HUTT RIVER

CHANNEL MANAGEMENT

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PREFACE

This Channel Management Study has been undertaken as part of the Hutt River Flood Control Scheme review. The objective of the study was to assess past and current management practices and protection works used in the Hutt River, to determine their appropriateness and effectiveness. The findings of the River Characteristics and Sedimentation studies have been important in assessing the effectiveness of past practices and works, and the nature of the river responses and the way in which the river channel has developed over time. Information on past practices and works was obtained from the Hutt River History report and a dossier of flood damage reports, while aerial photography taken at various times since 1936 has provided some information on the works that have been undertaken.

A brief for the study was completed in December 1990, and the study was commissioned in March 1991. The study covered the Hutt River from the mouth to the Te Marua recorder site, and during March walk-over field inspections were carried out along both banks. These inspections were carried out with Brendan Paul of the Wellington Regional Council. A river channel classification system covering the river regime and channel and bank conditions was developed, with status rankings determined for a variety of factors. A computer database was then set up by Sam Barnes on the Wellington Regional Council computer, to store this information in a manner that maximised data inquiry capabilities.

Discussions have been held with Wellington Regional Council staff, in particular John Easther, Colin Munn and Brendan Paul, on the effectiveness of past works and management practices, and the appropriateness of different types of river works and practices.

This report describes the computer database that has been generated and the information that is presented on plans. The complete database is given in a separate A3 volume, along with the plans of the existing works and design channels. The findings of the investigations into channel management practices are also given in the report, with the main findings being outlined in a summary at the beginning of the report.

SUMMARY

The existing protection works along the Hutt River have been identified from walk over field inspections and aerial photography, and are shown on 1:2500 plans. There is a diversity of works along the river, including rock and rubble linings, permeable timber groynes, concrete block groynes and willow vegetation strengthened with cabled rail fences. Different techniques have been applied over time, with roading authorities being involved as well as the river management authority. While there is often a lack of consistency along reaches of the river, the works in place do give rise to a degree of protection that is generally related to protection requirements.

A classification system for river management that has both descriptive and status or ranking factors has been developed. The classification categories cover river regime factors, and channel and bank condition factors. A database has then been set up using cross-section identifiers, and an overall status factor has been determined from a weighting of the various status factors. Selective inquiries can then be carried out to extract combinations of data over specified ranges. The overall status is an indication of the relative likelihood of the berms being eroded away, and along the Hutt River the overall status rankings are quite variable. This demonstrates a lack of consistency along the river.

There are few engineering records of past works and management practises, and an assessment of river responses and the effectiveness of works is hindered by this lack of records. The management approach of the Hutt River Board was one of constant repair, replacement, extension and repositioning of works, along with a management of the channel bed through gravel extraction operations. The lower reaches were enlarged and deepened up to the end of the 1930's. Above Melling the management aim was a narrow gently curving channel, and the continual loss and reinstatement of works was an inherent part of the management approach. The gravel extraction was aimed at straightening the channel and continually removing the sharp flow cross-overs that form within a narrow active channel. The extraction also gave rise to a degradation of the channel bed, and this entrenchment of the channel is considered to be crucial to the degree of straightening and narrowing that has been achieved along the Hutt River.

In the Upper Valley the imposition of a narrow gently curving channel took place much later, and was carried out more rapidly. The State Highway has been constructed over what had been active channel, and is generally very close to the river channel. A different approach has thus been taken with the narrow channel being fixed by the heavier and more rigid bank protection of rock linings. In recent years rock and rubble linings have also be constructed along the lower reaches of the river.

The Hutt River has been greatly modified over the last 100 years, and the river response will now be very different to what it was. Floodwaters are now contained within a narrow and more entrenched channel that has little curvature, and channel breakouts and large erosion embayments cannot occur as they have in the past. Lateral erosion now takes place over long lengths but with little width, and leaves high banks of alluvial gravel. Willow vegetation and permeable groyne works are less effective in restraining erosion, while the rate of erosion will progressively increase if the curvature of the eroding bank is allowed to increase. The river regime has probably been significantly altered by the channel development and the response of the river. There is now a progressive decline in the size of the bed material from Birchville downstream, and the bank material is now more easily transported than the bed material. The greywacke baserock has been exposed in a lot of places upstream of Taita Gorge, and the uneven outcropping of this hard material affects the natural channel formation processes.

Although seriously threatened, the flood defences have not so far been breached. Medium to large flood events have occurred since the inception of scheme works, but the largest flood of 1939 is less than the presently accepted design standard, and in recent years only medium flood events (of about a 10 year return period) have occurred. The security given by protection works, as well as river management flexibility, depends very much on the width of the berms (from channel edge to flood defences). There is a wide variation in berm widths, but only a few places where there is virtually no berm - in the lower reaches and at Gemstone Drive. Any river management approach must consider the effects of the relatively frequent small and medium flood event, as well as the protection requirements to withstand a large design flood.

Vegetation and groyne works carried out in the Upper Valley as part of the channel development have suffered severe damage, although they have not been subjected to floods in excess of a 10 year return period. Where rock linings have been constructed more recently, some non-conformity between the channel form and position of the linings has already developed, although only small floods have occurred since their construction.

General scour depths have been calculated from channel and flow characteristics using two empirically derived formulae, and a general scouring of the channel bed of around 1.5 to 3m should be expected along the Hutt River. Channel constriction affects scour depths, and additional local scouring takes place around significant obstructions, such as debris heaps, bridge piers and groyne heads.

The size of rock for rock linings or snub groynes has also been determined from two empirically derived formulae. The calculated flow velocities given by the hydraulic modelling have been used, although they are unusually high, and large-sized rock is required upstream of Kennedy-Good Bridge. The dimensions of a rock lining that requires little topping up have been determined, using the medium rock size as a basic dimension.

Permeable groynes have been used along the Hutt River, but the narrowness of the channel and height of the banks restricts their usefulness. They can be subjected to deep scouring at their head, and are relatively easily outflanked by bank erosion. Their effectiveness could, however, be improved by changes in their channel position, spacing and angle from the bank.

Willows are especially effective for vegetation buffer zones, but the entrenchment of the Hutt River into alluvial gravels means that there is now only a narrow strip along the channel edge where they can be easily established. In the past bands of willows have been established along the river, and a programme of willow planting has been carried out in recent years. Other species with different site tolerances but similar layering and root development characteristics, should be considered, and some alternative species have been suggested.

A minimum design channel has been drawn up from the river mouth to Maoribank, based on a natural threshold of motion meander pattern, and this channel is shown as an overlay onto 1:5000 aerial photographic plans. The channel fits well within the existing channel, and a realignment of the existing channel is required at only one place - at Ewen Bridge.

A wider design channel has been drawn up for the same reach and presented in the same way, using the flow dominant meander pattern. In general this channel could fit within the existing channel and berm area, but would require a substantial excavation of the berms and a reestablishment of bank protection works. There would be some encroachment of existing roads into the design berm areas, but the channel itself would only extend beyond the existing flood defences along the lower reaches, with a major extension at Ewen Bridge. The wider channel would allow natural channel processes to take place with less disruption, and lighter and less rigid bank protection measures could be used.

The minimum design channel could be fixed by continuous rock linings, but heavy linings that have a large bulk compared to the channel would be required. Benching above the linings would also be necessary because of the height of the banks. Where there are wide berms an opposite maintenance and repair approach could be applied. In this case vegetation buffer zones would be maintained by willow and groyne works, with eroded areas being reclaimed and replanted. Cross-blading of the channel bed reduces the amount of bank protection work that is required, and can be cost effective.

There are significant differences in the present condition of the river, and different management approaches should be assessed on a reach by reach basis.

There are trade offs within river management, of overall approaches, in the balance of different types of works, in the strength and layout of works, and in the programme of maintenance, and only a qualitative assessment of effectiveness is possible. River management also has many aims apart from flood mitigation. The cross-blading and vegetation works have impacts on the aquatic environment of the river and riverine landscape, and affect recreational uses of the river area.

The channel as it exists or modified in accordance with the minimum design channel, could be managed in different ways to accommodate a large flood with a peak flow of around 2000 m3/s. However, if the design flood was much larger, with a peak flow of 3000 to 4000 m3/s this channel is likely to be overwhelmed, regardless of the management approach taken. If the wider design channel was implemented and effective protection put in place, then the passing of these much large floods, with little risk of a breaching of the flood defences, may become a feasible proposition.

The transport of gravel bed material down the Hutt River takes place at a relatively slow rate. Although deeper scouring and more asymmetric channel forms can develop in the existing narrow channel, the rate of bed material transport may have declined due to protection of the banks and an armouring of the bed. There is probably no longer a balance of bed material transport along the Hutt River, and channel degradation is likely to continue due to the response of the river to prevailing conditions, even if there was no further gravel extraction. In spite of artificial channel enlargement and floodwater confinement along the lower reaches, the transport of bed material declines below the major change of grade, and material would naturally accumulate at the month. Gravel extraction at the mouth should continue at its present rate of 50000 m3 per year, and between Melling and Kennedy-Good Bridge, with extraction upstream of the mouth not exceeding 25000 m3 per year. Bed level changes should be monitored through repeat surveys of the channel cross-sections.

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1 EXISTING WORKS

1.1 Data Collection

The field inspections were used to determine the type and extent of existing works. The extent of rock and rubble linings and other structural works, such as groynes and cabled rail fences, was determined as far as possible from the visual inspections of a walk over survey. Isolated concrete blocks and lines of blocks were noted in places, and many such blocks undoubtedly exist under vegetation along the banks that were not noticed during the field inspections, and buried in the banks and bed of the river.

The general nature of the vegetation along the edge of the river channel was noted during the field inspections, with an emphasis on the presence of willows and poplars. The present extent of vegetation is clearly shown on colour aerial photography taken in November 1990, and the type of vegetation can also be determined to some degree from this photography.

1.2 Plans

The existing works along the Hutt River from the mouth to Te Marua are shown on a set of 34 plans of A3 size (see Volume of Plans and Database). The plans are at a scale of 1:2500, and can be overlaid on the aerial photographic plans of the Council. The plans show the visible structural works as noted during field inspections, included isolated concrete blocks, piles and outlet structures that were seen during the inspections. All known works of recent years were identified, and all the works described in the project reports of the History report - that are still present - could be identified in the field.

The tree vegetation is shown as young and more mature to give some indication of age, and to identify the more recent plantings of willows. Where there are stopbanks the tree vegetation has been shown from the channel edge to the stopbank toe, and the remaining area is grassed. Elsewhere only the important edge vegetation has been shown.

Where rock outcrops in the channel, or could be seen within the low flow channel, this has been indicated on the plans. Where the banks are formed within the greywacke baserock this is also shown on the plans. In many cases the rock does not extend the full height of the bank, but is covered by a layer of alluvial gravel. This gravel layer is very thick in places, particularly upstream of Birchville, and there are some high near vertical banks of gravel over rock.

The plans thus show the relevant features for river channel management.

1.3 Type of Works

In the lower reaches below Melling long lengths of bank are lined with rubble and rock. A lot of this lining work has been constructed during the last decade. There are also some remains of the timber groynes that were used extensively along the lower reaches from the initial scheme. Immediately below Ava Bridge a set of 4 groynes were reconstructed in the mid 1980's as part of a bank stabilisation trial. Above Ewen Bridge rock groynes and a rock-lining were constructed in 1990. The concrete block groynes around the outer bank of the bend upstream of Ewen Bridge were constructed in the 1960's when a lot of concrete block work was undertaken.

Around Melling Bridge a lot of structural works (permeable timber and solid gabion groynes) were constructed in the past, but these works are no longer visible, and there is now a band of willows along the banks of the river. Around Kennedy-Good Bridge willows have been planted on beaches along the inner channel side of existing willows, with cabled rail fence strengthening, in recent years. As the beaches moved with channel migration further planting was undertaken, to give a more or less continuous band of fenced plantings upstream and downstream of the bridge. This approach gives rise to a narrowing of the channel, and when the planted areas became subjected to direct attack, as channel migration continues, they have been eroded away and the fences progressively scoured out and destroyed.

There are two long reaches of concrete block groynes where the river flows close to the state highway opposite Taita. This concrete block work was first constructed as protection works along an imposed channel edge as part of the construction of the new state highway in the 1960's. The new highway was partly constructed over areas of active channel, and initially the concrete blocks were laid down in lines with some additional blocks at the landward end, and cabled together. Since then the channel has degraded, and although some recabling and regrouping repairs were carried out, the blocks are now no longer cabled and are in partly displaced groups, with some blocks well out from the bank in the deep channels that flow beside the block work.

Along the left bank at Pomare Bridge structural works have been built and destroyed many times over the years. The flood damage reports up to 1950 nearly all contain some mention of repairs or replacements of both timber and solid gabion groynes and weirs at this site. From recent records and aerial photograph since 1960 it is known that timber groynes and concrete block groynes have been constructed and destroyed. Later timber groynes have been outflanked and partly destroyed, and after repairs, strengthening and extensions further damage has occurred. In 1990 four substantial rock groynes were constructed. Some of the timber groynes remain in place downstream.

Between Kennedy-Good and Pomare Bridge a substantial amount of willow planting has been undertaken in recent years, particularly along the left side berm. Concrete block work undertaken in the 1980's along this reach is also visible in a number of places. Some of the block work is within a well vegetated bank, and some of it is along bare banks that are being actively eroded.

Concrete block work was undertaken beside the Manor Park Golf Course and in front of Stokes Valley in the 1960's. Further concrete block work was carried out in front of Stokes Valley in 1980 as part of the upgrading of the Stokes Valley Stream outlet, with some repairs after the May 1981 flood. These concrete blocks are still largely in place, with some remedial works having been carried out.

In the Upper Valley there is a lot of rock lining work that has been constructed in recent years as part of state highway construction works. From Silverstream to Moonshine Bridge there are alternating lengths of rock lining and willow bands with cabled rail fences. This work has been undertaken to a given meander pattern, with the rock along the outer banks. Channel migration has occurred, however, and there is no longer a complete conformity between the rock linings and the channel position. Baserock has also been exposed in the bed of the channel, and the outcropping rock is influencing the channel meandering, with very sharp low flow cross-overs being generated.

Between Moonshine Bridge and the Whakatikei confluence the channel is now well contained by exposed baserock. Above the Whakatikei some permeable groyne work has been used as well as rock linings. These groynes have suffered severe damage in places, with some groynes being completely removed. Around the Totara Park Bridge bands of willows strengthened by cabled rail fences have been established in recent years. The willows along the left bank have established well, but there have been large losses among the plantings along the right bank which have been on higher round, and in spite of replanting there are still large areas without well established willows.

At Maoribank two large solid groynes of concrete blocks and gabion mattresses were constructed on the left bank after the May 1981 flood. The incomplete groynes were damaged by a flood the following year. Deep scour holes formed in front of the groynes, and in later floods the gabion mattress bases were rolled back and the blocks moved. As part of the bypass highway construction the groynes were removed, and there is now a solid concrete wall downstream of the rock bluff at Maoribank, with a heavy permeable groyne and concrete blocks in front.

From 1985 a bank lining consisting of two rows of rails with gabions between and tied willow poles was constructed from Haukaretu at Harcourt Park. The willows have established well and this lining is in a sound condition.

In front of the Gemstone Drive stopbank a mattress of tied concrete blocks was constructed on the channel bed, with a geotextile covering and willow planting above, in 1983-84. The willows have become established, and although the concrete blocks were placed on a gravel bed, there has been no underscouring or displacement of the blocks.

The concrete block groynes and lining constructed immediately downstream of the Mangaroa confluence, in association with a highway realignment in 1980-81, have been underscoured, and are now partly held up by the cabling. A rock lining was apparently laid below the concrete block work, but there is now no sign of this rock, and baserock can be seen in the channel in front of the block work.

The cabled concrete blocks and tyres constructed by the Te Marua Golf Club have been partly undermined, and the cabling is holding the construction together. Concrete blocks have been used at a number of places along the Golf Course reach of the river, and although most of the visible works remain intact there has been some undermining and displacement of the blocks.

1.4 Consistency of Works

There is a diversity of bank protection works along the river. Different techniques have been used at different times, and the approach taken has been influenced by roading authorities as well as the river management authority. The intensity of bank protection works has varied along the river in response to differing interests and the degree of river attack. Thus the works now in place reflect the techniques being used at the time the works were first constructed, and the involvement of roading authorities.

Highways have been constructed over what had been active river channel, and for long reaches of the river highways are very close to the river edge. Where there are stopbanks there is a wide variation in berm widths, and some of these berm areas have significant recreational development in the form of playing fields and golf courses. Thus the strength of the bank protection measures should vary in relationship to the berm width and proximity of high value assets.

In spite of the different techniques that have been used, the existing works do give rise to a degree of protection that has a definite correspondence to protection requirements. Rock linings and concrete block groyne works are in about the right place for highway protection given the present channel position. Rock work has strengthened reaches at Pomare Bridge and Croft Grove that are subject to more severe river attack, and improved security at Ewen Bridge. Earlier rubble lining work at Alicetown has strengthened a particularly vulnerable length of stopbank. However, some works have been project driven, such as the strengthening in front of the Stokes Valley and Okoutu Stream outlets, or in response to specific requirements, such as the Haukaretu to Harcourt Park works. Many bank strengthening works have also been carried out as flood damage repairs in response to specific erosion events.

Up to about 1950 a consistent approach involving constant maintenance was implemented along the Lower Valley reach (of the Hutt River Board district) but virtually all the works put in place under this management approach are now either redundant or are no longer in existence. Since then heavier protection measures have been used, but they have been used more intermittently and in response to specific requirements (of protection or reinstatement).

In summary, the differences in approach and in techniques used has given rise to existing works that include many different types of works, and that often lack consistency along a reach.

There is still though, some overall appropriateness to the degree of protection given by many of the works (see Section 3)

2 DATABASE

2.1 Classification

A classification system for river channels that has both descriptive and status or ranking factors has been developed. The classification categories cover river regime factors, and channel and bank condition factors.

The river regime factors include the basic river characteristics of dominant flood flow, channel slope and bed material size, and the database calculates channel widths and dominant flow power from the values of these characteristics. A meander uniformity factor is included, and the database calculates river regime status factors from the regime information that has been entered into the database.

Descriptive factors for channel conditions cover shape, bed material and vegetation of the channel. The channel status factor of channel form is determined from the channel shape, and that of channel clearance from the channel vegetation.

Descriptive factors for bank conditions cover the height of the bank and the width and material of the berm; and a type plus description category for edge linings, groynes, vegetation strengthening and berm vegetation; and a type plus width category for edge vegetation. Bank status factors are then determined for the edge strength and berm resistance, from the type and nature of the edge and berms. A further channel position factor ranks the bank in terms of the existing channel position.

An overall status is determined from the weighted average of all the status factors. It gives a relative ranking, based on a qualitative assessment, of the likelihood of the eroding away of the berm under existing conditions. Where flood defences exists this is equivalent to the likelihood of flooding due to eroding away of the flood defences.

All status factors are given in terms of a ranking from 1 to 5, in 0.5 increments. For all factors the best condition is given a rank of 1 and the worst a rank of 5, so that factors can be combined and the resulting ranking retains the same relative order.

The database is set up with the key identifier factor being a cross-section number. The location is thus given in terms of cross-section number and associated profile distance, with the cross-sections listed in ascending order. All the database information is thus related to a cross-section. For the Hutt River 303 cross-sections were used from cross-section 30 to 3050, with the cross-sections being listed in the upstream direction.

The database is stored in two listings, one covered the river regime and channel conditions factors, and the other the bank condition factors with the left and right bank information given consecutively for each cross-section in turn. The first listing is made up of 24 columns of information, and the second of 20. Some of the columns have numeric values only, while for some of the descriptive factors priority rankings are possible, with the available symbols being listed down the relevant column in priority order.

In Appendix A under the factor headings all the database factors are described and the key to all the symbols used is given. The way in which the status factors are determined is given as well, with a representative range being given where the rankings are determined in a qualitative way.

2.2 Hutt River Database

The whole database for the Hutt River from the mouth to Te Marua, as determined in this study, is given as a complete listing in cross-section number order (see Volume of Plans and Database). There is a mass of data in this database - over 17500 possible entries excluding the cross-section identifiers. The database set up, though, provides calculated information, and allows selective inquiries. The overall status is calculated according to the applied weightings from the qualitatively determined status factors, and the resulting rankings can be extracted as a listing from the database - called an inquiry report. Other combinations of status factors can be listed, while all sorts of inquiries of cross-sections with given status factors can be carried out. Inquiries can also be carried out on the descriptive factors, and in fact any combination of factors.

The ranking of the overall status factor as determined for the Hutt River varies between 1 and 3.5. The lack of higher rankings arises because the Hutt River has a relatively uniform clear channel, and the river regime and channel status factors have relatively low rankings. The rankings are also quite variable, with very few reaches having consistent rankings (see Figure 1). This demonstrates a lack of consistency along the river, with the combination of the important factors - as determined in the database - not generating a reach by reach consistency. Some real differences in the degree of protection that is provided along reaches is, however, reflected in general differences in ranking.

A listing of the overall status in rank order is given for the left and right banks in Table 1. The edge strength and berm resistance are the important factors as far as resistance to erosion is concerned - leaving out differences in erosive power - and a listing of these two factors combined together in rank order is given in Table 2. This listing demonstrates the wide range in erosion resistance along the river, and again the variability in this combined factor (see Figure 2).

To show the sort of inquiries that can be carried out on the database, Table 3 gives the results of a few inquiries.

