RiverLink

Notices of Requirement for Designations and Applications for Resource Consent

Volume Four: Supporting Technical Reports

Technical Report #5

Geomorphology

IN THE MATTER OF	The Resource Management Act 1991
AND	
IN THE MATTER OF	Resource consent applications under section 88, and Notices of Requirement under section 168, of the Act in relation to the RiverLink project
BY	Waka Kotahi NZ Transport Agency Requiring Authority Greater Wellington Regional Council Requiring Authority Hutt City Council Requiring Authority

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RIVERLINK
TECHNICAL ASSESSMENT #5
GEOMORPHOLOGY

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1. INTRODUCTION

1.1 Qualifications and experience

1. This Geomorphology Assessment was prepared by Gary Williams, of G & E Williams Consultants.

2. I have the following qualifications and experience relevant to this assessment:

   i. Over 40 years professional experience in all aspect of catchment management and the nature of land and water resources, their uses and hazards. This includes investigations, design, contract specification and supervision of a wide range of works and measures in waterways, in particular on gravel-bed rivers through Aotearoa/New Zealand, from the East Cape of the North Island to Southland in the South Island

   ii. A Bachelor of Civil Engineering (Hons), Bachelor of Science (Physics) and a Master of Commerce (Hons) from the University of Canterbury.

   iii. A Fellow of the professional institution, Engineering New Zealand (FEngNZ), elected for: "his role in designing of flood management schemes that harmonise with the natural environment. He has led the development and dissemination of an approach based on working with nature by understanding the natural behaviour and form of waterways and then adding channels or fairways that augment rather than modify the natural behaviour."

   iv. I prepared, or been involved in undertaking geomorphology assessments for waterways and river systems throughout the country, and this work is summarised in the attached report of Appendix C. This technical report lists over 30 reports of studies on a geomorphic approach to river management for rivers throughout Aotearoa/New Zealand.

3. I was assisted by Mr Kyle Christensen of Christensen Consulting who has the following qualifications and experience relevant to this assessment:

   i. Mr Christensen has over 20 years professional experience in river engineering, sediment transport and geomorphology.

   ii. A Bachelor of Natural Resources Engineering (Hons) from the University of Canterbury and a Masters of Natural Resources Engineering specialising in the interaction of river engineering works and geomorphology from Lincoln University.

   iii. A chartered member of Engineering New Zealand (CMEngNZ) as well as an Engineering New Zealand assessor for the water resources and stormwater engineering practice areas, a Chartered Professional Engineer (CPEng) and an International Professional Engineer (IntPE(NZ)).

   iv. A member of the New Zealand Hydrological Society, New Zealand Freshwater Sciences Society, Water New Zealand, the New Zealand Society of Large Dams and was the past Chairman and current committee member of the Engineering NZ/Water NZ Rivers Group.

   v. Mr Christensen has prepared, or been involved in undertaking geomorphology assessments for the following projects:

      a. Lower Wairau River/Wairau Diversion - Sediment Transport & Geomorphic Assessment;

      b. Waihopai Dam Upstream - Geomorphic Assessment;

      c. Upper Ruamahanga River - Assessment of Geomorphology;

      d. Hurunui Water Project – Assessment of sediment transport and geomorphic effects of proposed dams on the Waitohi River and irrigation offtakes on Waiau River;

e. Tauherenikau River - Geomorphic Assessment;

f. Waikanae River – Channel design for strategic management of geomorphology; and

g. Clyde and Roxburgh Dams – Peer review of morphodynamic modelling and strategic management plan of reservoir geomorphology.

1.2 Code of Conduct

4. I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2014. This assessment has been prepared in compliance with that Code, as if it were evidence being given in Environment Court proceedings. In particular, unless stated otherwise, this assessment is within my area of expertise, and I have not omitted to consider material facts known to us that might alter or detract from the opinions expressed.

1.3 Purpose and scope of assessment

5. This assessment forms part of a suite of technical assessments prepared for the RiverLink project. Its purpose is to inform the assessment of effects on the environment (AEE) that accompanies the Notices of Requirement and resource consent applications under the Resource Management Act 1991 (RMA).

6. This assessment analyses the geomorphology effects of the RiverLink project (Project).

7. Geomorphology is the study of the interactions of waterways and landforms, their processes and their interdependence and connectedness. For river systems there is a systemic connectivity of channel form, flood flow patterns and the transport of sediments. In the context of the Project, the geomorphology assessment is focused on the changes proposed within the confined river corridor floodplain, and in particular to the active (bed material transporting) river channel and its margins. It is based on what is proposed, the design basis of the proposed river works, and the geomorphic effects that the proposed channel changes will have on the natural character and functioning of Te Awa Kairangi/Hutt River (River).

8. For the purpose of clarity Gary Williams was the designer of the river channel works for which there is a separate design report[1] explaining the technical basis for the design. The purpose of this assessment is to quantify the effects of the river channel design. This assessment is necessarily separate from the design report although it will be referenced where appropriate.

9. I have visited the site on numerous occasions since commenced work on the Project in 2016, and previously for other projects and investigations of the Te Awa Kairangi/Hutt River, including the Ewen Floodway Project along the reach downstream, and for the investigations of the Hutt River Floodplain Management Plan (HRFMP).

10. The following reports that I have written are attached as supporting information for this geomorphology assessment report:

    i. “Report on the Natural Character of Rivers and an Assessment of Natural Character for Scheme Monitoring” of February 2013

    ii. “Natural Character Guidelines for the Management of Gravel-Bed Rivers in New Zealand” of April 2017.

[1] Williams G.J. & Christensen K.J. (2021). Te Awa Kairangi (Hutt River) RiverLink Project – River Channel Design Report *Consent Stage River Channel Refinements.*

11. The supporting information attached to this report is as follows:

   i. Appendix A: Natural Character Plans;

   ii. Appendix B: Supporting Information – Report on the Natural Character of Rivers and an Assessment of Natural Character for Scheme Monitoring; and

   iii. Appendix C: Supporting Information - Natural Character Guidelines for the Management of Gravel-Bed Rivers in New Zealand.

2. EXECUTIVE SUMMARY

2.1 Scope of Assessment

12. This technical assessment analyses the effects of the proposed RiverLink Project on the geomorphology of Te Awa Kairangi /Hutt River (River).

13. Within the context of the Project, geomorphology is defined as the form and behaviour of the river within the Project area. The form of the river is defined by the key characteristics of width, section shape, plan form meander pattern, and longitudinal profile including the pool-run-riffle sequences. The behaviour of the river includes its plan form mobility as well as the sediment transport characteristics, including deposition of gravel on the bed.

2.2 Existing Environment

14. Within the Project area, Te Awa Kairangi/Hutt River is a highly confined and heavily managed river, and significantly changed from its natural form. This is a result of engineering works over the past 100 + years to confine the channel and build stopbanks, to manage the flood risk to the adjacent Hutt City Central Business District (CBD). These works were part of the overall management of the River along its valley length.

15. Currently Te Awa Kairangi/Hutt River is managed in accordance with the Hutt River Floodplain Management Plan 2001 (HRFMP).

16. The width of the main channel is especially constrained in the lower reaches as the river passes through the existing Melling Bridge and into the tightly confined lower CBD reach. The constrained width affects the type of channel, affecting its shape across the channel and its planform[2] along the river, with limited space for the movement of river meanders. The meander pattern is quite different from what would have been the case in the past.

17. This reach of the river is where its gradient reduces as it approaches the sea and the gravel bed material being transported from upstream will deposit on the riverbed. The estimated average rate of supply of gravel bed material to the reach from Belmont to Ava Bridge is around 30,000 to 45,000 m^3 per year. Periodic extraction of the gravel material, and re-shaping of the river channel, has been undertaken since the beginning of river management, with extensive interventions from the 1930s.

18. Although highly constrained and modified, the existing channel reach has an alternating bar form, with a low flow channel around large gravel beaches, and hence a sequence of riffles, runs and pools. At present there are 11 significant pools along the Project reach, although 5 of these are relatively shallow. Pools are an important feature for the assessment of aquatic habitat and are covered in more detail in the report by Mr Patrick Lees.

[2] The planform of the river is its width, meander pattern, sinuosity and channel form as viewed from above.

2.3 Proposed Changes Due to Project

19. In the lower reaches of the Project area (from Ewen Bridge to upstream of Melling Bridge) the river channel will be widened a small amount in some locations (typically 5 – 10 m) to achieve a consistent 70 m wide design channel, and with a widened river corridor to around 140m which requires retreating the stopbanks on the right bank, to provide sufficient capacity for floods without having to further increase the stopbank height.

20. The more major change in the lower reach is the lateral shifting of the main channel by up to 30 m. This is to achieve adequate berms either side of the main channel to provide security from erosion to the new stopbanks.

21. In the upper reach of the project area (from above Melling Bridge to Kennedy Good Bridge) the channel will be widened by up to 25 m to provide space within which a more natural channel with dynamic river processes can develop. Of importance to the future maintenance requirements of the river is the likely increase in the deposition of gravel bed material that will occur in this upper reach, due to the change in channel conditions of the design. This will increase extraction from this reach, but reduce the amount of gravel material being transported into the CBD reach and below.

22. There will be a slightly different meander pattern and channel shape, with the design channel having a more consistent meander and pool/riffle sequence. The number of pools would reduce from 11 to 10, but it is highlighted that almost half (5) of the existing pools are very small, whereas in the proposed channel the pools would be larger and deeper, with only 2 smaller ones being of similar size to the existing smaller pools.

23. During construction there is the potential for a greater degree of mobility of the gravel bed material of the river, due to disturbances of the river bed and the breaking up of the natural surface armouring of the bed, along with the removal of mature vegetation from the channel banks. This increase in sediment mobility could produce increased gravel deposition in the reach downstream of the Project boundary. Any gravel transported into the downstream reach would be excavated on completion of the Project as part of standard GWRC river bed level maintenance covered by existing resource consents. It is noted that there is currently in excess of 80,000 m^3 of gravel (solid measure) above the reference 1998 levels to be extracted from this reach.

2.4 Assessment of Effects

24. The assessment has been based on a first principle empirical analysis of meander patterns and calculations of sediment transport characteristics at each cross section for both the existing and proposed situations.

25. A Natural Character Index (NCI) has been determined for the present and proposed river conditions, using the assessment criteria of:

    i. width across the floodplain

    ii. width of the active (clear) bed of the channel

    iii. channel sinuosity from flow length and direct valley length, and

    iv. pool-run-riffle sequences.

26. This showed that the Project would result in a positive improvement in the geomorphic character of the river, albeit relatively small in terms of the natural character and dynamic processes of the river.

2.5 Summary of Effects

27. The increases in width provide for improved meander form, and in the upper reach of the project area more natural meander mobility with the flexible vegetative bank edge management.

28. The sediment transport characteristics will also be improved with a more consistent width in the lower reach and the significant widening in the upper reach allowing for more deposition in this natural deposition zone.

29. With effective management (i.e. extraction of excess gravel) in the upper reach the volume of gravel being transported downstream to deposit in the less accessible CBD reach will be reduced.

30. The number of pools will be reduced by one, but the depth and planform area of the pools is greatly increased by the Project works.

31. The overall area of riverbed will be increased by 38,000 m^2 in the lower reach and 40,000 m^2 in the upper reach.

32. The overall effects on the geomorphology of the River arising from the Project once completed are positive.

33. During construction there is the potential for increased sediment transport into the downstream reach due to the exposure of more mobile sediment and the removal of mature vegetation from the riverbanks.

2.6 Proposed Mitigation

34. While the Project will provide positive geomorphological outcomes for the river, measures will be required to mitigate potential adverse impacts from the construction of the Project, and through the establishment period. This includes the sequencing of river works, minimising the areas of exposed bank and disturbed channel and flood response arrangements. These will be provided for in the consent conditions.

35. The HRFMP monitoring of the riverbed will allow on-going assessments of bed material deposition rates and trends, including the potential for additional material to be flushed through the Project reach. A more regular surveying of bed material deposition rates and trends within the Project length and downstream should be undertaken through the construction period and over the following 10 years.

3. PROJECT DESCRIPTION

3.1 Proposal

36. The Project is the design, construction, operation and maintenance of RiverLink. Key components of the Project are as follows:

    i. Upgrade and raising of existing and construction of new stopbanks on both sides of Te Awa Kairangi/Hutt River between Ewen Bridge and Mills Street

    ii. Instream works between the Kennedy Good and Ewen Bridges to re-align, deepen and widen the active river channel

    iii. The replacement of the two signalised at-grade intersections of SH2/Harbour View Road/Melling Link and SH2/Tirohanga Road with a new grade separated interchange

iv. Construction of an approximately 215 m long and up to 7 span road bridge with a direct connection across the River from the new interchange to Queens Drive

v. Removal of the existing Melling Bridge

vi. Changes to local roads

vii. Changes to the Melling Line rail network and supporting infrastructure

viii. Construction of an approximately 177 m long and 4 span pedestrian/cycle bridge over the River

ix. Construction of a promenade located along the stopbank connecting with future development, running between Margaret Street and High Street. This includes new steps and ramps to facilitate access between the city centre and the promenade

x. Integration of infrastructure works with existing or future mixed-use development

xi. Associated works including construction and installation of culverts, stormwater management systems, signage, lighting, landscape and street furniture, pedestrian/cycle connections and landscaping within the project area.

37. A full project description is available in the Assessment of Environmental Effects report (AEE).

3.2 Proposed river works

38. The following section outlines the measures and works required to achieve the HRFMP River Management objectives (specific details of which are outlined in the Urban & Landscape Design Framework [ULDF][3] prepared for the Project), which are relevant to the assessment of geomorphic impacts/effects. This covers the river corridor between the stopbanks, including the alterations in the active channel (low flow and gravel bar areas where floodwaters move the gravel bed material of the river), berm land alongside this channel and vegetation changes throughout the corridor.

39. The Project involves a widening and realignment of the active channel, with reshaping of the riverbed to establish a natural meander pattern that suits the altered channel. This requires the removal of gravel bed material and vegetation across the full extent of the river channel, between Kennedy Good Bridge and Ewen Bridge.

40. For the lower reach of the Project, from Ewen Bridge to upstream of Melling Bridge the river corridor between the stopbanks will consist of a 70 m wide active channel, with a 10 m wide lower berm benched into the available berm land on each side, giving a channel width of 90 m, plus an upper berm width of at least 25 m on each side. The total minimum width of the river corridor will then be around 140 m. Rock linings will be placed along the outer (deep pool) side of the bends of the meandering active channel, from below bed levels to the level of the lower berm. (See Figure 2 in Appendix A)

41. The active river channel will be re-shaped to fit the natural meander pattern of the widened channel with its slightly different alignment. Additional rock works will be added along the rock linings and at the edges of the inner-side bars (gravel beaches) for aquatic habitat purposes.

42. The lower berm bench will provide access to the channel edge and rock works for maintenance purposes. Otherwise the pathways, vegetation, landscape and other features will be undertaken to meet urban access, recreation and river character objectives.

43. There is a transition to the upper reach upstream of Melling, and in the vicinity of the Transpower site, where the active channel widens from 70 to 100 m in width. A different edge management will then be used along the upper reach. A 30 m wide lower berm will provide a vegetation buffer zone that can be managed as a flexible river edge. Debris fences will be installed while the buffer vegetation is

[3] Riverlink – Urban & Landscape Design Framework. Isthmus, Wellington

establishing (for approximately 10 years). A rock lining will be installed on the true left bank in front of the existing Transpower substation, and where Harcourt Werry Drive comes close to the river. (See Figure 2 in Appendix A)

44. The vegetation buffers along both banks of the upper reach will initially be planted with willows to a depth of 25 m, with native tree species behind and on the bank up to the upper berm area. Native trees will also be planted in blocks along the lower berms, with a minimum width of 5 - 15 m wide at 60 – 120 m intervals. All this vegetation buffer area will be under-planted with native riparian shrub and groundcover species. The 5 metres at the back will provide access for river management purposes and act as an informal pathway, with native vegetation on both sides. There will also be gaps in the buffer vegetation around 10 – 15 m wide at intervals of 90 – 120 m, mostly coming out at gravel bars. This allows for the return of floodwaters in the buffer zones back to the main channel but will also provide viewing and access openings.

45. A transition from a willow management approach for the buffer vegetation to native vegetation is proposed along the upper reach of the Project. This will change the vegetative character as well as the management of the buffer zones. A sequence of schematic plans showing this vegetative transition over time is given in the ULDF. An extract showing these plans is given in an attachment in Appendix A.

46. This reach up to Kennedy-Good Bridge is a natural deposition zone for the gravel bed material of the river, and to maintain flood capacity periodic removal of this material will be necessary. The amount of gravel material that will, thus, be extracted along this reach will be greater than in the past, while the river conditions will be marginally different.

47. A summary of the changes in channel widths including lateral channel shifts is provided in Tables 1 and 2 below.

Table 1 Changes in channel width and planform location Lower Reach

Cross section reference	Current width (m)	Proposed design width (m)	Change (m)	Channel shift
XS320	90	90	0	
XS330	80	80	0	
XS340	70	75	5	
XS350	60	70	10	5m left
XS360	65	70	5	7.5m left
XS370	70	70	0	10m right
XS380	70	70	0	20m right
XS390	70	70	0	30m right
XS400	55	70	15	20m right
XS410	70	70	0	5m right
XS420	65	70	5	

Cross section reference	Current width (m)	Proposed design width (m)	Change (m)	Channel shift
XS430	65	70	5	
XS440	65	70	5	8m right
XS450	65	70	5	10m right
XS460	65	70	5	2m right
XS470	65	70	5	
XS480	60	70	10	
XS490	60	75	15	

Table 2 **Changes in channel width and planform location Upper Reach**

Cross section reference	Current width (m)	Proposed design width (m)	Change (m)	Channel shift
XS500	65	80	15	
XS510	65	85	20	
XS520	65	90	25	
XS530	70	95	25	
XS540	75	100	25	
XS550	75	100	25	
XS560	75	100	25	
XS570	85	100	15	
XS580	110	100	-10	Right Bank Erosion Bay
XS590	100	100	0	
XS600	90	100	10	
XS610	90	100	10	
XS620	100	100	0	
XS630	100	100	0	

Cross section reference	Current width (m)	Proposed design width (m)	Change (m)	Channel shift
XS640	100	100	0	
XS650	100	100	0	

48. These increases in width translate to a total increase of active river channel planform area of 38,000 m^2 in the lower reach[4] and 40,000 m^2 in the upper reach[5].

3.3 Proposed river works construction

49. The construction of the river works requires a complex construction methodology, which covers the sequencing of works as well as the type and nature of the activities, including all associated works and measures that are required to facilitate the works and mitigate adverse effects[6].

50. This methodology is important for the mitigation of adverse geomorphic effects, as well as to minimise damage to works in progress and for flood security during the construction period.

51. In terms of specific geomorphic effects during construction, large-scale excavations and vegetation removal would increase the input and mobility of gravel within the Project reach. This has the potential to increase the amount of excess[7] gravel deposited in the Ewen to Ava reach immediately downstream of the Project.

52. The construction methodology must, therefore, manage bank erosion and bed mobilisation impacts to minimise the effects on sediment transport.

53. The proposed methodology for the Project as a whole is described in the Construction Methodology section of the AEE.

3.4 Objectives of the river works

54. Te Awa Kairangi/Hutt River is managed by GWRC in accordance with the provisions of the Hutt River Floodplain Management Plan (HRFMP). The HRFMP was developed in 2001 following many years of extensive investigations and discussions. The key elements of the FMP relevant to the project are:

    i. Selected floodplain management measures constructed or established to an agreed standard are in place within the life of the Hutt River Floodplain Management Plan.

    ii. Solutions for floodplain management that balance benefits and costs to the community are put in place.

    iii. The selected measures account for a level of residual risk, which is acknowledged and accepted by the community.

    iv. The mitigation of the current flood risk from floodplain tributaries is recognised and provided for by the appropriate authorities.

    v. There is no reduction in the quality of public access to and along the river and opportunities are taken to enhance public access.

    vi. The exercise of kaitiakitanga by Tangata Whenua is recognised and provided for.

[4] Increase from 100,000 m^2 to 138,000 m^2
[5] Increase from 123,000 m^2 to 163,000 m^2
[6] Riverlink – Construction methodology. GHD
[7] Excess in terms of the required bed level to pass the design flood through this reach without overtopping existing upgraded stopbanks.

55. The objectives of the River works are presented in the Assessment of Environmental Effects (AEE) in Volume 2 of the application. The river works are described in more detail in the project description (Chapter 4 in the AEE) and the alternative design options considered in Chapter 7 of the AEE[8]. The investigations undertaken for the design, and the reasons why the proposed works were selected is given in the design report. The overall vision for the Project as included in the ULDF are:

i. Vitality: River First;

ii. Connectivity: River to City and;

iii. Identity: Te Awa Kairangi and overall whakataukī (proverb) for He Korowai reflects the values of Te Awa Kairangi (literally meaning the most precious, esteemed river).

56. Given the HRFMP objectives, consequential management plans and the Code of Practice for river management, the approach taken for the river works can be summarised as follows:

i. Making room for the river by widening the main channel and retreating stopbanks;

ii. Realigning the river to provide a more natural planform meander and to provide sufficient sacrificial buffers to ensure stopbank security;

iii. Utilising a mixture of willows and native vegetation in the upper reach to provide for natural river functioning in terms of lateral migration;

iv. Increasing sediment deposition in the upper reach to reduce the frequency of in-channel bed level management (gravel extraction) in the lower reach;

v. Enhancing the quality and quantity of aquatic habitat through provision of pools, instream features including scattered rock at the front of rock lines, large woody debris, and rock spurs;

vi. Providing appropriate capacity to pass the design flood.

57. The main findings of the design investigations and the reasons for the proposed approach and measures to be used are summarised in the following section.

58. The increase in the standard of flood protection along the Project reach, to meet the standards of the (HRFMP), and to provide a consistent level of protection along the River, is to be achieved by a number of measures in combination, as follows:

i. Raising the stopbanks in height and providing a wider and more massive earth embankment structure

ii. Enlarging the river channel by removing edge vegetation, widening the channel by excavating riverbank material and deepening the bed by excavation of gravel bed material

iii. Providing stronger bank edge protection, by lining the banks with a blanket of graded rock material and/or by lowering an area of the river berm land to provide a more effective band of vegetation to buffer flood flows, and

iv. Widening the river corridor along the lower reach to allow for the larger stopbanks and provide a consistent upper berm area along both sides of the River.

[8] Williams, G. J. 2017a: Hutt River City Centre — Riverlink Project; River Channel Design – Assessment of Options & Preliminary Design. G & E Williams Consultants Ltd, Otaki.
Williams, G. J. 2017b: Hutt River City Centre — Riverlink Project; River Channel Design – Preliminary Design & Project Refinements. G & E Williams Consultants Ltd, Otaki.
Williams, G. J. & K Christensen 2021: Riverlink Project; River Channel Design – River Channel Refinements. G & E Williams Consultants Ltd, Otaki & Christensen Consulting Ltd, Lower Hutt.

59. At the same time, the design has been based around the river dynamics and geomorphic processes along the Project reaches, to achieve a better balance between the natural responses of the river and the measures used to manage the river. This will reduce the degree of management intervention and the effort and costs required to maintain HRFMP objectives.

60. An important sedimentation objective is to encourage the natural deposition of gravel bed material, which takes place along the Project length of the river, within the widened upper reach, and reduce deposition along the more confined and sensitive (in relation to urban integration) lower City Centre reach.

61. The Project reach of the river is an especially complex reach, naturally and in terms of human use and proximity of high value assets. The river is transitioning from its relatively steep grade as a gravel-bed river to a low-grade tidal reach as it flows to the sea. The river loses grade, and hence sediment transport capacity, as it turns away from the valley fault line and crosses its floodplain to its mouth.

62. Given the confined nature of the river corridor, the high standard of the HRFMP is to be achieved by enlarging the river channel as well as increasing the height of the stopbanks. The design and management of the river is mostly concerned with protecting the stopbanks from river erosion, which would cause a breach in these flood defences.

63. Managing the dynamics of flood flows and the pulse nature of gravel bed material movement down the river is critical to the success of the flood mitigation measures.

4. EXISTING ENVIRONMENT

64. The Te Awa Kairangi/Hutt River flows from the high peaks at the southern end of the Tararua Range, southward to the basins along the Wellington Fault. Its upper catchment is mostly steep forested land, with tributaries draining the western side of the Remutaka Range. The remaining catchment is basin and hill land, with remnant terraces.

65. The river flows along the fault line in the Hutt Valley, and then across a short aggradation reach to the enclosed harbour of Te Whanganui a Tara/Port Nicholson. The gravel bed load of the river is partly deposited along its lower reaches and partly in the harbour at the river mouth. The Project is being undertaken in the lower reaches where the river is naturally depositing its gravel load.

66. The nature of the River and the changes that have taken place over time are described in the ULDF report.

67. Naturally the river would have migrated across its wider floodplain as confined between the eastern and western hills before arriving at the river mouth estuary where present day Petone is located. Prior to settlement and development of the floodplain it is likely that it would have been vegetated with a mixture of native trees. Figure 1 below provides an indication of the nature of the floodplain post clearance of vegetation but prior to substantive river control works being undertaken.

Figure 1 Photograph of the Hutt River and Hutt Valley from above the Western Hutt Road looking south towards present day Pomare and beyond circa 1888[9]

68. Over the last 100 years the river has been extensively managed with the channel confined and stopbanks built to manage the flood risk to the adjacent Hutt City Central Business District (CBD). The key aspects of these engineering changes to the natural form of the river have been:

    i. Stopbanks and rock lines constructed to confine the planform location of the river;

    ii. Gravel extraction to manage the ongoing deposition of gravel in the lower reaches and to keep the channel in its current location.

69. A detailed history of river management works on the Hutt River was published by the Wellington Regional Council in 1991 – The Hutt River Te Awa kai rangi A Modern History 1840 to 1990.[10]

70. This history covers the earliest Maori and European settlement of the Hutt Valley and then describes the historical river control schemes including –

    i. The First Scheme: Flood Control for the Lower Hutt Valley 1900-1924;

    ii. Exploitation of the Shingle Resource;

    iii. Scheme Improvements 1925 – 1945;

    iv. Scheme Review 1945 – 1970;

    v. Scheme Refinements 1972 – 1990;

    vi. Chronology of major works and events 1855 – 1990.

[9] Burton Brothers (Dunedin, N.Z.). Burton Brothers, 1868-1898 (Firm, Dunedin) :Photograph of Hutt Valley. Ref: PAColl-2417. Alexander Turnbull Library, Wellington, New Zealand. /records/22723941

[10] http://www.gwrc.govt.nz/assets/Our-Services/Flood-Protection/Hutt-River-A-Modern-History-1840---1990/00-The-Hutt-River-A-Modern-History-1840-1990-Introduction.pdf

4.1 Hutt River Floodplain Management Plan

71. The HRFMP studies of the 1990s included investigations of the natural character and sedimentation processes of the River, alternative management approaches and edge protection works, and a determination of channel widths and protection measures along the full valley reach of the River, from Te Marua to the river mouth[11].

72. These studies provided an overview of the River catchment and conditions along the Hutt Valley reach of the River.

73. The existing environment is summarised from the study reports, covering both the wider catchment context and the local reach conditions.

4.2 Catchment Geology

74. The primary landform of the Wellington Region is a set of tilted blocks, of greywacke material, reducing in height in the westward direction, and defined by active faults that have a pronounced horizontal movement. Along the Wellington Fault block, buckling has given rise to a series of basins that have been infilled with alluvial material. The River flows down these basins, and much of the main channel reach closely follows the fault line.

75. The geological processes at work within the catchment have given rise to three general groups of surface materials, as follows:

    i. The base rock of sandstone/argillite sequences, commonly called greywacke;

    ii. The lower quaternary gravels and admixtures of loess/gravel that form terrace deposits within and along the main basins and valleys, and capping higher ground to the west of the River, and

    iii. The reworked gravel and alluvium of the valley floor and present river channel.

76. The Project is being undertaken within the active gravel bed of the river as well as within the berms, parts of which are natural gravel alluvial deposits along with other parts that have been constructed of bulk/waste hardfill during earlier river management projects.

4.3 Catchment climate

77. New Zealand has a moist temperate climate with mild winters, and the central areas of the country tend to have the more equable climate. The Tararua Range, however, cuts across the west to east movement of the (anticyclone/depression) weather systems, and deflects the air flows through Cook Strait. Thus, in this river catchment the prevailing winds come from the northwest, and there are relatively frequent gales. Rainfall is reliable and evenly distributed through the year, but with somewhat more rain over the winter period. Rainfall intensities are generally greater in the higher range land of the catchment, but very intense localised rainfalls can occur throughout the catchment.

78. Marked changes in climate over geologically recent times have occurred in the catchment. During colder glacial periods the catchment has been denuded and severely eroded, with large accumulations of material in the valleys. During warmer interglacial periods, like the present, the catchment has been forested with soil build-up occurring, and the river system has cut down into the previously deposited material in the mid and upper catchment.

[11] Healy, M. 1999: HRFMP Phase 2 & 3: Channel Management and Protection Works. Greater Wellington Regional Council, Wellington.
Williams, G. J. 1991a: Hutt River Floodplain Management Plan — River Characteristics and Sedimentation. G & E Williams Consultants Ltd, Otaki.
Williams, G. J. 1991b: Hutt River Floodplain Management Plan — Channel Management and protection Works. G & E Williams Consultants Ltd, Otaki.

79. The future climate is expected to be warmer with higher rainfall intensities and a more intense flood regime, as well as rising sea levels. These future conditions are likely to result in increased amounts of sediment being transported in the river channel as well as a greater amount of gravel deposition that extends further upstream. This change in flood hydrology and sediment transport capacity will change the character of the river system, and give rise to a different natural character along the lower reaches, with a generally wider natural channel form.

4.4 River channel characteristics

80. The river channel is relatively narrow with a steep grade until there is a sudden transition to accommodate the sea level control at its outlet. There is a major change of grade around the Kennedy-Good Bridge, with a lesser reduction in grade upstream of the Ewen Bridge, where the river bends away from the Wellington Fault.

81. The Project is within the reach bounded by Kennedy-Good Bridge at the upstream end and Ewen Bridge at the downstream end, and is geomorphically defined as a deposition zone where gravel will naturally deposit on the bed.

82. The width of the river channel in the Project reach has narrowed significantly over the past 100 years, with the lower part of the reach being confined from previously being up to 100 m wide down to typically 60 – 70 m currently. The upper part of the Project reach from Transpower to Kennedy Good bridge was previously up to 200 m wide but is now typically 70 – 100 m.

83. The narrowing of the channel is largely anthropogenic due to river management works and gravel extraction over the period of settlement on the River floodplain. There is also the possibility of a reduced sediment supply in recent decades contributing to a natural narrowing of the channel. The reduced sediment supply is due to very limited flood and seismic activity in recent decades and a reasonably well vegetated and stable upper catchment.

84. The riverbed material is relatively coarse, with the median size reducing from a D50 of approximately 50 mm at the upstream end of the Project reach to a D50 of 25 mm in the middle and lower reaches.

85. Based on recent work by Cameron (2018)[12] the dominant sediment particle size that is expected to be in the water column as a result of in-river works is sand (0.06 – 2 mm diameter). This material is likely to make up approximately 10% of the total bed sediment within the Project reach.

86. Although it will be highly dependent on the flow in the river at the time, this material would not be expected to be transported more than 500 m downstream.

87. With regard to fine silt/clay sized sediment (< 0.06 mm diameter), the overall suspended sediment load generated by the whole catchment is estimated at 90,000 t/yr. Of this approximately 70% will be less than 0.06 mm diameter which provides a specific silt/clay yield of approximately 100 t/km^2/yr for the entire 639 km^2 catchment. The Project footprint includes approximately 0.15 km^2 of in-river works and a further 0.3 km^2 of works on land adjacent to the river for a total area of 0.45 km^2 or 0.07% of the total catchment. Based on the Project footprint and the specific silt/clay yield the amount of silt/sand particles likely to be present in the Project reach will be insignificant (<0.5%) relative to the natural supply of the entire catchment.

88. Along the Project reach of the River the particle size distribution of the material in the river channel is likely be similar to that of the adjacent floodplain, with the floodplain having been built up from river deposits when the river was free to migrate across the wider valley floor.

[12] Cameron, D.J, (2018). Baseline Monitoring of Aquatic Habitat Quality and Fish Communities (Hutt River)

5. ASSESSMENT METHODOLOGY

89. The assessment methodology has been based on design investigations and assessments of risk and impacts on the natural character, relevant to the Project reach. This included the design methods, the evaluation of alternatives, consideration of residual risk from the uncertainties and limitations of both the design and the future maintenance regime, and qualitative assessments of the natural character of the reach. The operational and construction effects of the Project have been assessed separately.

5.1 Design basis

90. The geomorphology assessment is based on methods used in the design of the river corridor measures, and the assessment of effects has been derived from on-going investigations and evaluations of effects over a long period of time, as upgrade works have been developed and implemented along the River.

91. This process started with the HRFMP, and the initial investigations of the River, its floodplain and its catchment. Relevant studies[13], for the river design and geomorphological assessment, include those on flood flow hydrology; hydraulic modelling of the river channel, its wider corridor and outflows over the floodplain; bed, bank and floodplain materials; suspended and bed material transport; the natural characteristics of the river; and channel management and protection measures.

92. Intensive and detailed investigations were undertaken for the Ewen Floodway Project in the 1990s, which covered the reach immediately downstream of the Project, and included channel realignment and widening, rock and vegetative protection measures, along with stopbank raising and reconstruction, and the construction of the present Ewen Bridge.

93. The scope of the investigations, risk assessments and option evaluation are very similar to that of the Project. For the Ewen Floodway Project a mobile-bed physical scale model of a reach of the River was undertaken, with a wide range of channel options investigated, as well as bridge pier local scour and flood flow impacts on rock and vegetation protection measures[14].

94. The results from the physical modelling of the river works for the Ewen Floodway Project have informed the design of the river works of the RiverLink Project. The Preliminary Design investigations for the Project included reach specific hydrology and hydraulic modelling; sediment transport and bed scour analyses; and calculations for rock works and berm velocities for local scour effects[15].

95. The assessment of effects is based on the information obtained from the earlier investigations, and in particular the Preliminary Design investigations of flood flows within the river corridor (active channel, edge berms and wider floodplain land between the stopbanks), sediment transport and bed scour calculations. An appreciation of the geomorphic context of the river reach and the dynamics of the natural processes of the river along the reach were especially important in the design of the channel meander and alignment, its widening and deepening, and the type and placement of different protection measures. Use was also made of the information and insights obtained from the physical mobile-bed scale modelling of the reach of the River undertaken for the earlier Ewen Floodway Project. The detailed calculations and numerical morphological modelling, along with an

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[13] See Hutt River FMP Reference List Pg 216- 219 http://www.gw.govt.nz/assets/Our-Services/Flood-Protection/Hutt/FP-Hutt-River-FMP.pdf

[14] Williams, G. J. 1993: Hutt River — Ewen Floodway Project; River Channel Improvements – Physical Model Study – Implications for River Works Design. G & E Williams Consultants Ltd, Otaki.

