" (Marlborough Catchment Board, August 1987).

Its principal recommendations related to the abandonment of the single thread river control programme on the Kowhai River, the abandonment of gravel retention structures in Floodgate Creek, Luke Creek and the Waimangarara, and the introduction of a comprehensive flood hazard mapping exercise for the Kowhai and Mt Fyffe Streams, and provision for the preparation, promotion, and implementation, of a floodplain management programme for the Kaikoura Scheme Rating District.

In essence, the strategy is the outcome of the work implemented to meet the above recommendations.

The relevance of the 1987 report to this investigation can be gauged from the following quotations from it:

> "The over-riding lesson in this exercise has been the necessity to recognise the extremes which are likely to be experienced on such rivers in terms of gravel levels, channel aggradation and degradation."

It is apparent that sedimentation issues will be fundamental to the investigation.

> "All scheme works need to take into account, in their respective designs, the two extreme conditions of aggradation and degradation. A continued vigilance is required, and a flexibility in approach, to match and manage, rather than try and control changes in these dynamic fluvial systems. It is misleading, and dangerous, to believe that absolute control will be achieved by scheme works, and for that reason a more comprehensive scheme strategy is demanded than that presented either in 1969 or 1981. This review has highlighted, in line with current National Practice, the requirement for flood hazard assessment to complement, and expand on, the original structural solution provided for in the scheme."

The width of the control channel will need to be re-visited.

> "A further departure from the original scheme appears to have been undertaken in the positioning of the rock armoured training banks. In the 1969 report, the active river bed is shown as some 8 chain (160m) in width; by 1981 this had been reduced to little more than 70m. In contrast the earliest aerial photographs of the river bed in 1942, and 1961, show the same bed to be in the order of 200 to 300m wide."

and-

> "There is an urgent need to allow the active river boundaries to be relaxed back to dimensions comparable with those observed from the 1942, and 1961, aerial photographs."

Undercutting plagued the training banks and rock size needs to be reviewed-

> "The ease and frequency with which rock training banks were being damaged, in moderate flood events, on the Kowhai River required re-appraisal."

and-

> "It is clear, however, from the March 1987 flood event, as it should have been in the earlier events, that the degree of bed scour experienced on this river, in even minor events, is sufficiently pronounced that it will exceed the limited protection provided, and,

> furthermore, that the hydraulic and fluvial conditions being experienced on this river are extremely aggressive, so much so that the plucking of rock rip-rap was a common occurrence. The warnings issued in the 1969 specification appear to have been either ignored, or simply lost sight of, in the determination to control the river, in plan form, to a single thread dominant channel. (Ref Pg 46: 1969 Report). The expectation, too, that rock of sufficient size could be quarried locally does not appear to have been realised in practice - this is particularly true of the rock lines between Swyncombe and the Bluff where boulders actively transported within the bed commonly match, or exceed, the bulk of the rip- rap provided for the training banks. No satisfactory explanation has been provided to explain this apparent and costly oversight."

The current investigations have not discovered any sources of large rock in the Kaikoura area. Economic expediency has dictated use of river rock strategically placed. This further underlines the need to widen the control channel of the Kowhai River.

There is much more in the report, all of it leading to a perception of the need for a "Balanced Integrated River and Flood Control and Flood Plain Management Strategy" for the Kowhai River and Mt Fyffe streams.

All aspects of the flood problem, technical or otherwise, needed to be addressed.

The new approach involves:

- reviewing the nature and causes of the Kaikoura flood and flood-borne sediment hazard, and the fundamental aims in dealing with floodwaters and sediment transport;
- appraising the actual, as opposed to the design, standards and performance of the Kaikoura protection works, together with their failure mechanisms;
- preparing flood hazard maps for the Kaikoura floodplain;
- evaluating the full range of possible adjustment options to the hazard, and making decisions relating to their use and optimum combination;
- developing policies and strategies leading to a Kaikoura Floodplain Management Strategy, aimed at providing continued reasonable protection from flooding, erosion, and deposition, by Stoney Creek, the Kowhai River, Floodgate Creek, Middle Creek, Luke Creek, the Waimangarara River, Harnetts Creek and possibly the Hapuku River.

The thrust of the above objectives is aimed at blending with, and managing, the overall system, based off a clear and thorough understanding of the physical and social nature of the flood and deposition problem, and the environment in which flooding and deposition occurs.

6.8 Sedimentation

The rise and fall of the shingle bed of an alluvial fan river, such as the Kowhai, is termed aggradation and degradation.

Where modified for flood control, the beds of these rivers have a strong tendency to aggrade, because the natural fan-building process is now confined to the narrow strip of fan which carries the river enclosed by protection works. If the river does aggrade, then the design standard of the scheme is being eroded as shingle replaces the area available for the waterway (between the stopbanks).

Degradation can occur if the river is attempting to sluice more material through the system than is being supplied, or if the rate of gravel extraction undertaken for purposes of river control, or commerce, also exceeds supply. A common misconception is that degradation is a good thing, since, by entrenching itself, the river does away with the need for stopbanks. Without structural mitigation measures the system reverts to the natural fan building process, as illustrated in the prologue. Also, if the river is degrading, the structural stability of banks and groynes becomes endangered by the risk of undermining.

In either situation, aggradation or degradation, the river will eventually break out, and recommence spreading flood sediment at random across the fan surface. In the absence of flood controls, such changes in stream course take place as a natural process referred to as 'avulsion'.

River protection systems are thus delicate balances with the powerful forces of nature at play.

The situation on the Kowhai River is relatively satisfactory at this time. In the vicinity of the Railway Bridge there is some aggradation but above there, all the way up to Sweeneys Bank, the position is relatively stable. Above that, to the Bluff, there is degradation.

The slope of the Kowhai River is steep, and, during floods, the bed load ranges up to boulders two metres and more in diameter. The boulder size reduces in the lower reaches, and, given the distance of travel, it is most probable that the larger stone becomes buried by finer-size sediment in the river bed. This has been investigated and the rock currently being utilised for Rating Area works has been mined from the river channel.

6.9 Hydraulics

Conventional hydraulic routing (the theoretical calculation of flood heights using observed flood levels of previous measured flows), as used on the large alpine rivers of the Canterbury Plains, is of limited relevance in the Kaikoura situation. For a start, there are no measured flows, or flood heights, to provide calibration (checking theoretical flow levels against actual recorded levels).

The lower stretch of the Kowhai River is not subject to debris flows[1] (as described below in Section 6.10 this has been confirmed by physical modelling at Lincoln University), but the steepness of the grade, coupled with the size and percentage composition of the bed load, and the absence of calibration data, means that the hydraulic routing would be principally academic. The approach taken instead was a practical one based on the project team's experience, the geomorphic history, and the experience of the project team's predecessors. A control width was set, and existing structures within the protection system were analysed in relation to that control width and the hydrology. Decisions were then taken with respect to those structures. New structures are being designed on a site-specific basis, an example being the new echelon bank recently built at Middle Ford.

This is consistent with the Project Team's decision, in consultation with the Community Advisory Committee, and the Rating Area Liaison Committee, to make progress with mitigation measures, bearing in mind the funds available.

Hind-casting of the December 1993 flood event, together with analyses of historical flood reports, has enabled a data base to be assembled, which allows for the detailed design of future structural mitigation measures.

6.10 Physical Modelling

A physical model of the Kowhai River was constructed in the Water Laboratory of the Department of Natural Resources Engineering at Lincoln University, and a study carried out of the hydraulics of the system.

The study concluded that river management strategies for the Kowhai River can be designed using conventional methods found to be reliable for rivers of gentler slope. As noted previously, the difficulty is the inability to calibrate the computer models.

6.11 Climate Change

Climate has always been variable and, while it is certain it will continue to be so, there is uncertainty regarding the size and timing of change.

[1] *Debris flows are where the composition of the flow has a very large percentage of solid mass and are somewhere between normal flood flows and rock avalanches.*

7 Floodplain Management Measures

7.1 Introduction

Historically, there has been substantial investment in physical works (stopbanks, groynes, plantings, etc.). Given the limited capacity of the Rating Base to provide funds for further protection measures, it is essential that any additional new measures taken will optimise the worth of existing facilities. Given the limits to present-day funding, this was accepted as commonsense by the Community Advisory Committee at its first meeting.

7.2 Selection of Measures

To start the process the project team, and the Community Advisory Committee, listed all the possible measures to reduce the flood hazard. Some measures were then eliminated for various reasons some of which are set out below.

7.2.1 Measures Eliminated

Weather modification and post-event response measures, such as loans and relief funds, were eliminated.

- Weather modification has no potential in the Kaikoura setting of severe weather patterns and very high rainfall.
- Loans and relief funds are already 'modus operandi'. Tax-deductions, loans and relief funds are all post-event measures put in place by Central Government for a range of disaster types, and they are dependent mainly on disaster severity, state of the public purse, and fiscal policy. Some funds are almost invariably contributed by public subscriptions as well. Measures seem to be already in place in this

area. For the purposes of this investigation they are not considered further.

7.3 Description of Specific Measures

7.3.1 Description of Specific Measures

Table 7.1 lists the 69 specific measures that remained and sets out the purpose of each measure, together with relevant comments with respect to the measure's purpose. Maps 7.1 a,b,c and 7.2 illustrate the locations of measures.

Table 7.1
Purpose of Specific Floodplain Management Measures

Specific Measure	Purpose/Comment
Kowhai River (Measures 1 to 26)	
1. Maintain those parts of the existing system which do not conflict with measures adopted herein.	• The benefits of the significant investment in works to date could be quickly lost without a maintenance operation. Damage is sustained continuously, and, if repairs are not effected continuously also, the damage escalates at an increasing rate, eventually resulting in the complete loss of the capital asset.
2. Adopt new control lines.	• To ensure adequate floodway capacity from the top of the system to the sea. The analyses have indicated that works on the Kowhai River system have encroached too far into the active channel. A study of the river system from 1940 until the present time, including when works have come on line, what has worked, and what has not worked, the identification of natural strong points, road reserves, river reserves, freehold land, and the undertaking of a physical modelling

	exercise, resulted in recommended control lines generally 200 metres apart from the bottom of the system up to Swyncombe. Upstream of Swyncombe, the river narrows into a gorge. The object is to allow adequate floodway for the floodwaters and bed load. Too narrow, or too wide, a floodway increases the chances of lateral attack and subsequent failure.
3. Construct new works at or outside the new control lines.	• Any new training banks, protective plantings, rock spurs, and, further back, echelon (deflector) banks, which would add to the protection system on the Kowhai River are, in future, to be constructed either on the control lines, or back from them, this to give effect to measure (2).
4. Abandon existing works which are within the new control lines.	• Having adopted new control lines with the objective of leaving the floodway between them clear, it follows that existing works within the control lines should be left to their inevitable fate, with expenditure being redirected outside the lines.
5. Remove existing works within the new control lines which are deemed to have an adverse effect on the system as a whole.	• Where the works are actively obstructing the floodway, or acting as diversions of floodwaters, resulting in undesirable alignment, and resultant lateral attack, the works should be removed, with the salvagable material being used for the works on, or beyond, the control lines.
6. Adopt protection tree planting as a primary method of protection, plus rock training on control lines at strategic points as needed. Where planting can only be of a lower standard, rock work, or other methods, may have to be increased to	• Where there are good buffers of protection planting, the protection mechanism has been observed to consist of the larger boulders dropping out near the river face of the plantings, followed by increasingly smaller diameter material being deposited as the flood wave passes through the plantings. This is a consequence of the