OVERALL STATUS — LEFT BANK

5	4.5	4	3.5	3	2.5	2	1.5	1
			900	100	30	150	1240	
			910	210	40	160	1250	
			930	300	50	170	2400	
			940	310	60	180	2410	
			950	330	70	190	2420	
			980	340	80	540	2430	
			1030	370	90	600	2440	
			1040	380	110	1440	2450	
			1050	390	120	1450	2460	
			1100	400	130	1460	2470	
			1130	650	140	1510	2480	
			1140	660	200	1520	2490	
			1150	670	220	1630	2500	
			1340	680	230	1640	2520	
			1690	690	240	1800	2530	
			2140	700	250	1810	2630	
			2150	710	260	1820	2870	
			2160	720	270	1890	3010	
			2170	730	280	1900	3020	
			2180	740	290	2270	3050	
			2240	750	320	2280		
			2540	800	350	2360		
			2550	810	360	2370		
			2620	820	410	2380		
			2760	830	420	2510		
				840	430	2570		
				850	440	2710		
				860	450	2720		
				870	460	2750		
				880	470	2860		
				890	480	2960		
				920	490	3030		
				960	500	3040		
				970	510			
				990	520			
				1000	530			
				1010	550			
				1020	560			
				1060	570			
				1080	580			
				1110	590			
				1120	610			
				1160	620			
				1170	630			
				1180	640			
				1190	760			
				1270	770			
				1280	780			
				1300	790			
				1310	1070			
				1320	1090			
				1330	1200			
				1350	1210			
				1360	1220			
				1370	1230			
				1380	1260			
				1390	1290			
				1400	1410			
				1660	1420			
				1670	1430			
				1680	1470			
				1700	1480			
				1710	1490			
				1720	1500			
				1730	1530			
				1740	1540			
				1770	1550			
				1780	1560			
				1790	1570			
				1830	1580			
				1840	1590			
				1850	1600			
				1860	1610			
				1870	1620			
				1880	1650			
				1910	1790			
				1920	1760			
				1930	1920			
				1950	1940			
				1970	2260			
				1980	2290			
				1990	2300			
				2000	2310			
				2010	2320			
				2020	2330			
				2030	2340			
				2040	2350			
				2050	2390			
				2060	2580			
				2070	2670			
				2080	2680			
				2090	2690			
				2100	2700			
				2110	2790			
				2120	2800			
				2130	2810			
				2190	2820			
				2220	2840			
				2230	2850			
				2250	2880			
				2590	2900			
				2600	2910			
				2610	2920			
				2640	2930			
				2650	2940			
				2660	2950			
				2730	2970			
				2740	2980			
				2770	2990			
				2780	3000			
				2830	3005			
				2890				

OVERALL STATUS — RIGHT BANK

TABLE 1

5	4.5	4	3.5	3	2.5	2	1.5
			210	220	30	50	1000
			580	240	40	150	1800
			710	250	60	160	1810
			720	260	70	180	1820
			730	280	80	190	1830
			750	290	90	350	1840
			780	300	100	360	1900
			860	310	110	1010	1910
			870	330	120	1020	1940
			880	390	130	1030	2430
			890	400	140	1320	2440
			940	410	170	1490	2450
			950	420	200	1540	2460
			960	460	230	1550	2470
			970	470	270	1790	2480
			980	480	320	1850	2500
			990	490	340	1890	2550
			1090	540	370	1920	2560
			1280	550	380	1930	2570
			1290	560	430	1950	2650
			1530	570	440	1960	2660
			1600	590	450	1970	2720
			1650	610	500	2260	2730
			1660	630	510	2270	2740
			1700	640	520	2300	2840
			1710	650	530	2400	2910
			1720	660	600	2410	2920
			1730	670	620	2420	2930
			1740	680	1230	2490	2940
			1750	690	1240	2510	2970
			1760	700	1260	2750	2980
			1770	740	1270	2830	3030
			2150	760	1290	2900	3050
			2230	770	1300	2950	
			2240	790	1310	2960	
			2250	800	1330	2990	
			2320	810	1780	3000	
			2330	820	1860	3005	
			2340	830	1870	3010	
			2350	840	1880	3020	
			2360	850	2060		
			2370	900	2280		
			2380	910	2290		
			2390	920	2670		
			2540	930	2680		
			2880	1040	2690		
			2890	1050	2700		
				1060	2710		
				1070	2760		
				1080	2770		
				1100	2780		
				1110	2790		
				1120	2800		
				1130	2810		
				1140	2820		
				1150	2850		
				1160	2860		
				1170			
				1180			
				1190			
				1200			
				1210			
				1220			
				1250			
				1280			
				1340			
				1350			
				1360			
				1370			
				1400			
				1410			
				1420			
				1430			
				1440			
				1450			
				1460			
				1470			
				1480			
				1500			
				1510			
				1520			
				1560			
				1570			
				1580			
				1590			
				1610			
				1620			
				1630			
				1640			
				1670			
				1680			
				1690			
				1980			
				1990			
				2000			
				2010			
				2020			
				2030			
				2040			
				2050			
				2070			
				2080			
				2090			
				2100			
				2110			
				2120			
				2130			
				2140			
				2160			
				2170			
				2180			
				2190			
				2200			
				2210			
				2220			
				2310			
				2520			
				2530			
				2580			
				2590			
				2600			
				2610			
				2620			
				2630			
				2640			
				2870			

EROSION RESISTANCE STATUS — TABLE 2

LEFT BANK

5	4.5	4	3.5	3	2.5	2	1.5	1
2620	100	50	30	150	170	1440	2720	1240
	300	60	40	160	180	1450	2860	1250
	310	110	70	190	590	1460	3020	2270
	340	120	80	200	600	1510	3030	2280
	370	140	90	510	630	1520	3040	2400
	380	210	130	520	640	1530		2410
	390	270	220	530	770	1580		2420
	940	280	230	540	780	1590		2430
	950	290	240	550	1260	1600		2440
	1050	320	250	560	1430	1630		2450
	1100	330	260	570	1470	1640		2460
	1130	350	430	580	1480	1650		2470
	1140	360	440	610	1490	1800		2480
	1150	400	450	620	1500	1810		2490
	2140	410	460	760	1620	1820		2500
	2150	420	470	790	1890	1900		2510
	2230	490	480	800	2260	2290		2520
	2240	650	500	810	2310	2300		2530
	2540	660	670	820	2320	2360		2630
	2550	890	680	830	2390	2370		2750
	2560	900	690	840	2790	2380		2870
	2590	910	700	850	2800	2570		2880
	2640	920	710	860	2810	2710		3010
	2760	930	720	1090	2820			3050
		960	730	1200	2890			
		970	740	1210	2900			
		980	750	1220	2960			
		990	870	1230	2970			
		1010	880	1420	2980			
		1020	1000	1540				
		1030	1070	1550				
		1040	1080	1560				
		1060	1170	1570				
		1110	1180	1610				
		1120	1290	1720				
		1160	1350	1750				
		1190	1360	1760				
		1270	1370	2010				
		1280	1390	2020				
		1300	1410	2250				
		1310	1660	2330				
		1320	1680	2340				
		1330	1690	2600				
		1340	1700	2690				
		1390	1710	2700				
		1400	1730	2830				
		1670	1740	2840				
		2050	1770	2890				
		2060	1780	2910				
		2110	1790	2920				
		2120	1820	2930				
		2130	1840	2940				
		2160	1850	2950				
		2170	1860	2990				
		2180	1870	3000				
		2190	1880	[illegible]				
		2200	1910					
		2210	1920					
		2220	1930					
		2500	1940					
		2600	1950					
		2610	1960					
		2630	1970					
		2660	1980					
		2730	1990					
		2740	2000					
		2770	2020					
			2040					
			2070					
			2080					
			2090					
			2100					
			2300					
			2670					
			2700					

RIGHT BANK

5	4.5	4	3.5	3	2.5	2	1.5	1
210	110	40	60	30	1780	1320	1790	1000
240	220	90	70	40	2060	1490	1890	1010
410	250	100	120	50	2800	1550	1920	1020
1740	280	260	140	130	2810	1950	1930	1030
1770	290	270	170	150	2820	1960	1940	1540
2320	300	340	230	160	2850	2260	2420	1800
2330	310	370	320	180		2270	2660	1810
	330	380	610	190		2280	2720	1820
	390	430	620	200		2290	2750	1830
	400	440	630	350		2300	2830	1840
	420	450	650	360		2400	2840	1850
	480	460	660	1040		2410	2970	1900
	580	470	670	1050		2490		1910
	720	490	680	1060		2950		1970
	730	500	690	1070		2960		2430
	750	510	900	1080		2990		2440
	780	520	1100	1230		3000		2450
	860	530	1130	1240		3005		2460
	870	540	1140	1250		3010		2470
	880	550	1150	1260		3020		2480
	890	560	1160	1270				2500
	940	570	1170	1290				2510
	980	590	1180	1300				2550
	990	600	1190	1310				2560
	1090	640	1200	1330				2570
	1300	700	1210	1860				2650
	1390	710	1220	1870				2730
	1430	740	1280	1880				2740
	1440	760	1340	1900				2900
	1450	770	1350	1990				2910
	1460	790	1360	2030				2920
	1470	800	1370	2040				2930
	1520	810	1610	2050				2940
	1530	820	1690	2670				2980
	1640	830	2000	2680				3030
	1680	840	2010	2690				3040
	1660	850	2020	2700				3050
	1730	910	2070	2710				
	1750	920	2080	2760				
	1760	930	2120	2770				
	2150	950	2130	2780				
	2340	960	2140	2790				
	2350	970	2160					
	2360	1110	2170					
	2370	1120	2180					
	2380	1400	2190					
	2390	1410	2200					
	2540	1420	2860					
	2600	1480	2870					
	2620	1500	2880					
		1510	2890					
		1560						
		1570						
		1580						
		1590						
		1600						
		1620						
		1630						
		1670						
		1680						
		1700						
		1710						
		1720						
		2090						
		2100						
		2110						
		2210						
		2220						
		2230						
		2240						
		2280						
		2310						
		2520						
		2530						
		2580						
		2590						
		2610						
		2630						
		2640						

		DATABASE - REPORT INQUIRIES			TABLE 3-A		
EDGE LINING OF RO		VEGETATION STRENGTHENING OF RF		W/Wt RATIO 0.9 - 1.1			
LEFT	RIGHT	LEFT	RIGHT	XS	W/Wt	XS	W/Wt
110	1400	620	590	2090	0.91	2260	1.01
120	1410	630	600	2100	0.91	2280	1.01
130	1420	640	610	2110	0.91	2080	1.06
140	1480	650	620	2950	0.93	2120	1.06
150	1490	660	630	2970	0.93	2130	1.06
160	1500	670	650	2980	0.93	2210	1.06
170	1550	680	660	140	0.96	2220	1.06
180	1560	690	670	350	0.97	2230	1.06
190	1570	880	680	380	0.97	280	1.07
200	1610	1360	690	160	0.98	290	1.07
320	1620	1370	1280	250	0.98	300	1.07
330	1630	1380	1290	270	0.98	320	1.07
1430	1670	1590	1300	410	0.99	150	1.09
1440	1680	1600	1430	420	0.99	180	1.09
1450	1690	1680	1440	450	0.99	210	1.09
1460		1730	1450	480	0.99	220	1.09
1500		1740	1460	540	1.00	240	1.09
1510		2050	1470	550	1.00		
1520		2060	1510	560	1.00		
1530		2070	1520	570	1.00		
1580		2080	1530	770	1.00		
1590		2090	1580	780	1.00		
1600		2100	1590	810	1.00		
1630		2110	1600	990	1.00		
1640		2120	1640	1000	1.00		
1650		2130	1650	1050	1.00		
1660		2140	1660	1060	1.00		
1680		2150	1700	1070	1.00		
1690		2160	1710	1110	1.00		
1700		2170	1720	1120	1.00		
1710		2180	1980	1130	1.00		
1720		2190	1990	1140	1.00		
1750		2200	2050	1260	1.00		
1760		2210	2060	1270	1.00		
1960		2220	2070	1290	1.00		
1970		2230	2080	1400	1.00		
1980		2240	2120	1410	1.00		
1990		2250	2130	1440	1.00		
2010		2260	2540	1470	1.00		
2020		2790	2800	1480	1.00		
2030		2800	2810	1490	1.00		
2040		2810	2820	1500	1.00		
		2820		1510	1.00		
		2960		1750	1.00		
				1760	1.00		
				1770	1.00		
				1780	1.00		
				1840	1.00		
				1910	1.00		
				2860	1.00		

DATABASE - REPORT INQUIRIES		TABLE 3-8	
EDGE VEGETATION WITH M AND WIDTH > 15M			
LEFT		RIGHT	
XS	WIDTH	XS	WIDTH
410	15	440	15
420	15	460	15
550	15	500	15
670	15	630	15
680	15	780	15
690	15	800	15
700	15	860	15
1360	15	870	15
1400	15	900	15
1610	15	1100	15
1620	15	1120	15
1720	15	1380	15
2590	15	1730	15
480	20	1760	15
530	20	2030	15
610	20	2110	15
620	20	2610	15
660	20	390	20
730	20	450	20
850	20	700	20
980	20	710	20
990	20	730	20
1110	20	750	20
1140	20	1090	20
1340	20	2850	20
1350	20	810	25
1370	20	890	25
1380	20	950	25
1410	20	960	25
1420	20	2100	25
1430	20	370	30
1470	20	650	30
1480	20	660	30
1490	20	670	30
1500	20	680	30
2740	20	760	30
2840	20	770	30
2940	20	880	30
580	25	940	30
830	25	1110	30
840	25	1370	30
860	25	2540	30
1030	25		
2920	25		
500	30		
510	30		
520	30		
540	30		
590	30		
600	30		
650	30		
810	30		
1130	30		
1270	30		
2600	30		
2610	30		
2810	30		
2930	30		
2950	30		
450	40		
470	40		
630	40		
640	40		
770	60		

3 PAST MANAGEMENT

3.1 Records

Management of the Hutt River in accordance with a defined engineering approach started at the beginning of this century, after the formation of the Hutt River Board and the initiation of a scheme of works. The River Board district only went as far upstream as Boulcott at first, but in 1910 the district was extended to Silverstream, and a programme of river works was then maintained over the whole of the Lower Valley reach of the river. The Upper Valley was not brought into the Board district until 1956.

There are some engineering records of the activities of the River Board, but much less than might be expected given the long period of river management, and the importance of this management to an increasingly urbanised area. There are some old plans of channel straightening and enlargement proposals along the lower reaches of the river below Ewen Bridge, and a few plans of the many timber and gabion groynes built by the Board over a long period of time. The river management undertaken by the Board was guided by a long term objective of achieving an "ultimate controlled channel" that had a very gently curving alignment. There are plans of this channel, which had a width of only 30 m above Ewen Bridge, and 40 to 50m downstream of the bridge. There is also a plan of a similar proposed "ultimate channel" for the Upper Valley, prepared in 1938 when an extension of the Board district upstream of Silverstream was proposed.

There are no substantial engineering reports of the Board's activities, and the available engineering comment is mainly restricted to monthly meeting reports and flood damage reports prepared for the Board meetings. This lack of records is partly due to the nature of river management, and the emphasis on continual maintenance rather than capital expenditure of the Board. River works are not designed in a quantitative manner according to a comprehensive analytical framework, and until computers became available there was little in the way of quantitative analysis to be recorded. The river management of the Board involved mainly a programme of timber and gabion groyne or retard construction and maintenance, the continual establishment of bands of willows, the removal of the large logs and debris that accumulated in the river channel (including the removal of forest remnants as they were exposed by channel degradation) and the supervision of gravel extraction from the river channel. The river works were funded from extraction royalties and rates, and there was a remarkably constant expenditure on works. Even major flood events did not seem to have a great effect on works expenditure. There were, then, no major works that would require capital funding and might warrant specific design and engineering comment.

Up to the 1950's the Board's activities were guided by just two engineers, Liang-Meason up to 1924 as a consultant to the Board, and H Sladden as the Board engineer. There was then a consistency in river management over a long period of time, and because of this a reasonable idea of the management approach can be obtained, in spite of the lack of records.

A relatively detailed engineering report was prepared on proposals for the Upper Valley in 1953 by the Ministry of Works, with accompanying plans of a proposed control channel and stopbanks. These proposals were not implemented, but the Upper Valley was soon incorporated into the River Board district. Extensive river works have been carried out in the Upper Valley in recent years in association with state highway improvements, and there was a definite design base to these works, and construction drawings were prepared.

For the more recent rock work carried out in the Lower Valley construction drawings were prepared, and in some cases the design basis has been recorded. The main maintenance activity in recent years has been willow planting, and like most maintenance the aims and extent of the activity have not been formally recorded.

Unfortunately there are virtually no engineering records from the 1950's until the River Board was incorporated into the Wellington Regional Water Board in 1972. During this period there was a substantial increase in gravel extraction, with major straightening and confining of the river channel in the Upper Valley. The first major channel realignment upstream of Silverstream was constructed in the later 1960's. In the Lower Valley around the Kennedy-Good Bridge area the channel was further confined to its present position, while upstream of Belmont substantial bank protection works were undertaken as part of state highway improvements. At the same time there was further channel degradation.

During this period major floods (of around a 10 year return period) occurred - in 1955, 1962, 1965 and 1966. But we know virtually no thing about the details of the works undertaken or the response of the river in these flood events.

The History report, prepared as part of the scheme review, documents the available records and summarises the information contained in these records. It also has plans of the river channel taken from aerial photography of 1936, 1951, 1967 and 1974 overlaid on aerial photography of 1985 for the Lower Valley and 1988 for the Upper Valley. This report and the original aerial photography have been a prime source of information for this study.

3.2 River Response

The Hutt River has been greatly modified over the last 100 years, and the way in which the river responds now will be different to the responses of the natural river. At the time of European colonisation the Hutt River had only a normal channel entrenchment within the alluvial material of the Upper and Lower Valley, and there was a vegetation cover of native forest. There would have been substantial channel movement during flood events through bank erosion and deposition, with new channels forming across the flood plain from channel break outs.

The records of flood events last century emphasis the mobility of the river channel, with extensive gravel deposition being formed on the recession of flood flows. There were also large accumulations of debris, which included very big logs. The large amount of debris can be attributed to the logging activity on the floodplain and in the catchment, and the destruction of much of the forest cover. The building up and bursting of log jams during intense storm events may have significantly affected the runoff characteristics of the catchment and tributary waterways, and the release of stored water by such bursting during the most intense period of rainfall (that can occur near the end of the storm event) may have increased the peak flow of the floods.

The accumulations of gravel along the river channel were also blamed on the removal of the forest cover in reports about these flood events. However, the people concerned probably did not appreciate the natural mobility and gravel transporting capacity of the river. The Hutt River catchment did not suffer from a lot of induced erosion due to the removal of the forest cover, as occurred elsewhere in New Zealand. The catchment consists mainly of relatively competent greywacke, and over much of the catchment there was never a total removal of the forest cover. The removal of the forest from the flood plain would, however, have increased the intensity of the bank erosion and deposition activity of the river, as the loss of forest vegetation increased the erodibility of the banks.

In the lower reaches the river channel was straightened and enlarged as part of the first scheme, with the banks being protected by substantial permeable timber groynes constructed at intervals along the bank. At the same time stopbanks and flood defence walls confined flood flows to this enlarged channel. There was then some complementarity between the channel enlargement and the confinement of flood flows. There seems to have been a reasonably well-established policy of on-going maintenance, with the groynes being repaired as required. Channel capacity continued to increase to the time of the 1939 flood, and the flood reports of H Sladden, the River Board engineer, indicate that serious erosion that would threaten the flood defences did not occur in the lower reaches below Ewen Bridge.

Serious erosion did occur in the reach around Melling Bridge, and this reach was considered to be a difficult one to manage until the Melling Cut was put through. Upstream of Melling the river channel changed from flood to flood, and river works had to be constantly repaired or replaced. The river works used by the Board included sets of short gabion groynes or of longer permeable timber groynes, long solid groynes across secondary channels or channel bays and gabion weirs to block off back channels, as well as bands of willows along the channel edges. These works were often damaged or destroyed in flood events, while the deflection of the river from one place could set up a sharp cross-over that would cause erosion problems further downstream. The flood reports of the River Board indicate that erosion of the banks could be substantial, for instance a 100-120 m bay up to 20 m wide and the removal of 60-80 m of an established band of willows and poplars leaving a 4 m high bare bank in the December 1939 flood event. Planting and cabling of willows was used to establish protective bands of willows, and these works could be completely removed or covered in gravel during significant (2 year return period or even lesser) flood events.

Gravel extraction played a very important part in the management of the Hutt River. Large gravel beaches could form on the recession of flood flows, with sharp low flow channel cross-overs between the deposits. These sharp cross-overs, or channel sets, would deflect flood flows into the bank, and cause direct flow attack to the banks. Gravel extraction was used to remove these deposits, and reduce the sharpness of the low flow channel. Substantial channel cuts were also carried out to straighten the river.

The gravel extraction and river works were then used together to maintain a much straighter and narrower channel. The river responded by forming tightly curving low flow channels with associated high beaches. This is the first phase of the development of a more curved meandering channel, and if the initial erosion is not checked an increasingly curved river bend would form. The constant reinstatement of bank protection works and removal of beach deposits was, therefore, fundamental to the successful maintenance of a narrow gently curving channel.

The width of bank erosion would generally remain quite small when the channel has little curvature. However, once a definite curvature develops river attack is concentrated against the outer bank and substantial erosion can take place very quickly. The development of one bend then directs the flood flows across to the opposite side downstream, increasing the pressures for a similar downstream development.