[15] Williams, G. J. 2017a: Hutt River City Centre — Riverlink Project; River Channel Design – Assessment of Options & Preliminary Design. G & E Williams Consultants Ltd, Otaki.
Williams, G. J. 2017b: Hutt River City Centre — Riverlink Project; River Channel Design – Preliminary Design & Project Refinements. G & E Williams Consultants Ltd, Otaki.

understanding of catchment and reach context, is important for an understanding of risks and long-term sediment management requirements.

5.2 Alternatives

96. Alternative channel widths, meander patterns and protection measures were considered for the Project reach as part of the HRFMP. In the Preliminary Design phase of the Project, the two most preferred channel options were investigated. One, named a Consistent Width Option, had a 90 m channel width throughout the Project reach. The other, named a Variable Width Option, had a 70 m active channel width along the lower reach of the Project and a 100 m channel along the upper reach, with a transition from upstream of Melling Bridge to the Transpower site.

97. For the lower river reach, from Ewen Bridge to Melling Bridge, the Variable Width Option had a 70 m channel with 10 m wide lower berms on each side (giving 90 m overall), plus a higher berm area of at least 25 m in width. The Consistent Width Option had a 90 m channel with berms at least 25 m wide. The preferred option at the start of preliminary design was initially the Consistent Width Option with a 90 m channel and 25 m berms, but as the assessment progressed the Variable Width Option was considered more favourable[16].

98. Upstream of Melling Bridge, from the Transpower site to Kennedy-Good Bridge, the stopbanks have already been upgraded, and the design river channel alignment and width had already been determined by earlier studies[17]. This design channel had a 100 m width, with a 20 m wide lower berm on each side for a channel edge vegetation buffer. As part of the further investigations and assessments of the Project, options for this upper reach were reconsidered, and in more detail (through the AoA6 evaluation of the AEE). The options were:

    i. **Vegetation Buffers**: Managed willow and native bio-engineered edge protection. 140 m management zone. Flexible channel, flexible edges

    ii. **Rock Groynes**: Rock groynes at 50 m spacing with native edge vegetation. 90 m management zone + edge management of groynes. Constrained channel, fixed edges

    iii. **Hybrid of Rock Groynes and Vegetation Buffers**: Rock groynes where the flow channel is against the bank and vegetation buffers at bars (lateral beaches), with fixed channel meander. 90 m management zone + edge management of groynes. Constrained and fixed channel, fixed edges, and

    iv. **Bank Hybrid of Rock Groynes one side and Vegetation Buffer the other**: Rock groynes and native planting on TRB and vegetation buffers on TLB. 110 m management zone + one edge management of groynes. Semi-flexible channel fixed and flexible edges.

99. Following an assessment of alternatives during the consent phase design, the channel edge vegetation buffer option was recommended as the preferred option, but with the lower berm widened out from 20 m to 30 m[18].

5.3 Residual risks

100. The river channel design is based on the investigations that have been undertaken for the Project, and the past investigations and design work on river management and flood mitigation measures along the lower reaches of the River as set out above. Rivers are, however, highly dynamic and ever-changing systems, which depend on complex physical and biological processes. River engineering is very dependent on experience and an approach of continual observation and adaptation as river

[16] Damwatch, 2017: Riverlink – Riverworks Preliminary Design – Technical report GW/Riverlink-T-17/09
[17] Williams, G. J. 2009: Hutt River – Boulcott & Hutt Golf Courses – Channel Improvements. G & E Williams Consultants Ltd, Otaki.
[18] Riverlink – AEE Chapter 7

systems respond and change. It is as much based on a practiced art, as on theories and guidelines derived from scientific experimentation. Risk management is inherent in the design, construction and operation of the flood mitigation measures, and there are always residual risks that cannot be managed by engineering practices.

101. The design and risk management approach taken for this Project is outlined in the attached report of Appendix C.

102. Most important is an understanding of the nature of the river system and the characteristics of its differing reaches. It is the assumptions made about the river processes at work along a given reach, and how they affect the form and dynamics of the river channel that is critical to the design and its effectiveness. This is the essence of the geomorphological evaluation and is critical to any assessment. These assumptions are addressed in the assessment, as outlined below.

103. There are many uncertainties in river dynamics, and about the relative effects and influences of climate variations and differing catchment processes. While there may be a general predictability in river responses and the effectiveness of management works and measures, local expressions and the detail of impacts can be quite unpredictable. Thus the ease or difficulties in making repairs or re-establishing protection measures and berm land or vegetation, is difficult to predict.

104. The design channel is an initial state for construction purposes, and the channel form and extent will change with flood events. Repairs and re-establishment will be undertaken in response to what happens, given the pattern of flood events and the type and degree of flood damage. The management approach that is taken, available time and budgets, and limitations on work programs, also affect repair works and hence risk exposure.

105. There are really two different reaches in the Project area, one from Kennedy-Good Bridge to Transpower (upper reach), and then a transition to a different reach from above Melling to Ewen Bridge (lower reach). There are significant differences in likely river responses and uncertainties between these reaches.

106. The uncertainties and limitations of the design affect any assessment of geomorphic effects, and what may happen, during construction, the establishment period of vegetation and ground stabilisation, and operationally in a fully functional state. However, it is highlighted that similar works have been undertaken on the river over the past 100 years and particularly so in the past 20 years with regards to Hutt River FMP works in the reach immediately downstream of the Project. Nonetheless, the risks that are particularly relevant to design functionality and a geomorphic assessment, are as follows (taking account of the different nature of the two reaches):

    i. The low flow meander pattern and the cross-sectional shape of the main channel will vary over time, and this depends on the timing and intensity of flood events. The channel along the lower reach will have a relatively stable form and be fixed in place by the bank edge rock linings, but there is an area of poorer form and more variable sediment transport between Melling Bridge and the Marsden Bend. The channel form along the upper reach will shift and change with flood events, and the management approach involves a vegetation buffer zone that allows a moveable edge as channel migration takes place.

    ii. Changes in channel form with meander migration may outflank the proposed rock linings and in-channel rock works, and extensions or rearranging of these works may be required in response. Scour hole development along the linings may also affect the integrity of the rock works and require topping up and/or re-assembling of the rock works.

    iii. The design flood for capacity containment is a very extreme event, and the impacts on the riverbed and banks of such a flood event may be significantly different to floods of a lesser size. The physical modelling undertaken of the River (for the Ewen Floodway Project) indicated that large bed dune formation and movement could take place, and the river activity in such an event may be much more severe than the floods that have been recorded and observed in the Hutt River. The knowledge and standards developed for floods up to a 100-year return period event may be insufficient for such larger events as the design flood.

iv. The rock linings along the riverbanks are generally high, with vertical heights of up to 4 to 5½ m. In large flood events some damage is to be expected, and in floods close to the design standard extensive damage and loss may occur. A primary reason for the 25 m berms is to accommodate bank erosion in large events given the failure of bank edge protection works.

v. The proposed vegetation layout and planting arrangements on the river corridor berms, along with the pathways and various facilities and structures, will give rise to complex flow patterns, and severe erosion and deposition is likely in localized areas because of this complexity. The lower berm areas in the narrower lower reach will be inundated quite frequently, and some scour and deposition will occur because of this flooding. Along the upper reach, this lower berm area will be fully vegetated, and loss of edge vegetation will occur as part of the expected management regime. The lower berm within the narrower lower reach will be more impacted given the more diverse and less dense vegetative cover, and there are more features and structures that will be affected in this reach. Calculated berm velocities of the hydraulic modelling are averages across the area of the berms, and there will be significant localised variations around these averages. Variations around vegetation edges, gaps and openings, as well as at structures, will add further to these localised fluctuations.

vi. The gravel bed material of the river will accumulate along the Project reach, as it is a natural deposition area. The upper reach has been designed to act as a storage area, and a regular extraction of bed material from this reach will be necessary to maintain flood capacity and the river management approach. Bed aggradation will, however, extend into the lower reach and downstream of the Project, and this will impact on river management and the amenity, recreational, landscape and environment objectives for this reach.

vii. The amount of maintenance effort will depend on how much the different Project objectives are to be maintained, and to what level of service. The range and intensity of use along the lower reach will make maintenance in this area especially complex, and undoubtedly trade-offs will be required over time, as the impacts of floods are demonstrated by actual events.

viii. The confinement of the River along the Project length, the transition nature of the reach with its depositional tendencies, the assets at risk and the range and intensity of human uses of the river corridor, combine to give rise to a relatively high level of unpredictability, and hence design and maintenance uncertainties. The residual risks for flood mitigation are likewise more uncertain. The multiple objectives of the Project, and the maintenance issues this raises, can impact on flood security, and in unpredictable ways because of the uncertainties.

ix. It is highlighted that the level of risk and uncertainty is generally being reduced by the Project, through the widening of the river channel and the strengthening of erosion protection in the lower reaches and the widened vegetated buffers in the upper reach.

x. The expected maintenance regime for the river works is described in the design report and these works can be undertaken using the existing river management maintenance consent.

5.4 Natural character

107. When assessing natural character effects, we have assumed the following understanding of natural character, which has also been used in the overall AEE and the Landscape and Visual Assessment (Technical Report #14). It has been adapted for the purposes of RiverLink from a Department of Conservation (DOC) Guidance Note on natural character in the content of the coastal marine area and the New Zealand Coastal Policy Statement.

108. Natural character is the term used to describe the natural elements of the river environment (for the purpose of this assessment assumed to be the area between the stop banks). The degree or level of natural character within an environment depends on:

i. The extent to which the natural elements, patterns, and processes occur

ii. The nature and extent of modification to the ecosystems and landscape/riverscape

iii. The degree of natural character is highest where there is least modification

iv. The effect of different types of modification upon natural character varies with context and may be perceived differently by different parts of the community, and

v. In this context 'elements, patterns and processes' means 'biophysical, ecological, geological, and geomorphological aspects; natural river/landforms such as beaches, berms and braiding of the active channel; and the natural movement of water and sediment.

109. The assessment focuses on the physical aspects of natural character in the river corridor, taking into account the wider catchment context, with specific reference to (i), (ii) but excluding ecosystems specifically, (iii) and (iv). The broader human perception aspect (iv) is covered in the natural character assessment in Technical Assessment No. 14 Landscape and Visual Assessment.

110. A reach of a river has a natural character, which is expressed in its form (channel shape and pattern) and functional relationships (of flow, sediment transport and vegetative interactions). It is not a state of the river, as it depends on the dynamics of its processes and their connectivity. The geomorphic expression of a river is derived from its catchment setting, of geology, landscape and climate, and the processes of movement and exchange along the river system.

111. The natural character of a river changes along the river, from the headwaters to the sea, and when characterising a river this is done by reaches. It is a given reach that can be characterised, not a river. The nature, character and responses of a river change from reach to reach, as the forces and processes at work change, and a given character can only be defined for a reach where there is a similarity of river processes along it.

112. A consideration of the natural character of a river reach can then be used to make a qualitative assessment of the geomorphic impacts of changes in the upstream watershed or along the reach itself. As the natural character of a river reach depends on the overall setting, of climatic regime and catchment conditions, as well as the local physical and ecological conditions along the reach, any determination must take into account both the catchment setting and the reach conditions. As a dynamic expression of the processes at work and the variations over time and space of the influencing forces, this determination must be based on a holistic appreciation. The overall setting and pattern of connectivity are especially difficult to categorise and quantify.

113. An assessment of the natural character of the River has been previously undertaken where the river reach is first characterised by general type, as it relates to its catchment setting, and then, for that given type, measurable local conditions can be used to evaluate and rank the reach, to give a Natural Character Index (NCI)[19]. The measurable local conditions included the following parameters: widths

[19] See Fuller, I.C., Death, R.G., & Death A.M (2015) Developing an index of natural character to monitor change in river condition in response to river engineering. https://www.graie.org/ISRivers/docs/papers/1B15-47719FUL.pdf

across the floodplain, of active (clear) bed of the channel, the bankfull width and the permitted floodplain width; channel sinuosity from flow length and direct valley length; and pool-run-riffle sequences.[20]

114. The reference condition for the indices was evaluated based on the earliest available aerial photography for the River. The date of this photography was 1941-43 for Te Awa Kairangi and therefore did not reflect a completely unmodified state, prior to any human intervention. The indices therefore provide a measure of the changes in physical conditions over a defined period of time, and hence a basis for assessing further changes over time and do not reflect a measure of change from some “natural state”, in whatever way that may be defined or determined.

115. The physical features as shown on the earliest aerial photography were compared with those same features (as measured) on the latest photography, and the index value obtained by dividing the current measured value by the earlier one, to give a condition ratio. The determination was done from aerial photography and contour information produced from Lidar imagery surveying.

116. In addition, an assessment of the number and sequences of pools and riffles was undertaken through a determination of the significant pools present along the unit reaches from the aerial photography. Only those pools that were clearly deep-water pools were included. This is a simplified measurement, and the pool number was expressed as pools per kilometre, given the different lengths of the unit reaches.

117. This previous NCI was, then, based on physical features, and a comparison over a defined period of time, but the same methodology can be used for future comparisons, to give consistent and comparable assessments that can track trends in river conditions.

118. This indexing has been applied to the Project reach as a follow up from the original study, using the same approach, to determine the likely future trend from the existing (current) conditions to the future design conditions achieved by the Project. This NCI assessment was a significant part of the geomorphological assessment of the river corridor changes and impacts of the Project proposals. It is highlighted that the reference conditions for assessing the effects of the Project are the current river characteristics and not those from the previous study which assessed changes from mid last century.

5.5 Operational effects

119. The assessment of operational effects is based on the conditions that would exist after construction and the full establishment of the design measures that ensures design functionality. This would include any settling in of the rock in rock lining or groyne works, and sufficiently established channel edge and berm vegetation to be effective as a vegetation cover and fulfil the Project objectives and management requirements to maintain the integrity of the Project.

120. Vegetation, both natives and exotics, will take years to establish, and there is a transition period between the end of the construction program and achieving conditions that allow the proposed design operation. There are effects during this period that are different to both the construction period and when the Project is functionally complete.

121. The following assessment methodology has been used to assess the operational effects of the Project:

    i. A wide range of information, as outlined in the previous sub-sections of this Assessment Methodology section, has been used to assess the changing nature of the river reach and the impacts this has on the geomorphic processes and character of the river reach. The large

[20] Williams, G. J. 2013: Western River Schemes — Natural Character – Natural Character of the Rivers and an Assessment of Natural Character for Scheme Monitoring. G & E Williams Consultants Ltd, Otaki.

degree of uncertainty about the processes and likely changes has been noted, within the Residual Risk sub-section, which highlights design and effectiveness risks, also highlighting the uncertainties and risks from a geomorphological perspective

ii. The focus of the assessment is on any changes in the natural character of the reach and how the processes of flooding, sediment transport and channel movement and meander migration may affect the character of the reach. The interaction and relationship connections between the physical processes and the reach biology and ecological systems are also very relevant, and

iii. The methods are necessarily qualitative and depend on an understanding of the whole waterway system and its connections and dynamics. However, some monitoring variables of the NCI can, and have, been used to give an indication of the potential degree of change because of the Project. This NCI assessment has been applied to the Otaki and Waikanae rivers, as well as Te Awa Kairangi/Hutt River in the Wellington region.

5.6 Construction effects

122. The construction effects can be more definitely itemised and quantified than operational effects, at least in terms of the quanta of works and the likely consequences of these works. This is in contrast to the operational effects, which depend on the actual responses of the river to the Project and the future frequency and intensity of floods. The construction works will have much wider effects than those that affect geomorphic processes, but this assessment of effects has been restricted to a geomorphological perspective. This does, though, include the effects of changes in vegetation, and the issues that arise from the formation of raw banks and channel disturbances.

123. The following assessment methodology has been used to assess the geomorphological effects during the construction of the Project:

i. Consideration of the quantities of earthworks in the channel and the duration of works in the channel;

ii. Consideration of the quantities of earthworks on the berms and duration of works on the berms;

iii. Consideration of the construction requirements to find the rock linings or groynes below river bed levels;

iv. Requirements for temporary works, particularly diversions and bunding of working areas; and

v. The sequencing of the works and the geomorphic implications of the proposed progressive channel enlargement in an upstream direction.

6. ASSESSMENT OF OPERATIONAL EFFECTS

6.1 Bank erosion

124. The Project works include extensive widening and relocation of the main river channel. Without the proposed bank protection works there would be long lengths of raw riverbanks that would be highly prone to erosion. This could put the newly constructed stopbanks at a high risk of failure and could also add significant volumes of additional sediment to the system.

125. However, the proposed measures, once established, will provide a much greater degree of security against bank erosion effects than at present.

126. The effective mitigation and management of bank erosion and sedimentation risk is fundamentally important to achieving the Project's flood management outcomes. The methods proposed for mitigating the geomorphic risks from bank erosion are discussed below in the Mitigation section.

6.2 Sediment management

127. The effective management of sediment is also of fundamental importance to the long-term success of the project. The Project design is based on a concentration of bed material deposition in the upper reach, to allow easier extraction and minimise the frequency and magnitude of extraction along the lower reach. The design channel will also enable more extraction from gravel bars above low flow water levels along the upper reach. Some extraction in flowing water would still be required to maintain a natural channel shape with pool/riffle sequences, and any extraction along the lower reach would involve in-water work.

128. The transport of gravel bed material through the Project reach will, thus, be different to what occurs at present with more gravel expected to be deposited and extracted in the upper reach and less frequent extraction in the lower reach. This was a fundamental design objective and considered to be a positive outcome in terms of limiting the extent and frequency of in-channel gravel extraction.

129. The design conditions will, though, allow an easier and less disruptive sediment management regime.

6.3 Habitat

130. The widespread earthworks in the channel to widen it and shift it laterally, as well as the use of rock protection measures, have the potential to affect the quality and diversity of the aquatic and terrestrial habitat. Virtually all the existing edge vegetation along the Project reach (mainly willows and understory weeds) will be removed and replaced with a more extensive river margin (buffer) of willows and natives. The completed Project will, therefore, give rise to different river edge vegetation, and a different vegetation management approach. The proposed vegetation is described in Technical Assessment No 15: Landscape and Visual Assessment prepared by Ms Lisa Rimmer. It should be noted that the existing vegetation is largely willow edge vegetation and grassed berms, with small areas of natives.

131. Geomorphological processes are intimately connected with riparian vegetation, and geomorphic conditions and habitat character are inter-dependent. The changes in habitat and mitigation measures concerning habitats are addressed in Technical Assessment No. 6: Freshwater Ecology Assessment prepared by Mr Patrick Lees, and Technical Assessment No. 7: Terrestrial Ecology Assessment prepared by Ms Georgia Cummings.

6.4 Natural character

132. The design of the river corridor works, and in particular the channel works, has been based on improving the geomorphic flexibility and natural dynamics of the River. The active channel area, where bed material transport takes place, will be widened and aligned to fit a natural meander pattern of the River. This will affect the pattern of flood flows and sediment transport, allowing a more geomorphically natural river behaviour within the wider space available for the active river processes of sediment transport.

133. A number of criterion can be used in the NCI (set out above) including widths across the floodplain of active (clear) bed of the channel; the bankfull width and the floodplain width; channel sinuosity from flow length and direct valley length; and pool-run-riffle sequences. For this study floodplain width was deemed the most appropriate measure of the wider river system geometry.

134. A Natural Character Index assessment has been undertaken, comparing the present river channel and the proposed. The present conditions, with the river corridor, active river channel, thalweg (or line of maximum depth along the low flow channel) and presence of pools, are shown on Figure 1 of Appendix A. The same criteria features are shown on Figure 2 for the proposed design.

135. Measurements taken off the surveyed river cross-sections [21] of the Riverlink design plans have been used to determine average changes in the river corridor and active channel, while the aerial plans have been used to measure sinuosity along the Project reach. Pools have been assessed as geomorphically (and ecologically) significant and rated as main or minor. It was considered appropriate to only use the main pools for the NCI calculations.

136. An overlay of the design over the present conditions is shown on Figure 3 in Appendix A, and the results of the NCI assessment are given in Table 3 below, with the lower and upper reaches assessed separately. This reach division aligns with the reaches used in the NCI assessments that have been carried out along the managed reach of the river along the Hutt Valley, in a previous study[22].

Table 3 Natural character index assessment – results

	Lower reach		Upper reach	
(Average values for reach)	Existing	Design	Existing	Design
Geomorphology assessment				
Floodplain width (m)	159.1	161.5	wide	unchanged
Active channel width (m)	67.1	72.6	86.7	98.0
Channel sinuosity	1.08	1.11	1.06	1.06
Pool sequence (main)	3	3	3	5
Natural character index				
Floodplain width	1.00	1.02	1.00	1.00
Active channel width	1.00	1.08	1.00	1.13
Channel sinuosity	1.00	1.03	1.00	1.00
Pool sequence	1.00	1.00	1.00	1.67
Index (existing = 1.0)	**1.00**	**1.03**	**1.00**	**1.20**

[21] See Tonkin & Taylor Design River Cross Sections
[22] Williams G.J. (2013). Western River Schemes Natural Character

137. The existing condition is given a value of 1, with the design index being the ratio of the criteria values for the existing and design conditions. The overall index is an average of the calculated values for the individual criteria. The change in this value is then an indicator of the proportional change from the existing conditions to that of the design. An increase in the value indicates an improvement in the geomorphic condition of the river reach. For the purpose of providing context a change of < 0.05 (5%) is considered minor and a change of greater than 0.1 (10%) is considered more significant although there is still debate around the interpretation and use of the NCI .

138. The Project will increase the width and improve the meander form of the active channel, increase the bankfull width and marginally increase the floodplain width available to the river in flood events. The channel sinuosity will be more defined along the lower reach of the project, although there will still be an over straight reach of unnatural form around the Melling Bridge. Along the upper reach, the wider active channel will allow a more natural channel sinuosity and meander mobility, although over-tight channel meanders may still form because of the bed material deposition along the reach within a channel that remains very straight overall, and relatively confined.

139. As the NCI assessment values indicate, the differences are small from a geomorphic viewpoint in the lower reach, with relatively small percentage increases in the index value from 1.0 to 1.03 (+ 3%). The increases are more significant in the upper reach due to the more extensive channel widening and the index value increasing from 1.0 to 1.20 (+ 20%).

140. The design will, therefore, give rise to some improvement to the natural character of the river reach while increasing the standard of flood protection. The key improvements are:

    i. Deeper pools;

    ii. Greater lateral freedom in the upper reach;

    iii. More natural alignment and meander form in the lower reach;

    iv. Reduced frequency of in-channel interventions in the lower reach;

    v. More in-channel features – scatter rock, large woody debris, rock spurs.

141. The additional city land that will be acquired along the lower reach has allowed a slightly wider river corridor to be developed, although this additional land has been used to accommodate the wider stopbank as well as provide additional berm land. The channel alignment along this reach has been shifted to provide the same width of upper berm on both sides, and hence an equal level of protection to both sides. This has been achieved without altering the overall form of the river channel.

142. There will be additional rock linings along the lower reach, between Marsden Bend and upstream of the existing Melling Bridge, and an existing lining will be extended. The rock works along the river banks will not be continuous, being placed strategically along outer bank lengths. This bank edge protection allows the access and landscape improvements of the Project along this lower reach of the River.

143. The effect of such rock linings on channel shape and bed scouring will be mitigated by the additional rock works of spurs on the bank linings and scattered rock on the bed. This reach of the River has been very stable in channel form and shape due to its geomorphological character as well as because of past river works and river management. The rock linings fit this channel form and retain a natural meander pattern. Thus, while there is a change in the overall river environment, from all the Project works, the geomorphic character of the channel will be maintained without significant constraint compared to existing conditions.

144. There will be an additional rock lining in the upper reach, to protect the Transpower site and because of the strong return flows to the main channel from floodwaters that flow into the golf course area. Harcourt-Werry Drive is also close to the (widened) river channel in this area.

145. The outcrop of the Transpower site is a natural control on the river, and the rock lining will tie into this landform. The river channel is also wider here, although it is a transition zone. The rock works will prevent further widening of the river but would not significantly alter the nature of the convergence transition that will occur in this area.

146. The Project merges into the Ewen Floodway Project at its downstream end. This earlier project improved the geomorphic form and natural dynamics of the River reach downstream of the Project. The active channel was widened and realigned in a similar way to that of the Project, with further improvement measures undertaken later, down to the Ava Rail Bridge. The Project then extends these improvements in a manner consistent with the natural character of the river reach up to Kennedy-Good Bridge.

6.5 Flood damage and erosion vulnerability

147. For the years following the construction and prior to the vegetative buffers becoming established in the upper reach there will be more intensive maintenance activities. This may include works in the active channel to realign it away from where vegetation buffers are being established.

148. When the Project measures are fully established and effective in terms of the design standard, flood damage within the river corridor will be reduced and more easily remedied following flood events. There will be on-going maintenance and repair works, but this requirement will be mitigated by the standard of the proposed works and management measures, and their relationship to the natural dynamics of a geomorphically improved reach.

149. The flood capacity standard has been set at a very high level, and in more extreme flood events there will be substantial damage to edge works and loss of berm land, affecting the channel edge and berm vegetation and structures on the berms. Given the high standard, these events will be very rare, and the design conditions would be re-instated as flood damage repairs, albeit substantial repairs, after such an event.

150. The Project will, therefore, reduce flood damage and erosion vulnerability while increasing flood capacity.

6.6 Summary of Effects

151. The completed Project will give rise to a river channel that will allow an easier and less intrusive management of the river, with a better bed material deposition regime for sediment management, and an overall improvement in the river's geomorphic condition.

152. The river corridor will be wider, with more space for the active channel, giving rise to larger gravel bars and a low flow channel with more pronounced pool/riffle features. The lower reach will have more secure banks from the rock works, and the upper reach will have wide vegetation buffers on both sides. This will reduce the intensity of management interventions and the impact of interventions on the river character. The extraction of the gravel bed material that naturally builds up along the Project reach for river management purposes will be easier to achieve, with less overall disruption to the river bed and its low flow channel.

153. Overall the operational effects are assessed to be moderately positive.

7. ASSESSMENT OF CONSTRUCTION EFFECTS

154. To allow the Project works to be undertaken will require large earthmoving equipment working in the active channel of the river for a significant period of time, as outlined in the AEE Construction Methodology.

155. The need to construct the foundations of the rock linings below the river bed level will require excavation within the active channel.

156. There will be temporary works required to relocate and divert the low flow channel away from working areas, including around foundation construction for the new bridges (pedestrian & Melling Bridge).

7.1 Bank erosion

157. The construction activities will include excavation along the riverbanks and in the river channel. Exposed raw banks are very susceptible to erosion in flood events, and additional bank erosion at working sites would give rise to channel shape distortions and the input of both fine and gravel materials. As well as being a security risk and causing damage to works in progress, any substantial erosion would affect the channel conditions and geomorphic responses.

158. Limiting the lengths of bank exposed and areas of channel worked on will be very important in minimising these effects. The construction methodology used to limit security and damage risks, would then also minimise any geomorphic effects. An upstream enlargement of the river channel is, however, important in minimising geomorphic impacts and channel distortions, which would increase bank erosion activity.

7.2 Sediment management

159. The requirement to excavate within the active channel means there will be sediment released and increased turbidity in the downstream channel. The relatively coarse nature of the channel bed material, and the downtime over nights and weekends means that turbidity effects should not be extensive. These effects are discussed in detail in Technical Assessment No. 3: Construction Water Quality and Erosion Sediment Control prepared by Mr Ed Breese.

160. These channel works will be undertaken in an upstream direction to progressively develop the design shape and improve the channel form and sediment transportation. However, during construction there will be channel and bank edge distortions, with transition effects and temporary exposures that will affect river channel dynamics and hence the transport of bed material along the river channel.

161. This disruption is inevitable to achieve the benefits of the completed works and more natural channel form, with the desired alteration in sediment transport and gravel bed material deposition.

162. There is the possibility that the rate of sediment transport into the downstream reach will increase during the construction phase and in the years immediately following construction. This would be a result of the disturbance of the armour layer on the riverbed and the exposure of more mobile underlying sediments as well as the removal of mature bank vegetation. The mitigation measures proposed to avoid and mitigate these effects are described in Mr Breese's assessment.

163. Deposition of sediment would take place along the lower reaches of the River, below Ewen Bridge, where there is already a build-up of gravel that is affecting channel capacity. Any additional gravel deposited in this reach as a result of the Project could be removed as part of the overall gravel management program of the Greater Wellington Regional Council[23]. The degree of effect can be determined by the river bed surveys undertaken by the Council, with more regular surveys at a 2 year interval carried out over the 5 to 10 year establishment period of the Project.

7.3 Summary of effects

164. The requirement to undertake large-scale earthworks, to lower, widen and laterally relocate the Hutt River, as well as the construction of two new bridges and erosion protection works, means that the construction phase of the Project will, with the avoidance and mitigation measures proposed, have minimal adverse short-term effects on the river channel character and morphology, and could potentially increase short-term sediment deposition in the downstream reach.

8. MEASURES TO AVOID, REMEDY OR MITIGATE ACTUAL OR POTENTIAL ADVERSE EFFECTS

165. There will be significant adverse impacts on the river channel and its dynamics during the construction period. The overall mitigation of the construction effects is that the Project works will create an environment that is better than the existing situation. To achieve this improved end there will have to be temporary adverse impacts during construction

166. Future operational interventions will be minimised through the approach being taken to manage the flood risk and maintain design criteria. Specifically, operational works will only be required on a regular basis over a relatively short reach of the River, at the upstream end of the Project reach. The downstream channel can be largely left alone with relatively infrequent flood damage repair or gravel extraction operations.

167. Specific measures to mitigate adverse effects on geomorphic processes and the dynamics of the river channel by means of enhancement are described below. These measures can also mitigate the adverse effects on other aspects of the river system. Mitigation for other effects is covered in the reports of other specialists, as noted above.

168. The design has been based on a geomorphic understanding, with the aim of allowing the river to undertake its natural processes with the least constraints possible, given the highly constrained and managed nature of the river under present circumstances. Channel changes and protection measures have been designed to fit the natural dynamics of the river as far as practical given the constrained conditions. The operational management requirements of different measures have also been considered in this context.

[23] Permitted by the GWRC global river maintenance consent

8.1 Operational

169. The long-term effects of the Project on the geomorphic nature of the river are positive, and the principal measures to achieve this result are as follows:

8.1.1 Bank erosion

170. The bank erosion effects are proposed to be managed through two primary methods – rock rip-rap linings and vegetative buffers. These measures will result in a higher standard of protection than exists at present.

8.1.2 Rock linings

171. In the lower confined reach of the project downstream of the Transpower substation where the channel narrows from 100 m down to 70 m, the best option to manage lateral bank erosion is with the use of rock rip-rap linings. These bank linings will be effective in mitigating the risks to flood protection measures from lateral erosion and reducing the addition of further sediment into the lower reaches of the River from erosion in small to moderately large flood events.

172. During very large design floods (2800 m^3/s +) it is likely that these rock linings would fail in places due to the significant riverbed scouring and bed mobility. During these conditions there would be significant sediment inputs from the upstream catchment as well as from bank erosion during the event. Following an event of this type it would be expected that there would be repair and recovery of displaced rock as well as extraction of deposited sediment.

8.1.3 Vegetative buffers

173. Upstream of Transpower the design channel widens out to 100 m and the stopbanks are set well back from the channel, so there is greater flexibility in the type of erosion management undertaken in this reach. Wide vegetation buffers will, thus, be used along this reach.

174. Once established, the vegetative buffers can effectively manage bank erosion during smaller floods. During larger flood events some erosion will likely occur, but this is considered to be beneficial in terms of allowing more natural river plan form variability, with an activation of a wider area, and hence a more natural channel movement and migration of the main flow channel.

175. Although there is a desire to use more natives in the vegetative buffers it is still considered necessary to use the fast growing and proven method of willows for the frontline protection, with natives planted in behind and in panels amongst the willows. The willows allow on-going re-establishment as erosion bays form, and thus a flexible edge to the active channel, with a larger overall space being provided for the River.

176. This vegetative edge is a more natural river edge condition, which better allows the dynamics of geomorphic processes, while providing both shade and nutrient supply to the aquatic environment.

8.1.4 Sediment management

177. Effectively managing sediment transport and deposition trends is fundamental to the long-term success of the Project, as a flood mitigation measure and to maintain a geomorphologically functioning river system. Left unchecked, continuing sediment deposition will fill up the channel within the Project reach so that the agreed level of flood protection is not achieved. It is, however, noted that removing sediment (gravel extraction) can be disruptive to the aquatic ecology, and mitigation of these effects is covered in Technical Assessment No. 6: Freshwater Ecology Assessment prepared by Mr Patrick Lees.

178. The river channel has been specifically designed to manage the long-term effects of sediment transport, in particular the transport of the gravel bed material through the Project reach. The widening of the upper reach upstream of Transpower to 100 m wide and the use of 30 m vegetative buffers makes this reach a preferential deposition reach, with the deposition being managed here, so that less frequent interventions are required in the downstream channel.

179. The key benefit of extracting in this upper widened reach is that it can largely be done on dry beaches rather than in the wetted channel.

180. The decision to go with the Variable width 70/100 m option was significantly influenced by the design objective of keeping sediment transport rates high through the lower reach so that there would be less need for future frequent extraction. This lower reach is tightly confined and has a much higher use for a range of purposes than the upper reach.

181. Overall, the design of having a widened dedicated sediment deposition and extraction zone in the upper reach and the narrower zone with less intervention in the lower reach, is considered an appropriate and effective way of mitigating the adverse effects of future sediment management within the Project extents.

8.1.5 Natural character

182. The design of the river works is based on an improvement to the natural character of the river reach while increasing the standard of flood protection. The net effect on natural character is, therefore, positive.

183. This is due to enabling the river to move more freely within the vegetated buffers of the upper reach and the widened and more natural planform achieved through the realignment of the lower reach.

8.2 Construction

184. The short-term effects of Project construction on the river channel and its geomorphic processes without mitigation could be substantial. Measures to avoid or mitigate the temporary adverse impacts of the Project construction on the river environment and natural character have been considered, as follows:

8.2.1 Bank erosion

185. The sequencing of the works within the river corridor is fundamentally important to limiting erosion risks and potential impacts on both security and geomorphic processes. Restricting working areas and re-establishing exposed banks and disturbed berm areas as soon as possible, given seasonal and climatic limitations, is also very important.

186. The mitigation measures proposed to mitigate these effects are described in Technical Assessment No. 6: Freshwater Ecology Assessment prepared by Mr Patrick Lees.

187. Having flood warning systems and planned responses to flood events for security and to limit damage to works in progress, would also minimise channel condition and geomorphic impacts.

8.2.2 Sediment management

188. The sequencing of works and the limiting of areas of the channel that would be worked as a specific construction activity are also important for sediment transport reasons. Restricting the area of disruption of the channel form and disturbance of the armouring layer of the riverbed would minimise the effects on transportability of the bed material. The potential for increased bed material transport in flood events should be taken into account when determining work areas and levels of activity.

189. The mitigation measures proposed to mitigate these effects are described in Technical Assessment No. 6: Freshwater Ecology Assessment prepared by Mr Patrick Lees.

8.2.3 Natural character

190. The natural character of a river reach arises from the holistic interactions and connections of the river system. Short-term construction activities will affect the river responses, but there are not specific measures that can mitigate short-term variations in the overall responsiveness and trends of river systems. The mitigation is the longer term improvements that arise from the Project.

9. CONCLUSION AND RECOMMENDATIONS

191. The longer-term operational effects of the Project on the geomorphology of the River along the Project reach and its natural character are positive.