compensate.	floodwater velocities decreasing as the distance into the plantings increases. The plantings act as a front line of defence for strategically-placed echelon banks situated away from the active channel and its control lines. The objective is to effect a filter so that echelon banks behind the plantings have only to divert floodwaters and silt. The construction of the banks (compacted gravels) requires this.
7. Maintain existing plantings outside the new control lines.	• The District has a very valuable asset in the substantial existing protection plantings outside the new control lines which have been, and are now, extremely beneficial. It is essential that, as an integral part of this plan, they be maintained.
8. Identify where additional plantings should go.	• By looking at the system as a whole, and the protection strategy that has evolved through measures (1) to (7), areas have been identified where additional plantings should go, to improve the overall protection standard.
9. Implement the additional plantings.	• To effect measure (8).
10. Implement in-channel works between the new control lines. Many specific examples follow.	• To create a clear, and well-aligned, floodway from the top of the system to the sea. Flood flows tend to follow, particularly as the flood flow is increasing, the alignment of the low flow channel that existed prior to the event. It is advantageous to carry out works aimed at providing a smooth sinusoidal flow path for the low-flow active channel. In practice, this low-flow channel may silt up with finer material, with the river meandering away from it during times of low flow. If this effort is consistent, these silts could flush out quickly during flood

	events, thus providing the preferred flow path for the flood wave.
11. Remove obstructions within the channel. i.e. trees and remnants of old banks.	• To effect measure (10). Anything which obstructs the floodway, or worse, causes diversions of floodwaters into undesirable alignments, increases the potential for system failure.
12. Strategically align the channel where bad alignment exists.	• To effect measure (10). By having a smooth curved channel prior to flood events, the potential for failure is reduced.
13. Identify and remove rock blockages.	• To effect measure (10). Erosion resistant cobbled plugs of large rock have been identified at various points in the Kowhai River system. These can divert floodwaters away from desirable alignments, and towards banks, thus increasing the potential for failure. This is an example of work that can be carried out as a pro-active protection mechanism.
14. Remove the constricting remnants of Sweeneys Bank, including part of the echelon link bank into the Old Board Bank (north side).	• Sweeneys Bank intrudes into the control channel, and also deflects the principal flow channel onto an undesirable alignment.
15. Upgrade existing River Board bank downstream of the Floodgate Creek diversion bank (north side).	• This will provide protection along the control channel boundary. Implementation of measures (11) and (14) can be combined with this measure.
16. Re-align the Middle Ford bank upstream of the ford (north side). Clear and grass-cover the return channel which enters at this point.	• The present line of this bank upstream of the ford, intrudes into the control channel. Re-alignment, using existing fill and armouring, will bring the end of this bank into line with the bank extension above (15).

17. Re-align and shorten the downstream end of the stopbank below Middle Ford (north side). This is a contingency 'wait and see' measure. The second part of the purpose/comment has been effected. Any additional shortening and re-alignment relates to the first bullet point.	The purpose here is twofold: • The first - to ensure the 200 metre control channel width is maintained down- stream to Glen Kowhai (south side). • The second - to allow return flows from the new echelon bank, plantings and return channnels in this vicinity - measures (23), (24) and (25).
18. Pull back Harnetts echelon to the control lines. This is another 'wait and see' measure. Because it is not overly intrusive it may, or may not, be effected dependent on the success or otherwise of other measures such as (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13), and in particular (14).	• This is necessary to effect the required fairway width, because Harnetts Bank is too intrusive at this point. Rock retrieved can be used to expedite measure (19).
19. Extend a new stopbank downstream from Harnetts Echelon to link with Kennedys Bank (south side).	• This provides protection along the control line, and clearly defines on the ground the extent to which vegetation is to be lost into the fairway.
20. Extend Kennedys Echelon further west, towards the Inland Road.	• This provides protection for Middle Ford Road, and also for farmland between here and the sea. The concept of planting and echelon banks should be effected equally on the north and the south sides for equity reasons.
21. Trim back the downstream end of Kennedys Bank to rid the bank of deflective curvature and extend the bank on a line down to Middle Ford Road (south side). *This has been done.*	• This bank mis-directed flow across to the site of the December 1993 break-out. Re-alignment will smooth the flows through this reach.

22. Construct a complementary echelon at Glen Kowhai (south side). If strategically placed, this could be a relatively short length of bank. Also raise the upstream end of the existing echelon and adjust the downstream end to improve the entry conditions into the Kowhai River.	• This will realign the re-entry of upstream break-outs back into the Kowhai River. However, because of the grade and resultant velocities, the new bank will need to be rock armoured
23. Construct a new echelon east of the December 1993 break-out point (north side). *This has been done.*	• To redirect breakouts at this point back into the Kowhai River. This general area was identified through the investigations as a weak area in the system as a whole. The echelon bank will be parallel to the echelon bank immediately upstream of Middle Ford, and will re-direct any future outbreaks at this point back into the main channel between the Peninsula foothills and the new truncated end of the main Middle Ford bank. The echelon will provide strategic back-up for the control bank.
24. Plant-out the area between the above echelon and the river, as follows - 5 blocks (4 rows), 50 metre gap, 3 blocks (4 rows), 20 metre gap, 2 blocks (4 rows), 1 block (4 rows) along the echelon. Leave 20 metres clear adjacent to Middle Ford Road (north side). *This has been done.*	• This will protect the new echelon by slowing breakout flows and filtering out the bed load. The channels will encourage return flow to the Kowhai River. Planting here will mean that the protection planting belt on the north-east side of the Kowhai River will extend into the Peninsula foothills.
25. Construct channels in the above plantings, aligned back to the Kowhai River; place 1 channel @ 50 metres and 1 channel @ 20 metres (north side).	• To allow substantial flows to develop back to the Kowhai River. With the channels strategically aligned through the plantings, return flows will be encouraged.

26. Extend the existing stopbank further upstream of the railway bridge (south side).	• To prevent river gravel deposition onto adjoining farmland during flood events, and to encourage flushing of the active channel so that the flow capacity will be restored.
Floodgate Creek (Measures 27 to 35)	
27. Retain existing layout, acknowledging that, in spite of the present monitoring and maintenance regime, the creek could break out of the existing constructed channel.	• This enables the community to retain the 'status quo', although the layout may be fundamentally flawed in that the existing channel design came too far down the fan (because of land acquisition difficulties) before it turned into the new chute. The cross-fan gradient is too low to generate the velocities required to transport sediment through to the Kowhai River system as was originally intended.
28. Maintain the existing channel by excavating any gravel deposits which reduce capacity.	• To ensure the channnel has adequate flood capacity at all times. By ensuring the channel is kept in a hydraulically efficient state, the risk of uncontrolled failure is reduced. The existing system is not working at all well and deposition occurs rapidly and regularly, reducing flood capacity markedly.
Measures **29.** to **33.** are pro-active measures which regognise the moderate to high risk of floodwaters breaking out.	
29. Purchase the block of planted land immediately seaward of the turn into the chute and form a gravel trap. This is in advance of potential failures at this point and does not involve turning the creek into the trap.	• To enable this block of land to act as a gravel trap. The block is in a strategic location to act as a gravel trap and would mean that the flows between there and the entry to the Kowhai River can more easily be managed. Utilising the existing plantings in this manner would serve a two-fold purpose: one,to slow flood flows; two, to filter-out bed-load.

30. Strengthen the partial bank/planting line which already extends from the existing channel bank on Floodgate down to Postmans Road, using the material obtained from measure (28) above.	• To pre-empt uncontrolled failure which may affect the commercial centre of Kaikoura. This bank/planting line, constructed by Mr. T. J. Boyd, is well sited to contain flows and gravel inundation south-west of the better lands to the east, and direct them to the Kowhai River. The intention here is to continue to use the works that have been constructed, while preparing for the inevitable. This influences, to some degree, where failure will occur, and continues to allow channelling of flood flows into the Kowhai via the old diversion channel, rather than letting it spill into Mill Creek, Lyell Creek, and thence into the commercial centre of Kaikoura.
31. Construct a drain to run down along the east side of the above 'partial bank/planting line'.	• Because of a build-up of riverbed material if measure (29) is implemented and utilised, groundwater levels are likely to rise in the area and impact adversely on land use of the better lands to the east. A drain would help to control this, and would go some way to compensating for any adverse effects as a result of the proposed works.
32. Construct an echelon bank to extend out from the left bank of the existing chute, upstream of Chapmans Road bridge, to direct floodwater break-outs against the west side of the bank which is to be strengthened as measure (30).	• To ensure floodwaters are discharged in a controlled manner down a defined channel rather than dispersing at random across the fan**.** This would form a throttle directing flood/debris flows through the gravel trap and down into the old Floodgate Creek channel.
33. Use excavated material to effect an even grade out of the existing Floodgate Creek channel (before it enters the diversion chute) and into,	• To lessen the possibility of headward erosion when, or if, a break-out does occur. At present, there is a considerable drop from the diversion chute to the seaward fan.