While the aim of the gravel extraction may have been channel bed management, it also gave rise to channel deepening. The gravel bed material of the Hutt River is transported at a relatively slow rate, and in the Lower Valley (above Ewen Bridge) channel degradation has occurred from at least 1944 onwards. As the channel management worked the river into a narrower and straighter channel, the channel was deepened. This increased the flood flow capacity of the channel, but reduced the ability of the river to break out and increased the amount of material that had to be eroded away for a given lateral movement of the channel.

The flood hydrographs of the Hutt River and quite sharp, and high flows are not sustained for long periods of time. This restricts the amount of erosion that can occur in any one flood event. To contain erosion and prevent breakouts, protection works need to remain intact or at least still function for short periods only, and the protection level can be reinstated by repair or remedial works carried out after the flood event.

For the Lower Valley reach between Melling and Taita, the river channel shown in the 1951 aerial photography is approximately along the alignment of the present channel (unlike that of 1936) but is substantially wider.

In the 1967 photography the channel is in nearly the same position as the present channel, but is still somewhat wider from below Kennedy-Good Bridge to opposite Fraser Park. In the

1974 photography the channel is virtually the same in plan position as the present channel throughout the Lower Valley. Over this period of time the channel had been progressively degrading.

The management approach taken and the river response in terms of damage to works and erosion is, however, not known due to the lack of records.

Very substantial changes to the river channel were being imposed along the Upper Valley reach over this same period (from the 1950's to early 1970's) and this is clearly shown in the aerial photography. Again the lack of records seriously hinders any assessment of the works carried out and the river response. Gravel extraction was directed to the Upper Valley between 1968 and 1972, and in this case extraction was used for major channel development. Cross-blading of the channel, which involves the reforming of the channel bed to eliminate the high beaches and sharp cross-overs that form within the imposed channel, probably began during this period. Gravel extraction was then not so closely associated with elimination of the sharp cross-overs.

Substantial degradation has occurred in the Upper Valley since the first channel survey of 1950, and there has been the same general changes in the Upper Valley as occurred earlier in the Lower Valley. The channel degradation has not, however, been as great, and the greywacke baserock has been exposed in the channel in places along the Upper Valley reach.

Flood damage reports have been prepared for significant flood events since the mid 1970's, and during the major (about 10 year return period) flood events of the early 1980's, long lengths of bank erosion occurred throughout the river (below Birchville). This bank erosion extended from around 100 m up to 400 m, but was generally only a metre or two deep. Erosion occurred downstream of Ewen Bridge in a similar way to that upstream of the bridge, but by then there was no longer a continual series of groynes, although some still remained. The channel had only a slight curvature throughout the Lower and Upper Valleys, but the banks were bare of tree vegetation over long lengths.

Since then rubble and rock linings have been constructed along the lower reaches, and substantial lengths of bank in the Upper Valley have been lined with rock. Willow planting has also been carried out, with the bands of willows being wider than previously, and strengthened by cabled rail fences in many places. The response to these works can not yet be properly assessed as there have not been any major floods since their construction. Erosion of the fenced plantings has occurred during small floods, when they came under attack, in spite of the continual cross-blading work that has been carried out. The outer bank flow channels have partly moved off the rock linings in the Upper Valley, and exposed baserock is now influencing channel migration, and in places this is giving rise to even sharper cross-overs.

The river channel is now very much straighter and deeper than it was. Baserock has been exposed in the Upper Valley and there is a marked decline in the size of the bed material from Totara Park, with a rapid decline below Ewen Bridge. The berm material is in contrast quite uniform and of smaller size. The channel banks are generally very high for a gravel river, especially in the Lower Valley, and the bank material is more easily transported than the channel bed material. The relativity between the erodibility of the channel banks and transportability of the channel bed material is an important determinant of river regime. This relativity may have been significantly altered (see River Characteristics and Sedimentation Study).

3.3 Effectiveness

The flood defences of the initial scheme have not been breached by river attack, although erosion up to the stopbanks has occurred downstream of Melling Bridge, upstream of Ewen Bridge and at the bridge itself, by Alicetown and at Croft Grove. In the Lower Valley upstream of Melling farmland was affected by erosion, gravel deposition and flooding, and roads have been washed out, but urban areas have not been seriously affected since the commencement of river management under the (second) Hutt River Board. Large floods have occurred since river management commenced, with the largest in 1939 (estimated peak flow of 1600 m3/s, and high flood levels sustained for about 10 hours) and the next largest in 1931 (estimated peak flow of 1400 m3/s, with relatively high levels sustained for about a week). Medium-sized flood events have occurred in 1913, 1915, 1924, 1948, 1955, 1962, 1965, 1966, 1980, 1981, and 1982. The river management that has been undertaken, over a long period of time in the Lower Valley has, therefore, been tested(if not to the present design standard) and the primary aim of flood control has been achieved.

In assessing the effectiveness of river management it is important to bear in mind that losses are an inherent part of most river management approaches. River works are seldom intended to remain intact through all flood events up to same design standard. Only when very heavy engineering works are used is any failure unlikely, and even then costly maintenance can still be required.

Rivers are naturally highly dynamic and mobile, and river management approaches that take account of their natural variability will generally be more cost-effective in the longer term. Constant losses and the continual repair and replacement of river works does not then in itself indicate a lack of effectiveness. There are many trade-offs in river management, between overall approaches, in the balance of different types of works, in the strength and layout of works and in the programme of maintenance. None of these trade-offs can be properly quantified, and an assessment of effectiveness necessarily involves a qualitative weighing of the evidence, and a reliance on engineering judgement.

Whenever river management is undertaken the effects of the small and medium-sized floods, that occur with relative frequency, must be considered, as well as the effects of the large flood events that may be the design standard. In what way are the effects of the more frequent floods going to be accommodated, so that the inplace protection is sufficient to withstand the effects of a large flood without a failure of the flood defences themselves? How much redundancy should there be in the protection works to facilitate repairs and to insure against the non-repair of works prior to a design event?

When the design standard is a large flood event, such as a 100 year return period flood, the design conditions are likely to involve two large flood events in quick succession. Large floods on the Hutt River have occurred in pairs - in January and September 1858, March and August 1893, June and November 1898, and on a lesser scale in November 1930 and April 1931, and ?? and December 1939. Large floods have occurred in pairs on many other rivers in New Zealand, and the occurrence of more than one large flood within a short period of time appears to be a general condition in New Zealand.

The security provided by a given set of river works and channel management practices very much depends on the berm width - from the channel edge to the flood defences (stopbanks or walls). The amount of damage and losses that can be allowed within any given management approach also depends very much on the berm width. Where there is a substantial berm there is much more flexibility and a wider range of river management approaches can be considered. On the Hutt River there are substantial berms along many reaches, with recreational parks, playing fields and golf courses giving rise to a wide separation between the river channel and urban areas. In fact in only a few places is there virtually no separation - Croft Grove, Alicetown, Ewen Bridge area and Gemstone Drive. There are long lengths were the state highway is very close to the river, but a lower level of protection against erosion may be appropriate for the highway compared to urban flood defences.

Upstream of Melling the management approach of the Hutt River Board was one of containment by means of river works that were continually being repaired, replaced, extended or repositioned, and through managed extraction of the gravel bed material. Even quite small floods could overwhelm the protection works, but over time the river channel was moved towards a defined channel alignment, and with many set-backs was slowly reduced in width. The river channel in the 1951 photography is markedly different to that of the 1936 photography, and between these two sets of photographs the same management approach was applied, and the large 1939 flood event occurred. The continual repair and adaption of the river works to changing river channel conditions was undoubtedly important to the effectiveness of the river management. When works were lost they were not necessarily reestablished to the same layout as before, on the contrary the layout was adapted to the then prevailing conditions, with the alignment of the 'ultimate control channel' acting as the overall guide. By the nature of the management aim works would become redundant. When back channels or parts of the active channel were successfully blocked off, the works used to achieve this would not longer be exposed to river attack, and new works would be necessary to further contain the active channel.

However, the channel deepening that was generated by the gravel extraction was probably crucial to the degree of straightening and narrowing that has been achieved along the Hutt River. Back channels and other active channel areas could become inaccessible to the river simply through height differences. In the Lower Valley above Melling the channel degradation probably took place slowly at first, but even by the time of the 1939 flood it is obvious (from the records of flooding or lack of flooding) that many areas that had been prone to flooding could no longer be reached by floodwaters. For instance, overflows at Taita to the Waiwhetu Stream did not take place during the 1939 flood event, and further downstream the flooding was also of a relatively restricted extent compared to the flooding that occurred during the flood events of the 19th century. The really pronounced narrowing, though, took place after 1950, when the amount of gravel being extracted was substantially greater and continuing channel degradation occurred. Above Kennedy-Good Bridge average channel bed levels have dropped from 3.5 to 5.5 m since 1944, and from 1.5 to 3 m since 1964.

In the Upper Valley the channel straightening and narrowing was carried out over a much shorter period of time, with gravel extraction being used to carry out more substantial cuts and give rise to a much quicker repositioning of the active channel. Along the Upper Valley average bed levels have dropped around 2 to 3 m since 1950.

Severe erosion and damage to protection works has occurred in the Upper Valley, although floods in excess of a 10 year return period event have not occurred since the large scale channel realignment and narrowing was carried out. The first Silverstream cut was also unsuccessful, with bank protection works not being fully maintained, and the river breaking back into its old channel.

With the more rapid establishment of a narrow straightened channel in the Upper Valley the accompanying channel degradation has been less pronounced than in the Lower Valley, while the closeness of the baserock to the surface has had a restricting effect on channel deepening. Once a design 'control channel' has been established heavier bank protection works can then be constructed along the channel edges. No further imposed repositioning of the channel is intended, so protection works no longer become redundant, while the aim of the protection works becomes one of fixing the channel edges. Thus when the state highway was constructed beside the Hutt River along the Upper Valley, there was a change in approach towards heavier bank protection works. Rock linings were used to fix the channel edge, and between Silverstream and Moonshine Bridge these works were positioned according to a design meander pattern.

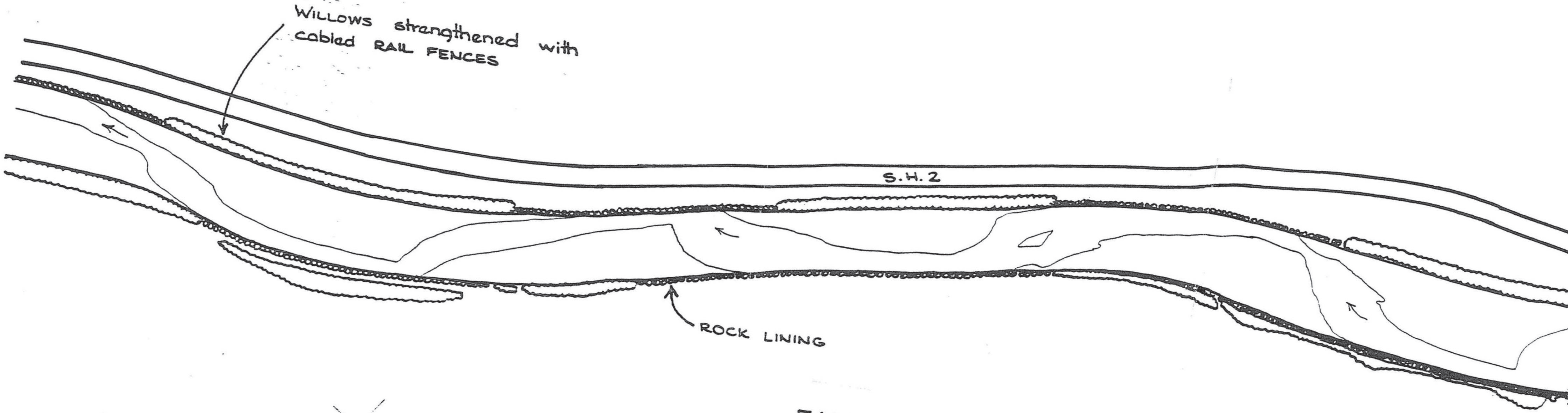
The approach taken between Silverstream and Moonshine Bridge involved alternating rock linings according to a specified meander pattern. The rock linings were placed along the outer banks of the design meander, with a band of willows strengthened by cabled rail fences between the rock linings along the inner banks. The design, which was undertaken by the Ministry of Works, then assumed not only the fixing of the channel, but the fixing of the meander pattern within that channel. A strictly uniform design has not, however, been imposed. There is some variation in the width of the channel, and the rock linings do not overlap consistently according to a design meander. On the left bank in particular the works have been modified on account of existing vegetation, and in some places these modifications were a requirement of the Wellington Regional Council. On Figure 3 the actual channel with the rock linings and willow bands as constructed is shown for a reach of these works, along with a consistently designed channel for the same reach.

The channel meander has not stayed in the same place along this reach, and on Figure 3 the channel position in the 1988 aerial photography is shown. Since then further downstream migration has taken place, with the outer side of the channel bends being taken further downstream and into the lengths of willow bands. The channel cross-overs have also become sharper. The rock linings are thus no longer in the most effective position, and during flood rises are subjected to very direct attack. At present the channel cross-overs still take place within the rock linings, and in most places a considerable downstream migration is necessary before the cross-overs would direct attack against the much lighter willow protection. However, following a major flood event that mobilised the whole of the channel bed, a quite different meander pattern could be set up that was quite unrelated to the rock lining pattern.

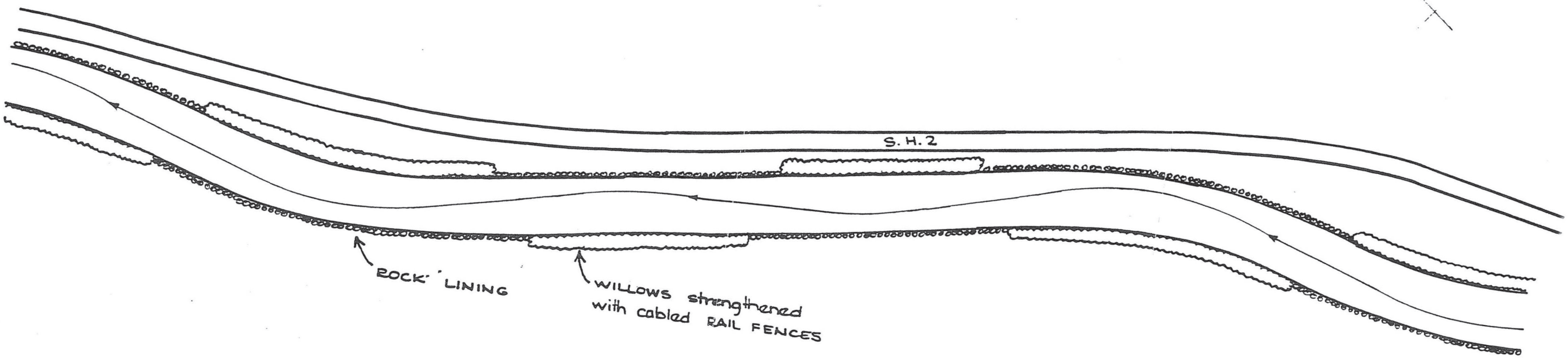
The artificial reworking of the channel bed by cross-blading has been used to take out the sharp cross-overs that are naturally set up by the river on the recession of floods. This work can only have a temporary effect, taking out the channel set that influences the pattern of flood flows in the next flood event. But the natural reworking of the flood flows reinstates the sharp cross-overs. The higher flood flows have a relatively straight natural form, and bank erosion and damage to protection banks from these flows can be greatly reduced by maintaining a relatively straight channel. However the overall response from the flow variations of flood hydrographs and the intermittent nature of floods of varying size is one of variable channel curvature and continual changes in channel form. For cross-blading to be effective in reducing damage it must be undertaken on a continual basis. It then becomes a substitute for continual repairs and/or strengthening of bank protection works. There is, in fact, a trade off between the channel management of cross-blading and directed gravel extraction, and the type and strength of bank protection works that are used.

A narrow channel does not have to be maintained by heavy bank protection works (such as rock linings) that fix the channel edge. Where there is sufficient berm width a more flexible boundary can be maintained by vegetation and groyne works. The channel edge works are then reinstated after damage, or established to reinstate the channel edge after bank erosion, to a generally defined channel position. The width and position of the channel remains the same, but the channel edge is less rigidly maintained, and in major flood events substantial erosion of the berms could occur.

However, where the channel has become deeper, with floods even up to a large size being contained in the channel with little



EXISTING CHANNEL AND WORKS



CONSISTENT CHANNEL AND WORKS

Scale 1 : 5000

FIXED CHANNEL WORKS

UPSTREAM OF SILVERSTREAM

Figure

or no berm flow, this more flexible approach to channel management is no longer a viable option. The channel edges are well defined by the entrenchment itself, and the channel boundary can no longer be easily varied by the river. At the same time groyne works are more difficult to construct, and tree vegetation is more difficult to establish and less effective in restraining bank erosion. On the berms the groundwater levels are deeper, while the root mass is relatively high compared to channel bed levels and scour depths.

4 PROTECTION WORKS

4.1 Scour

The energy available from the variable flow regime is expended on the transporting of material down the river. This transportation takes place through a continual picking up and depositing of material, with both bank erosion and accumulation and bed scouring and reforming taking place. The general scour that recurs during flood events can be estimated by using empirically derived formulae. In this study two formulae have been used, as given in Appendix B.

The required channel and flow characteristics (of width, depth, area, velocity and flow) have been obtained from the hydraulic modelling of specific flood flows, carried out by the Wellington Regional Council. In this modelling the surveyed cross-sections were taken as a fixed bed representation of the river channel, and the flow conditions for a steady flow were calculated by an iteration process. There is then some variability in the calculated flow depths and velocities due to the calculation method of the modelling, while in reality the scouring that takes place will give rise to an adjustment in flow depths and velocities to give more consistent flow conditions.

The general scour depth (as assessed in this study) is the maximum depth of the bed of the river below water level that may occur at some time during a flood event, with a given peak flow, due to the variations in bed levels that arise from the normal processes of bed material transportation. The area of the bed that is deeply scoured is usually quite small and can vary from flood to flood depending on the particular flow pattern of each event. Where there is a relative constriction in the river channel, for instance where bridge abutments extend into the channel, a general scouring of the bed can take place over a considerable length of the channel. A general lowering of the whole bed of the river by scouring can, though, only take place along the lowest reach of the river, where bed material can be exported through the river mouth to a large receiving body of water.

A scouring out of the lower reaches from about Ewen Bridge appears to have occurred in 1955, with very deep channel bed lowering being recorded at Ava Bridge. A medium sized flood event occurred in 1955, but why such a large amount of bed scouring should have occurred during this flood with only a gradual recovery in bed levels is not known. There is little information available about this flood event. The water level recorder plots do, however, show that a series of four floods of progressively larger flow peaks occurred one day after the other from 17 to 20 February. This sequence of flood events may have caused a progressive lowering of the bed of the river along its lower (tidal) reach because there was no time for a recovery and settling down of the bed material between the events.

An additional deepening of the bed can occur around significant obstructions within the river channel, such as groyne heads and bridge piers. Then a local scouring must be added to any general scour to obtain the total possible lowering of the river bed.

Judgement must be exercised in deciding what general scour depths to take for design purposes, given the variation in calculated depths of the different formulae applied in different ways, and using parameter values derived from hydraulic modelling. The interaction of the scouring itself on the parameter values must be considered, and whether the variation in scour depths calculated at different cross-sections reflects a likely real variation in scouring along the channel, or just a range of possible scour depths, must be decided.

General scour depths have been calculated for a selected set of cross-sections from the hydraulic modelling of estimated 2, 10 and 100 year return period flood flows. The results using the central channel flow only are given in Tables 4 to 6. The NZ Railways formula uses a flood level rise factor and this formula is not applicable to tidal reaches. Along the lower reaches there is a rapid reduction in the size of the bed material, and the Maza & Echavarria formula gives an indication of the increase in general scour depths that could take place due to this size reduction.

General scour depths have also been calculated using the whole channel flow, and the results for the estimated 100 year return period flood flows are given in Table 7. In this case the two formula give very different results, with the NZ Railways formula giving quite unrealistic scour depths in places, while the Maza & Echavarria results would suggest that there was no effective scour. Both formulae apply to well defined channels, and the shallow berm flows along the Hutt River give rise to inappropriate parameter values. In the case of the Maza & Echavarria formula the unit discharge parameter becomes inappropriate, while in the NZ Railways formula the adjustment for channel asymmetry has an extreme effect.