192. The construction effects on river processes could be substantial if unmitigated, and accordingly mitigation measures that manage the sequence and extent of works are required to minimise potential adverse effects. Monitoring of the river channel to determine any increase in sediment transport and deposition of gravel in the downstream reach should be undertaken.

193. There will be adverse impacts during construction that cannot be fully mitigated by proposed measures, given the physical requirements of the Project and the magnitude of the river channel changes. The overall mitigation is the improved river environment achieved by the Project.

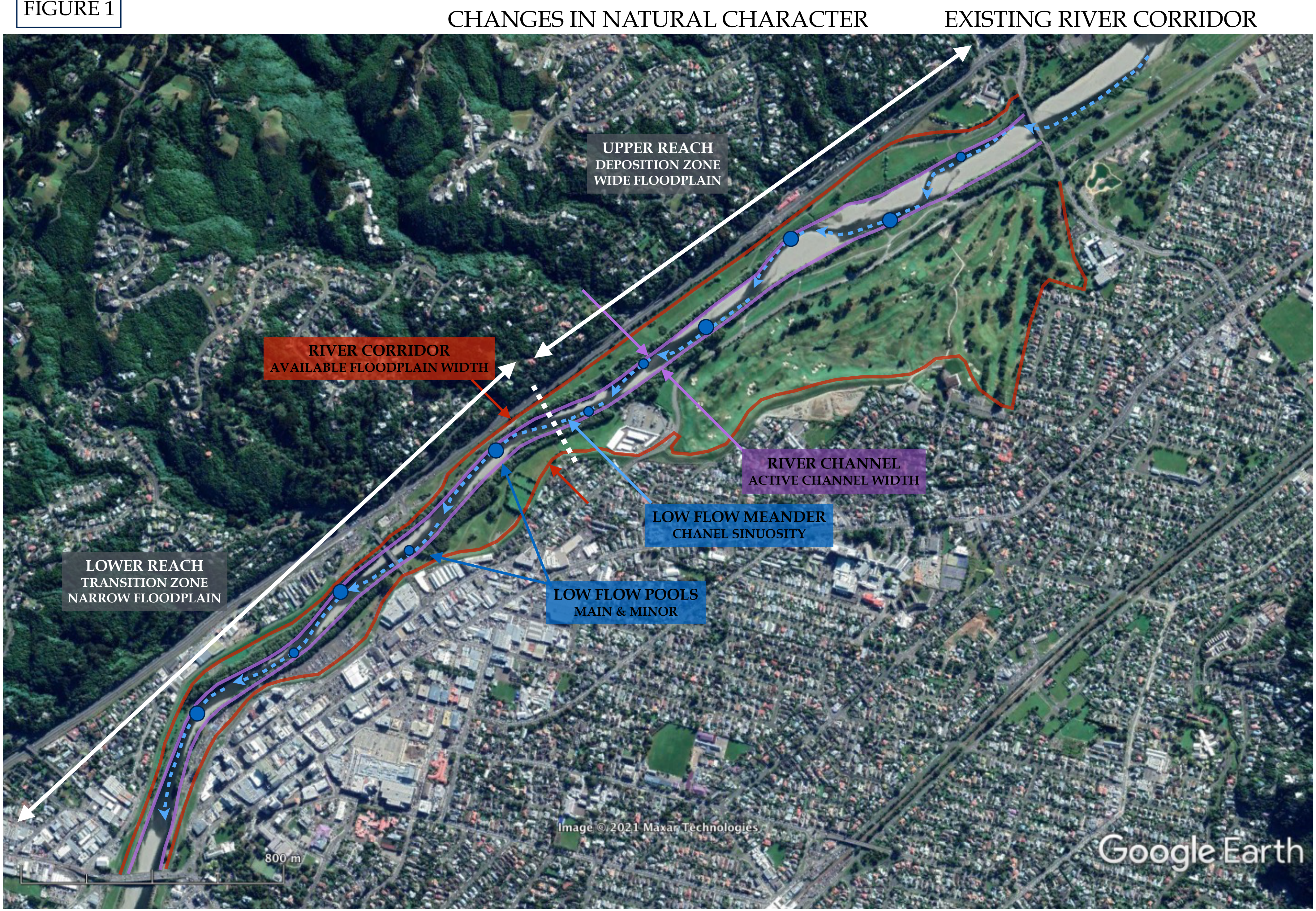
23 July 2021

Gary Williams

Appendix A - Natural Character Plans

HUTT RIVER – GEOMORPHOLOGY

FIGURE 1



HUTT RIVER – GEOMORPHOLOGY

FIGURE 2

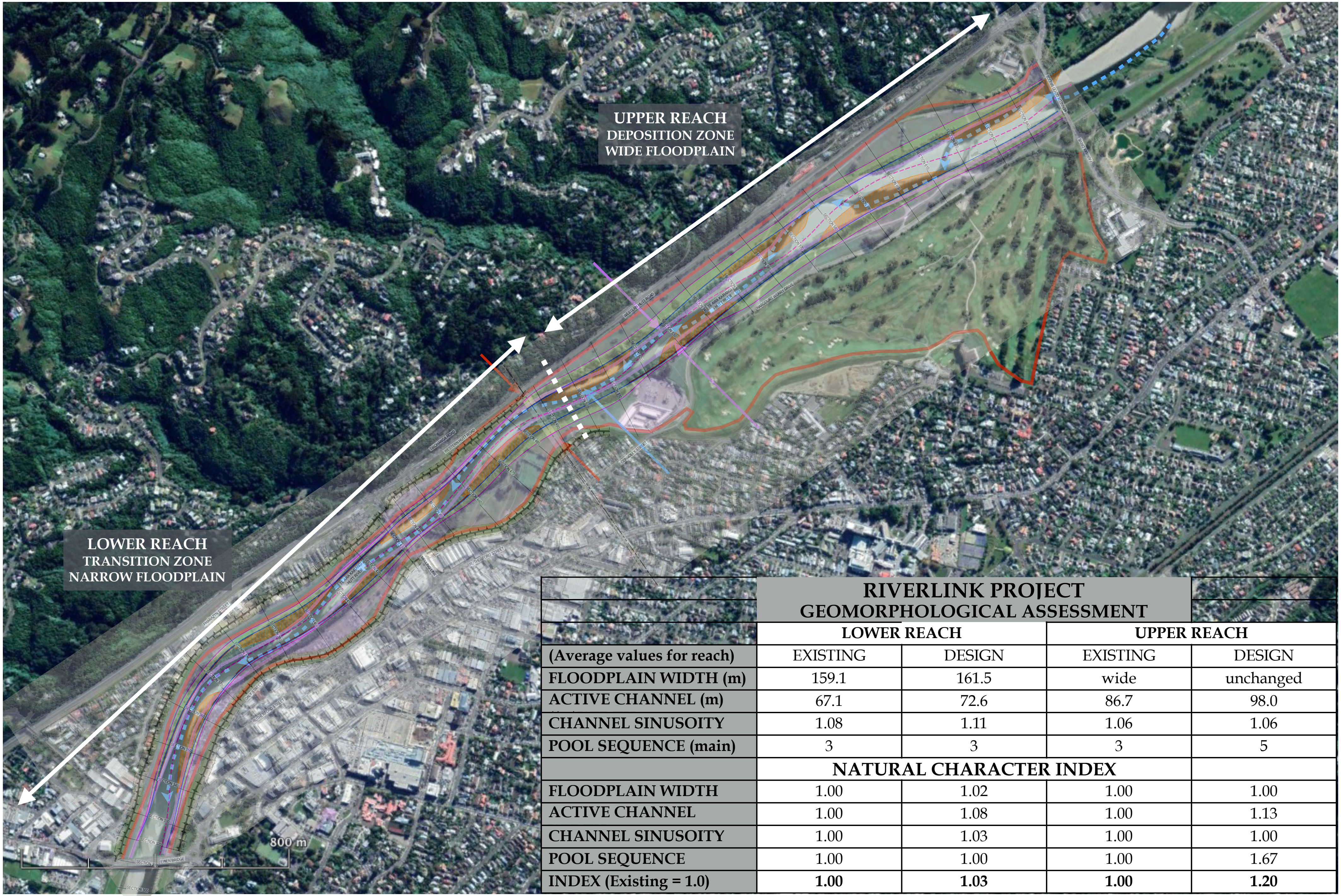
CHANGES IN NATURAL CHARACTER

DESIGN RIVER CORRIDOR

FIGURE 3

HUTT RIVER – GEOMORPHOLOGY

CHANGES IN NATURAL CHARACTER EXISTING to DESIGN



	RIVERLINK PROJECT GEOMORPHOLOGICAL ASSESSMENT			
	LOWER REACH		UPPER REACH	
(Average values for reach)	EXISTING	DESIGN	EXISTING	DESIGN
FLOODPLAIN WIDTH (m)	159.1	161.5	wide	unchanged
ACTIVE CHANNEL (m)	67.1	72.6	86.7	98.0
CHANNEL SINUSOITY	1.08	1.11	1.06	1.06
POOL SEQUENCE (main)	3	3	3	5
	NATURAL CHARACTER INDEX			
FLOODPLAIN WIDTH	1.00	1.02	1.00	1.00
ACTIVE CHANNEL	1.00	1.08	1.00	1.13
CHANNEL SINUSOITY	1.00	1.03	1.00	1.00
POOL SEQUENCE	1.00	1.00	1.00	1.67
INDEX (Existing = 1.0)	**1.00**	**1.03**	**1.00**	**1.20**

Upper Reach.

Vegetated (bio-engineered) lower berm buffers are the upper reach river engineering response for flood protection.

An adaptive management approach initially utilises a combination of willow - for their speed in achieving a strengthened edge - and indigenous successional tree species, with indigenous species underplanting, with managed transition over time to indigenous species lower berm buffers.

This staged adaptive managed approach delivers a step-change in thinking - an expression of Te Awa Kairangi, improved mana and mouri, while providing opportunity to better connect - visually and physically to the river.

Upper Reach key outcomes
In addition to the approach and outcomes described in the previous pages key outcomes and opportunities specific to the upper reach are:

- To achieve a transition to indigenous species flexible vegetated buffer flood protection.
- Minimum required use of debris fences, constructed from natural materials (rather than steel irons and wire).

The outcomes sought - specifics that will support this principle - are:

- A staged approach - as described indicatively.
- Use of fast growing and successional species.
- Providing for diverse terrestrial and aquatic habitats.
- Consideration of the korowai narrative including the use of e.g. flowering kowhai to mark Maraenuku and species that will be a future mahinga kai and weaving resource.

Indicative adaptive management staging diagrams are shown opposite. Further consideration in future design stages should be given to further reducing the required willow plantings generally, and at specific sites and locations including areas where the berm is protected by beaches.

Lower berm bio-engineering indicative plant lists:

Stage 1:
Native successional tree species replacing willows:

- Kahikatea, Dacrycarpus dacrydioides
- Marie tawake, Swamp maire, Syzygium maire
- Pukatea, Laurelia novae-zelandiae
- Totara, Podocarpus totara
- Matai, Prumnopitys taxifolia

Fast growing, shade tolerant native tree and shrub species - underplanting and infill rows:

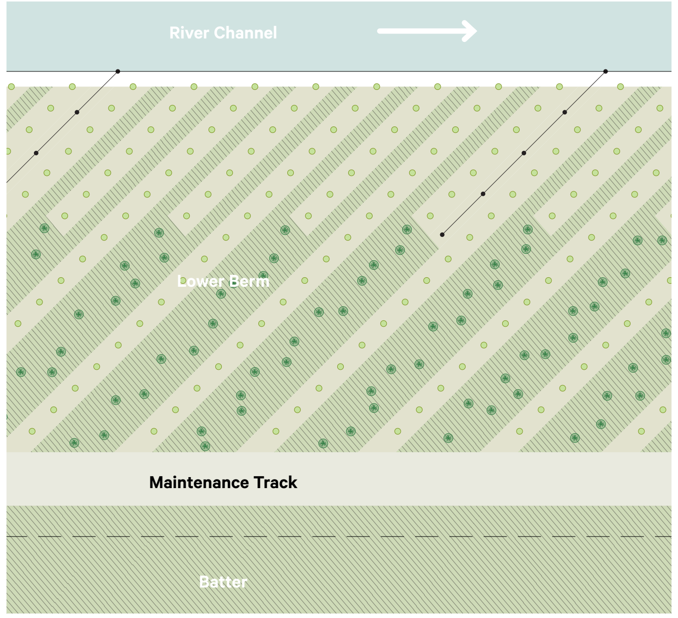
- Carex species incl. C. secta; C. virgata
- Harakeke, Phormium tenax
- Hangehange, Geniostoma ligustrifolium
- Karamu, Coprosma robusta
- Kowhai, Sophora tenuifolium
- Koromiko, Hebe stricta
- Mahoe, Whiteywood, Melicytus ramiflorus
- Makomako, Wineberry Aristotelia serrata
- Manatu, Ribbonwood, Plagianthus regius
- Mingimingi, Coprosma propinqua
- Ponga, Silver fern, Alsophila dealbata
- Poroporo, Solanum aviculare
- Tarata, Pittosporum eugenioides
- Taupata, Coprosma repens
- Ti kouka, Cordyline australis
- Toetoe, Cortaderia spp

Stages 2-5:
Additional native tree species replacing willows - includes less shade tolerant, successional species

- Kahikatea, Dacrycarpus dacrydioides
- Marie tawake, Swamp maire, Syzygium maire
- Pukatea, Laurelia novae-zelandiae
- Totara, Podocarpus totara
- Matai, Prumnopitys taxifolia

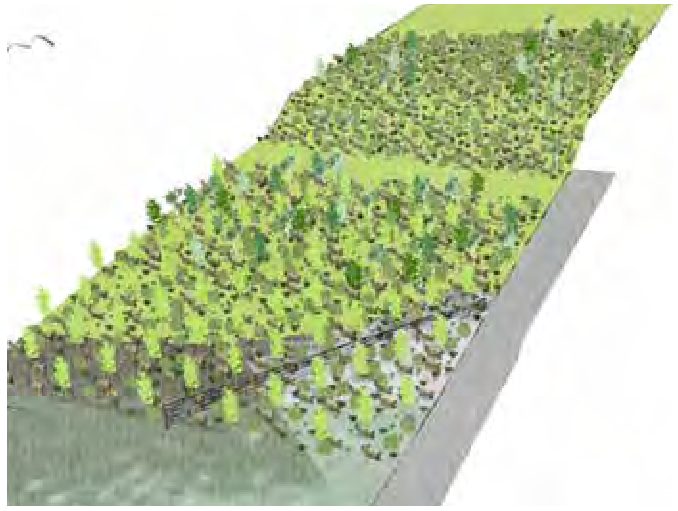
plus:

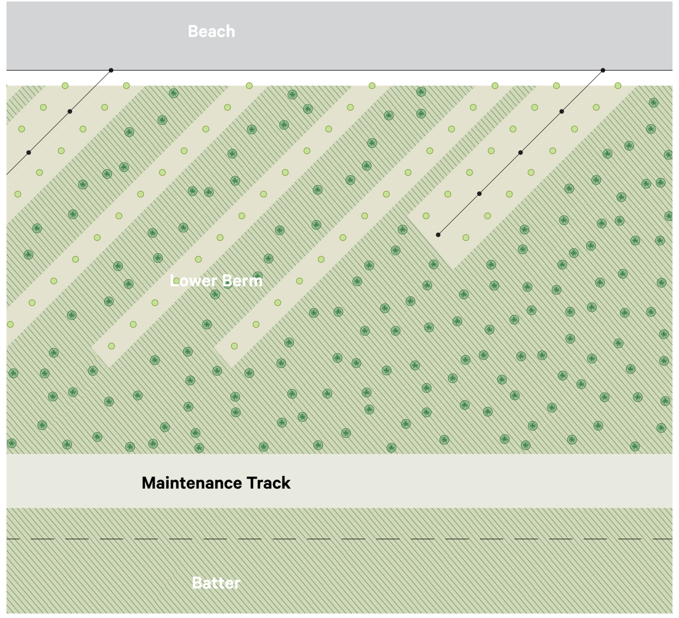
- Mānuka, Leptospermum scoparium
- Kānuka, Kunzea ericoides
- Mahoe, Melicytus ramiflorus
- Tawa, Belischmiedia tawa
- Miro, Prumnopitys ferruginea



Stage 1.

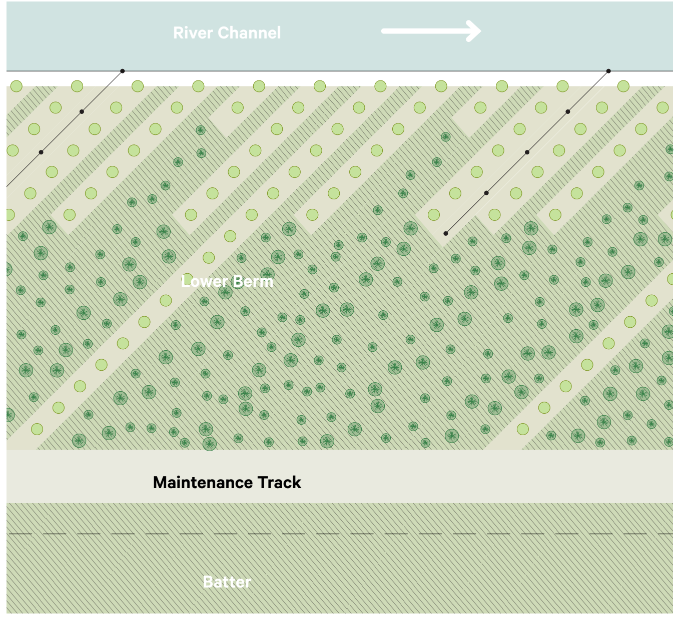
For berm areas against the active channel edge willow pole rows with native successional tree species in alternating rows to back half of berm. Mixed native species underplanting. Debris fences to front half of berm at regular spacings.





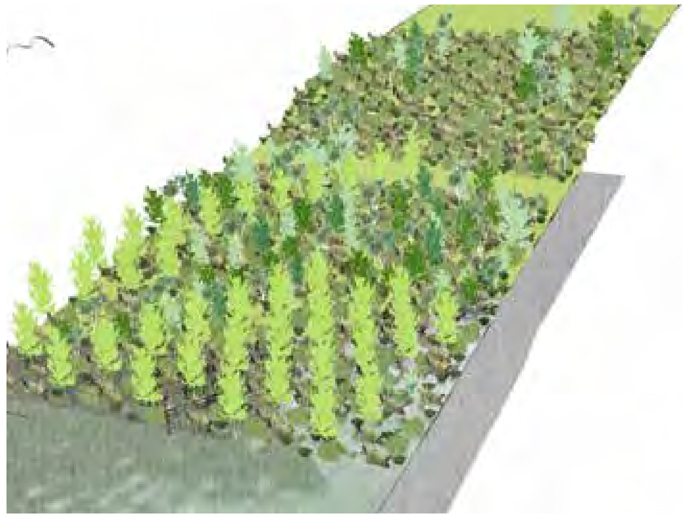
Stage 1.

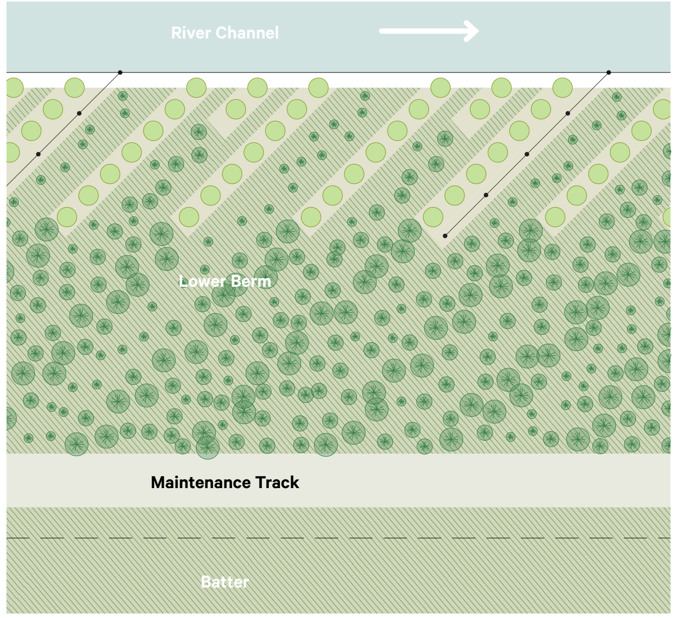
For lower berm areas protected by gravel beaches native successional tree species with mixed native underplanting (no willows) to the central 1/4 of the length of each beach, graduating out with alternating rows of willow and native trees to the active channel edge.



Stage 2.

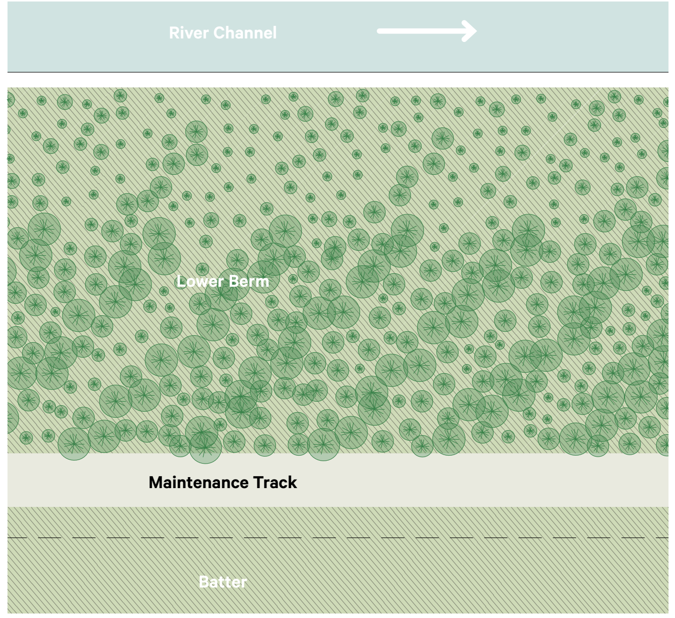
Willow lines removed from full width of berm and replaced with native successional tree species. Native species underplanting supplemented with successional species. Debris fences retained.





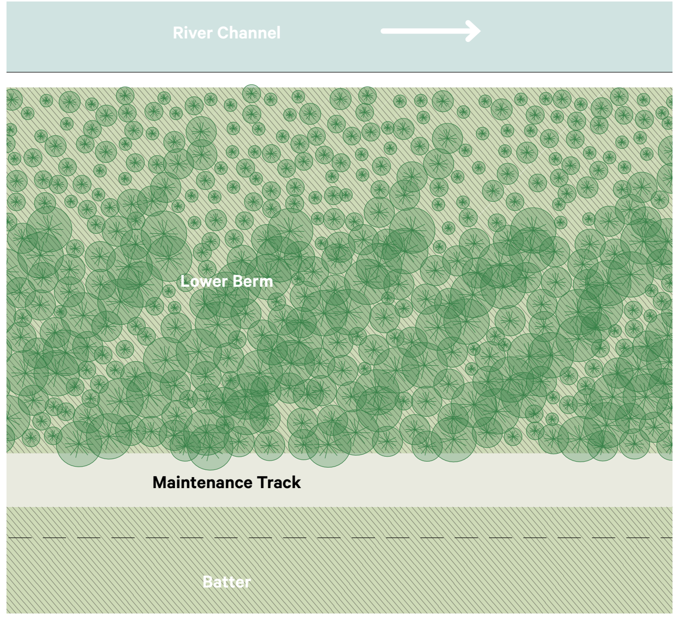
Stage 3.

Further willow lines removed and replaced with native successional tree species. Native species underplanting supplemented with successional species. Debris fences retained.



Stage 4.

Further willow lines removed and replaced with native successional tree species. Native species underplanting supplemented with successional species. Debris fences removed.



Stage 5.

Remainder of willow lines removed and replaced with native successional tree and groundcover species.

Appendix B - Report on the Natural Character of Rivers and an Assessment of Natural Character for Scheme Monitoring

GREATER WELLINGTON REGIONAL COUNCIL

WESTERN RIVER SCHEMES

NATURAL CHARACTER

REPORT ON
THE NATURAL CHARACTER OF THE RIVERS
AND AN ASSESSMENT OF NATURAL CHARACTER
FOR SCHEME MONITORING

Report prepared by

Gary Williams

FEBRUARY
2013

G & E WILLIAMS CONSULTANTS Otaki

WESTERN RIVER SCHEMES — NATURAL CHARACTER

ASSESSMENT OF NATURAL CHARACTER FOR SCHEME MONITORING

1 INTRODUCTION

Investigations into the natural character of the scheme reaches of the Otaki, Waikanae and Hutt rivers has been undertaken as part of the Assessment of Effects for consents for river management measures and works along the scheme reaches. This has been part of coordinated investigations into the effects of river management, carried out through a consultation science group.

This report provides background on river character and what gives rise to the natural character of a river reach. It outlines the climatic and landscape setting that determines the character of rivers, and the dynamic variations and changing influences that impact on the flow, sediment transport and channel forming processes of rivers. A general description of the river reaches and their formative context is given with reference to previous studies of river characteristics and sedimentation processes.

Approaches used for the assessment of natural character are briefly described, along with the assessment based on some physical features that has been used in this study. A general natural character index [NCI] has been determined using available aerial photography to measure the physical features, and comparing conditions in early photography with that of the current (2010) aerial photography.

This NCI provides an indication of changes in the physical conditions of the river reaches, and hence general trends in environmental health. It can, therefore, be used as a monitoring tool for consent conditions.

2 RIVER CHARACTER

2.1 GENERAL

A river reach has a natural character that depends on the overall setting, of climatic regime and catchment conditions, and the local physical and ecological conditions along the reach. This character is not fixed, but varies over time and along river reaches. It is a dynamic expression of the processes at work and the variations over time and space of the influencing forces. It is more a matter of the processes at work than a specific state or channel condition.

The natural character of a river, thus, changes along the river, from the headwaters to the sea, and when characterising a river this is done by reaches. It is a given reach that can be characterised, not a river. The nature, character and responses of a river change from reach to reach, as the forces and processes at work change, and a given character can only be defined for a reach where there is a similarity of river processes along it.

From steep forested headwaters to wide flat marshy alluvial plains, rivers change their form, and over time they change with climatic variations and changes in the intensity of floods. These changes alter the ecology of the river, which in turn feeds back and alters the physical processes and form of the river.

The natural character of a river reach, in its physical expression, arises from a complex interplay of the flow forces, the rate of supply and nature of the river sediments, and the channel form and resistance to erosion of the river bed and banks. The self-similarity of river channels, that form and re-form to a characteristic pattern from flood to flood, arises from an interconnection or feedback loop between flow pattern, sediment transport and channel shape. Flow pattern is a function of channel shape. Channel shape is a function of the erosion and deposition processes of sediment transport. Sediment movement is a function of the flow pattern. Thus, while the river channel moves, its meander form stays the same, through a feedback loop connecting all these aspects of the physical behaviour of the river.

Flow pattern Q = **f**unction of (Channel shape C)

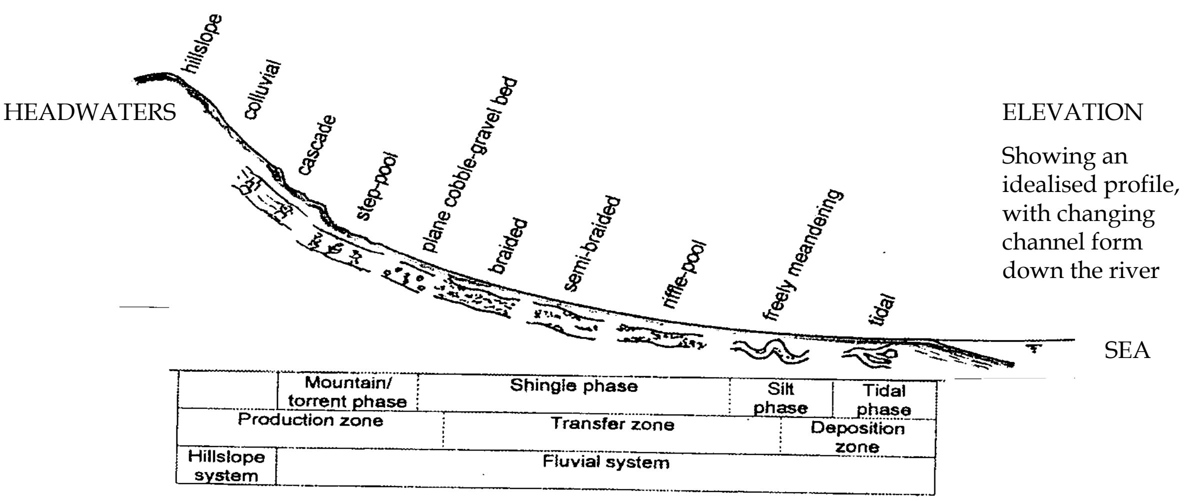
Channel shape C = **f**unction of (Sediment movement S)

Sediment movement S = **f**unction of (Flow pattern Q)

River management that alters channel shape thus has direct effects on flow patterns and sediment transport. Conversely, channel shape is very important in river management.

The diagram below is an example of the characterisation of changes in channel form down a river.

RIVER TYPES — Down a River



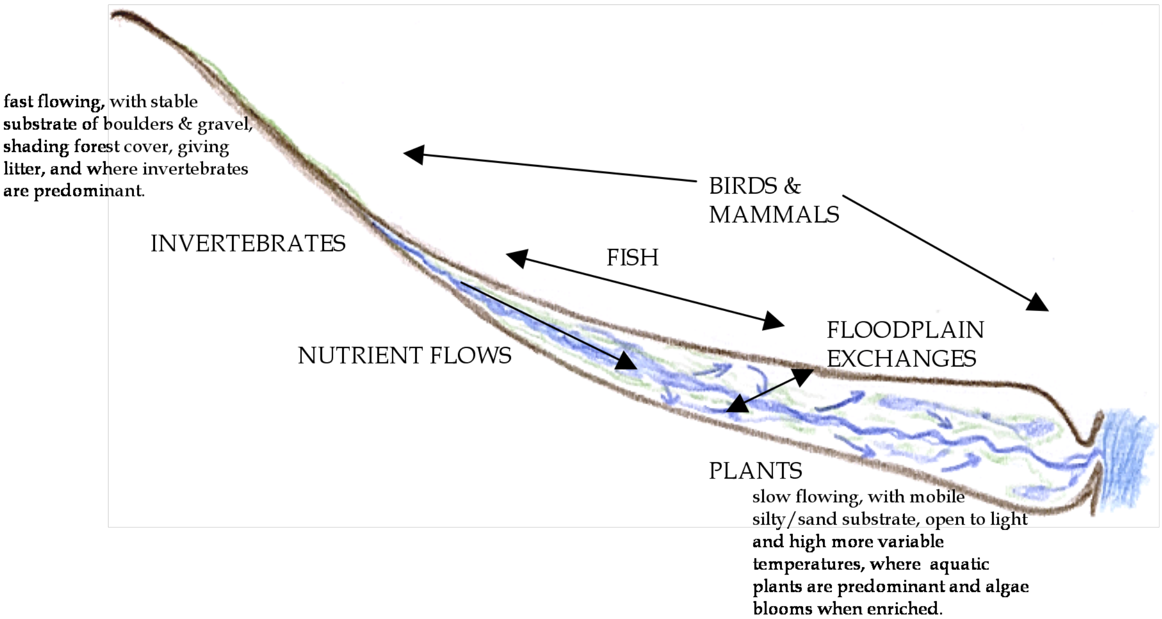
CREDITS: "Gravel Bed Rivers", by Paul Mosley & Stanley Schumm

Rivers and their margins have an especially diverse ecology, given the availability of water, edge effects, and the dynamic interactions between surface and ground water, and channels and floodplains. The ecological systems are highly linked and inter-dependent. There are complex interactions between the biology of flora and fauna along waterways and the physical nature of the waterways. The physical processes and ecological relationships of aquatic and terrestrial habitats form an inter-dependent and inter-connected system. Most noticeable are the interactive effects of vegetation in rivers, with river margins providing diverse vegetative habitats, and vegetation affecting the channel form through island colonisation and channel splitting. The deposition of logs and snagging of vegetative matter also encourages the growth and spread of vegetation within the channel.

The primary biological energy input to a forest stream is the leaf litter, while the primary energy input to an open river channel is from in-stream algae and macrophytes. This gives rise to very different eco-systems, which in turn impact on the channel form.

ECOLOGICAL PROFILE — Along a River

Biological activity adds layer on layer of interconnected processes, which give rise to very complex and dynamic river systems of inter-dependent ecosystems and physical exchange systems.



A characterisation of waterways would then extend beyond a determination in terms of the physical features of river reaches. Along with physical form, it would include the hydrological regime (of flow variations over time), the riparian (and floodplain) vegetation or habitats, and the aquatic life (of invertebrates and fish). An assessment of the natural character of a river reach can then be undertaken in terms of a number of broad categories, with each aspect or influence determined or characterised in a way appropriate to its form, pattern, speciation or behavioural type.

2.2 RIVER MANAGEMENT

The natural character of a river reach can be used to guide river management along that reach, to make use of, and work in with the natural forms and patterns of the river.

Studies of river characteristics and the processes of sediment transport and channel formation can be used to determine the natural channel form of a river reach, and its variability over time and climatic cycles. From this, appropriate active channel areas and overall river corridors, comprising an active channel and margin vegetation buffers, can be determined. River management can then be directed at the maintenance of clear fairways for the active working of the river bed material, and of dense vegetation margins to buffer and absorb the channel migration and splitting or braiding that occurs as part of this activity. The natural form of the channel along the reach can also guide in-channel works and alterations to the active channel, while the wider river corridors define the overall space sufficient for the river to change and move according to its natural dynamic.

Allowances have to be made for the changes in channel form and increase in width during periods of high flood intensity, as compared to more quiescent periods. The buffer zones absorb the erosion and deposition processes of the river, without an encroachment onto productive land or threat to valuable assets. They also provide sufficient reserve to allow a slow re-establishment of lost vegetation over time, as the river naturally moves on and attacks other areas of the buffer. Remedial action can, therefore, be less intensive, with greater reliance on the re-establishment of vegetation over time.

The river corridor, therefore, defines a suitable area for the river, and the outer boundary beyond which productive uses can be made of the land alongside the river reach.

The character of a river reach, in terms of its channel form, can be determined at a more detailed level, as a way of representing channel conditions. Channel parameters, such as: - the ratio of the active bed width to the flood effected width; the substrate material and woody debris present; the degree of braiding or channel splitting, and the sinuosity of low flow channels or braids; the type of channel features of beaches, bars and islands; and low flow channel forms, in particular pools, riffles and runs - can be used to define the reach conditions, and then repeat determinations over time can be used as a monitoring mechanism. These physical parameters can be taken as indicators of the naturalness and health of the river reach, with changes being indicative of enhancement or degradation of river health.

In this way a Natural Character Index [NCI] can be developed and used as a measure of the state of the river reach, through its physical form. Changes over time would provide an indication of the environmental effects arising from the natural dynamic of the river and artificial interventions in the river channel. The index would not differentiate between naturally influenced changes and river management effects, and would include the indirect impacts from catchment or climatic changes, as well as direct impacts from local river system changes affecting river reaches.