and along, the old channel-course which parallels the bank to be strengthened as measure (30). This would be merely 'formwork' for the following measure which requires well graded rock overlying filter fabric.	
34. Construct a control weir in the existing left bank of the present channel, to ensure that any break-out is to the 'old channel' - design to minimise draw-down or back-scour of the fan material.	• The purpose of this is to control the point at which the creek will be re-diverted down the fan, with a design aimed at minimising the risk of 'headward erosion' back up the creek bed.
35. Physically re-direct flows into the old Floodgate Diversion Channel.	• To allow flows to follow the natural alignment of the fan rather than trying to cross the fall of the fan. This means accepting that the system will surely fail, and carrying out work immediately to re-direct Floodgate Creek back to its former channel, and thence to the Kowhai River. This has high up-front costs which may not be necessary all at once.
Luke Creek (Measures 36 to 39)	
36. Extend Pooles Road Echelon to the outer limit of the flood control planting. Rock-armour the downstream end. At present the echelon extends to a natural terrace. Detailed survey is needed to determine the desirability of this measure.	• To ensure flood control overflows are directed down into the sediment trap. This echelon protects the lower flood-prone south-western area of the fan. The bank should be extended to the outer limit of flood control planting to ensure Luke Creek does not outflank the echelon and flow overland down to Middle Creek.
37. Extend Stokes Echelon for a distance of about 100	• This echelon was constructed to cover periodic breakouts which enter shallow

metres towards Mt. Fyffe Road.	channels in the vicinity of the farm downstream. These channels direct floodwater south-east away from the river across Mt. Fyffe and Postmans Road. Its efficiency would be enhanced by its extension.
38. Extend flood plantings along the west bank upstream of Postmans Road. At present, the plantings extend to a private property boundary, so additional plantings would be subject to negotiation and possible land purchase.	• Historically, flows have bypassed the trap to the south and entered the Middle Creek system. This measure, along with measure (39) below, is aimed at intercepting such flows, and re-directing them to the sediment trap.
39. Construct an echelon to extend out from the upper western end of the sediment trap for a distance equivalent to the length of Stokes Echelon. Land acquisition is an issue here again.	• As above, this being the bank component of the combined bank/planting echelon approach being recommended all across the floodplain.
Waimangarara River (Measures 40 to 46)	
40. Extend and raise Adams Echelon. At the design stage the impact of overtopping of this bank will have to be examined as there is a large fall on the downstream side.	• The western end of this echelon is in danger of being overtopped or outflanked. The works will protect developed farmland down-fan from the bank.
41. Extend the existing sediment trap to the east. A high priority is suggested for this extension.	• There is strong evidence of outbreaks to the east which cross SH 1. This could be part of a suite of measures (more follow) to further confine the Waimangarara River to the top of its fan.
42. Extend the sediment trap to the west.	• The existing gravel trap is quite narrow considering the extent of the fan

	above, the width of the protection planting, and the echelon coverage upstream.
43. Re-align Hislops Echelon. A philosophy of concentrating works upstream of Postmans Road might suggest another supporting echelon, further up the fan from Hislops Echelon.	• If the trap is widened to the west, then the lead-in echelon would need to be re-aligned to take advantage of the full width of the trap.
44. Extend the sediment trap to the south.	• Inevitably the fan will continue migrating coastwards. If the opportunity arises, the identified block of land could be purchased with a view to extending the trap seawards in advance of, or along with, the fan's natural migration.
45. Construct an overlapping pair of echelon banks on the east side of the fan to lead outbreaks back into the sediment trap.	• These banks would provide back-up to Mackles and Harnetts echelons, and lead break-outs down into the extended gravel trap. The latter two banks provide strategic protection for SH 1, and for the lands east across to Harnetts Creek. • Future echelons to protect this area are possible, but would be relatively expensive. • SH 1 itself is on a good alignment and, with increased height, could provide a convenient echelon cut-off.
46. Land acquisition associated with measures (41), (42) and (44).	• To enable the implementation of measures (41), (42) and (44). By identifying the desired land, purchase could be effected if the land came up for sale, or, alternatively, negotiations could be entered into sooner.

Measures 47 to 50 relate to Lyell Creek	
47. Re-construct the Lyell Creek right stopbank (looking downstream) and maximise the capacity of Lyell Creek from SH 1 bridge to the sea. This could involve raising the bank to give a total capacity of 190 m^3/s over the length of Lyell Creek from the SH1 bridge to the sea if measure (49) is adopted.	• The Lyell Creek stopbank consists of loess, for which Fulton Hogan Canterbury provided the following technical data (Report by P. Yellowlees). The loess has a naturally high water content, typically 25%. This is because the individual particles are all of the same size which makes for the maximum amount of voids around them. During flood times, with high water pressure on one side and none on the other, the bank will become porous. The high void content makes the mass per volume low (1400 kg/m^3). By comparison the water it is attempting to hold back is 1000 kg/m^3). A more suitable material would be M4 AP 40 aggregate (a Transit specification material). It has a compacted mass of 2350 kg/m^3 and an average water content of 3.5%. Of note here is that the compaction achieved during the implementation of measure (23) is 2350 kg/m^3, with 4 passes of a vibrating roller and a moisture content of 2.5%. • The other flaw of the Lyell Creek stopbank is its inadequate profile because of space limitations. If a bank is to be relied on in this area, it will need to be totally re-constructed with appropriate material and be of adequate dimensions. The foregoing could be developed in conjunction with the landowners of the commercial buildings on the north east side of West End to achieve the flood protection objectives and to enhance the access and appearance of the area. • The second part of this measure relates to enabling a larger volume of floodwater to pass to the east of the commmercial centre of the town safely to sea. During the December 1993 flood event, a flow of 140 $m^3.s^{-1}$ was passed by the Lyell Creek channel. The greater the volume that can pass through

	this channel, without bank failure, the lower the risk to the town.
48. Construct a weir in the right bank immediately below SH 1 at the location of the December 1993 breach. *This measure has been completed.*	• To dictate where the system can discharge excess flows at a controlled rate once the capacity of Lyell Creek has been reached. If Lyell Creek is flowing full without bank failure, then substantial flood events are being catered for. By allowing controlled flows through West End for even more extreme events, the pressure can be relieved from the Lyell Creek system, while advantage is being taken of the existing floor level heights of the commercial centre. The capacity of Lyell Creek when the weir is just about to overtop is 125 m^3/s. With this discharge, the water depth in the carpark at the downstream end of the shopping area would be 400mm under existing conditions.
49. Extend the right bank all the way to the sea.	• At present, the Lyell Creek bank ends short of the open area north of the Information Centre. Once flood flows are above the natural channel, they flow around the end of the bank, and enter the commercial centre by way of an alley beside the Butcher's premises. By extending the bank, this avenue would be blocked.
50. Maintain a supply of sand bags at Kaikoura and develop a contingency plan to implement sandbagging, as well as implementing other mitigation measures such as pumping, and removing part of the Lyell Creek bank as required (if measure 49 is adopted) immediately upstream of the Information Centre.	• For general emergency activities.

Measures 51 to 69 apply to the floodplain as a whole	
51. Encourage appropriate gravel extraction in aggrading floodplain channels.	• To maintain the flood-carrying capacity of the river by managing the bed load. Aggradation, or bed level build-up, increases the potential for failure. Degradation, or lowering of the bed level, can also be a problem where protection structures are undermined. However, on balance, degradation tends to be a plus in the Kaikoura situation.
52. Adjust developments to recognise flood risk.	• This measure is aimed at ensuring development in hazardous areas is compatible with flood damage potential. It is important to note that no attempt is being made to restrict development simply because the land is flood-liable. If development is to proceed in such areas, for whatever reasons, then the concern is simply to ensure measures are implemented which minimise flood damage. Ways of achieving this include: • Raising of floor levels (54); • Elevation of building sites (57); • Secondary flow paths (58); • Extension of existing building codes (59); • Banks and walls (60); • Development of techniques and methods of waterproofing (61); •Technical advice programme (62); • Development of existing floodwarning and forecasting systems (63); • Identification of areas for evacuation and safe areas for evacuees (64); • Identification of buildings with contents having high damage potential (65); • Development of techniques and methods for floodfighting (66); • Differential premiums based on flood risk (67); • Assessment of numbers and locations of flood affected persons (68); and • Assessment of nature and scope of

	disruption to services (69).
53. Re-zoning.	• Match land use to flood liability. Applicable to vacant land zoned urban in high hazard areas, as well as to redevelopment in the high hazard areas. One example, in the Kaikoura situation, would be to re-zone the West End area, and progressively relocate the higher value commercial activities to a lower hazard area.
54. Raising of floor levels.	• Construct floor levels above flood levels.
55. Control, relocation, or exclusion, of dangerous uses.	• Remove especially, or potentially, dangerous materials from potentially flodable areas. Applicable particularly to toxic chemicals, timberyards, etc.
56. Building line restrictions.	• Set buildings back from stopbank systems, so that, if bank failure does occur, structures will not be in the path of deep, fast flowing floodwaters. This measure is applicable to new development. The lines run parallel to stopbanks.
57. Elevation of building sites.	• Raise the building areas of complete subdivisions above flood levels. This measure is applicable to new development.
58. Secondary flowpaths.	• To allow breakout floodwaters to flow through development with a minimum of damage. Development can be designed leaving clear channels for the dispersal of floodwaters.
59. Extension of existing building codes.	• Adopt materials and design of foundations and structures to withstand flooding conditions. Applicable to new development.

60. Banks and walls.	• Prevent flooding of individual assets. Recommendations can be made to owners of assets. This measure complements building codes.
61. Development of techniques and methods of water proofing.	• Reduce damage to buildings and contents by sealing openings. This can be by way of recommendations to owners of assets, and, as above, complements building codes.
62. Technical advice programme.	• Advise floodplain residents about suitable responses to flooding.
63. Development of existing flood warning and forecasting systems. Also ensure liaison systems are in place with the other relevant authorities.	• Improve accuracy of predictions of flood size and arrival time. In the Kaikoura situation, this must be done off real time rainfall because of the impracticality of measuring flood flows. Because of the obvious need, a telemetered rainfall station has been installed at Snowflake, and this, as well as the rainfall station on Luke Creek, is monitored continuously.
64. Identification of areas for evacuation and identification of safe areas for evacuees.	• Prevent casualties by moving people away from floodwaters. This measure would be effected by way of recommendations to Civil Defence and Emergency Services.
65. Identification of buildings with contents having high damage potential. Promote 'mezzanine' or upper floor goods contingency plan for West End shops.	• Locate contents permanently above potential flood levels. This is applicable particularly to art gallery, museum, high value use, and emergency services.
66. Development of techniques, methods, and resources, for floodfighting.	• Contain or divert floodwaters locally, and reduce casualties and damage to possessions.

67. Differential premiums based on flood risk.	• Discourage inappropriate development in high flood risk areas. Internationally, this is occurring already, and the Insurance industry has investigated, and is investigating, Kaikoura.
68. Assessment of numbers and locations of flood-affected persons.	• Provide information for planning post-disaster management. This measure would be implemented through recommendations to Civil Defence and related agencies.
69. Assessment of nature and scope of disruption to services.	• Provide information for planning post-disaster recovery.

The next step in the process towards formulating options was to evaluate the measures using the following criteria.

Table 7.2
Evaluative Criteria for Floodplain Management Measures

Category	Main Factors Considered
Physical	• damage reduction performance • maintenance level • implementation problems • timing of effect • limitations and conditions • future flexibility
Economic	• cost level • benefit to cost ratio • user pays
Social	• disruption • recreation opportunities • cultural and political matters • land acquisition • health and safety • diversion of hazard • public information
Environmental	• ecology (plant and animal communities and habitat) • visual or aesthetic amenity • water quality

In the following table (7.3), the potential Benefit to Cost Ratio (BCR) of each of the 69 proposed management measures is listed under column 3 (Economic). This ratio is a comparison of benefits with costs. A value judgement scale was used ranging through extremely high, very high, high, neutral, moderate and low.

