Technical Committee - 29 November 2017 Attachments

Minutes of a meeting of the Technical Committee held in the Council Chambers at Otago Regional Council on Wednesday 18 October 2017, commencing at 10:30 am

Membership

Cr Andrew Noone	*(Chairperson)*
Cr Ella Lawton	*(Deputy Chairperson)*
Cr Graeme Bell	
Cr Doug Brown	
Cr Michael Deaker	
Cr Carmen Hope	
Cr Trevor Kempton	
Cr Michael Laws	
Cr Sam Neill	
Cr Gretchen Robertson	
Cr Bryan Scott	
Cr Stephen Woodhead	

Welcome
Cr Noone welcomed Councillors, members of the public and staff to the meeting.

1. APOLOGIES
Resolution

That the apologies for Cr Brown be accepted.

Moved: Cr Noone
Seconded: Cr Woodhead
CARRIED

Resolution

That the apologies for Cr Brown be accepted.

Moved: {mover}
Seconded: {seconder}
CARRIED

2. LEAVE OF ABSENCE
The Leave of Absence by Cr Deaker was noted.

3. ATTENDANCE

Peter Bodeker *(CEO)*
Nick Donnelly *(DCS)*
Tanya Winter *(DPPRM)*
Sian Sutton *(DSHE)*
Gavin Palmer *(DEHS)*
Scott MacLean *(DEMO)*
Dean Olsen *(Manager Resource Science)*
Deborah Mills *(Environmental Scientist)*
Lauren McDonald *(Committee Secretary)*

4. CONFIRMATION OF AGENDA

The agenda as tabled was confirmed.

5. CONFLICT OF INTEREST

No conflicts of interest were advised.

6. PUBLIC FORUM

No public forum was held.

7. PRESENTATIONS

No presentations were held.

8. CONFIRMATION OF MINUTES

Resolution

That the minutes of the meeting held on 13 September 2017 be received and confirmed as a true and accurate record.

Moved: Cr Robertson
Seconded: Cr Hope
CARRIED

9. ACTIONS

(Status report on the resolutions of the Technical Committee). No actions required.

10. MATTERS FOR COUNCIL DECISION

10.1. Director's Report on Progress

The report provided information on the: Heavy rainfall event of 21 and 22 July; Southern Alpine Lakes; Climate change and sea level rise; Leith Flood Protection Scheme engineering works; Robson lagoon improvements and Urban Water Management.

Southern Alpine Lakes - Dr Palmer confirmed the initial focus was for the identification of the scientific research and information jointly sought by ORC, Environment Canterbury and Environment Southland. He confirmed this would be aligned into the ORC Long Term Plan.

Resolution
That this report is noted.

Moved: Cr Robertson
Seconded: Cr Neill
CARRIED

10.2. Air Quality Research Opportunities
The report outlined the development and implementation of the national research strategy and its alignment with ORC's air quality research needs. The report included current strategic thinking for national interest research topics, emission control technology opportunities and public health considerations.

Ms Mills responded to questions on air quality reduction initiatives for domestic chimneys, monitoring of particulates, public health impacts and affordable residential monitoring methods.

A request was made for the report *Health Affects of Ambient Air Quality in Otago* to be circulated to Councillors, to assist with future discussion.

Resolution

a) That this report be noted.
b) That the ideas presented in this report are endorsed for consideration for inclusion into the 2018/28 Draft Long-Term Plan.

Moved: Cr Robertson
Seconded: Cr Scott
CARRIED

11. MATTERS FOR NOTING
There were no items tabled.

12. NOTICES OF MOTION
There were no Notices of Motion tabled.

13. CLOSURE
The meeting was declared closed at 11:10 am.

<u>Chairperson</u>

Summary of recommendations

The legal and planning framework for flood hazard management

a. Efforts to complete the application of the hazard management framework and associated documents should be ramped up to ensure comprehensive cover of all of the region.

b. Particular attention needs to be paid to areas with high vulnerability, such as small rural townships where resilience may be low.

The College Road floodwall

c. An automatic river water level monitoring device should be installed close to any critical structures, such as a floodwall, to enable accurate water levels to be recorded both for design purposes and for public record of flood levels.

d. Passive pressure acting around the bottom edge of foundation slabs should not be included as resistance in the design of structures, and reference to this at the end of section A3 of the Bay of Plenty Regional Council Guideline 2014/01 "Stopbank Design and Construction Guidelines" should be removed.

e. The Regional Council should review the design of, and reconsider any impermeable barriers that they have, or are intending to, put in place near to the landward side of any floodwall or stopbank.

f. The risk to flood defence structures from uncertainties around ground conditions should be minimised by carrying out comprehensive investigation, design, and construction supervision for all stopbanks and floodwalls. Investigations should be located so as to be representative of the ground on which the structure is to be placed.

g. Flood defence structures should rely on simple and robust designs which minimise the potential impact of natural ground variability. Caution should be taken in the application of sophisticated analyses for stopbanks and floodwalls due to the high potential for natural variability in the ground conditions along their lengths.

h. Residual risk to flood protection structures from variability in ground conditions should be taken into account in land use planning and emergency planning, including alert and evacuation procedures.

i. Specifications drawn up for placement of fill for flood defence walls should recognise that a higher quality of fill is needed for floodwalls than for stopbanks, and should be subject to quality control.

j. Consideration should be given to the outcome of a study by Cardno that is currently underway into the effects of daily ramping of river levels on river bank stability as against damage from floods, and appropriate action taken to minimise these effects.

k. The College Road floodwall should not be replaced with another wall, but ways sought to enable a stopbank to be constructed in its place (noting that the properties closest to the breached wall have been acquired by the Regional Council).

l. Floodwalls should not be used in areas characterised by variable and piping prone ground conditions unless specially engineered with extended cutoffs, or riverside blankets to control seepage.

m. The existing fill at the College Road floodwall and the remnants of the floodwall itself should be removed or thoroughly investigated before construction of a new flood defence structure/stopbank. Investigation and inspection of the fill carried out at that time should be used to provide further insight into its condition and significance to the failure.

n. The condition of the foundations of the 'downstream' floodwall (89 to 101 College Rd) following the 2017 floods should be investigated.

Operation of Matahina Dam

o. Review the Lake Matahina Flood Management Plan with the aim of:
   - discussing and agreeing a clear protocol around forecasts and timing that requires 70.0mRL as the target lake level. This should be particularly focused on achieving 71.6mRL earlier in an event so there is sufficient time to make the decision to give approval to go to 70.0mRL and to achieving that level without excessive spillway flows;
   - developing a template for use in written communications during flood drawdown mode that includes specific details on the timing and rate of outflows required to achieve specified lake levels at specified times;
   - reviewing the target maximum lake level for determining optimum outflow, with the possibility of using a level between maximum operating level and maximum flood level;
   - requesting Trustpower to consider whether modifications can be made to improve dam safety when lake level drops below 71.6mRL including lengthening the debris boom so that it remains functional

p. Review monitoring and maintenance plans for the current rain and river gauge network and improve reliability of operation.

q. Review number and location of upstream rain gauges to improve accuracy and confidence in flood forecasting. Consideration to be given to spatial coverage as well as redundancy to provide back-up if one or more gauges are non-operational during an event. The current coverage appears limited for the Upper Whirinaki and entire western side of the catchment in particular.

r. Consider additional/back-up river flow gauges to provide better information on upper catchment flows that will provide opportunities for improved optimisation of dam outflows and use of the upper range of Lake Matahina storage during flood events. This could be combined with an enhanced flood forecasting model that includes measured flow data assimilation up to the time of forecast.

s. Work with Pioneer Energy to investigate the possible use of storage in Lake Aniwaniwa during large floods to further reduce downstream peak flows.

t. Work with Pioneer Energy to provide real-time Aniwaniwa outflows and lake levels to the Regional Council during flood events.

Reid's Floodway

The recommendations for the completion of Reid's Floodway are provided in Section 6 – Long-term strategy and design philosophies.

Evacuation planning

u. Evacuation plans need to be developed to manage the risk of stopbank failures. This will require the evaluation of the "safe" capacity for both overtopping and geotechnical failure modes and planned evacuations for flood events which exceed the assessed "safe" capacity.

v. Consideration should be given to variable river level trigger thresholds where the residual risk of geotechnical failures is being managed through evacuation plans. This is in recognition of the importance of antecedent groundwater conditions as well as the duration of elevated river levels in the development of geotechnical failure mechanisms.

w. Specific consideration needs to be given where large capital works upgrades, such as Reid’s Floodway and Spillway, are not yet completed and operational.

x. The development of an evacuation plan for Edgecumbe is something to be urgently completed by the Regional Council, Civil Defence and the Whakatāne District Council working together.

Long-term strategy and design philosophies

y. The Regional Council should give high priority to developing and implementing long term sustainable flood risk management solutions for the Rangitāiki Plains to manage the effects of climate change as well as providing ecological and cultural value to the wider community.

z. The stopbank raising for both banks of the upper reach of Reid’s Floodway allowed for in the current (2015-25) long term plan would appear to be a poor option given the well-known geotechnical complexities of the underlying geology. It is also considered that stopbank raising is not aligned with the visions and objectives of the Rangitāiki River Document or generally accepted best practice.

aa. The work the Regional Council is currently undertaking to examine the feasibility of spill compartments and an additional outlet from Reid’s Floodway as well as a lower fixed crest for Reid’s Spillway should be pursued using all of the tools available including designations (s166-186, Resource Management Act, 1991), and if necessary, the Public Works Act 1981.

bb. The flood hydrology of the Rangitāiki River needs to be updated to include the April 2017 event. It is recommended that a “naturalised” annual maxima flood series is developed that uses estimated Matahina Lake inflows rather than flows at Te Teko as its basis.

Community engagement

cc. Engagement of the full community (including Edgecumbe township) should be undertaken when considering further options for Reid’s Floodway. This should include full notification of any notices of requirement and/ or application for resource consent.

Rangitāiki River Scheme Review – April 2017 Flood Event

Final Report

18 September 2017

Rangitāiki River Scheme Review – April 2017 Flood Event

Final report as supplied to Bay of Plenty Regional Council

18 September 2017

Prepared by the Rangitāiki River Scheme Review Panel

Cover Photo: provided by Bay of Plenty Regional Council 2017

Use of Report and Documents

This report has been prepared solely for the purposes stated in this report and should not be relied upon for any other purpose.

The statements and opinions expressed in this report have been made in good faith, and on the basis that all information provided to us and relied upon is true and accurate in all material respects, and not misleading by reason of omission or otherwise.

We reserve the right, but will be under no obligation, to review or amend our report, if any additional information, which was in existence on the date of this report, was not brought to our attention, or subsequently comes to light.

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Contents

1. Background and introduction

On Thursday 6 April 2017, at approximately 8:30am, the Rangitāiki River breached a **stopbank** at College Road, Edgecumbe resulting in the flooding of much of the township. Thankfully no loss of life occurred, but the disruption to the lives of many residents was of major significance.

Some fifteen houses were rendered permanently uninhabitable while in excess of 250 more required repairs of a level which necessitated their being evacuated for a considerable period (Whakatāne District Council, 2017a). Many people have had to find alternative accommodation for weeks or months. As they return they will need and want assurances that everything possible is being done to avoid a repetition of the flood and to ensure their safety in their homes.

This independent review was commissioned by the Bay of Plenty Regional Council to provide answers to the people of Edgecumbe and the wider Eastern Bay of Plenty about what happened and why. The Review Panel comprises three members; Sir Michael Cullen (Chair), Kyle Christensen, and Charlie Price. Their backgrounds and qualifications are outlined in Appendix A. In order to underline the Review Panel's independence a Wellington firm, Tregaskis Brown Ltd, was employed to provide the necessary support, servicing and administration requirements.

Draft terms of reference were discussed between the Chair of the Regional Council (Doug Leeder), senior staff, and Sir Michael before being finally approved at an extraordinary meeting of the Council on 18 May (see Appendix B). The Council resolved that the purpose of the review is:

> "to understand the circumstances that led to the breach of the Rangitāiki stopbank at College Road, Edgecumbe, and the resulting flooding through the town on 6 April 2017".

The scope of the review has two interlinked parts:

1. the operation of the Rangitāiki River Scheme assets, including design, engineering, maintenance and management, that Bay of Plenty Regional Council manages on behalf of the community;
2. implementation of the flood management role that the Council delivered during the ex-Tropical Cyclone Debbie event up until the breach and in response to that breach.

The terms of reference relate to those matters for which the Regional Council is responsible. It does not include, therefore, Whakatāne District Council's roles and responsibilities. Nor does it include the Civil Defence Emergency Management Bay of Plenty Group's role in and response to the event. The other exclusion covers the processes by which resource consents were granted for the dams, hydroelectric power stations and **spillways** on the Rangitāiki River upstream of Edgecumbe, the appropriateness and effectiveness of the terms and conditions of those consents, and their monitoring (other than in respect of flood management).

The Review Panel has, nevertheless, taken a liberal interpretation of these terms to ensure that they do not inhibit the capacity of the Review Panel to arrive at its best judgment as to the nature of the reasons for the failure of the flood control system to prevent the Edgecumbe flood and what lessons can be learnt for the future.

Of necessity, much of this report is very technical in nature. To help the general reader a glossary can be found in Appendix C. All bolded words are included in the glossary.

1.1 The Rangitāiki River and its people

The Rangitāiki River is the largest in the Bay of Plenty. Starting south of the Taupō-Napier highway, some 740m above sea level, it winds its way northwards for 174km, passing through or by such communities as Murapara, Galatea, Waiohau, Te Mahoe, Te Teko, Edgecumbe and Thornton before entering the sea near Thornton by way of an artificial channel created a little over a century ago.

On its way it is fed by a number of **tributaries**, notably the Otamatoa, Wheao, Whirinaki, and Horomanga Rivers. It also passes through two artificial lakes: Lake Aniwaniwa (still referred to by many as Lake Aniwhenua) and Lake Matahina. These two lakes are the result of hydroelectricity development on the river. There is also a third hydroelectricity **scheme**, the Flaxy-Wheao in the upper reaches of the **catchment.**

The history of the Rangitāiki River and its catchment area certainly bears out the description of New Zealand as "an irredeemably pluvial country" by a former Prime Minister, Sir Geoffrey Palmer. Much of that history over the last 150 years is one of periods of more or less frequent floods and of many different attempts to control or mitigate those floods.

The fact that four of the seven places on the river mentioned above have names of Māori origin, while the other three names are of pākehā origin, speaks to a divided history with two distinct views of what has happened to the Rangitāiki over that period. The Eastern Bay of Plenty remains essentially a bicultural region. The vast bulk of the population are of Māori and/or European (mainly British or Irish) origin – roughly 95% of the residents of the Whakatāne District according to the 2013 Census. Of those living in the Rangitāiki catchment, 61% identify as Māori. These two ethnic groups have lived together, often intermarrying, over many generations. Yet they still encompass two views of the river and its history.

The four Bay of Plenty iwi who identify with the river (which is to say that their being and that of the river are inextricably intertwined) are Ngāti Manawa, Ngāti Whare, Tuwharetoa (ki Kawerau), and Ngāti Awa. Edgecumbe lies within the rohe of Ngāti Awa (recognising Tuwharetoa ki Kawerau also have interests in the area). But all four iwi identify with the river as a whole. For them the river has its own mauri, or life force. This expresses itself through the behaviour of the river, which humans interfere with at their own peril. (Since the formation of the River Forum Ngāti Hineuru have joined it as their rohe includes the headwaters of the Rangitāiki).

It is not surprising, therefore, that *Te Ara Whanui o Rangitāiki* (*The Pathways of the Rangitāiki*), the 2015 document issued by the Rangitāiki River Forum, emphasises the degradation of the river resulting from the various modifications made to its natural behaviour by dams and flood control and **drainage schemes**.

In the Forum's summary of the Māori experience these have "reduced [the river's] spiritual values and compromised the ability of iwi to exercise kaitiakitanga (stewardship) and conduct their tikanga (customs) and kawa (ceremonies)" (Rangitāiki River Forum, 2015). To address these realities, *Te Ara Whanui o Rangitāiki* makes forty-six recommendations designed to lead, over the long term, to the restoration of the health and wellbeing of the river. The Review Panel has taken careful note of these recommendations.

For those who came some centuries later, the settlers from Great Britain and Ireland, the river was seen in a different frame of reference. The settlers, and their successors, tended to see natural resources as either things to be exploited or as barriers to economic development. A river with a tendency to flood frequently and its accompanying low-lying floodplains presented challenges to be overcome with European technology and science, not a life force to be respected and protected. Two different views of the world clashed on the Rangitāiki Plains, as they did elsewhere in Aotearoa/ New Zealand. The outcome was never in doubt. But the future presents an opportunity to seek a reconciliation between them.

While echoes of this clash can still be heard today, there is beginning to be a gradual convergence of views. Those who live and work on the Rangitāiki Plains, Māori and pākehā, deserve the best possible protection from damaging floods. At the same time, future changes to the flood control and drainage schemes and the operation of the hydroelectricity schemes can be framed within the context of allowing the river to express itself more readily. This will enable the aspirations outlined within *Te Ara Whanui o Rangitāiki* to be more fully met. Those aspirations reflect the gradual convergence of views which is symbolised by the fact that the Rangitāiki River Forum is a joint forum of iwi and regional and district councillors set up as a result of Treaty settlements.

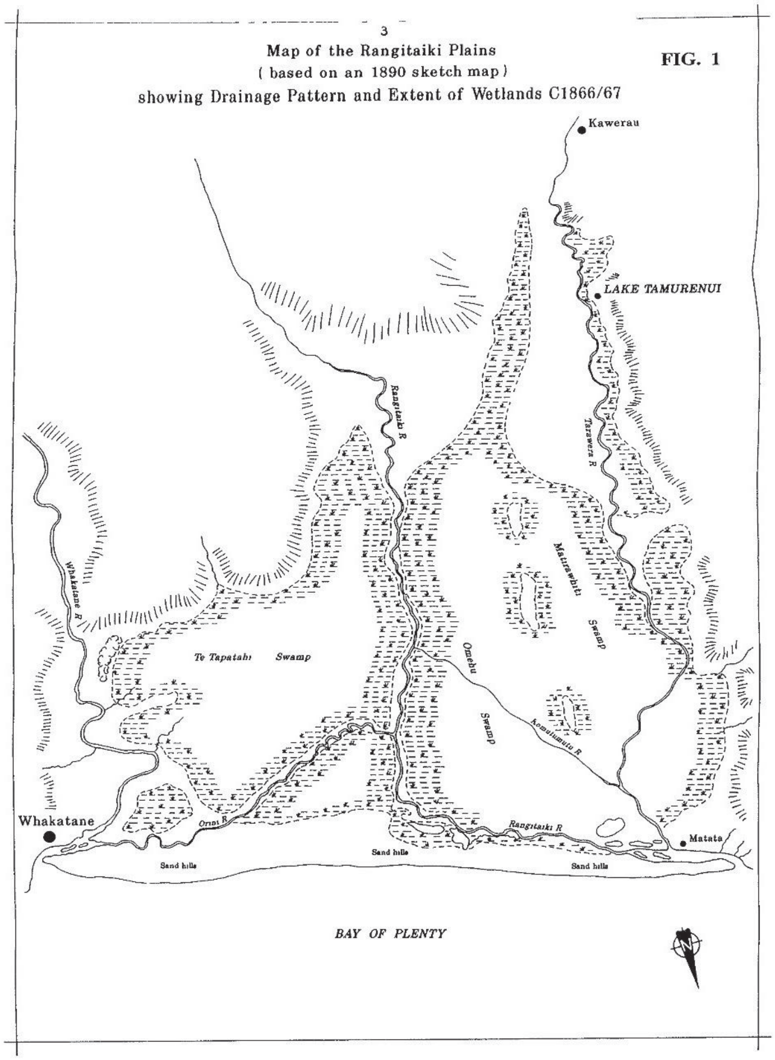

Figure 1: Rangitāiki Plains Historical Sketch showing drainage pattern c 1866/67 (Source: Bay of Plenty Regional Council Maps and Plans Archive, R722)

1.2 The Rangitāiki River Flood Scheme

The Rangitāiki River flood scheme has developed over a long period of time. In that respect, it is important to distinguish between **flood control schemes** and drainage schemes. Reflecting the settlers' views described above, the original purposes of the latter were largely directed towards draining wetland and low-lying areas in order to create usable agricultural and horticultural lands. The most notable of these followed on from the passage of both general and specific legislation (Rangitāiki Land Drainage Act, 1910). Some 40,000 hectares of wetland was drained and converted to farmland. In addition, a new direct outlet to the sea was created near Thornton for the Rangitāiki River. This replaced the previous dual outlets towards the Tarawera River estuary to the west and the Whakatāne River to the east. Further significant drainage works were undertaken in the years after World War I.

Within a day of the new outlet being opened in May 1914 the level of the Rangitāiki in the lower Rangitāiki Plains area dropped about 1.5 metres. This fall in river levels encouraged additional agricultural and horticultural development. In order to protect this expanding primary sector, the overwhelmingly dominant economic sector in the Eastern Bay until the late 1950s, **floodbanks** and associated works developed in a somewhat ad-hoc fashion over many years, with **drainage boards** taking a key role.

However, the largest single modification to the Rangitāiki's natural flow and behaviour was built for neither drainage nor flood control purposes. The Matahina Dam was built for the purpose of hydroelectricity generation and was commissioned in 1967. There was considerable pressure exerted at the time, especially by the Rangitāiki Drainage Board, to make the dam available for flood control purposes. However, there was considerable resistance to that proposition from the Ministry of Works, then in its full pomp of hydroelectric dam construction.

In the end, it was agreed that the dam would be operated so as to enable the spilling of water before the arrival of a flood peak. Lake Matahina could thus be used as a storage area for the floodwaters. The Bay of Plenty Catchment Commission (the predecessor to the Regional Council) prepared guidelines to reflect that agreement (Bay of Plenty Catchment Commission, 1964).

Subsequent events proved that the dam had been built in a less than ideal geological position. Between 1967 and 1987 the dam moved one metre downstream. In the latter year, the Edgecumbe earthquake moved the dam a further 150mm downstream. The dam was weakened by the earthquake and subsequently considerable strengthening of it took place.