Effective river management depends on an understanding of the larger hydrological system and the ecosystems of the landscape or watershed, and in particular the inter-active and dynamic variability of these systems. Characterising river reaches and determining their natural character in terms of formative influences and the system processes of rivers, provides an appropriate basis for the definition of river management zones, and at the same time gives an indication of the overall environmental condition of the river reaches. A more detailed characterisation can be useful in determining whether the natural character of a reach is being maintained, enhanced or degraded.

A formal determination of the natural character of rivers and their margins, in a manner understood by all parties, can provide a useful environmental indicator, while assisting river management to be more comprehensive and effective.

2.3 LANDSCAPE SETTING

The natural character of river reaches in the western Wellington region depends on the catchment conditions and climatic regime of the lower North Island of New Zealand. The primary catchment influences are geology, topography and vegetation, and how this impacts on erosion and sediment movement processes along the river system. The climatic regime depends on the nature of the weather systems, their varying intensities, and the influence of climatic circulations and oscillations on the local weather.

New Zealand is made up of large islands on the tectonic boundary of the Pacific "ring of fire", where a small area of continental crust has been pushed and shoved, raised and sunk, over long periods of geological time. It has a mountainous backbone along the line of this boundary, with rapidly uplifted and shattered base rocks, and steep gravel-bearing rivers that have a short run from the mountains to the sea. It has a southern mid-latitude oceanic location, where the mountain ranges cut across the westerly circulation of anti-cyclones and depressions, giving rise to high intensity rainfalls.

Flood flows are generated very rapidly, and give rise to sudden but brief flooding of floodplains, under natural conditions. The relatively high flood flows and steep grade of rivers in New Zealand give rise to powerful highly turbulent flows that move large amounts of sediments and debris, and the river channels are highly mobile and change rapidly even over human time spans. However, the short time span of these floods suddenly truncates sediment transport and channel movement, and this can leave sharp hook embayments and other channel distortions in the river bed following flood events. The steep landscape of weak fault-broken base rocks gives rise to high catchment input of sediments even with the natural forest cover of New Zealand.

The oceanic climate is highly variable, with an unstable seasonal pattern, and longer term variations from the oscillations of large global circulations, of the southern oceans circulation (around Antarctica) and circulations around the South Pacific. The back and forth movement of a convergence zone of these two large circulations gives rise to a decades long variation in the New Zealand climate. The diverse landscape and climatic regions of New Zealand are affected at different times and in different ways through this pulsating dynamic of the Interdecadal Pacific Oscillation [IPO]. Thus in a given region there are periods of high flood intensity followed by a generally quiescent period, before a return to more and larger floods. The river system responses to these changes, and this is reflected in changes in channel form and vegetation extent.

Over the last 2 million years, of the Pleistocene geological era, the major slip-strike faults of the Wellington region developed with mountain uplift and block faulting. This has given rise to a set of tilted blocks, split by the main (presently active) faults, with periodic uplift and horizontal displacement. The rivers of the region generally follow the fault lines, with a step-wise pattern around fault formed blocks. Block buckling has also occurred, especially along the Wellington Fault, where there is a series of infilled basins along the Hutt Valley and in the Wainuiomata and Whiteman's valleys.

Over this same time period, there has been marked swings in climate, from cold glacial periods, with large ice caps at the poles, to relatively warm interglacial periods, as at present. The mid-latitude position of New Zealand makes the climatic changes particularly pronounced, with the vegetation in the Wellington region shifting from cold tundra-like grasslands to the very dense multi-species rain-forests of the present native forests.

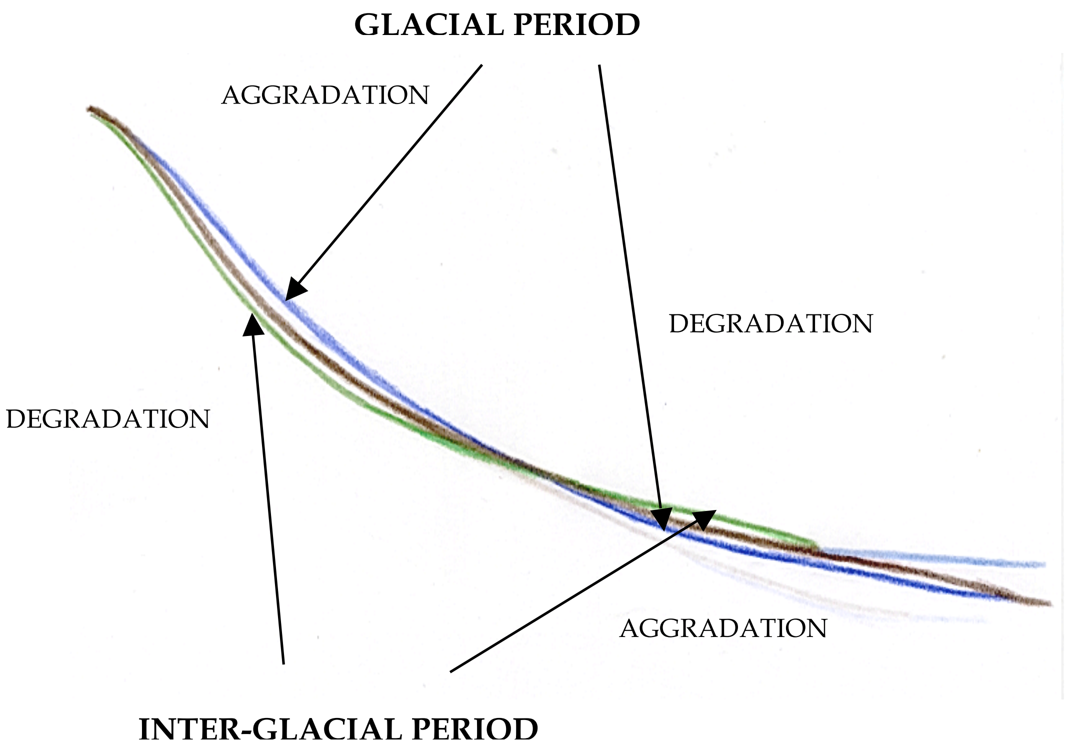
At the same time, sea levels have gone up and down, with ice accumulations at the poles lowering sea levels by over 100 m compared to interglacial periods.

These climatic changes have given rise to alternating periods of aggradation and degradation. In glacial periods there is a high sediment supply from the steep catchment land with valley infilling, but channel entrenchment on the plains down to a lower and further out coastline. In the shorter interglacial times the forest cover reduces catchment erosion, but more intense rainstorms degrade the rivers into the valley fill. At the same time, the higher sea level gives rise to aggradation and plains building at the coast, with coastline aggradation or wave attack retreat, as a new coastline forms.

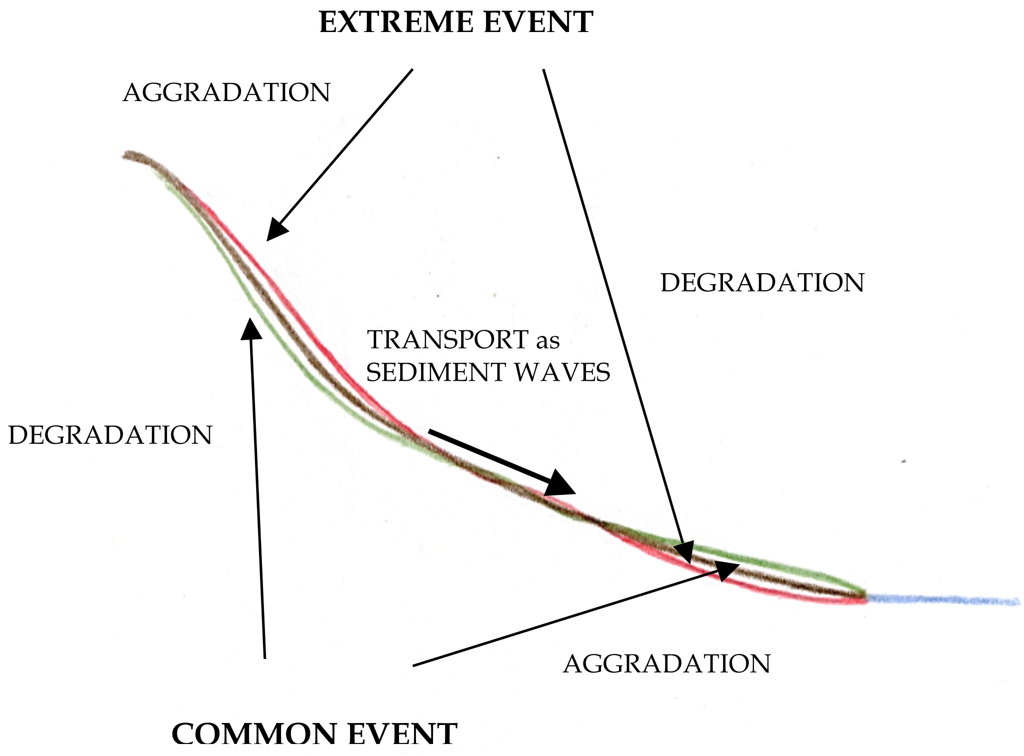
There is a similar effect from floods under present conditions, with the variations in catchment erosion and sediment movement between common and more extreme flood events giving rise to a down river pulse of sediment. In large storm events there is a high sediment input from the steeper upper catchment, and a flushing out of the lower reaches by the large flood flows. In more common flood events the upper catchment input is re-worked down the system and the lower reaches re-built.

RIVER PROFILES — Flood Intensity & Climate Change

Sediment transport and channel effects from Glacial to Interglacial periods



Sediment transport and channel effects between Common and Extreme floods



Particularly severe storms can destabilise catchments, giving rise to large erosion scars and greatly increase sediment input from the event itself and for many years afterwards. There was widespread erosion and wind damage to vegetation in the Tararua Range in the severe storms of 1936 and the 1950s, and these storms resulted in a large input of material to the river system, which continued over a period of many years. This material is transported down the waterways by lesser events, and over a period of time the large slip and infill deposits are eroded away and re-worked down the river system.

This pulse input of materials gives rise to a wave-like movement of the bed material gravels down the lower reaches of the river, as the storm deposits are re-worked and transported downstream. Bed levels at any given point will, then, vary due to the migration of channel meanders and the throughput of these gravel waves.

At present, there are relatively few active erosion scars in the Tarauras, with many of the old scars vegetated over. The main erosion activity is along the waterways themselves, with a re-working of the gravel sediments in the river systems.

2.4 WESTERN RIVERS

The Otaki, Waikanae and Hutt rivers are located on the south-western end of the North Island, and flow from headwaters in the Tararua Range mountains. The Otaki River flows from the Tararua Range divide westward to the Tasman Sea. Its watershed is mostly very steep forested land with very high rainfall intensities during storm events. It crosses a narrow coastal plain, initially within a terrace system, and supplies large quantities of gravel to the coastline.

The Waikanae River flows from lower but rugged rangeland of the Tararua Range. Its watershed is mostly a complex and broken up basin that is partly forested. It then passes through coastal hills to a coastal plain, where it has widened out due to the effects of

Kapiti Island on coastal aggradation. The gravel bed load of the river is all deposited on this coastal plain.

The Hutt River flows from the high peaks at the southern end of the Tararua Range, southward to the basins along the Wellington Fault. Its upper catchment is mostly steep forested land, with tributaries draining the western side of the Rimutaka Range. The remaining catchment is basin and hill land, with remnant terraces. The river flows along the fault line in the Hutt Valley, and then across a short aggradation reach to the enclosed harbour of Port Nicholson. The gravel bed load of the river is partly deposited along its lower reaches and partly in the harbour at the river mouth.

WESTERN RIVER CATCHMENTS

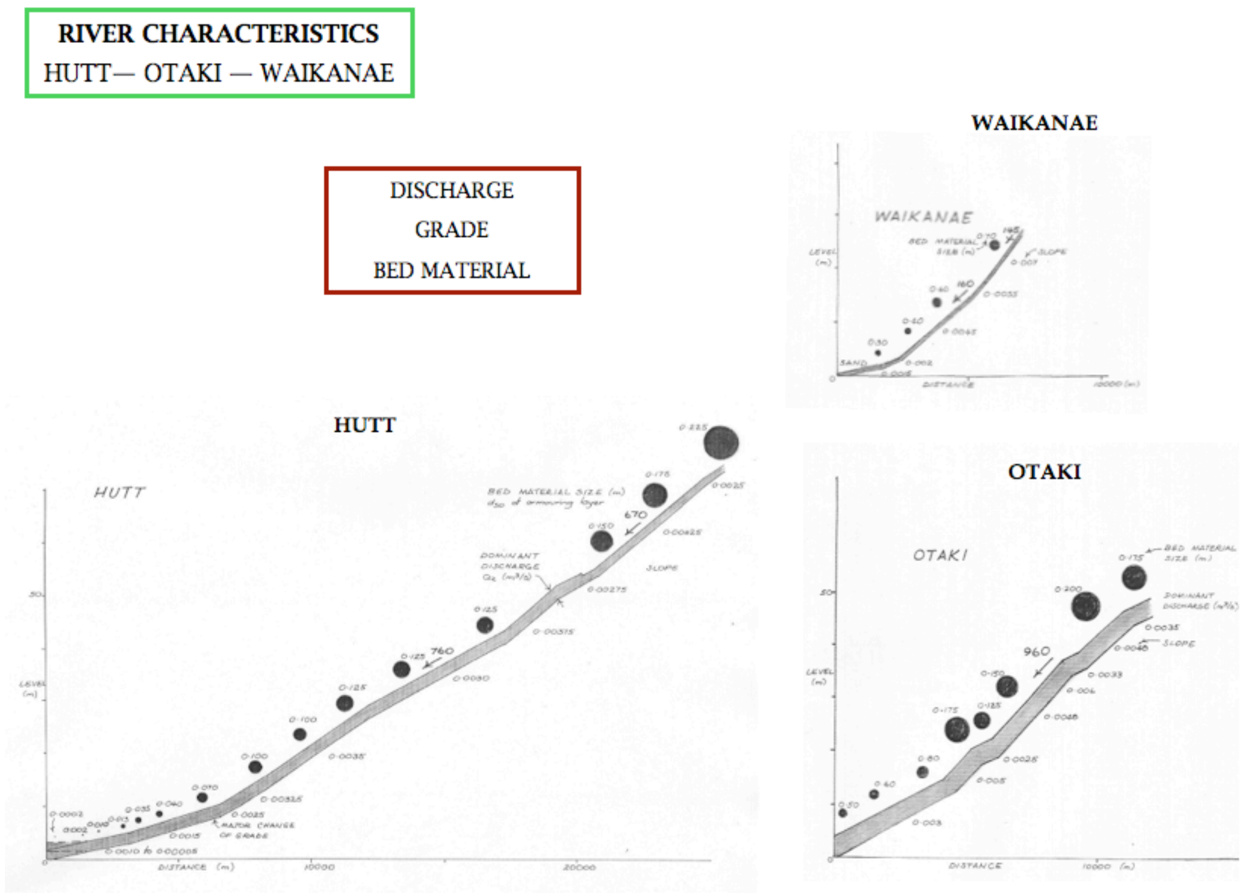
Catchment boundaries and major active faults shown

The type and form of river reaches along the three main rivers of the western region have been determined from the general characteristics of the reach and empirical relationships based on the determining factors of flow energy, gradient and bed material size. There is a basic relationship of the power of a river, derived from the flow mass and slope, being expended on the transport of bed (or bank) sediments, with the amount being moved dependent on the size and grading of the bed material. Given the interrelationships of flow, sediment transport and channel form, natural meander widths can be determined from formulae using the dominant flood flow (or 2 year return period flow), the slope and the medium size of the armouring bed material. The radius of curvature and wavelength of a channel meander can then be derived from its width using general wave relationships. In general, the radius of curvature of the meander is taken as 4 to 6 times the width, and the wavelength 10 to 12 times the width.

These three main characterising parameters are shown diagrammatically below, with the river characteristics plotted to the same scale.

RIVER CHARACTERISTICS

Representation of river grade, bed material size and dominant discharge



2.5 OTAKI RIVER

The river management scheme on the Otaki River extends from the river mouth to the lower gorge, over some 10 kilometres of river length. The river is tightly confined within a channel entrenched in base rock upstream of the scheme. Below this gorge the river has a narrow floodplain defined by high terraces, where the river has degraded into older (glacial period) plain deposits over the current interglacial period. The terraces become lower downstream and the river alignment is affected by fault movements along an active fault (at Chrystalls Bend). Below a low marine cut terrace parallel to the coast, the floodplain consists of an indistinct series of sand dunes and wind blown material, as well as alluvial deposits, and naturally the river was unconfined with widely separated channels.

The earliest plan records (of the 1870s) show the Otaki River having multiple channels, which could be widely separated, especially near the river mouth, and within the area of high terraces, upstream of Chrystalls Bend. The channels were highly mobile, with channel splitting and break outs during flood events.

The gravel bed material is relatively coarse, with the medium size for the whole of the bed material of around 50 to 80 mm, and varying from 50 to 200 mm for the surface armouring layer. There is a significant reduction in the armour layer size below the bridges, which may be due to a combination of river confinement and gravel extraction from the river bed, as well as the lesser grade of the river down to the sea. The river transports around 50,000 to 100,000 m3 a year. A substantial proportion of this sediment load can be transported to the sea, and feeds the coastline south of the river.

The river has been confined and managed by gravel extraction, in-channel reshaping and realignment works, edge vegetation establishment and reinstatement, pile and cable fences and a range of solid bank linings, mostly of rock in recent decades, and some rock groynes. Below the bridges, a straight channel was cut to the sea in the late 1940s, with the gravel bed material used to construct large bunds as stopbanks alongside the formed channel. Upstream of the bridges, the river channel was also tightly confined by river management over a period of time up to the 1990s. Since then a wider and more consistent channel has been developed, with more extensive and continuous vegetation buffers along the river channel. A major realignment at Chrystalls Bend was part of this development, with the old channel being formed into a wide vegetation and wetland buffer area.

There are now extensive lengths of rock lining along the river banks from Chrystalls Bend to the river mouth. Gravel extraction and channel reshaping is undertaken along much of the scheme length, as well as vegetation enhancement and reinstatement works.

Aerial photography of the scheme length of the river is available as follows:

DATE	SURVEY	DATE	SURVEY
Oct - 39	135	May - 91	8827
Apr - 48	198	Jul - 91	9168
Apr - 66	1847	Feb - 92	CPs
Oct - 68	3022	Apr - 92	8850
Dec - 72	CPs	98	
Feb - 74	CPs	Mar - 98	CPs

DATE	SURVEY	DATE	SURVEY
Nov - 75	6377	Mar - 99	CPs
Mar - 76	C 2963	Apr - 00	CPs
Nov - 78	5309	Mar - 01	LC
Mar - 83	8171	02	
Nov - 85	11208	Feb - 05	LC
Mar - 86	8628	Feb - 07	LC
Mar - 88	CPs	Feb - 09	LC
Apr - 90	CPs	Feb - 10	
Feb - 91	11776		

A fuller description of the Otaki River catchment and river channel is give in the 1992 report of the Floodplain Management Plan investigations, on River Characteristics and Sedimentation (see Reference 1).

2.6 WAIKANAE RIVER

The river management scheme on the Waikanae River extends from the river mouth to the Water Treatment plant, upstream of the bridges, over some 5 kilometres of river length. The river passes through the coastal hills in a well defined and entrenched channel, and is then bounded by low terraces before crossing a depositional fan. The river then flows around sand hills to a relatively large estuary area with a sandy base. The coastal sand hills were large shifting dunes until they were mostly stabilised by the planting of marram grass. There is naturally a significant coastal spit at the mouth, with a southern set.

The earliest plan records (of 1890) show the Waikanae River with two separate branches below the bridges, with one branch generally following the present river channel, and the other the present course of the Waimaha Stream. The river channels would have been relatively shallow, within a wetland and forest swamp environment.

The gravel bed material is relatively fine, with the medium size for the whole of the bed material of around 25 mm, and varying from 25 to 60 mm for the surface armouring layer. The bed material transport capacity decreases with the lessening of the river grade below the bridges, and the surface bed material becomes finer, with a sand bottom in the estuary. The gravel bed material, thus, naturally deposits on the coastal plain, and adds to the general coastline accretion from longshore drift. The river transport capacity along the lower reaches is small, at around 5,000 m3 a year.

A river management scheme commenced in the 1950s, following a series of large flood events. As well as flood mitigation stopbanks, this scheme included channel clearing and diversions, willow bank protection works and some rock linings. Over time a relatively well defined meandering channel was developed, with margin vegetation. Substantial amounts of gravel were extracted up to 1975, when extraction was closed down due to a lack of material. From 2000 substantial river works have been undertaken, along with riparian planting and recreational developments. The river works include rock linings, groynes and a weir, with the river channel developed to a design width and meander pattern.

Aerial photography of the scheme length of the river is available as follows:

DATE	SURVEY	DATE	SURVEY
Nov - 49	Oblique	Apr - 86	8640
Apr - 52	198	Feb - 91	9145
Apr - 57	1005		
Apr - 66	1847		
Apr - 68	3022		
Oct - 73	3686		
Nov - 85	11208		

A fuller description of the Waikanae River catchment and river channel is give in the 1992 report of the Floodplain Management Plan investigations, on River Characteristics and Sedimentation (see Reference 2).

2.7 HUTT RIVER

The river management scheme on the Hutt River extends from the river mouth to above Upper Hutt, over more than 25 km of river length. The river enters the infilled basins along the Wellington fault at Te Marua, where it is generally confined by both high and low terraces. The river is then entrenched in base rock, around Emerald Hill and past the Akatarawa River confluence, until it crosses the fault and flows within the Upper Hutt basin. Below the Taita gorge the river flows across the Lower Hutt basin, generally along the line of the fault on the western side, before turning away from the fault and losing grade, as the river adjusts to the sea level control at its mouth.

The present condition of the Hutt River within the two large basins of the valley is very different to what it was prior to European settlement. Early surveys of 1852 and 1867 show large meandering loops and split channels in the basins, and a substantial estuary at the river mouth, with three main channels entering the estuary. These channels would have been relatively shallow and mobile, with floodwaters spreading out over the lower basin and into the tree contributory channels of the estuary.

The Hutt Valley had been uplifted by a large earthquake around 1420, and the lower end of the valley would have been prograding through deltaic deposition. Another major earthquake in 1855 raised the valley by about another 2 metres, and the river would have degraded into the estuary materials and become more entrenched. Over time the river channel has been progressively straightened and confined, with the extraction of the gravel bed material being used to define and confine the river. The river channel has, thus, become substantially entrenched into the alluvial materials of the basins. The river straightening and entrenchment occurred later in the upper basin, starting in the 1950s.

The gravel bed material is relatively coarse, particularly above the Taita gorge, with the medium size for the whole of the bed material generally reducing downstream, from around 100 mm at the top end of the upper basin, to around 50 mm at the top end of the lower basin, and around 20 mm at the major change in grade. There is a similar reduction in the armour layer size from over 200 mm down to 30 to 40 mm at the major grade change, and then finer along the flat graded reach to the river mouth. The extraction of bed material and the entrenchment of the river into the underlying alluvial materials has probably given rise to a coarsening of the bed material. The river transport capacity is around 75,000 m3 a year, based on repeat channel surveys and extraction records. Somewhat over half of this supply is deposited in the natural deposition area above the major grade change, with the rest mostly deposited at the river mouth.

Timber and concrete block groynes were constructed along the river, over a long period of time, with edge vegetation being established and maintained as buffer zones. Rock linings were extensively used along the upper basin when the river channel was defined as part of the state highway development along the western side of the basin. Since the 1990s rock linings and groynes have been used in many places along the river, to a defined channel width and alignment, with more consistent vegetation buffer zones being established along the margins.

In-channel reshaping and beach raking works are undertaken along the river for channel management and in association with bank works. The river bed is being lowered along the natural deposition reach upstream of the major change in grade to maintain flood capacity. This is being done by pushing material from the low flow channel onto the gravel beach, and then removing this material from the beach over time. The in-channel work is undertaken one beach (or half meander) at a time, and the excavation is being undertaken to the natural meander pattern of the river reach and with pools and riffles being maintained.

Aerial photography of the scheme length of the river is available as follows:

DATE	SURVEY	DATE	SURVEY
1936	AF 20	1977	5146
1939	128 & 129	1978	5200
1941-43	163	1980	5497
1949	613	1983	8254
1950	718	1985	8457
1951	570	1988	8909
1957	1005		

DATE	SURVEY	DATE	SURVEY
1958	1093		
1959	1256		
1965	2001		
1966	1407	Feb - 05	LC
1969	3185	Feb - 07	LC
1973-74	3672		
1974	3783		

A fuller description of the Hutt River catchment and river channel is give in the 1991/1994 report of the Floodplain Management Plan investigations, on River Characteristics and Sedimentation (see Reference 3).

2.7 HUTT RIVER TRIBUTARIES

The Hutt River scheme includes some management along short reaches of tributary streams from their confluences with the Hutt River.

2.7.1 TE MOME STREAM

The Te Mome Stream takes storm water from the Petone stormwater system to the mouth of the Hutt River. It is an old tidal channel of the Hutt River, on one side of what was Gear Island. The channel has been cut off, and is now a narrow remnant channel, connected by road culverts to the Hutt River. The stream has a flat channel, and there are floodgates at the outlet to the river. However, inflows of tidal water and seepage gives rise to some tidal fluctuation, and hence to bare banks within the tidal range. The main management activity is the removal of rubbish and debris, and some channel clearing.

2.7.2 SPEEDY'S STREAM

A short reach at the lower end of Speedy's Stream is with the Hutt River scheme. The stream enters the Hutt River on the downstream side of the Kennedy-Good Bridge, after flowing through large culverts under S H 2 and around Belmont School. The stream catchment covers an area of relatively steep land on the western side of the Hutt River valley, up to the loess-covered terraces and upland of the Belmont hills. The waterways are well entrenched into the greywacke base rock, and confined at the bottom of steep sided valleys. The scheme reach has been modified and enclosed by the long road culverts, but upstream of S H 2, the stream retains its natural character, with dense regenerating native forest along the main waterway reaches of the stream and its tributaries. The only real management activity is the removal of debris from a coarse debris collector upstream of the culverts.

2.7.3 STOKES VALLEY STREAM

The Stokes Valley Stream is the main waterway of a small basin, between the lower and upper Hutt basins, formed by buckling on the down thrust side of the Wellington Fault.

The stream has been highly modified along its lower reaches, as part of the urban subdivision of the valley. It has been straightened, lined and enclosed by culverts. The lower 1.6 km of the stream is maintained by the Hutt scheme. This includes an outlet channel parallel to the Hutt River, where a separation bund takes the stream mouth about 300 m downstream. The scheme reach is very artificial, as a uniformly shaped straight channel with sharp bends, and with culverts, weir and stilling basin, and concrete lined banks along the upper part. The main management activity is the removal of rubbish and debris, with some structural repairs as required.

2.7.4 AKATARAWA RIVER

The Akatarawa River is one of the larger tributary rivers that flow in the Hutt River along the upper basin reach. Only a very short reach at the river confluence is within the scheme, and the only management measures are at the confluence itself.

3 ASSESSMENT OF NATURAL CHARACTER

3.1 METHOD

The characterisation of river reaches has been undertaken in different ways and for different purposes. A 'river styles' approach has been undertaken in Australia, with the most comprehensive application being the Tasmanian River Condition Index [TRCI] for the State of Tasmania (see Reference 4).

The TRCI has been developed as a framework for assessing the condition of Tasmanian river systems, and it does this by evaluating the condition of four key aspects of waterways: Aquatic Life, Hydrology, Physical Form and the Streamside Zone. These sub-indices of the TRCI can be used separately, or combined into an overall index.

The TRCI is designed as a practical tool to establish the existing condition and monitor changes from this baseline into the future. It is a referential approach whereby the current condition of sites is compared with a pre-European reference condition.

The TRCI can provide:

- a baseline assessment of condition from which changes can be monitored over time;
- an assessment of the effectiveness of natural resource management;
- monitoring of the impacts of human activity in catchments on river systems (such as water extraction and regulation, vegetation clearance, and in-stream structures); and
- data for relevant information systems.

A similar characterisation was undertaken, in a general way, for the plains (and scheme) reach of the Waingawa River in the Wairarapa. In this case the categories used were: Hydrological Regime, Channel Form, Riparian Vegetation and Aquatic Life. A more detailed inventory of the physical form of the river channel was also carried out based on channel features and pools, riffles and runs (see Reference 5).

However, there have not been any well defined and documented assessments of natural character for waterways in New Zealand, as a means of reach characterisation. There have been studies of river types and the characteristics of different types of rivers, which is directly applicable to New Zealand rivers. The natural meander pattern of rivers has also been assessed for many different types of rivers and reaches in New Zealand, to assist in river management, and to determine appropriate management corridors. The specific channel condition for a given reach was assessed from the general characteristics of the reach, based on repeat aerial photography and channel cross section surveys, and empirical relationships based on the determining factors of flow energy, gradient and bed material size.

As part of the investigations for the Scheme Consents, a basic assessment of natural character has been undertaken, based on a few physical features of river channels. This physical condition assessment should be understood in relation to the other investigations, in particular of aquatic life and river vegetation and bird habitat. The previous studies of river character should also be referred to, with the information they contain on channel conditions and hydrological data. This includes assessments of the natural form and responses of the river channels and their variability over time, the nature and size of bed material, and sediment transport rates for the hydrological regime and flood pattern of the rivers.

3.2 ASSESSMENT OF PHYSICAL CHARACTER

A NCI has been determined using some basic physical features of the channel for the scheme reaches of the Otaki, Waikanae and Hutt rivers, to give a high level index of natural character. These features are:

- the active (clear) bed of the channel, the bankfull width and the permitted floodplain width;
- channel sinuosity from flow length and direct valley length;
- and pool-run-riffle sequences.

A braiding index could be used as well, but the river reaches do not naturally have much braiding. Prior to catchment modification and alteration of the river channels through management measures, the river reaches had some channel splitting tendency, with separated channels and flood carrying back channels. The active channel areas, though, generally consisted of a single low flow channel with wide gravel beaches and some gravel islands. These active areas were surrounded by floodplain vegetation, and there was generally a dense forest cover where there had been no modification from fire or mechanical clearing.

The scheme length of the three rivers has been divided into generally consistent reaches, which are also used for management purposes. Indices have been determined for each of these reaches, as a unit, from measurements of the physical features. The NCI is, then, a combined index obtained from the average of the values obtained for each of the physical features.

The reference condition for the indices was taken from the earliest available aerial photography for the scheme reach of the three rivers. The date of this photography was different for each river, and the degree of modification of the river reach by that time also varied. The reference standard was not, therefore, an unmodified state, prior to any human intervention. The indices provide a measure of the changes in physical conditions over a defined period of time, and hence a basis for assessing further changes over time. They are not a measure of change from some "natural state", in whatever way that may be defined or determined.

The physical features as shown on the earliest aerial photography have been compared with those same features (as measured) on the latest (2010) photography, and the index value obtained by dividing the current measured value by the earlier one, to give a condition ratio. The determination has been done from aerial photography and contour information produced from Lidar imagery surveying.

This NCI is based on physical features, and a comparison over a defined period of time, but if the same methodology is used in future determinations, then consistent and comparable assessments can be obtained and used to track trends in river conditions.

4 NATURAL CHARACTER INDEX

The physical features that provide the parameter values for a general index of natural character have been measured from aerial photography. This assessment has been undertaken as a Massey University project, and the methodology is explained in the university report on this project (Reference 6). The assessment of the pool-riffle sequences was undertaken separately, and added to the Massey project.

The determination of the indices that make up the overall NCI is briefly summarised below.

Bed width ratios —

> Three indices have been obtained from measurements of channel widths. These indices are ratios of the actively worked channel width, the bankfull width before overflows to the floodplain, and the width of floodplain available to flood water (or the permitted floodplain width) compared to the natural (unrestricted) floodplain width. For each of the scheme reaches along the three rivers, which are the unit reaches for each river, a series of width measurements were taken along the reach, and an average value obtained for the four required widths. Thus, the active width was measured over a set of cross sections along the reach, the bankfull width was measured for a similar set of cross sections, and the permitted flood extent width and the natural floodplain width similarly determined from sets of cross sections.

Channel sinuosity —

> An index of sinuosity has been obtained by measuring the flow length (or length along the thalweg line of maximum flow depth) along each unit reach, and dividing this by the direct length from the top to the bottom of the reach.

Pool-riffle sequence —

> An assessment of the number and sequences of pools and riffles was undertaken through a determination of the significant pools present along the unit reaches from the aerial photography. Only those pools that were clearly deep water pools were included. This is a simplified measurement, and the pool number was expressed as pools per kilometre, given the different lengths of the unit reaches.

The consistent reaches used in the NCI determination are given in Table 1. This defines the reaches in terms of river survey cross sections, and gives river distances. This table also gives the results of the pool count, with the position of the pools defined by cross section number.

The results of the NCI determination are given in Table 2 for the three rivers. The values are the ratios of the present to historic measurements, where 1 means no change over the assessment time period. The lower the ratio value the greater the change. The overall index is an average of the indices included in it. The table gives an overall index for the three bed width ratios, as determined using the Lidar topographical information overlaid on the aerial photography, and for the sinuosity and pool count values. The indices can, though, be used separately or in combinations, and when future re-assessments are undertaken, trends can be seen in each of the contributing indices (and hence the relevant physical feature) as well as through overall index changes.

The determination of the indices has been set up so that lower ratio values indicate a decline in the natural character of the river reach. Thus the lower the ratio the less the reach condition expresses its natural character, while a higher ratio indicates an improvement or enhancement of the natural character of the reach. Index values of greater than 1 mean that present conditions are an improvement on those at the time of the reference earlier aerial photography.

The Otaki River was relatively unmodified at the time of the earliest reference photography (of 1939), although recent severe storms in the Tararua Ranges had destabilised the river catchment and there was a high gravel bed load supply to the river at the time. Apart from the sinuosity parameter, there has been a substantial decline in the physical condition of the river, and hence in its natural character, as indicated by this NCI assessment.

The reference photography for the Waikanae River is more recent (at 1952), and there has been relatively little overall modification of the river channel, although river management has given rise to a more defined and consistent channel. The assessed NCI is, thus, close to 1.0, with some improvement in the width consistency and channel condition generally.

For the Hutt River there had been substantial modification of the lower basin reaches by the time of the reference photography (of 1941-43), but little river management intervention along the upper basin reaches. There has been some reduction in the active widths of the river, especially in the confinement of flood waters. While there has been a general decline in pool count, there has been some improvement along the lower reaches, which were been extensively reworked at the time of the earlier photography.

5 SCHEME MONITORING

5.1 MONITORING AIMS

The NCI has been produced, along with other baseline data and studies, to provide a basis for monitoring the condition of the scheme reaches of the three rivers and as a guide to river management. The index is a proxy for the environmental condition and health of the waterways, with its repeatability allowing trend monitoring and an indication of changes in condition. Significant changes in the index would then trigger investigations into what has given rise to the changes.

This NCI is based on readily determined physical features using an easily repeated data base, of aerial photography and Lidar imagery surveying.

Repeat river surveys have been set up along the scheme reaches of the rivers, and past surveys have allowed trends in channel shape and bed levels to be monitored. These surveys are carried out after significant flood events or at around 5 yearly intervals.