Table 7.3
Evaluation of Floodplain Management Measures

Measure	Physical	Economic	Social	Environmental	Assessment of Acceptability
Kowhai River measures 1 to 26					
1. Maintain those parts of the existing system which do not conflict with measures adopted herein.	• high performance • high maintenance level • immediate effect	• low cost • extremely high benefit/cost ratio (BCR)	• can complement recreation	• neutral	• very high
2. Adopt new control lines for the Kowhai River.	• High performance • low maintenance • effect as measures come on line	• low cost • high BCR	• neutral	• neutral	• very high
3. Construct new works at, or outside, the new control lines.	• medium performance • high maintenance • immediate effect	• moderate cost • moderate BCR	• equity needs to be maintained	• visually intrusive • requires landscaping	• high to moderate
4. Abandon existing works which are within the new control lines.	• medium performance • no maintenance • immediate effect	• no cost • high BCR	• neutral	• poor aesthetics	• high
5. Remove existing works within the new control lines which are deemed to have an adverse effect on the	• high performance • no maintenance • immediate effect	• moderate cost • high BCR	• neutral	• improves aesthetics	• very high

system as a whole.					
6. Adopt protection tree planting as a primary method of protection, plus rock training on control lines at strategic points as required. Where planting can only be of a lower standard, rock work or other methods may have to be increased to compensate.	• high performance • moderate maintenance level • effect increases with development of the plantings	• relatively low cost • very high BCR	• increases recreation opportunity	• high visual amenity • provides habitat	• very high
7. Maintain existing plantings outside the new control lines.	• high performance • high maintenance level • on-going effect	• low cost • extremely high BCR	• maintains leisure opportunity	• high visual amenity • provides habitat	• very high
8. Identify where additional plantings should go.	• high performance • no maintenance • optimises effect	• low cost • extremely high BCR	• enhances leisure opportunity	• improves environment	• very high
9. Implement the additional plantings.	• high performance • high maintenance level • effect increases with development of plantings	• low cost • extremely high BCR	• enhances leisure opportunity	• improves environment	• very high
10. Implement in-channel works between the new control	• high performance • high maintenance	• moderate cost • high BCR	• neutral	• minor visual intrusion on natural river environment	• high to moderate

lines. Many specific examples follow.	level • on-going effect				
11. Remove obstructions within the channel. i.e. trees and remnants of old banks.	• high performance • no maintenance • immediate effect	• moderate cost • high BCR	• neutral	• improves aesthetics	• high
12. Strategically align the channel where bad alignment exists.	• very high performance • high maintenance • immediate effect	• moderate cost • high BCR	• neutral	• minor visual intrusion on the natural river environment	• high to moderate
13. Identify and remove rock blockages.	• high performance • high maintenance level • immediate effect	• moderate cost • high BCR	• neutral	• minor visual intrusion on natural river environment	• high
14. Remove the constricting remnants of Sweeneys Bank, including part of the echelon link bank into the Old Board Bank (north side).	• moderate performance • moderate maintenance level • cumulative effect with other measures	• moderate cost • moderate BCR	• neutral	• neutral	• moderate
15. Upgrade the existing River Board bank downstream of the Floodgate Creek diversion bank. (north side).	• moderate performance • moderate maintenance level • cumulative effect with other measures	• moderate cost • moderate BCR	• neutral	• neutral	• moderate
16. Re-align the Middle Ford	• moderate performance	• moderate cost	• neutral	• neutral	• moderate

bank upstream of the ford (north side). Clear and grass-cover the return channel which enters at this point.	• moderate maintenance level • cumulative effect with other measures	• moderate BCR			
17. Re-align and shorten the downstream end of the stopbank below Middle Ford (north side). This is a contingency 'wait and see' measure. Allownace of return flows in this vicinity have been effected. Any additional shortening relates to ensuring the 200 metre control channel is maintained down-stream to Glen Kowhai (south side).	• moderate performance • moderate maintenance level • cumulative effect with other measures	• moderate cost • moderate BCR	• neutral	• neutral	• high
18. Extend Harnetts Bank to join Harnetts Echelon behind the armoured head (south side). Leave a gap, for return flows into the river, and remove the hook from the head of the echelon.	• moderate performance • moderate maintenance level • cumulative effect with other measures	• moderate cost • moderate BCR	• neutral	• neutral	• moderate
19. Extend a new stopbank downstream from Harnetts	• moderate performance • moderate maintenance	• moderate cost • moderate BCR	• neutral	• neutral	• moderate

Echelon to link with Kennedys Bank (south side).	level • cumulative effect with other measures				
20. Extend Kennedys Echelon further west, towards the Inland Road	• good performance • moderate maintenance level • cumulative effect with other measures	• moderate cost • moderate BCR	• neutral	• minor visual intrusion	• moderate
21. Trim back the downstream end of Kennedys Bank to rid the bank of deflective curvature, and extend the bank on a line down to Middle Ford Road (south side). *This has been done.*	• moderate performance • moderate maintenance level • cumulative effect with other measures	• moderate cost • moderate BCR	• neutral	• neutral	• moderate
22. Construct a complementary echelon at Glen Kowhai (south side). If strategically placed, this could be a relatively short length of bank. Also raise the upstream end of the existing bank and adjust the downstream end to improve the entry conditions into the Kowhai River.	• moderate performance • moderate maintenance level • cumulative effect with other measures	• moderate cost • moderate BCR	• neutral	• neutral	• high to moderate
23. Construct a new echelon	• high to moderate	• high to moderate	• neutral	• moves the outer edge	• very high

east of the December 1993 break-out point (north side). *This has been done.*	performance • moderate maintenance level • immediate effect	cost • high BCR		of the existing protection further east	
24. Plant-out area between the above echelon and the river, as follows - 5 blocks (4 rows), 50 metre gap, 3 blocks (4 rows), 20 metre gap, 2 blocks (4 rows), 1 block (4 rows) along the echelon. Leave 20 metres clear adjacent to Middle Ford Road (north side). *This has been done.*	• high performance • low maintenance • effect increases as plantings develop	• low cost • very high BCR	• Neutral	• high visual amenity • provides habitat	• very high
25. Construct channels in the above plantings, aligned back to the Kowhai River, placing 1 channel @ 50 metres and 1 channel @ 20 metres (north side).	• high performance • low maintenance • effect increases as plantings develop	• low cost • very high BCR	• Neutral	• Neutral	• very high
26. Extend the existing stopbank further upstream of the railway bridge (south side).	• moderate performance • low maintenance • immediate effect	• Moderate cost • low BCR	• Neutral	• Minor visual intrusion	• High to moderate
Floodgate Creek (Measures 27 to 35)					
27. Retain existing layout	• moderate-low	• moderate cost	• Neutral	• Neutral	• low

acknowledging that, in spite of the present monitoring and maintenance regime, the creek could break out of the existing constructed channel.	performance • high maintenance • existing effect	• moderate BCR			
28. Maintain the existing channel by excavating any gravel deposits which reduce capacity.	• moderate performance • high maintenance level • immediate effect	• high cost • moderate BCR	• neutral	• disposal of material is a problem	• moderate to low
29. Purchase the block of planted land immediately seaward of the turn into the chute and form a gravel trap. This is in advance of potential failures at this point and does not involve turning the creek into the trao.	• neutral	• moderate cost	• neutral	• neutral	• high
30. Strengthen the partial bank/planting line which already extends from the existing channel bank on Floodgate down to Postmans Road, using the material obtained from measure (28) above.	• high performance • low maintenance • effect when required	• moderate cost • moderate BCR	• neutral	• neutral	• high

31. Construct a drain to run down along the east side of the above 'partial bank/planting line'.	• high performance • moderate maintenance • immediate effect	• low cost • neutral BCR	• neutral	• neutral	• high
32. Construct an echelon bank to extend out from the left bank of the existing chute, upstream of Chapmans Road bridge, to direct floodwater break-outs against the west side of the bank which is to be strengthened as measure (30).	• moderate performance • moderate maintenance level • effect if and when required	• moderate cost • moderate BCR	• neutral	• bank visually intrusive	• high
33. Use excavated material to effect an even grade out of the existing Floodgate Creek channel (before it enters the diversion chute) and into and along the old channel-course which parallels the bank to be strengthened as measure (30). This would be merely 'formwork' for the following measure which requires well graded rock overlying filter fabric.	• high performance • high maintenance level • effect if and when required	• low cost • high BCR	• neutral	• neutral	• high

34. Construct a control weir in the existing left bank of the present channel, to ensure any break-out is to the 'old channel' - design to minimise draw-down or back-scour of the fan material.	• high to moderate performance • high maintenace level • effect if and when required	• moderate cost • moderate BCR	• neutral	• neutral	• high to moderate
35. Physically redirect flows into the old Floodgate Diversion Channel.	• high performance • moderate maintenance level • immediate effect	• low cost • high BCR	• neutral	• neutral	• high to moderate
Luke Creek (Measures 36 to 39)					
36. Extend Pooles Road Echelon to the outer limit of the flood control planting. Rock-armour the downstream end. At present the echelon extends to a natural terrace. Detailed survey is needed to determine the desirability of this measure	• high performance • low maintenance level • immediate effect	• moderate cost • moderate BCR	• neutral	• neutral	• high to moderate
37. Extend Stokes Echelon for a distance of about 100 metres towards Mt. Fyffe Road.	• high performance • low maintenance level • immediate	• moderate cost • moderate BCR	• neutral	• neutral	• high to moderate

	effect				
38. Extend flood plantings along the west bank upstream of Postmans Road. At present the plantings extend to a private property boundary, so additional plantings would be subject to negotiation and possible land purchase.	• high performance • high to moderate maintenance level • effect increases as plantings mature	• low cost • high BCR	• neutral	• high visual amenity • increased habitat	• high
39. Construct an echelon to extend out from the upper western end of the sediment trap for a distance equivalent to the length of Stokes Echelon. Land acquisition is an issue here again.	• moderate performance • low maintenance level • effect if and when required	• moderate cost • moderate BCR	• neutral	• neutral	• moderate
Waimangarara River (Measures 40 to 46).					
40. Extend and raise Adams Echelon. At the design stage the impact of overtopping of this bank will have to be examined as there is a large fall on the downstream side.	• high performance • moderate maintenance levels • effect immediate	• moderate cost • high BCR	• neutral	• neutral	• high

41. Extend the existing sediment trap to the east. A high priority is suggested for this extension.	• high performance • high maintenance level • effect immediate	• high cost • high to moderate BCR	• neutral	• larger area of gravel trap	• high
42. Extend the sediment trap to the west.	• high to moderate performance • high maintenance level • effect immediate	• high cost • high to moderate BCR	• neutral	• larger area of gravel trap	• high
43. Re-align Hislops Echelon. A philosophy of concentrating works upstream of Postmans Road might suggest another supporting echelon, upfan of Hislops Echelon.	• high performance (essential if measure 41 is adopted) • high maintenance level • effect immediate	• moderate cost • high to moderate BCR	• neutral	• neutral	• high
44. Extend the sediment trap to the south.	• moderate performance • high maintenance level • effect in medium term	• high cost • moderate BCR	• neutral	• neutral	• high
45. Construct an overlapping pair of echelon banks on the east side of the fan to lead outbreaks back into the sediment trap.	• moderate performance • low maintenance level • effect when required	• high cost • moderate BCR	• neutral	• additional banks on the flood fan	• high to moderate
46. Land	• neutral	• high cost	• neutral	• neutral	• high

acquisition associated with measures (41), (42) and (44).					
Measures 47 to 50 relate to Lyell Creek					
47. Re-construct the Lyell Creek right stopbank (looking downstream) and maximise the capacity of Lyell Creek from SH 1 bridge to the sea. This could involve raising the bank to give a total capacity of 190 m^3/s over the length of Lyell Creek from the SH1 bridge to the sea, if measure 49 is adopted.	• high performance • similar maintenance as existing • effect as required	• relatively low cost • high BCR	• opportunity exists for a pleasant area on the banks of Lyell Creek	• significant gains	• very high
48. Construct a weir in the right bank immediately below SH 1 at the location of the December 1993 breach. *This measure has been completed.*	• high performance • low maintenance • effect as required	• low cost • high BCR	• neutral	• neutral	• high
49. Extend the right bank all the way to the sea.	• high performance • low maintenance • effect as required	• low cost • high BCR	• neutral	• neutral	• very high
50. Maintain a supply of sand bags at	• high performance • low	• low cost • high BCR	• neutral	• neutral	• very high