The scour depths given by the two formula using the central channel flow are reasonably consistent and can be taken as an indication of likely scour depths. The net scour depth (or bed lowering) given by the Maza & Echavarria formula increases in a progressive manner with increasing flood flow. In the case of the NZ Railways formula, while the scour depths increase, the net scour is more variable and does not necessarily increase with greater flood flows. The scour depths given by the NZ Railways formula are, though, generally somewhat greater. Interestingly, if the medium size of the bed material is taken

					HUTT RIVER - SCOUR DEPTHS (m)						TABLE 4
					2 YEAR FLOOD FLOW						
					CENTRAL CHANNEL						
SECTION	FLOW	WIDTH	AREA	MAX. DEPTH	MEAN DEPTH	RISE	MATERIAL	N.Z. RAILWAYS		MAZA & ECHAVARRIA	
XS	Q	W	A	D	Dm	R	d50	Ds	Ds-D	Ds	Ds-D
40	760	170	450	3.80	2.75	1.00	0.0002	1.3	-2.5	6.2	2.4
110	760	160	495	3.90	3.20	1.20	0.0020	1.2	-2.7	4.0	0.1
200	740	120	350	5.10	2.90	1.90	0.0100	3.3	-1.8	5.5	0.4
320	760	85	300	4.85	3.80	3.30	0.0200	4.4	-0.5	4.8	-0.1
440	720	65	285	6.10	4.50	4.40	0.0200	4.7	-1.4	6.0	-0.1
470	715	65	275	5.25	4.65	4.40	0.0200	4.6	-0.7	5.0	-0.3
550	750	80	290	4.80	3.75	3.75	0.0300	4.8	0.0	4.7	-0.1
690	760	140	295	3.30	2.50	2.55	0.0300	6.1	2.8	3.1	-0.2
770	660	95	255	3.60	3.25	3.25	0.0400	5.5	1.9	3.1	-0.5
850	750	115	245	2.85	2.10	2.20	0.0400	5.2	2.4	3.6	0.7
920	740	85	250	4.30	3.25	2.95	0.0500	5.3	1.0	4.2	-0.1
990	760	80	205	3.30	2.80	2.70	0.0500	5.7	2.4	4.0	0.7
1070	755	80	255	3.55	3.50	3.35	0.0500	4.6	1.1	3.4	-0.1
1150	760	75	225	3.95	3.30	3.15	0.0600	5.5	1.6	4.2	0.2
1230	755	60	210	4.15	3.85	3.70	0.0600	5.4	1.2	4.5	0.3
1300	755	80	235	3.70	3.20	3.20	0.0600	5.4	1.7	3.8	0.1
1460	735	80	230	3.10	2.65	2.80	0.0700	4.3	1.2	3.7	0.6
1520	750	85	250	4.30	3.05	3.00	0.0700	5.4	1.1	4.3	0.0
1600	725	85	240	3.50	2.95	2.65	0.0700	4.4	0.9	3.5	0.0
1740	755	85	200	2.95	2.25	2.50	0.0800	5.7	2.8	3.9	1.0
1820	760	75	245	4.50	3.55	3.70	0.0800	5.9	1.4	4.2	-0.3
1880	725	80	240	3.70	3.15	3.05	0.0800	4.8	1.1	3.6	-0.1
1980	665	120	260	4.40	2.50	2.50	0.0900	6.9	2.5	3.6	-0.8
2040	670	115	265	4.40	2.65	2.70	0.0900	6.7	2.3	3.5	-0.9
2110	665	75	215	3.85	3.20	2.90	0.1000	5.0	1.2	3.5	-0.4
2180	630	90	185	2.65	2.05	2.10	0.1000	5.1	2.4	3.1	0.5
2340	670	65	200	3.70	3.45	3.40	0.1000	5.3	1.6	3.5	-0.2
2420	670	50	205	8.20	4.55	4.45	0.1000	7.2	-1.0	7.2	-1.0
2500	670	55	245	6.65	4.65	4.40	0.1000	4.9	-1.7	5.3	-1.3
2590	430	45	130	3.35	2.90	2.85	0.1000	4.1	0.8	3.6	0.2
2700	445	45	135	3.90	3.00	3.00	0.1000	4.5	0.6	4.1	0.2
2800	370	95	180	2.85	2.00	1.90	0.1000	3.7	0.9	2.2	-0.7
2860	380	65	130	3.95	2.30	2.35	0.1000	6.4	2.4	3.6	-0.4
2930	320	40	110	4.05	2.95	2.45	0.1000	3.8	-0.3	3.7	-0.4
3050	365	30	80	4.05	2.85	2.85	0.1000	6.0	2.0	5.3	1.2

					HUTT RIVER - SCOUR DEPTHS						TABLE 5
						(m)					
					10 YEAR FLOOD FLOW						
					CENTRAL CHANNEL						
SECTION	FLOW	WIDTH	AREA	MAX. DEPTH	MEAN DEPTH	RISE	MATERIAL	N.Z. RAILWAYS		MAZA & ECHAVARRIA	
XS	Q	W	A	D	Dm	R	d50	Ds	Ds-D	Ds	Ds-D
40	1270	170	515	4.20	2.60	0.85	0.0002	1.5	-2.7	10.9	6.7
110	1270	160	590	4.50	3.65	1.65	0.0020	2.0	-2.5	6.1	1.6
200	1195	120	455	5.95	3.75	2.75	0.0100	4.3	-1.7	7.2	1.3
320	1250	85	385	5.85	4.75	4.25	0.0200	5.4	-0.4	6.8	1.0
440	1135	65	370	7.35	5.80	5.70	0.0200	5.5	-1.9	8.0	0.7
470	1150	65	355	6.50	5.95	5.70	0.0200	5.6	-0.9	7.0	0.5
550	1130	80	400	6.15	5.15	5.15	0.0300	5.2	-0.9	6.0	-0.1
690	1255	150	420	4.20	3.40	3.45	0.0300	7.6	3.4	4.1	-0.1
770	965	95	340	4.45	4.10	4.10	0.0400	5.7	1.2	4.0	-0.4
850	1225	115	335	3.65	2.90	3.00	0.0400	6.2	2.5	4.9	1.2
920	1210	85	330	5.25	4.25	3.95	0.0500	6.4	1.1	5.8	0.5
990	1265	80	260	4.00	3.55	3.45	0.0500	7.3	3.3	5.7	1.7
1070	1235	80	350	5.20	4.70	4.55	0.0500	5.9	0.7	5.5	0.3
1150	1250	75	300	4.95	4.30	4.15	0.0600	6.6	1.7	5.9	1.0
1230	1250	60	280	5.30	5.00	4.85	0.0600	6.5	1.2	6.5	1.2
1300	1240	80	320	4.80	4.30	4.30	0.0600	6.5	1.7	5.4	0.6
1460	1125	80	315	4.15	3.75	3.90	0.0700	5.1	1.0	4.9	0.7
1520	1145	85	340	5.35	4.10	4.05	0.0700	6.0	0.6	5.6	0.2
1600	1150	85	305	4.25	3.75	3.45	0.0700	5.5	1.3	4.8	0.6
1740	1255	85	245	3.45	2.75	3.00	0.0800	7.2	3.7	5.6	2.2
1820	1200	75	355	5.95	5.05	5.20	0.0800	6.3	0.4	5.6	-0.3
1880	1085	80	320	4.75	4.20	4.10	0.0800	5.5	0.8	4.7	0.0
1980	1155	120	350	5.15	3.25	3.25	0.0900	7.9	2.7	5.0	-0.2
2040	1150	115	365	5.25	3.50	3.55	0.0900	7.4	2.1	4.9	-0.4
2110	1140	75	270	4.55	3.90	3.60	0.1000	6.4	1.8	5.2	0.6
2180	1055	90	260	3.40	2.85	2.90	0.1000	5.8	2.4	4.3	0.9
2340	1155	80	280	4.90	4.70	4.65	0.1000	9.0	4.1	4.4	-0.5
2420	1160	55	285	7.00	6.10	6.00	0.1000	7.6	0.6	6.6	-0.4
2500	1150	55	350	8.60	6.65	6.40	0.1000	5.9	-2.7	7.3	-1.3
2590	735	45	195	4.80	4.35	4.30	0.1000	4.9	0.1	5.2	0.4
2700	760	45	185	5.05	4.20	4.20	0.1000	5.7	0.6	5.8	0.7
2800	560	95	240	3.50	2.80	2.70	0.1000	4.5	1.0	2.6	-0.9
2860	530	65	160	4.35	2.70	2.75	0.1000	6.5	2.2	4.4	0.0
2930	425	40	115	4.10	3.35	2.85	0.1000	5.0	0.9	4.1	0.0
3050	600	30	105	4.95	3.75	3.75	0.1000	7.3	2.3	7.2	2.3

					HUTT RIVER - SCOUR DEPTHS (m)						TABLE 6
					100 YEAR FLOOD FLOW						
					CENTRAL CHANNEL						
SECTION	FLOW	WIDTH	AREA	MAX. DEPTH	MEAN DEPTH	RISE	MATERIAL	N.Z. RAILWAYS		MAZA & ECHAVARRIA	
XS	Q	W	A	D	Dm	R	d50	Ds	Ds-D	Ds	Ds-D
40	1900	165	395	3.45	2.45	0.70	0.0002	2.5	-1.0	13.3	9.8
110	1890	160	650	4.85	4.15	2.15	0.0020	3.0	-1.8	7.8	3.0
200	1660	120	555	6.80	4.60	3.60	0.0100	5.1	-1.7	8.7	1.9
320	1840	85	455	6.70	5.65	5.15	0.0200	6.7	0.0	8.9	2.2
440	1560	65	450	8.60	7.00	6.90	0.0200	6.1	-2.5	10.0	1.4
470	1490	65	435	7.85	7.25	7.00	0.0200	6.1	-1.8	8.5	0.7
550	1320	80	515	7.60	6.55	6.55	0.0300	5.0	-2.6	6.6	-1.0
690	1840	150	480	5.10	4.30	4.35	0.0300	10.8	5.7	5.4	0.3
770	1300	95	435	5.45	5.10	5.10	0.0400	5.9	0.5	5.0	-0.4
850	1770	115	430	4.50	3.75	3.85	0.0400	7.0	2.5	6.2	1.7
920	1770	85	405	6.15	5.15	4.85	0.0500	7.5	1.3	7.5	1.4
990	1870	80	315	4.70	4.20	4.10	0.0500	8.5	3.8	7.7	3.0
1070	1800	80	450	6.40	5.95	5.80	0.0500	6.7	0.3	7.2	0.8
1150	1720	75	385	6.15	5.45	5.30	0.0600	7.2	1.1	7.5	1.3
1230	1740	60	350	6.50	6.20	6.05	0.0600	7.3	0.8	8.3	1.8
1300	1810	80	390	5.70	5.20	5.20	0.0600	7.6	1.9	7.2	1.5
1460	1490	80	395	5.15	4.70	4.85	0.0700	5.5	0.4	6.0	0.9
1520	1510	85	430	6.35	5.10	5.05	0.0700	6.2	-0.2	6.6	0.2
1600	1620	85	375	5.00	4.45	4.15	0.0700	6.1	1.1	6.3	1.3
1740	1780	85	345	4.65	3.95	4.20	0.0800	7.6	3.0	6.9	2.3
1820	1640	75	435	4.50	6.15	6.30	0.0800	5.2	0.7	4.5	0.0
1880	1500	80	380	5.45	4.95	4.85	0.0800	6.3	0.8	5.9	0.5
1980	1740	120	435	5.85	3.95	3.95	0.0900	8.8	3.0	6.4	0.6
2040	1670	115	445	5.95	4.20	4.25	0.0900	8.3	2.3	6.1	0.2
2110	1650	75	320	5.20	4.55	4.25	0.1000	7.5	2.3	6.8	1.6
2180	1560	90	330	4.15	3.60	3.65	0.1000	6.7	2.6	5.7	1.5
2340	1700	80	370	6.10	5.90	5.85	0.1000	9.5	3.4	5.9	-0.2
2420	1760	55	365	8.40	7.50	7.40	0.1000	8.5	0.1	8.9	0.5
2500	1700	55	460	10.55	8.60	8.35	0.1000	6.6	-4.0	9.5	-1.1
2590	1090	45	280	6.65	6.20	6.15	0.1000	5.3	-1.3	6.8	0.2
2700	1180	45	215	5.65	4.80	4.80	0.1000	7.0	1.4	8.0	2.3
2800	725	95	375	4.90	4.05	3.95	0.1000	3.8	-1.1	3.1	-1.8
2860	855	65	190	4.85	3.15	3.20	0.1000	8.0	3.2	6.1	1.2
2930	605	40	155	5.10	4.05	3.55	0.1000	4.9	-0.2	5.5	0.4
3050	885	30	135	5.90	4.65	4.65	0.1000	7.9	2.0	9.4	3.5

TABLE 7

HUTT RIVER - SCOUR DEPTHS

(m)

100 YEAR FLOOD FLOW

WHOLE CHANNEL

SECTION	FLOW	WIDTH	AREA	MAX. DEPTH	MEAN DEPTH	RISE	MATERIAL	N.Z. RAILWAYS		MAZA & ECHAVARRIA	
XS	Q	W	A	D	Dm	R	d50	Ds	Ds-D	Ds	Ds-D
40	1900	165	395	3.45	2.45	0.70	0.0002	2.5	-1.0	13.3	9.8
110	1900	170	655	4.85	4.15	2.15	0.0020	3.3	-1.5	7.5	2.7
200	1900	260	775	6.80	4.60	3.60	0.0100	8.9	2.1	5.3	-1.5
320	1900	105	495	6.70	5.65	5.15	0.0200	8.1	1.4	7.7	1.0
440	1900	150	650	8.60	7.00	6.90	0.0200	12.9	4.3	6.1	-2.5
470	1900	265	895	7.85	7.25	7.00	0.0200	14.2	6.4	3.4	-4.4
550	1900	500	1135	7.60	6.55	6.55	0.0300	16.4	8.8	2.1	-5.5
690	1900	210	605	5.10	4.30	4.35	0.0300	11.8	6.7	4.2	-0.9
770	1900	255	810	5.45	5.10	5.10	0.0400	9.6	4.2	3.1	-2.3
850	1900	165	500	4.50	3.75	3.85	0.0400	9.7	5.2	4.9	0.4
920	1900	130	475	6.15	5.15	4.85	0.0500	11.3	5.2	5.7	-0.4
990	1900	110	340	4.70	4.20	4.10	0.0500	12.5	7.8	6.1	1.4
1070	1900	170	580	6.40	5.95	5.80	0.0500	14.1	7.7	4.2	-2.2
1150	1900	255	550	6.15	5.45	5.30	0.0600	25.2	19.0	3.1	-3.1
1230	1900	255	510	6.50	6.20	6.05	0.0600	35.1	28.6	2.9	-3.6
1300	1900	205	490	5.70	5.20	5.20	0.0600	23.0	17.3	3.6	-2.1
1460	1900	290	725	5.15	4.70	4.85	0.0700	13.0	7.9	2.7	-2.5
1520	1900	300	785	6.35	5.10	5.05	0.0700	13.7	7.3	2.9	-3.4
1600	1900	230	595	5.00	4.45	4.15	0.0700	12.8	7.8	3.3	-1.7
1740	1900	205	445	4.65	3.95	4.20	0.0800	20.0	15.4	3.7	-1.0
1820	1900	215	675	4.50	6.15	6.30	0.0800	12.7	8.2	2.2	-2.3
1880	1900	245	685	5.45	4.95	4.85	0.0800	12.6	7.1	3.0	-2.5
1980	1760	160	465	5.85	3.95	3.95	0.0900	12.5	6.6	5.2	-0.7
2040	1760	215	525	5.95	4.20	4.25	0.0900	16.6	10.6	3.9	-2.0
2110	1760	205	415	5.20	4.55	4.25	0.1000	23.8	18.6	3.2	-2.0
2180	1760	160	420	4.15	3.60	3.65	0.1000	11.4	7.3	4.0	-0.2
2340	1760	125	410	6.10	5.90	5.85	0.1000	16.5	10.4	4.3	-1.8
2420	1760	55	365	8.40	7.50	7.40	0.1000	8.5	0.1	8.9	0.5
2500	1760	125	550	10.55	8.60	8.35	0.1000	18.0	7.4	5.1	-5.4
2590	1220	80	390	6.65	6.20	6.15	0.1000	7.4	0.7	4.8	-1.9
2700	1220	90	250	5.65	4.80	4.80	0.1000	16.5	10.9	4.8	-0.9
2800	920	355	855	4.90	4.05	3.95	0.1000	4.4	-0.5	1.3	-3.6
2860	920	230	340	4.85	3.15	3.20	0.1000	15.8	10.9	2.4	-2.5
2930	920	205	455	5.10	4.05	3.55	0.1000	8.4	3.3	2.1	-3.0
3050	920	40	160	5.90	4.65	4.65	0.1000	9.1	3.2	7.8	1.9

HUTT RIVER - RIP-RAP MATERIAL

ROCK LININGS

100 YEAR FLOOD FLOW

TABLE 8

SITE XS	MEAN VELOCITY Vm (m/s)	VELOCITY FACTOR	EFFECTIVE VELOCITY Ve (m/s)	DEPTH D (m)	WALLINGFORD 2:1 D50 (m)	WALLINGFORD 1.5:1 D50 (m)	CALIFORNIA HIGHWAYS PRACTISE 2:1 BATTERS W33 (kg)	2:1 BATTERS spheric D33	2:1 BATTERS cubic D33	1.5:1 BATTERS W33 (kg)	1.5:1 BATTERS spheric D33	1.5:1 BATTERS cubic D33
110	2.90	1.3	3.77	4.85	0.24	0.28	59	0.35	0.28	92	0.40	0.33
200	3.00	1.5	4.50	6.80	0.34	0.40	170	0.50	0.40	266	0.58	0.46
320	4.05	1.5	6.08	6.70	0.85	0.99	1030	0.91	0.73	1609	1.05	0.85
440	3.50	1.5	5.25	8.60	0.48	0.56	429	0.68	0.55	670	0.78	0.63
470	3.40	1.5	5.10	7.85	0.46	0.54	361	0.64	0.51	563	0.74	0.60
550	2.55	1.5	3.83	7.60	0.20	0.23	64	0.36	0.29	100	0.42	0.34
690	3.35	1.5	5.03	5.10	0.55	0.64	330	0.62	0.50	515	0.72	0.58
770	3.00	1.5	4.50	5.45	0.38	0.44	170	0.50	0.40	266	0.58	0.46
850	4.15	1.5	6.23	4.50	1.11	1.30	1193	0.95	0.77	1862	1.10	0.89
920	4.35	1.5	6.53	6.15	1.09	1.28	1582	1.04	0.84	2470	1.21	0.98
990	5.95	1.5	8.93	4.70	3.20	3.74	10361	1.95	1.58	16173	2.27	1.83
1070	4.00	1.5	6.00	6.40	0.83	0.97	956	0.88	0.71	1493	1.02	0.83
1150	4.45	1.5	6.68	6.15	1.17	1.37	1813	1.09	0.88	2830	1.27	1.02
1230	4.95	1.5	7.43	6.50	1.57	1.83	3435	1.35	1.09	5362	1.57	1.27
1300	4.60	1.5	6.90	5.70	1.34	1.57	2212	1.17	0.94	3453	1.36	1.09
1460	3.75	1.5	5.63	5.15	0.77	0.89	649	0.78	0.63	1014	0.90	0.73
1520	3.55	1.5	5.33	6.35	0.59	0.68	467	0.70	0.56	730	0.81	0.65
1600	4.35	1.5	6.53	5.00	1.21	1.42	1582	1.04	0.84	2470	1.21	0.98
1740	5.15	1.5	7.73	4.65	2.09	2.44	4357	1.46	1.18	6801	1.70	1.37
1820	3.75	1.5	5.63	4.50	0.82	0.96	649	0.78	0.63	1014	0.90	0.73
1880	3.95	1.5	5.93	5.45	0.87	1.01	887	0.86	0.69	1384	1.00	0.81
1980	4.00	1.5	6.00	5.85	0.87	1.02	956	0.88	0.71	1493	1.02	0.83
2040	3.75	1.5	5.63	5.95	0.71	0.83	649	0.78	0.63	1014	0.90	0.73
2110	5.15	1.5	7.73	5.20	1.97	2.30	4357	1.46	1.18	6801	1.70	1.37
2180	4.75	1.5	7.13	4.15	1.73	2.02	2682	1.25	1.00	4187	1.45	1.17
2340	4.60	1.5	6.90	6.10	1.30	1.52	2212	1.17	0.94	3453	1.36	1.09
2420	4.85	1.5	7.28	8.40	1.30	1.51	3039	1.30	1.05	4744	1.51	1.21
2500	3.70	1.5	5.55	10.55	0.51	0.60	599	0.76	0.61	935	0.88	0.71
2590	3.90	1.5	5.85	6.65	0.76	0.88	822	0.84	0.68	1283	0.97	0.79
2700	5.50	1.5	8.25	5.65	2.31	2.69	6464	1.67	1.35	10090	1.94	1.56
2800	1.95	1.5	2.93	4.55	0.11	0.13	13	0.21	0.17	20	0.24	0.20
2860	4.50	1.5	6.75	4.70	1.39	1.62	1939	1.12	0.90	3027	1.30	1.05
2930	3.95	1.5	5.93	4.45	0.96	1.12	887	0.86	0.69	1384	1.00	0.81
3050	6.65	1.5	9.98	5.90	3.99	4.65	20194	2.44	1.97	31523	2.83	2.28

as 0.02 m, which is about the medium size of the berm material, and thus possibly of the original bed material (see River Characteristics and Sedimentation Study), then the scour depths given by the Maza & Echavarria formula are about the same as those of the NZ Railways formula.

Upstream of the river mouth a lowering of the bed due to general scour of around 1.5 to 3 m should be expected. The calculated scour depths should not be taken as applicable to a specific cross-section, instead the range of values should be used as an indication of likely scour, the variations being more due to the particularities of the hydraulic modelling than real differences in scour potential.