5.2 CONSENT MONITORING

The consent conditions are based on an adaptive management approach, and the NCI, as determined in this study, can be used as a general indicator of the overall impact of river management, and other influences, on the river. The index values are specific to each river and its reference conditions, but changes in the values over time do provide an indication of general changes in the natural character of the scheme reaches.

The periodic aerial photography and Lidar aerial surveying that is carried out as part of the management of the schemes should therefore be used to update the NCI, and this will provide a trend indicator to guide and assess the impacts with an adaptive management approach.

6 CONCLUSIONS

The scheme reaches of the Otaki, Waikanae and Hutt rivers have been substantially modified by river management and flood mitigation works, and on going management is required to maintain design standards of protection. These rivers are naturally highly mobile gravel bed rivers, with changing channels and very dynamic sediment transport processes. The natural character of the scheme reaches has, therefore, been affected by containment of the rivers and management aimed at protecting people and economic or social assets from flood damage.

An assessment of natural character has been undertaken to provide information on the present condition of the scheme reaches, and to set up a general index of natural character to provide a monitoring tool that will give an indication of changes in the condition and environmental health of the river.

The index is quite general and is based on changes from a given point in time, which was taken as the earliest available aerial photography (giving complete coverage). It is a relative measure, and can be re-assessed in the future to provide an update of river conditions, as indicated by the physical features that make up the index.

The NCI assessment gives an indication of changes from the reference time, which is different for the three rivers. Thus, the NCI values cannot be directly comparable from one river to another. They are a relative measure of changes over time, specific to each river and its reference conditions.

The NCI provides a monitoring tool, with the measurement of the physical features that make up the index been repeatable from the aerial photography and Lidar surveying that is obtained as part of scheme management. As aerial photography is updated, the NCI can be re-assessed, and changes in the index, and its constituent parts, determined. This can then provide an overall indication of natural character, and whether there have been improvements or not.

February 2013 G J Williams

Water & Soil Engineer

G & E Williams Consultants Ltd,
R D 3,
OTAKI. (06) 3626684

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Appendix C - Natural Character Guidelines for the Management of Gravel-Bed Rivers in New Zealand

TECHNICAL PAPER

RIVER NATURAL CHARACTER

NATURAL CHARACTER GUIDELINES FOR THE MANAGEMENT OF GRAVEL-BED RIVERS IN NEW ZEALAND

By

Gary Williams

APRIL
2017

G & E WILLIAMS CONSULTANTS   Otaki

RIVER NATURAL CHARACTER

GUIDELINES FOR THE MANAGEMENT OF GRAVEL-BED RIVERS

1 INTRODUCTION

1.1 CONTEXT

Rivers and their wider waterway networks are dynamic and responsive systems, influenced by both physical and biological processes. As open energy-exchanging systems they continually respond to changes in both local and wider catchment conditions. The character of any river reach thus reflects the processes taking place along it, which move water, sediments and woody debris, and the wider catchment influences from the connectivity of these processes.

Rivers are an integral part of the hydrological cycle, collecting the water that falls on the land and carrying it to the sea, along with nutrients and sediments. Rivers both divide and integrate the landscape, taking water from the land and releasing it back onto floodplains and into groundwater, thereby generating a range of natural margins and boundaries in the landscape. Rivers both form and are formed by the wider landscape, and their character depends on the nature and intensity of the influencing forces of climate and catchment setting.

The effectiveness of any management of rivers can be enhanced by an understanding of the larger patterns of watershed processes, recognising the diversity of river types and reach character, and the changes that take place over time due to the variability of the influencing forces.

This paper outlines an approach to river management based on the natural character of gravel-bed river reaches and the different channel forms and response dynamics of river reaches. The approach has been developed for active gravel-bed rivers in New Zealand [NZ]. It is framed by the nature of the New Zealand environment, while recognising the modifications and disturbances arising from human activities and past management regimes.

In this approach to river management, an active channel area is defined for a given reach, based on the river type and the nature and rate of channel changes over time. This active channel area provides space for the interactive processes of moving water, sediments and debris/organic matter. Along the edges, a vegetation buffer zone provides a diffuse and flexible boundary that assists in the containment of this activity. The active channel, vegetation buffer zones and additional reserve areas give rise to a defined river corridor, which is the area set aside for the river.

The width and alignment of the active channel area is determined from empirical relationships and the local character of a river reach, to give a channel area that is appropriate for the channel form of the reach, and its pattern and rate of adjustment over time. River survey data and repeat aerial photography, along with early survey plans of river beds, are used to determine the river type and channel variability. Then theory and field based relationships are used to determine a width that suits the reach type.

The width of the buffer zones is based on potential erosion embayments, which is linked to the size and patterns of the channel forms present along the reach. The design channel areas and vegetation buffers do not, though, have fixed boundaries. The design allows for the management of moving edges, but it is based on the present channel conditions and alignment, and not ancestral or historical conditions. The drawn lines of any design are guidelines for the prevailing conditions, with the interface between the active channel and edge vegetation being a movable boundary. The aim is to provide space for the river processes, thereby minimising management interventions by allowing river activity to come and go within the channel area and its margin vegetation.

The design philosophy is one of flexibility and adaptive response, which recognises that catchment processes and boundary conditions change over time, and this changes river behaviour and the space occupied by the active channel areas.

If reach conditions change significantly, for instance, due to a large flood event or cyclical change in flood intensity, a pulse of bed material sediments passing through the reach, or the spread of vegetation across the active channel area, then the design channel area and management approach may have to change in response. Any design is a management guideline for the conditions of a time and place, and the drawn boundaries of the interface between the active channel area and vegetation buffers are based on medium term averages, derived from the current dynamics of channel movement and the shifting back and forth over time of channels in gravel-bed rivers. The outer boundary of the river corridor is, though, a more fixed boundary, with the aim of separating the assets and activities of people from the habitats and activities of the river.

Effective river management does, though, require ongoing maintenance and remedial measures after flood events, whatever the river conditions or defined channel and buffer zone areas. The approach outlined here includes management interventions and reestablishment works to attend to the effects of sediment fluxes over time, the spread or removal of vegetation, and the movement of the active channel area. However, in contrast with other approaches, it neither imposes a fixed edge to the active river channel, nor does it leave the river channel completely alone. It involves an intermediate degree of management, with the long term aim of minimising the economic costs of both river management and damage or loss of land and infrastructure assets, while maintaining or enhancing the diversity and ecological productivity of the river environment.

The paper outlines the development and application of this approach to river management to river reaches of different types and character, along gravel-bed rivers throughout New Zealand.

The paper is structured as follows. It begins with a brief overview of the New Zealand environment, followed by historical management practices since European colonisation of Aotearoa/New Zealand. This is the context in which the approach was developed, and the understanding of the NZ landscape and climate that underlay the development of an alternative approach to river management, relative to historical practices. The general principles that guide the assessment of natural character and the form of river reaches are then outlined, prior to documenting the methodology itself. The management principles that arise from this approach are discussed, as well as implementation options and constraints. Finally, examples are given of the application of the management approach, mostly on rivers flowing from the main axial mountain ranges of the NZ landmass.

Before outlining the approach and its design philosophy and methodology, however, a brief summary is given of the development of the approach, to give an historical context and the reasoning behind its genesis.

1.2 DEVELOPMENT OF THE RIVER MANAGEMENT APPROACH

The approach was first developed, in its fully applied form, based on both catchment and reach studies, to the gravel-bed rivers of the Ruataniwha Plains in central Hawke's Bay. The investigation studies and river management proposals were part of a comprehensive review of the "Upper Tukituki Catchment Control Scheme", carried out in the mid 1980s, for the Hawke's Bay Catchment & Regional Water Board.[18]

The original "Upper Tukituki" scheme was implemented in the 1950s and 1960s. The river channels had become congested with willows, and the main works involved the clearing of willows, gorse and lupin vegetation, the establishment of protective vegetation belts along the channel margins, and the construction of flood retaining stopbanks. Medium-sized flood events in the 1970s highlighted the channel aggradation that was occurring along the plains reaches, given the high bed material input from the headwaters in the Ruahine Ranges. The extraction of gravel from the river channels and raising of the stopbanks was proposed in response, along with further edge planting and vegetation strengthening works. For a number of reasons a revised scheme did not proceed, but a primary concern was the high input of sediment from the headwaters and the deposition of this material that was continuing to occur within the rivers crossing the Ruataniwha Plains.

The management approach that came out of the review investigations was influenced, and enabled, by two developments. First, the availability of accurate plan-form aerial photography, with repeated photographic runs taken at intervals over a period of decades, which provided a reliable information base to assess channel form and river adjustments over time. The first comprehensive vertical aerial photography of New Zealand was taken during World War II in the 1940s. By the 1980s repeated coverage at intervals of around 5 years was available, including accurate ortho-rectified aerial photographic plans. This provided a clear and accurate picture of river channels, showing their form and extent of vegetation, and importantly, the rate of change of channel features and vegetation. The aerial plans also provided a very useful and informative base plan for the drawing up of design channels and edge zones of protection vegetation.

Second, research investigations and theoretical developments about channel form and sediment transport processes undertaken from the 1950s to the 1970s transformed the understanding of river dynamics and geomorphic processes. The 1980s investigations drew on this improving understanding, and in particular on studies concerning channel widths and form undertaken around the world, and especially on gravel-bed rivers of the Rocky Mountain ranges in Canada and the USA, and the Caucasus Mountains of the then USSR.[5, 6, 10, 13, 14]

Related studies on sediment transport processes and channel form had also been undertaken in New Zealand. Applying the differing theoretical frameworks and empirical formulae to NZ rivers in the context of the NZ environment was essential for effective management practices on the types and character of NZ river reaches.[4, 7, 8]

The examples attached to this paper include two reaches on the Ruataniwha plains, one on the Tukituki River and one on the Waipawa River. The aerial maps show the original design of the 1980s investigations, which has guided river management on these rivers since that time.

Asset management plans have also provided guidelines on the maintenance of the vegetation buffers, as flexible and erosion absorbing margins, with different responses as more of the vegetation is eroded away.

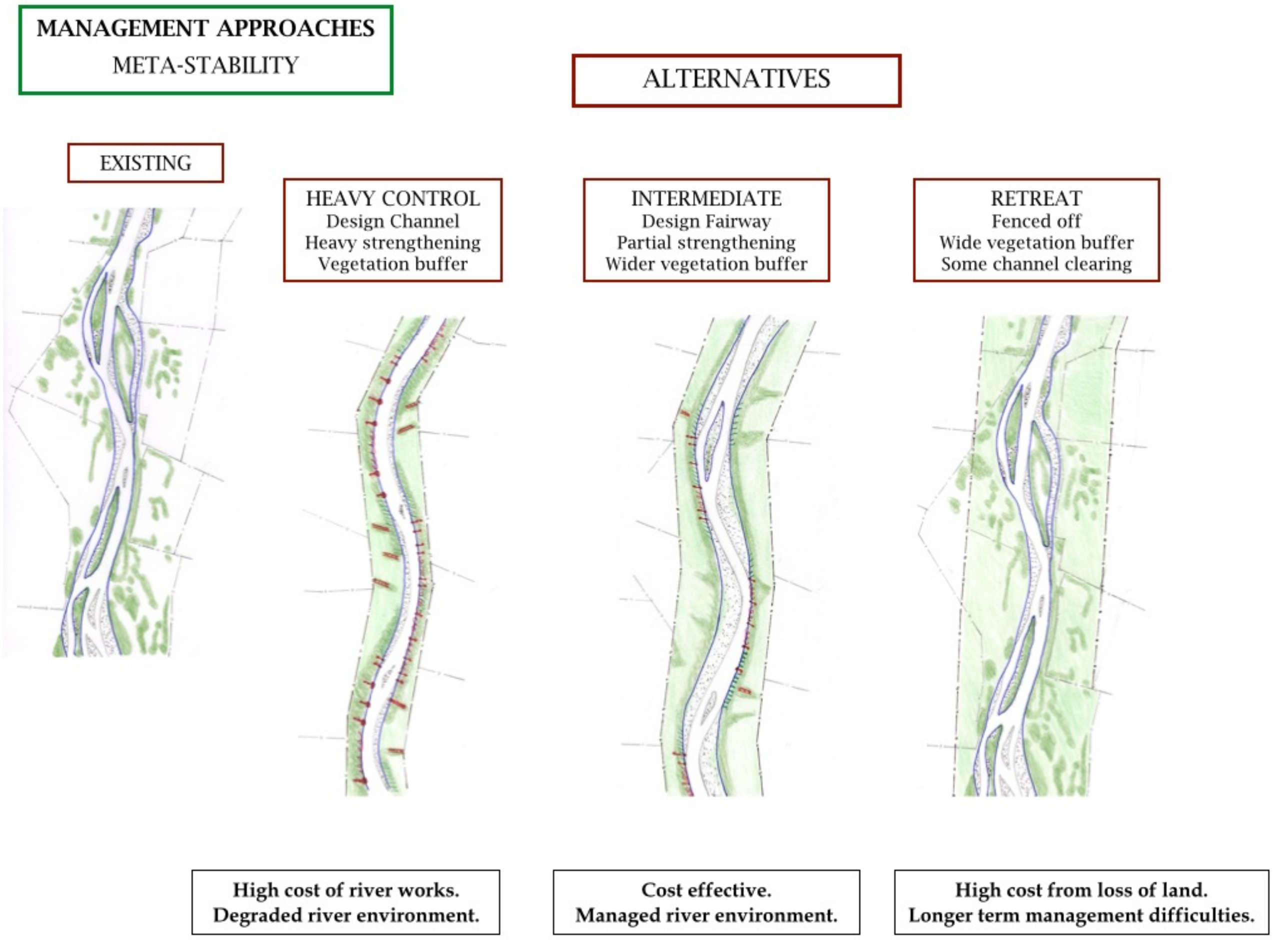
A range of alternatives, from a narrow closely managed channel to a wide corridor where the river can move and adjust with minimal interventions, was considered when developing a management alternative for the Ruataniwha Plains rivers. Then in the late 1980s, an economic and environmental assessment of these different river management approaches was carried out for reaches of the gravel-bed rivers of the Wairarapa Valley. General alternatives were considered for reaches of the Ruamahanga, Waingawa and Waiohine rivers, and later the Tauherenikau River.[21] This was undertaken as part of a reassessment of river management and a review of options, because of the withdrawal of central government from the management of watersheds and rivers, and their natural hazards, and the loss of government subsidies for catchment and river management schemes.

A diagrammatic representation of the main alternatives considered in these studies, and used for community consultation and explanations of the alternatives, is given in Figure 1. The studies showed that the approach with a defined active channel area within wide vegetation buffers that allow channel migration and a give-and-take at the channel edges, would be the most cost effective in the longer term, while maintaining an environmentally diverse river corridor. This approach was seen as an intermediate alternative, between a heavy control that fixed the channel edge, and a retreat that provided a wide river corridor, but one that would become densely vegetated. The main problem with a wider set back and minimal intervention option was that recently introduced (non-native) species would rapidly colonise the space and choke flood flows. Not only would the willows introduced by past vegetation management spread, but also self-seeding gorse, broom, tree lucerne and other invasive pioneers would colonise the river corridor. In time there would be breakouts from this enlarged area because of the deflection effects of the vegetation, and ana-branching of channels through the vegetation.[21]

Essentially, the approach involves a systemic balancing of the human occupation of floodplain land, with the risks of flooding, land loss and damage to assets this entails, and the space required by rivers for the natural processes that transport water, sediments, debris and nutrients, given the impacts that introduced vegetation is having on these processes.

Figure 1

RIVER MANAGEMENT ALTERNATIVES — Evaluation



2 RIVER MANAGEMENT

2.1 NEW ZEALAND ENVIRONMENT

New Zealand is made up of large islands on the tectonic boundary of the Pacific "ring of fire", where a segment of continental crust has been pushed and shoved, raised and sunk, over long periods of geological time. It has a mountainous backbone along the line of this boundary, with rapidly uplifted and shattered base rocks, and steep gravel-bearing rivers that have a short run from the mountains to the sea. It has a southern mid-latitude oceanic location, where the mountain ranges cut across the westerly circulation of anti-cyclones and depressions of these latitudes, giving rise to high intensity rainfalls.

Flood flows are generated very rapidly, and give rise to sudden but brief flooding of floodplains, under natural conditions. The relatively high flood flows and steep grade of rivers in New Zealand give rise to powerful highly turbulent flows that move large amounts of sediments and debris over short periods of time. As a result, alluvial (self-forming) channels are highly mobile and change rapidly, even over human life spans. However, the short duration of these floods suddenly truncates sediment transport and channel movement, and this can leave sharp hook embayments and other channel distortions in the river bed following flood events. The steep landscape of weak fault-broken and weathered base rocks gives rise to high catchment input of sediments, even with the natural forest cover of New Zealand.

The oceanic climate is highly variable, with an unstable seasonal pattern, and longer term variations from the oscillations of large global circulations, southern oceans circulations (around Antarctica) and circulations around the South Pacific. The back and forth movement of a convergence zone of two large circulations gives rise to decadal long variations in the New Zealand climate. The diverse landscape and climatic regions of New Zealand are affected at different times and in different ways through the pulsating dynamic of these natural oscillations. In particular, the Interdecadal Pacific Oscillation [IPO] is a major driver of regional variations in storm intensity and flood flows. Thus, in a given region, there are periods of high flood intensity followed by a generally quiescent period, before a return to more and larger floods. The river systems respond to these changes, and this is reflected in changes in channel form and vegetation extent within and along river channels.

During the last glacial age, NZ was mostly covered by open grasslands and scrublands, with forests on the margins and ice-fields along the higher mountain ranges. From around 15,000 years ago, there was a progressive covering and diversifying of forests, with the warmer climate and greater rainfall of the present inter-glacial period.

The isolation of NZ gave rise to unique and highly diversified temperate climate rainforests, with its own soil life and a fauna based on highly speciated birds, lizards and snails, and grasslands with a profusion of small flowering plants. The geological submergence of NZ meant that mammals had been eliminated from the ecology. Lowland podocarp forests, in particular, are highly diversified, as multi-layered forests with a complex mosaic of species and interactions between plant and soil life. These NZ forests have adapted to a high energy regime, with intense rain and strong winds, on steep erodible land, and have high resilience to climatic extremes.

The tectonic location of NZ, with its earthquake, volcanic and land uplift and subduction activity, has given rise to a very active landscape, with steep and fractured mountain ranges and fast-flowing and very mobile rivers. Its oceanic location gives rise to a highly variable climate, and its mid-latitude position means that global climate changes have a very pronounced effect on the climate.[9, 16, 17]

2.2 NEW ZEALAND RIVER MANAGEMENT

Significant habitation by people, which affected the environment, is very recent in Aotearoa/New Zealand. Polynesian migrations less than 1000 years ago brought the cultivation of sub-tropical vegetables, and the use of fire for cultivation, clearing and hunting. The hunting of large ground birds and the use of fire, along with climate changes, led to the conversion of large areas of forest to grassland, especially in the South Island, and the extinction of many large birds, including all of the flightless moa. The introduction of rats and dogs also led to the extermination of many small birds and invertebrates.

In the last 200 years, European exploration and settlement has had a much larger effect, especially in the North Island, and given rise to a very mixed up ecology, from introduced species and altered ecosystems. There has been the introduction, both by association and deliberately, of a vast array of plants and animals from all around the world, including grazing and predator mammals, game birds, freshwater fish, insects and many viral, bacterial and fungal organisms. At the same time, the large lowland and coastal wetlands were drained for farming use, with over 90% of all wetland areas being drained. Most of the lowland forests have been cut and burnt for pastoral farming, including steep hill country, with forest cutting for timber taking place up into steep range land.[1, 9, 16]

Apart from the remaining native forests on the steep mountain and range land of the main axial ranges of NZ and some volcanic mountains, the environment has been highly modified by human activities, most significantly by pastoral agriculture. Many invasive species of plants have been introduced, and introduced mammals, both domestic and wild, have profoundly altered ecological relationships, and the health of present ecosystems.

Alongside the large-scale impacts on catchment vegetation and erosion processes, there have been a whole host of direct and intentional interventions in waterways and river systems. Many of these interventions have been to use land and water as economic resources, and then to protect productive assets from flooding and erosion.

Rivers and waterways have been confined and their movement restrained for flood and erosion mitigation purposes, as well as being modified or dammed for hydro-electric power, despite the high energy regime and sediment transport loads of most NZ rivers. At the same time, the introduction of invasive species that rapidly colonise waterways has profoundly altered the riparian vegetation and vegetative regime of rivers where the native forest cover has been removed.

The lower reaches of most rivers in NZ, including nearly all the larger rivers, are managed, and there are many flood and erosion mitigation schemes throughout NZ. The main aim of many of these schemes was the protection or development of agricultural land.

This, combined with a generally localised urbanisation along rivers and low population density, has meant that river management has been carried out using relatively inexpensive low strength methods. There has been a general reliance on vegetation alongside the river channel, and willows, in particular, have been used to manage bank erosion. Infertile varieties of willows have been used, but willows grow rapidly from cuttings, and snagged material can quickly spread willow vegetation across river channels.

Willows have been planted along waterways from the early days of European colonisation, and many waterways have become choked with willows due to their rapid growth and spread in the NZ environment. The use of willows for river management, while widespread, is very much a two-edged sword, and a periodic alternation between the clearing of willows from channels and the planting of willows along banks is not uncommon.[1]

Rivers are dynamic systems with continual losses and regrowth of vegetation in and along river margins. Besides willows, many other rapidly colonising species that have been introduced, including gorse, broom, lupin, tree lucerne and a range of acacia species from Australia. These introduced species have established and spread rapidly along NZ waterways, and this has changed the vegetative makeup of NZ rivers, altering the way they behave and migrate in flood events. Native vegetation is much less invasive, and generally establishes slowly by seed, and not by vegetative propagation.

At the same time that river channel were being modified in these ways, the clearing of forests, especially from the rolling to steep hill land that makes up a large proportion of the NZ landmass, has markedly affected catchment conditions and the supply of sediment and debris to and down waterways. Large flood events in early European times were very heavily laden with debris, and in the denuded catchments soil debris flows could form during intense rainfalls on saturated soils. A sequence of blockages from debris and sediment flows and then bursting flows down waterways could also give rise to much more severe flood flows than runoff alone.

Initial flood management was mostly by earth stopbanks along river channels. Machinery was used to remove vegetation from channels, and reshape the channels of shallow gravel-bed river. Extensive use was made of gravel extraction from river beds for commercial uses in construction and road making. In many instances this resulted in entrenched waterways and distorted channels that have given rise to ongoing management difficulties.

Severe storms caused widespread catchment erosion and very extensive sediment deposition as well as flooding around NZ in the 1930s. In response, the NZ Parliament passed the "Soil Conservation and Rivers Control Act" in 1941, during World War II. After the war, major flood mitigation schemes were constructed along the lowland reaches of rivers, along with soil conservation measures in the pastoral hill country. The increasing availability of machines, and of increasing power and sophistication, gave rise to two major trends in river management.

Firstly, there was much more intervention in rivers, with the straightening of channels and the reshaping of the active gravel-bed areas of rivers, using draglines and bulldozers. This did result in the clearing from river beds of the invasive introduced vegetation, although the disturbed river beds facilitated a rapid re-colonisation, giving rise to repeated channel clearing. This activity also induced very significant alterations to the channel form and the pattern of low flow channels, braiding and flood overflow channels. At the same time, more substantial and higher stopbanks were constructed alongside river channels. Generally, these flood defences were close to the edge of main channels or the gravel bed area as present at the time of construction.[1]

Later, quarried rock was used to construct rock protection works along river banks, generally as a solid lining of the bank, using hydraulic excavators. This resulted in fixed river banks that prevented any further channel migration. However, a rock lining on one side of a river could aggravate erosion on the other side, as the river channel moved and flood flows were more sharply deflected across to the other side. The increasing use of rock works gave rise to more constrained channels, which increased bed scour and bank erosion pressures, hence generating the need for further rock works.

Vegetated margins were still widely used, and some intermediate strengthening measures were developed. This included fences of driven piles joined by two or three cables to form a flow retarding measure, without blocking off the flood flows within the vegetated berm land. The river edge of the vegetation was also strengthened by sets of permeable groynes spaced along the river bank. These permeable groynes could be made of different materials, but involved tied together pile structures spaced at regular intervals along the river edge and oriented in a downstream direction. They deflected the main body of floodwaters away from the river bank, as small deflections, while still allowing a flow of floodwaters through the groynes and vegetation along the river margin.

The combination of highly mobile and powerful rivers with a low habitation density, but economic reliance on agricultural produce, has given rise to a particular NZ approach to the management of rivers. Although it has involved hard edge protection works, in general rivers have not been fully constrained, with relatively frequent interventions of channel clearing and reshaping, and the reinstatement or strengthening of margin vegetation.

Each river system has, though, its own history of modifications, and there are on-going and cumulative effects from past alterations of channel form, flow patterns and sediment delivery. These past changes affect the present river conditions, and hence potential future modifications and adjustments to river management practices. The river channel and margin vegetation has a particularly significant impact on channel form and roughness, and changes in vegetation extent and density can alter the type and planform of river reaches. The vegetative status of a river reach is, thus, critical to river management, and management options.

2.3 RESPONSE TO HISTORICAL MANAGEMENT PRACTICES

The starting point of the reassessment of past and present practices of river management was a better understanding of geomorphological processes, and how rivers are formed and altered over space and time. In simple terms, rivers expend the energy they have from water flowing downhill on moving material, given form and friction energy losses from changing channel shape and vegetative interference. The movement of sediments, from catchment inputs and channel re-working, is thus an inherent associate of hydraulic (flood) flows, and hence also of the alteration and migration of channels.

River management to contain flood flows or to reduce erosion losses (of land or assets) directly affects channel width and form, and hence impacts on sediment transport, as well as flood levels and velocities. The relationship between flow containment, altered channel form and the scouring and deposition processes that move channel bed materials, was a fundamental principle of the review of management practices.

The aim was to work with the processes of nature, and not against them, and thereby achieve a more effective and cost efficient management of rivers over the longer term. The aim of engineering design is to select options that have the least overall cost in the long term, where costs may be evaluated over a range of management objectives, and not just financial or budgetary costs.

The repeat aerial photography provided a means for assessing channel form and rates of change, and these changes could be related to the magnitude and frequency of floods and historical variations in the intensity of flood flows. Comparisons of multi-decadal records of aerial photographs showed similarities of channel form over time, with characteristic forms along given river reaches. Channels adjusted around a self-similar form, with the width and radius of curvature of channel meanders remaining the same as channels moved and were reformed by flood events, and these patterns of change were repeated over time in concert with the intensity of flood events. The nature of the channel would change as the hydrologic regime shifted from a quiescent period to one of more frequent and larger floods and then back again, but the shape and width of channels and their meander forms would remain the same, for a given regime, although differently located.

These patterns of channel form and behaviour indicated that a river reach had a characteristic way of behaving and range of variation. Determining the characteristic form of a river reach and its variability over time can then provide the basis for an appropriate space for the river to maintain its natural processes associated with flood flows and sediment transport. From this a clear channel area could be determined along with zones of riparian vegetation on each side. This provided a defined area for the re-working processes of bed material transport, while allowing for channel migration and expansion, but with some containment of flood flows and erosion pressures.

The 'intermediate' approach that was developed in this way was a compromise, given the altered river conditions from past interventions, the confinement of the natural spread of flood waters and the vigorous growth of river channel vegetation. The 'heavy control' approach was expensive, and required continual repairs and maintenance because of the extent and rate of river adjustments to the works, while a 'retreat' option required the retirement of productive land and the management of large areas of vegetation.

The objective was to obtain better environmental and economic outcomes, by maintaining a more natural waterway that is managed in a way that recognises and works with river processes. This objective was, however, constrained in its implementation by many factors, including: the availability of river-side land, costs and economic impacts, funding arrangements, the presence of introduced invasive plants, the use of willows for river edge management, natural bed and bank controls that deflected and distorted channel features and meander patterns, artificial controls at important assets, and changes in upstream or catchment conditions.

3 NATURAL CHARACTER

There is a wide spectrum in river character and behaviour, depending on the catchment context of river reaches and the landscape conditions along reaches. Reaches may be tightly constrained by bedrock and have a limited capacity to adjust, or be within their own alluvial material and be fully self-adjusting, while maintaining a characteristic form. Along alluvial reaches, where there is continual interaction between the actively moving channels and a wider floodplain, a river can have different forms, from a single channel meandering within the floodplain, to a wide multi-channeled braided river. These different types of alluvial rivers have varying levels of activity and rates of adjustment.

Defining the natural character of rivers is, thus, not straightforward, given the dynamic and changeable nature of river systems, responsive to the many influences of climate and landscape, as well as to human modifications of these influences. Alluvial river reaches can be particularly dynamic, and respond markedly to relatively small variations in climatic and landscape conditions.

A river reach does, though, have specific characteristics, which depend on both its overall setting, of climatic regime (especially flood patterns) and catchment conditions (including geology and erodibility), and the local physical and ecological conditions along the reach. The natural character of any river reach depends on the interplay of physical forces of flow, sediment transport and channel resistance, and the ecology of the reach. This character is not fixed, but varies over time and along a river course. It is a dynamic expression of the processes at work and the variations over time and space of the influencing forces. It is more a matter of the processes at work than a specific state or channel condition. Thus, river reaches that have been modified by catchment and riparian changes can still have a natural character, through the expression of the processes at work. The channel dynamic and form will be different because of the different formative influences or changes in their strength and intensity, but it will still have the characteristics of a particular type of river reach, which occurs along rivers because of the natural processes at work in river systems.

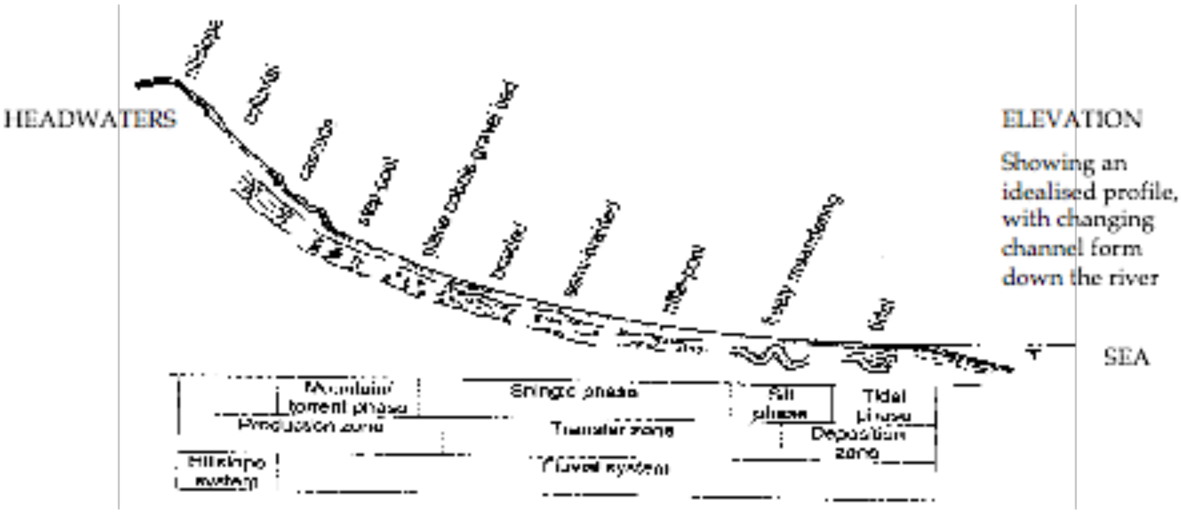
The natural character of a river, thus, changes along the river, from the headwaters to the sea, and when characterising a river this is done by reaches. It is a given reach that can be characterised, not a river. The nature, character and responses of a river change from reach to reach, as the forces and processes at work change, and a given character can only be defined for a reach where there is a similarity of river processes along it. A reach for river management purposes is then a length of river that has a relative uniformity of form and behavioural responses.

The reaches are, though, connected within the whole river system, and there are patterns of reaches along a river with changes in channel character and river type. These changes can be gradual transitions or sharp transformations, as at the entry or exit from gorges. The patterns of sediment delivery and storage will also vary from catchment to catchment, with varying degrees of connectedness, or efficiency of sediment supply.

The diagram below (Figure 2) is an example of the characterisation of changes in channel form down a river.

Figure 2

RIVER TYPES — Down a River



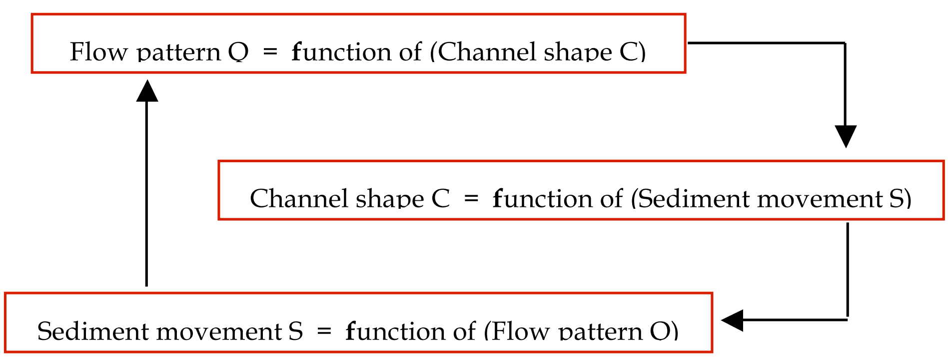
CREDITS: "Gravel Bed Rivers", by Paul Mosley & Stanley Schumm

These changes in channel form, with their different characteristic behaviours, occur in both space and time. From steep forested headwaters to wide flat marshy alluvial plains, rivers change their form. Over time rivers evolve, changing in response to climatic variations or alterations in the pattern or intensity of floods, and to tectonic events and changes in the landscape and sediment supply factors. These changes alter the ecology of the river, which in turn feeds back and alters the physical processes and form of the river. Human activities can modify many of these relationships and evolving trends, accelerating or suppressing natural tendencies in differing circumstances.

The natural character of an alluvial river reach, in its physical expression, arises from a complex interplay of the flow forces, the rate of supply and nature of the river sediments, and the channel form and resistance to erosion of the river bed and banks. The self-similarity of river channels, that form and re-form to a characteristic pattern from flood to flood, arises from an interconnection or feedback loop between flow pattern, sediment transport and channel shape. Flow pattern is a function of channel shape. Channel shape is a function of the erosion and deposition processes of sediment transport. Sediment movement is a function of the flow pattern. Thus, while the river channel moves, its form stays the same, maintaining a characteristic form at a reach scale, for a given regime of influencing factors. The diagram below (Figure 3) expresses these relationships as a feedback loop connecting these aspects of the physical behaviour of rivers.

Figure 3

INTER-DEPENDENT PROCESSES — Flow/Channel/Sediment



This interplay of form and function, as water and sediments pass down the river system, can be constrained or modified by the interactions of the river with its landscape. Sediments are stored on the floodplain and older deposits removed by the interactions between the active channels and the adjacent floodplain. Base rock in the channel bed will restrict bed scouring and direct the sediment transport processes to the banks. Conversely, rocky or cohesive banks will restrict bank erosion, and deflect channel migration.