Kaikoura and develop a contingency plan to implement sandbagging, as well as implementing other mitigation measures such as pumping, and removing part of the Lyell Creek bank as required (if measure 49 is adopted) immediately upstream of the Information Centre.	maintenance • effect as required				
The following measures (51 to 69) are common to the Kaikoura Floodplain as a whole.					
51. Encourage appropriate gravel extraction in aggrading floodplain channels.	• high performance • requires careful management • essential for river stability (channel location and channel stability)	• very low cost • very high BCR	• disruptive on site (noise, dust, traffic) • reduces extent of land based extraction along with its negative impact on groundwater quality and its poor aesthetics	• visually intrusive (stock piles)	• high
52. Adjust development to recognise flood risk.	• high performance • low maintenance level • difficult to implement	• high cost • moderate BCR	• normal town planning social impact • politically very sensitive	• neutral	• high
53. Re-zoning.	• low performance • low maintenance level	• moderate cost • low BCR	• high town planning social impact • politically	• preserves habitat, existing wetlands and aesthetic	• low

			very sensitive	amenity	
54. Raising of floor levels.	• high performance • low maintenance level • protection limited to specific flood range	• moderate cost • high BCR	• architectural and aesthetic constraints of high occupied floor level	• adverse visual amenity	• high to moderate
55. Control, relocation or exclusion of dangerous uses.	• high performance • no maintenance	• high cost • moderate BCR	• important for public health and safety	• reduces risk to plant and animal communities particularly from water-borne chemicals.	• high
56. Building line restrictions.	• high to moderate performance • no maintenance • continual development pressure	• low cost • low BCR	• reduce casualties • high town planning social impact • politically sensitive	• neutral	• high to moderate
57. Elevation of building sites.	• high performance • low maintenance level • protection limited to specified flood range	• moderate cost • moderate BCR	• could increase hazard in adjacent properties	• may affect visual amenity positively or negatively	• high to moderate
58. Secondary flowpaths.	• high performance • continual development pressure	• very high cost • low BCR	• neutral	• can be landscaped, shaped, and utilised to greatly enhance the environment	• moderate
59. Extension of existing	• low performance	• moderate cost	• neutral	• • neutral	• low

building codes.	• no maintenance • development pressure against restrictions	• moderate BCR • user pays			
60. Banks and walls.	• moderate performance • moderate maintenance level • immediate effect • protection limited to a specific flood range • limited to individual building sites	• moderate cost • moderate BCR • user pays	• increases hazard at adjacent sites • site may be isolated	• visually intrusive • requires landscaping	• low
61. Development of techniques and methods of water proofing.	• moderate to low performance • high maintenance level • limited to building type and materials	• high cost • moderate to low BCR • user pays	• neutral	• neutral	• low
62. Technical advice programme.	• moderate to low performance • high maintenance level	• low cost • high potential BCR	• increases awareness and readiness • reduces social impact of flooding • essential for emergency action	• neutral	• very high
63. Development of existing floodwarning and forecasting systems. Also ensure liaison	• very high performance • high maintenance level • applies over	• high to moderate cost • very high BCR	• informs community • reduces social disruption • provides	• neutral	• very high

systems are in place with the other relevant authorities.	the full flood range		time for effective social response		
64. Identification of areas for evacuation and identification of safe areas for evacuees.	• high to moderate performance • moderate maintenance • difficult to implement • often no alternative	• moderate to low cost • moderate BCR	• very high social disruption	• neutral	• high
65. Identification of buildings with contents having high damage potential. Promote 'mezzanine' or upper floor goods contingency plan for the West End shops.	• very high performance • limited maintenance	• moderate cost • very high BCR	• reduces loss of artefacts and memorabilia • maintains operation of emergency services	• neutral	• high
66. Development of techniques and methods for floodfighting.	• moderate performance • limited maintenance • difficult to implement	• low cost • moderate BCR	• provides limited security • increases awareness and readiness	• neutral	• high
67. Differential premiums based on flood risk.	• low performance • low maintenance • difficult to implement in isolation of global shift in insurance companies' approach	• low cost • low BCR • user pays	• may reduce cover to those with limited means	• neutral	• low
68. Assessment	• moderate	• low cost	• high social	• neutral	• high

of numbers and locations of flood-affected persons.	performance • low maintenance • continually changing	• moderate BCR	impact		
69. Assessment of nature and scope of disruption to services.	• high performance • low maintenance • changes slowly	• low cost • high BCR	• neutral	• neutral	• high

8 Floodplain Management Options

8.1 Introduction

The work described in the report to date, illustrates that further damage reduction activities are desirable, and that there are practicable means of achieving a reduction.

This section groups measures together to give eight possible options, ranging from the 'do nothing more but maintain the existing system' option, through to a comprehensive package of measures aimed at reducing the risk. Between the two, are six options spanning the difference. A ninth option could be to completely abandon the existing system, and build a structural system aimed at coping with all possible events.

The purpose of the Options was to aid the community in deciding on its preferred response.

8.2 Formulation of Options

Table 8.1 sets out the options.

They range from the absolute minimum which could be regarded as acceptable, up to the maximum that can be justified on economic, social, and environmental grounds. It is not the maximum, however, that could be considered as mentioned in Section 8.1 above.

It should be noted that these are not the only combinations possible.

They were the suggestions of the project team, the community advisory committee, and interested members of the Kaikoura district, based on the investigations. They were a starting point for the community in its deliberations.

Members of the community were invited to express their own opinions and suggestions, especially if they perceive other measures which should be considered, and which may have been overlooked by the team.

8.3 Description of Options

8.3.1 Option 1 (Table 8.1)

Option 1 involves maintenance of the existing system. This is regarded by the project team as the minimum response. The existing structural system has been valued in excess of $15 million. If the system is not maintained, it will very quickly be lost. Initial damage, if not repaired, would accelerate, until the capital asset ceased to exist. In this regard an Asset Management Plan has been prepared for the Kaikoura Rivers Rating District, and the Kaikoura Drainage Rating District.

8.3.2 Option 2 (Table 8.1)

Option 2 is option 1, plus a suite of *structural measures*, reflecting a new tactical approach, particularly with respect to the Kowhai River.

For the **Kowhai River**, new control lines have been defined, beyond which existing works will be abandoned, and, where appropriate, removed. New works will be constructed behind the control lines, and protection planting will be effected where gaps in the system were identified.

The **Floodgate Creek** layout will be retained and maintained by excavation.

On **Luke Creek,** some existing echelons will be extended, a new echelon constructed, and the flood plantings extended.

Adams Echelon on the **Waimangarara fan** will be extended and raised.

Works will be carried out on **Lyell Creek,** and gravel extraction will be further developed within the floodplain.

8.3.3 Option 3 (Table 8.1)

For the **Kowhai River**, Option 3 is as for Option 2.

Pro-active works are proposed for **Floodgate Creek** should the existing system fail. These involve:
• land purchase and the formation of a gravel trap;
• strengthening the existing downstream partial bank/planting line;

• constructing a drain on the east side of this line to mitigate possible adverse drainage effects as a result of the gravel trap; and
• constructing a new echelon bank from the left bank of the existing chute, upstream of the bridge at Chapmans Road, to direct floodwaters against the strengthened bank referred to above.

Luke Creek and **Waimangarara River** works are as for Option 1 and again gravel extraction will be further developed throughout the floodplain.

8.3.4 Option 4 (Table 8.1)

Kowhai River works are as for previous options.

Luke Creek and **Waimangarara River** works and gravel extraction are as for previous options.

Similarly for **Floodgate Creek**, with the addition of the construction of a control weir in the existing left bank to ensure any break-out is directed into the 'old channel'.

8.3.5 Option 5 (Table 8.1)

Option 5 is as for Option 4, except that on the **Waimangarara fan** land would be acquired, and the existing sediment trap would be extended eastwards. Overlapping echelon banks leading down to the trap are part of this proposal.

8.3.6 Option 6 (Table 8.1)

Kowhai River works are as above.

Floodgate Creek would be physically diverted into the old Floodgate Diversion Channel.

Luke Creek would be as above, and land would be acquired to the west of the existing sediment trap. The trap would be extended westwards, and Hislops Echelon would be re-aligned to utilise the full width of the trap.

It can be seen how, thus far, each Option develops as an extension, or variation, of the previous one. So far, the Options have consisted of *structural measures* only. Options 7 and 8, which follow, will introduce in addition to the structural measures, *non structural mitigation measures*.

8.3.7 Option 7 (Table 8.1)

Kowhai River measures are as before.

The **Floodgate Creek** proposals here include:
• maintenance of the existing channel by excavation;

• purchasing the block of planted land immediately seaward of the turn into the chute and constructing a gravel trap;
• strengthening the partial bank/planting line from Postmans Road upstream to the existing channel bank;
• constructing a drain on the eastern side of the above bank;
• constructing an echelon bank from the left bank of the existing chute, upstream of the bridge at Chapmans Road, to direct floodwaters against the strengthened bank; and
• constructing a control weir in the existing left bank to ensure any break-out is directed into the 'old channel'.

The **Luke Creek** measures are as before, plus:
• land acquisition and sediment trap construction to the east, west and south;
• Hislops echelon would be realigned on the west side of the enlarged trap;
• an overlapping pair of echelons would be constructed on the eastern fan, to lead outbreaks back into the sediment trap;
• gravel extraction as before.

The *non-structural measures* propounded as part of this option include:
• adjust developments to recognise flood risk (ensuring development reflects the flood risk of the area);
• raising of floor levels (construct floor levels above flood levels);
• control relocation or exclusion of dangerous uses (remove especially or potentially dangerous materials from the reach of flooding);
• building line restrictions (set buildings back from stopbank systems);
• elevation of building sites (raise sites above flood levels);
• secondary flowpaths (allow breakout floodwaters to flow through development with a minimum of damage);
• technical advice programme (advise floodplain residents about suitable responses to flooding);
• development of existing floodwarning and flood forecasting systems (improve accuracy of predictions of flood size and arrival time);
• identification of buildings with contents having high damage potential (locate contents permanently above potential flood levels);
• identification of areas for evacuation and identification of safe area for evacuees (prevent casualties by moving people out of the way of floodwaters);
• development of techniques and methods of flood fighting (contain or divert floodwaters locally and reduce casualties and damage to possessions);
• differential premiums based on risk (discourage inappropriate development in high flood risk areas);
• assessment of numbers and locations of flood affected persons (provide information for planning post-disaster management); and,
• assessment of nature and scope of disruption to services.