4.2 Rock Works

The size of rock required for rock linings or snub groynes has been determined using two empirically derived formulae, given in Appendix C. These formulae use an effective velocity as the main parameter and this velocity has been determined from the main channel mean velocity given by the hydraulic modelling, multiplied by a velocity factor to give an effective flow velocity against the rock work. The following factors are a general guide:

1.25 for straight reaches

1.5 for bends

2.0 for groyne heads

The resulting rock sizes using the flow velocities and depth of a 100 year return period flood flow as determined at a selected set of cross-sections is given in Tables 8 and 9. The sizes have been calculated for batter slopes of 1.5:1 and 2:1, and using a velocity factor of 1.5 for rock linings and 2.0 for groynes.

The rock size is sensitive to the mean velocity value, and the velocities determined by the hydraulic modelling are unusually high. But the high velocities occur at many cross-sections and are not just isolated values. The Hutt River channel is now very different to its natural channel, and flood flows are contained within a much narrower and more entrenched channel. It may be, then, that higher than usual velocities can be generated within this channel. There appears to have been a sorting of the channel bed material, with an unusual downstream reduction in the size of the bed material. A response to higher velocities in terms of a downstream sorting of the channel bed material that leaves a more heavily armoured bed could be expected. Thus the possible changes in bed material and higher than usual calculated flow velocities are mutually supportive.

The calculated flow velocities should, therefore, be used in sizing rock material, but average velocities along a reach should be used rather than the velocity calculated at a specific cross-section. In Table 10 the rock sizes are given for a 1.5 velocity factor using average reach velocities.

TABLE 9

HUTT RIVER - RIP-RAP MATERIAL

ROCK GROYNES

100 YEAR FLOOD FLOW

SITE	MEAN	VELOCITY	EFFECTIVE	DEPTH	WALLINGFORD		CALIFORNIA HIGHWAYS PRACTISE					
XS	VELOCITY	FACTOR	VELOCITY		2:1	1.5:1	2:1 BATTERS			1.5:1 BATTERS		
	Vm (m/s)		Ve (m/s)	D (m)	D50 (m)	D50 (m)	W33 (kg)	spheric D33	cubic D33	W33 (kg)	spheric D33	cubic D33
110	2.90	2.0	5.80	4.85	0.87	1.01	780	0.83	0.67	1218	0.96	0.77
200	3.00	2.0	6.00	6.80	0.81	0.94	956	0.88	0.71	1493	1.02	0.83
320	4.05	2.0	8.10	6.70	2.00	2.34	5790	1.61	1.30	9038	1.87	1.51
440	3.50	2.0	7.00	8.60	1.14	1.33	2412	1.20	0.97	3765	1.39	1.12
470	3.40	2.0	6.80	7.85	1.10	1.28	2027	1.13	0.92	3164	1.32	1.06
550	2.55	2.0	5.10	7.60	0.47	0.55	361	0.64	0.51	563	0.74	0.60
690	3.35	2.0	6.70	5.10	1.30	1.52	1854	1.10	0.89	2895	1.28	1.03
770	3.00	2.0	6.00	5.45	0.90	1.05	956	0.88	0.71	1493	1.02	0.83
850	4.15	2.0	8.30	4.50	2.63	3.07	6702	1.69	1.36	10462	1.96	1.58
920	4.35	2.0	8.70	6.15	2.59	3.02	8889	1.86	1.50	13876	2.15	1.74
990	5.95	2.0	11.90	4.70	7.59	8.85	58215	3.47	2.80	90872	4.03	3.25
1070	4.00	2.0	8.00	6.40	1.98	2.31	5374	1.57	1.27	8389	1.82	1.47
1150	4.45	2.0	8.90	6.15	2.78	3.24	10188	1.94	1.57	15903	2.25	1.82
1230	4.95	2.0	9.90	6.50	3.72	4.34	19300	2.40	1.94	30127	2.79	2.25
1300	4.60	2.0	9.20	5.70	3.18	3.72	12430	2.08	1.67	19403	2.41	1.94
1460	3.75	2.0	7.50	5.15	1.82	2.12	3649	1.38	1.11	5695	1.60	1.29
1520	3.55	2.0	7.10	6.35	1.39	1.62	2626	1.24	1.00	4099	1.43	1.16
1600	4.35	2.0	8.70	5.00	2.88	3.35	8889	1.86	1.50	13876	2.15	1.74
1740	5.15	2.0	10.30	4.65	4.95	5.77	24478	2.60	2.10	38210	3.02	2.44
1820	3.75	2.0	7.50	4.50	1.94	2.27	3649	1.38	1.11	5695	1.60	1.29
1880	3.95	2.0	7.90	5.45	2.06	2.41	4983	1.53	1.24	7779	1.78	1.43
1980	4.00	2.0	8.00	5.85	2.07	2.41	5374	1.57	1.27	8389	1.82	1.47
2040	3.75	2.0	7.50	5.95	1.69	1.97	3649	1.38	1.11	5695	1.60	1.29
2110	5.15	2.0	10.30	5.20	4.68	5.46	24478	2.60	2.10	38210	3.02	2.44
2180	4.75	2.0	9.50	4.15	4.11	4.79	15069	2.21	1.79	23523	2.57	2.07
2340	4.60	2.0	9.20	6.10	3.08	3.59	12430	2.08	1.67	19403	2.41	1.94
2420	4.85	2.0	9.70	8.40	3.07	3.59	17076	2.31	1.86	26655	2.68	2.16
2500	3.70	2.0	7.40	10.55	1.22	1.42	3366	1.34	1.08	5255	1.56	1.26
2590	3.90	2.0	7.80	6.65	1.80	2.10	4617	1.49	1.20	7206	1.73	1.40
2700	5.50	2.0	11.00	5.65	5.47	6.38	36317	2.97	2.39	56690	3.44	2.78
2800	1.95	2.0	3.90	4.55	0.27	0.32	72	0.37	0.30	113	0.43	0.35
2860	4.50	2.0	9.00	4.70	3.28	3.83	10895	1.99	1.60	17006	2.31	1.86
2930	3.95	2.0	7.90	4.45	2.28	2.66	4983	1.53	1.24	7779	1.78	1.43
3050	6.65	2.0	13.30	5.90	9.46	11.03	113465	4.34	3.50	177117	5.04	4.06

TABLE 10

HUTT RIVER - RIP-RAP MATERIAL
ROCK LININGS
100 YEAR FLOOD FLOW
AVERAGE VELOCITIES

SITE	MEAN	VELOCITY	EFFECTIVE	DEPTH	WALLINGFORD		CALIFORNIA HIGHWAYS PRACTISE					
XS	VELOCITY	FACTOR	VELOCITY		2:1	1.5:1	2:1 BATTERS			1.5:1 BATTERS		
	Vm (m/s)		Ve (m/s)	D (m)	D50 (m)	D50 (m)	W33 (kg)	spheric D33	cubic D33	W33 (kg)	spheric D33	cubic D33
110	3.00	1.3	3.90	4.85	0.26	0.31	72	0.37	0.30	113	0.43	0.35
200	3.00	1.5	4.50	6.80	0.34	0.40	170	0.50	0.40	266	0.58	0.46
320	4.00	1.5	6.00	6.70	0.81	0.95	956	0.88	0.71	1493	1.02	0.83
440	3.50	1.5	5.25	8.60	0.48	0.56	429	0.68	0.55	670	0.78	0.63
470	3.50	1.5	5.25	7.85	0.50	0.59	429	0.68	0.55	670	0.78	0.63
550	3.00	1.5	4.50	7.60	0.32	0.38	170	0.50	0.40	266	0.58	0.46
690	3.50	1.5	5.25	5.10	0.63	0.73	429	0.68	0.55	670	0.78	0.63
770	3.50	1.5	5.25	5.45	0.61	0.71	429	0.68	0.55	670	0.78	0.63
850	4.50	1.5	6.75	4.50	1.42	1.65	1939	1.12	0.90	3027	1.30	1.05
920	4.50	1.5	6.75	6.15	1.21	1.41	1939	1.12	0.90	3027	1.30	1.05
990	4.50	1.5	6.75	4.70	1.39	1.62	1939	1.12	0.90	3027	1.30	1.05
1070	4.00	1.5	6.00	6.40	0.83	0.97	956	0.88	0.71	1493	1.02	0.83
1150	4.50	1.5	6.75	6.15	1.21	1.41	1939	1.12	0.90	3027	1.30	1.05
1230	4.50	1.5	6.75	6.50	1.18	1.37	1939	1.12	0.90	3027	1.30	1.05
1300	4.50	1.5	6.75	5.70	1.26	1.47	1939	1.12	0.90	3027	1.30	1.05
1460	4.00	1.5	6.00	5.15	0.93	1.08	956	0.88	0.71	1493	1.02	0.83
1520	4.00	1.5	6.00	6.35	0.84	0.98	956	0.88	0.71	1493	1.02	0.83
1600	4.50	1.5	6.75	5.00	1.34	1.57	1939	1.12	0.90	3027	1.30	1.05
1740	4.50	1.5	6.75	4.65	1.39	1.62	1939	1.12	0.90	3027	1.30	1.05
1820	3.75	1.5	5.63	4.50	0.82	0.96	649	0.78	0.63	1014	0.90	0.73
1880	3.75	1.5	5.63	5.45	0.74	0.87	649	0.78	0.63	1014	0.90	0.73
1980	3.75	1.5	5.63	5.85	0.72	0.84	649	0.78	0.63	1014	0.90	0.73
2040	4.00	1.5	6.00	5.95	0.86	1.01	956	0.88	0.71	1493	1.02	0.83
2110	4.75	1.5	7.13	5.20	1.55	1.81	2682	1.25	1.00	4187	1.45	1.17
2180	4.75	1.5	7.13	4.15	1.73	2.02	2682	1.25	1.00	4187	1.45	1.17
2340	4.75	1.5	7.13	6.10	1.43	1.67	2682	1.25	1.00	4187	1.45	1.17
2420	4.75	1.5	7.13	8.40	1.22	1.42	2682	1.25	1.00	4187	1.45	1.17
2500	4.75	1.5	7.13	10.55	1.09	1.27	2682	1.25	1.00	4187	1.45	1.17
2590	4.25	1.5	6.38	6.65	0.98	1.14	1376	1.00	0.80	2148	1.16	0.93
2700	5.00	1.5	7.50	5.65	1.73	2.02	3649	1.38	1.11	5695	1.60	1.29
2800	2.00	1.5	3.00	4.55	0.12	0.14	15	0.22	0.18	23	0.26	0.21
2860	2.50	1.5	3.75	4.70	0.24	0.28	57	0.35	0.28	89	0.40	0.32
2930	4.00	1.5	6.00	4.45	1.00	1.17	956	0.88	0.71	1493	1.02	0.83
3050	6.50	1.5	9.75	5.90	3.73	4.35	17611	2.33	1.88	27490	2.71	2.18

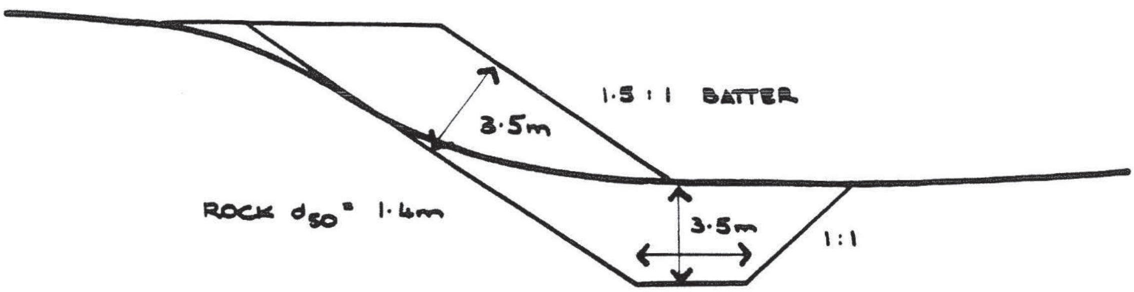
The stability of the rock material depends on the degree of turbulence of the flood flow as well as its velocity, but this influence is not directly taken into account in the formulae. Thus the rock size taken for design purposes again depends on judgement, this time relating to the degree of turbulence implicit in the derivation of the formulae and the functioning of rock works in practice. The difference between the equivalent spheric and cubic dimensions for a given weight as calculated by the California formula can be used as a turbulence factor. Large sized rocks tend to have an average dimension (the average of the overall rock width as measured in three directions) that is closer to the cubic dimension, and where the flow is not too turbulent the design rock size can be taken as the cubic dimension. Conversely where there is more turbulence the spheric dimension can be used, and this will give rise to a heavier rock than the calculated weight, thereby providing an additional weight margin for turbulence.

Taking account of the results from both formulae, the medium size of rock for linings should then be as follows:

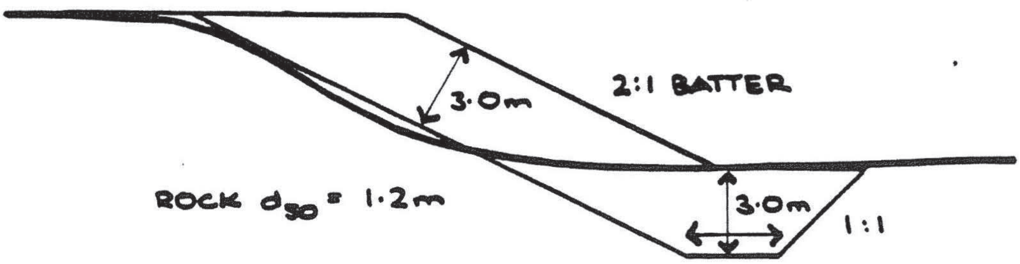
	1.5:1	2:1	
Downstream of Ewen Bridge	0.40	0.35	Grading A
Ewen to Kennedy-Good Bridge	0.65	0.55	Grading B
Kennedy-Good to Moonshine Bridge	1.40	1.20	Grading C
Moonshine to Totara Park Bridge	0.95	0.80	Grading B-C
Totara Park to Mangaroa Confluence	1.50	1.30	Grading C

The width of the lining should be 2 to 3 times the medium size dimension, depending on the degree of security required. Rock linings can be constructed with sufficient depth and bulk to cope with normal scour without much movement and hence topping up, or they can be constructed as lighter linings from the existing bed level and topped up as the rock settles, with additional follow on topping up. Either way the amount of rock tends to be about the same, just the proportion of initial rock to topping up being different.

If the more capital intensive lining is constructed, then a toe with a thickness and width about the same as the lining thickness should be constructed at the bottom of the lining, with the lining extending down to about the depth of general scour. The top of the lining should generally be at around the normal bankfull height of the 2 year return period flood level. In the case of the Hutt River a toe that started at the normal bed level would extend to about the general scour depth for the thicknesses of linings that are required. Localised scour against the rock would extend scouring below the lining in places, and some topping up would still be required. But for a cost effective lining some maintenance topping up should be carried out to provide extra rock where and when required. The design dimensions for this type of lining are shown on Figure 4.



REPRESENTATIVE LINING CROSS-SECTIONS



ROCK LININGS

Scale 1:250 **Figure 4**

Snub rock groynes could be used in places along the Hutt River, but the narrowness of the present channel restricts their use. Heavier rock would also be required, and upstream of Kennedy-Good Bridge the design velocities result in exceptionally large rock sizes and massive thicknesses.

4.3 Groynes

Permeable groynes of timber or rail have been used along the Hutt River. Where they have been maintained along the lower reaches they have been quite effective, but the groynes from Pomare Bridge upstream have been severely damaged when under direct attack. The high river banks make the construction of effective groynes more difficult, and with the deep channels that can form beside the outer banks under the constrained channel conditions, severe scouring can take place around the groynes when this type of protection is undertaken along such banks. Localised scouring takes place around the groyne heads, and when a set of groynes are placed along a bank this localised scouring can interact with the general bed scour, and give rise to unusually deep scouring.

To minimise the scouring around the groyne head, the groynes should be angled slightly downstream, but at a lesser angle than the existing groynes. The groyne spacing should be related to the curvature of the minor meander of the threshold of motion regime, or be about the same as the channel width. The later criterion is normally more conservative, and imposes a tighter control over the bank alignment. When the groynes are closer together there is more likelihood of a linking together of the local scour holds, and it is generally more cost effective to use fewer groynes of greater strength and/or stability. The existing groynes are mostly closer together, at spacings of about a half to a quarter of the channel width.

Permeable groynes can be effectively sited upstream and downstream of a bend, rather than along the bend. The groynes are then sited where there is less bed scouring, and provide protection by guiding the channel form at the bend. The extent of any lateral erosion is then restricted because of the minimum curvature of the natural channel forms. If a gentler curvature must be maintained, then some additional groyne work can be constructed at the centre of the bend, and this may take the form of snub rock groynes.

The cabled rail fences, while giving rise to a general strengthening, are easily damaged by head end scouring when the bank is under attack. Once they are exposed in the river channel they become a liability, as they generate turbulence and increase the flow pressures against the bank. Thus, they should either be removed when they are exposed, or the end of every third or fourth fence could be strengthened to form a groyne, with a lesser downstream angle.

Permeable groynes are generally more effective as river training works than as bank protection works. They can be used to deflect the river flow as part of the development of a different active channel alignment, and they can then be quite long structures. When they are short structures down high banks the prevention of outflanking from bank erosion can be difficult, while at the other end they suffer from the deep scouring that can be generated. In the Hutt River there is little space for channel realignment, but permeable groynes could be used to resist downstream channel migration while relieving some of the flow pressure against the banks.

4.4 Vegetation Buffers

The amount of bank erosion that takes place during a flood event can be markedly reduced by tree vegetation. Willows are especially effective because of their fibrous root mass, adaption to saturated water conditions and ability to sprout from layered material and cuttings. They grow very quickly and soon provide both a dense surface cover and root mass. Cut poles must, however, have their ends buried to summer groundwater levels for good establishment, and willow poles will not grow in dry gravels.

To be effective willow vegetation should be established in bands along the channel edges. Then as erosion occurs the willows that remain beside the bank can be partly cut and layered down in a lopping and layering operation. This willow material will then sprout with new roots being put down, and in this way the eroded area can be progressively reclaimed. To be an effective buffer the willow band must be wide enough to contain the bank erosion that will normally occur during flood events, and leave some willows for reestablishment, and the natural channel meander widths can be used to size consistent vegetation buffer zones (see River Characteristics and Sedimentation Study).

The willows bands established by the Hutt River Board were quite narrow, probably no more than 10 m wide, and they were often totally removed by bank erosion. Willows have continually been reestablished, however, and narrow bands of mature willows do exist along some reaches of the Hutt River, mainly in the Lower Valley. In recent years a programme of willow planting has been implemented, and there are now much wider bands of young willows, with bands of 30 m or more having been established in places.

In general the larger the pole and the deeper it is buried the better the willow establishment. However, lighter stakes can be used, especially on channel beaches where water levels are close to the surface. More closely spaced poles produce a thicker initial vegetation, but this is obviously more expensive, and after a few years the resulting vegetation may not be very different. Where relatively deep and fast flows can occur over the planted area, a quickly achieved denseness can be useful in reducing flow velocities and providing a self-protection to the plantings.

Willows should be established along the edge of the channel to give as strong a vegetative edge as possible, and there needs to be sufficient willows to provide the source material for reestablishment of the buffer zone as erosion occurs. Other species can, however, be used, and poplars also grow quickly and establish from cut poles. Some alder species are well suited to alluvial gravels, and they can be established from cuttings. Alders have a deep root system which will penetrate waterlogged soils. There are many acacia and eucalyptus species that grow well in alluvial gravels, as well as native species such as totara, and some eucalypts and totara are growing on the berms in the Upper Valley.

Tamarix and some acacia species are salt tolerant, while striking from layering and producing a prolific suckering growth from damaged roots, the same as willows and poplars. They can, therefore, be used as a substitute for willows and poplars along tidal reaches.

The high banks along the Hutt River combined with the gravel material of the berms seriously reduces the effectiveness of vegetation buffers, while making vegetation establishment more difficult. In many places willows can only be established in close proximity to the channel edge, or on the channel beaches. This restricts the width of the willow band, and when bank erosion occurs tree roots quickly become ineffective because of their height above the channel bed. Other species that tolerate drier conditions should thus be considered on the higher ground. Robinia is a fast growing tree that has been used in erosion control works, and it tolerates drier conditions, while having the same suckering root growth and striking from layering of willows. Sycamore is another relatively fast growing tree that suckers and prefers drier river bank conditions.

In New Zealand there has been an almost exclusive reliance on willows for erosion control along river banks, with some use of poplars. Silver poplars were used quite extensively, and there are some silver poplars along the Hutt River from earlier plantings, but their rapid spreading by root suckering can make them difficult to control. Willows also have a serious disadvantage in their ability to grow from broken off material, as this allows them to spread rapidly over a river channel. The constant working of the gravel bed by gravel extraction and cross-blading has prevented any serious problem of willow spreading from arising in the Hutt River. It has, in fact, a remarkably clear channel.

There is, of course, an enormous diversity of trees to select from, but there is little knowledge in New Zealand of the appropriateness or effectiveness of species other than willows and poplars. Given the restricted applicability of willows in the Hutt River, with a very narrow range at the channel edge, a search for alternatives is more pertinent, and only a few tentative suggestions can be made in this report.

5 DESIGN CHANNELS

5.1 Minimum Channel

The natural meander patterns of the river can be used as a guide when the width and shape of design channels is being determined. The more the design channel fits that natural form of the river, and allows for the natural channel meandering that takes place over time, the easier it will be to maintain the channel. The extreme minimum design channel is based on the larger of the threshold of motion meanders (see River

Characteristics and Sedimentation Study). These meanders are highly mobile and would normally migrate with the channel reforming that takes place from flood to flood, but in this case a fixed meander pattern is imposed. The channel then has a natural form, but normal channel migration cannot occur.