Rivers and their margins have an especially diverse ecology, given the availability of water, edge effects, and the dynamic interactions between surface and ground water, and channels and floodplains. The ecological systems are highly linked and inter-dependent, with many complex interactions between the biology of flora and fauna along waterways and the physical nature of the waterways. The physical processes and ecological relationships of aquatic and terrestrial habitats form an inter-dependent and inter-connected system. Most noticeable are the interactive effects of vegetation in rivers, with river margins providing diverse vegetative habitats, and vegetation affecting the channel form through island colonisation and channel splitting. The deposition of logs and snagging of vegetative matter can affect the formation of bars and pools, while also encouraging the growth and spread of vegetation within the channel.

The interactive processes of the physical dynamics are, thus, modified by the river ecology, and especially by the in-channel and riparian vegetation along the river course.

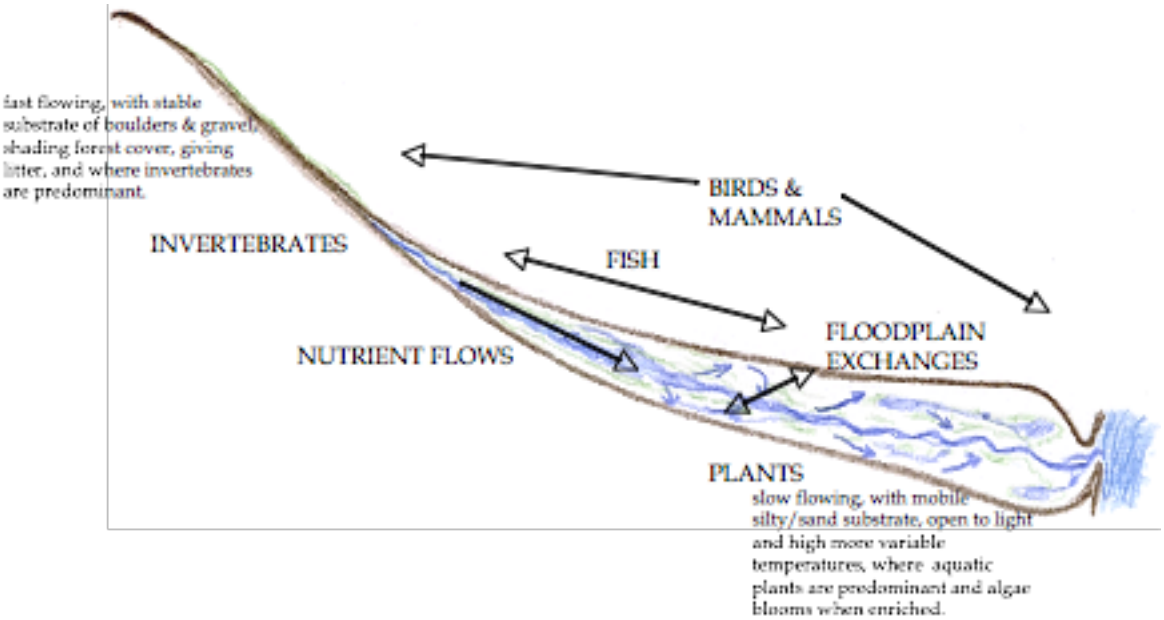
There are different drivers of these waterway ecosystems. The primary biological energy input to a forest stream is the leaf litter, while the primary energy input to an open river channel is from in-stream algae and macrophytes. This gives rise to very different aquatic eco-systems, which in turn impact on the channel form. In many instances, floodplains have a wide range of habitat types with complex interdependencies, and they have a fundamental role in maintaining the ecological functionality and health of a river reach.

A very simple diagram that shows some of the main ecological interactions along a river and its primary ecological base, is given in Figure 4.

Figure 4

ECOLOGICAL PROFILE — Along a River

Biological activity adds layer on layer of interconnected processes, which give rise to very complex and dynamic river systems of inter-dependent ecosystems and physical exchange systems.



A characterisation of waterways would then extend beyond a determination in terms of the physical features of river reaches. Along with physical form, it would include the hydrological regime (flow variations over time), the riparian (and floodplain) vegetation or habitats, and the aquatic life (invertebrates and fish). An assessment of the natural character of a river reach can then be undertaken in terms of a number of broad categories, with each aspect or influence determined or characterised in a way appropriate to its form, pattern, speciation or behavioural type.[45]

In the approach to river management outlined in this paper, the physical template (and associated process interactions) provides the platform for assessing appropriate river corridors and active channel areas. Hence the focus is on the physical processes of rivers and their interactions with riverside vegetation.

New Zealand lies on a tectonic plate margin, which is characterised by active mountain building and block faulting. Frequent earthquakes, with fault movements and associated landslides, as well as volcanic activity, affect river systems. This geological activity determines and continually alters catchment form, of valleys and hill slopes, and river profiles. It also influences the supply of gravel bed material to the river system. Over geomorphic time frames, river systems trend towards a dynamic equilibrium that balances these various formative forces and influences. However, many New Zealand rivers are unable to establish such an equilibrium because of the geologically active and high-energy environment of New Zealand. The uplift and incision rates vary across the landscape and over time. Hence, the past and more recent geological and landscape history is an important part of the catchment setting of a river system.

Over the last 2 million years, of the Pleistocene period, there have been marked swings in climate, from cold glacial periods, with large ice caps at the poles, to relatively warm interglacial periods, as at present. Sea levels have gone up and down, with ice accumulations at the poles lowering sea levels by over 100 m compared to interglacial periods.

These climatic changes have impacted on the character and sediment transport processes of rivers, resulting in alternating long-term trends of aggradation and degradation. In glacial periods high sediment supply from the steep catchment land results in valley infilling and low land aggradation. On present-day coastal and inland floodplains there was sediment deposition and re-working, with river courses extending beyond the present coastline, down to the lower sea level. In the shorter interglacial times the forest cover reduces catchment erosion, but more intense rainstorms degrade the rivers, which incise into the deposits laid down in the glacial period. Remnant surfaces and terrace formations reflect recurrent phases of activity. At the same time, the higher sea level gives rise to aggradation and plains building at the coast, with coastline aggradation or wave attack retreat, as a new coastline forms.

Similar aggradation and degradation trends occur under present (interglacial) conditions. Variations in catchment erosion and sediment movement between common and more extreme flood events give rise to down-river pulses of sediment. Large storm events create high sediment input from the steeper upper catchment, and a flushing out of the lower reaches by the large flood flows. In more common flood events the upper catchment input is re-worked down the system and the lower reaches re-built.[7, 9]

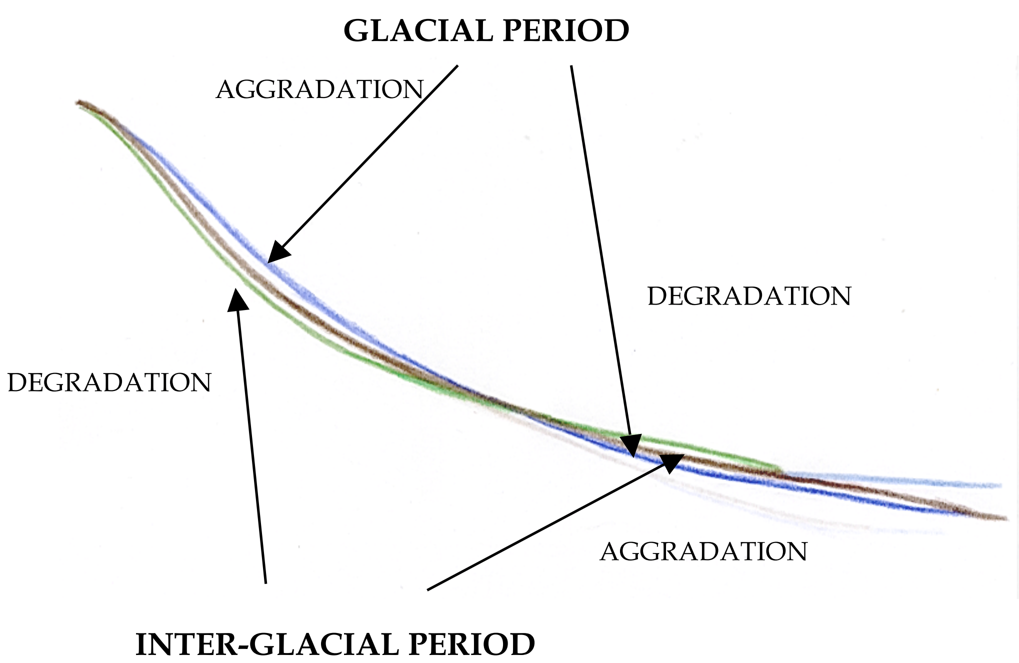
Particularly severe storms can destabilise catchments, giving rise to large erosion scars and greatly increased sediment input from the event itself and for many years afterwards.

These oscillating trends in river dynamics and transport of sediments are indicated in a very general way in Figure 5, for the conditions during glacial and interglacial periods, and for extreme and more common events under present climatic conditions. These climatic variations and geological activity give rise to complex landscapes, with diverse and system-specific interactions of rivers with their watersheds and floodplains. River dynamics is affected by paleo-deposits and other legacy features, with these features arising from past activities over a long period of time.

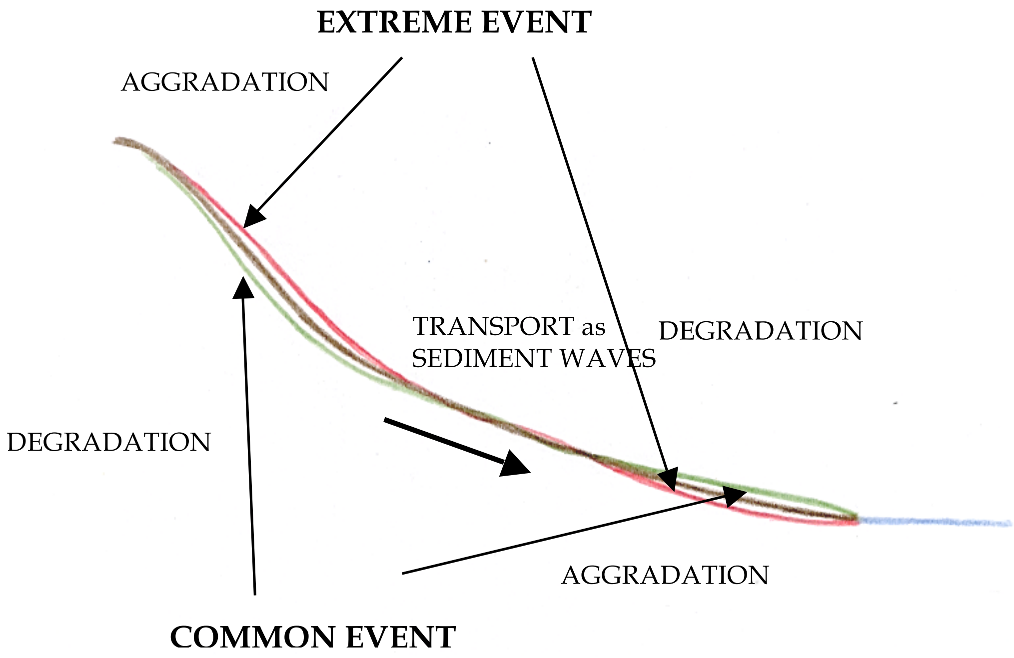
Figure 5

RIVER PROFILES — Flood Intensity & Climate Change

Sediment transport and channel trends in Glacial and Interglacial periods



Sediment transport and channel effects between Common and Extreme floods



In general terms, for many rivers in New Zealand, finer-grained materials from former glacial periods underlie the contemporary river bed materials laid down by the current flow regime. This layering of different materials can affect river processes, especially during large flood events. When uncovered, exceptionally large and deep scouring of the underlying finer-grained sediments may occur, inducing a geomorphic instability.

The pulse input of materials from the longer term periodicity of storms and the severe catchment erosion and sediment input of large events, gives rise to a wave-like movement of the bed material gravels down the lower reaches of the river, as the storm deposits are re-worked and transported downstream. Bed levels at any given point will, then, vary due to channel migration and the throughput of these gravel waves.

The particular expression of these processes and trends varies markedly within the New Zealand landscape. The evolution of a river system and the trajectory of change at a reach scale is greatly influenced by the pattern of sediment transfer and distribution of storages throughout the system. It is the connectivity of the system and the ability of a river to adjust its form within its containing landscape that determines its channel patterns and the characteristics of its reaches.

Understanding the various timescales of river adjustment and their catchment to catchment variability is crucial to an appreciation of sediment transfer processes and rates, and hence channel patterns and their variability, in any given river system. The particular nature and history of a river is fundamental to a determination of the appropriate space to allow for the natural processes of a river along a given reach.

Thus, the character of a reach varies over time, at different time scales, and this can give rise to changes in the type of reach, active channel widths and the patterns of channel adjustments. This reach character can be affected by recent human modifications of the landscape, as well as recent significant natural events.

Any channel design and overall river corridor has to take into consideration this variability and longer term trends in river behaviour.

4 METHODOLOGY

4.1 GENERAL

The assessment of the natural character of a river reach and the determination of appropriate design channels and management corridors is based on investigations of the geomorphologic context of a reach, its channel patterns and how they change over time, and analyses based on the main factors that influence channel formation and variation.

Studies of river characteristics and the processes of sediment transport and channel formation are undertaken within a catchment context, to provide the climatic and catchment setting of the reaches under consideration. The natural channel form and its variability over time, in relation to climatic cycles and other influences on catchment processes, is assessed for any given river reach, from aerial photography and early survey plans of the reach. Surveyed channel cross sections provide information on channel trends and sediment transport processes, directly and through hydraulic modelling and transport calculations.

Empirical formulae of channel widths, which have been derived from theory and field studies of natural meander forms, are used to determine design channel widths. These formulae are based on the main river forming influences of flood flows, channel slope and bed material size. The layout of design channels or multi-channel fairways, where active bed load movement takes place, is then guided by these design channel widths, and wave form relationships between width, radius of curvature and wavelength. The design channels or fairways are adjusted to follow the existing river course, with account being taken of the existing channel area and alignment, given natural and artificial constraints or control features.[5, 6, 8, 10, 14]

From this, appropriate active channel areas and margin vegetation buffers are determined, to give a defined river management area. This management is directed at the maintenance of generally clear channels or fairways for the active working of the river bed material, and of dense vegetation margins that buffer and absorb the channel migration associated with the channel re-working processes. The development of this management area takes time, as vegetation has to be established, cleared and re-used, depending on where it is within the design area. The aim is to have a clear gravel area, with minimal roughness/resistance elements other than what arises from channel form and boundary conditions, within restraining but flexible boundaries of riparian vegetation.

The natural form of the active channels along the reach can also guide in-channel works and alterations to the active channel, and the curvature or layout alignment of edge strengthening measures. The more detailed layout of works and shaping of channels then follows the natural channel forms and movement, to be both more effective and less disruptive of the river environment and its natural conditions.

Beyond the active channel and margin buffer zones, a wider river corridor is drawn up that includes reserve area and allows a more diverse riparian environment. This wider river corridor defines the overall space sufficient for the river to change and move according to its natural dynamic, over periods of differing flood patterns and intensity, and potential catchment changes. The active channel area and management buffers are, thus, set within a wider corridor, and they can move within this corridor over time.

The channel form, along with the extent and width of margin buffer vegetation, depends on the type of river reach. Four types of alluvial river reaches, where channel beds and banks can be moved and altered, have been differentiated for this design process. These reach types cover most of the managed reaches of gravel-bed rivers in NZ, which are generally lower reaches on plains or within relatively wide valleys with a valley floor of alluvial materials. The river types used can be briefly described as follows:

- **Meandering** — well defined single sinuous channel, with inner point bar and oscillating sectional asymmetry around bends, with a slow migration of the channel as a whole in a downstream direction.
- **Alternating Bar** — well defined low flow channel, meandering around alternating bars, and migrating within an overall (active) channel that has some meander curvature and definition within the floodplain.
- **Semi-braided** — semi-defined main channel with mobile channels that migrate within an area of gravel bars and islands, and with back channels and flood overflow paths across a wider partly vegetated area.
- **Braided** —wide gravel bed area of multiple channels that continually shift and re-form in flood events, with shallow flood flows of concentrated flows that move across the bed and give rise to rapidly moving channels and highly pulsating bed material movement.

Aerial photographs of river reaches of NZ rivers that show different channel forms are given in Attachment 1.

The first step in the drawing up of a design channel or fairway for a given reach is to select the appropriate reach type, as this effects which empirical formula is more applicable or what combination/arrangement of channels will most suit the reach. Selecting the reach type is normally straightforward, as they look different and the rate and manner in which channel migration takes place is different.

There are meander forms that are associated with these different types of reaches, with channel meandering being repeated at scale as channel meanders are incorporated in a larger scale meandering, up to the meandering of belts of braids in wide fully braided river reaches. The theoretical meander forms that the formulae relate to and are associated with the threshold of motion of the bed material or with live-bed conditions of flow dominant meandering, can then be related to these reach types and hence guide the determination of design channels or fairways. This can be done despite the fact that the formulae were not necessarily derived for this purpose, or to represent the different channel forms and patterns in the alluvial river beds of these different river types.

Example diagrams of these meander forms within design fairways are given in Attachment 2. One is taken from the report on the original investigations of the "Upper Tukituki" scheme, and the other from the river characteristics and sedimentation report on the Hutt

River, which was part of the floodplain management plan investigations for the floodplain of the Hutt River valley.[18, 24]

An understanding of the geomorphological processes at work along different types of rivers is useful in determining river types and for the design process as a whole. However, a detailed understanding of the different processes and ways of behaving of alluvial rivers is not essential for the practical application of the design method to determine appropriate active channel areas and vegetation buffers for river management purposes under the prevailing conditions. It has been applied as an engineering practice to assist in a form of river management that provides more space for river activity and more effective management because it is based on the natural processes and character of alluvial rivers.

Some pointers on the characteristic behaviour of different types of rivers can, of course, be useful, but the differences between the river types of the design methodology of the practice being outlined makes the type selection reasonably obvious. Single channel meandering rivers do migrate across the available valley floor, and have distinctly asymmetrical sections at bends, with an inner side point bar and relatively deep pools alongside steep outer side banks. Alternating bar channels have longer lateral bars along alternating banks, which tend to translate downstream within some relative confinement. When there is lesser edge confinement and more activity or mobility along a reach, the channel becomes partly braided, with side channel and islands, and in floods back channels that have become quite vegetated then become active. Braided rivers have multiple channels that freely migrate. The channels or braids continually change, with a complex arrangement of runs, riffles and pools at the channels bend, converge and diverge.

These river types have different capacities to adjust, and differing sensitivities to changing inputs and riverside conditions. Studying catchment conditions to assess sediment and debris supplies, the system storage and translation capacities, and how this may vary over time is, thus, an essential part of the design methodology. The likely range of reach-scale channel adjustments over the longer term is important for the determination of the wider river corridor, within which river processes of sediment transport and channel adjustments, and the management of these processes, takes place. These adjustments will be of a different nature and scale for different river types, and are catchment and reach specific.

The most difficult part of the design process is this determination of longer term trends and the magnitude of channel variations with changing conditions, and hence the defining of the outer limits of the wider river corridor. This is where an understanding of the geomorphic processes at work within the catchment and along the management reaches is most helpful. Any assessment of longer term trends does, though, depend on the information available about the specific catchment and reaches, and there is generally a paucity of relevant geomorphic data for most river systems in NZ. The assessment of likely changes in river type and the magnitude of channel variations over time for a given reach within a particular catchment context is generally qualitative and experience-based. Because of this, a methodology for this part of the design process can not be spelt out. It is something that has to be learnt and applied site by site.

Given a defined active channel area and margin vegetation buffers, the aim of the management approach is to allow the margin buffer zones to absorb the erosion and deposition processes of the river, without an encroachment onto productive land or threat to valuable assets. The buffer vegetation is lost and re-established over time as the river channels move and migrate, with sufficient reserve to allow a slow re-establishment of lost vegetation over time, as the river naturally moves on and erodes other areas of the buffer.

Remedial action can, therefore, be less intensive, with greater reliance on the re-establishment of vegetation over time. The buffer zone can also have sufficient width to provide a reserve for channel widening during high flood intensity periods, and to absorb the impacts of severe events.

Additional allowances may, however, be necessary to accommodate changes in reach type that substantially increases the active channel width during periods of high flood intensity, as compared to more quiescent periods, or for predictable changes in river conditions because of changes taking place in the upstream river and catchment. The river corridor should, therefore, define a suitable area for the river over the longer term, as well as this can be done with the available information and technical knowledge. The outer boundary of the river corridor then provides a line beyond which productive uses can be made of the land alongside the river reach.

4.2 DESIGN PROCESS

The reach type and its general character is first assessed from the catchment and climatic setting and reach conditions along the river. A given reach is determined by its geomorphic context and connections, with a given reach having a relatively consistent form and similarity of behaviour over time, so that it can be considered as a unit in terms of river processes. Reaches may be further subdivided by management objectives and the presence of artificial constraints. This differentiation in terms of management requirements is, though, a secondary matter, that follows on from the geomorphic determination. At the same time, these reaches that have a similarity of form and functional character, are connected to, and conditioned by, the larger river system, and this connection to the river system as a whole has to be recognised and accepted with any management approach.

The investigations of river characteristics, to determine the wider context and reach type and variability, include an assessment of the geological and climatic history of the catchment and salient present and past impacts on the current river conditions. The assessment of a reach then involves the study of repeat aerial photography and historical survey plans of the river reach, and the semi-theoretical analyses based on the empirical formulae for channel widths.

The historical record from aerial photography and plans show the channel patterns and temporal rates of migration, movement and alteration of these patterns. When aerial photography is available over a long enough time period (of decades), the change in reach type with changes in the hydrological regime and/or sediment input can also be observed.

Based on this assessment of the reach character and its channel form, the appropriate regime formula and its associated channel width can be determined for a design channel or fairway. The reach assessment should consider the wider context of: the flood history and how the present channel relates to cycles of quiescent and intense flood periods; the pattern and extent of vegetation, and vegetational trends; sediment input rates from the upstream catchment and riparian re-working, and whether the reach has a degradation or aggradation tendency; bed material stability and likely changes in substrate composition.

In addition, river channel surveys, which are mostly surveyed cross-sections at intervals along the river course, provide information on the magnitude of cross-sectional variations over time and along the river. They also provide information on channel slope, including the location of significant changes of slope. Channel resistance can be derived from hydraulic modelling, when this is available, using the channel cross-section data, and sediment transport rates assessed from the modelling output, using appropriate sediment transport formulae.[46]

Repeat channel surveys provide a record of cross-sectional changes over time, and appropriately spaced cross-sections allow hydraulic modelling of given flood flows. This aids the assessment of river conditions and allows a quantitative estimation of sediment transport rates.

Information on the bed material is required for all the meander theory formulae, and for estimation of bed load transport rates. The size of the bed material can be obtained from samples of bed material taken from the river channel, which are then sieved to give size grading curves. There will normally be considerable variability in the size gradings from sample to sample, and in gravel bed rivers a heavier armouring layer is present on the surface where the bed material has been actively worked within a channel or braid. The median size of this armouring layer is used in the meander formulae, while the median size of the whole of the bed material is used in the transport formulae.

The method that has been used to determine bed material sizes involves selecting an area that is representative of the bed armouring, and then taking a surface layer sample in a consistent manner, to give a standardised sampling. When grading curves are determined from a number of samples that represent the range of bed material at the site, and a combined grading obtained, then a very approximate relationship has been found to hold between this grading curve for the whole of the bed and a grading curve of just the armour layer. The median (50%) size of the armour layer is then generally about the same as the 75% passing size of the whole of the bed.[46]

Photographs are taken of the samples, prior to removal and afterwards, and this has provided a library of photographs of graded samples from many river reaches around New Zealand. This allows a photographic comparison of graded samples from many different reaches and river sites.

The 2 year return period flood flow is taken as a representative flow for the power of flood events, and this dominant flood flow is used in the meander formulae. It can be determined from flood frequency analyses of flood flows at recorder sites, or from flood estimation procedures using rainfall data and catchment area, or regional flood estimation methods. Reasonable estimates of the 2 year return period flood flow can be obtained from short periods of records, and transferred along a river using factored catchment areas.

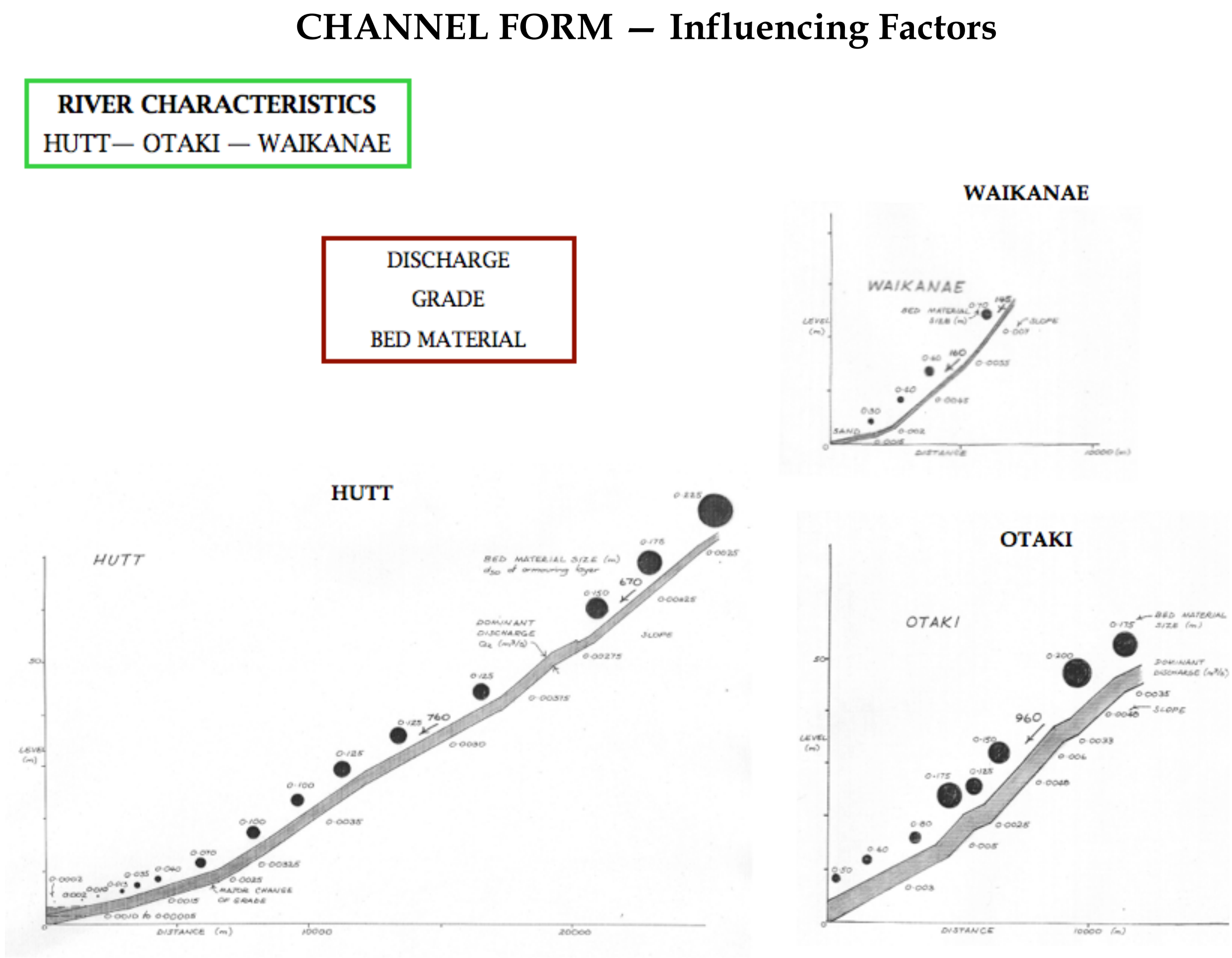
The empirical formulae have been developed in different ways on different types of rivers, and the use of a dominant discharge is a very coarse proxy for the power of a spectrum of flood flows. It may not be that representative of the channel forming power of flood flows. However, the application of the formulae and their use in defining channel widths has been found to apply consistently and fit the actual river channels of many river reaches and river types in New Zealand.

The meander formulae for channel widths use different combinations of the main channel forming characteristics of flood flow, channel slope and the size of the channel bed material. They have been found to relate well to different channel forms and meander patterns, and hence provide a design basis that can be consistently applied. Simple wave form relationships are used to relate these widths to the radius of curvature and wavelength of channel meanders and design fairways. Again, river reaches do show these wave form relationships, which are repeated at different scales for different types of reaches.

The formulae used for the design channel or fairway determination of the river management approach outlined in this paper are given in Attachment 2. This attachment includes a table of results for selected river reaches from regions throughout NZ. Examples are also given of tables that have been used to summarise the formulae and their design applications. This data shows the variation in these influencing factors and in the resulting widths given by the formulae, for a wide range of river types and reach locations around NZ.

A diagrammatic representation of the three main channel forming influences is given in Figure 5, for the Hutt, Waikanae and Otaki rivers of the Wellington region. The river slope or grade is given by the profile, the dominant discharge by the thickness of the profile line and the bed material size by the diameter of the circles. This example shows a typical variation in these river forming influences for rivers in the same region, which all flow from the Tararua Range.

Figure 5



The channel width formulae have been derived from measurements on different types of rivers, and relate to channel forms under different regime conditions. The formulae do not, though, define the plan configuration of the channel, and the type of channel has to be assumed from the general nature of the river when applying the results of the regime formulae.

The channel meandering and migration also takes place in different ways and at different scales in river reaches. There is meandering within meanders, and meandering channels can be contained within a larger scale of meandering. In a wide braided river the movement and meandering of braids takes place within a meandering ‘braid belt’ that itself moves with a characteristic meander form. In small single channel reaches bed material movement can be constrained, and there is one meandering channel with alternating beaches. Meanders related to the threshold of motion of the (alluvial) gravel bed material form within an active channel that is semi-braided and where this active channel form moves it does so to a meander form as well.

The determination of the channel pattern and its make-up in terms of meandering channels at different scales is critical to the selection of a design channel or fairway for a given river reach.

The diagrams of design fairways and channel meanders in Attachment 2 are schematic examples of how different channel meanders fit within different design fairways.

4.3 DESIGN CHANNELS

Once an appropriate channel type has been determined for a reach, a design channel or fairway can be drawn up that suits the river alignment and channel area, fitting in with the natural constraints or controls on the channel position, as well as artificially imposed constraints from human activities and assets. The design will generally be drawn up to fit the existing reach alignment and channel configuration. However, it should be understood as just one design possibility, and as reach conditions change over time, from normal channel movements, or due to changing influences external to the reach itself, the design may have to be altered to suit. While the pattern of the reach channel(s) and their overall number and extent can persist over time, for similar influencing conditions, the actual position of channels and their meandering within the active bed area will move as part of natural river processes. The pattern stays the same while its expression constantly changes.

There is, therefore, always some flexibility in the drawing up of a design channel, and consideration should always be given to the likely trends and the time span of changes that would impact on the design, as a management guide. It should be consistent in width and with a well-formed alignment, which reflects the natural character and form of the reach, but is not something to be rigidly followed. The design lines indicate an overall alignment and average width over time, to guide the extent and layout of river management measures within the active channel area and margin vegetation zones. The actual width of the active channel and vegetation buffers will vary over time, within the wider river corridor that allows for varying reach conditions.

Thus, any design will relate to particular prevailing river conditions and the current alignment of the river reach. If these river conditions change significantly, then the design and the associated river management methods must be re-assessed, and revised as necessary to fit different conditions.

The design channel, or fairway of multiple channels, is based on relationships about river channel forms and widths, and the design width provides an appropriate area for the channel adjustments that take place along a reach in a manner that relates to the channel movements and migration behaviour of the reach. The design widths, therefore, depend on the reach type and character, with the reach type being determined first, and then a design drawn up for that type of reach. These design widths are for unconstrained rivers, and the design must be adjusted to take account of features that constrain its adjustment capacity, and hence impact on the river and its channel form or alignment.

The relationships between channel types and the empirical determinations of channel widths is used to select an appropriate width for a given reach type. The way in which different design channels or fairways are then determined for different types of rivers can be described as follows.

The smallest meandering channels of gravel-bed rivers are formed as 'threshold of motion meanders', which are determined by the ability of flood flows to move the bed material, and become fixed on flood recessions, as sediment transport stops. They are seen as low flow channels in gravel-bed rivers, and there are two forms: a narrower meander based on the regime slope for the reach; and a wider meander based on the actual slope of the reach.

The narrower meanders tend to be well formed, with a radius of curvature of around 4 times the width. The wider meanders tend to be somewhat distorted, because of the slope adjustment they accommodate, and have a radius of curvature of around 6 times the width. There also tends to be an oscillation between these meanders, to achieve the slope adjustment, with a corresponding change in the radius of curvature.

Where a river reach has a meandering single channel form (Meandering type), or has a relatively tightly constrained single channel within its floodplain materials (Alternating Bar type), then a narrow design channel, based on the threshold of motion meanders, can be applied. This gives a well defined channel which can have a consistent meander amplitude and wavelength, generally using a radius of curvature of 4 to 6 times the width.

For meandering single channel reaches, with well-defined bends, this design channel is lined by a buffer zone around the outer bank (erosion) side, with the buffer width taken as that of the smaller meander width. This well defined channel has a natural tendency to migrate in a downstream direction, and some allowance has to be made for this channel movement, when defining the channel and buffer zone areas for management purposes.

For constrained single channels that are relatively straight, the design channel is lined by buffer zones continuously along both banks. For this type, wider buffer zones can be used, depending on the erodibility of the banks and floodplain materials.

These reaches are generally along floodplains where the alluvial deposits are relatively coarse and more resistant to flood flows, or where flood flows spread out over the floodplain and in-channel flows are relatively weak. They can also occur where the river has an under-sized channel within a landscape formed under a different climatic regime, generally that of the preceding glacial period.

This design channel can also be applied where the river is already constrained by past river management, and it requires the highest level of on-going management. In these circumstances, a particular channel alignment and meander pattern, of many possible channel positions, is defined and has to be maintained. Downstream translation of lateral bars will continue to occur, and to minimise long term river management efforts under this regime a consistency from bend to bend is important, without any one bend becoming especially enlarged or over-sharp. Thus, consideration must be given to what is happening along a series of bends, and the downstream responses from management interventions at any given bend.

This **threshold of motion** meander form is, thus, applicable, as a design channel for management purposes, to narrow and well-defined single channels, of either the Meandering or Alternating Bar type. This single channel form may exist naturally within the river floodplain, or arise from past management as a response to channel confinement.

Where there is a less defined and more mobile main channel within a wider channel area, then a wider design channel can be applied, based on the 'dominant flow meander' width, which arises when flood flows of a dominant flow or greater can fully mobilise the river bed material. This channel width provides sufficient space for the active main flow channels to migrate, within a channel area edged with buffer zones of tree vegetation. The threshold of motion meanders associated with bed material movement can then migrate within this channel, with adequate curvature, but with not so much curvature that they tend to split up or form sharp cross-overs that directly attack the bank and buffer vegetation. In this case the radius of curvature of the meanders is taken as 4 times the width. The buffer zones on each side restrain and absorb the meandering flow channels, and the buffer width can be based on a full width incursion of the wider threshold of motion channel. This provides sufficient width to accommodate some channel migration and its associated erosion, with the buffer vegetation being re-established as deposition occurs with further channel migration.