8.3.8 Option 8 (Table 8.1)

This is the 'all-in' option.

Kowhai River, as above.

Floodgate Creek, as above, with the complete diversion into the old channel.

Luke Creek works as above.

Waimangarara River works, with the sediment trap extension to the east, west and south and with the accompanying echelon works.

All the above *non-structural measures* within Option 7, with the addition of:
• rezoning (match land use to flood liability);
• extension of existing building codes (adopt materials and design of foundations and structures to withstand flooding conditions);
• banks and walls (prevent flooding of individual assets); and
• development of techniques and methods of waterproofing (reduce damage to buildings and contents by sealing openings).

Table 8.1 Possible Options For Floodplain Management Measures

Floodplain Management Measures	Option 1	Option 2	Option 3	Option 1	Option 5	Option 6	Option 7	Option 8
Kowhai River measures 1 to 26								
1. Maintain those parts of the existing system which do not conflict with measures adopted here-in.	x	x	x	x	x	x	x	x
2. Adopt new control lines for the Kowhai River.		x	x	x	x	x	x	x
3. Construct new works at, or outside, the new control lines.		x	x	x	x	x	x	x
4. Abandon existing works which are within the new control lines.		x	x	x	x	x	x	x
5. Remove existing works within the new control		x	x	x	x	x	x	x

lines which are deemed to have an adverse effect on the system as a whole.								
6. Adopt protection tree planting as a primary method of protection, plus rock training on control lines at strategic points as needed. Where planting can only be of a lower standard, rock work or other methods may have to be increased to compensate.		x	x	x	x	x	x	x
7. Maintain existing plantings outside the new control lines.		x	x	x	x	x	x	x
8. Identify where additional plantings should go.		x	x	x	x	x	x	x
9. Implement the additional plantings.		x	x	x	x	x	x	x
10. Implement in-channel works between the new control lines. Many specific examples follow.		x	x	x	x	x	x	x
11. Remove obstructions within the channel. i.e. trees and remnants of old banks.		x	x	x	x	x	x	x
12. Strategically align the channel where bad alignment exists.		x	x	x	x	x	x	x
13. Identify and remove rock blockages.		x	x	x	x	x	x	x
14. Remove the constricting remnants of Sweeneys Bank, including part of the echelon link		x	x	x	x	x	x	x

bank into the Old Board Bank (north side).								
15. Upgrade existing River Board bank downstream of the Floodgate Creek diversion bank. (north side).		x	x	x	x	x	x	x
16. Re-align the Middle Ford bank upstream of the ford (north side). Clear and grass-cover the return channel which enters at this point.		x	x	x	x	x	x	x
17. Re-align and shorten the downstream end of the stopbank below Middle Ford (north side). This is a contingency 'wait and see' measure. Allownace of return flows have been effected in this vicinity. Any additional shortening relates to ensuring the 200 metre control channel width is maintained down-stream to Glen Kowhai (south side).		x	x	x	x	x	x	x
18. Pull back Harnetts echelon to the control lines. This is another 'wait and see' measure. Because it is not overly intrusive it may, or may not, be effected dependent on the success or otherwise of other measures such as (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13), and in particular (14).		x	x	x	x	x	x	x
19. Extend a new stopbank downstream from Harnetts Echelon to link with Kennedys Bank (south side).		x	x	x	x	x	x	x

20. Extend Kennedys Echelon further west, towards the Inland Road.		x	x	x			x	x
21. Trim back the downstream end of Kennedys Bank to rid the bank of deflective curvature and extend the bank on a line down to Middle Ford Road (south side). *This has been done.*		x	x	x	x	x	x	x
22. Construct a complementary echelon at Glen Kowhai (south side). If strategically placed, this could be a relatively short length of bank. Also raise the upstream end of the existing echelon and adjust the downstream end to improve the entry conditions into the Kowhai River.		x	x	x	x	x	x	x
23. Construct a new echelon east of the December 1993 break-out point (north side). *This has been done.*		x	x	x	x	x	x	x
24. Plant-out area between the above echelon and the river, as follows - 5 blocks (4 rows), 50 metre gap, 3 blocks (4 rows), 20 metre gap, 2 blocks (4 rows), 1 block (4 rows) along the echelon. Leave 20 metres clear adjacent to Middle Ford Road (north side). *This has been done.*		x	x	x	x	x	x	x
25. Construct channels in the above plantings, aligned back to the Kowhai River; place 1 channel @ 50 metres and 1 channel @ 20 metres (north side).		x	x	x	x	x	x	x

26. Extend the existing stopbank further upstream of the railway bridge (south side).		x	x	x	x	x	x	x
Floodgate Creek (Measures 27 to 35)								
27. Retain existing layout, acknowledging that, in spite of the present monitoring and maintenance regime, the creek could break out of the existing constructed channel.		x	x					
28. Maintain the existing channel by excavating any gravel deposits which reduce capacity.		x	x	x	x		x	
29. Purchase the block of planted land immediately seaward of the turn into the chute and form a gravel trap. This is in advance of potential failures at this point and does not involve turning the creek into the trap.			x	x	x	x	x	x
30. Strengthen the partial bank/planting line which extends from the existing channel bank on Floodgate down to Postmans Road, using the material from (28**)** above.			x	x	x	x	x	x
31. Construct a drain to run down along the east side of the above 'partial bank/planting line'..			x	x	x	x	x	x
32. Construct an echelon bank from the left bank of the existing chute, upstream of the Chapmans Rd bridge, to direct floodwater break-outs			x	x	x	x	x	x

against the bank strengthened as measure (30).								
33. Use excavated material to effect an even grade out of the existing Floodgate Creek channel (before it enters the diversion chute) and into and along the old channel-course which parallels the bank to be strengthened as measure (30). This would be merely 'formwork' for the following measure which requires well graded rock overlying filter fabric			x	x	x	x	x	x
34. Construct a control weir in the existing left bank of the present channel, to ensure that any break-out is to the 'old channel' - design to minimise draw-down or back-scour of the fan material.				x	x	x	x	x
35. Physically redirect flows into the old Floodgate Diversion Channel.						x		x
Luke Creek (Measures 36 to 39)								
36. Extend Pooles Road Echelon to the outer limit of the flood control planting. Rock-armour the downstream end. At present the echelon extends to a natural terrace. Detailed survey is needed to determine the desirability of this measure.		x	x	x	x	x	x	x
37. Extend Stokes Echelon for a distance of about 100 metres towards Mt. Fyffe Road.		x	x	x	x	x	x	x

38. Extend flood plantings along the west bank upstream of Postmans Road. At present the plantings extend to a private property boundary, so additional plantings would be subject to negotiation and possible land purchase.		x	x	x	x	x	x	x
39. Construct an echelon to extend out from the upper western end of the sediment trap for a distance equivalent to the length of Stokes Echelon. Land acquisition is an issue here again.		x	x	x	x	x	x	x
Waimangarara River (Measures 40 to 46)								
40. Extend and raise Adams Echelon. At the design stage the impact of overtopping of this bank will have to be examined as there is a large fall on the downstream side.		x	x	x	x	x	x	x
41. Extend the existing sediment trap to the east. A high priority is suggested for this extension.					x		x	x
42. Extend the sediment trap to the west.						x	x	x
43. Re-align Hislops Echelon. A philosophy of concentrating works upstream of Postmans Road might suggest another supporting echelon, up-fan of Hislops Echelon.						x	x	x

44. Extend the sediment trap to the south.							x	x
45. Construct an overlapping pair of echelon banks on the east side of the fan to lead outbreaks back into the sediment trap.					x		x	x
46. Land acquisition associated with measures (41), (42) and (44).					x	x	x	x
Measures 47 to 50 relate to Lyell Creek								
47. Re-construct the Lyell Creek stopbank (looking downstream) and maximise the capacity of Lyell Creek from SH1 bridge to the sea. This could involve raising the bank to give a total capacity of 190 m^3/s over the length of Lyell Creek from the SH1 bridge to the sea if measure 49 is adopted.		x	x	x	x	x	x	x
48. Construct a weir in the right bank immediately below SH 1 at the location of the December 1993 breach. *This measure has been completed.*	x	x	x	x	x	xx	x	x
49. Extend the right bank all the way to the sea.			x	x	x	x	x	x
50. Maintain supply of sand bags at Kaikoura and develop a contingency plan to implement sandbagging as well as implementing other mitigation measures such as pumping and removing part of the Lyell Creek bank as required (if		x	x	x	x	x	x	x

measure 49 is adopted) immediately upstream of the Information Centre.								
The following measures (51 to 69) are common to the Kaikoura Floodplain as a whole								
51. Encourage appropriate gravel extraction in aggrading floodplain channels..		x	x	x	x	x	x	x
52. Adjust developments to recognise flood risk.							x	x
53. Re-zoning.								x
54. Raising of floor levels.							x	x
55. Control, relocation or exclusion of dangerous uses.							x	x
56. Building line restrictions.							x	x
57. Elevation of building sites.							x	x
58. Secondary flowpaths.							x	x
59. Extension of existing building codes.								x
60. Banks and walls.								x
61. Development of techniques and methods of water proofing.								x
62. Technical advice programme.							x	x
63. Development of							x	x

existing floodwarning and forecasting systems. Also ensure liaison systems are in place with the other relevant authorities.								
64. Identification of areas for evacuation and identification of safe areas for evacuees.							x	x
65. Identification of buildings with contents having high damage potential. Promote 'mezzanine' or upper floor goods contingency plan for the West End shops.							x	x
66. Development of techniques, methods and resources for floodfighting.							x	x
67. Differential premiums based on flood risk.								x
68. Assessment of numbers and locations of flood-affected persons.							x	x
69. Assessment of nature and scope of disruption to services.							x	x

9. The Strategy

9.1 Introduction

The submissions received were analysed and considered by the Community Advisory Committee at a workshop on the 22nd of July, 1999.
Fifty six measures were selected to make up the strategy, and they are set out in this chapter along with purpose/comment brought forward from Table 7.1 (page 46), and updated, where appropriate, with further comment emanating out of the CAC workshop.

9.2 Overview

The strategy is aimed at living in harmony with the naturally occurring processes, based on a reasonable perception of the physical and social nature of the flood and deposition problem. A continuous vigilance is called for, along with adaptability, to manage the hazard, rather than trying to impose control on the powerful naturally occurring processes.