The construction of the dam coincided roughly with a period from 1958 to 1972 that was marked by unusually frequent high river levels and floods. In those fifteen years, peak flows at Te Teko exceeded 250**m^3/s (cubic metres per second)** on seven occasions, including three on which the peak flow exceeded 550m^3/s, compared with a median flow of around 62m^3/s at that point (see Figure 2). The 1962 flood in particular prompted the preparation of an integrated plan for extensive new and upgraded works - the Rangitāiki-Tarawera **Flood Protection Scheme**. This was constructed between 1965 and 1983. Significant upgrades have occurred since then, usually following flooding or seismological events.

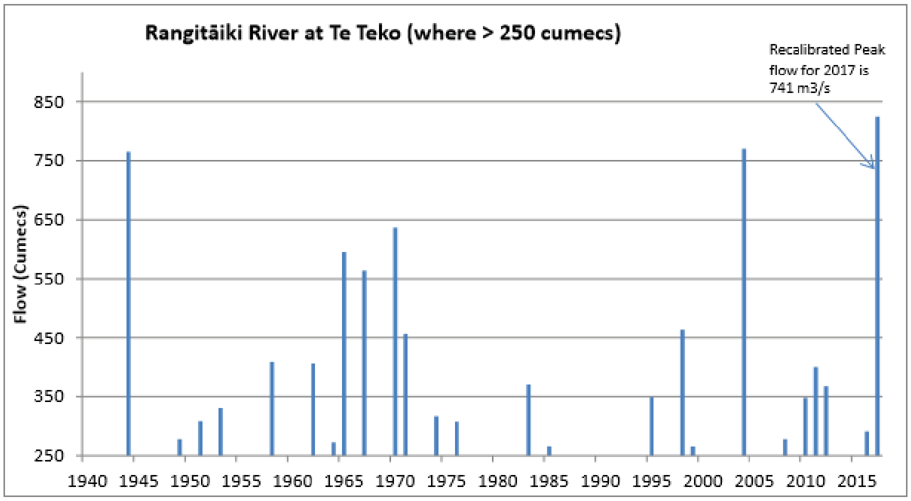

Figure 5 Flood peak history of the Rangitāiki River at Te Teko from 1944 to 2017 (from Te Teko gauging station, plotted by Fransen 2017). 2017 Peak flow has been recalibrated to 741m^3/s (Ellery, 2017)

Figure 2: Flood peak history of the Rangitāiki River at Te Teko from 1944 to 2017 (Source: Bay of Plenty Regional Council, 2017)

Since 1989, the scheme's management, maintenance, improvement and control has come under the authority of the Bay of Plenty Regional Council. Following a further major flood in 2004, a flood management plan was agreed between the Regional Council and Trustpower. The new plan covered the procedures to be followed in the event that it was desirable to utilise the dam to reduce the probability and severity of any downstream flooding. It was recognised that the extent to which that can be done is limited by a number of factors, largely related to ensuring the structural integrity of the dam.

Nevertheless, it would be fair to describe the Matahina Dam as now being, in terms of the flow of the river, the first part of an interconnected four-part scheme to protect Edgecumbe from floods and to reduce the frequency and severity of flooding elsewhere in the lower Rangitāiki Plains. The second part comprises the extensive floodbanks on either side of the river. The design standard is that these stopbanks are high enough to contain a **one-in-100 year flood**. In addition, stopbanks in rural areas normally have 300mm of **freeboard** (that is, additional height) while those in Edgecumbe and the two other urban areas (Te Teko and Thornton) have 600mm of freeboard.

The Regional Council's own information shows that the current stopbanks do not meet the one-in-100 years design standard. However, the additional freeboard in Edgecumbe should mean that, in a very serious flood event, assuming no stopbank failures, **overtopping** of the stopbanks would occur in the rural areas first.

The third part of the system is formed by Reid's **Floodway** and Spillway. This is intended to divert part of the river flow above Edgecumbe out of the river into a substantial canal. While it did that in the 2004 flood, it was determined after that event that there should be a significant upgrade undertaken which is now well behind the original schedule for completion. The reasons for, and implications of this, are traversed in Section 5.2 – Reid's Floodway.

The final part is the drainage systems which carry excess surface water, in particular from farms to the west of Edgecumbe. This is discharged into the Omeheu Canal and then into the Tarawera River. The intention is to prevent the water spilling into the town, which is now lower lying than most of the surrounding areas.

These four parts should not be imagined as a four-layered defence system, with the first layer being Matahina Dam. Rather, the first line of defence is always the stopbanks, with Reid's Floodway intended to be the second line, being used only in the more extreme events to divert water away from the town. The role of dam management is to lower the lake level before a flood peak so that, at peak flows, the outflow from the dam can be kept significantly lower than the inflow for as long as possible consistent with the safety of the dam.

The reconsenting process for the dam in 2013 under the requirements of the Resource Management Act led to further discussions between Trustpower and the Regional Council around just how the dam's flood control role was to be managed. The agreed protocols in relation to flood control formed part of the consents that were issued by the Environment Court. Some aspects of those consents remain matters of controversy in the local community.

Figure 3: Rangitāiki River catchment area and critical structures related to the 2017 flood event (Source: Bay of Plenty Regional Council, 2017)

1.3 The review process and the key questions

How the lake levels were actually managed in early April, including what reduction in peak flow downriver was achieved as a consequence, and whether or not the lake levels could have been managed more effectively to reduce further the peak flow, are two of the key questions that the Review Panel has sought to answer. All of the questions that the Panel has addressed in the main body of this report have been raised by one or more of the individuals and groups who have been consulted by and/or made submissions to the Panel.

This process to gain input from the community has attempted to reflect the Bay of Plenty Regional Council's express wish that "all members of the community affected by, and all stakeholders with an interest in, the flood event are given the opportunity to provide information, input, and receive feedback".

This was done in a number of ways. The Panel met with the river iwi's representatives on the Rangitāiki River Forum, while Sir Michael met on other occasions separately with representatives of Ngāti Awa. A drop-in session was held on a Saturday for Edgecumbe which was kindly facilitated by the Chairperson, Charelle Stevenson, and other members of the Rangitāiki-Edgecumbe Community Board. Sir Michael had previously met with Ms Stevenson and been briefed on local issues. Sir Michael, and later the Panel as a whole, met with members of the Rangitāiki Tarawera Rivers Scheme Liaison Group. Sir Michael also met with members of the executive of the local branch of Federated Farmers. Later, the Panel met with Peter Askey, who had participated in the Federated Farmers meeting and had been involved in the Opus reports referred to in subsequent sections of this report.

Written submissions were received from a number of individuals as well as from most of the organisations mentioned in the last paragraph. *Te Ara Whanui o Rangitāiki* effectively represented the River Forum's written submission. The Whakatāne District Council made a written submission and Sir Michael met with Mayor Tony Bonne and CEO Marty Grenfell along with Councillor Gerard van Beek to discuss it.

The most common questions that were raised in these meetings and community input focus around six issues: the intended performance characteristics of the flood scheme as a whole; the management of the Matahina Dam, particularly immediately before and during the flood event; the reasons for the breach of the stopbank at College Road; the issues around the failure of the Reid's Floodway to operate effectively; the level of pre-flood coordination between various authorities; and the nature and effectiveness of community input and knowledge of the risks and management of floods.

The Panel has also been able to use *New Zealand Standard 9401 2008: Managing Flood Risk* (Standards New Zealand, 2008) as a framework for organising its work. This document provides the only systematic New Zealand generated standard around the issues of relevance to flood management. As such it provides an independent analytical framework which has been of considerable assistance to the Panel. Interestingly, the great majority of the questions raised from the community input can be encompassed within NZS 9401: 2008[1].

Some of the most important material that the Panel has used to answer these questions have come from the process of community engagement. Photographs, videos, eye-witness descriptions and the memories of those familiar with the Rangitāiki Plains have all been of considerable assistance. The Panel's conclusions do not always reflect all the different views expressed by members of the community and others. This does not mean that those views have been ignored. Apart from the fact that those views are by no means uniform, the weight of evidence and the analysis has led the Panel to form its own conclusions.

In that respect, the Panel has had access to a very large amount of technical data. Much of this is contained in previous reports to and by the Regional Council and in the monitoring work which continually generates information about rainfall, hydrology, and other key variables. As this data has been analysed by the Panel's technical experts, Kyle Christensen and Charlie Price, so further questions have arisen. That has often led to requests for more information as well as for the modelling of scenarios. The Panel acknowledges all those who have assisted in that respect, particularly the staff of the Regional Council.

The final draft of this report was sent to the Regional Council, Ngati Awa (representing the river iwi), the Whakatāne District Council, Trustpower, Pioneer Energy, and Opus International Consultants (Opus). This was to enable them to make comments on the conclusions and recommendations of the Panel in order to ensure that due process was followed. Subsequently meetings were held with Opus and the Regional Council to discuss matters they had raised. The Panel then finalised its report and delivered it to the Regional Council.

It is in the nature of an event such as the Edgecumbe flood that many of the Panel's conclusions cannot be asserted with one hundred per cent certainty. For example, the breach itself destroyed some of the most important evidence to explain what happened. Therefore, many of the Panel's most important conclusions are of necessity expressed in terms of things being more or less probable. That applies both to the "why" questions and to the "what if" questions. Sometimes certainty cannot be given even when it is most wanted.

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2. The storm (ex-Cyclone Debbie)

Cyclone Debbie began its destructive existence in the Coral Sea on 23 March 2017, becoming a named tropical cyclone three days later. After further strengthening, it landed on the Queensland Coast on 28 March. Though it quickly degraded to a tropical low, it caused widespread flooding and damage, including loss of life, in south-east Queensland and northern New South Wales.

It then began a slow move across the Tasman Sea before veering in a south-easterly direction towards northern New Zealand. While no longer of cyclonic intensity the now sub-tropical storm continued to amass more moisture as it crossed the Tasman. Simultaneously, a frontal system moved north-eastwards across the South Island, stalling over the central North Island on Monday 3 April as it met the sub-tropical storm approaching from the north-west.

It had been clear for some days that there was an increasing probability that ex-cyclone Debbie would hit northern New Zealand. On the morning of 3 April MetService issued forecasts of the potential for heavy rain, reaching warning criteria, for the Coromandel Peninsula and the Bay of Plenty/Rotorua areas from the morning of Tuesday 4 April to Wednesday night. By Tuesday morning that had firmed up to forecasting 200 to 350mm of rain in the next 45 hours in the Eastern Bay of Plenty.

These forecasts proved accurate in terms of both quantity and timing. The very high rainfall, combined with the already well-above average levels of **soil saturation** after a very wet March, caused abnormally high river levels in both the Whakatāne and Rangitāiki Rivers. The Whakatāne River exceeded its previous highest recorded levels at a number of its recording stations. This was also true of the Rangitāiki River at Lake Matahina, with estimated inflows of 920m^3/s (cubic metres per second). This was about 20% larger than in the 2004 flood and roughly equates to a one-in-200 year flood at that point. As we shall see later, the use of the dam to manage flows reduced this to a less than one-in-100 year flood downstream of the dam.

The magnitude of the April 2017 flood event clearly brought it within the scope of the Regional Council's flood hazard management procedures. The nature of those procedures and how well they were implemented is the subject of the next two sections.

3. The legal and planning framework for flood hazard management

The following section identifies what the role of a Regional Council is in managing floods, and how that has been undertaken by the Bay of Plenty Regional Council.

The legal framework for natural hazard management is spread across a number of statutes and organisations. From a flood hazard management perspective, the main framework is set out in the Resource Management Act (RMA) 1991. Roles and responsibilities are set out below.

3.1 Resource Management Act 1991

Under the Resource Management Act 1991 (RMA) Regional Councils are charged with the responsibility to control the use of land for the purposes of avoidance or mitigation of natural hazards (including flood hazard management). They are not the only agencies responsible for natural hazard management, but have a leading role at the regional level. Detailed roles and responsibilities are set out in Appendix D.

Regional Councils have a number of tools at their disposal to discharge their responsibilities. They include the planning regime under the RMA, delivery of works and services (such as flood protection schemes), bylaws to protect flood and drainage assets, warning systems, education and information, and emergency management functions.

Regional Councils have a particular duty, through their **regional policy statements**, to set out responsibilities for natural hazard management with territorial local authorities.

3.1.1 REGIONAL POLICY STATEMENT

In July 2016, the Bay of Plenty Regional Council adopted *Change 2 (Natural Hazards)* to its existing *Regional Policy Statement* (RPS). This change sets out a policy framework for managing natural hazard risk. The stated objective is "*avoidance or mitigation of natural hazards by managing risk for people's safety and the protection of property and lifeline utilities*". The framework identifies a suite of policies to achieve the objective, based on taking a risk management approach, following the New Zealand Standard AS/NZS IOS 31000:2009 (Joint Technical Committee OB-007, Risk Management, 2009). The benefit of this approach is that it is far more comprehensive in its approach to risk and, in particular, risks of low likelihood but high consequence. The RPS does not provide specificity around particular geographic areas. However, it does direct how this is to be implemented through regional and district plans.

This RPS replaced the former *1999 Regional Policy Statement* (Environment Bay of Plenty, 1999), which provided strong guidance on identification of natural hazards, including development of a register, working closely with district councils to provide a coordinated and cooperative response in the event of a large-scale event, and maintaining effective flood monitoring and flood warning systems. Further, it directed that district councils identify district and relevant regional natural hazards in registers or district plans, and provide this information in Project Information Memoranda (PIMs) and **Land Information Memoranda (LIMs).**

3.1.2 REGIONAL PLANS FOR NATURAL HAZARD MANAGEMENT

No specific plans have been adopted for natural hazard management. However, considerable effort has gone into developing non-statutory frameworks and strategies for management of flood risk as set out later in this section.

3.1.3 WHAKATĀNE DISTRICT PLAN

Under the RMA, District Plans must give effect to regional policy statements. It is apparent that the Regional Council has been active in promoting its natural hazard policies and approach to Whakatāne District Council, including through submissions.

The *Whakatāne District Plan* has been reviewed and very recently adopted (Whakatāne District Council, 2017c). It is worth noting that specific controls exist in this plan, including constraints on activities in the Reid's Floodway (described as the Rangitāiki Floodway in the *Whakatāne District Plan)*, and rules protecting the integrity of flood management assets. There are no flood hazard-related planning controls or hazard overlays in the Edgecumbe township area, and it does not appear that the Regional Council has sought specific controls in Edgecumbe, other than a standard requirement for floor heights in buildings to be above the anticipated 100-year flood level.

3.2 Local Government Act 2002

Under the Local Government Act 2002 (LGA) avoidance and mitigation of natural hazards is set out as a core service that councils must pay particular regard to. Councils are obliged to identify flood protection and control works (including any negative effects on local communities) and how it will manage these assets in the long term.

These obligations are discharged through the various accountability documents including the **Long Term Plan**, **Annual Plans**, and Asset Management Plans. How they are discharged is described in various documents including Floodplain Management Strategies.

3.3 Local Government Official Information and Meetings Act 1987

Under the Local Government Official Information and Meetings Act, District Councils are obliged to disclose known information on matters including potential inundation (flooding) that affect any property to the extent that this information is not apparent from the relevant district plan. District Councils are required to maintain records on known natural hazards, and to make that information known through any Land Information Memorandum (LIM) that is sought in respect of any property. The Whakatāne District Council has confirmed in a letter to the Review Panel that it does not appear to possess specific information on flood risks for the Edgecumbe township (Whakatāne District Council, 2017b).

3.4 Other relevant legislation

Flood control, mitigation schemes and drainage schemes were largely established under previous legislative frameworks, such as the Land Drainage Act 1908 and the Soil Conservation and Rivers Control Act 1941 (now largely repealed). The Rangitāiki catchment has its own empowering legislation (Rangitāiki Land Drainage Act, 1956) that extends the scope of bylaws available. The Regional Council administers these and other bylaws, including bylaws to protect the integrity of scheme assets.

A schema for how these different responsibilities fit together is set out in Figure 4.

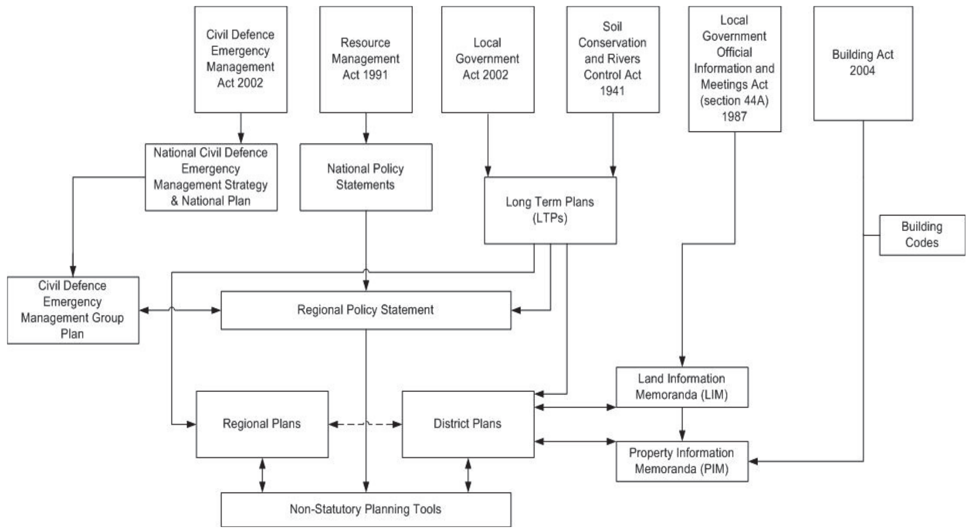

Figure 4: Legislative framework for natural hazards (Source: Quality Planning website - www.qualityplanning.org.nz)

3.5 Floodplain management planning

Following on from the overall legal and planning framework for flood hazard management in New Zealand it is now worth considering in more detail the process of investigating and implementing floodplain management solutions at a more operational level. The recommended process for managing flood risk in New Zealand is explained in the New Zealand Standard NZS 9401:2008 with a summary shown below in Figure 5.

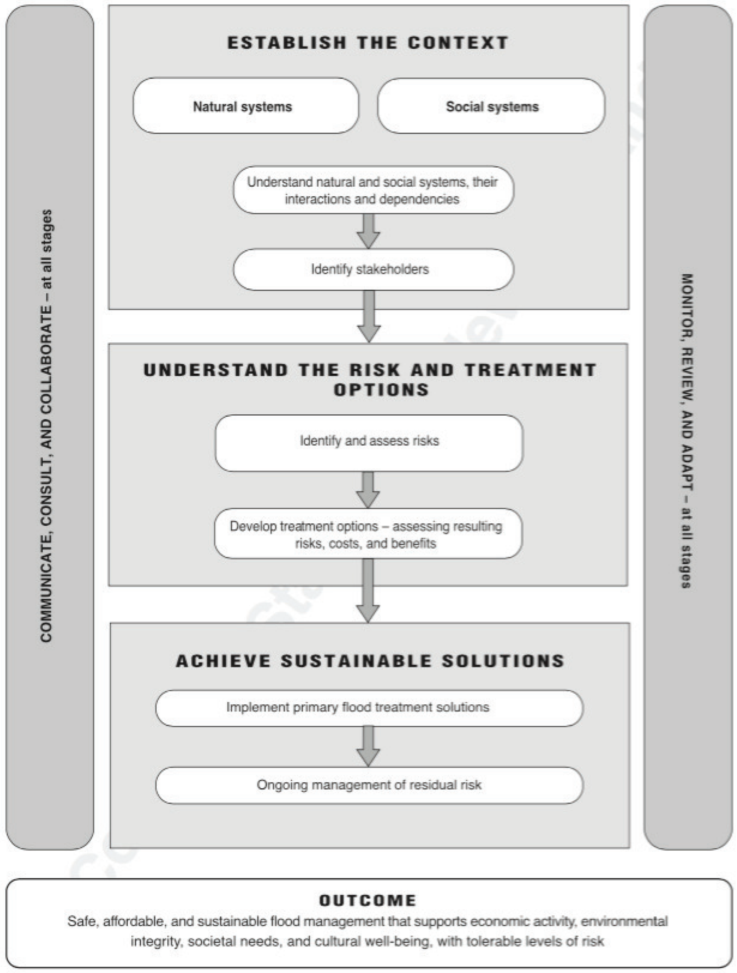

Figure 5: The process for managing flood risk in New Zealand (Source: Standards New Zealand[2])

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The overall process is divided into three key phases as shown in Figure 5 with communication, consultation and collaboration occurring throughout the process in parallel with monitoring, reviewing and adaption.

Successful implementation of the overall process should produce the following six sustainable flood risk management outcomes as described in NZS 9401:2008[3] –

1. Engaging communities and stakeholders;
2. Understanding natural systems and catchment processes;
3. Understanding the interaction of natural and social systems;
4. Decision making at the local level;
5. All possible forms and levels of management;
6. Residual risk.

It is these six outcomes that have been used as the basis for the overall evaluation of the Regional Council's management of the Rangitāiki River and catchment and to determine the areas for detailed analysis and reporting by the Review Panel. Appendix E provides an outline of which chapters in the report are relevant to each of the six outcomes.

Further explanation around the meaning of "all possible forms and levels of management" is provided below to provide some context around the Panel's evaluation of a much broader range of elements than simply the structural flood defences.

The four key categories of tools for managing flood risk along with examples of each are summarised in Table 1 below. These have been summarised from the New South Wales Government's *Floodplain Development Manual* (2005) and the Greater Wellington Regional Council's *Guidelines for Floodplain Management Planning* (2015).

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Table 1: Tools for managing flood risk (Source: New South Wales Government, 2005; Greater Wellington Regional Council, 2015)

1. River Management & Maintenance
• Gravel extraction, sand/**silt** dredging; • Weed spraying/removal (aquatic and terrestrial); • River bed and beach recontouring (with bulldozers or large excavators); • Hard river bank protection (groynes, rock revetments); • Planted willow buffer zones and other riparian planting.
2. Structural Works
• Stopbanks; • Flood diversion channels; • Detention dams; • Floodplain storage compartments; • Pump stations; • Raising or flood proofing buildings.
3. Planning & Land Use Controls
• Designations; • Flood hazard maps or zones (often included in District Plan); • Restrictions on subdivision or building; • Minimum floor levels; • Voluntary or compulsory property purchase.
4. Emergency Management
• Flood risk awareness and education; • Community readiness; • Flood forecasting and warning; • Evacuation triggers and procedures; • Inspection of key structures (e.g. floodgates, stopbanks); • Planned emergency works (e.g. deployment of sand bags, installation of temporary flood barriers); • Asset monitoring and reactive emergency works (e.g. additional earth reinforcement of stopbanks for **seepage** and **heave**, rock placement for erosion); • Insurance.