Under this management regime the buffer zones do not have to be repaired so promptly, following erosion damage, and reinstatement can take place over a period of time, as river conditions change and main flow channels move. Thus wider buffer zones are used, but repairs are less expensive as more gradual reclamation of eroded areas can be achieved using mainly vegetative means. The wider channel is, though, more prone to re-vegetation, especially by vigorous introduced species, and some regular channel clearing, especially of higher beach areas, may be necessary as part of this approach.

This **dominant flow** meander form is applicable, as a design channel, to river reaches that are relatively mobile, with a main low flow channel and gravel beaches (bars), and may have secondary channels and flood overflow paths. It provides more space for channel movement in Alternating Bar reaches, and can be applied as a relatively contained channel for Semi-Braided reaches. It allows the channel movement associated with the transport of the river bed material, with sufficient space for the processes of bed scour/deposition and bank erosion/accretion of this movement, but does constrain the overall width and alignment of the river, reducing its natural variations and wandering within its floodplain.

Where there is sufficient space available, and the river tends towards a wider semi-braided to braided form, then an even wider design channel, or fairway, can be applied. In this case the fairway is taken as 1.7 times the dominant flow meander width, as this provides sufficient space for this dominant flow meander form to migrate along the channel with a minimum of restraint (at a meander sinuosity of 1.1 to 1.2), but is sufficiently narrow to inhibit channel splitting. For wide gravel rivers this width is a good compromise between the conflicting requirements of minimised bank attack, low flood rise, efficient sediment transport and reduced channel area.

The management approach is, then, one of quite frequent but low level interventions, mainly of channel clearing and re-vegetation of eroded areas within the buffer zones. For a mainly vegetation, soft edge, approach to river management, the buffer zones have to be correspondingly wider, and are normally the width of the dominant flow meander. Localised strengthening of the channel edge may still be necessary, to reduce buffer zone losses and assist in re-establishment after loss.

This **fairway** design is applicable to wider channels of a Semi-Braided or Braided type, where sufficient area of floodplain land is, or can be made available, to provide the space for the channel changes that naturally occur in these reaches of rivers.

The wider the design channel (or fairway) the wider the buffer zones on each side, and the width of a meander form smaller than that used for the design channel can be used to determine the buffer zone width. The buffer zones can then be determined in accordance with natural channel forms, and thereby be consistent from river to river and for different types of reaches. In general, the buffer zone width, on this approach, is about a half the design channel width.

Different buffer widths could be used, giving different overall channel widths, of active channel areas and vegetated margins. Narrower buffer zones have been used, especially in the earlier applications of this approach to river management. However, the wider buffers provide more space for channel widening and changes in channel form during periods of high flood intensity. The adequacy of the buffers is really a matter of experience over time and on a range of river types, but a general rule based on meander widths, as determined from theory and practice, has been used for the intermediate management approach outlined in this paper.

For wide fully braided rivers, where braid belts form and move as a whole, and large islands can form within the active riverbed area, then an even wider fairway is necessary to suit this larger pattern. In this case, fully developed braid belts meander as a whole and with a similar form relationship to the meanders of semi-braided or single channel reaches. However, the design fairway width has to be determined empirically using a series of repeat aerial photographs of the river reach, and any other photography or plans of braid movement. The meander belt widths and their overall meandering trends are determined from a comparison of braid patterns within a reach and their movement over time.

This has shown consistent widths to meander belts of well-formed multiple braids, and a repeating pattern in the changes in channel braiding, with a split form developing at a relatively well defined channel width. The channel widening response (and vegetation clearance) with large floods or periods of high flood intensity, which occurs in single channel and semi-braided rivers, is also seen at a larger scale in fully braided reaches. This wider fairway design, based on widths that do not have a split form around large islands has, for instance, been applied to the large Canterbury rivers, such as the Waimakariri and Waitaki rivers.

4.4 RIVER CORRIDOR

Once the appropriate design channel or fairway is selected for a given reach, an overall river corridor area can be defined. This corridor should be sufficient to provide enough space for the river channel and the vegetation buffer zones alongside the channel. It should also take into account the long term variations in river behaviour, form and extent, including the effects of large or more extreme flood events. Flood flow conditions become significantly different and more intense when flows are greater than around a 20 year return period frequency of recurrence, with more severe runoff and sediment generating conditions.

There are continual changes in natural channels, as the pattern and intensity of floods varies. Large flood events widen the active channel or fairway, and can cause very pronounced erosion embayments into the floodplain. A period of high flood intensity can change the channel from of unconstrained gravel-bed rivers— from single channel to semi-braided, and from semi-braided to fully braided — while a more quiescent flood regime will re-establish a narrower and less complex channel form. Thus, when drawing up river corridor boundaries, allowance should be made for the widening that occurs over periods of high flood intensity or from large events, as well as to accommodate the more regular channel migration and its erosion embayments.

The boundaries of this river corridor also provide a clear demarcation line between the land available for productive uses, infrastructure facilities and human habitation, and the river area required, given a specific management approach. The river corridor then provides for both flood capacity and the management of bank erosion and channel movement over the longer term (and hence through periods of high flood intensity). It also provides a wider and more diverse area for other objectives of river management, such as habitat, amenity, recreation and the ecological functionality of channel-floodplain exchanges.

In drawing up the boundary, account is taken of natural features, such as terrace edges, that are a natural boundary, and existing vegetation, as well as fixed structures and legal boundaries. The design buffer width is a minimum, and additional space, especially if covered in tree vegetation, increases security in larger events.

Management of rivers will be more effective, and less costly overall (taking account of both non-river and river management costs) when account is taken of the natural processes of the rivers, and the way in which they respond over time to natural variations and to imposed management changes. Vegetation management should also consider the natural spread of vegetation and the way in which the channel form will alter depending on the nature and extent of channel and edge vegetation.

5 MANAGEMENT PRINCIPLES

This approach to river management is most applicable to gravel-bed rivers with a wide and shallow bed where channels flow within their own alluvial material. The aim is to provide a clear river bed area where bed load is transported through scour and deposition processes, bounded by vegetation buffer zones that provide a diffuse and flexible edge to the active channel. The buffer vegetation absorbs flood flows, rather than blocking them, with the slower body of water buffering away strong currents, and thereby reducing edge pressures.

The thickness of the buffer zone means that edge vegetation can be removed, and erosion embayments formed, without management intervention. The aim is to allow natural channel movement to occur with erosion and deposition along the channel margins, and re-establish vegetation on deposited gravel beaches after channel movements or meander migration has shifted the flood flow pressure away from these areas. The buffer provides a margin of flexibility that allows a vegetative management of the channel edge, with loss and re-establishment over time.

The high intensity and short duration of floods can give rise to substantial and often sharply-formed erosion embayments at the channel edges, as well as tight channel forms as deposition occurs on flood recessions. Managing the buffer edge does, then, require the cutting away of buffer areas (with re-use of the trees), as well as the re-vegetation of areas, both retreat and reclamation. Sharply hooked embayments attract erosion pressures and aggravate losses. Sharply deflecting deposits in the active channel can also have a similar aggravating effect.

There is, then, a management aim to realign the more severe embayments and sharp channel cross-overs, while allowing the natural processes of bed scour/deposition and bank erosion/accretion to take place with the least interference. This results in some reduction in channel complexity and a moderation in the variability of channel features, but reduces the management effort required over the longer term.

The emphasis in this approach to river management is on managing the buffer vegetation and re-establishing losses, as a soft edge to the river, rather than a hard fixed edge. This is less costly over the longer term, as well as being more in tune with the natural river processes. The focus is a flexible containment along the river edge or bank, with a minimum of interventions in the channel itself.

However, the clearing of vegetation from the active channel area is important. Introduced weedy species that spread rapidly along waterways have changed the vegetation responses in New Zealand rivers, and they can quickly colonise the gravel beaches/bars and islands of gravel-bed rivers. This vegetation increases channel resistance, deflects floodwaters, traps suspended silt material and reduces bed mobilisation, and hence the transport of bed material. Quiescent times in the periodicity of floods provide ideal conditions for vegetation spread, and this can change the nature of river reaches.

In response to these changed conditions, channel works are mostly the clearing of this vegetation from gravel bed areas. Beach ripping, which disturbs the surface layer of gravel beaches/bars, can also be used to clear vegetation, while increasing bed material mobilisation. This allows bed load transport with less variability in channel form and fewer sharp cross-overs across the active channel area. Any work in flowing water, of low flow channels, is minimised, and would mainly be channel realignments associated with large erosion embayments that threaten to outflank the buffer zone. This realignment should, though, be carried out in accordance with the size and alignment of the channels along the reach, following a natural meander curvature.

Ideally, buffer vegetation should be uniformly dense, to filter floodwaters without creating preferential flow paths. Different species can, though, be used through the buffer width and in reserve areas, and the buffer layered with understory and shrubs, as well as taller trees. This can include native species, and nursery areas to provide source material for edge re-establishment. The buffers can, as well, be structurally strengthened to retard erosion losses and reduce the degree of encroachment in a flood event, for example by lines of cables through the vegetation held by driven piles. The river edge can be strengthened by sets of permeable groynes, and even by light rock spurs or knobs added at the edge. However, this gives rise to a more fixed edge, and these works should be understood to be temporary, as part of buffer establishment, and will require topping up or replacement after significant flood events.

Composite arrangements of vegetation and structural works can be used to provide transition measures at natural controls or at artificial constraints, such as bridge crossings. For example, cable fences and permeable groynes can be used to strengthen the vegetation buffer where there is a transition from vegetative management to a solid rock lining that fixes the bank position at bridge abutments.

The clear channel and edge vegetation buffers can be applied to gravel-bed rivers that have a single channel form, provided the channel is not too entrenched. The degree to which river edge vegetation can be used to manage channel movement depends on the effectiveness of the trees in reducing flood forces along the banks, and the ability of the tree roots to hold and bind together bank material. The height of the bank and flood rise is critical in this regard.

In general, a consistent design channel or fairway based on the natural character and meander patterns of a river reach can be developed for mobile gravel-bed rivers, and this will reduce management efforts and generally enhance the effectiveness of management measures. The meander patterns can also guide the layout and spacing of bank protection and river training works. Thus, when repairing protection works at bends, the re-established works can be laid out to fit in with the width, radius and amplitude of natural meanders. Continuous protection works around the full length of a bend, to the curvature of a natural meander, will be more effective than works that only repair an erosion gap, and do not fit in with upstream and downstream conditions, and the overall alignment of the channel.

6 MANAGEMENT BENEFITS

The dynamic nature of river systems means that river management has to be responsive, and adjust as flood events occur and river conditions change. Any significant flood that mobilises the bed material, which is generally around the 2 year return period flood flow for single channel to semi-braided gravel-bed rivers, alters river conditions and channel form. In wider braided rivers, parts of the river bed can be mobilised during smaller events, as this depends on the size and flow in the braids.

Apart from on-going programmes of maintenance of the buffer vegetation and active channel area, management effort is flood related. Repairs and reinstatement is undertaken following flood events, in response to what has occurred. The standard of protection from flooding or loss of land and assets arises from the on-going management efforts and the space provided for the natural processes of rivers. The management effort is undertaken to provide the best initial pre-flood conditions when medium to large flood events occur. The management standard relates to these larger events, and interventions after smaller events are to maintain conditions that can pass the large floods of the management standard. The more consistent the channel and the fewer the sharp changes in channel shape and alignment, and variations in the overall pattern, the less the flood damage and the lower the risk of erosion causing a channel breakout or direct damage to valuable land and assets.

A relatively consistent channel along a river reach, based on appropriate natural meander forms, decreases localised variations in sediment transport and flood capacity. This reduces the amount of bank erosion and flood damage, and hence the repairs and maintenance effort required to maintain protective vegetation and river works. As flood capacity, channel form and sediment transport are all inter-related, changes in one of these aspects of a river affects the others. There are, therefore, real channel management benefits from channel consistency, with less variation in the erosion and deposition activity of the river as it transports its gravel bed load, and less localised variation in flood capacity. The natural variability of rivers in the complex and highly dynamic environment of New Zealand does, though, mean that consistent reaches may be relatively short, and design channels or fairways change along scheme lengths of rivers. Transitions and areas of instability around constraints, grade changes and confluences have to be taken into account in any design and management approach.

The high power but short duration of flood events in NZ rivers can give rise to tight bends and sharp cross-overs, with cusp-shaped erosion embayments, high beach/bar deposits and half-formed meanders where channels turn sharply into the bank. It also means that the amount of re-working of bed material and hence damage to protective measures is limited by the short duration. Repairs and mitigation measures can then be carried out before the next event to minimise exposure or vulnerability to damage in following events. Quick and regular responses at a low level (as in 'fix it in time before it gets worse'), is thus an important principle of river management with the approach outlined in this paper. The approach allows these smaller and less intrusive measures, while also requiring a programme of regular interventions.

A clear and consistent active channel area allows the conveyance of floodwaters and the processes of sediment transport to take place with a minimum of disruption and deflection of the river's energy. Uniformly dense vegetation buffers alongside this channel area allow some absorption and release of floodwaters while minimising damage from erosion and deposition. A thick buffer zone provides a margin area where erosion and deposition can take place. The buffer vegetation can be lost and reestablished, as channels adjust and meander along the river course, and these channel adjustments can be accommodated without threatening productive land and assets.

The buffer vegetation provides a margin of riparian vegetation that is a zone for river activity as a flexible river border, while always maintaining a riverside habitat of trees and understory.

The channel clearing ensures an active gravel bed area of adjusting channels and gravel beaches/bars and islands, and the appropriate channel widths ensure that channel migration can take place while maintaining the natural channel features, such as riffles, pools and runs. Maintaining a channel appropriate to the natural character of a reach allows a natural migration of the channel features that can form and move in a selfmaintaining way. This maintains the pattern of channel features and their aquatic habitats, while reducing erosion pressures and the need for management interventions.

This management does, though, modify the river channel and reduce the variability that could form within the active channel area. It is based on an intermediate approach between a tight control and a full withdrawal. As with any human management, there are choices based on values and priorities, while the management interventions alter what occurs along a river, in foreseen and unforeseen ways. There is an emphasis on vegetation clearance because of the effects of rapidly spreading introduced plants on New Zealand rivers. This mixed and rapidly colonising vegetation now constrains management options, while impacting on the channel conditions and sediment transporting processes of rivers.

The definition of a river corridor boundary that has a basis in the natural character of reaches, and is consistently determined along reaches, provides landowners and interested parties with a consistent management policy. All asset and land owners along and on both sides of a river are then affected on the basis of a naturally defined corridor, and all have the same information about the management approach being taken and its implications along management reaches.

7 MANAGEMENT OPTIONS & CONSTRAINTS

The implementation of a design channel or fairway and associated vegetative buffers can be undertaken at different levels of management effort, and developed over varying time periods. There are, then, management options for any given design and river corridor determination, which have a range of costs and benefits, and varying residual risks.

The vegetation of buffer zones takes time to grow and become effective, and there is likely to be a staging of buffer establishment. Structural measures and in-channel re-shaping and redirection of main flow channels may be required during the initial phases. Buffer widths can be increased to match up with natural features, and to line up with legal boundaries. This allows more space for a greater diversity of plants, including native species, to enhance the riverside environment.

The development of clear fairways and vegetation buffers has to take into consideration natural climatic cycles, and the differing effects of periods of high flood intensity and quiescent times. Intense storms or multiple storms over a short period can severely impact on catchment conditions and the supply of sediments to river systems, as well as altering reach conditions from high levels of channel activity and migration. Management practices must be responsive and adapt to these natural cycles and activities. The development of a management approach based on natural processes and providing sufficient space for river activity, cannot, then, be fully programmed, but on the contrary has to be flexible and adaptive — like rivers.

Natural constraints or control features, such as base rock exposures in the river bed, or hard banks and high cliffs at the channel edge, affect the expression of natural character along a reach, and hence the layout of design channels and implementation programmes. Reaches may be defined by natural controls, and the local channel form may be different at tight bends, where there may also be a significant change in the river alignment. These control features provide a useful starting point for the development of design channels/fairways and the establishment of full width buffers.

Buffer development can take place progressively along a reach, in space and time, and this will depend on channel conditions and activity at the river edge, as well as the availability of land and access to sites. Channel clearing is carried out in an upstream direction when progressively opening up a congested channel, to provide a clear flow path downstream and minimise working in flowing water. However, the programming of clearing and other channel works will also depend on channel conditions and areas of activity and pressure along the river edge.

Materials other than the normal bed material can be present in river channels, and this affects the implementation of design channels, and can alter development and protection measures used along a reach. For example, large boulders can be present in rivers of volcanic landscapes, as residual materials from lahar flows down waterways, or from the long term movement and concentration of laharic boulders in a waterway. These boulders alter sediment transport processes, and they can be rearranged for differing purposes, such as channel form, bank protection and fish passage.

Finer sediments, derived from earlier glacial period processes, may underlie the alluvial bed material, and they can be exposed in large flood events or because of scouring around obstructions in the channel. This exposure of finer materials alters the transport of bed material and can give rise to unusually large scour depths. Bridge piers can act as obstructions with this effect. Bridges generally have a narrow waterway opening compared to the natural channel width at the crossing site, and are often problematic constrictions for design channels to natural channel widths.

The constriction of waterways by bridges can give rise to channel splitting and widening upstream, with a central depositional island directly above the bridge, and bed scouring at the bridge itself from flow concentration. This distortion of the sediment transport processes can have a marked effect on channel form and activity along the river reach, while requiring substantial transition works to manage flood flows and bed material transport through the bridge site.

The historical management of a river reach and the river responses to this management has to be taken into account in the drawing up of design channels and in their implementation. For example, there are many instances of rivers and streams being straightened by channel excavation and diversion works, and stopbanks constructed to confine floodwaters to main channel areas. Along the lower reaches of many of the larger rivers in NZ, river behaviour has been substantially altered by confinement, entrenchment and alterations to riverside vegetation. Channel movement and sediment transport is restricted and disrupted by these alterations. This constrains what is realistically achievable though contemporary management intervention.

The proximity of human habitation and assets to river channels, and stopbanks positioned alongside main channels, constrains river management, and the practicality of different approaches. An approach that provides sufficient space for river processes to take place with a minimal of constraint or hindrance can, thus, be in direct conflict with the human occupation and use of riverside and floodplain land.

At localities where there are valuable assets and dense human habitation close to waterways, more solid and stronger bank protection measures that fix the channel edge are used. These measures, though, compromise the edge flexibility that is an essential part of an approach to river management that seeks to work with the natural processes and behaviour of rivers. Hard rock edges, using sets of groynes or continuous bank linings, is a different approach to river management. In this case, berm land alongside the active channel is a reserve area to accommodate failure of the edge protection during large flood events, without flood defences or valuable assets being damaged or lost. This berm land may have a vegetation cover for various management objectives, but it provides no real benefit from a protection perspective.

Providing the space for a river to move and behave in its naturally characteristic way is the critical issue, and generally the most difficult to resolve. However, confining a river reach does not, in itself, change the magnitude of flood flows or the sediment and debris that is transported to the reach. The water and sediments that come from the upstream catchment must go somewhere, and the more confined the river the greater its erosive power, as the intensity of turbulence, vortices and cross-currents increases. The more space that can be provided for rivers, the lower the likelihood of failures of protection measures and flood-retaining stopbanks.

Human activities have had, and continue to have, very substantial impacts on the landscape, markedly affecting catchment erosion and the supply of sediments and debris to river systems. Land clearance and changes in land use that decrease ground infiltration and surface detention of rainfall not only increases storm runoff, it changes catchment responses to intense rainfalls and hence erosion and sediment movement into waterways. The damming of rivers traps bed load and can alter the hydrologic regime depending on the operating procedures of the dam.

Global climate change, as forecasted, will also increase the frequency of a given flood flow, and the greater frequency of intense storms will alter the response regime of catchments to storm events. Storm runoff and sediment input rates increase as rainfall intensities increase, and catchment responses significantly change from small frequent floods to medium (5 to 20 year return period) events, and even more so from medium to large flood events. The shift in the frequency of flood flows with climate change will then increase runoff rates even more than rainfall, while increasing sediment supply and transport rates. There will be compounding effects, and the standard of flood mitigation of a given stopbank or particular flood defence measure will decline over time because of these climate change effects.

All river management measures have a protection standard, albeit not necessarily well determined or even predictable, and there will always be a flood event that can overwhelm protective defences. There is always a residual risk of flooding and flood damage, and it is only a matter of time for any protected area to be flooded.

The constraints imposed on rivers should be understood in this context. Rivers behave according to their own character, and whatever we do, rivers will respond and exert their own rules. We would do well to give rivers more room to move, and work with the forces of nature instead of trying to impose our rules and desires on rivers.

The approach of this paper is one way of working with the natural processes of rivers. It provides more space for river activity using a consistently applied methodology based on an assessment of reach character and response behaviour.

8 EXAMPLES

The management approach outlined in this paper has been applied, to differing degrees, on river reaches throughout NZ, ranging from small rivers with a well-defined single channel form up to wide multi-braided reaches. They have generally been on rivers flowing from the main axial ranges of the North and South Island, and a list of rivers in NZ that I have undertaken investigations for this approach and drawn up design channels or fairways, with associated buffer zones, is given in Attachment 3.

Examples from a range of rivers and reach types are given in this Attachment. In each case, comment is given on the catchment setting, the reach character and changes over time, and the lessons learnt from successes and failures. Repeat aerial photography, generally from the earliest to the most recent, is shown for the example reaches, with the design channel and buffer zones or river corridor boundary shown on each of the repeat aerials.

These examples include reaches from the earliest applications to the most recent, and for different types of river reaches, from single channel meandering river reaches to wide fully braided reaches. The repeat aerials from the earliest available also show that the designs relate to prevailing reach conditions and alignment. In most cases, the active channel area has been (generally) maintained to the design guidelines. However, significant changes in catchment, climatic or reach conditions would require amendments to the design guidelines, and reviews have been undertaken to re-assess the guidelines in many cases.

9 CONCLUSIONS

River systems are dynamic and responsive, but river reaches do have specific channel forms and characteristic behaviour patterns that can be determined by appropriate investigations. A methodology has been developed to assess reach character and draw up design channels based on this reach-specific character to guide a river management approach that works with the characteristic behaviour of rivers.

The approach involves the determination of an appropriate channel width for the active river processes of flood conveyance and sediment transport. This width depends on the type of river reach, and whether it has a single meandering channel, multiple channels with flood overflow paths or is fully braided with many flow channels. The reach type depends on the prevailing conditions and formative influences, and this can change over time from climatic cycles, which can give rise to a periodicity in the supply of bed material.

Vegetation buffer zones on both sides of the active channel area provide a flexible edge, which absorbs flood waters and flow pressures. The active channel area and this vegetation margin provide the space where scour and deposition processes and channel migration can occur with a minimum of management intervention. On going management measures go with and facilitate the river activity, through appropriate vegetation clearing and reestablishment.

The vegetation buffer zones, along with the active channel, define the management area, which is the space provided for river activity and movement. A wider river corridor provides reserve areas to accommodate changes in channel form and active channel widths, as catchment and reach conditions change over time. The outer edges of this river corridor provide a boundary line between the river and productive land uses, infrastructure facilities and human habitation. It can follow existing natural features and include existing riparian vegetation. It provides a continuous corridor of terrestrial and aquatic habitats, while providing reserve areas for river channel expansion during periods of high flood intensity.

The design of active channel areas and margin buffer zones has been applied to many river reaches on rivers throughout NZ, and to a range of reach types from single channel to fully braided. This diverse and wide-ranging application of the methodology, and the successful drawing up of design channels or fairway that fit existing river channels and their meandering characteristics, has demonstrated its applicability and usefulness.

There are, however, many constraints on the appropriate and effective application of this natural character based approach to river management. The most critical is the confinement of rivers that has already taken place, and the continual pressure to further restrict and control rivers. The proximity of human occupation and valuable assets, and a general reluctance to give up land for river purposes, pressures river management into hard edge and rigid controlling measures. Failure can then be catastrophic, with little reserve land available to absorb the severe erosion pressures of failure conditions.

Bridge crossings and adjacent infrastructure assets have to be accommodated, and transition lengths with structural strengthening measures or edge reinforcing may be necessary to still obtain a reasonable degree of reach consistency. Natural hard points and control features also have to be taken into account, and designs drawn up that relate to the river character at these features and any change in river course they impose.

River management measures and flood defence works do not change the flood flows and sediment loads supplied to river reaches. The straightening, confinement and entrenchment of rivers, to facilitate human activities and land uses, actually increases the erosive pressures of floods and generates tight bends and acute flow angles at banks that further increase erosive pressure on river banks.

Global climate change will increase the frequency of intense storms and of any given flood flow. This will reduce the standard of existing flood defences, and increase channel activity and damage to protection measures, while increasing channel variability from flood activity within the river course. Providing more space for rivers, and managing them in a way that is in accord with their natural processes, would be a worthwhile response to the present threats from flooding and erosion hazards, and provide a greater reserve for the increasing risks from the effects on rivers of climate change.

Assessments of alternative management practices have shown that this intermediate approach is effective in reducing river management costs compared to either a tighter control over the river channel or a wider corridor with minimal intervention, while decreasing residual risks of damage to human assets in large flood events. The approach also maintains a wide diversity of aquatic and riparian habitats, while minimising the spread of rapidly colonising introduced plants within the active channel area of rivers.

The aim is to provide river management practitioners with an approach that is based on the natural character and behaviour of river reaches, and hence is more effective, while allowing a flexible and adaptive management. This requires an understanding and experience of river behaviour in different types of reaches by the managers, and a wider space in which to move for the rivers.

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G J Williams
Water & Soil Engineer

G & E Williams Consultants Ltd,
R D 3,
OTAKI. (06) 3626684

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RIVER TYPE PHOTOGRAPHS

MANGATAINOKA RIVER — Single Channel - Meandering

LOWER WAIMEA RIVER — Single Channel - Alternating Bars

(Banks strengthened by rock works)

LOWER OTAKI RIVER— Semi-braided, with flood overflow paths

LOWER WAIMAKARIRI RIVER — Fully Braided

ATTACHMENT 2

MEANDER WIDTHS

CHANNEL WIDTH FORMULAE

Threshold of Motion

Regime $W_r = 1.222\, Q^{0.46}/d^{0.15}$

H Chang (at Slope) $W_a = (3.10 + 0.405(\ln((0.672\, d^{1.15})/(s\, Q^{0.42})))^2)\, Q^{0.47}$

Live Bed

Lacey $W_l = 4.85\, Q^{0.5}$

Russian $W_s = 1.45\, Q^{0.5}/s^{0.2}$ I

or $W_s = 4.14/s^{0.2}\, (Q/g^{0.5})^{0.4}$ II

Where

W = meander width (m)

Q = dominant discharge (m^3/s)

s = energy slope

g = acceleration of gravity (m/s^2)

d = effective stone size of bed material (m)

CHANNEL WIDTHS for NEW ZEALAND RIVERS

A table of results given by these channel width formulae, for selected river reaches from regions throughout NZ, in given in Table 1.

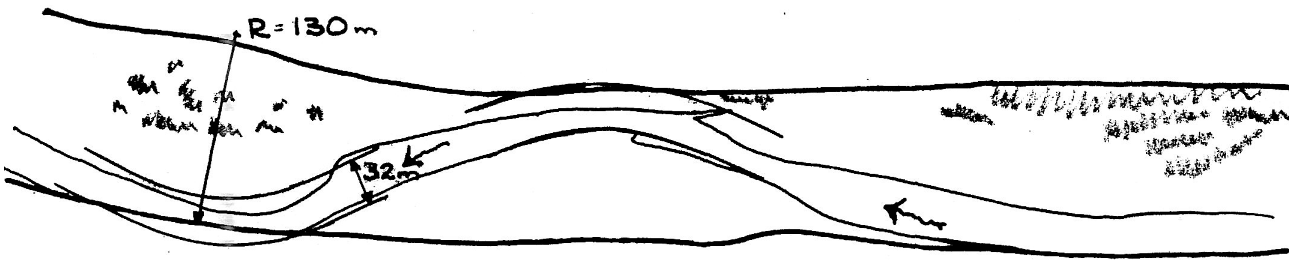
CHANNEL MEANDERING within CHANNEL FAIRWAYS

Schematic diagrams of the different theoretical meander forms associated with the empirical meander formulae drawn within design fairways, are given in the figures below. One is taken from the report on the original investigations of the "Upper Tukituki" scheme, and the other from the river characteristics and sedimentation report on the Hutt River, which was part of the floodplain management plan investigations for the floodplain of the Hutt River valley.

RIVER CHANNEL MEANDER FORMS

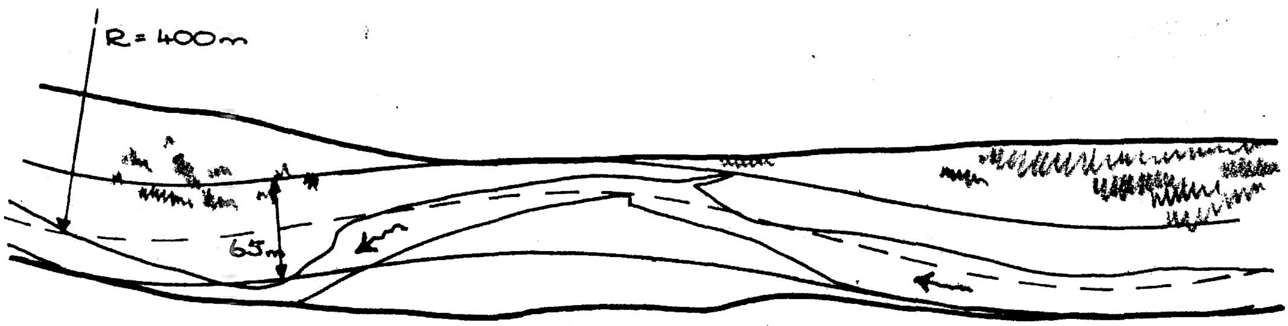
The different meander forms, as they are present along the Hutt River, are indicated as representative examples on a river reach as follows:

[A] Threshold of motion - minor meander
Well formed at regime slope.



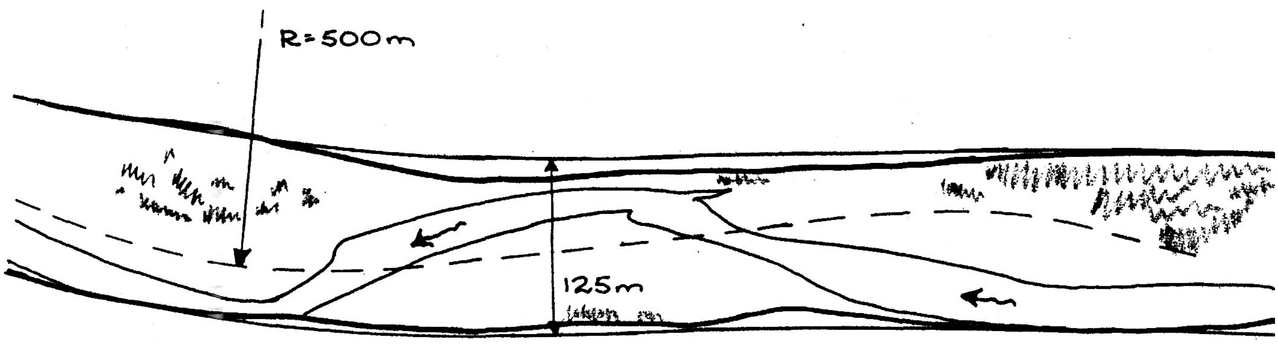
Minor meanders attempting to form at the bends, but constained by high straight banks.

[B] Threshold of motion - major meander
At actual channel slope.



Low flow channel follows distorted major meander with a relatively straight form.

[C] Flow dominant [live bed]



Straight flow dominant form expressed in the limits of the overall [low flow/beach] channel.

Figure from "Hutt River Floodplain Management Plan" report

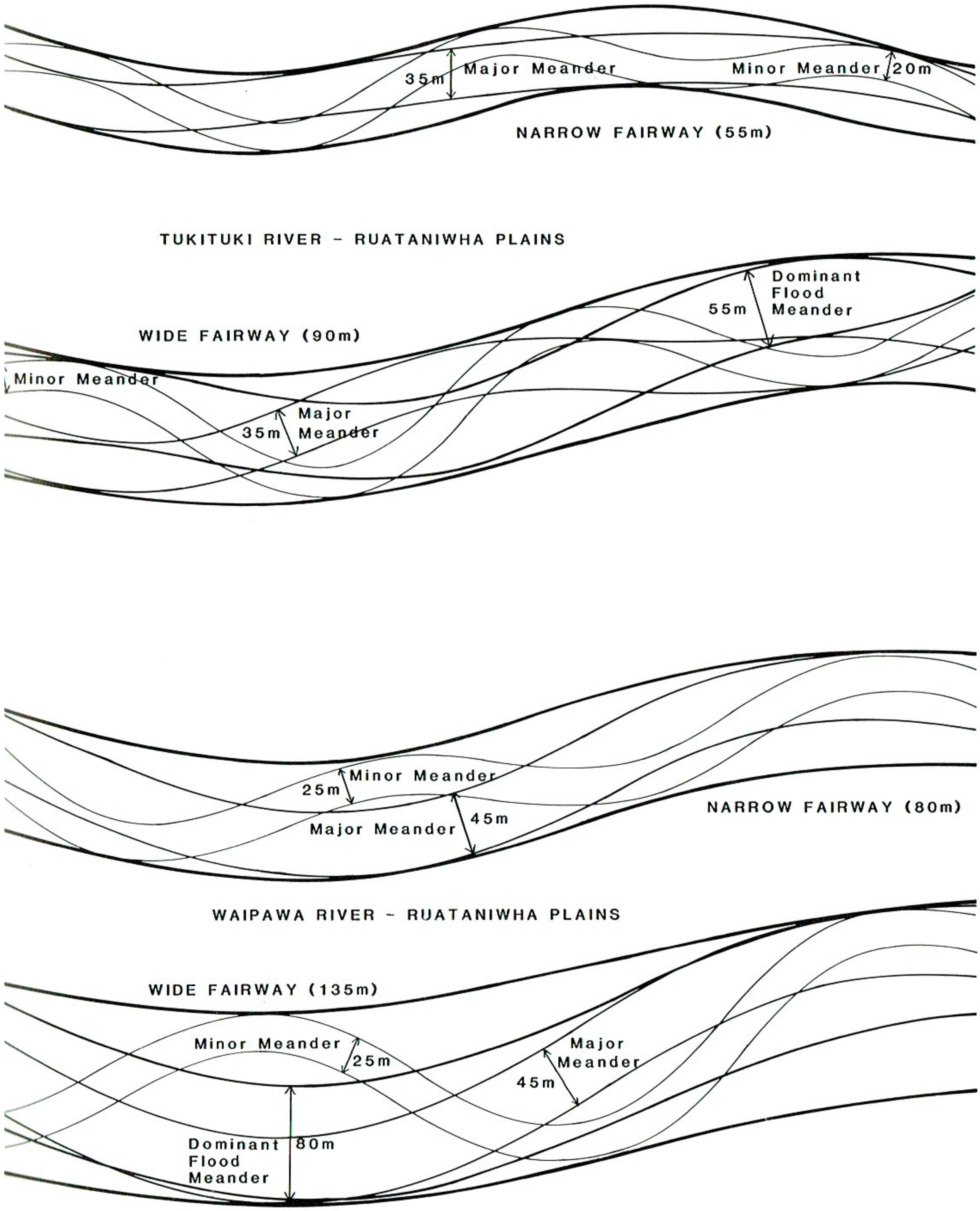


FIG. B-6

MEANDER PATTERNS

(Stylised meanders)

EXAMPLES OF APPLICATION

NATURAL CHARACTER DESIGNS

This list covers rivers in New Zealand that I have investigated for a natural character design and drawn up a design channel or fairway and associated buffer zones. The names in brackets have had designs drawn up, mainly from the study of aerials, but without investigations on catchment and reach conditions, as per the methodology outlined.