A design minimum channel has been drawn up from the river mouth to Maoribank, using the channel parameter values given in Table 11.

This channel is shown as an overlay on a set of 13 A3 size plans, using the aerial photographic plans of the Council at a 1:5000 scale as a base (see Volume of Plans and Database).

The channel fits well within the existing channel, with some adjustment of the meander wavelength to fit the general alignment of the channel. The existing channel has a meander form that closely fits the major meander of the threshold of motion regime, and the river has responded to the channel confinement by forming this meander pattern consistently along its length. There is not the constant interchange of minor and major meanders as normally occurs, and there are few well formed meanders with a curvature radius of around 4 times the width rather than 6 times.

A design channel with a curvature radius of 4 times the width is shown on Figure 5, along with the channel with a radius of 6 times, for two reaches of the river. Around Melling Bridge the narrow existing channel is relatively well formed, and the lesser radius gives rise to a design channel that better fits the existing channel. In the somewhat wider channel below Totara Park Bridge there are some better formed meanders. For the two reaches shown on the figure there is, therefore, a better than usual fit with the lesser radius. But in general the design channel soon gets out of step with the existing channel when the lesser radius is used, and the greater radius has to be used for a consistent design channel along the Hutt River.

The only place where a significant realignment of the existing channel is required is at Ewen Bridge, where the design channel cuts into the existing flood defences. There are some other places along the lower reaches where there is insufficient berm, and immediately upstream of Silverstream the state highway is within the berm area. Generally the design channel involves some narrowing, although in many places it involves only a minor filling out of the berms along the inner side of bends.

The design channel is drawn up as a consistent channel along the Hutt River, but it can be adapted to suit local site conditions and more closely fit the existing channel, at some loss of consistency. In this case there is a trade off between channel modifications and bank protection measures.

5.2 Wider Channel

If the main channel is to be enlarged throughout the study reach it should be enlarged substantially to give a channel size and shape that relates to the flow dominant meander

DESIGN CHANNELS

Table 11

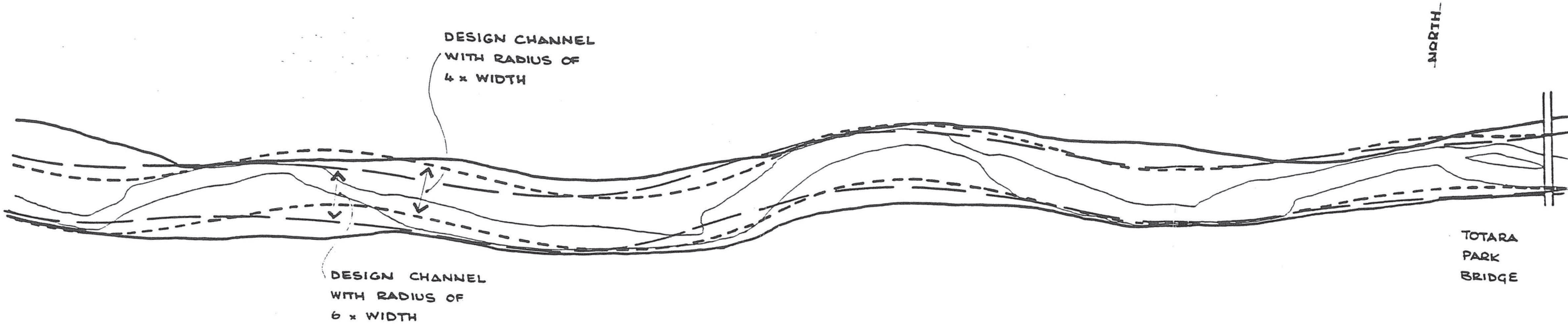
(m)

Minimum Design Channel - Threshold of Motion Regime

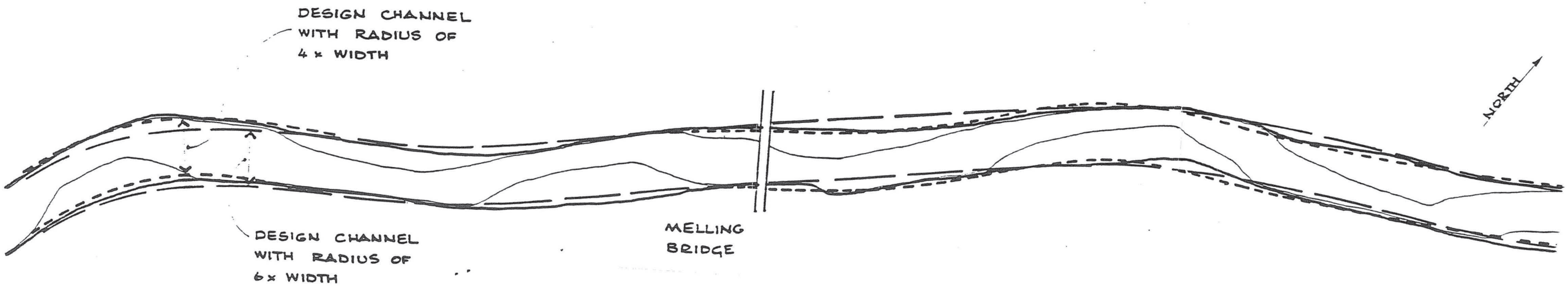
REACH	CHANNEL WIDTH	RADIUS OF CURVATURE		BUFFER WIDTH
		4xW	6xW	
Estuary to Ewen Bridge	85	350	500	22½
Ewen to Whakatikei	70	275	425	17½
Upstream of Whakatikei	65	250	400	16

Wider Design Channel - Flow Dominant Regime

REACH	CHANNEL WIDTH	RADIUS OF CURVATURE		BUFFER WIDTH
		4xW	6xW	
Estuary to Ewen Bridge	155	625		45
Ewen to Kennedy-Good	145	575		40
Kennedy-Good to Whakatikei	135	550		35
Upstream of Whakatikei	125	500		32



TOTARA PARK REACH



MELLING REACH

Scale 1 : 5000

MINIMUM DESIGN CHANI

DIFFERING RADIUS

Figure 5

pattern. A minimal enlargement is not necessarily of any advantage if the resulting channel does not conform to any of the natural channels of the river. A progressive enlargement can also give rise to a quite unstable river channel. There are definite states of dynamic equilibrium in river systems, with river channels undergoing sudden changes in state (or behaviour patterns) when the controlling characteristics change significantly. Thus, whenever an artificial channel is imposed on a river, it will respond - with either channel widening or narrowing - to shift the channel towards a natural equilibrium state. The further away from this state the artificial channel is, the more severe the response and the more dynamic are the processes of bed and bank erosion and deposition.

A wider channel based on the flow dominant form (as determined in the River Characteristic and Sedimentation Study) has been drawn up from the river mouth to Maoribank. The design channel has been fitted around the existing channel, with the meander wavelength being varied to fit the general alignment of the river channel, using the channel parameter values as given in Table 11. This channel is shown as an overlay on another set of the aerial photographic base plans (see Volume of Plans and Database).

In general the wider channel, including its berms, can fit within the existing channel and berm area. The state highway, that has been positioned close to the existing channel, would encroach into the berm area of this design channel, and along the reach from Silverstream to Moonshine Bridge would come close to the main channel in places. There would be some encroachment below Silverstream opposite Taita, while the Eastern Hutt Road would in a few places be within a defined berm area along the Taita Gorge reach - where it is not cut into the baserock cliffs. Upstream of the Moonshine Bridge the existing state highway is outside the design berm area, but opposite Totara Park the highway is relatively close to the outer edge of the berm.

The design main channel itself extends beyond the existing berms only along the lower reaches, mainly in the Ewen Bridge area. The channel would cut through the stopbank around the point at Croft Grove and at Melling Bridge, and the channel edge would be along the line of the existing stopbanks on the right bank downstream of Melling Bridge, upstream of Ewen Bridge and at Alicetown. The major extension beyond the existing stopbanks is on the left bank at Ewen Bridge, and the channel edge extends beyond the stopbanks from the top end of Strand Park to the upper car park area.

The wider channel does affect the electricity break down station and Harcourt Werry Drive at Boulcott, and recreational areas would be affected, including Sladden and Strand Park, and golf courses, especially Manor Park Golf Course.

The wider channel allows less intensive bank protection measures to be used along the channel edge - for a given design standard - with vegetation buffers on the wider berms giving a substantial level of protection. The smaller threshold of motion channel forms - that become fixed as flood flows recede and are seen in the low flow channel forms - can migrate without undue restraint, and there is less pressure against the banks, although river attack can occur at any point along the channel. Vegetation buffers are thus particularly effective. However, where there are roadways within the design berm area a heavier and more fixed type of protection would have to be used. To minimise land taking when the channel extends beyond the existing stopbanks heavy protection works such as rock linings could be used with a minimal berm, and walls could be used instead of stopbanks for the flood defences.

The wider channel also provides greater capacity for flood flows, and a larger channel bed area for the transport of the bed material load. The erosion and deposition associated with the transport of bed material would take place with less channel asymmetry, and the bed forms would be less variable with generally lesser scour depths.

5.3 Management Alternatives

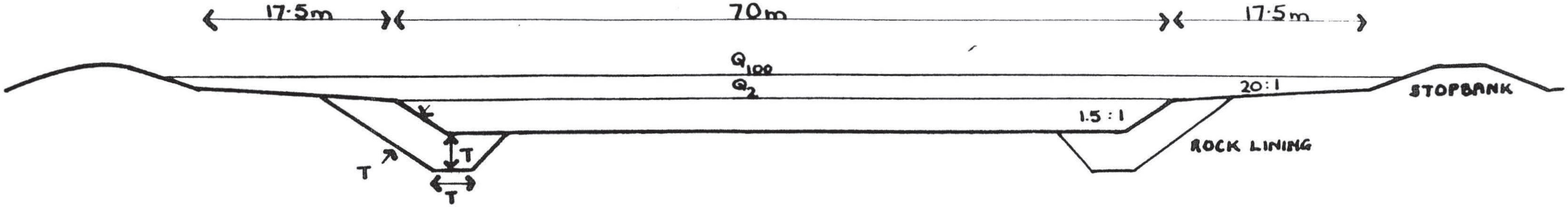
The minimum design channel requires the fixing of a meander pattern that is normally highly mobile. Sharp flow cross-overs develop in this narrow channel and flood flows directly attack the banks. The low flow channel will still move and over time the direct river attack can occur anywhere along the banks. To resist the severe flow pressures heavy protection works such as continuous rock linings could be used, and to meet design standards large sized rock and thick linings would be required. The design channel cross-section with the design widths is shown on Figure 6 along with representative rock linings. This cross-section is at a natural scale (of 1:500), and the large bulk of the linings compared with the channel size can be clearly seen. The flow area is relatively small because of high velocities within the well defined channel, but these high velocities necessitate heavy rock linings.

The entrenchment of the Hutt River channel means that the rock lining layout would have to be adapted, and a benching of the berms would be an appropriate way of keeping the rock linings to the design dimensions and rock requirement. Some examples of this are also shown on Figure 6.

The channel bed would develop severe section asymmetries and plan distortion with this approach, but it could be left alone, with no cross-blading or vegetation maintenance, and no gravel extraction outside of specific extraction zones (see Section 6). The rock linings would only be topped up when slumping occurred, and only intermittent maintenance (in both time and space) would be undertaken.

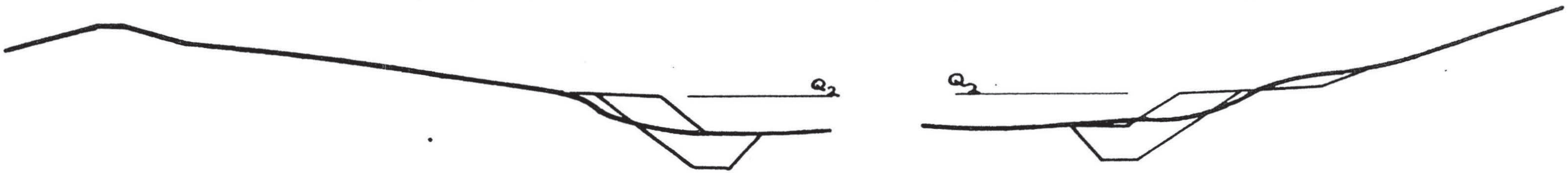
The rock linings would, of course, be very expensive, and a large capital expenditure would be required to put them in place. Except for a few places, the existing berms are much wider than the minimum design berm, and where there are wide berms an opposite maintenance and repair approach can be taken. The long term costs may still be very high, but expenditure is spread over time, while being dependent on the pattern of flood events and hence damages.

This approach could involve a planting and vegetation maintenance programme, with vegetation buffers being



DESIGN CROSS-SECTION

REPRESENTATIVE ACTUAL CHANNEL BANKS



MINIMUM DESIGN CHANNEL

Scale 1 : 500

Figure 6

established along the channel banks out to the design channel edge and on the lower berm areas. The vegetation could be strengthened by fences and groynes, but continual repairs and reestablishment of the buffer zone would be necessary. The aim would be to maintain the narrow gently curving design channel, so that when a large flood event does occur the erosion is minimised because of the lack of tight bends, and is not likely to be of sufficient extent to threaten the flood defences themselves. When bank erosion occurred vegetation would be reestablished along the exposed bank, and erosion bays would be reclaimed and replanted. Cabling and groyne work would be needed to protect layering and planting, and cross-blading of the channel bed could be used with varying regularity to assist in the reestablishment by directly the main flow away from the reclamation area.

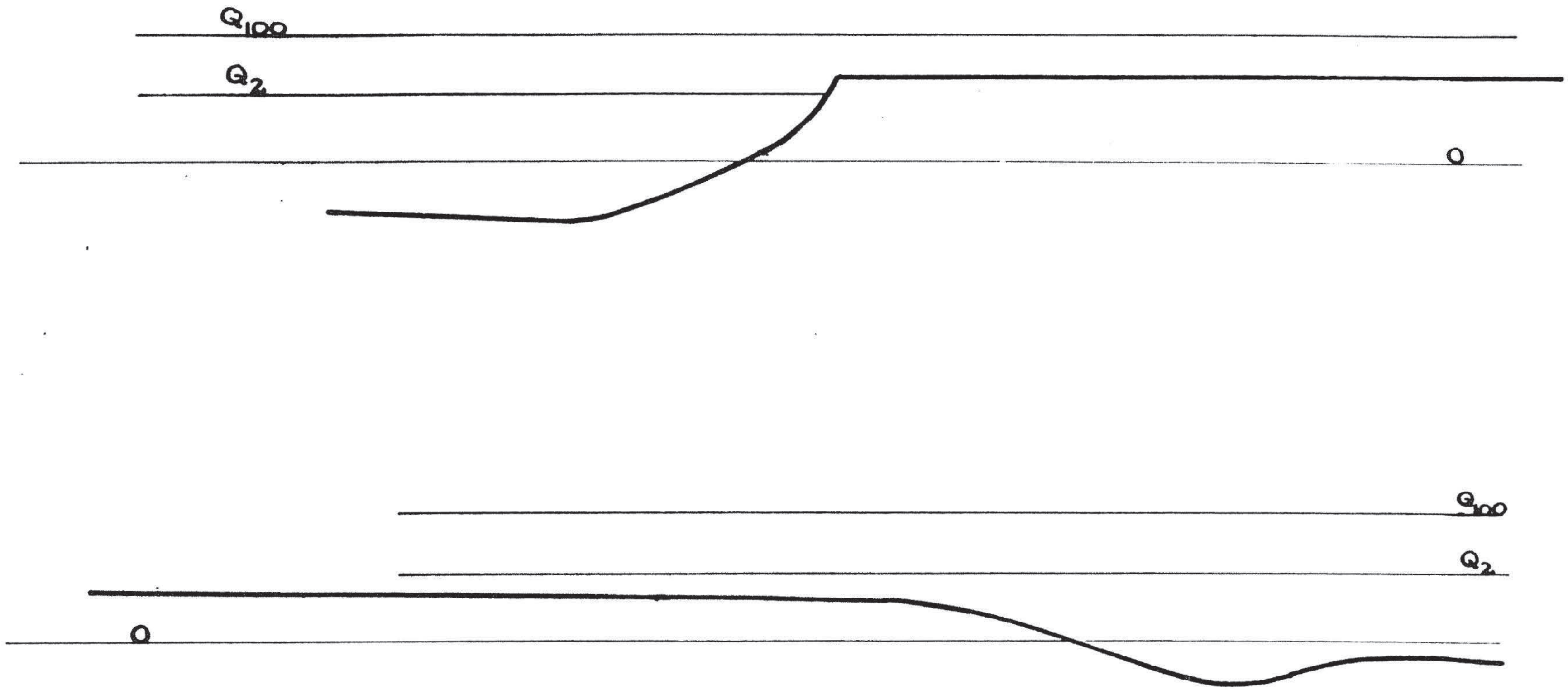
For this management approach to be successful a maintenance programme must be put in place that is properly funded (with both on-going and flood damage reserve funds) and carried out by permanent maintenance gangs with readily available machinery. The workforce must be made up of people who are knowledgeable about the behaviour of the river and can react immediately in accordance with the management aims.

There are significant differences in the present condition of the river channel, and this affects the appropriateness of different management approaches. The protection works that are in place also vary greatly, and account has to be taken of the existing works when considering management alternatives. Along the lower reaches (downstream of Kennedy-Good Bridge) the dominant flood flow (of a 2 year return period) is generally contained within the main channel, and the channel has an appropriate bankfull capacity. In large floods the berm flow is relatively deep, with the flow extending across berms of varying width. Upstream of the Kennedy-Good Bridge the flood flows are much more contained within the main channel, and even in large flood events berm flows can be very minor if they do exist. In the Upper Valley the bankfull capacity is generally the dominant flood flow again, with berm flows for larger floods being quite variable.

The channel banks for a number of representative cross-sections are shown as a set of figures (see Figure 7) with the estimated flood levels for 2 and 100 year return period flood flows being indicated.

In considering alternatives and defining management approaches the Hutt River should be considered in reaches. The rock and rubble linings along the lower reaches, and the rock linings in the Upper Valley impose fixed channel edges, and although much of the rock could be reclaimed and reused, the existing linings are substantial protective assets along a well defined channel edge. The few places where there is little or no berm require special attention, particularly as any retreat of the flood defences involves expensive urban land taking.

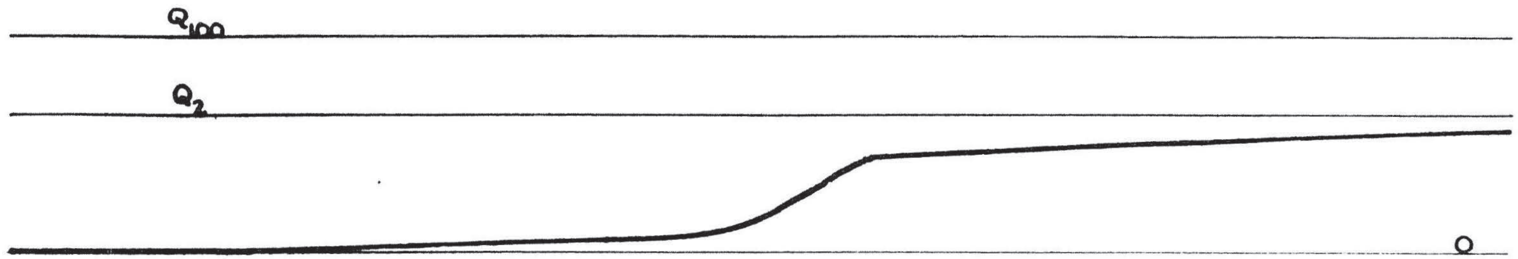
A solid wall has been constructed along the channel edge at Maoribank, and solid walls have been proposed at the Ewen Bridge site if a narrow channel is retained when the bridge is replaced. Walls must be deeply founded to remain stable under