It must be highlighted that effective floodplain management requires consideration of all four categories of tools for the full range of flood events up to very extreme events beyond the capacity of the primary structural works. It is the development and agreement of a comprehensive, combination of options across <u>all four</u> categories that provides the overall flood risk management solution. This is where the process becomes particularly complex as the selection of the option for each category is dependent on what options have been selected for the other categories. A summary of key trade-offs when considering different combinations of options is provided in Figure 6 below.

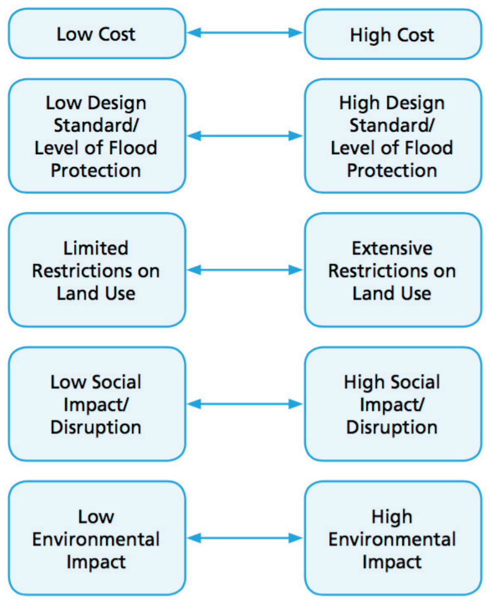

Figure 6: Trade-offs when considering flood risk management options (Source: Greater Wellington Regional Council, 2015)

A final point to note on the overall philosophy of floodplain management planning is to recognise the guiding principles described in the guideline, *Preparing for Future Flooding: A Guide for Local Government in New Zealand* (Ministry for the Environment, 2010). A summary of these guiding principles is provided below:

- Take a precautionary approach;
- Use flexible or adaptive management options;
- Use no or low regrets options;
- Avoid making decisions that potentially compromise future options;
- Progressive risk reduction;
- Integrated sustainable approach.

The Review Panel has taken these guiding principles into account when completing the evaluation of the Regional Council's use of the various flood risk management elements described above for achieving the sustainable flood risk management outcomes as described in *NZS 9401:2008*[4].

3.5.1 IMPLEMENTATION

The Regional Council has a number of initiatives in place or underway to give effect to its various obligations under the legislation, its policies in the RPS, and its responsibilities for floodplain management planning. A schema for how these fit together is set out in Figure 7 below.

Relevant initiatives and strategies include:

- Te Ara Whanui o Rangitāiki: Pathways of the Rangitāiki River (2015), developed by the Rangitāiki River Forum;
- River Scheme Sustainability (in development 2014);
- The Regional Risk Management Framework (Forecast established in 2013, currently being piloted in two areas);
- The Rangitāiki Tarawera Floodplain Management Strategy (in development);
- The Flood Warning Manual (updated 2016) including Standard Operating Procedures.

The Regional Council has very recently commenced a project identifying hazards for the region through its Bay Hazards programme. Flood hazards are being mapped, but it is noted that the Whakatāne/Edgecumbe area is not yet covered.

In addition, there are also a significant number of investigations, reviews and reports on matters relating to flood management on the Rangitāiki plains, and initiatives and projects in train to increase the level of protection.

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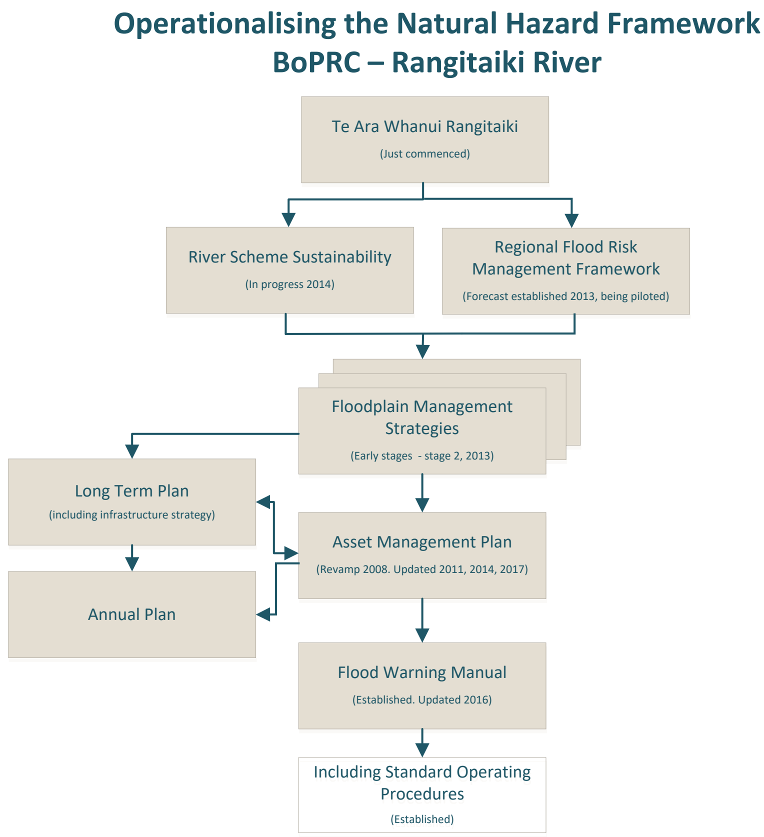


Figure 7: Operational framework for flood hazard management in the Bay of Plenty Regional Council

3.6 Flood event management

3.6.1 ROLES AND RESPONSIBILITIES

A number of different bodies have roles and responsibilities during flood events. The Bay of Plenty Regional Council has responsibility for flood forecasting and monitoring during events, management of the flows through the Matahina Dam in accordance with the *Lake Matahina Flood Management Plan*, monitoring the performance of its assets, (ie flood protection measures) and providing information and advice to the other agencies with responsibilities in flood events.

Trustpower has a role in managing the water levels and flows through the Matahina Dam as set out in the *Lake Matahina Flood Management Plan* (Trustpower, 2016).

Whakatāne District Council has responsibility for protecting the local community. This is set out in the Whakatāne District Council Flood Response Plan 2013.

Civil Defence has responsibility for coordinating the response to the effects of the flood on the community. Others with roles include the Police and Fire Service.

Event management in a natural disaster situation relies upon some fundamental aspects. These include effective communications between the various parties, including the community, immediately affected or otherwise; monitoring of the situation; and on the ground mitigation actions to either prevent or minimise effects of the situation. The Regional Council has a fundamental role in flood events as it is the only agency with all of the information about the impact of any event on river systems and associated flood protection assets.

3.6.2 FLOOD WARNING MANUAL

How the Regional Council manages flood events is set out in the *Flood Warning Manual* (Bay of Plenty Regional Council, 2016). This is a comprehensive document that identifies the roles and responsibilities in an event, triggers for and activation of the Flood Room, staffing and reporting structures, flood management tools, communications, and information and procedures specific to each flood management area (such as the Rangitāiki River). This includes matters such as protocols for communications.

Standard Operating Procedures are appended to the manual. These procedures include protocols with dam operators, and triggers for inspection alarm and issuing of warnings and notifications.

The box below describes the relevant components of the *Flood Warning Manual* for this review.

Regional Council Flood Management roles and responsibilities

Part 2 of the *Flood Warning Manual* describes the role of the Flood Manager and the responsibilities of the Flood Management Team, and the relationships to others with hazard management responsibilities (such as Civil Defence and Emergency Management).

Figure 8 in Section 4.1.1 sets out the role and structure of the team for any significant event.

Communications

Part 4 of the *Flood Warning Manual* outlines the requirements for communications during a flood event. This provides relevant information on who the Regional Council should contact and how. It outlines the requirements for logging of communications and actions, briefings, situation reporting and reporting to the public.

Part 10.3 of the *Flood Warning Manual*, specifically relating to the Rangitāiki River, has particular requirements for communicating with outside parties.

Flood management tools

Section 10.4 of the *Flood Warning Manual* has a comprehensive section on the automated Flood Forecast system, Section 10.10 describes the Flood control system and operation of the Rangitāiki Spillway, including road closure procedures and warnings that need to be made in the event that the spillway operates.

Monitoring

The *Flood Warning Manual* sets out clearly what monitoring is used, and triggers for action. This applies to the nature of forecasts that will trigger the activation of the Flood Room. Triggers include forecasts, modelling of scenarios, and automatic alarms when river levels reach certain levels.

Generic processes are identified in the *Flood Warning Manual* (such as the processes leading to activation), and catchment specific information is also provided with detailed information about trigger levels, specific actions (in the case of the Rangitāiki River catchment detailed procedures are included for communicating with Matahina Dam operators)

The *Flood Warning Manual* (Section 10.12) also identifies specific monitoring procedures for Edgecumbe, and actions to be taken if certain events are observed (for example the pressure relief trench monitoring procedure).

3.7 Legal and planning framework recommendations

a. Efforts to complete the application of the hazard management framework and associated documents should be ramped up to ensure comprehensive cover of all of the region.

b. Particular attention needs to be paid to areas with high vulnerability, such as small rural townships where resilience may be low.

4. The 2017 Rangitāiki Flood Event

This section summarises what happened in the few days leading up to the breach of the College Road floodwall in Edgecumbe at 08:30 on Thursday 6 April. In particular, it describes the Bay of Plenty Regional Council's actions across the Rangitāiki River Scheme in response to the storm arising from ex-Cyclone Debbie. It then goes on to explain a number of potential geotechnical reasons for the breach.

A log of the key events related to the April 2017 flood are outlined in Appendix F. This starts from 3 April, when it became known that a sizeable rainfall event was forecast, until the end of 6 April. This includes key communications made, and the events at the College Road floodwall.

The log is drawn from the substantial amount of information provided by a wide range of sources. Much of it is from the written logs that Trustpower and the Regional Council have submitted as a definitive record. These have been supplemented by people's recollections of the events. Comments and assessments made throughout this report rely upon the actions and observations submitted to the review. The Review Panel is mindful that other actions and communications may well have been carried out but not recorded in the stress of the event.

4.1 April 2017: Flood management by the Regional Council

As outlined in Section 3.6.2 the *Flood Warning Manual* describes the roles and responsibilities during a flood and the standard operating procedures and communications that support the Regional Council's response.

It appears that most of the fundamental requirements were undertaken. A significant departure was that a key staff member had exceeded his duty time during a critical time around the peaking of the Whakatāne River. As a result, one member of staff was left covering both rivers (the Whakatāne and the Rangitāiki) for a period through what proved to be a critical phase of the Rangitāiki event. The possible consequences are discussed below.

4.1.1 MANAGEMENT STRUCTURE

The Regional Council reports that it activated its Flood Room at 09:20 on Wednesday 5 April and it remained active until 17:00 on Saturday 8 April. The management structure adopted for ex-Cyclone Debbie appears to be smaller and differ slightly from the typical structure outlined in the *Flood Warning Manual*.

Figure 8 below summarises the Flood Management Team Structure roles that were filled during the ex-Cyclone Debbie event.

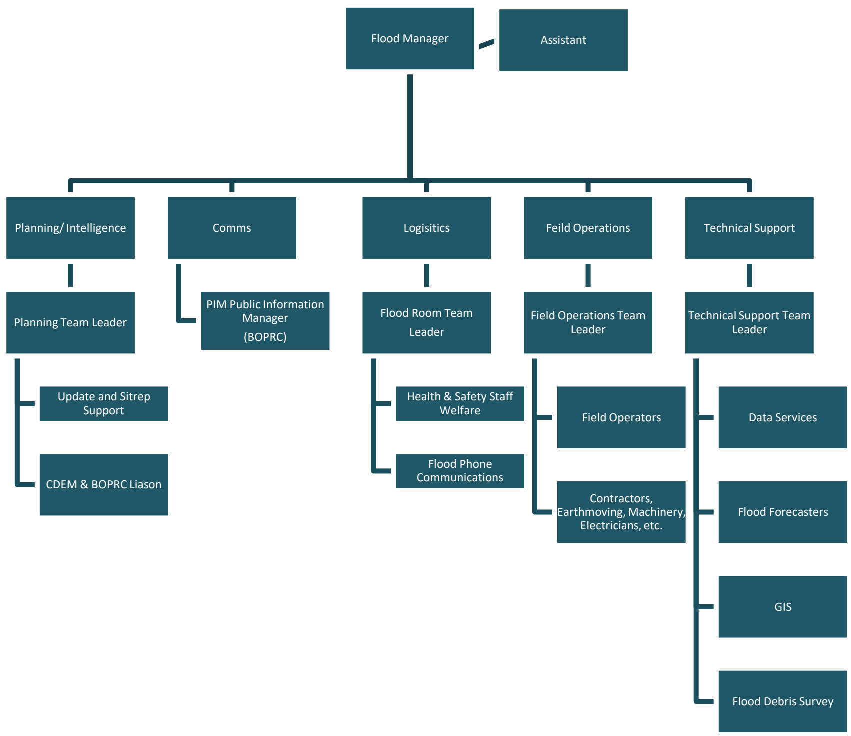


Figure 8: Flood Management Team roles filled during the ex-Cyclone Debbie event (Source: 2016 Flood Warning Manual, Bay of Plenty Regional Council)

The Flood Room was staffed with at least one flood manager and logistics person at all times. However, from 05:30 to 08:00 on 6 April there was only one flood manager on duty as the other had been working (or on call) continuously for 25 hours (comments by staff to the Panel on Friday 26 May). This was non-compliant with Part 2.5 of the *Flood Warning Manual*, which requires that "no person is to be permitted to work more than 12 hours in a 24-hour period" (Bay of Plenty Regional Council, 2016). Advice from Regional Council staff is that preferred practice during an event in the Whakatāne/ Rangitāiki catchments is to keep two Flood Managers on duty at all times (one to manage the Rangitāiki-Tarawera catchment, one to manage other rivers) to ensure that close attention is paid to all catchments. It is apparent from logs and from communications from staff that there was significant concern about the levels in the Whakatāne River, as well as those in the Rangitāiki River. The Whakatāne River was being monitored closely until the critical phase (high tide) had passed. That the length of time staff were on duty did not meet the requirements of the Flood Warning Manual, and that the resourcing of the Flood Room did not meet preferred practice may indicate a shortage of suitably qualified and experienced people to undertake such work.

4.1.2 COMMUNICATIONS

The Regional Council is responsible for direct communications with a number of groups during a flood event (Section 10.3 of the *Flood Warning Manual* (Bay of Plenty Regional Council, 2016)). The detail of the known communications is summarised in Table 2 below with additional detail in the log of Appendix F.

Table 2: Identification of communications with external groups during the ex-Cyclone Debbie event

Group identified	Communications 4-6 April from Bay of Plenty Regional Council
Flood warning groups (farmers and other key stakeholders)	Two warnings sent to landowners downstream of Matahina Dam: • 16:04 4 April – potential for Matahina Dam spillways to be used. Move stock to higher ground. • 16:49 5 April – potential operation of Reid's Floodway.
Trustpower and Pioneer Energy (dam owners/ operators)	See Section 5.1 – Operation of Matahina Dam for further information
Whakatāne District Council/ local Civil Defence Emergency Management via the Emergency Operations Centre (EOC)	Evidence of communications and interaction between the Flood Room and the District Council and Civil Defence has been shared with the Review. Key communications identified are: • 17:00 5 April - Flood Room advised that Reid's spillway and floodway would likely be needed as an overflow and roads should be closed within the 2 hours' notice provided. • Off-duty flood manager briefed EOC staff at 20:40 hours • EOC sent updates from the Flood Room via *Regional Council Flood Management Team*

Group identified	Communications 4-6 April from Bay of Plenty Regional Council
	Situation Reports. 13 reports between 17:00, 4 April and 07:00, 8 April. • Advise to evacuate at 08:10, 6 April.
Police	No evidence of direct communications with Police outside of the engagement with the EOC
Radio stations	Two radio broadcast requests made for warnings to the wider public about: • Warning for Eastern Bay of Plenty Rivers, including start of controlled spilling from Matahina Dam. 06:29 5 April. • Floodway and Reid's Central Canal likely to start working – sent at 17.17 5 April.

Flood Warning Groups

The warnings to Flood warning groups were in accordance with the procedures set out in the *Flood Warning Manual*, and appear to have been sufficient.

Contact with Civil Defence

There is evidence of Regional Council/ Flood Room's occasional contact with Whakatāne District Council and local Civil Defence; however it does not appear to give a particular sense of concern. It is apparent that until the shift change at 08:00 on 6 April, no particular risk had been identified for the Edgecumbe Community, and therefore had not been communicated. It is worth noting here that no specific communication protocols exist within the *Flood Warning Manual* for the Edgecumbe community, other than monitoring. Flood Room staff would therefore be reliant on either information being relayed from stopbank monitoring staff that an issue was developing, or personal knowledge of the capacity of the scheme and any potential risks.

The contact required with Whakatāne District Council and the Emergency Operating Centre (EOC) by the *Flood Warning Manual* is focused on communications about the operation of Reid's Floodway and associated road closures.

The operation of the Civil Defence procedures is out of scope for this review, and the Review Panel has not examined what actions are undertaken by the Emergency Operations Centre in response to warnings issues by the Flood Room.

The Whakatāne District Council has reported a disconnect between the operation of the flood team and the Whakatāne Emergency Operating Centre (Whakatāne District Council, 2017b).

Police

No communications were evident with Police outside of updates provided to the Emergency Operating Centre. Again, it seems likely that there were no unusual or particular perceived risks that would have required police attention.

Radio

Communications over broadcast radio are consistent with the *Flood Warning Manual*. Again, they are focused on the requirements of the rural community, which needed to shift stock, and to be alerted to road closures.

Interestingly, warnings given over the radio were not heard by most community members that attended the drop-in day. Only one couple out of approximately 30 families reported hearing warnings. This may indicate low awareness of standard Civil Defence advice in storm events (tune in to your local radio station). In this case, warnings were broadcast via radio station 1XX.

Other communications

Guidance on public information provided during a flood event is outlined in the *Flood Warning Manual.* The communications provided during the April 2017 flood event are outlined in Table 3.

Table 3: Proposed channels for public information sharing during flood events and what was provided during the April 2017 flood event

Potential channel for public information	Communications 4-6 April
Media releases	No media releases were provided prior to the breach.
Issuing warnings to the media (Radio)	As above – two warnings broadcast via 1XX on 5 April.
Regional Council website	Unclear what updates, if any, were posted on the website during ex-Cyclone Debbie prior to the breach
Regional Council social media	The Bay of Plenty Civil Defence Facebook page included 11 posts between 4 April and the evacuation of Edgecumbe on 6 April. This was primarily about weather warnings, forecasts and surface flooding. Potentially high river levels were not mentioned. The Bay of Plenty Regional Council Facebook page had fewer updates provided.

Given that staff advise there were significant concerns about flooding in the Whakatāne River (posing risks to the Whakatāne community), which, as previously noted, was reaching a critical phase in the early hours of 6 April, it seems somewhat surprising that there were not warnings about high river levels posing possible inundation risks to the community. This is further discussed in Section 5.3 – Evacuation planning.

4.1.3 FLOOD FORECASTING AND FLOOD MANAGEMENT DECISIONS

Flood forecasting and the key decisions about flow of the Matahina Dam based on this forecasting information are an important part of the Regional Council flood management operations. This is assessed in Section 5.1 – Operation of Matahina Dam.

4.1.4 MONITORING

Monitoring of rainfall, river flow and lake levels is discussed in Section 5.1 – Operation of Matahina Dam.

The Regional Council reported that stopbank inspection teams were set up on Wednesday 5 April. These two-person teams worked 12 hour shifts from 19:00 on Wednesday 5 April through to 07:00 Friday 7 April, and completed visual inspections of stopbanks, pressure relief valve outlets and geotechnical monitoring at specific locations along the Rangitāiki River.

The visual inspection results were fed back to the Flood Room for management decisions during the event. This included visual inspections of the College Road floodwall at 01:33 and 05:37 on 6 April. No obvious signs of seepage or observations of concern were reported after either inspection.

4.1.4.1 Community observations of the stopbanks and floodwalls on College Road

Community members raised concerns about stopbank issues in Edgecumbe via Whakatāne Civil Defence Emergency Management and direct calls to the Fire Service and Regional Council. One resident visited the Regional Council Works Engineer raising concerns about water seepage at the wall. The Principal Works Engineer met the Works Coordinator and a contractor at the wall around 08:00 to inspect the wall. The following observations were made:

> "Clear water was seen seeping through the **cribwall** and some seepage through the wall joints…. We also observed a soft spot at the southern end of [the] wall on [the] grass verge above the cribwall".

The local fire station received a call at about 07:45 from a local resident reporting that the stopbank "was leaking". The first truck response arrived at 07:51, followed by a second at 08:06. Fire officers onsite decided to advise residents in College Road between Rata Street and the Library to prepare for evacuation around 08:15. It is noted that this happened in parallel to the Duty Flood Manager from the Regional Council advising the Civil Defence Controller to evacuate Edgecumbe. The decisions and actions around the evacuation are out of scope in this review.

4.1.5 MITIGATION

Once it was realised that there was an issue at the College Road floodwall, the Regional Council Principal Works Engineer, Works Coordinator and a Regional Council contractor decided to undertake mitigation works by putting "some weight on the soft spot and **toe-load**/ some weight along the length of wall for security" (Bay of Plenty Regional Council, 2017b). As a first step, fire officers were asked to remove the walkway handrail so a **membrane** could be laid down. There are conflicting reports on who exactly made the request, but this was a part of the decisions made by the Principal Works Engineer. The Regional Council representatives then left to gather further materials for the mitigation works and continue hot spot inspections.