There are many other river and stream reaches where an appreciation of the type of reach and its natural character and present expression has guided design and construction.

Example reaches are given below for the river names in bold.

North Island:

Bay of Plenty — Whakatane, Waioeka, (Waimana), (Otara) (Rangitaiki), (Kaituna).

Gisborne — Karakatuwhero, (Awatere), (Waipu), (Waipaoa).

Hawke's Bay — **Ngaruroro** (lower and **middle**), Tutaekuri, Esk, **Tukituki** (lower, middle and **upper**), **Waipawa**, Mangaonuku, Tukipo, Makaretu, (Wairoa).

Taranaki — Waitara, Kakihi, (Waiwhakaiho), (Stony).

Manawatu-Whanganui — Whanganui (lower, middle and upper), Manawatu (lower and upper), Oroua, **Kiwitea**, **Pohangina**, Tamaki, **Mangatainoka**, Ohau.

Greater Wellington — Waitohu, **Otaki**, **Waikanae**, **Hutt**, Mangaroa, Wainuiomata, Waiwhetu, Waipoua, **Waingawa**, **Waiohine**, Tauherenikau, Ruamahanga (lower, middle and upper) (Kopuaranga), (Whangaehu).

South Island:

Tasman — **Waimea**/Wairoa, **Motueka** (lower and upper), Motupiko.

Marlborough — (Wairau)

West Coast — (Arnold), (Taramakau), (Waiho)

Canterbury — **Waimakariri**, **Ashburton** (**lower**, **north** and south branches), Rangitata, Waitaki.

Otago — Clutha (lower), **Kakanui/Kauru**, Pomahaka, Strath Taieri, (Matukituki).

Southland — Whitestone, Weydonburn.

EXAMPLE REACHES

Examples of design channels or fairways, showing the clear active bed area and the margin vegetation buffer zones, are given below for a range of rivers and reach types. In each case, comment is given on the catchment setting and reach character, changes over time, and the application of the management approach, with lessons learnt. Sets of repeat aerial photography are showed, as attachments, for each example reach. The design channel and buffer zones or river corridor boundary are shown on each of the repeat aerials, which are generally from the earliest to the most recent available.

The repeat photography shows the changes that have occurred in the plan form of the river reaches, from natural processes and from human riverside occupation and river management activities. The designs relate to the current river alignment and active channel areas, and the application to a particular, and more managed, river condition is apparent in many of the examples.

NGARURORO RIVER [20]

The upper reaches of the Ngaruroro River cut across the main axial ranges of the North Island where they are wide and especially complex. There is a range of volcanic materials on the range land, which has substantial areas of limestone formations within the uplifted greywacke of the ranges. The river rises in the Kaimanawa Mountains, and winds through gorges around the Kaiweka Range, before cutting through the main line of the axial ranges in the northern extent of the Ruahine Range. On leaving the ranges the river is deeply entrenched within a large upland plain, and develops a wide braided form where it is not constrained into a gorge.

Along its lower reaches the river crosses a large plain formed by deposition of alluvial materials within a subduction zone between limestone capped hills. The river has moved around within this plain, along with the Tutaekuri and Tukituki rivers, and the present course of the river is an artificially developed and constrained one. The gravel bed load of the river can not be transported to the sea, and the plain was naturally aggrading behind a barrier beach that is mostly formed by the coastal transport of material from the Tukituki River. Extraction of the gravel bed material is required to maintain the flood capacity of the stopbanked river, and the present form of the artificial diversion channel.

The river now flows along an edge of the plain in its upper part, but the river can flow between large outcrop hills onto the plains from this reach. The aerial photography shows this reach, which became congested and distorted by the spread of willows. The clearing of the willows and development of willow buffer zones along both sides was undertaken in accordance with a design fairway, and this was successfully implemented through a long term programme over many years.

The introduction of a willow sawfly to the Heretaunga Plains gave rise to very severe infestations, with repeat population plagues that destroyed most of the willow vegetation of the buffer zones in this reach — and elsewhere on the Plains. Mobile-bed physical modelling of a reach of the river was undertaken to develop and evaluate structural edge strengthening options. This led to the use of a mixed vegetation buffer with structural strengthening of solid groynes, but with articulating units, and pile and cabling fences.

The exposure of the land with the willow die off allowed the rapid growth of a wide range of weedy colonising species, however effective tree buffer zones have been re-established, and there has been a natural decline in the damage caused by the sawfly.

The river corridor design provided effective guidelines throughout these developments, from the initial willow clearing through to the present more diverse approach of mixed vegetation and structural measures.

TUKITUKI RIVER [18]

The Tukituki River rises in the steep and erodible Ruahine Range of the main axial ranges of the North Island, and crosses the inland plains of the Ruataniwha Plains formed behind uplifted limestone hills, before following a fault-formed valley through limestone hill country down to the Heretaunga Plains. The remnant terraces along the range reaches of the river are evidence of cycles of deposition and entrenchment, with severe storms causing catchment erosion and high sediment input rates to the river system, and the gravel bed load then being moved downstream by regular flood events. This gives rises to waves of gravel bed load moving down the river, and associated changes in the channel form.

A large landslide blocked the river near the bottom of the ranges in 1968, and this trapped all the bed load material of the river. The loss of supply led to a change in the channel form of the river downstream, from a semi-braided pattern to a well-defined single meandering channel. When the natural dam was breached and the accumulated sediments released, an opposite change occurred back to a semi-braided to braided form, as the gravel bed material moved into the downstream reach. These changes in channel form diminished down the river, with much less marked changes apparent along the Ruataniwha Plains reach.

The Tukituki River, and other rivers that cross the Ruataniwha Plains, have naturally migrated across the plains, with channels developing, aggrading and then breaking out into new channels. Older river courses are clearly visible in the plains topography.

The plains reach had stopbank flood mitigation measures, which had been built and re-built over time, while willow vegetation planted to reduce bank erosion had spread over the river channel. This vegetation spread had given rise to a partially blocked channel, of complex and variable form. A design fairway and buffer zones was determined to guide substantial channel clearing, widening and realignment to give a consistent width of active channel area. The willow vegetation was re-developed to give dense buffer zones on each side of the active channel area. At the same time, the stopbanks were raised and re-levelled, with secondary defence banks added as overlapping wing banks to act as a backup flood defence in case of river break-outs.

The aerial photography shows a part of the plains reach where the river is naturally unconfined, and where a design fairway and vegetation buffers has been fully developed.

A programme of mechanical raking of beaches (dry gravel areas during low flows) was implemented to reduce vegetation colonisation and increase the mobility of the gravel bed material. This reduced the sharpness of channel cross-overs and the degree of channel section variability. It requires extensive machinery work, but the cost is not a large proportion of the maintenance budget, and it has been very effective in reducing flood flow pressure into the buffer zones, and hence buffer vegetation losses. The rapid spread of introduced weedy species and the infrequency of mobilising flood events means that such a measure can be cost effective, especially when the channel edge is managed by vegetation alone.

The design river corridor and management regime have maintained a relatively clear gravel-bed channel, while a programme of planting and re-establishment of the buffer vegetation has contained edge erosion and very much reduced the risk of channel breakouts onto the plains. This has been done without any use of structural measures or the fixing of the river edge by hard engineering works.

WAIPAWA RIVER [18]

The Waipawa River has a similar catchment in the Ruahine Range as the Tukituki River, and a similar channel form and character across the Ruataniwha plains. It has, though, a larger range catchment, and carries a larger gravel bed load. The channel aggradation rate along the plains reach is thus greater, and over a wider and more braided active channel. The older courses evident on the plains also indicated a trend of channel migration to the south, from a fault movement tilting of the plains.

The design fairway and river corridor is thus similar to that for the Tukituki River, and was implemented in the same way. More extensive works were required for this wider and more powerful river. However, a relatively clear fairway edged by continuous buffer zones has been developed and maintained, without the use of rock works or other structural measures. Aggradation within the now-defined river corridor remains an issue, and this can be managed by well-directed extraction of the bed material. Suspended load silt and sand material does build up in the wide buffer and reserve areas between the stopbanks.

The aerial photography shows a part of the plains reach of the river.

KIWITEA STREAM [36]

The Kiwitea Stream rises in a steep dissected landscape formed in uplifted marine surfaces, and then flows down a sloping inland plain to the Oroua River. Below this confluence, the Oroua River flows across the flat Manawatu Plains to the Manawatu River. The marine deposits include layers of sand that are easily eroded and then transported into the waterways. Along its lower reaches the stream has a single channel form, with gravel beaches, and the meandering channel wanders across the wide area of plains. The stream is edged with tree vegetation of variable width, density and tree species.

Management of the stream was undertaken as part of a scheme, but at a low level of intervention, and mostly of the edge vegetation. A design channel was drawn up to guide this management and to develop more consistent, if thin, buffer zones along the full scheme length of the stream.

Little had changed when a very large flood event occurred in February 2004, with an intense storm affecting a wide area, including most of the Manawatu River catchment. The flood severely affected the stream, with bank erosion removing much of the edge vegetation and substantially widening the stream bed, with large erosion embayments being formed. The flood effects were so severe that the stream character and channel form was completely altered.

The design channel, which was based on the stream character as generated by the more frequent flood events, could then be used to re-develop a channel that suited this flood regime and its associated channel form. Remedial measures could be guided by the design channel, with the large embayments reclaimed and the active channel width reduced and realigned to that of its more usual pattern.

The channel re-forming was then undertaken to an appropriate pattern, consistently applied along the stream, with the channel curvature and meandering of a natural channel form. Structural measures, mainly pile and cable fences and some rock works, were used to reclaim large areas of erosion and sediment deposition.

In response to the massive damage, the works undertaken were probably more than necessary, and there could have been more reliance on the natural reforming processes of the stream channel. The stream has now, though, a reasonably well defined channel, with a more consistent pattern than prior to the flood event, but there are still areas of instability.

POHANGINA RIVER

The Pohangaina River flows down the western side of the Ruahine Range, with tributaries from the range on one side and from a steep dissected landscape formed in uplifted marine surfaces on the other. The different geology of the two halves of the catchment gives rise to a mixed sediment input, with greywacke gravel material coming from the range tributaries. The river is confined by the steep landscape and terraces alongside the river, and has only a narrow floodplain area along its lower reaches. The river character changes along its lengths because of variations in confinement and sediment input from its tributaries.

The channel form thus varies from a single thread meandering form, to semi-braided or a split channel form, with quite long relatively straight reaches. There is generally a band of vegetation along the river, and the scheme management of the river channel is mostly repairs and re-establishment of this edge vegetation. During more intense floods, and where there is a relative accumulation of gravel bed material, the river channel will develop a more split or semi-braided form, and can break through the confining edge vegetation to form long parallel channels around the vegetation. Management efforts have been directed at suppressing the semi-braiding response of the river, and following break outs, to re-instate a single thread channel.

A river corridor design was drawn up in 2001, as part of a scheme review. Given the natural variations in river character and the effects of past management, the design included three different channel forms along different reaches of the river. River management measures were guided by these design channels or fairways, however the edge buffer zones remained relatively thin, and channel break-outs remained an on-going hazard.

There were severe floods in the Pohangina River as well in 2004, with extensive channel widening, large erosion embayments, bed aggradation, and break-outs onto the floodplain. The design river corridor provided a template for remedial and re-instatement measures, but there was continual damage to the structural works used to reconstruct bank edges. Break-outs were blocked off and channel re-shaping undertaken along with vegetation re-establishment, plus some rock works at critical places (in terms of major assets, such as bridges). However, river management has been especially problematic since the floods, and there remain inconsistencies of width and meander pattern along reaches, with some large erosion embayments and areas of channel instability. The long length of river with a narrow floodplain makes it difficult to fund protection works on this river.

MANGATAINOKA RIVER [38]

The Mangatainoka River rises in the northern end of the Tararua range, but has a very small range catchment area, and flows down a broad valley formed between fault lines, with terrace formations along the valley. The river has a relatively steep grade down the infill valley, with sediment transport defined more by the re-working of the alluvial deposits of the valley floor than supply from the upper catchment. The river has a single channel form, and this meandering channel is very mobile as it moves around the flat floodplain of the valley. The bed of the river has a thin layer of alluvial gravel over base rock.

The tight loops of the meandering channel and the rapid movement at bends makes management of the river unusually difficult, and a range of management approaches, with various setback arrangements, have been investigated and tried out over recent decades. The use of weirs across the active channel is a feature of the river management, with the weirs being located upstream and downstream of bends. The margin vegetation is very thin, and the entrenchment of the channel makes it prone to under scour loss.

There have been a number of medium to large flood events in this river since 2000, and design channels were first drawn up for short reaches of the river, and a set of management measures determined for these reaches. Later a design channel was drawn up for the full valley length of the river.

The tightness of the channel meandering and the distorting and deflecting effects of both valley side bluffs and base rock controls in the bed, plus the large number of road and rail bridge crossings of the river, meant that the design channel was relatively variable in its alignment and curvature. However, a consistent channel with natural meander curvatures could be fitted to the existing river, and this design has been used to guide bank protection and flood damage repair works.

The river management scheme has been through a number of reviews over the years, and funding the protection and repair works has always been difficult, given the extent of the scheme, the relatively narrow valley flats at risk and pastoral grazing use of the land. The design does mean that works are aligned to the meander curvatures of the river, although the mobility of the river gives rise to channel compression against solid protection works around bends and to protect bridges. The weirs are also fixed features in the river. At the same time, a vegetation buffer is not that effective in retarding the meander migration of the well-defined but mobile single channel of the river, whatever its density or thickness.

OTAKI RIVER [30]

The Otaki River rises in the very steep land of the Tararua Range at the main divide, and the catchment is mostly rugged forest-covered range land. Severe storms in 1936 and 1955 caused widespread slipping and damage to the forest cover, and sediment input to the river system increased substantially after these events. The lower reaches cross a narrow coastal plain that consists of glacial period outwash materials with sandhill formations near the coast. The present river channel has degraded into these deposits, with high gravel terraces bounding the floodplain downstream of the foothills. The river carries gravel bed material through to the coast, but there is a natural deposition of some of the bed material near to the coast, where the river grade decreases, with the river crossing a fault line.

The lower reaches naturally have a semi-braided active channel with flood overflow paths, to below the fault line, where the river splits and migrates within a flat floodplain that extends through the sandhills along the coast. This lower reach, below the SH 1 Bridge, has been straightened and confined by stopbanks alongside the formed channel. The design channel for this reach is a very straight form of a live-bed or dominant flow channel. There is little space for buffer vegetation, and there has been a progressive increase in the use of rock works, with linings being added and extended over time.

The bend at the fault line became increasingly tight over time due to continual reinforcing of the outer bank of the bend, and a channel diversion was undertaken to realign the bend to a more natural curvature. Upstream of this bend a narrow reach of the river was widened, and the stopbank set back. These works allowed a wider fairway to be drawn up for the upper part of the coastal plains reach of the river.

The aerial photography shows the reach from the fault line bend to above the area of channel widening.

The lower reach below SH 1 is problematic because of the past straightening and confinement. While an alternating main channel does form around gravel beaches, there is insufficient space for appropriate buffers or for any channel widening in large flood events.

Above SH 1 a clear fairway has been developed to a consistent width that allows channel meandering, and substantial buffer zones have been established that allow an effective use of this vegetation. However, the coarse bed material and intense short duration floods of the river means that complex channel forms do arise in the fairway, and channel re-shaping and re-alignments continue to be undertaken. The more intense channel works are undertaken to reduce the erosion risk to high terrace cliffs.

WAIKANAE RIVER [28]

The Waikanae River rises in the lower range land of the Tararua Range, and a number of tributaries come together within an inland basin area of hills and terrace land, before passing through uplifted coastal hills. The lower reaches then flow across a depositional fan and through sandhills to the sea. There were two distinct channels across the fan, but one was cut off and the other developed into a well-defined channel. Over time, river management has given rise to a meandering channel of nearly constant width, with the river having a single channel form with a low flow channel around alternating beaches.

All the gravel bed material of the river is deposited in the fan area, and there is a natural aggradation trend along the lower reaches, down to a short estuarine reach. The present river channel tends to migrate as a whole along the fan area, and the design channel fixes a particular position, but with a meander curvature that is appropriate to its single channel form. The design channel width is thus based on the characteristic threshold of motion meanders of the river, throughout the scheme length.

A mixture of management measures has been used to suit local site conditions and the channel alignment. As well as the vegetation buffers, measures include permeable groyne sets, solid rock groynes around bends, rock linings and rock weirs across the channel.

The aerial photography shows the reach below the SH 1 bridge along the upper part of the fan.

A well-defined channel has been maintained through a flood regime that included medium to large flood events, with relatively little damage, and without any significant channel realignment or break outs. The relatively low power and small gravel bed load means that the river can be managed to a single channel form using standard NZ measures of vegetation and structural works.

Repeat cross section surveys of the active river channel suggest that the development of a constant width well-aligned channel may be increasing the throughput of the bed material down to the estuarine reach. Bed material deposition will, though, continue along the fan area of the river.

HUTT RIVER [25]

The Hutt River rises in the southern end of the Tararua Range, and flows south down a fault split landscape of tilted blocks. The lower reaches follow the Wellington Fault, where buckling has given rise to substantial basins that have been infilled with alluvial materials.

Where the river leaves the fault line to flow into Wellington Harbour, there is a major change in river grade, and bed material deposition naturally takes place around the grade change, and at the river mouth.

The catchment is mostly rugged forest-covered range land and the present supply of gravel bed material is relatively small. The lower reaches through the basins of the Hutt Valley have been entrenched by a river management approach of channel straightening through gravel extraction from the bed, straight channel cuts and continual reshaping of the bed following flood events. The river now has a single channel form with a low flow channel around alternating beaches, and an unusually coarse bed material. The straightness of the river course means that the main flow channel cannot develop fully formed meanders, and there is a pattern of half-formed meanders with very sharp cross-overs. There is a direct attack to the bank at the cross-overs, with a deep and narrow scour hole along the bank downstream.

Vegetation buffer zones have been established along the channel edge, however the height of the gravel banks makes vegetation relatively ineffective. Thus, rock linings, or sets of rock groynes have been constructed progressively over time, mostly along the outer bank of meanders. The meanders migrate downstream and this has led to incremental extensions of rock linings, while other lining lengths become redundant.

The aerial photography shows the reach in the Lower Hutt Valley, from the start of the grade transition and bed load deposition reach.

A riverside park has been developed along the Hutt River, and urban development, including recreational parks and golf courses, has resulted in a constrained river channel. This has reduced river management options, although the river corridor does include the riverside recreational areas.

The Hutt Valley is now fully urbanised, and river management must consider a range of objectives, which are not all compatible. While vegetation has been used as much a possible, for environmental and economic reasons, the river condition and close proximity of flood defences protecting urban areas severely constrains a flexible approach to river management. The river channel entrenchment and lack of unused space along the river also prevents the adoption of a more resilient approach to river management that allows for the natural movement of the river channel.

An understanding of the natural character of the present constrained river and its response behaviour can, though, guide the layout and construction methodology of works, to give better outcomes environmentally, as well as being economically more effective.

WAINGAWA RIVER [21, 45]

The Waingawa River rises in the central part of the Tararua Range at the main divide, and the catchment is all within this very steep and rugged forest-covered range land. The river system follows the main fault lines and cross-faults of the block displace landscape, and large slips extend up the steep valley sides. The lower reaches cross the wide Wairarapa Valley at a relatively steep grade down to the Ruamahanga River on the other side of the valley. Across the plains, the river has a very narrow floodplain, with no tributary inflows. The active West Wairarapa Fault follows along the edge of the range land, and movement of this fault affects the position and grade of the river where it entered the valley.

The river follows a relatively direct path across the plains, but is affected by fault lines within the valley and remnant terraces from fault movements and the long-term degradation trend of the valley rivers. The coarse bed material and the rapid spread of introduced plants gives rise to channel splitting and the build up of islands in the channel. The channel then tends to become perched in places with the potential for breakouts to one side or the other, into the narrow floodplain area alongside the river.

The lower reaches show a marked change in channel form as the flood intensity varies over time, from a meandering channel split around large islands in quiescent periods, to a wider active channel area with a semi-braided form in periods of high flood intensity.

A wider fairway design has been applied to the lower reaches, and the aerial photograph shows a mid-plains reach, where there is a tendency for the river to deposit bed material and widen its overall channel.

The establishment of buffer zones has been slow and intermittent along the river, but a relatively clear fairway has been developed and maintained. This has required continual channel works, including channel re-alignments and repeated re-direction of main flow channels at areas of edge attack.

There has not been a sufficient development of buffer zones to allow a less interventionist approach to river management, and funding constraints have prevented the adoption of a different approach.

WAIOHINE RIVER [21]

The Waiohine River has a very similar range catchment to the Waingawa River, and its entry to the Wairarapa Valley is similarly affected by movements of the West Wairarapa Fault. The Waiohine River is, however, substantially entrenched into the plains below the ranges, and bounded by high terraces. The river then flows across the plains and can move across a wide area as channel build up and breakouts occur. There is a major reduction in river grade, and consequential change in channel form, around the area of the SH 2 Bridge.

The channel below the bridge was an existing channel when river management commenced, and channel loops have been cut off, and the channel stabilised by on-going management measures. The channel is now relatively consistent in width and meander pattern, with edge vegetation and structural measures along the banks, although there are high banks that are difficult to protect.

Above the bridge the river has a shallower and wider channel, which would naturally be semi-braided with flood overflow and breakout paths. The town of Greytown is at risk from this reach of the river, and it has been more intensively managed over a long period of time.

A wider fairway design has been applied to the lower reaches above the S H 2 Bridge, and the aerial photograph shows the reach above Greytown. The river had been especially narrowed and constrained at the Kuratawhiti Street/River Road crossing, and this narrows has been removed, although there are still on-going effects from the past channel variations in width and form.

The river tends to form large erosion embayment in flood events, with a more sinuous meandering being set up. Over time these embayments have been reclaimed, and more continuous and wider buffer zones established. However, there have been continual channel interventions, with long straight re-alignments being formed. Some entrenchment of the channel, because of its constant artificial re-working and containment, has increased bank heights. This has improved the flood capacity of the river channel, but reduced the effectiveness of the edge vegetation and adversely affected vegetation reestablishment.

WAIMEA RIVER [47]

The Waimea River crosses the Waimea Plains, and has two main tributaries, the Wairoa River to the south-east, which flows from the Richmond Range through steep range land, and the Wai-iti River to the south-west, which flows through the Moutere Gravel hill country.

The Waimea and lower Wai-iti Rivers flow through an alluvial plain of recent gravel deposits that is bounded by older Quaternary gravels. The plains lengths of the rivers, including the Wairoa River, have been significantly entrenched by past extraction of gravel bed material. They have also been confined and straightened, and high rock linings have been placed along the outer erosion side of bends to contain erosion. There is, though, a narrow band of edge vegetation along most of the plains length of the Waimea and Wairoa Rivers.

The rivers have a relatively coarse gravel bed material, and the entrenchment and upstream back cutting of the rivers would have given rise to a coarsening of the bed material. The upper plains reach of the Wairoa River is especially coarse, and the lack of finer gravels and sand would reduce bed material transport rates, and increase the sharpness of channel forms generated on the recession of flood events.

The Waimea Plains are intensively used, with large areas in horticulture, and with urban and industrial areas. The Waimea and Wairoa Rivers have continuous stopbanks on both banks along the plains reaches, and there is a relatively narrow berm between the channel edge and the stopbanks. The river channels are kept clear of vegetation, and the banks are maintained using both vegetative techniques and rock works.

A fairway based on the flow dominant meander form of the river has been drawn up for the Waimea River down to where the river grade reduces as the river adjusts to the sea level control at its mouth. A threshold of motion design channel has been drawn up for the short transition reach to the estuary. The river channel has an alternating bar pattern, with some regularity to the low flow channel meandering, but the channel form is relatively mobile, with some channel splitting. The design fairway fits this channel but is quite straight, with a low sinuosity.

The aerial photograph shows the reach upstream of the grade transition.

The design provides a guideline for the alignment and curvature of bank protection measures, and for their overall connectivity along the river in relation to the channel form.

UPPER MOTUEKA RIVER [47]

The Motueka River rises in the steep range land of the Richmond Range, which consists of old sedimentary rocks and intrusive volcanic rocks in the Red Hill area. This range headwaters is a small part of the Motueka catchment, and the upper Motueka River flows down a wide straight infilled valley of old Quaternary gravels, within the dissected Moutere Gravel hill country.

There is a relatively low supply of gravel bed material from the headwater ranges, with a re-working of old Quaternary gravels along the valley of the upper Motueka River. There is little recent deposition (of the present inter-glacial Holocene period) along this river valley, and the river would have a degradation trend under the present climatic regime. Substantial volumes of bed material have been removed over many years by gravel extraction operations, and comparisons of repeat river cross section surveys show that the river channel has degraded in proportion to this extraction.

The upper Motueka River valley has been cleared for farming, and the vegetation alongside the river is made up of introduced species, especially willows. There has been river management activity over a long period of time, with on-going efforts to develop a defined clear channel or river fairway and vegetation buffer zones on both sides of this channel. The channel and margin vegetation, though, remain variable in extent and definition, and lack continuity and consistent thickness.

A design fairway has been drawn up that suits the existing river channel form, variability and alignment. The development of this river channel would, though, involve significant realignments and both vegetation clearance and establishment. The past management has contained and re-directed the river channel, but the river does not have a consistent meander pattern, and there is considerable variability in form and alignment, with some are sharp cross-overs and tight bends.

The design, then, provides an overall objective and general guidelines on channel form for the river management that is being undertaken along the upper Motueka River.

WAIMAKARIRI RIVER [41]

The Waimakariri River and its main tributaries rise in the Southern Alps at the main divide. The river has a large mountainous catchment, with inland basins and gorges. From the lower gorge through the foothills ranges, the Waimakariri River crosses the wide Canterbury Plains. Over geological time the plains have built up from fluvial deposits derived from erosion in the Southern Alps, with several phases of extension or progradation during the cold glacial periods of the last 2 million years (of the Pleistocene period), when sea levels were lower. During the warmer inter-glacial periods (as at present), there has been a trend of incision or entrenchment, with terrace development, in the upper plains, and deposition with further extension of the lower plains to a higher sea level.

Prior to containment of the lower river by stopbanks and river works, the Waimakariri River had a very extensive floodplain, with river channels and flood waters spreading out to both sides of Banks Peninsular, from north of Kaiapoi to Lake Ellesmere (Waihora), just north of the Rakaia River.

The plains reach of the Waimakariri River can, then, be divided into sections of significantly different natural character.

- ⋆ The upper reach, below the gorges, is entrenched into the plains and contained by terraces, which progressively reduce in height down the river. The river is relatively steep, and has a wide fully braided channel of coarse to fine gravel and sand. The gravel bed material is transported through this reach, with the river obtaining additional bed load from the terrace faces when they are undermined by river attack.
- ⋆ A transition reach where the river grade reduces (to accommodate the present sea level) and there is a type of fan development with channel break outs. Here the river bed intersects the surface of the plains, and the river can escape the confinement of the upstream terrace system.
- ⋆ The lower aggrading reach, where the river breaks up naturally into many different channels, as it crosses a depositional plain to the sea. The confinement of the river has given rise to an accumulation of gravel bed material within the river channel, with all the gravel material transported down the river being deposited in this reach.

★ A prograding reach at the sea, where sand material is deposited, and lagoons form within the tidal zone.

For the upper entrenched reach, where the river has a fully braided channel form, the nature of the river has not been altered by stopbank confinement or river works. However, introduced plants have changed the vegetation dynamic along the reach, with various fast growing colonising species now being present in the river channel. Vegetation buffer zones have also been established along the edge of the river channel, and alongside the terrace faces, using mainly willows. The aim of this buffer zone planting has been to reduce erosion attack to the terraces (and hence reduce the amount of gravel material introduced into the river from the terraces) and to protect farm land from erosion (due to changes in course).

Vegetation buffers have also been established along the lower plain reach, but the channel edge is mostly defined by large rock groynes. The erosion embayments around the groynes direct strong erosive forces onto the groyne banks, especially onto the upstream side, and deep local scour holes are formed at the groyne heads. This affects the development of braids, and especially the larger braids that form over relatively long distances. The vegetation between the groynes is, then, really a back-up to suppress the erosion embayment activity, and does not really give rise to a diffuse and moveable edge to the river channel as flood intensity and braid activity varies over time.

A wide river corridor is managed as public land with vegetation buffers were being established, along with the rock works. Design fairways and channels were drawn up to provide guideline boundaries for the planting programme. The aim was to determine a consistent width for each of the distinctly different reaches, to reduce the sideways pressure from channel, or braid belt splitting. For much of the river course across the plains the river has a wide fully braided form, and a very wide fairway was determined from a study of braiding patterns and the formation and movement of belts of braids, which are a composite of braids that migrate together.

Extensive vegetation buffers have been established along the river course, as a wide flexible vegetative margin and as infill between and behind rock rocks.

The aerial photography shows a fully braided reach of the Waimakariri River, where it transitions from its confinement by terraces to the lower depositional reaches.

ASHBURTON RIVER [42]

The Ashburton River rises in range land behind the Canterbury Plains, and crosses the plains between the Rakaia and Rangitata rivers, which extend back into the Southern Alps. The river forks into two main branches upstream of the town of Ashburton, and the river channels across the plains are managed, through a community scheme, including the upper plains tributaries of Taylors, Bowyers and Pudding Hill streams. The catchment across the plains is relatively narrow, being less than 10 km wide along the lower 40 km. The Canterbury Plains have been formed by glacial outwash and alluvial deposits, and wide fans have formed beside the rivers crossing the plains. The fans of the North and South branches of the Ashburton River merge into the much larger fans of the mountain fed rivers of the Rakaia to the north and the Rangitata to the south.

There are important differences in channel processes across the plains, affecting channel form, sediment transport and flood or channel break out potential. Along the Ashburton River system there are three main segments of significantly different natural character.

- The upper reaches, where the rivers and streams are entrenched into the plains and contained by terraces. These terraces progressively reduce in height down the plains, and become more intermittent in form.
- The mid reaches, where there are more complex changes in terrace containment, channel incision and river grade. Along the South Branch there is a well defined terrace along the northern side, to about Blacks Road, where the stopbanks begin. Along the southern side containment of the river is less well defined, but flood waters generally follow the river course. On the North Branch there is a major change in grade, where the natural tendency of the river is to split up and break out into different courses. Confinement of the river to a narrow fairway, with flood containing stopbanks, has given rise to substantial channel aggradation from the build up of the gravel bed material. Generally, there is a tendency towards a split channel form with channel break outs and changes in course along this transition zone. There is, though, some terrace development with intermittent terraces and channel incision.
- The lower entrenched and degrading reach of the main stem, where the river grade steepens again and terraces re-develop, with increasing height in the downstream direction.

The main aim of the river management is to reduce flooding and the risks of channel break outs. Stopbanks have been constructed along the main stem, below the confluence of the South and North branches, along the North Branch and along the northern side of the South Branch. Channel fairways, defined by vegetation buffer zones have been developed along all the scheme reaches, and management is aimed at keeping the fairways clear of vegetation, while maintaining the edge vegetation as a buffer against erosion, channel break outs and flood overflows.

Past river management, before the present scheme as well as through the scheme, has substantially altered the river channels. Tree vegetation, mostly willows and poplars, has been used to contain the rivers and narrow the river channels. Other introduced plants have changed the vegetation dynamic within the river channels, with various fast growing colonising species now being present. Substantial areas alongside the river channels were planted under the development phases of the scheme, especially where the aim was to narrow the river channel. There are now continuous vegetation buffer zones throughout the scheme, but they vary greatly in width, as well as vegetative density and vigour. The protection vegetation is being adversely affected by weed species, especially vines and creepers, such as the introduced Old Mans Beard (Clematis vitalba), and diseases. The smothering by Old Mans Beard is particularly severe in the lower reaches of the Ashburton River, including the lower South Branch.

Design channel and fairway widths, for the different regime conditions, were determined for the South and North branches of the Ashburton River and its main stem, to provide consistent management guidelines that are related to the river reach conditions.

The design river corridor fitted into the existing channel and vegetation buffer areas, and a consistent meandering could be achieved, with very few exceptions. The main variation to fit the existing conditions and river course was in the amplitude of meandering.

The aerial photography shows a reach of the main stem of the Ashburton River below the South and North Branch confluence, passed the town of Ashburton, and a reach of the North Branch along its confined length across the plains.

KAKANUI & KAURU RIVERS [48]

The Kakanui River and its main tributary the Kauru River rise in the Kakanui Mountains. This range land is deeply dissected with narrow gorges, especially in the lower range land. The Kakanui Mountains is mostly schist, of varying ages and foliation, but with a capping layer at the higher elevations of basaltic volcanic rock. There is some sedimentary rock along the lower range land, as well as the rolling hill country, while the plains are mostly covered in older alluvial of the Pleistocene, with some recent alluvial of the present interglacial.

The river bed material is then derived from a small proportion of hard basalt and mostly schist material that is quickly broken down, especially because of abrasion from the basaltic stones. The river channels in the range land have much exposed baserock with small gravel beaches. The catchment supply is, thus, relatively small, and would be very episodic, depending on the more extreme storms and flood flows, and follow on transportation along the rocky river channels.

The alluvial plains have been built up from material supplied from the southern high land, and there is a high terrace along the northern side of the plains reach of the Kakanui River, from land tilting and uplift. The baserock is also very close to the surface along this northern extent of the plains, with frequent exposures in the river channel. There are terrace formations on the plains, with some loess cover, and the terraces alongside the lower Kauru River indicate a long-term cutting down during the present interglacial period.

The Kauru River has a rapidly changing form along its short plains reach, from a single meandering channel, to wandering and semi-braided, to a wide area of channel activity with channel splitting and braid migration. This is despite a constant grade and no tributary inflows. The channel becomes wider and shallow, with low banks, and channel splitting and breakouts would occur naturally, especially along the lower reach.

The Kakanui River does not have the same apparent supply of bed material to the plains, but it may just be more episodic, due to the constrained and complex channel it has above the plains, where there are definitely localised deposition and re-working areas. The slight steepening of grade below the Kauru confluence would be due to bed material deposition at this confluence. The Kakanui River then flows along one edge of the alluvial plain, beside a high terrace, where it has a semi-braided to wandering partly split channel form. There is another deposition reach mid way down the plains, with a change in grade as the river flows away from its northern (terrace) constraint and across its flatter lower plains, down to the coast. Along this lower reach the river has a single channel form winding across the plain down to a short estuarine reach.

Different design channels and fairways have been drawn up, which reflect the varying river types and conditions of the lower reaches of the rivers. The complex landscape and varying river characteristics is then reflected in the different designs, but together they form a connected river course that takes account of the natural transitions and controls over the river form.

The aerial photography shows a reach of the Kakanui River below the Kauru River confluence.