9.3 Description of the Strategy

The strategy consists of a combination of structural and non structural measures.
On the Kowhai a control width has been decided upon. Between the defined lines the channel will be kept reasonably clear, and in channel works will be effected as part of an on-going programme aimed at enhancing the natural channel's ability to effectively pass floodwaters and sediment through the system to the sea without impacting on developed lands to the north-east and south-west.
Protection planting has been adopted as a primary method of protection along with echelon (cross fan deflector) banks, rather than banks parallel to the channel.
It is proposed to retain the existing Floodgate Creek layout requiring constant monitoring and maintenance, both during flood, and non flood, periods. A rock weir will be constructed to minimise the risk of 'headward erosion' in the event of failure

downstream of the bend where the channel starts its flat run across the fan. Efforts will be made to improve the hydraulic efficiency of the channel.
Middle Creek will be maintained as at present, as indeed will all the drains and channels that make up the Kaikoura Rivers Rating District, and the Kaikoura Drainage Rating District.
Poole's Road echelon on Luke's Creek is to be extended and strengthened, Stoke's echelon will be extended towards Mt Fyffe Road.
Discussions will be entered into with the private land-owner in regard to the extension of protection plantings along the west bank upstream of Postman's Road.
On the Waimangarara fan, Adams echelon will be modified and it is recognised that inevitably the fan will migrate seawards.
Lands have been identified where structural protection is not possible, and which could be purchased if the opportunity arose for control of the fan migration and consequent deposition in the short to medium term. Benefits to the Rating Area include a reduction in maintenance requirements to the downstream channels.
Through the town, the right bank of Lyell Creek is to be re-constructed and extended to the sea. This will protect West End from floodwaters emanating from the Mt Fyffe streams, including Floodgate Creek and the Kowhai River, for floods up to and greater than that which occurred in December 1993.
A suite of non-structural measures have been incorporated into the strategy to be effected through the Kaikoura District Council's planning processes and emergency management procedures if deemed appropriate through those processes and procedures.

Table 9.1
Kaikoura Floodplain Management Strategy

(The measure numbers are in brackets, as the final numbers list is different from the list used in the document to date, the reason being, some measures have not made it through to the preferred strategy)

Specific Measure	**Purpose/Comment**
Kowhai River [Measures (1) to (26)]	
(1) Maintain those parts of the existing system which do not conflict with measures adopted herein.	• The benefits of the significant investment in works to date could be quickly lost without a maintenance operation. Damage is sustained continuously, and, if repairs are not effected continuously also, the damage escalates at an increasing rate, eventually resulting in the complete loss of the capital asset.

(2) Adopt new control lines for the Kowhai River.	• To ensure adequate floodway capacity from the top of the system to the sea. The analyses have indicated that works on the Kowhai River system have encroached too far into the active channel. A study of the river system from 1940 until the present time, including when works have come on line, what has worked, and what has not worked, the identification of natural strong points, road reserves, river reserves, freehold land, and the undertaking of a physical modelling exercise, resulted in recommended control lines generally 200 metres apart from the bottom of the system up to Swyncombe. Upstream of Swyncombe, the river narrows into a gorge. The objective is to allow adequate floodway for the floodwaters and bed load. Too narrow, or too wide, a floodway, increases the chances of lateral attack and subsequent failure.
(3) Construct new works at, or outside, the new control lines.	• Any new training banks, protective plantings, rock spurs, and, further back, echelon (deflector) banks, which would add to the protection system on the Kowhai River are, in future, to be constructed either on the control lines, or back from them, this to give effect to measure (2).
(4) Abandon existing works which are within the new control lines.	• Having adopted new control lines with the objective of leaving the floodway between them clear, it follows that existing works within the control lines should be left to their inevitable fate, with expenditure being redirected outside the lines.
(5) Remove existing works within the new control lines which are deemed to have an adverse effect on the system as a whole.	• Where the works are actively obstructing the floodway, or acting as diversions of floodwaters, resulting in undesirable alignment and resultant lateral attack, the works should be

	removed, with the salvagable material being used for the works on, or beyond, the control lines.
(6) Adopt protection tree planting as a primary method of protection, plus rock training on control lines at strategic points as needed. Where planting can only be of a lower standard, rock work, or other methods, may have to be increased to compensate.	• Where there are good buffers of protection planting, the protection mechanism has been observed to consist of the larger boulders dropping out near the river face of the plantings, followed by increasingly smaller diameter material being deposited as the flood wave passes through the plantings. This is a consequence of the floodwater velocities decreasing as the distance into the plantings increases. The plantings act as a front line of defence for strategically-placed echelon banks situated away from the active channel and its control lines. The objective is to effect a filter, so that echelon banks behind the plantings have only to divert floodwaters and silt. The construction of the banks (compacted gravels) requires this.
(7) Maintain existing plantings outside the new control lines.	• The District has a very valuable asset in the substantial existing protection plantings outside the new control lines which have been, and are now, extremely beneficial. It is essential that, as an integral part of this strategy, they be maintained.
(8) Identify where additional plantings should go.	• By looking at the system as a whole, and the protection strategy that has evolved through measures (1) to (7), areas have been identified where additional plantings should go, to improve the overall protection standard.
(9) Implement the additional plantings.	• To effect measure (8).
(10) Implement in-channel	• To create a clear and well-aligned

works between the new control lines. Many specific examples follow.	floodway from the top of the system to the sea. Flood flows tend to follow, particularly as the flood flow is increasing, the alignment of the low flow channel that existed prior to the event. It is advantageous to carry out works aimed at providing a smooth sinusoidal flow path for the low-flow active channel. In practice, this low-flow channel may silt up with finer material, with the river meandering away from it during times of low flow. If this effort is consistent, these silts should flush out quickly during flood events, thus providing the preferred flow path for the flood wave. Whilst this general philosophy is more applicable to rivers on much gentler grades, and with much smaller bed-load, some of the submitters and the CAC felt it was worth experimenting with on the Kowhai. In particular, it could be effected in those areas which could affect floodplain channels that have higher potential damage costs (the Bluff and Middle Ford are two such areas). The approach can be adapted and modified in the light of experience which is consistent with the overall strategy.
(11) Remove obstructions within the channel. i.e. trees and remnants of old banks.	• To effect measure (10). Anything which obstructs the floodway, or worse, causes diversions of floodwaters into undesirable alignments, increases the potential for system failure.
(12) Strategically align the channel where bad alignment exists.	• To effect measure (10). By having a smooth curved channel prior to flood events, the potential for failure is reduced.
(13) Identify and remove rock blockages.	• To effect measure (10). Erosion resistant cobbled plugs of large rock have been identified at various points

	in the Kowhai River system. These can divert floodwaters away from desirable alignments, and towards banks, thus increasing the potential for failure. This is an example of work that can be carried out as a pro-active protection mechanism.
(14) Remove the constricting remnants of Sweeneys Bank, including part of the echelon link bank into the Old Board Bank (north side).	• Sweeneys Bank intrudes into the control channel, and also deflects the principal flow channel onto an undesirable alignment.
(15) Upgrade the existing River Board bank downstream of the Floodgate Creek diversion bank (north side).	• This will provide protection along the control channel boundary. Implementation of measures (11) and (14) can be combined with this measure.
(16) Re-align the Middle Ford bank upstream of the ford (north side). Clear and grass-cover the return channel which enters at this point.	• The present line of this bank upstream of the ford, intrudes into the control channel. Re-alignment, using existing fill and armouring, will bring the end of this bank into line with the bank extension above (15).
(17) Re-align and shorten the downstream end of the stopbank below Middle Ford (north side). This is a contingency 'wait and see' measure. The second part of the purpose/comment has been effected. Any additional shortening and re-alignment relates to the first bullet point.	The purpose here is twofold: • The first - to ensure the 200 metre control channel width is maintained down- stream to Glen Kowhai (south side). • The second - to allow return flows from the new echelon bank, plantings and return channels in this vicinity - measures (21), (22) and (23).
(18) Pull back Harnetts echelon to the control lines. This is another 'wait and see' measure. Because it is not overly intrusive it may,	• This is desirable to effect the required fairway width, because Harnetts Bank intrudes into the control channel, although not by much.

or may not, be effected dependent on the success or otherwise of other measures such as (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13), and in particular (14).	
(19) Extend Kennedys Echelon further west, towards the Inland Road.	• This provides protection for Middle Ford Road, and also for farmland between here and the sea. The concept of planting and echelon banks should be effected equally on the north and the south sides for equity reasons.
(20) Trim back the downstream end of Kennedys Bank to rid the bank of deflective curvature and extend the bank on a line down to Middle Ford Road (south side). *This has been done.*	• This bank mis-directed flow across to the site of the December 1993 break-out. Re-alignment will smooth the flows through this reach.
(21) Construct a new echelon east of the December 1993 break-out point (north side). *This has been done.*	• To redirect breakouts at this point back into the Kowhai River. This general area was identified, through the investigations, as a weak area in the system as a whole. The echelon bank will be parallel to the echelon bank immediately upstream of Middle Ford, and will re-direct any future outbreaks at this point back into the main channel between the Peninsula foothills and the new truncated end of the main Middle Ford bank. The echelon will provide strategic back-up for the control bank.
(22) Plant-out the area between the above echelon and the river, as follows - 5 blocks (4 rows), 50 metre gap, 3 blocks (4 rows), 20 metre gap, 2 blocks (4 rows), 1 block (4 rows) along the echelon. Leave 20	• This will protect the new echelon by slowing breakout flows and filtering out the bed load. The channels will encourage return flow to the Kowhai River. Planting here will mean that the protection planting belt on the north-east side of the Kowhai River will extend continuously into the Peninsula

metres clear adjacent to Middle Ford Road (north side). *This has been done.*	foothills.
(23) Construct channels in the above plantings, aligned back to the Kowhai River; place 1 channel @ 50 metres and 1 channel @ 20 metres (north side).	• To allow substantial flows to develop back to the Kowhai River. With the channels strategically aligned through the plantings, return flows will be encouraged.
(24) Extend the existing stopbank further upstream of the railway bridge (south side).	• To prevent river gravel deposition onto adjoining farmland during flood events, and to encourage flushing of the active channel so that the flow capacity will be restored.
Floodgate Creek [Measures (25) to (29)]	
(25) Retain existing layout, acknowledging that, in spite of the present monitoring and maintenance regime, the creek could break out of the existing constructed channel.	• This enables the community to retain the 'status quo', although the layout may be fundamentally flawed, in that the existing channel design came too far down the fan (because of land acquisition difficulties) before it turned into the new chute. The cross-fan gradient is too low to generate the velocities required to transport sediment through to the Kowhai River system, as was originally intended.
(26) Maintain the existing channel by excavating any gravel deposits which reduce capacity.	• To ensure the channel has adequate flood capacity at all times. By ensuring the channel is kept in a hydraulically efficient state, the risk of uncontrolled failure is reduced. The existing system is not working at all well and deposition occurs rapidly and regularly, reducing flood capacity markedly.