As the contractor's digger was being unloaded from its transport truck it became apparent that the wall was in danger of imminent collapse and the operation was urgently abandoned.

4.2 The breach

4.2.1.1 The 2017 flood and the failure of the floodwall

An eye witness description of the failure of the floodwall on 6 April 2017 was given by a Regional Council Contractor, the contractor who was present at the wall from soon after 07:30 and through the commencement of the failure. His description of the failure and a sketch follow.

> "On arriving there were people including the fire brigade looking at the wall. On my initial investigation I saw water leaking through the **expansion joints.** The water was clean and clear and I saw no problem with the concrete. As I was talking to the people there the [Works Coordinator] turned up and I discussed the situation with him further, we were standing on the road at the time. We decided before we leave to take one last look along the wall. As we were walking north I noticed the ground heaving and turning spongy on the edge of the retaining wall.
>
> I asked the fire brigade to cut off the hand rail that went around the foot path of the wall.
>
> The river water was 500-600mm below the top of the wall at this time.
>
> As I stood there a fountain of water came out of the ground just on the inside of the retaining wall [cribwall], next to the road. Then it proceeded in approximately 100mm increments north like a fan for about 15 meters [sic]. The water was about 500mm to 1 meter [sic] high in the air. I knew straight away the outcome of this wasn't going to be good so screamed at my truck driver to get in the truck and get out of harms way. I then proceeded to yell to the people around us and in the houses to get to safety. I watched as the ground from road level up push out. Then the concrete wall opened like two gates, with the wall splitting in the middle and water flooding through. The wall edges broke off and were pushed towards the west. At no time did the walls topple over they stayed upright. I then rang the [Works Coordinator] and informed him that it had breached. This was around 8.30am."

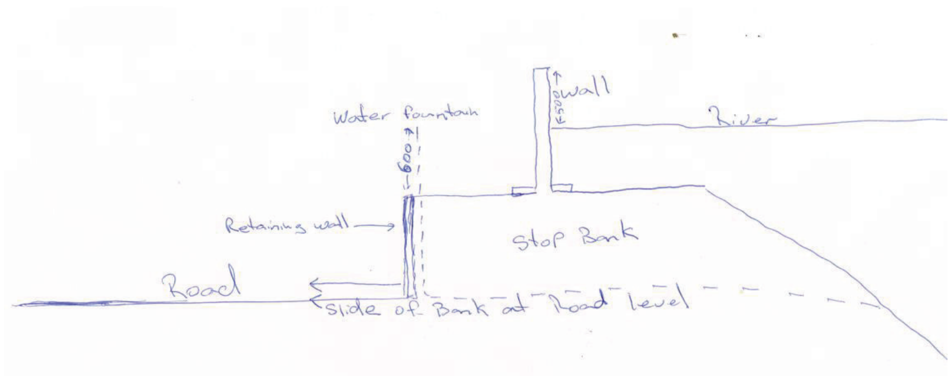


Figure 9: Sketch of the College Road floodwall breach (Source: Regional Council Contractor, 2017)

Subsequent to giving this written statement the observer indicated that he could not be certain where the fountains sprang from, whether from the upper surface above the cribwall or from road level in front of the cribwall.

4.3 The College Road floodwall

4.3.1 BACKGROUND

The geology and makeup of the Rangitāiki floodplains provide challenging ground conditions for flood protection structures, be they stopbanks or floodwalls. The soils which form the floodplains are highly variable and **stratification** is pronounced with layers of pumice sands interbedded with peats and **silts**. It is well known that 'the foundation conditions make the stopbanks prone to **piping** failures under flood conditions' (Opus International Consultants, 2007)

It is clear from the work of various engineers over the years that "Historical and recent scheme experience is that there are substantial issues around the structural strength of the banks and foundations", and as a result there is "some residual risk of seepage (piping) erosion in the embankment foundations, even with rigorous investigations", (Opus International Consultants, 2007).

Coupled with the above geological conditions is the tendency of recently deposited alluvial soils to settle with time as the soil consolidates, and this has been further exacerbated by **subsidence** from the 1987 earthquake. Deposition of sediment in the river corridor has raised the river above the floodplains, and as a result seepage readily passes through the layered soil beneath flood protection structures and rises outside the flood defences.

These issues form the backdrop to the design, construction and, above all, maintenance of flood protection structures along the Rangitāiki River, and the contents of this section of the report should be viewed in this context.

4.3.2 WALL CONSTRUCTION AND HISTORY

4.3.2.1 The early days of the flood protection scheme

The need for a floodwall in Edgecumbe was first identified in the original 1964 Rangitāiki River Major Scheme plans (Bay of Plenty Catchment Commission, 1968) where it states:

> "The main road through Edgecumbe passes close to the river bank here and there is not sufficient room to construct a stopbank. It is proposed to build a concrete wall 4ft to 5ft high over a length of 5 chains".

Two flood protection walls were constructed in Edgecumbe in around 1973 as part of the Rangitāiki -Tarawera Major Rivers Scheme, one between 89 and 101 College Rd, and the second one further upstream between 54 and 64 College Rd, 500m downstream of Edgecumbe Bridge. The latter is referred to as the 'College Road Floodwall' and is the subject of this section of the report. Walls were constructed rather than raising stopbanks to higher levels due to the lack of space for adequate width stopbanks between the first line of properties and the river, and, in the case of the upstream wall, including a road within that space.

The term 'College Road floodwall' in this report generally includes the concrete wall and slab, and the ground which supports it and on which it depends for its stability.

4.3.2.2 The 1987 earthquake

A magnitude 6.5 earthquake occurred in 1987 with its epicentre just north of Edgecumbe. This event caused subsidence of the land to the immediate south of Edgecumbe by up to 2m, and around 0.5m to 1m in the immediate vicinity of College Road, as indicated in Figures 10 and 11. The subsidence of the stopbank system put Edgecumbe and surrounding areas at significant risk from flooding from the Rangitāiki River. The ground continued to settle after the earthquake and by 2002 some areas had subsided by another 0.5m.

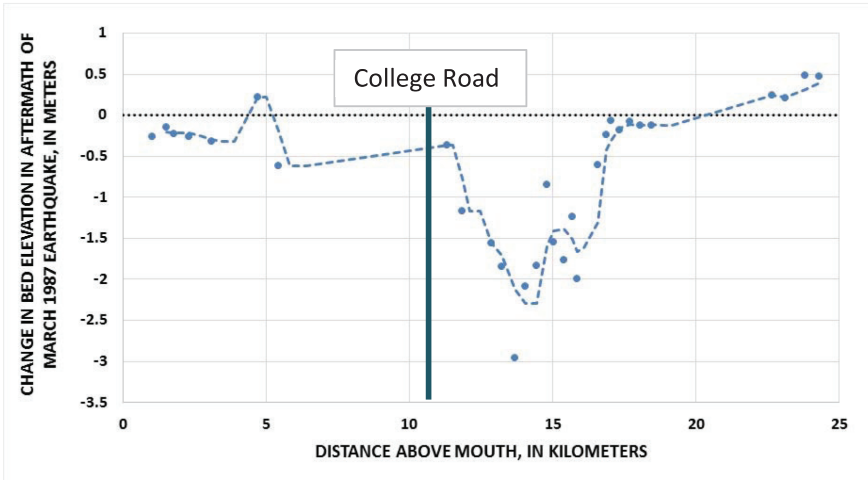


Figure 10: Changes in elevation of the Rangitāiki River bed in the aftermath of the 1987 Edgecumbe earthquake. The dotted line is a 3-point moving average (Source: Cardno, June 2017)

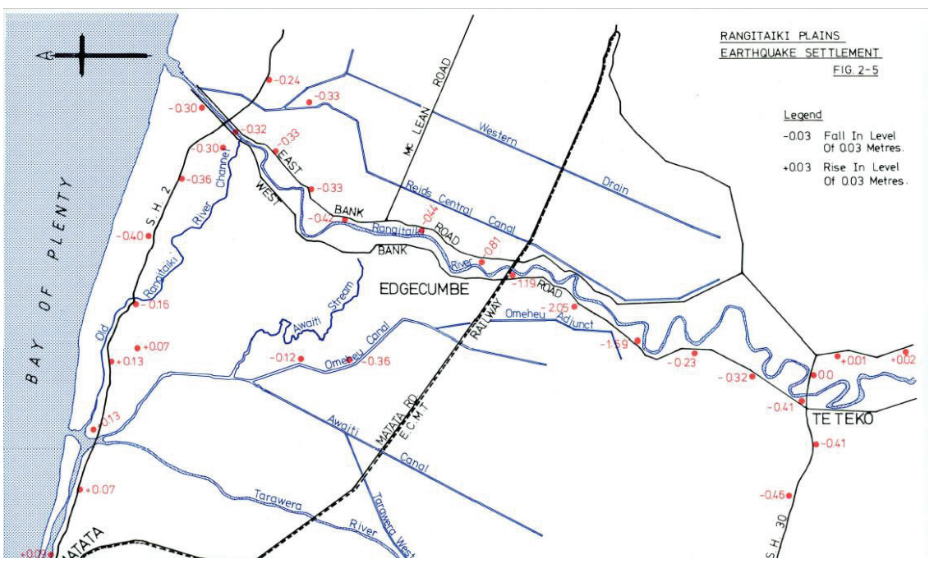


Figure 11: Regional subsidence from the 1987 Edgecumbe earthquake, as recorded in 1987/88 (Source: Bay of Plenty Regional Council)

Slumping of **river berms** had a profound effect on the stopbank system along the river, although major failures of the stopbanks only occurred in areas where foundations were known to be very permeable and where the fault line rupture crossed the river. A report on the effects of the earthquake (Bay of Plenty Catchment Commission, 1987) outlines damage to flood protection structures.

The College Road floodwall is placed in a damage category by itself, IB, being one of only two concrete walls referred to in the damage list (the other being categorised as damage type IC, which includes damage to the concrete itself). The College Road floodwall suffered foundation failure, and the initial estimates of damage rated this section as the most costly of all left bank works on the Rangitāiki River, at $46,350. The damage was described as "river bank slumping" and "foundation failure of concrete walls", requiring "stabilisation of the **toe** above and below the plane of failure is required by placement of rock" and "re-establishment of the original structure" (Bay of Plenty Catchment Commission, 1987). The report provides a Figure to illustrate type I damage (Figure 12).

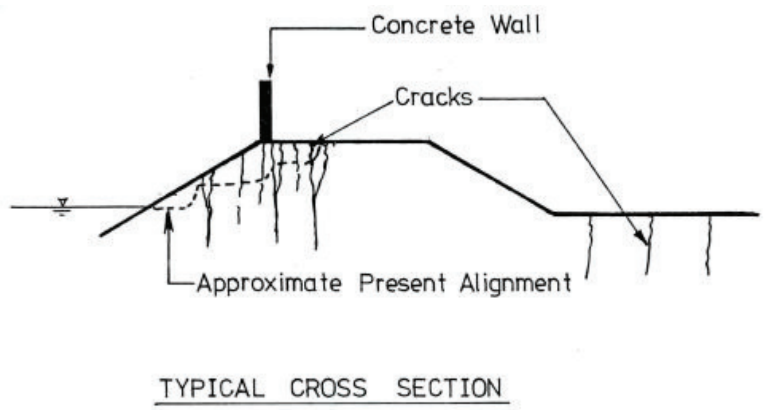


Figure 12: Damage Type I. Slumping of Foundations with Structures on Top (Source: Bat of Plenty Catchment Commission, 1987)

4.3.2.3 Recovery from the earthquake

Extensive stopbank raising and river bank repairs were carried out following the earthquake in order to bring flood protection levels back to an acceptable level. Between October 1993 and January 1994 the downstream floodwall at Edgecumbe, initially 620mm high, was raised by 680mm, the stem thickened, the base extended to maintain its stability under load, and a 400mm deep key added to the riverside end of the slab to improve stability and seepage control.

4.3.2.4 The design and construction of the College Road floodwall

Two options were considered for the upstream wall between 54 and 64 College Road (the "College Road" floodwall). The option implemented was to remove the existing 2ft (610mm) high wall entirely and to construct a 98m long, 1.4m high wall in its place with a design crest level of 6.85m**RL** (Figure 13). The contract documents indicate that two 5m long sections of the old wall were to be “re-established” at each end of the new wall.

The contract documents for the remediation work on the walls included earthworks. However, all of these earthworks were associated with the alternative option, which was not implemented. There was no requirement for any constructive earthworks for the option implemented. Instead the construction drawings required that the existing stopbank be *lowered*: “existing stopbank lowered to R.L. equal to top of footing RL”, Drawing 93-02 R674, sheet 2 of 4 dated August 1993 (Bay of Plenty Regional Council, 1993), Figure 14. The drawings also required the wall to be constructed “on the same location as the old wall”.

All of this suggests that the 1993 wall was constructed on the same foundation on which the 1973 wall was built. The possibility that some fill may have been placed in this area after the 1987 earthquake cannot be ruled out on the basis of the available information, but any earthworks carried out on the ground directly under the concrete wall itself could only have been done during the period between removal of the old wall and construction of the new, and this was not included in the new wall construction contract. The fact that “foundation failure” (Bay of Plenty Catchment Commission, 1987) had occurred to the wall during the earthquake suggests that some earthworks should have been needed to repair the underlying foundation fill. It appears that none was done.

4.3.2.5 2017 investigations

Recent investigations carried out since the breach have found fill consisting of a weathered rock material known locally as “rotten rock” beneath the wall. This is a weathered Greywacke rock commonly used in Regional Council works, and is supplied as “quarry floor scrapings” without a specification or any control on its properties. This material is not found naturally on the site and would have been brought in from a nearby quarry. A number of quarries exist not far away in the Awakeri area, and further afield, and different quarries are likely to have been the source for this at different times. “Rotten rock” was also used to rebuild the river berm adjacent to the College Road floodwall following erosion during the July 2004 flood.

4.3.2.6 The 1993 wall

The original (1993) design drawings indicate the wall crest design elevation to be 6.83mRL. Following the April 2017 flood event the crest of the remaining intact part of the wall has been shown to lie between 6.74mRL and 6.761mRL. Assuming the wall to have been constructed at the design elevation it appears to have subsided by some 8cm since construction, suggesting that the 0.5m of subsidence found to have occurred in years subsequent to the earthquake had mainly occurred during the period 1987 to 1993, or did not occur in this immediate area.

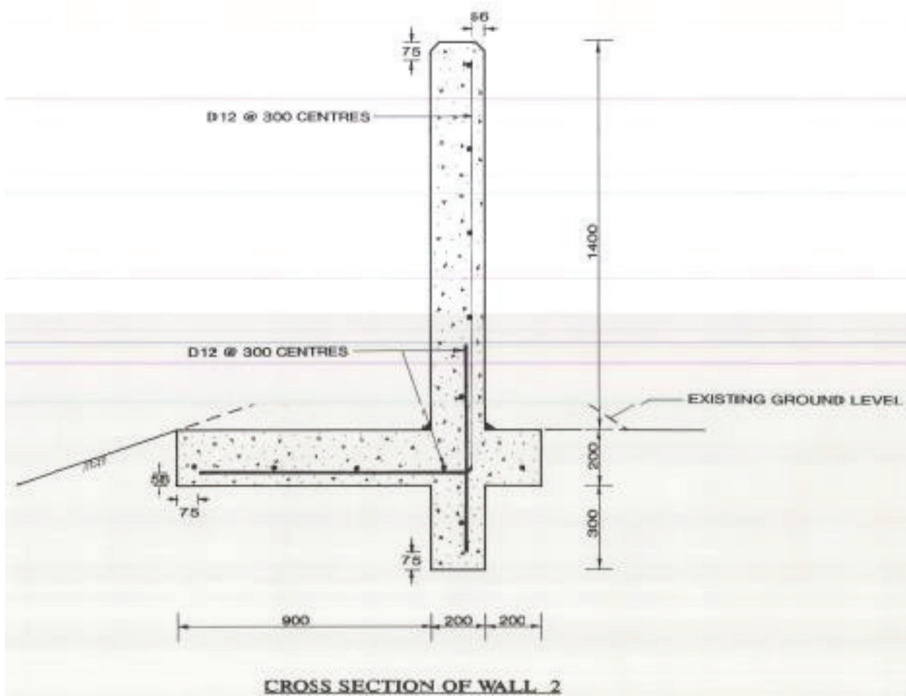


Figure 13: Cross Section of the 1993 College Road Floodwall (Source: Bay of Plenty Regional Council, 1993)

4.3.2.7 The 1998 Flood

A major flood event in July 1998, which was the first to cause water levels to rise above the original **river bank crest** level since the wall was constructed in 1993, caused seepage and slight heave of stopbanks in Edgecumbe township. Following an initial assessment of stopbank stability shortly after the 1998 flood event Opus was commissioned to carry out subsurface site investigation and additional analyses to assess the effects of the subsurface conditions on the stopbank performance in five areas, including the College Road floodwall.

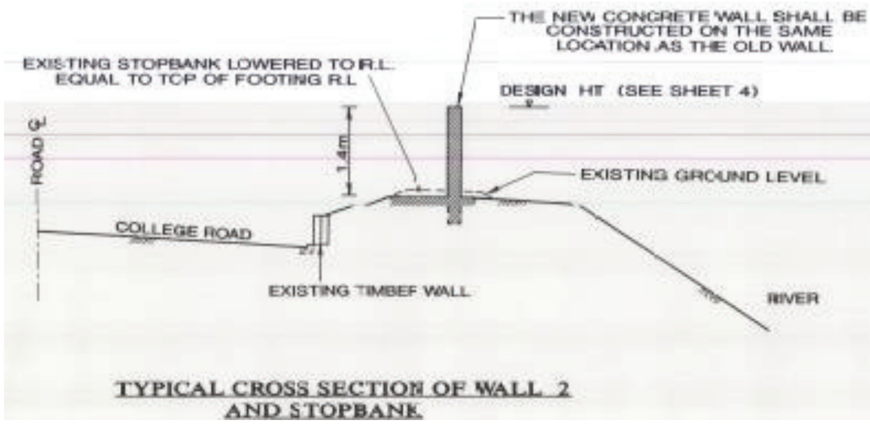


Figure 14: Typical Cross Section of the College Road Floodwall and Stopbank (Source: Bay of Plenty Regional Council, 1993)

4.3.2.8 The Floodwall Toe Drain

Opus's work concluded that the wall and stopbank on which it was constructed had inadequate **factors of safety**, and that vertical exit **hydraulic gradients** were high. They recommended that drainage be improved by the installation of **a cutoff drain** along the landward toe of the wall, with a cribwall overlying the drain and supporting the stopbank toe. These drainage works were designed by Opus in 1999, the design drawings signed off in December 1999 and their construction was commenced in May 2000. The drain arrangement shown on the tender drawings stamped 'EBOP Plan No R723' is shown in Figure 15.

The **toe drain** consists of a 2m deep trench lined with **geofabric** and filled with "**drainage metal**". The cribwall sits on top of the riverside side of this trench, as shown in Figure 15, and the recent investigations have shown that it is filled with a very coarse and open angular gravel/cobble sized free-draining fill. It is usual to use geotextile in these situations, and is explicitly recommended for cribwalls in a similar situation in Section 3.5.4 of the *Regional Council Stopbank Design and Construction Guidelines* (Britton Consultants, 2014)

The river berm adjacent to the wall was eroded away during the July 2004 flood (Ice Geo & Civil, 2006) and was subsequently reconstructed by the Regional Council, and **rip rap** added. This river bank in this area had slumped in the 1987 earthquake.

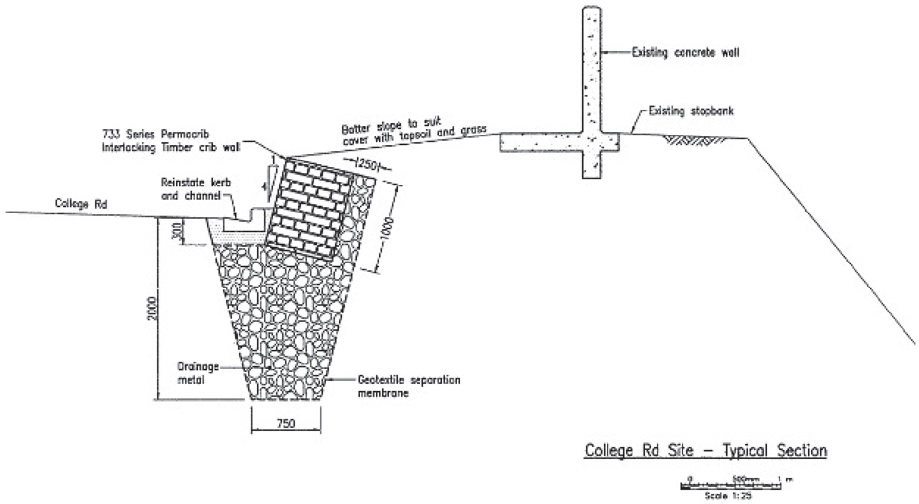


Figure 15: Typical Cross Section of the College Road Floodwall and drainage system constructed in 2000. The spacing between wall and drain shown in the cross section is 'typical' and does not represent the true proximity of the two at the location of the breach (Source: Opus International Consultants, 1999)

4.3.2.9 Installation of the Handrail and "Mowing Strip"

A handrail and concrete walkway ("mowing strip") were constructed over a 20m long section of the cribwall in 2012 as part of the 2km long Rangitāiki River Walkway. These are shown on the photograph Figure 18. The concrete surface was cast to create a wide footpath and wheel chair access past the floodwall, and was approved by the Regional Council under the Authority of the Floodway and Drainage Bylaw, 2002, through an application made by the Edgecumbe Community Board. The Regional Council have indicated that this application was approved by a Regional Council staff member with some 25 years of varied experience on flood protection work, including working closely with their geotechnical specialist.

The concrete slab, about 75mm to 100mm thick, covered the ground surface between the top of the cribwall and the edge of the slab connected to the floodwall. The handrail was installed into footings shown on the Bylaw Application as 300 x 300 x 400mm concrete footings sunk into the top of the cribwall. Details of the arrangement, as submitted on the Application for Bylaw Authority, are shown on Figure 16. This sketch shows the mowing strip at its narrowest and its full extent can be better gauged from the photograph in Figure 18.