CHANNEL BANKS

Scale 1 : 250

Figure 7-A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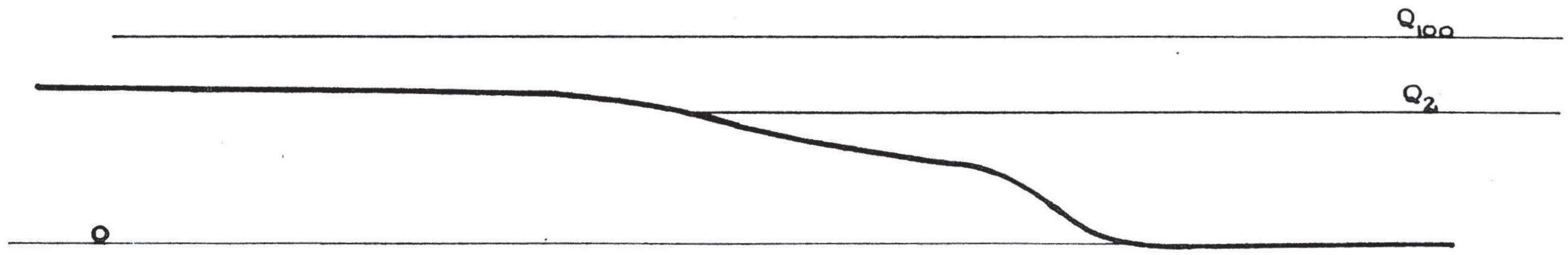
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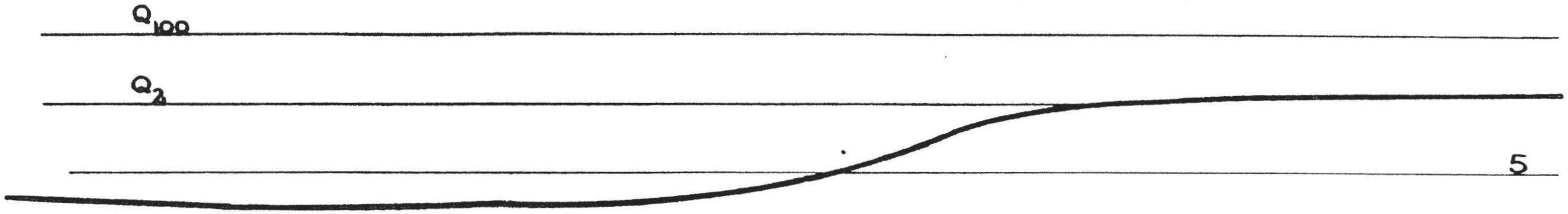
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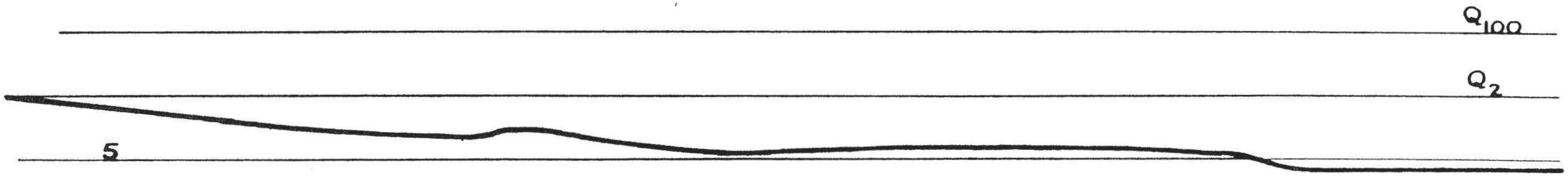
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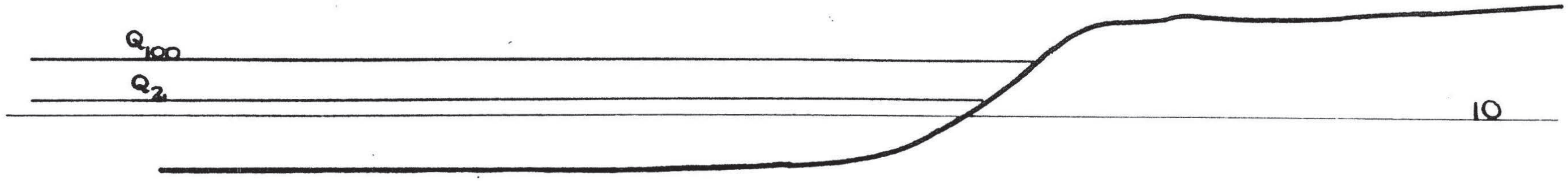
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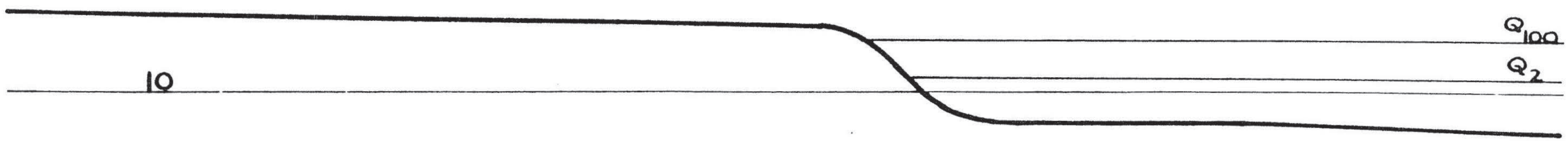
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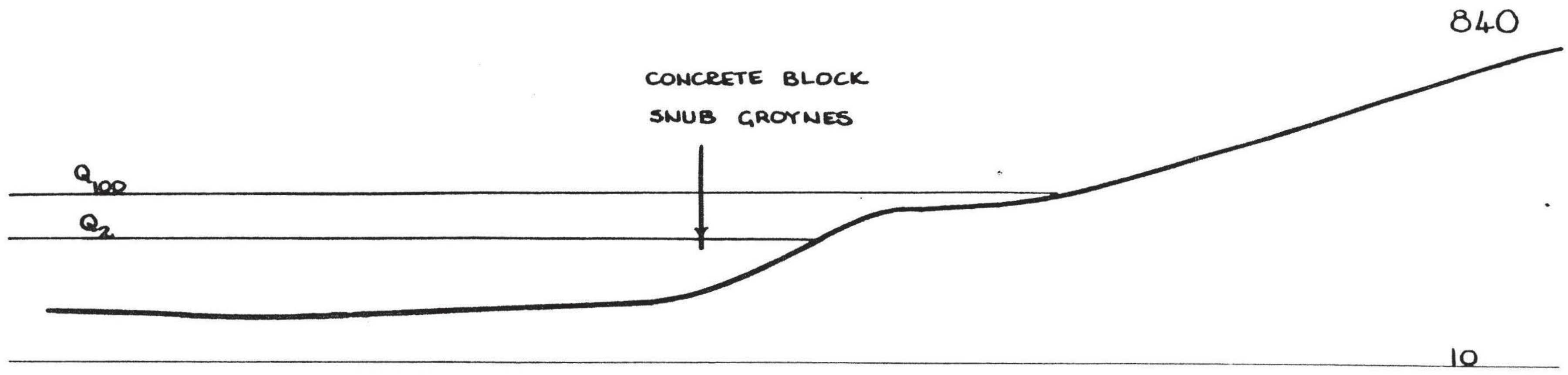
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Q2
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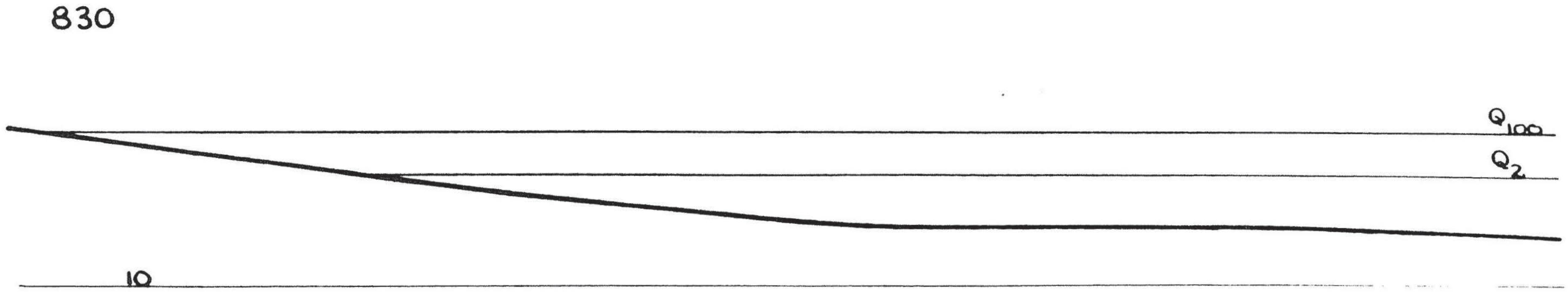
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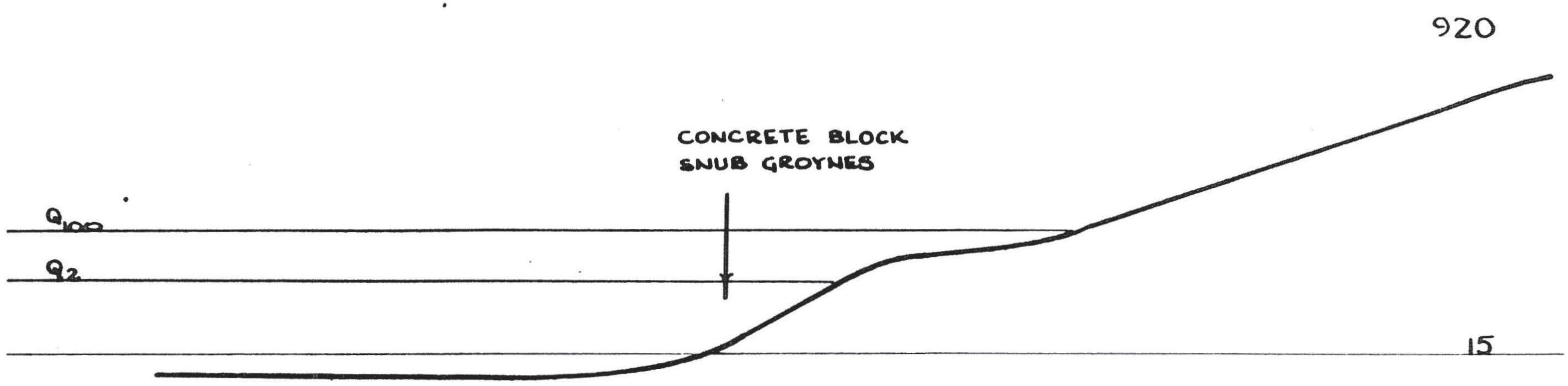
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Q_{100}
Q_2
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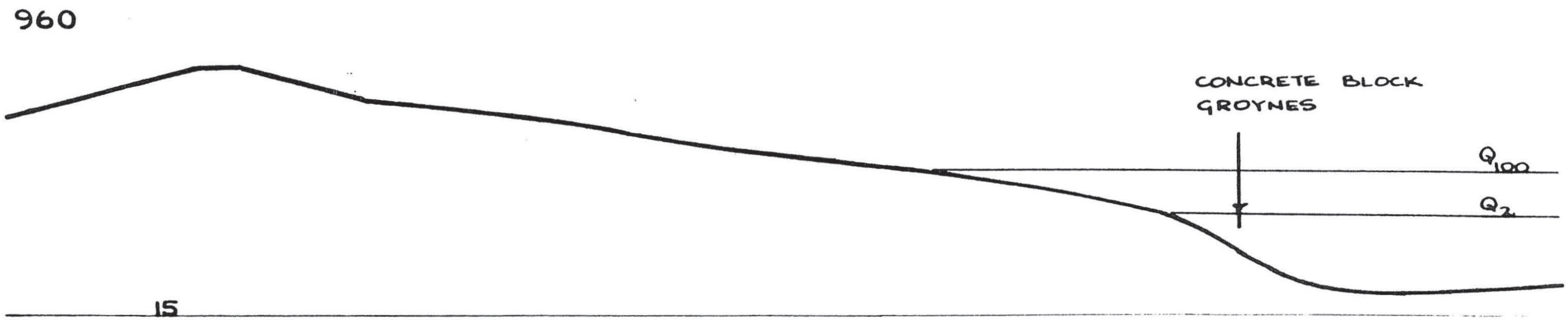
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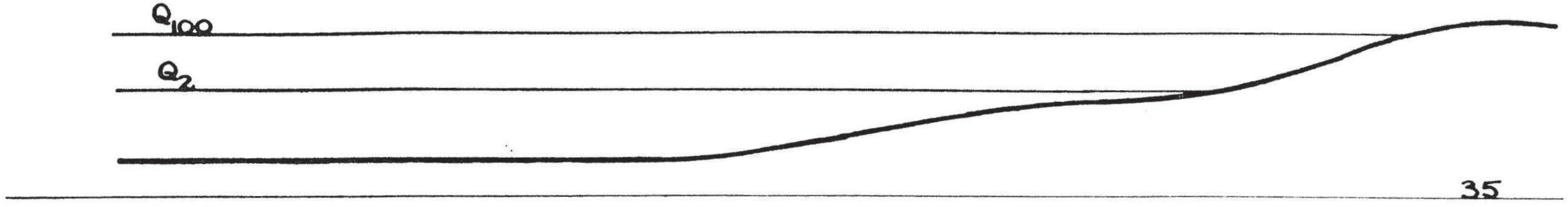
CONCRETE BLOCK
GROYNES
Q_{100}
Q_2
15



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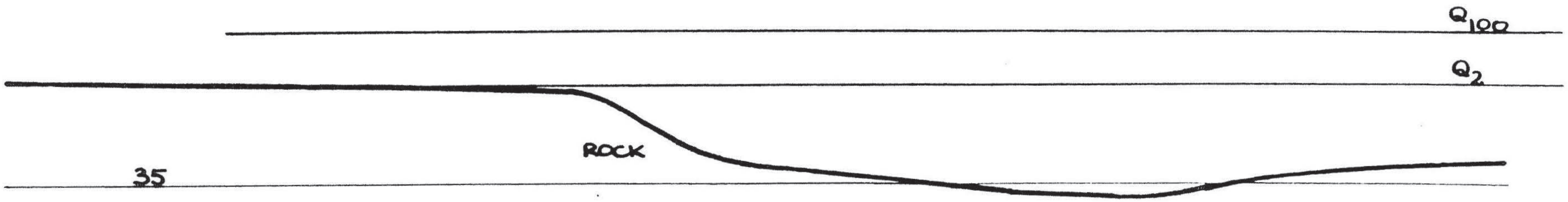
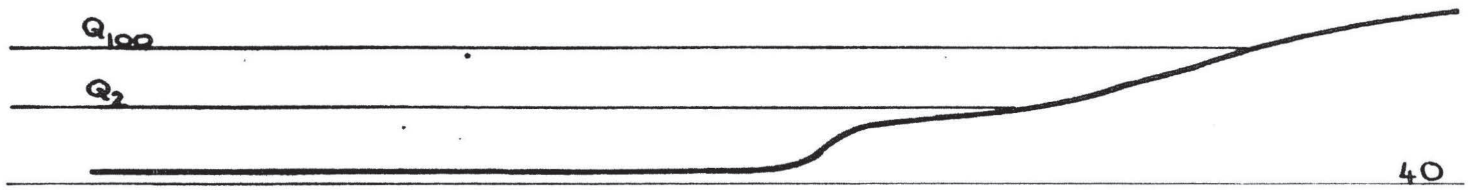
Q2
35



Q100
Q2
ROCK
35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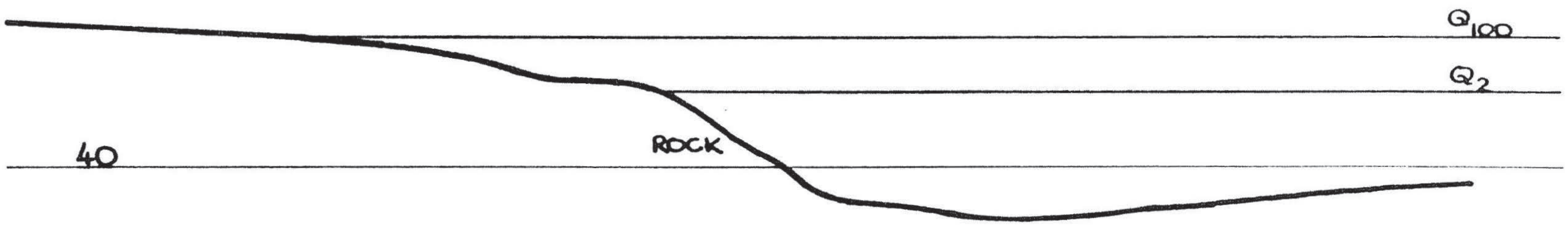
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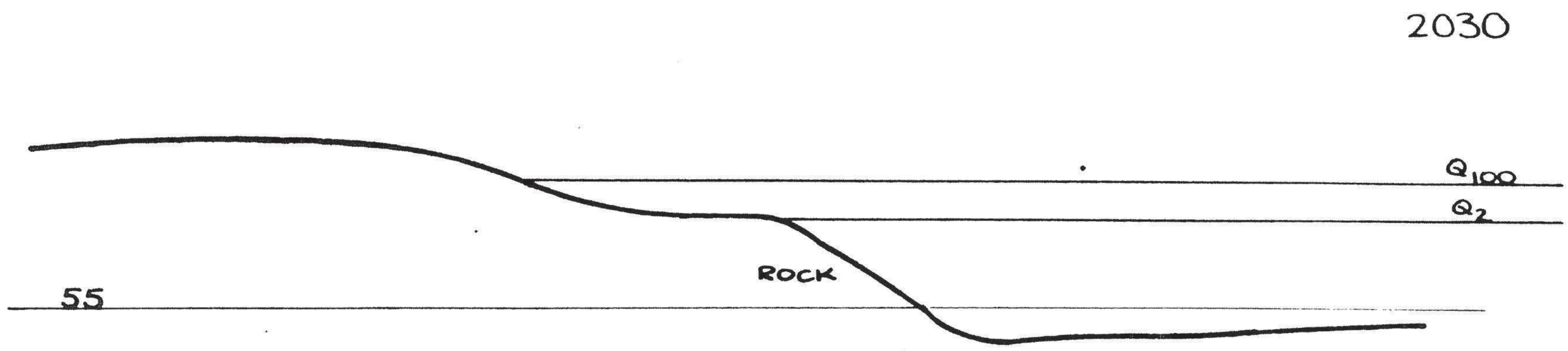
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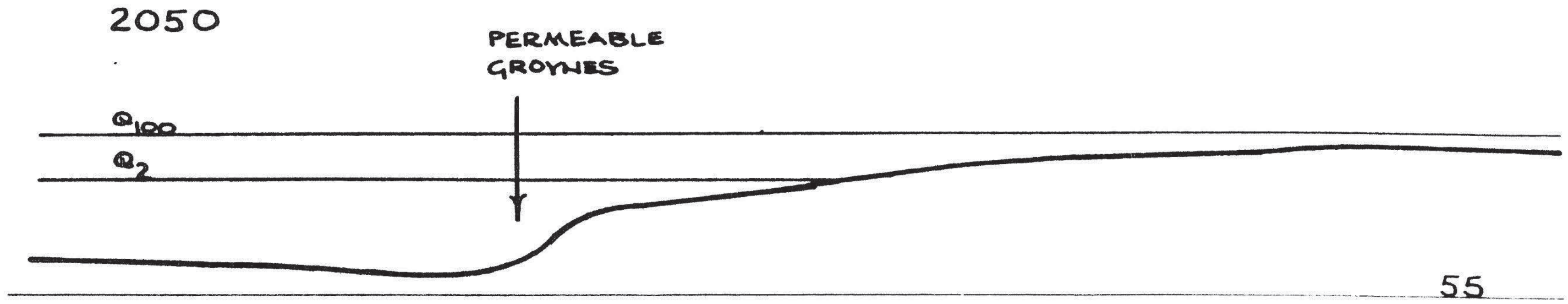
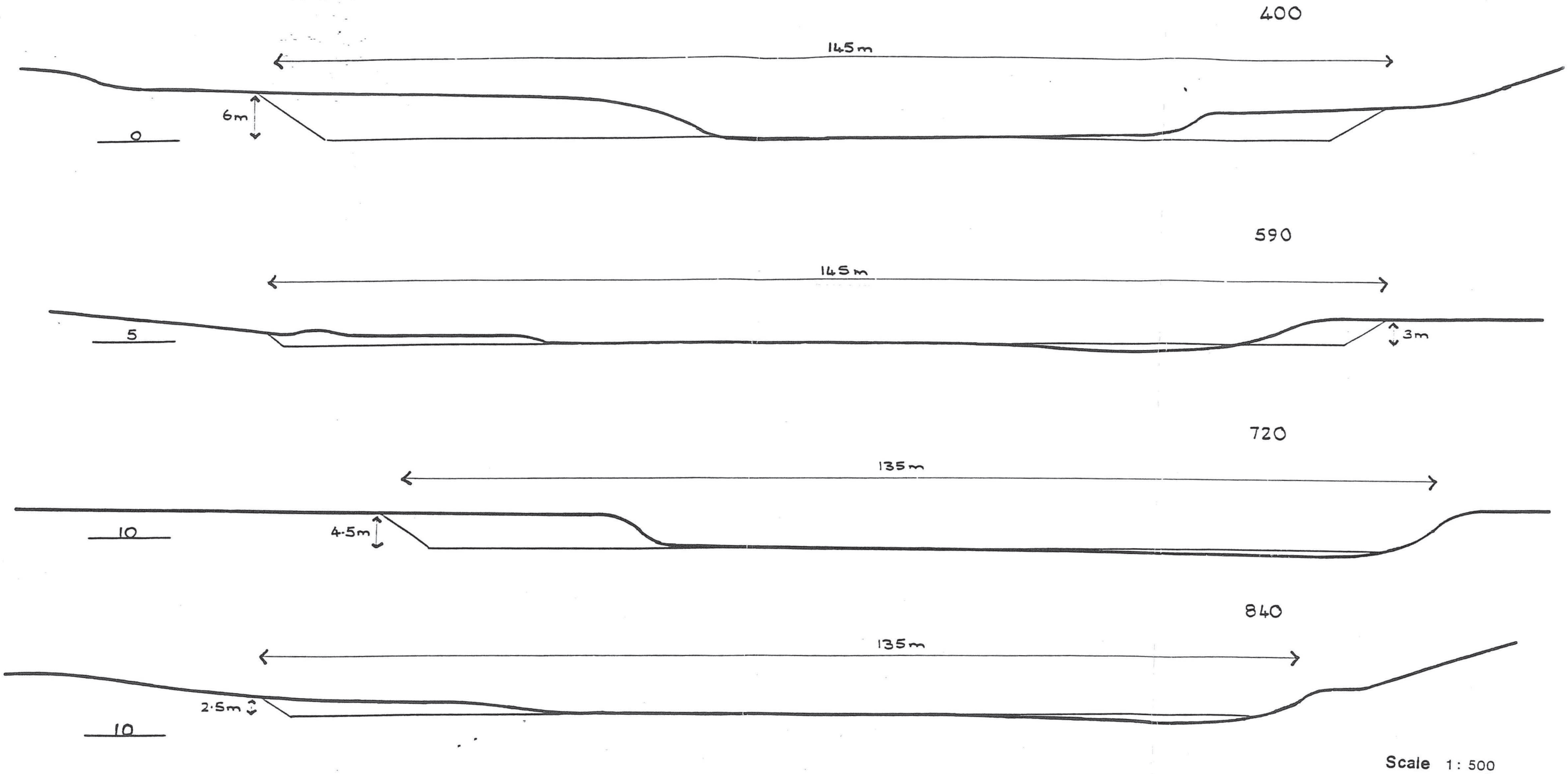

2050
PERMEABLE
GROYNES
Q_{100}
Q_2
55

design scour conditions - if they cannot be founded in hard material - and are very expensive, although heavy rock linings can be as expensive - given the high cost of suitable rock in the Wellington Region. Exceptionally deep scouring can be generated beside vertical walls, and if they fail the turbulence created around the failure tends to generate a wide erosion bay behind. Walls should only be considered as a last resort in special circumstances.