Measures (27) to (29) are pro-active measures which recognise the moderate to high risk of floodwaters breaking out.	
(27) Strengthen the partial bank/planting line, as required, which already extends from the existing channel bank on Floodgate Creek down to Postmans Road, using the material obtained from measure (26) above.	• To pre-empt uncontrolled failure which may affect the commercial centre of Kaikoura. This bank/planting line, constructed by Mr. T. J. Boyd, is well sited to contain flows and gravel inundation south-west of the better lands to the east, and direct them to the Kowhai River. The intention here is to continue to use the works that have been constructed, while preparing for the inevitable. This influences, to some degree, where failure will occur, and continues to allow channelling of flood flows into the Kowhai via the old diversion channel, rather than letting it spill into Mill Creek, Lyell Creek, and thence into the commercial centre of Kaikoura.
(28) Use excavated material to effect an even grade out of the existing Floodgate Creek channel (before it enters the diversion chute) and into, and along, the old channel-course which parallels the bank to be strengthened as measure (27). This would be merely 'formwork' for the following measure which requires well graded rock overlying filter fabric.	• To lessen the possibility of headward erosion when, or if, a break-out does occur. At present, there is a considerable drop from the diversion chute to the seaward fan.
(29) Construct a control weir along the existing left bank of the present channel, to ensure that any break-out is to the 'old channel' - design to minimise draw-down or back-scour of the fan material.	• The purpose of this is to control the point at which the creek will be re-diverted down the fan, with a design aimed at minimising the risk of 'headward erosion' back up the creek bed.

Luke Creek [Measures (30) to (32)]	
(30) Extend Pooles Road Echelon to the outer limit of the flood control planting. Rock-armour the downstream end. Bulk up the existing structure. At present the echelon extends to a natural terrace. Detailed survey is needed to determine the desirability of this measure.	• To ensure flood control overflows are directed down into the sediment trap. This echelon protects the lower flood-prone south-western area of the fan. The bank should be extended to the outer limit of flood control planting to ensure Luke Creek does not outflank the echelon and flow overland down to Middle Creek.
(31) Extend Stokes Echelon for a distance of about 100 metres towards Mt. Fyffe Road.	• This echelon was constructed to cover periodic breakouts which enter shallow channels in the vicinity of the farm downstream. These channels direct floodwater south-east away from the river across Mt. Fyffe and Postmans Road. Its efficiency would be enhanced by its extension.
(32) Possibly extend flood plantings along the west bank upstream of Postmans Road. At present, the plantings extend to a private property boundary, so additional plantings would be subject to negotiation and possible land purchase. This measure does not have a high priority from the CAC but has 'survived the cull' for future consideration.	• Historically, flows have bypassed the trap to the south, and entered the Middle Creek system. This measure is aimed at intercepting such flows, and re-directing them to the sediment trap.
Waimangarara River [Measures (33) to (38)]	
(33) Extend and raise Adams Echelon. At the design stage the impact of overtopping of this bank will have to be	• The western end of this echelon is in danger of being overtopped or outflanked. The works will protect developed farmland down-fan from the

examined as there is a large fall on the downstream side.	bank.
(34) Extend the existing sediment trap to the east. This has been flagged by the CAC as another 'wait and see' measure. The existing landowner is aware of the risk and prefers to accept that risk rather than selling at this point in time. The land is very good land. The Rating Area Liaison Committee might consider purchase of the land, if, or when, it came up for sale again. Off site benefits, apart from controlling the fans migration in the short to medium term, are reduced maintenance requirements of the seaward channels and drains.	• There is strong evidence of outbreaks to the east which cross SH 1. This could be part of a suite of measures (more follow) to further confine the Waimangarara River to the top of its fan.
(35) Extend the sediment trap to the west. Another measure flagged by the CAC as a 'wait and see' measure. The same comments apply here as for measure (34).	• The existing gravel trap is quite narrow considering the extent of the fan above, the width of the protection planting, and the echelon coverage upstream.
(36) Re-align Hislops Echelon. This measure is only required if, or when, measure (35) is effected.	• If the trap is widened to the west, then the lead-in echelon would need to be re-aligned to take advantage of the full width of the trap.
(37) Extend the sediment trap to the south. This is the third priority 'wait and see' measure in this area. The CAC is of the opinion land purchase options should only be pursued if absolutely necessary, and the situation is a 'win/win' situation both	• Inevitably the fan will continue migrating coastwards. If the opportunity arises, the identified block of land could be purchased with a view to extending the trap seawards in advance of, or along with, the fan's natural migration.

for the Rating Areas and the landowners concerned.	
(38) Land acquisition associated with measures (34), (35) and (37).	• To enable the implementation of measures (34), (35) and (37). By identifying the desired land, purchase could be effected if the land came up for sale or, alternatively, negotiations could be entered into sooner.
Measures (39) to (42) relate to Lyell Creek	
(39) Re-construct the Lyell Creek right stopbank (looking downstream) and maximise the capacity of Lyell Creek from SH 1 bridge to the sea. This involves raising the bank to give a total capacity of 190 m^3/s over the length of Lyell Creek from the SH1 bridge to the sea if measure (41) is adopted.	• The Lyell Creek stopbank consists of loess, for which Fulton Hogan Canterbury provided the following technical data (report by P. Yellowlees). The loess has a naturally high water content, typically 25%. This is because the individual particles are all of the same size, which makes for the maximum amount of voids around them. During flood times, with high water pressure on one side and none on the other, the bank will become porous. The high void content makes the mass per volume low (1400 kg/m^3). By comparison, the water it is attempting to hold back is 1000 kg/m^3). A more suitable material would be M4 AP 40 aggregate (a Transit specification material). It has a compacted mass of 2350 kg/m^3 and an average water content of 3.5%. Of note here, is that the compaction achieved during the implementation of measure 23 is 2350 kg/m^3, with 4 passes of a vibrating roller, and a moisture content of 2.5%. • The other flaw of the Lyell Creek stopbank is its inadequate profile because of space limitations. If a bank is to be relied on in this area, it will need to be totally re-constructed with appropriate material, and be of adequate dimensions. The foregoing could be developed in conjunction with the landowners of the commercial buildings on the north east

	side of West End to achieve the flood protection objectives, and to enhance the access and appearance of the area. • The second part of this measure relates to enabling a larger volume of floodwater to pass to the east of the commmercial centre of the town safely to sea. During the December 1993 flood event, a flow of 140 $m^3.s^{-1}$ was passed by the Lyell Creek channel. The greater the volume that can pass through this channel, without bank failure, the lower the risk to the town.
(40) Construct a weir in the right bank immediately below SH 1 at the location of the December 1993 breach. *This measure has been completed.*	• To dictate where the system can discharge excess flows at a controlled rate once the capacity of Lyell Creek has been reached. If Lyell Creek is flowing full without bank failure, then substantial flood events are being catered for. By allowing controlled flows through West End for even more extreme events, the pressure can be relieved from the Lyell Creek system, while advantage is being taken of the existing floor level heights of the commercial centre. The capacity of Lyell Creek when the weir is just about to overtop is 125 m^3/s. With this discharge, the water depth in the carpark at the downstream end of the shopping area would be 400mm under existing conditions, or zero if measure (41) is implemented. Once the weir is operational, the Lyell Creek bank would be breached, in a controlled manner, in the vicinity of the Information Centre.
(41) Extend the right bank all the way to the sea.	• At present, the Lyell Creek bank ends short of the open area north of the Information Centre. Once flood flows are above the natural channel, they flow around the end of the bank, and enter the commercial centre by way of an alley beside the Butcher's premises. By extending the bank, this avenue would be blocked.

(42) Maintain a supply of sand bags at Kaikoura and develop a contingency plan to implement sandbagging, as well as implementing other mitigation measures such as pumping and removing part of the Lyell Creek bank (if measure 41 is adopted) immediately upstream of the Information Centre.	• For general emergency activities.
Measures (43) to (46) apply to the floodplain as a whole	
(43) Encourage appropriate gravel extraction in aggrading floodplain channels.	• To maintain the flood-carrying capacity of the river by managing the bed load. Aggradation, or bed level build-up, increases the potential for failure. Degradation, or lowering of the bed level, can also be a problem where protection structures are undermined. However, on balance, degradation tends to be a plus in the Kaikoura situation.
(44) Adjust developments to recognise flood risk.	• This measure is aimed at ensuring development in hazardous areas is compatible with flood damage potential. It is important to note that no attempt is being made to restrict development simply because the land is flood-liable. If development is to proceed in such areas, for whatever reasons, then the concern is simply to ensure measures are implemented which minimise flood damage. Ways of achieving this include: • Raising of floor levels (45). • Elevation of building sites] (48). • Secondary flow paths (49). •Technical advice programme (50). • Development of existing floodwarning and forecasting systems (51). • Identification of areas for evacuation and safe areas for evacuees (52).

	• Identification of buildings with contents having high damage potential (53). • Development of techniques and methods for floodfighting (54). • Assessment of numbers and locations of flood affected persons (55). • Assessment of nature and scope of disruption to services (56).
(45) Raising of floor levels.	• Construct floor levels above predicted flood levels.
(46) Control, relocation, or exclusion, of dangerous uses.	• Remove especially, or potentially, dangerous materials from flood paths. Applicable particularly to toxic chemicals, timberyards, etc.
(47) Building line restrictions.	• Set buildings back from stopbank systems, so that, if bank failure does occur, structures will not be in the path of deep, fast flowing floodwaters. This measure is applicable to new development. The lines run parallel to the stopbanks or echelon banks.
(48) Elevation of building sites.	• Raise the building areas of complete subdivisions above flood levels. This measure is applicable to new development. This measure and measure (49) are complementary.
(49) Secondary flowpaths.	• To allow breakout floodwaters to flow through development with a minimum of damage. Development can be designed leaving clear channels for the dispersal of floodwaters.
(50). Technical advice programme.	• Advise floodplain residents about suitable responses to flooding.
(51) Development of existing flood warning and	• Improve accuracy of predictions of flood size and arrival time. In the Kaikoura situation this must be done off

forecasting systems. Also ensure liaison systems are in place with the other relevant authorities.	real time rainfall because of the impracticality of measuring flood flows. Because of the obvious need, a telemetered rainfall station has been installed at Snowflake, and this, as well as the rainfall station on Luke Creek, is monitored continuously.
(52) Identification of areas for evacuation and identification of safe areas for evacuees.	• Prevent casualties by moving people out of the way of floodwaters. This measure will be effected through the medium of Civil Defence and Emergency Services.
(53) Identification of buildings with contents having high damage potential. Promote 'mezzanine' or upper floor goods contingency plan for West End shops.	• Locate contents permanently above potential flood levels. This is applicable particularly to art gallery, museum, high value use, and emergency services. • Make provision for temporary storage of property at short notice.
(54) Development of techniques, methods and resources for floodfighting.	• Contain or divert floodwaters locally, and reduce casualties and damage to possessions.
(55) Assessment of numbers and locations of flood-affected persons.	• Provide information for planning post-disaster management. Again this measure would be implemented through Civil Defence and related agencies.
(56) Assessment of nature and scope of disruption to services.	• Provide information for planning post-disaster recovery, and also pro-active actions to prevent damage.

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The Kaikoura floodplain, in terms of its geomorphic setting and hydrology, has been found to pose analytical problems quite different from those encountered on the floodplains of most other river systems investigated by Canterbury Regional Council prior to this study. The need for this study, which had already commenced, was heightened by the sudden damaging flood of December 1993, in which the Kowhai River broke its banks and entered the low-lying urban and commercial sectors of the town.

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