Placement of the concrete footings for the steel handrail has been investigated and discussed with the operators who carried out the installation in 2012. The concern of the Review Panel was whether the concrete was fluid enough to flow down into the cribwall fill, and whether a significant quantity was lost in this way. It was established that the footing holes were not lined, but the operators were clear that concrete was not lost into the ground beneath the footings.

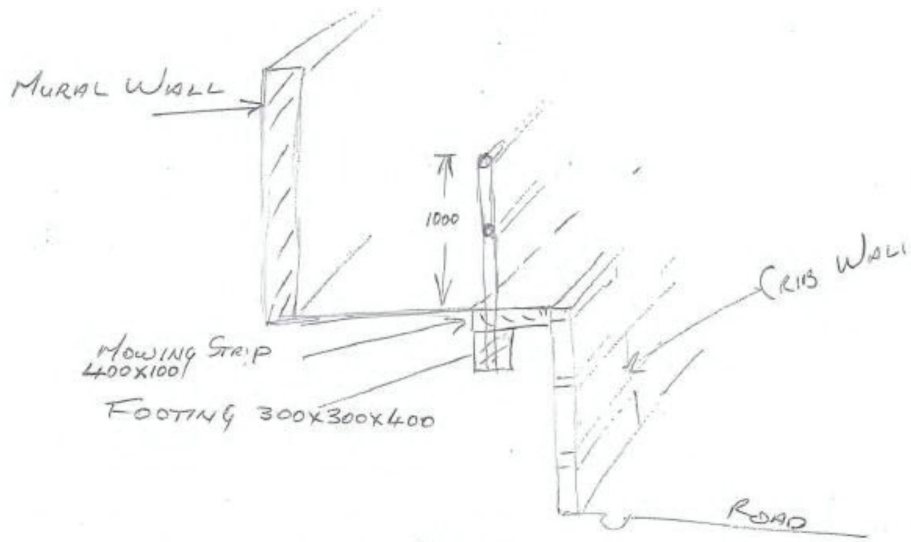


Figure 16: Section through proposed mowing strip and handrail, as proposed on the Application for Bylaw Authority (Source: Bay of Plenty Regional Council, 2012)

4.3.3 FLOODS AND THEIR EFFECT ON THE COLLEGE ROAD FLOODWALL

Two aspects of a flood are of particular importance to floodwall and stopbank stability: the maximum level of the floodwater and the duration of the flood. Maximum water level dictates the maximum pressure that is applied against a structure. This is explicitly and relatively simply allowed for in design. The duration of a flood is equally important, but its effects are not so simple to analyse or to take into account in design. Seepage through soil develops with time, that is, flood duration, and is dependent on the **permeability** of the soil and the continuity of the more highly permeable soil layers. These are particularly difficult to determine with any precision, and while they may be reasonably well approximated in places, this is usually not the case throughout the entire soil profile. This causes difficulties when considering seepage related issues, and both are important factors for the College Road floodwall.

These issues are further complicated when river banks have been reconstructed, as happened here on at least two occasions, following the earthquake in 1987 and after the 2004 floods. This reconstruction would have entailed placement of fill below water level, resulting in segregated material with highly permeable zones containing little fines. Such fill would not provide low permeability material between the river and the wall foundations, and preferential seepage paths would most likely exist.

Two significant seepage related factors which develop as a flood progresses, and need to be kept under control, are the water pressure in the soil (the **pore water pressure**), and the exit hydraulic gradients (the rate of **head** loss through the soil as seepage water leaves the ground at the end of its flow path). High exit hydraulic gradients are responsible for **piping**, a phenomenon which is common in the geological environment along the Rangitāiki River, affecting uniformly graded silts and fine sands in particular. High pore pressures are a problem only where the pore pressure reaches the level of the overlying pressure from soil and structures, at which point uplift occurs and the ground loses its strength and ability to resist any applied load. This is the phenomenon known as "quicksand". The effect of high pore pressures was evident at the floodwall immediately before the breach on 6 April, with heave occurring in a grassed area above the cribwall immediately south of the concrete 'mowing strip' and jetting of water up out of the ground. These are discussed in more detail in section 4.3.2.3.

A further effect which occurs particularly following floods, either from floodwater scour or due to flow in the ground back towards the river as flood waters subside, and also occurs during regular operation of the river, is the creation of caves, or tomos, in the river banks. These eventually cause the overlying river bank (the berm) to collapse, and the loss of these berms has an adverse effect on seepage during flood events. It is difficult to envisage how these can be avoided from flooding, but daily rise and fall of the river may also cause these effects and this should therefore be minimised where possible.

4.3.3.1 Flood levels

The highest river levels at the Edgecumbe floodwall since its construction in 1993 are indicated by Regional Council records to have reached 6.190mRL on 6 April 2017, 6.047mRL on 18 July 2004, and 5.19mRL during the 1998 floods. The base of the floodwall lies at 5.35mRL, and therefore only the 2004 and 2017 flood levels have ever inundated the floodwall, with the 1998 flood only reaching the base slab. The 1998 flood was the first to rise above the level of the original river bank crest since the 1993 wall was constructed (the original river bank has been reconstructed and this level is obscured, but it is assumed to have been roughly at the present road elevation), and was also probably the first since the 1973 wall was constructed. Flood levels in 2011 were some 700mm below the 1998 level upstream at Te Teko, so would not have reached the wall level, but would have risen to just above the level of the road surface on College Road. The river is therefore unlikely to have ever risen against the 1973 wall, and only twice against the 1993 wall.

River levels were sustained above the wall base for 9 hours and 12 minutes during the 2004 floods, and for 5 hours in April 2017 before the wall failure occurred, which are the only times in its history that the wall itself was inundated. The durations of the 2004 and 2017 floods varied somewhat, but the duration of floodwater above the surface level of the College Road, 4.4mRL were similar in the two events, at 12 hours 55 minutes and 11 hours 45 minutes respectively. The 1998 floods were of long duration but were not as high as the 2004 or 2017 floods, inundating only the foundation soils (not the wall) and at a relatively low head.

4.3.3.2 Effects of previous floods on the College Road floodwall

Due to the fact that the 1998 floods only reached the level of the wall base, it is unlikely that they caused significant damage to the very shallow foundation soil immediately below the wall base. However some low level of seepage damage could have been initiated. It is known that seepage under the wall was a problem in this flood, and this is thought to have emanated from deeper high permeability soil layers: Ice Geo & Civil (2005a) reported, in a discussion concerning the left bank immediately downstream of the College Road floodwall, that

> "Seepage under the concrete wall just upstream from the property was a problem in the flood in 1998. Investigations showed layers of sandy fill, silt and peat with coarse sand at 7.0m depth. Due to the short seepage path the sandy layers appeared to have enough permeability to cause a seepage problem and a toe drain was recommended and has been constructed".

The Draft Brief for the investigations which lead up to the recommendation for the toe drain (Bay of Plenty Regional Council, n.d.) was issued "…….in response to some stopbank seepage and slight heaving that occurred during the flood of 11-14 July 1998", and this included investigations for the floodwall.

A sand layer 100mm to 200mm thick with permeability higher than the surrounding ground has been identified at around 4.5m below the base of the wall in this area, with a much thicker layer of sand below 5.5m. These layers are reasonably consistent across **boreholes** straddling the site of the breach and confirmed by four CPTs located adjacent to the road alongside the breach, and may have been the pathway for the seepage.

During the 2004 flood "several areas of seepage and potential heave were noticed along the toes of the stopbanks, mainly within Edgecumbe" (Ice Geo & Civil, 2005a; Ice Geo & Civil, 2005b). However, a questionnaire responded to by residents did not identify any particular issues along the College Road floodwall section, and a review of the Rangitāiki River stopbank stability by Ice Geo & Civil in 2005 does not indicate any damage in this area (Ice Geo & Civil, 2005a). A thorough inspection of the wall after 09:00 on the morning of 18 July, 2004 by the Regional Council, when floodwaters were at their peak, found water leaking through a **construction joint** in the wall. Inspection of the grassed area around the foot of the wall, however, showed that this was firm and no heave was identified. These observations are indicative that the addition of the toe drain along the floodwall in 2000 had had a significant and positive effect on seepage. Opus, 2007, states that following the 1998 flood a number of stopbank improvement works were undertaken including improvements to stability and drainage of stopbanks and floodwall at College road in Edgecumbe, and that "these works appear to have improved the stopbank structural stability of the treated sites as no problems were observed at these locations in the July 2004 flood. Leakage through construction joints in the wall is not significant for the structural integrity of the wall, as each wall section is designed to be stable in its own right.

No reference to damage from the 2011 flooding has been noted.

The river berm adjacent to the College Road floodwall was eroded away during the July 2004 flood, and was subsequently rebuilt with "rotten rock" to a higher level, avoiding the recreation of a berm, and rip rap added to prevent further erosion. This was typical of repairs carried out following the 2004 floods, as indicated in Figure 17.

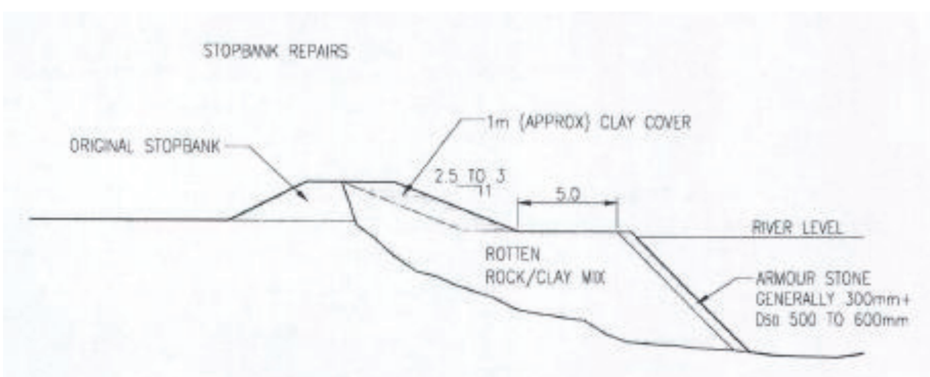


Figure 17: Diagram of typical repairs carried out following the 2004 floods (Source: Opus International Consultants, 2007)

Loss of the river bank adjacent to a stopbank can be a significant issue as this reduces the seepage path beneath the stopbank, leading to higher exit hydraulic gradients, increased flow and increased likelihood of seepage damage. Although no seepage issues have been noted in the vicinity of the wall from the 2004 flood it is possible, or even likely, that some erosion damage may have initiated during the period after the loss of the berm, and in particular during drawdown when the flood waters were subsiding. Some piping damage may have initiated at this time due to reverse flow of seepage back towards the river. The degree of damage to river banks incurred from ramping of the river level during non-flood periods is not known. However, this is likely to cause some loss of material from the banks and to lead to some undercutting. This is currently the subject of a study by Cardno for the Regional Council.

4.3.3.3 The 2017 flood and the failure of the floodwall

The floodwall failed at around 08:30 on 6 April 2017 with floodwaters at an elevation of 6.19m, some 113mm higher than in the 2004 flood. Floodwater had risen up above the base of the wall at 03:30 that morning, for only the second time in its history, remaining against the wall for a period of 5 hours, and above the College Road surface level (4.4mRL) for approximately 11 hours 45 minutes before the breach. This period of inundation above road level is very similar to the 2004 flood (12 hours 55 minutes) but considerably shorter against the wall than in 2004 (9 hours 12 minutes).

The section of wall which breached is pictured in Figure 18, 15-20 minutes before the breach occurred. The image shows the floodwall, the timber cribwall, the concrete walkway and handrail, and the degree of seepage at that point in time. Leakage through the construction joints in the wall and up through the slab, as seen in Figure 18, is thought to be the source of the water that can be seen flowing out of the face of the cribwall at a high level.

Figure 18: The Edgecumbe Floodwall, known locally as 'The Painted Wall', at 08.14 on 6 April, 15-20minutes before the breach (Source: Bay of Plenty Regional Council, 2017)

An eye witness observation of the actual failure as it occurred on 6 April has been made by a Regional Council Contractor and this is provided in Section 4.2.1.1. His observations are crucial to understanding how and why this failure occurred.

The Regional Council Contractor initially observed "the ground heaving and turning spongy" in a grassed area above the cribwall immediately next to the southern end of the concrete walkway and handrail (at the far end of the handrail, as seen in Figure 18). The handrail was then removed by the fire brigade and the Regional Council Contractor prepared to load the toe of the floodwall with "rotten rock". As he stood and watched "a fountain of water came out of the ground just on the inside of the concrete retaining wall, next to the road". This is shown on the sketch by the observer in Figure 9.

In his written statement the observer states that this fountain appeared to emanate from the upper surface immediately behind the cribwall. The fountain rose between 500mm and 1m into the air, which amounts to the full head of river water, or close to the full head, and implies a direct connection between the two. Other fountains then began to appear next to the first and these progressively moved northwards along the walkway for about 15m (the concrete walkway was about 20m long). The ground above road level, that is the cribwall and the ground behind, then 'pushed out' across the road, followed by the concrete wall which ‘opened like two gates’. These wall sections remained upright and did not topple over.

Subsequent to giving the written statement the observer indicated that he could not be certain where the fountains sprang from, whether from the upper surface above the cribwall or from road level in front of the cribwall. However, it is difficult to envisage a discrete ‘fountain’ originating within a large body of coarse drainage material such as that which existed immediately below the road channel, as water pressure would be expected to dissipate throughout the coarse drainage material, and the uplift pressure of around 1.5m at the road level would lift the road surface. Observations suggest that the road surface did not heave, and some seepage did occur at the kerb/tarmac interface during the period leading up to the breach.

Observations by others, supported by one photograph taken at 07:04 (Figure 19), have confirmed that seepage was seen rising out of the surface immediately next to the wall during the last couple of hours before the breach, and that this seepage occurred “the whole way along the wall”, “between the handrail and the wall”, and “around the steel handrail”. The obvious seepage showing in the photograph in Figure 19 appears to emanate from a construction joint in the concrete slab, as does a second seepage point further along the wall. This seepage may come directly from the river side by passing through the joint in the key below ground level, but alternatively it may simply reflect pore pressure escaping from below the slab. Observations were also made by the same observer that some water was flowing up between the tarmac seal and the concrete kerb at the road edge.

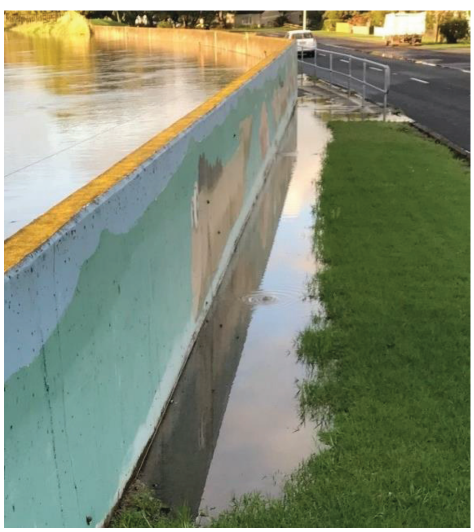


Figure 19: Seepage immediately in front of the floodwall at 07:04 on 6 April, an hour and a half before the breach (Source: an Edgecumbe resident, 2017)

Figure 20: The breached Floodwall at Edgecumbe, looking downstream; image file date-stamped 08:35 6 April, some 5 minutes after the breach (Source: Bay of Plenty Regional Council Contractor, 2017)

Figure 20 shows the wall section closest to the camera still standing upright in the floodwaters immediately after the breach, confirming a sliding failure rather than rotation of the wall. In the foreground a part of the concrete slab previously covering the ground surface between the floodwall and cribwall can be seen severely tilted, with the edge closest to the cribwall having dropped and the other edge lifted to the level of the top of the floodwall. It appears that the ground underlying to concrete surface slide out from beneath the concrete.

Figure 21: The breached Floodwall at Edgecumbe, at 11:00 6 April. Some of the wall sections can be seen still standing upright in the floodwaters some 2.5 hours after the initial breach (Source: Bay of Plenty Regional Council, 2017)

The observation by the Regional Council contractor describes a classic sliding failure of the ground containing the cribwall (and some of the ground behind it), followed by sliding failure of the wall. This is a 'progressive failure'. The descriptions of ground heave in the grass next to an impermeable (concrete) surface, the seepage bubbling up through the joints in the concrete slab, and the fountains of water provide evidence of high pore pressures in the ground on the immediate landward side of the floodwall. These pore pressures were able to rise to the degree indicated by the fountains because of the confining effect of the impermeable concrete surfaces. The pore pressures exerted both lateral load against the ground immediately behind the cribwall and uplift pressure under the concrete walkway and wall slab, reducing the resistance of the ground and wall to the water pressure and causing first the ground and then the wall to slide forward.

4.3.4 THE PERFORMANCE OF THE COLLEGE ROAD FLOODWALL

Much of the evidence as to why the failure occurred was destroyed by the floodwaters as they passed through the breach, scouring a hole into the river bank and removing the remnants of the stopbank and sections of the wall. Little direct physical evidence is therefore available to assist with inquiries over the cause of the failure. Intrusive investigations of the foundation carried out since the breach have therefore concentrated on the remaining parts of the wall and foundation soil next to the breach, and much of the information relied on in this review has been obtained from this and pre-existing reports and historical knowledge.

4.3.4.1 Analysis of the Wall

We have undertaken seepage and stability analyses in order to provide some insight into conditions needed to create the observed phenomena.

Seepage analysis of the 1993 wall arrangement (without a toe drain) supported on fill similar to that assumed in the Opus 2000 analysis confirms that exit gradients are expected to be high under steady state seepage conditions (Opus International Consultants, 2000). This confirmed that modifications to the floodwall, as built in 1993/4, were required to improve its stability under steady state seepage conditions. This was a criteria on which Opus was relying to verify the adequacy of the design.

Seepage analysis confirmed that the addition of a toe drain 2m deep, in the position indicated by the Opus design in 2000, would be expected to control seepage passing through the foundation and eliminate high exit hydraulic gradients. It also confirmed that the presence of the "rotten rock" in the wall foundation in place of **homogeneous** (or anisotropic) silt and sand material as assumed in the Opus design, would not be expected to adversely affect seepage conditions. On the contrary, if homogeneous "rotten rock material has a lower permeability than the underlying silt and sand, saturation of the shallow ground would be slowed and seepage reduced, improving conditions. Irrespective of the fill type, pore pressures under the concrete surfaces on the landward side of the wall were shown to be minimal under steady state seepage conditions, due to the presence of the drain. Even without the drain in place the duration of the 2017 flood was shown to be insufficient for seepage to saturate the ground on the immediate landward side of the wall, assuming homogeneous fill of the types mentioned above. This is somewhat uncertain however, as the condition of the ground in the re-built river bank is unknown.

The above analyses all assumed homogeneous (or anisotropic) foundation soils, without any preferential flow paths. In order for pore pressures to increase under the concrete surfaces on the landward side of the wall the analyses showed that either flow had to be prevented from entering the toe drain (that is, a barrier to flow on the river side of the drain), or a direct connection was needed between the river and the fill on the landward side of the wall (a preferential flow path, or discontinuity). Either of these cases could lead to conditions similar to those observed immediately prior to the breach.

Conditions which could lead to increased pore pressure as observed at the wall breach are examined in the following sections.

Checks on the stability of the wall structure have shown that it had adequate factors of safety against both rotation and sliding, assuming that the drain was functioning, that is, no build-up of pore water pressure occurred within the zone on the landward side of the wall. Our analysis shows that factors of safety for sliding or rotation of the wall as a whole could be expected to be above 1.5 for river water levels as high as the wall crest, assuming pore water pressure is not elevated within the fill on the landward side of the wall. The cribwall itself also had a factor of safety in excess of 1.5 under these conditions. This analysis is sensitive to a number of factors and assumptions, including the strength properties of the ground which can vary considerably, even within a limited volume of ground.

As described by the observer, the cribwall zone initially slid out onto the road by itself, without the wall. The wall then followed. Analysis indicates that sliding of the cribwall zone could have been induced by a head of only around 1m acting in the ground across its 'back' face. This is a very similar pressure to that which would be required to produce fountains 500mm to 1m high from the slab surface, as observed, and verifies that this pore pressure would have been sufficient to cause sliding of the cribwall.

4.3.4.2 Factors in the performance of the floodwall

The Wall Foundations

It has already been established that the 1993 wall was founded on pre-existing fill, rather than on earthworks specifically constructed as a floodwall foundation at the time the wall was constructed. This fill was either placed prior to the construction of the original wall in 1973 or was possibly placed after the 1987 earthquake to elevate the stopbank, but the latter is unlikely for reasons given earlier. No records have been found of the earthworks construction, such as a specification or quality control of the placement, but it is likely that this was placed in a similar manner to that specified (but not implemented) for the stopbank raising at College Road in 1993. This specification requires the fill to be placed in level layers no more 300mm thick, but the only requirement for compaction is that:

> "If the fill is being placed and spread on the stopbank using a tractor drawn scoop, motor scraper or similar machine, the plant shall traverse the length of the stopbank under construction during the delivery of each load and care shall be taken to ensure an even distribution of travel os [sic] obtained over the full width of stopbank formation".

It is notable that this specification treats the fill as "stopbank filling" and does not require formal compaction or quality control, even though the intention was for it to act as a floodwall foundation. Fill for a floodwall is more critical than for that of a stopbank as stresses are higher and seepage paths much shorter than in a stopbank. A higher standard of fill quality should, therefore, be required for a floodwall, which can only be achieved with carefully controlled compaction and quality control.

The Regional Council publication '*Stopbank Design and Construction Guidelines*" (Britton Consultants, 2014) provides an outline of a typical modern specification for fill for stopbanks, and recognises that differences exist between the requirements for new build, repair, adaption and decommissioning. This specification includes specific requirements for placement, compaction and quality control of fill, and provides a typical target density to be achieved for stopbank fill. We consider these to be mandatory requirements to achieve appropriate quality fill. They are viewed as normal practice nowadays, but are likely to have been absent when the floodwall fill was placed.

Acceptable construction practices have changed over the years. It is likely that normal earthworks practice in 1973 would have been similar to, or more relaxed than, the 1993 specification. The earliest stopbanks were constructed on an ad-hoc basis without any specification.