The different types of river works and management practices that can be carried out cannot be considered in isolation, as there are many interactive effects. The flood mitigation aims of river management also have to be balanced against other aims. The Hutt River has a relatively large low flow, and the water is clear and retains a high natural quality as it passes down the urbanised flood plain. It is certainly unusual to have such a steep gravel bed river with clear fast flowing water within a city environment. The berm areas are used for both passive and active recreation, and the river is an important landscape feature when adds interest and diversity.

The in-channel cross-blading works reduce the amount of buffer vegetation and/or bank strengthening works that is required, but continually disrupts the aquatic environment. On the other hand widening vegetation buffers to provide compensating protection if cross-blading is discontinued could reduce active recreational areas and restrict passive recreational access to the river. An on-going maintenance approach implies constant river works, damaged works that are unsightly and potentially hazardous, and a public perception of constant failure. The use of vegetation has a definite landscape impact, which can be seen as adverse, but which gives rise to enhancement opportunities if suitable species are used in an appropriate manner. The cross-blading prevents willow vegetation establishing within the main channel area. If it was not undertaken willows would spread over the channel, and chemical spraying instead of mechanical removal has other environmental implications.

The wider design channel necessitates the removal of much of the existing protection works, and the reestablishment of channel edge protection. While the design channel fits within the existing channel and berm area along most of the study reach, if the channel is to be extended at around the existing channel bed level, deep excavations of the existing berms would be necessary in a lot of places (see Figure 8). There would be even higher banks along the channel edge, making the vegetation that should then be an appropriate form of protection even less effective. The channel enlargement should proceed from the mouth in an upstream direction, and to be really effective should extend along the full reach of the river that threatens a given flood plain area, that is up to Melling for the Petone area, and the Taita Gorge for Lower Hutt. However, the very expensive land taking that would be involved is along the lower reaches. If reasonable transitions could be incorporated and a significant reach was more readily enlarged, then a partial implementation of the wider channel could be considered in terms of overall cost effectiveness. Given the difficulties of implementation this is, though, unlikely.



CHANNEL CROSS-SECTIO
WIDER DESIGN CHANNEL

Figure 8

The existing river channel as it is, or modified in accordance with the minimum design channel, could be managed in different ways to accommodate a large flood of say a 100 year return period - peak flow of about 2000 m3/s. However, if the design standard was raised to a much larger flood, with a peak flow of 3000 or 4000 m3/s, this narrow channel is likely to be so overwhelmed with severely turbulent flood waters that its ability to pass the flood flows without the flood defences being threatened must be doubtful, regardless of the management approach taken. Wide erosion into the berms must be likely, and even where heavy protection works were in place the severity and duration of high flows could be sufficient to cause failures, and then very deep and distorted erosion bites could be generated.

The effects of such large floods are, though, unpredictable. They are so much more extreme than normal flood events that their effects are really beyond the limits of predictability. ~~and~~ This precludes any reasonable comparison of different management approaches.

The theoretical capacity of the existing channel, with flood defences, may in some reaches be as much as 3000 to 4000 m3/s in terms of hydraulic conveyance with normal channel resistance characteristics, but the flood flows that could in reality be passed through are likely to be much less. The problem is not one of capacity, but of preventing the flood defences from being eroded away by river attack. If the wider design channel was implemented, and effective protection (through edge strength and/or berm resistance) was put in place, then the passing of a larger flood than the design flood (with a 2000 m3/s peak) with little risk of a system failure, would become feasible. What the extra capacity would be for any given management approach would, though, be very difficult to judge, and should also be considered beyond prediction, at least from the investigations that have been carried out. The only tool that may provide some useful guidance is physical modelling using a mobile bed.

6 GRAVEL MANAGEMENT

The gravel bed material of the Hutt River channel is reworked from flood to flood, and large amounts of material are moved. Extensive new beach deposits can be formed during floods, while channel degradation can occur that is much greater than the amount of gravel bed material that has been extracted. However, the average rate of transport of bed material down the river is not high (see River Characteristics and Sedimentation Study). Gravel extraction disturbs the natural armouring layer on the channel bed, and the constant working of the material can result in greater localised transportation by the river. The deepening of the channel may then arise from both the extraction itself and the river response to the extraction activity.

The transport of bed material involves a continual reworking of the bed and banks of the river, with material being moved only a short distance in any one flood event. In the Hutt River much of the bed load is related to a channel reworking, with little gravel material being derived from the catchment. Over geological time the river has been cutting into the alluvial deposits along its length, and the river regime is based on a gradual entrenchment as the alluvial deposits are eroded away by the river activity.

Gravel supply to any point on the river is, then, episodic and there is an interdependence of erosion and deposition along the river. Degradation in the Upper Valley will, for instance, supply gravel material to the Lower Valley. Given this regime, it does not take much extraction to cause both localised degradation and a general lowering of the bed.

The narrowing of the river channel and the generation of higher flow velocities should have increased the transport of bed material. However sufficient source material must be available for transport, and bank protection works have restricted the supply from bank erosion. At the same time the bed material size may have been increased through a process of differential sorting, and baserock is now exposed in the river channel in places upstream of Taita. Thus deeper scouring may be generated in the narrower channel, while the overall transport of bed material is less than it was.

These channel changes may have affected the transport balance between reaches. Naturally a river can change its width and meandering in accordance with changes in channel slope to maintain a transport balance for a given bed material. In the Hutt River changes in channel width and meandering have been imposed, while the overall (valley) slope remains unaltered, and there has been a response in terms of bed material size. In these circumstances there will probably no longer be a natural balance, rather the river will be responding in a way that attempts to reestablish such a balance. The calculated rates of bed material transport do show significant differences between reaches. The highest rates are along the most degraded reach of the river upstream from Belmont (see River Characteristics and Sedimentation Study, and the database).

The series of medium sized flood events in the early 1980's gave rise to some aggradation in the upper reaches above Birchville, which has subsequently been taken away. In the Upper and Lower Valley down to about Kennedy-Good Bridge, channel degradation occurred during the early 1980's, with some recovery in bed levels since, except for the Totara Park reach where channel degradation has continued.

During the early 1980's substantial gravel extraction took place in the Upper and Lower Valley as well as at the mouth. Since then extraction has stopped in the Upper Valley, and been markedly reduced in the Lower Valley. In spite of this, degradation has continued in the Upper Valley as well as further upstream, while there has been only a minor recovery downstream.

The Hutt River transports bed material through to its mouth, and under the present artificial channel conditions the supply to the mouth is much greater than it would be naturally. Continual removal of material from the mouth is necessary to maintain a sufficient mouth opening for flood flows, and minimise flood level rises along the lower reaches. Transport rates along the lower reaches vary greatly with tidal fluctuations, while there is a very rapid decline in bed material size. Bed material transport is thus more complex and dynamic, but bed material would accumulate at the mouth if there was no extraction.

Transport rates decline below the major change of grade around the Kennedy-Good Bridge, and some extraction at the present site between Melling and Kennedy-Good Bridge should be maintained.

In the lower reaches the flood capacity is not much greater than the 100 year return period design standard (about 2000 m3/s peak flow) and channel aggradation would occur if some gravel extraction did not continue. Elsewhere gravel extraction is not required to prevent channel aggradation, as flood capacity is not the problem (for a 2000 m3/s flow). On the contrary aggradation would have a beneficial effect through the reduction in bank heights, although the nature of the accumulation could have some adverse impacts on channel form and hence cross-over attack.

The recommended gravel extraction policy is, then, as follows:

(1) Extraction at the present rate of about 50000 m3 per year at the mouth

(2) Extraction up to 25000 m3 per year upstream of the mouth

(3) Extraction upstream of the mouth to be concentrated in the reach between Melling and Kennedy-Good Bridge

(4) Extraction for channel management purposes to be kept as low as possible

The total annual extraction of gravel would then be no more than 75000 m3, with all extraction upstream of the mouth being less than 25000 m3.

The changes in bed levels should be monitored, as there is a lot of uncertainty about bed material transport and hence the effects of any given level of gravel extraction. To do this, it is recommended that at last every fifth cross-section of the set of river cross-sections between the river mouth and Te Marua be resurveyed at no longer than five yearly intervals. This would give comparative cross-sections at a spacing of around 500 m, for a set of about 60 cross-sections.

7 CONCLUSION

The Hutt River has been greatly modified over the last 100 years. Along the lower reaches below the major change of grade, the channel has been enlarged and flood waters have been confined to a relatively narrow channel and berm area. Upstream a consistent narrow channel with a gentle curvature has been developed, and the channel has become much more entrenched into the alluvial gravel of the valleys. In many places the berms would only be flooded in large floods, and even then the berm flows would generally be quite shallow. The berms vary greatly in width, and there are large recreational areas, including a number of golf courses, that give rise to a wide separation between urban areas and the river channel.

The protection works along the channel edges vary greatly, with different types of works of differing strength and maintenance requirements. Although there is often a lack of consistency along reaches of the river, the works in place do give rise to a degree of protection that is in general related to the assets at risk and the likelihood of erosion reaching either roadways or the flood defences. There are a few places where there is virtually no berm, and flood defences are relatively vulnerable. Except for the Gemstone Drive stopbank, where the protection works have so far been surprisingly effective, these vulnerable places are all along the lower reaches.

A consistent design channel could be developed within the existing channel using the extreme minimum channel of the threshold of motion meanders, except for a small extension along the left bank at Ewen Bridge. The channel could be managed through an on-going maintenance and repair approach, where the channel edge was defined by a vegetation buffer, and eroded areas were reestablished by willow and groyne works. Alternatively the channel could be rigidly fixed by rock linings, with occasional topping up of the rock as required. Different reaches of the river could be treated differently, while the river management approaches that could be taken have differing impacts on the river environment and recreational uses of the river area.

If a larger channel is to be redeveloped, a substantial enlargement to a channel based on the flow dominant meander should be undertaken. This would involve large scale excavation of the existing berms, and the reestablishment of edge protection works. Very expensive land taking would also be necessary along the lower reaches. However, if a design standard much greater than the 2000 m3/s peak flow is to be considered, then this wider channel may be the more appropriate design channel.

Whatever management approaches are taken, the aims and associated implementation policies should be clearly spelt out, and a greater consistency achieved along reaches. Gravel extraction should be minimised and bed level changes monitored by repeat cross-section surveys. An extraction of 50000 m3 per year at the mouth, and no more than 25000 m3 per year upstream of the mouth is recommended.

July 1991 G J Williams

Water & Soil Engineer

ACKNOWLEDGEMENTS

Discussions on river works and management practices with John Easther, Colin Munn and Brendan Paul have been very helpful, and their contributions to the assessments presented in this report is acknowledged with thanks. The computer database was set up by Sam Barnes, while Dennis Finnigan checked the data entries and provided inquiry reports.

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DATABASE CLASSIFICATION

1 CHANNEL LISTING

LOCATION

Cross-Section - Identifier number

Profile Distance - Associated distance upstream from the mouth (m)

RIVER CHARACTERISTICS

Flow - Dominant flood flow, taken as the 2 year return period flood flow (m3/s)

Slope - Channel slope, taken as the energy gradient at the dominant flood flow

Bed Material - Medium size of the armouring layer of the channel bed material (m)

DOMINANT FLOW

Power - Power generated by the dominant flow, that is $\rho \, g \, Q_2$ (kW/m)

Transport - Estimated transport of bed material (m3/s)

CHANNEL WIDTH

Threshold - Width of threshold of motion meander (m), given by the empirical formula of Chang (see River Characteristics and Sedimentation Study)

Flow - Width of flow dominant meander (m), given by the empirical formula of Lacey (see River Characteristics and Sedimentation Study)

Actual - Width of the existing river channel (m)

DIMENSION

Min W/D - Minimum width to depth ratio of the channel cross-section

Numeric values only for this factor, and there must be a value. Thus where the ratio has not been calculated this is indicated by a -1.

MEANDER STATUS

W/Wt - Ratio of actual to threshold of motion width

W/Wf - Ratio of actual to flow dominant width

Uniformity - Assessed factor of the uniformity of the channel meander in plan. Range from 1.0 to 1.9 in increments of 0.1

CHANNEL CONDITIONS

Shape -

Type - General nature of the channel

SS = straight single channel
US = uniformly meandering single chanel
HS = half meander form single channel

SC = split channel with one larger than the other
DC = double channels of similar size

PB = partially braided channel
FB = fully braided channel

Distortion - Distortion of the general channel form

D = disturbed form
H = tightly hooked or deflected form
B = broken up form

Bed Material -

Type - General nature of the bed material

C = clay
M = silt
S = sand
G = gravel
L = large gravel/cobbles
B = boulders
R = rock

More than one symbol can be used, with a priority ranking of the more predominant to less predominant material

Base - Proximity of the baserock

O = rock outcrops
R = exposd baserock

Vegetation -

Channel - Low flow channel with symbols as below

Beach - Active beach areas of the channel with symbols as below

	Channel	Beach
C =	clear	clear
S =	some snags	scrub
T =	large snags/tree	scrub and scattered trees

RIVER REGIME

Power/Transport - For both the power and transport values the range of values is split into 5 equal intervals (excluding extreme values - beyond 95% range) and each value is ranked accordingly. The two ranking scores are combined and divided by two to give a rank between 1 and 5 in 0.5 increments.

Meander Status - The width ratio is selected on the basis of W/Wf if W/Wf > 0.9, otherwise W/Wt. The width ratio and uniformity value are then given a rank as follows:

Rank	1	2	3	4	5	6	7	8	9	10
Uniformity	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
Width ratio	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	>1.9
		0.95	0.9	0.85	0.8	0.75	0.7	0.65	0.6	<0.6

The two ranking scorces are then combined and divided by four to give a rank between 0.5 and 5 to the nearest 0.5.

CHANNEL STATUS

Channel Form - Status ranking based on the channel shape as follows:

SS = 1 US = 2 HS = 3 SC = 3 DC = 3.5 PB = 2 FB = 3

for D add 1 to 1.5
H add 1.5 to 2
B add 2

where there is rock influencing the channel form, reduce by 0.5 to 1

Channel Clearance - Status ranking given by the channel vegetation as follows:

CC = 1 CS = 1.5 SC = 2 CT = 2.5 SS = 3 TC = 3.5
ST = 4 TS = 4.5 TT = 5

2 BANK LISTING

LOCATION

Cross-Section - Identifier number

Side - L = left bank
R = right bank

BANK

Height - Height of the main channel bank in metres from 0.5 to 5.0 in 0.5 m increments. Numeric values only, and 5.5 means all heights greater than 5 m.

BERM

Materials -

Type - General nature of the berm material.

The symbols used are the same as for bed material, and can also be ranked in order, but includes an extra symbol F for fill.

Depth - Depth of the layer of berm material in metres.

Numeric values only, and there must be a value, thus 0 is used to indicate that there is no available information, while a -1 is used when the material is known but the depth has not been determined. Where there is more than one symbol for the type of berm material, the depth value is repeated.

Width - Width of the berm in metres, to the hearest 5 metres, up to 100 m. Numeric values only, and 101 means all widths greater than 100 m. There must be a value, thus where there is no clearly defined berm (and the width is therefore indeterminate) this is indicated by a -1, while a 0 is used where there is no berm.

EDGE LINING

Type - General lining category

SO = solid
BL = blocks
RO = rock
RU = rubble
PE = permeable
VE = vegetation

Description - Open field for some descriptive labels, eg Gabions

GROYNES

Type - General groyne category

The symbols used are the same as for linings

Description - Open field for some descriptive labels and/or lengths and interval distances, eg Timber of 10 at 40 - for 10 m long timber groynes at 40 m intervals

STRENGTHENING

Type - General vegetation strengthening category

LB = line of blocks
RF = driven rails and cable fences
RT = ratard of anchoured trees
TT = tied down trees
PT = large placed trees

Description - Open field for some descriptive labels and or lengths and interval distances, eg 20 at 40 - for 20 m long fences at 40 m intervals.

EDGE VEGETATION

Type - General type of vegetation

A = alders
G = grass
M = mature wilows
N = natives
O = other (trees)
P = poplars
S = scrub
T = scattered trees
W = scattered willows
Y = young willows

More than one symbol can be used, with a priority ranking of the more predominant to the less predominant type.

Width - Width of the edge vegetation in metres, to the nearest 5 m.

Numeric values only, and there must be a value, thus 0 is used where there is no edge vegetation, and a -1 when there is no clearly defined width to the vegetation.

BERM VEGETATION

Type - General type of vegetation

The symbols used are the same as for edge vegetation, and can also be ranked in order.

Description - Open field for some descriptive labels eg. Golf Course

BANK STATUS

Channel Position - Status ranking of the bank in relation to the existing channel position

Inner bank and large gravel beach	1
Inner bank	2
Outer bank	3
Outer bank on a tight bend	4
Outer bank on a very tight bend with a deep hole	5

Edge Strength - Status ranking based on the type and strength of edge protection works. A representative ranking is as follows:

Rock, high exposure	1
Rock at base of bank	1.5
Solid lining	1.5
Substantial rock groynes or linings	2
Rock lining and rubble base	2
Rock lining, less massive dimensions and rock	2.5
Rubble lining	2.5
Premeable groynes and willows	3
Thick buffer of willows with fence strengthening	3
Willow buffer with fence strengthening	3.5
Thick buffer of willows	3.5
Thin buffer of willows	4
Willows and other trees	4
High bank with willows	4.5
Low bank with grass	4.5
High bank with no vegetation	5

Berm Resistance - Status ranking based on the resistance to erosion of the berm taking account of berm vegetation, materials and width. A representative ranking is as follows:

Rock material	1
Cohesive material	1.5
Alluvial material, tree vegetation with strengthening, wide	2
Alluvial material, tree vegetation, wide	2.5
Alluvial material, grass vegetation, very wide	1.5 - 2.5
Alluvial material, tree vegetation, intermediate width	3
Alluvial material, grass vegetation, wide	3
Alluvial material, tree vegetation, close	4
Alluvial material, grass vegetation, intermediate width	4
Alluvial material, grass vegetation, close	5

High berm, reduce by 0.5

OVERALL STATUS

A weighted average of all the status factors as follows:

Total of 3 x Edge Strength; 2 x Berm Resistance; 1.5 x Meander, Power/Transport, Channel Form, Channel Clearance; 0.5 x Channel Position. This total is divided by 10 to give a ranking between/and 5, rounded to the nearest 0.5

EMPIRICAL SCOUR FORMULAE

Maza & Echavarria

$$D_s = 0.365 \frac{D}{D_m}\left(\frac{Q}{W}\right)^{0.784} \frac{1}{d^{0.157}}$$

N.Z. Railways

$$D_s = K \frac{R}{(A/W)^{0.5}} \quad \frac{C\,Q}{A}\left(\frac{D}{A/W}\right)^{0.67}$$

$$\text{and } K = \left(\frac{W}{4.83\ Q^{0.5}}\right)^{0.5} \quad \text{but} \not> 1$$

where

D_s = maximum depth of scour (m)

D = maximum depth of water (m)

D_m = mean depth of the bed (m)

R = rise of the water level above the low flow level (m)

W = width of the water surface (m)

A = cross-section area (m^2)

Q = design flow (m^3/s)

d = medium size of bed material (m)

C = 1.2 for converging flows, otherwise C=1

EMPIRICAL FORMULAE FOR RIP-RAP

California Highways Practise

$$W_c = \frac{0.0113 \quad V^6 \quad Sg}{\sin^3(70-\theta) \quad (Sg-1)^3}$$

$W_{max} = 3.6\ W_c$ and $W_{min} = 0.22\ W_c$

$d_c = k\ W_c{}^{0.33}$ and k = shape factor (0.09 for sphere)

$T = 1.5\ l_c$ if placed, or $1.875\ l_c$ if dumped

Wallingford

$$d = C \left(\frac{V}{(gD)^{0.5}} \right)^3 D$$

$d_{max} = 2\ d$ and $d_{20} = 0.5\ d$

$T = 2\ d$ or d_{max}

where W_c = weight of the critical rock - 2/3 heavier (kg)

d_c = size of the critical rock (m)

d = medium size of the rock material (m)

V = effective velocity (m/s)

D = depth of water upstream (m)

S_g = specific gravity of the rock

θ = slope of the rip-rap material (^{o})

C = slope and safety factor (e.g. 0.3 for 2:1 slope)

T = thickness of the rip-rap layer (m)

l_c = longest dimension of the critical rock (m)

$_{max}$ for maximum, $_{min}$ for minimum etc.