The purpose of quality control of earthworks is to regulate the uniformity of the placed material and its state of compaction in particular, which are fundamental to production of a fill which is fit for purpose. These aspects largely dictate the potential for defects to develop in fill under seepage conditions, for which the main concern would be the presence of layers of segregated coarse particles, and layers of poorly compacted fine non-cohesive soils. Poorly controlled fill with the potential for these types of defects is not suitable for a stopbank and even less for a foundation for a structure as critical as a flood protection barrier.

The "rotten rock" material which forms the foundations for the wall is supplied as "quarry floor scrapings" without any specification, and can, therefore, be expected to be highly variable. In consequence, some variability can be expected between layers, with some consisting of fine materials, some coarse, some comprising segregated larger particles with little fines in between, and some with only fine particles. Fill of this type is highly susceptible to movement of soil particles from seepage forces. It is quite likely that an open pathway developed in the foundation fill at College Road, forming a preferential seepage path as a result. A pathway of this type would have had serious consequences, and could have made a significant contribution to the floodwall failure.

Identification of Foundation Issues

At least two opportunities existed during which potential issues with foundation materials might have been identified. The first of these was in 1993, when the earlier wall was removed and the new wall constructed. The second was when investigations were carried out into the stability of the wall in 1998 (Opus International Consultants, 2000). In each case investigations may have been expected to identify the presence of the "rotten rock" fill (which was not known to be present until the 2017 investigations), and more detailed examination may have provided the opportunity to recognise its condition.

It appears that no investigations were carried out in 1993, even though the wall was recorded as suffering "foundation failure" in the 1987 earthquake. No records have been identified to suggest that this foundation failure was considered in the design of the new floodwall in 1993, or that any investigations were carried out to attempt to identify foundation damage from the failure, such as subsurface fissures which may not have been visible on the ground surface. A fissure underlying the floodwall would be expected to have serious consequences in terms of seepage and wall stability.

In 1998 Opus were commissioned by the Regional Council to carry out subsurface investigations and provide in-depth stability assessments with factors of safety for five sections of the Rangitāiki stopbanks in Edgecumbe, including the College Road floodwall. The assessment was to include calculating factors of safety for the water level at stopbank crest level, and at 0.25 metres below stopbank crest level (water level at half freeboard level).

The College Road investigations included two **GPR** profiles, one of which was conducted along the top of the stopbank and the other along the toe, plus one borehole.

One handwritten comment on the GPR survey plots included in the report is of interest. This survey line is located on the top of the stopbank, and the handwritten comment states:

> "Investigate any of these highly reflective zones and compare with the zone from 140-160m which appears to have little dielectric contrast".

There is no further reference to this in the report, and no sign that it was investigated. It is understood that these reflections were considered by the geophysicist and his judgement was that they were not significant. The borehole was located to the north of the wall, rather than adjacent to it, and encountered silty fine sand fill in the stopbank at that location, and no "rotten rock". Silty fine sand is typical of the type of fill available locally, and design was carried out assuming that the wall foundation consisted of this material. Had the borehole have been placed centrally along the wall, or further intrusive investigations carried out to check on the comments on the GPR records, the presence of "rotten rock" would most likely have been identified and further consideration given to its presence and condition. However, it is quite likely that any layering or particle segregation present would not have been identified in a borehole. A trial pit may have identified this, but excavation of a pit next to the wall could itself have created a weakness and may not have been considered acceptable.

Whatever the reasons for the borehole not being placed directly next to the wall, and no other intrusive work being carried out there, we consider the borehole placement to be a failing of the investigation unless some complimentary intrusive investigation work was carried out adjacent to the wall. None was done, to our knowledge. The reasons for this are unknown, but could include constraints of the contract, such as available budget.

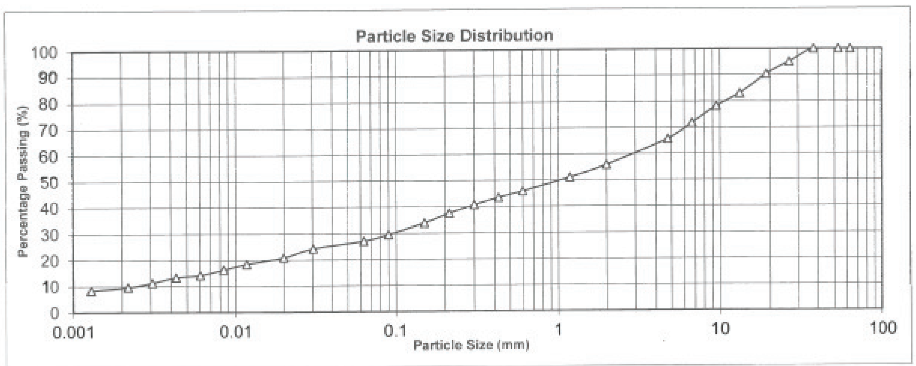
"Rotten Rock"

Investigations in June 2017 identified "rotten rock" to depths of up to 3m below the base of the wall in boreholes within 0.5m of the river side of the wall, and also beneath the slab on the landward side of the wall, in a **trial pit.**

Particle size distributions obtained from samples of the "rotten rock" recovered from the wall foundation indicate that around 25% of those samples of the material is of silt or clay size particles, with just under 10% by weight being clay size particles (finer than 0.002mm), as shown in Figure 22. A homogeneous material with this proportion of fine particles can be expected to have a low permeability, of a similar order to or lower than that of the silt alluvium, and much lower than the typical locally found fine sands which are commonly used in stopbanks. If properly placed and compacted, this material would be expected to provide a good foundation for a floodwall, and even act as a **cutoff** below the wall if it penetrates sand layers. Where it has been placed under water, which may have happened to rebuild the river bank, but probably not the wall foundation, the material will most likely have segregated and formed zones of high permeability. Since the river bank appears to have been rebuilt both after the earthquake and again in 2004 it is quite possible that open channels existed within this zone, providing a foreshortened seepage path to the wall foundation soil.

The simple presence of this material in the wall foundation is therefore not a concern; the concern would be its potential for variability and its condition if placed in an 'uncontrolled' manner, or if fissured.

The presence of layering in the fill could have been identified in a trial pit, but is unlikely to have been picked in a borehole unless it was suspected and appropriate drilling methods used to identify it. However, as any layering present is likely to vary from one place to another, it may not have been identified in any case. It is pertinent that layering was not identified in the trial pit excavated next to the wall in June this year following the wall failure.



% Clay	% Silt	% Sand	% Gravel	Max. Particle Size
9	18	29	44	26.5mm

Figure 22: Particle Size Distribution of "rotten rock" recovered from the wall foundation (Source: Beca, 2017)

Waterstops

The design of the concrete wall included Flexcell waterstop in the construction joints between wall sections all the way from the wall crest to the bottom of the key below ground level. The waterstop between the keys below ground level forces seepage down to the bottom of the key and prevents a shorter seepage path being followed along the underside of the slabs at the construction joints.

Examination of the concrete wall sections indicates that waterstop was not present in all construction joints. Where present, the actual waterstop material itself has been lost in the flood, but it has been possible to visually identify some sections of key which clearly did not have Flexcell forming a seal between the two adjacent concrete edges. Two of these are shown in the photographs in Figure 23.

Gaps at construction joints between the keys would have allowed seepage to pass directly from the riverside to the landward side below slab level without being forced down to the bottom of the key and significantly shortening the intended flow path. This would have had the effect of increasing pore pressure below the base slabs on the landward side of the wall. Seepage which may be attributed to this can be seen in Figure 19, but the source of the seepage seen in the photograph is not obvious.

Figure 23: College Road floodwall - Views of the ends of two of the wall sections, showing the subsurface keys (Source: Bay of Plenty Regional Council, 2017)

It is doubtful that the effect of missing waterstop between the keys could have been solely responsible for the high pore pressures observed, since these only occur at 5m intervals (the length of the concrete sections), but their absence is undoubtedly a contributory factor. A further consideration is that pore pressures were not an issue in the 2004 flood, which had a longer duration above the wall base level and the same waterstops, and therefore seepage through the joints is unlikely to be the primary cause of the increased pore pressures. However, as often happens with seepage damage, it is possible that some damage was initiated here or elsewhere in 2004 and developed further in the 2017 floods.

If flow through these gaps in the keys were the primary origin of the observed pore pressure the pressure would be expected to be most highly developed immediately beneath the concrete. This would have caused uplift under the concrete structure, probably leading to failure of the structure first, rather than the cribwall. A defect connecting the river water directly to the underside of the slab, rather than within the underlying fill, is therefore considered unlikely to be the prime cause of the failure.

Stability reassessment following the 1998 floods

Following an initial assessment of stopbank stability after the 1998 flood event Opus was commissioned to carry out additional analyses and investigations to assess the effects of the subsurface conditions on the stopbank performance in five areas, including the College Road floodwall (Opus International Consultants, 2000). Some aspects of the investigations and analysis have been discussed previously, including the resulting recommendation to install a toe drain.

Recent seepage analysis carried out by the Review Panel supports the general outcome of the Opus (2000) report, showing unacceptably high upward exit hydraulic gradients at the landward toe of the stopbank/wall without the drain in place, and that the drain would be suitable to minimise these. All the analyses show negligible hydraulic gradients once the drain is included. However, examples of the seepage analysis output included in the Opus report indicates some inconsistencies with the modelling of the wall.

Although the outline of the full wall structure is not shown on the output in the Opus report, it is clear that the wall foundation slab has not been included correctly in the presented analysis. The slab appears to have been modelled on the riverside instead of the landward side of the wall. In other words the wall structure was modelled in a reversed position. In addition the base key, 300mm deep on the construction drawings, appears to have been omitted.

The report presents overall factors of safety, without identifying what failure mechanism these represent. By implication from the presented stability analysis output image they probably refer to rotational slippage of the landward stopbank surface, rather than a failure of the wall itself. We would have expected to see factors of safety reported separately for both sliding and rotational mechanisms. However, a failure of the landward slope by itself is akin to

the first part of the progressive failure as observed on 6 April, albeit rotational failure rather than sliding. In this respect the report output is adequate.

Causes of failure

Two factors have been cited as potential causes of the high pore pressures in the stopbank fill on the landward side of the wall. The first of these is the presence of a preferential seepage path through to the river water, and the second is the possibility of a barrier to flow on the riverside of the drain. The former could have arisen from one of the mechanisms already mentioned: layering of the fill, fissures from the earthquake, lack of waterstop in the wall keys, or commencement of piping in earlier floods.

Possibilities for the second potential cause of high pore pressure, a barrier to flow, are more difficult to identify. Some consideration has been given to the potential effect of clogging of the geofabric surround to the trench. Seepage modelling has indicated that in order for clogging to have a significant effect on the pore pressures the fabric would be required to have an unreasonably low permeability. This has therefore been discounted. An alternative is that the ground between the cribwall and the floodwall was itself of a much lower permeability than the fill on which the floodwall sat (the “rotten rock”). However, as pore pressure does not appear to have built up during the 2004 flood this is unlikely to be the prime cause in the April 2017 floods.

The most significant factor that has changed since the 2004 floods is the addition of the concrete surface above the cribwall for the walkway. The effect of this has been to prevent the dissipation of seepage to the surface during the floods, confining the pore water pressure within the ground between the floodwall and the cribwall. This has resulted in an escalation of pore pressure in the ground on the landward side of the wall. Fountains of water first appeared in a grassed area immediately next to the concrete surface, indicative of this pore pressure which was responsible for sliding failure of the ground in this zone.

The addition of the 'mowing strip' concrete surface is a significant contributory factor in the failure. However, in order for the seepage to arrive at the underside of the concrete in the short duration of the flood it is necessary to first have a preferential flowpath, which is considered to be the primary cause of the failure. The concrete surface is considered to be a secondary cause of failure.

4.3.5 CONCLUSIONS

The Review has identified a number of causes which could have contributed to the failure of the College Road floodwall. It is clear that the failure was the result of a build-up of pore water pressure in the ground on the landward side of the wall, and that a progressive failure occurred, first with the cribwall and then the floodwall itself sliding out onto the road.

Two factors appear to have combined to produce these effects: firstly, it is considered that a preferential flowpath was present in the shallow fill, or developed during the flood. A preferential flowpath would be necessary in order for seepage to have reached the area beneath the concrete slabs on the landward side of the wall in the short duration of the wall inundation. It is notable that similar issues did not occur during the 2004 floods, and therefore it is unlikely that this seepage originated simply via porous flow. Secondly, the concrete surfaces on the landward side of the wall, i.e. the slab attached to the wall and the "mowing strip", confined the seepage and prevented it from dissipating to the surface, thus causing the build-up of pressure. As the "mowing strip" was placed in around 2012 it was not in place during the 2004 floods and represents a significant point of difference between the two events.

An alternative mechanism which could potentially account for the build-up of pore pressure would be the presence of a barrier to flow on the river side of the drain. The possibility of the geofabric drain lining being responsible for this has been discounted as its permeability would not be expected to decrease sufficiently to prevent dissipation of pressure into the drain, even in a clogged state. The possibility of concrete placed in footings for the steel handrail forming a barrier to seepage has also been considered and ruled out.

It is likely, however, that failure would have eventually occurred even without the presence of the concrete “mowing strip”, as the seepage would have produced uplift pressures on the wall slab and caused heave immediately next to it, as had been observed in a grassed area at the southern end of the mowing strip shortly before failure. Such heave would have removed the passive support to the wall on its landward side and most likely lead to failure.

Seepage emanating from deeper natural ground is considered to be unlikely to be responsible for this pore pressure. This is because of the depth of “rotten rock” beneath the wall, and the proximity of this “rotten rock” to the drain. It is considered highly unlikely that seepage would bypass the very substantial drain, seeking out a flowpath reaching up to what is effectively a high point on the ground surface.

A preferential flow path in the shallow ground below the wall could have arisen from a number of sources, but two factors are considered to be most significant: firstly, the likelihood that the fill forming the wall foundation was placed without proper quality control, leading to variable fill quality, and secondly the fact that foundation failure which occurred during the 1987 earthquake was not rectified before the wall was reconstructed. Waterstop missing from the keys below the wall slabs is likely to have contributed to the build-up of pore pressures. Damage could have commenced during the 2004 flood, which inundated the wall for 9 hours and 12 minutes before dropping rapidly.

There is a great deal of variation in estimates of floodwater levels on the floodwall by members of the public. An automatic water level monitoring device located close to any critical structures would be helpful to enable accurate water levels to be recorded both for design purposes and for public knowledge of water levels. It would also be useful to have a monitoring point downstream of the Reid’s Floodway spillway from a flow monitoring perspective, which might be fulfilled by a monitoring device here.

It has been noted that the *Bay of Plenty Regional Council Guideline 2014/01* “Stopbank Design and Construction Guidelines” explicitly allows passive pressure acting around the bottom edge of foundation slabs to be included as resistance in the design of structures. Ground in this surface zone is unreliable in terms of either the type of material present, or the likelihood of it being missing altogether for any number of reasons, such as excavation for utilities installation or natural erosion. Passive pressure in this zone should not be relied on in design, and reference to it in section A3 of Stopbank Design and Construction Guidelines should be removed.

Caution should be taken in the application of sophisticated analyses for stopbanks and floodwalls due to the long linear nature of these structures and therefore the high potential for natural variability in the ground conditions along their length. Preference should be given to simple and robust designs which minimise the potential impact of natural ground variability. There will always be some residual risk around flood protection because of uncertainties around ground conditions and, particularly flow paths under flood defence structures. This residual risk can be minimised with detailed investigation, design and construction supervision but will never be eliminated entirely. Emergency planning should consider this risk of failure in establishing alert and evacuation procedures.

Foundations for flood defence walls should be of a higher quality than that of stopbanks due to their higher stresses and the shorter seepage paths in the former. Fill placed for use as a stopbank should not be assumed to be adequate as a foundation for a flood defence wall.

The 1993 floodwall appears to have been constructed on pre-existing fill without due investigation or consideration of damage inflicted by the 1987 earthquake. Investigations should have been carried out both to confirm the condition of the fill, and to investigate earthquake damage. Either or both of these factors may have played a significant part in the wall failure by providing a seepage pathway.

The borehole drilled for the 1998/2000 Opus investigations was located north of the floodwall, rather than part way along it, and encountered different ground to that which has later been found beneath the wall. A more centrally placed borehole would have encountered more representative conditions and may have led to a different outcome.

The degree of damage to river banks incurred from ramping of the river level during non-flood periods as against damage during floods is uncertain, however some loss of river bank material is likely to be caused by the ramping effect. This is the subject of a study currently being undertaken by Cardno, and should be addressed when that report is available.

4.3.6 COLLEGE ROAD FLOODWALL RECOMMENDATIONS

c. An automatic river water level monitoring device should be installed close to any critical structures, such as a floodwall, to enable accurate water levels to be recorded both for design purposes and for public record of flood levels.

d. Passive pressure acting around the bottom edge of foundation slabs should not be included as resistance in the design of structures, and reference to this at the end of section A3 of the Bay of Plenty Regional Council Guideline 2014/01 “Stopbank Design and Construction Guidelines” should be removed.

e. The Regional Council should review the design of, and reconsider any impermeable barriers that they have, or are intending to, put in place near to the landward side of any floodwall or stopbank.

f. The risk to flood defence structures from uncertainties around ground conditions should be minimised by carrying out comprehensive investigation, design, and construction supervision for all stopbanks and floodwalls. Investigations should be located so as to be representative of the ground on which the structure is to be placed.

g. Flood defence structures should rely on simple and robust designs which minimise the potential impact of natural ground variability. Caution should be taken in the application of sophisticated analyses for stopbanks and floodwalls due to the high potential for natural variability in the ground conditions along their lengths.

h. Residual risk to flood protection structures from variability in ground conditions should be taken into account in land use planning and emergency planning, including alert and evacuation procedures.

i. Specifications drawn up for placement of fill for flood defence walls should recognise that a higher quality of fill is needed for floodwalls than for stopbanks, and should be subject to quality control.

j. Consideration should be given to the outcome of a study by Cardno that is currently underway into the effects of daily ramping of river levels on river bank stability as against damage from floods, and appropriate action taken to minimise these effects.

k. The College Road floodwall should not be replaced with another wall, but ways sought to enable a stopbank to be constructed in its place (noting that the properties closest to the breached wall have been acquired by the Regional Council).

l. Floodwalls should not be used in areas characterised by variable and piping prone ground conditions unless specially engineered with extended cutoffs, or riverside blankets to control seepage.

m. The existing fill at the College Road floodwall and the remnants of the floodwall itself should be removed or thoroughly investigated before construction of a new flood defence structure/stopbank. Investigation and inspection of the fill carried out at that time should be used to provide further insight into its condition and significance to the failure.

n. The condition of the foundations of the ‘downstream’ floodwall (89 to 101 College Rd) following the 2017 floods should be investigated.

5. Could the breach have been avoided?

5.1 Operation of Matahina Dam

Since the commissioning of Matahina Dam in 1967 it has been recognised that lowering Lake Matahina in advance of floods provides a useful way of reducing downstream peak flood flows. In 1968 the Bay of Plenty Catchment Commission produced a report titled "*The Operation of Matahina Dam During Floods*" (Bay of Plenty Catchment Commission, 1968). This report provided an operating protocol of lowering Lake Matahina based on information from ten manual upstream rain gauges and two telegauge river level recorders at Kopuriki and Galatea. When a flood of about 15,000 **cusecs** (425m^3/s) was expected, the lake was to be lowered to 240ftRL. It is not clear whether there have been datum changes since this time, especially post the 1987 earthquake, but, assuming there has not been, this would equate to a lake level of 73.15mRL relative to the modern datum (Moturiki), which is equal to the current minimum of the normal **operating range**.

It is not known how effectively this protocol was applied in the intervening years but it was not until 2004, when the largest flood since construction of the dam occurred, that it could have been put to significant use. By this time the dam had been sold to Trustpower and it is unclear what dam flood operating protocols were in place. During the 2004 flood the lake was lowered to 73.9mRL but this was not sufficient to provide any meaningful storage and the full peak inflow of approximately 800m^3/s into the dam was discharged downstream. Trustpower have commented to the Review Panel that the storage that was available in the lake was used on the rising limb of the flood rather than at the peak of the flood under instruction from the Regional Council. A subsequent investigation demonstrated that if Lake Matahina had been lowered to 71.6mRL the 2004 flood peak could have been reduced by 150m^3/s down to 650m^3/s (URS Corporation, 2011).

The current operating protocol for Lake Matahina is described in the *Trustpower Limited – Lake Matahina Flood Management Plan* (Trustpower, 2016). This plan was developed and agreed with the Bay of Plenty Regional Council as part of the reconsenting process for the dam in 2013. The plan describes specific instructions relating to dam operations for minor floods (greater than 300m^3/s) and major floods (greater than 500m^3/s) and relate to resource consent conditions 42 and 43 (Bay of Plenty Regional Council, 2017a).

The key operations as described in section 5.8 of the *Lake Matahina FMP* (Trustpower, 2016) are:

> "Where inflow is forecast to exceed 500m^3/s within the next 24 hours, lake drawdown will be managed by Trustpower to reach and maintain a lake level between 71.6mRL and 70.0mRL before inflows exceed 500m^3/s.
>
> Trustpower shall not however, lower the lake level such that it falls below 71.6mRL without the prior approval of the Chief Executive, BOPRC".

The roles and responsibilities for managing Lake Matahina during flood flows are described in the following sections along with analysis of what occurred during the April 2017 flood event. It is also worth noting that there are two other hydropower operations in the Rangitāiki catchment, Aniwaniwa and Flaxy-Whaeo. The Flaxy-Whaeo is a run of **river scheme** with no notable storage and the current flood operating protocol for Aniwaniwa effectively makes it run of river during floods as well. Further discussion on opportunities for better utilising information and or storage from Aniwaniwa is discussed further within this chapter.

5.1.1 REGIONAL COUNCIL RESPONSIBILITIES

The flood forecasting system for the Rangitāiki River is the key tool that the Regional Council uses for predicting floods and thereby estimating how to **optimise the operation of Lake Matahina** so as to minimise downstream flood flows. The flood forecasting system is based on an automated, multi-basin, non-linear reservoir hydrological model (Bay of Plenty Regional Council, 2015b). The system utilises forecast rainfall from the NZ Meteorological Service (MetService) which is provided in an 8km grid at six-hourly intervals (Bay of Plenty Regional Council, 2015b). The model also uses rain radar information scaled and calibrated to measured rainfall, as well as directly measured rainfall, from rain gauges within the Rangitāiki catchment as well as adjacent catchments.

The general concept of flood forecasting is that the accuracy of the forecast improves as the flood event progresses and the model can use measured rainfall rather than forecast rainfall as well as measured river flows in the upper catchment. The trade-off is that the longer the flood event progresses, the less time there is available to do anything with the information that the forecast provides.

The accuracy of the **flood forecasting model** during an event is highly dependent on the upper catchment rain and river flow gauges being operational. The event timeline provided below describes some of the issues that were encountered during the April 2017 event with a number of rainfall and river level gauges within the Rangitāiki catchment.

It is understood from briefings held with Trustpower and the Regional Council Engineering team that during floods the Regional Council have access to the most accurate flood forecasting information. Trustpower suggested that they have the best understanding of "normal" flows in this system through daily operation and **optimisation** of Lake Matahina for electricity generation. During floods, however, Trustpower are reliant on the Regional Council flood forecasting system to advise them when floods greater than $500m^3/s$ are forecast to occur and when lake drawdown to 71.6mRL is required. On the basis that the Regional Council have the most accurate forecast inflow information it should also be the Regional Council providing specific instructions on the required dam outflows to reach the target lake levels. This is not clear or consistent with the *Lake Matahina FMP* which states that "lake drawdown will be managed by Trustpower" (Trustpower, 2016). This is an important point to note when considering the actions taken during the event.

5.1.2 TRUSTPOWER RESPONSIBILITIES AND ACTIONS

Trustpower are responsible for operating Matahina Dam safely in accordance with their resource consent which includes provisions for specific requests from the Regional Council during floods. The dam safety issues that are particularly associated with a lake drawdown below 71.6mRL described by Trustpower in their briefing with the Review Panel include:

1. the station no longer being able to generate its own power to operate the spillway gates (reliant on local line supply or back-up generators);
2. debris booms becoming suspended, adding to the risk of log jams or damage to spillway gates;
3. greater uncertainty around dam and reservoir slope stability, especially with rapid changes in upstream water levels.

Notwithstanding the above, the *Lake Matahina FMP* does provide the option for the Regional Council to authorise Trustpower to lower Lake Matahina to 70.0mRL during a major flood (Trustpower, 2016).

A summary of key levels relating to Matahina Dam and Lake Matahina is provided in Table 4 below.

Table 4: Key Levels at Matahina Dam

Description	Level (Moturiki Datum)	Comments
Design Flood Level	76.8mRL	Shall not exceed this level in all except "Emergency Condition" situations (as defined in (Trustpower, 2016).
Maximum Normal Operating Level	76.2mRL	Upper limit for normal operations.
Minimum Normal Operating Level	73.15mRL	Lower limit for normal operations.
Minimum Level (flood pending)	71.60mRL	No generation below this level. Spillway gates reliant on mains power or back-up generator.
Extreme Minimum Level (major flood >500m^3/s)	70.0mRL	Approval required from Bay of Plenty Regional Council to go below 71.60mRL to extreme minimum of 70.0mRL.

5.1.3 EVENT ANALYSIS

Table 5 below provides a timeline of the key events and actions that occurred during the April 2017 event. The effects that these actions had on the Lake Matahina water level and dam outflows is shown in graphical form in Figure 24 which was provided by Trustpower to the Review Panel. Trustpower have informed the Panel that the Matahina Scheme inflow (peak 960m^3/s) presented in Figure 24 was derived from approximate calculations undertaken on measured upstream flows. More detailed post event analysis undertaken by Trustpower suggested that the actual peak instantaneous flow was most likely in the region of 920 to 930m^3/s.

There is also a 50mm difference in the minimum Lake Matahina level presented in Figure 24 (71.62mRL) compared with the minimum lake level (71.57mRL) presented in Table 5. Trustpower have explained that they have three water level measuring instruments over the operational range of the lake. The lower level presented in Table 5 was the instantaneous level displayed at Trustpower's Operations Centre during the event, whereas the higher level presented in Figure 24 was from one of the other level measuring instruments. This difference is explained by the different instrument types, calibration intervals, signal frequency and wave action. This explanation is accepted by the Panel and the presentation of the levels available at Trustpower's Operations Centre during the event is considered reasonable.

Table 5: Timeline of April 2017 Flood Event – Operation of Matahina Dam

Time of Request[5]	Request by Bay of Plenty Regional Council	Actual Lake Levels Achieved[6]	Actual Dam Outflows During Period	Review Panel Comments
16:20 4 April	Aim for 71.6mRL by 12:00 5 April. Regional Council advised Trustpower that dam spillway flow of between 30-60m^3/s likely to be required overnight to achieve desired lowering. Regional Council issued warnings of dam spillway operation to downstream landowners.	72.67mRL at 08:00 5 April The lake level would have been 71.90mRL at 08:00 if lowering at constant rate to achieve target level by 12:00.	Machine flow of approximately 140m^3/s through to 08:15 on 5 April. No spillway flow.	Trustpower did not activate dam spillway flows overnight to continue dam lowering. Spillway flows would have been required from midnight to continue lowering. At 08:00 the lake level was approximately 0.75m higher than it could have been if there had been a constant rate of lowering to the target level.
07:30 (followed in writing at 09:18) 5 April	Aim for 71.6mRL by 16:00 on 5 April. Total outflow required 350m^3/s. Peak Matahina inflow based on measured rainfall is only estimated to be 200m^3/s but is > 800m^3/s based on forecast rainfall. At this point three key rain gauges are out of commission (Kokomoka, Ranger and Galatea) along with the water level gauge from Aniwaniwa Barrage. Rainfall for the	71.96mRL at 16:00 5 April.	Dam spillway flow commenced 08:30 on 5 April with total flow increasing from 195 m^3/s to 345 m^3/s at midday. 400m^3/s at 16:00 on 5 April.	Trustpower slow in ramping up flows to 350m^3/s. It is acknowledged that one machine went down at 10:45. Regional Council noting high flood forecast but monitoring actual rainfall before wanting to increase

[5] Time of request based on information supplied by Trustpower
[6] Lake Levels based on instantaneous levels available at Trustpower's Operations Centre during the event

Time of Request[5]	Request by Bay of Plenty Regional Council	Actual Lake Levels Achieved[6]	Actual Dam Outflows During Period	Review Panel Comments
	mid-upper catchment is being based on the rain gauge at Tarapounamu)			flows from the dam to increase rate of lake lowering.
15:32 5 April in writing	Aim for 71.6mRL slightly before 22:00. Peak Matahina inflow based on measured rainfall to 12:00 only 400m^3/s but is still > 800m^3/s based on forecast rainfall. Galatea rain gauge is working at this point but Ranger and Kokamoka still non-operational along with water level gauge from Aniwaniwa Barrage.	71.59mRL at 22:00 5 April.	426m^3/s at 15:30 on 5 April.	No specific instructions given by Regional Council on outflow requirements at this point. Regional Council still noting high flood forecast but actual rainfall (based on limited operational rain gauges) still not predicting a particularly large flood.
17:35 (followed in writing at 18:00) 5 April.	Approval to drop lake level below 71.6mRL to a minimum of 70.0m "…that level may not be attainable in the timeframe". Flows to ramp up to 550m^3/s. Peak Matahina inflow based on measured rainfall 500m^3/s but very high rainfall measured in lower/mid catchment (60mm in 2 hours at Waihua) plus further forecast rainfall suggesting a peak flow of 900m^3/s.	71.57mRL at 21:30	439m^3/s at 18:00 427m^3/s at 19:00 444m^3/s at 20:00 548m^3/s at 20:30.	Regional Council are now on EXTREME high alert and have given approval to go to 70.0mRL and have requested a dam outflow of 550m^3/s (which in itself is approximately a 20-year return period flood) Approximately 3-hour delay in Trustpower ramping up flow to 550m^3/s. Even if Trustpower had ramped up to 550m^3/s immediately the Lake would have only

Time of Request[5]	Request by Bay of Plenty Regional Council	Actual Lake Levels Achieved[6]	Actual Dam Outflows During Period	Review Panel Comments
				been lowered to 71.19mRL. Noted that generation ceased at 20:00.
22:32 5 April (in writing)	Outflow to 600m^3/s. Flood forecasting model now using measured rainfall. Optimisation being undertaken to minimise outflow without exceeding maximum operating level.	71.63mRL	603m^3/s at 22:45	Instruction followed.
23:58 5 April	Outflow to 650m^3/s. Flood forecasting model now using measured rainfall. Optimisation being undertaken to minimise outflow without exceeding maximum operating level.	71.82mRL	644m^3/s at 00:15	Instruction followed.
00:40 6 April	Outflow to 710m^3/s. Flood forecasting model now using measured rainfall. Optimisation being undertaken to minimise outflow without exceeding maximum operating level.	71.96mRL at 01:00 74.12mRL at 10:00	708m^3/s at 01:00. Outflow varied from minimum of 696 m^3/s to maximum of 738 m^3/s between 01:00 and 10:00.	Instruction followed. Acceptable range of outflow given accuracy of spillway gate operating in this range. Generation commenced at 07:30.
09:50 6 April	Outflow to 780m^3/s Flood forecasting model now using measured/calculated inflow. Concern that	74.12mRL at 10:15 74.50mRL at 13:00	799m^3/s at 10:15. Outflow varied from minimum of 783m^3/s to	Instruction followed. Acceptable range of outflow given accuracy of

Time of Request[5]	Request by Bay of Plenty Regional Council	Actual Lake Levels Achieved[6]	Actual Dam Outflows During Period	Review Panel Comments
	maximum operating level would be exceeded if outflow wasn't increased.		maximum of 799m^3/s between 10:15 and 13:00.	spillway gate operating in this range.
13:20 6 April	Reduce outflow to 700m^3/s. Flood forecasting model now using measured/calculated inflow. No longer predicted to exceed maximum operating level.	74.59mRL at 13:30. Max lake level of 75.06mRL at 18:15. Max operating level = 76.20mRL. Max flood level = 76.80mRL.	684m^3/s at 13:30. Outflow varied from minimum of 697m^3/s to maximum of 712m^3/s between 13:30 and 21:15. Note for 15 minutes at 13:15 outflow reduced to 618m^3/s as one of the machines came back online.	Instruction followed. Acceptable range of outflow given accuracy of spillway gate operating in this range. Didn't use all of available storage up to maximum operating level. More accurate inflow information including Aniwaniwa outflows could have been useful.
21:20 6 April (in writing)	Reduce outflow to 650m^3/s	74.98mRL at 21:30.	650m^3/s at 21:30	Instruction followed.

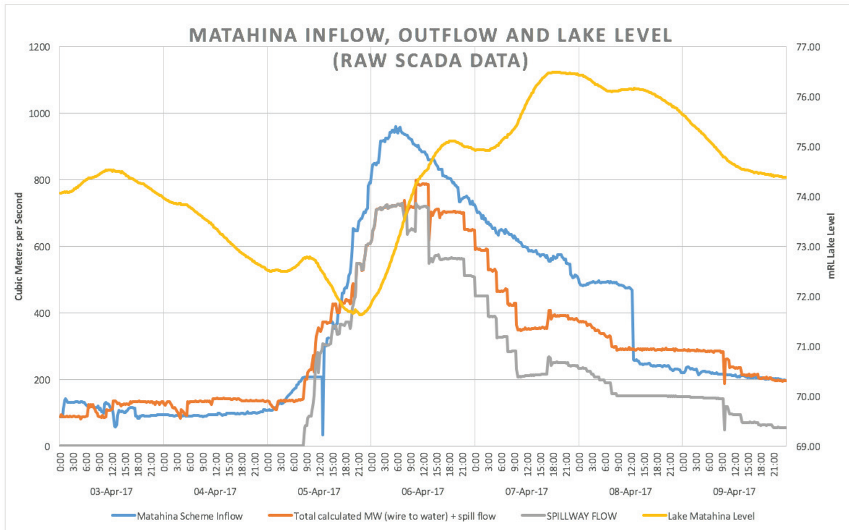


Figure 24: Matahina Dam Operation 3 – 9 April 2017 (Source: Trustpower, 2017)

The event highlighted some inadequacies in the *Lake Matahina FMP*, particularly around communications and clarity of roles: specifically, whether it was the Regional Council or Trustpower managing the drawdown in terms of setting dam outflows. It also highlighted inadequacies in the Regional Council rain gauge and river flow coverage and reliability. These items are discussed in detail below.

5.1.3.1 Event Communications and Roles

Based on the written instruction/request issued by the Regional Council on 4 April at 16:20 it was understood by the Regional Council that Trustpower would continue lowering the lake overnight to be reaching a target of 71.60mRL at midday on 5 April. This was not the case and by 08:00 on 5 April the level was 72.67mRL which was approximately 0.75m higher than it would have been if Trustpower had strictly followed the previous day's request and continued lowering at a constant rate. This represented a lost opportunity to lower lake levels while inflows were relatively low.

There is some conflicting information when comparing the telephone communication logs provided by Trustpower and the Regional Council relating to the period from 07:30 to 08:30 on 5 April. The Regional Council communications log suggests that the midday target of 71.6mRL was still the objective whereas the Trustpower logs suggest that 16:00 was the new agreed time to achieve the target. However, the written communication from the Regional Council at 09:18

clarified that the 71.6mRL target was now shifted to four hours later in the day (16:00) and also requested/advised that, based on the Regional Council flood forecasting model, a flow of 350m^3/s would be required to achieve this. It was not until around 11:00 on 5 April that the lake lowering began in earnest (> 100mm/hr) when flows were increased to 350m^3/s.

At this point there was insufficient certainty in the flood forecast to justify increasing the dam outflows beyond 350m^3/s, which would have been required to lower the lake at a faster rate (i.e. to achieve 71.6mRL by midday). It is worth noting that an outflow of 180m^3/s greater than the inflow is required to lower the lake by 0.3m/hr. By midday on 5 April inflows into Lake Matahina were approximately 250m^3/s.

There were further intermediate telephone discussions and some apparent inconsistencies as to whether the target time for achieving 71.6mRL was still 16:00 or had shifted to 19:00. The written confirmation from the Regional Council at 15:32 clarified that the target of 71.6mRL was to be achieved “slightly before” 22:00.

At 18:00 on 5 April the measured rainfall in the upper catchment had confirmed the earlier rainfall and flood forecast information. It was clear that this was going to be a very major flood. At this point the Regional Council gave approval to Trustpower to go below 71.60mRL to 70.0mRL and to increase discharge to 550m^3/s. Trustpower did not ramp up the flow to 550m^3/s until 20:30. This did not result in any meaningful difference in lake levels with only an additional 400mm of lowering possible if dam outflows had been increased to 550m^3/s at 18:00. Although Trustpower did not strictly follow the instruction as intended by the Regional Council, they were still operating within the *Lake Matahina FMP* which states that “lake drawdown will be managed by Trustpower” (Trustpower, 2016).

The events during the flood drawdown phase highlighted that there appeared to be a lack of clarity around who was managing the dam drawdown in terms of setting the timing of when specific dam outflows had to be achieved. It is acknowledged that this was the first time that the procedures for managing floods >500m^3/s had been tested under the current *Lake Matahina FMP*.

Once the Matahina Dam reservoir began to fill, the instructions for specific dam outflows from the Regional Council were very accurately and quickly achieved by Trustpower. This is highlighted as being equally important for managing downstream flood peaks and acknowledged as being somewhat challenging given the need to maintain constant outflows with a variable lake level. The outflow from the dam via the spillway is shown in Figure 25.

Figure 25: Matahina Dam spillway operating during April 2017 flood (Source: Chris McKeen/Fairfax NZ)

It must also be highlighted that after the breach of the College Road floodwall occurred, flows from the dam had to be increased to $780m^3/s$ to ensure the safe maximum level (design flood level) in the dam was not exceeded. The discharge of $780m^3/s$ was maintained for approximately three hours from 10:00 to 13:00 on 6 April. In the end, this was shown to be somewhat conservative as the maximum lake level that was reached (75.06mRL) was 1.1m below the maximum operating level (76.2mRL) and 1.7m below the maximum design flood level (76.8mRL). This is discussed further below with regard to the accuracy of the flood forecasting system, in particular the upper catchment river flows and outflows from Lake Aniwaniwa.

Overall, it can be concluded that Trustpower's actions did not always match the requests from the Regional Council, particularly in regard to timing. This does not mean, however, that Trustpower's overall management of Lake Matahina during the event was not in accordance with the *Lake Matahina FMP* and the associated resource consent conditions. Crucially, a lake level of between 71.6mRL and 70.0mRL was achieved prior to the peak inflow reaching $500m^3/s$. This, combined with floodplain routing reduced the size of the flood in the downstream Rangitāiki River (at Te Teko) from $920m^3/s$ to $740m^3/s$ (a 20% reduction). The significance of this reduction downstream of the dam was that it reduced what might have been a 200-year flood event to one that was less than a 100-year event. The eventual peak flow of $740m^3/s$ being approximately a 70-year return period flood event based on the existing flood frequency analysis.

5.1.3.2 Accuracy of Flood Forecasting system

During the event a number of key rain gauges and water level recorders were out of commission. It is not clear why these gauges were not operating during the event. There was however a “stand-in” rain gauge at Tarapounamu that provided valuable information on upper catchment rainfall which resulted in the escalation of the event at around 18:00 on 5 April.

It is questionable whether additional rain gauges further up the catchment would have provided any further advanced information than was not already available from the operational gauges at Waihua and Tarapounamu. There does, however, appear to be gaps in the coverage of the rain gauge network for the western side of the catchment as well as the upper Whirinaki.

Delaying the decision to give approval to lower Lake Matahina to 70.0mRL until around 18:00 on 5 April is considered prudent given that it only became apparent at this time that very significant rainfall had actually fallen and that the risks associated with increasing outflows from the dam were justified in continuing to lower the lake as much as possible.

The lack of upper catchment information became more of a factor with regard to optimisation of the dam outflows once lake filling commenced. At this point Lake Matahina inflows should have been reasonably accurately known based on upstream measured river flows. With the water level recorders on the Rangitāiki River at Murupara, Lake Aniwaniwa at Barrage and the Waihua River at Gorge not operational there was a degree of uncertainty around the prediction of inflows into Lake Matahina.

It is understood that the NIWA rated water level recorder downstream of Aniwaniwa Dam was operational and accessible throughout the event but not the spillway or power-house flows from Aniwaniwa Dam itself. The information provided by Pioneer Energy suggests that the NIWA Aniwaniwa tailrace gauge (which is assumed to be the site that the Regional Council refers to as being operational in the email response sent to the Review Panel on 14 July (Bay of Plenty Regional Council, 2017b)) decreases in accuracy when the flow exceeds $400m^3/s$. Relying on this gauge for estimating peak inflows into Lake Matahina is, therefore, questionable.

The spillway and power-house flows from Aniwaniwa Dam could have provided greater certainty on the flow in the river at this point, although there would have still been uncertainty around the Waihua River and other **tributary** inflows that enter the Rangitāiki River between Lake Aniwaniwa and Lake Matahina.

Although the Regional Council flood forecasting models have not been reviewed in detail, it does not appear that they use any form of river flow data assimilation to update the model at the time of forecast using the available river flow measurements. This is somewhat a moot point for this particular flood event, given that a major inflow from the Waihua River, as well as the upper catchment flow measured at the Murupara gauge, were unknown due to failure of the stations and the fact that the accuracy of the NIWA site at the Aniwaniwa tailrace is questionable for large flood flows.

More reliable and additional upstream river flow information, along with direct use in flood forecasting models, is highlighted as being an area for possible improvement. This is particularly so, given the length of the catchment and the possibility of using measured upper catchment river flows to estimate downstream flood flows rather than relying on rainfall-runoff models which have a high degree of uncertainty.

It is considered that the missing river flow information due to non-operation of several key river flow gauging stations and the subsequent reliance on rainfall generated river flow estimates contributed to slightly sub-optimal use of the full Lake Matahina capacity with an additional 1.1 to 1.7m of reservoir storage not utilised at the upper end of the storage range.

5.1.4 ALTERNATIVE SCENARIOS

The Regional Council Engineering team provided a range of alternative Lake Matahina management scenarios in their presentation to the Review Panel. The Panel requested some additional scenarios regarding the operation of Matahina dam to be tested in the existing hydraulic model of the lower Rangitāiki River.

Retrospective analysis undertaken by the Regional Council indicates that if a lake level of 70.0mRL had been achieved then the downstream flows could have been reduced by a further 25 to 30m^3/s, which is a further 3% reduction in addition to the 20% that was actually achieved. This has been considered in terms of the failure of the College Road floodwall by determining how long this would have delayed the river level reaching the level at which the wall actually failed.

It is noted (and discussed further in Section 4.3 – The College Road floodwall) that the failure is not simply a matter of the river level reaching a certain threshold. The duration and degree of soil saturation is also very important. Notwithstanding this, it is still worthwhile to consider the delay in the river reaching this threshold level if the lake had been lowered to 70.0mRL. The outcome from the Regional Council modelling of this scenario, as requested by the Panel, demonstrated that it would have delayed the level of 6.19mRL being reached at the College Road floodwall by approximately one hour.

It is noteworthy that at the point at which the wall failed (about 08:30) that a Regional Council contractor and an employee were on-site and about to begin emergency works to toe-load the College Road floodwall due to concerns over seepage and softness of the road. Earthmoving equipment was just being unloaded when the wall failed at 08:30, so no emergency works were undertaken.

If the failure had been delayed by one hour it is possible that some works could have been completed which may have lessened the likelihood of the wall failing. The Regional Council have estimated that approximately 40 to 50m^3 of weathered rock could have been placed within one hour of operations commencing at this site. The rock was being sourced from the Awakeri Quarry, approximately 8.5km from Edgecumbe. The proposed works were to commence with a toe buttress along the front of the cribwall from road level to the top of the cribwall.

The failure mechanism (See Section 4.3 – The College Road floodwall) was observed to be sliding of the cribwall followed by the concrete wall itself. There is the possibility that if the failure had been delayed by one hour that there would have been sufficient material at the toe of the wall to prevent the initial sliding of the cribwall. It is questionable to whether preventing the sliding of the cribwall would have prevented the failure of the concrete wall above it. Equally, the delay in the failure of the wall could have in fact put the contractors who were working on the wall at risk of being seriously harmed or even killed if they had been in the direct path of the flood waters when the wall failed.

Another plausible scenario resulting from the one hour delay in the river reaching 6.19mRL is that the conditions and subsequent observations at the wall that triggered the mobilisation of the emergency operations could have also been delayed by one hour. If this had been the case, no emergency works would have been done by 09:30 and therefore it is likely that the College Road floodwall would have failed at some point between 08:30 and 09:30.

Based on the above it is therefore inconclusive, but probably unlikely, that failure to achieve a level of 70.0mRL in Lake Matahina, and the resulting possible one hour delay in a river level of 6.19mRL being reached, would have prevented the breaching of the College Road floodwall.

The above analysis and conclusion also applies to not fully utilising the upper end of the reservoir storage capacity. With more accurate inflow information it may have been possible to reduce the dam outflows by 25 to 30m^3/s and achieve the same one hour delay in the critical river water levels being achieved.

It is worth noting that if both the minimum lake level of 70.0mRL and the maximum design level of 76.8mRL had been utilised then there could have been a total of 50 to 60m^3/s reduction in downstream flood flows. If this had been the case, it may have further delayed the failure of the wall and, therefore, allowed emergency remedial works to be further progressed. As with considering either of these scenarios in isolation, it is inconclusive whether this would have prevented the failure of the College Road floodwall. But it is likely that it would have extended the time that emergency works could have been undertaken and thus somewhat reduced the likelihood of failure.

5.1.5 ANIWANIWA DAM

Aniwaniwa Dam is a relatively small structure approximately 10m high with a normal operating range of 0.7m and an associated lake volume of 1.2Mm^3 (1.2 million cubic metres) compared to the 11Mm^3 of storage available in Lake Matahina (See Table 6 below for key levels). Aniwaniwa Dam was purchased by the Southern Generation Partnership with shareholding partners including Pioneer Generation Investments (Pioneer Energy) from Nova Energy in 2016. There is a Flood Management Protocol in place for Aniwaniwa Dam which is described in the *Guidelines for the Drawdown of Lake Aniwaniwa During High Inflows, and the Subsequent Refilling of the Reservoir* (Bay of Plenty Energy, 2012), provided by Pioneer Energy and dated May 2012 (See Appendix G).

Table 6: Key Levels at Aniwaniwa Dam

Description	Level (Moturiki Datum)	Comments
Emergency Spillway	148.6mRL	It is noted that there is substantial storage (4.4Mm^3) between the Maximum Normal Operating level and the Emergency Spillway. Consideration of using the upper range of storage would need to consider dam safety and operational risks as well as the upstream reservoir inundation effects.
Maximum Normal Operating Level	146.8mRL	Upper limit for normal operations. Limited storage (1.2Mm^3) available between normal minimum and maximum levels.
Minimum Normal Operating Level	146.1mRL	Lower limit for normal operations.
Extreme Minimum (inflows >330m^3/s). At discretion of the Generation Engineer.	144.1mRL to 144.9mRL	There is potentially an additional 1 – 2Mm^3 of storage available once the lake is drawdown to 144.1mRL.

The *Guidelines* specify a drawdown protocol for inflows greater than 330m^3/s. The drawdown protocol is to achieve a lake level of between 144.1mRL and 144.9mRL at the discretion of the Generation Engineer when the inflows exceed 330m^3/s. This flow would have been exceeded from around 18:30 on 5 April for approximately 48 hours. It is interesting to note that the refilling protocol provided in the *Guidelines* states that the lake shall remain at the lower limit of 144.1mRL to 144.9mRL while the inflow is greater than 330m^3/s. This effectively means that the lake storage cannot be used to reduce peak flood flows and it is effectively a "run of river" scheme during events greater than 330m^3/s.

The reason for holding the lake at its lowest levels during the period of peak flood flows is for the purpose of flushing sediment deposited at the head (upstream) of the lake down into the deeper downstream parts of the lake below the minimum operating level (Callander & Duder, 1979; Pickens, Leyland, & Duder, 1984). This is a standard method for reservoir **sediment flushing** and is an important operational management tool for maintaining the reservoir storage capacity in catchments with high sediment loads.

A request was made by the Regional Council to Pioneer Energy during the April 2017 event (See Appendix F for communication detail) to provide storage in lake Aniwaniwa to reduce the downstream peak flood flows. This request was declined by Pioneer Energy as the provision of storage is not provided for in the *Guidelines* for operation of the dam during floods and it was unknown what dam safety issues could arise from operating outside the agreed *Guidelines*. This is considered by the Review Panel to be the only prudent course of action that could have been taken during the flood event and that making ad-hoc decisions outside of the agreed protocol would not have been best practice and could have led to significant adverse effects.

Even though storage is not provided as part of the *Guidelines* for Aniwaniwa Dam there is still a requirement for Pioneer Energy to manage the lake levels in accordance with their *Guidelines*. Pioneer Energy have provided lake level information during the event which demonstrates that they followed the drawdown protocol as specified in their *Guidelines* and that they kept the lake between 144.1mRL and 144.9mRL while inflows were greater than 330m^3/s.

Pioneer Energy have offered to work with the Regional Council to explore opportunities for using storage in Aniwaniwa Dam during floods to minimise downstream peak flood flows and to provide more information on dam outflows and lake levels during flood events. The use of storage within Lake Aniwaniwa would have to consider operational dam safety issues as well as the possible adverse effects relating to reservoir sedimentation, which is what the current *Guidelines* are based around managing.

5.1.6 CONCLUSIONS

- Trustpower managed Lake Matahina in strict accordance with the Flood Management Plan and achieved a lake level of 71.57mRL prior to inflows reaching 500m^3/s before the peak of the flood;
- There were difficulties in the communications between the Regional Council and Trustpower and the latter's actions did not always match the former's requests, particularly on timing;
- It is inconclusive, but probably unlikely, that achieving a lower lake level of 70.0mRL during drawdown or a higher lake level of 76.2mRL (or above) during filling would have prevented the failure of College Road floodwall.

5.1.7 OPERATION OF MATAHINA DAM RECOMMENDATIONS

o. Review the Lake Matahina Flood Management Plan with the aim of:

  - discussing and agreeing a clear protocol around forecasts and timing that requires 70.0mRL as the target lake level. This should be particularly focused on achieving 71.6mRL earlier in an event so there is sufficient time to make the decision to give approval to go to 70.0mRL and to achieving that level without excessive spillway flows;
  - developing a template for use in written communications during flood drawdown mode that includes specific details on the timing and rate of outflows required to achieve specified lake levels at specified times;
  - reviewing the target maximum lake level for determining optimum outflow, with the possibility of using a level between maximum operating level and maximum flood level;
  - requesting Trustpower to consider whether modifications can be made to improve dam safety when lake level drops below 71.6mRL including lengthening the debris boom so that it remains functional at 70.0mRL.

p. Review monitoring and maintenance plans for the current rain and river gauge network and improve reliability of operation.

q. Review number and location of upstream rain gauges to improve accuracy and confidence in flood forecasting. Consideration to be given to **spatial coverage** as well as redundancy to provide back-up if one or more gauges are non-operational during an event. The current coverage appears limited for the Upper Whirinaki and entire western side of the catchment in particular.

r. Consider additional/back-up river flow gauges to provide better information on upper catchment flows that will provide opportunities for improved optimisation of dam outflows and use of the upper range of Lake Matahina storage during flood events. This could be combined with an enhanced flood forecasting model that includes measured flow data assimilation up to the time of forecast.

s. Work with Pioneer Energy to investigate the possible use of storage in Lake Aniwaniwa during large floods to further reduce downstream peak flows.

t. Work with Pioneer Energy to provide real-time Aniwaniwa outflows and lake levels to the Regional Council during flood events.

5.2 Reid's Floodway

5.2.1 BACKGROUND

From 1965 to 1980 major flood protection structures were built for the purpose of alleviating flooding on the Rangitāiki plains and providing 100-year flood protection between Te Teko and the river mouth (Britton, R, 2008). The structures included stopbanks, floodways, floodwalls and channel edge protection works. A major feature of the flood protection infrastructure was Reid's Floodway, running parallel to the main Rangitāiki River channel from upstream of Edgecumbe to Thornton.

The design of Reid's Floodway is described in the 1968 Bay of Plenty Catchment Commissions Report – Rangitāiki River Major Scheme Review Volume 1 (Bay of Plenty Catchment Commission, 1964). The 1968 Scheme review provides an overall design flow of 28,000 cusecs (793m^3/s) for the Rangitāiki River upstream of Reid's Floodway, which is effectively the same as the current 100-year design flood of 800m^3/s from the analysis of Blackwood in 2011. The floodway was designed to begin operating at a flow of 21,000 cusecs (59m^3/s) with a peak inflow increasing to 5,000 cusecs (142m^3/s) with the remaining 23,000 cusecs (651m^3/s) flowing down the main Rangitāiki River past Edgecumbe to the sea. Figure 26 shows the general arrangement of the key flood protection works for the lower Rangitāiki Plains proposed in the 1968 Scheme Report.

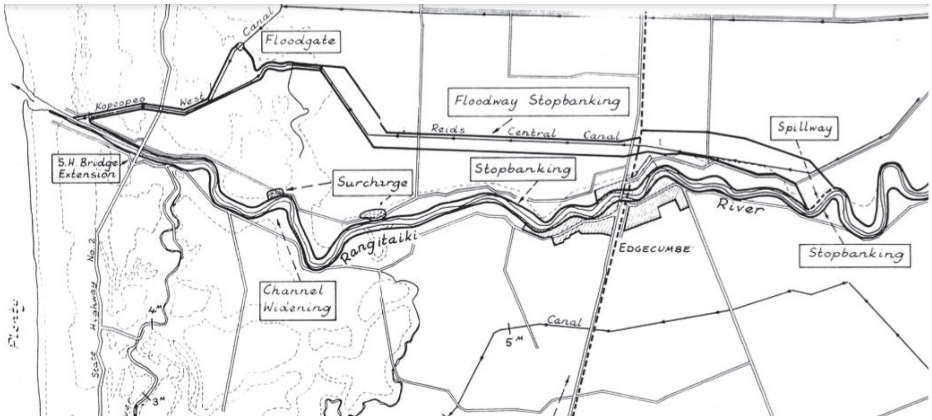


Figure 26: Proposed Rangitāiki Plains Scheme Works (Source: 1968 Rangitāiki Catchment Commission Scheme Report - Volume 4)

An interesting design feature of Reid's Floodway, as described in the 1968 Scheme Review, was that it was supposedly intended to be a flood storage structure as opposed to a **conveyance system**. There is some speculation (Opus International Consultants, 2007) that the restricted capacity in the lower reaches of Reid's Floodway, that made it a flood storage structure, was not the preferred design arrangement but was in fact due to landowners not wanting to give up land to be within the floodway.

Notwithstanding the reason behind the decision to have a narrowed lower section of approximately 50m in width, the design outflow from the system at Thornton was restricted to 2500 cusecs (71m^3/s) which resulted in the need for 2500 cusecs (71m^3/s) (being the net difference between floodway inflow and outflow at the peak) to go into storage. The storage required was therefore 150 x 10^6 cubic feet (4.25Mm^3). As a point of comparison, the storage available in Lake Matahina between 71.6mRL and 76.2mRL is approximately 10Mm^3.

The most significant flood event in recent years, until this year, occurred in 2004 when a major breach of the Rangitāiki River stopbank occurred at Sullivan's bend upstream of Edgecumbe (see Figure 27). The breach occurred at a flow of 690m^3/s (approximately a 60-year flood event) when the floodway had only just started to operate for the first time since its construction in the 1970's. The stopbank breach resulted in approximately 250m^3/s of flood water spilling into the floodway, exceeding its capacity of 85 m^3/s and causing widespread inundation of predominantly rural land to the east of the Rangitāiki River (Opus International Consultants, 2007). This highlighted the limited utility of the floodway. It had never had any floodwater flowing down it since its construction 30 years earlier and it failed to provide any notable benefit during the 2004 flood due to its threshold for operation being set at such a high level.

Figure 27: 2004 Flood showing effects of breach and overflows into Reid's Floodway (Source: Whakatāne Beacon)

5.2.2 FLOODWAY UPGRADE

In 2007 options for mitigating flooding, including an option to increase the capacity of Rangitāiki River and the floodway, were presented in a report by Opus (2007). The report recommended widening the lower 3.7km of the floodway by 50m to a total width of approximately 100m. This would double the capacity to 190m^3/s which would lower the water level in the main river by 0.5m in a 100-year flood event (Opus International Consultants, 2007). This was effectively changing the floodway from its original design of being a storage system to a conveyance system, albeit with a somewhat restricted lower reach of 100m in width. Figure 28 shows the existing lower floodway cross section in blue (approximately 50m wide) and the upper floodway (over 200m wide).

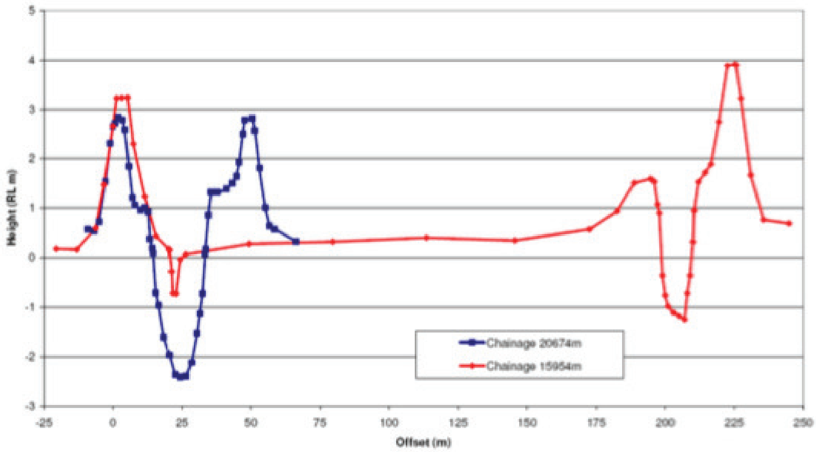


Figure 28: Existing (pre-2010) typical cross sections of Reid's Floodway (Source: Opus, 2007)

Also included in the analysis was an option of only widening the floodway by 20m, which did not provide enough benefit, as well as widening it to 200m, being approximately the same width as the section upstream of McLean Rd to the confluence of the main river. It was reported by Opus (2007) that widening the lower reach out to 200m reduced maximum water levels significantly, "particularly from the SH2 Bridge to upstream of the confluence with the main river channel", with a flood level reduction of 0.88m. Inspection of the model outputs shows that the option to widen the lower floodway to 200m also reduced flood levels by approximately 0.5m from McLean Road to Cross Section 9 when compared with the option to widen the lower floodway by 50m (See Figure 29).

It is interesting to note, given the benefits highlighted above, that the decision was made to recommend widening the channel by only 50m rather than out to 200m. This appeared to be driven by the conclusion that the 50m widening provided adequate benefit and the design flow of 200m^3/s could be "accommodated within the floodway at current design levels" (Appendix 12 – Summary of Scheme Design Parameters Opus, 2009). It was highlighted that this "accommodation" was only marginally achieved as there was still minor stopbank "top-ups" required which would be provided for through longer term asset renewals in the Regional Council Asset Management Plans. On this basis, the 50m widening was concluded by Opus "to be optimal" (Opus International Consultants, 2007).

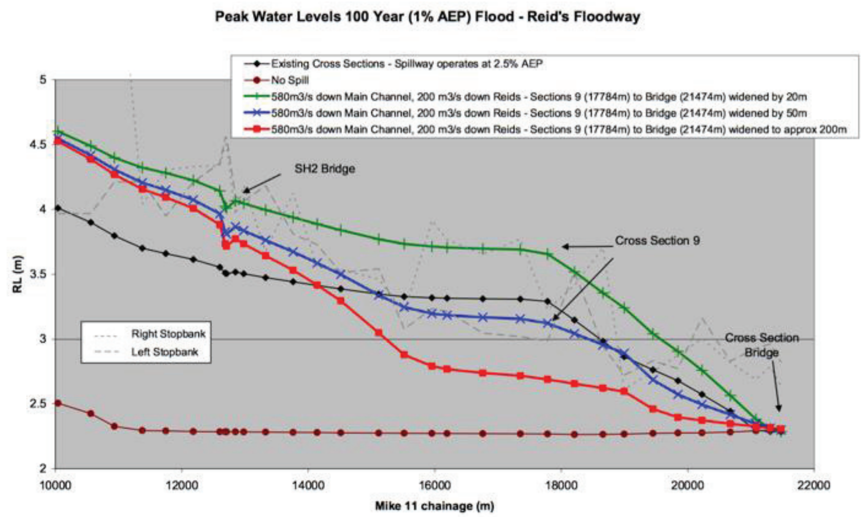


Figure 29: Comparison of Lower Floodway Widening Options (Source: Opus International Consultants, 2007)

It would appear that widening the lower floodway to 200m to reduce flood levels as much as possible to reduce geotechnical risks of failure, and provide more than the bare minimum of freeboard, would have been a more prudent decision at this point. It is however necessary to consider and balance the most prudent technical solution with non-technical implementation issues such as land ownership, community disruption, resource consent constraints, programme urgency and cost. Widening the lower floodway out to 200m, to be the same width as the upper floodway, would have increased the need for landowner negotiations and potential acquisition or compensation for land that would be subject to more frequent flooding. This would have potentially increased the overall costs and resulted in a prolonged programme for completion.

The decision made by the Regional Council to accept the lesser widening option of 50m recommended by Opus suggests that the landowner issues were given higher regard than the fundamental technical (hydraulic and geotechnical) issues for the project. It was these same landowner concerns regarding the "loss" of productive land that faced the Rangitāiki River Commission in 1968, with the original design of the lower floodway and its very restricted width.

It is acknowledged that there would have been potentially greater cost and difficulty with implementation of a 200m wide floodway due to landowner issues but the overriding technical benefits from a geotechnical and hydraulic risk perspective should have been given higher regard in the decision-making process.

Notwithstanding the above benefits and issues of a 200m wide floodway, the lower floodway widening option was limited to 50m, taking the total width to approximately 100m (see Figure 30).

In addition to the lower floodway widening, it was proposed to upgrade the spillway section into the floodway with a **control gate** to enable management of the flow split between the floodway and the main Rangitāiki channel during flood events. It appeared that the control structure's primary purpose was to limit the operation of the floodway to the existing high threshold for operation (that is, a 40-year event). When it was absolutely necessary, in emergency situations such as early signs of stopbank stability issues on the main Rangitāiki River banks, the structure would allow for activation of the floodway at a lower level.

There was no consideration at this point of a lower fixed crest spillway into the floodway to improve its utility and to permanently reduce the pressure on the urban section of the main Rangitāiki channel through Edgecumbe. This again highlighted an overall philosophy of giving higher regard to landowner concerns within and adjacent to the floodway rather than the most prudent technical solution for the benefit of the overall community.

As highlighted in the Opus 2009 resource consent application (Whakatāne District Council, 2009), the stopbanks in the upper reaches of the floodway (upstream of McClean Road) would also need minor "**topping up**". Consequently, a placeholder amount of $800,000 was included in the 2008/2009 Rivers and Drainage Asset Management Plan (Bay of Plenty Regional Council, 2009). The works appeared to be low priority and not required prior to the main Reid's Floodway upgrade work on the basis that they were scheduled to be completed in Year 10 of the Asset Management Plan (that is, completed in 2018/2019). This was some five years after the intended completion of the floodway spillway control structure in 2013/2014. It is not clear whether these works could have been completely avoided, or at least substantially reduced, if the 200m lower floodway widening option had been pursued.

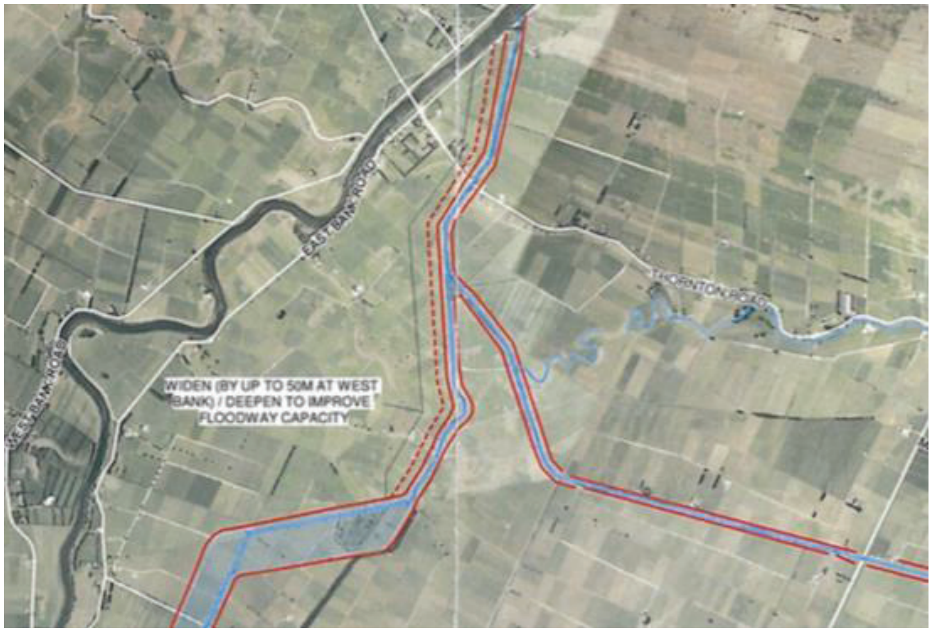


Figure 30: Extent of lower floodway widening indicated by red dashed line (Source: Opus International Consultants, 2011)

The recommendations regarding works in the 2007 Opus report were accepted by the Regional Council and a resource consent application was progressed with the required community and stakeholder consultation and input. In parallel, an application for Central Government funding was made and granted for a total of $3.367M in June 2009. In September 2009 the resource consents for the upgrade of the floodway and modification of the spillway were granted. The consented design included widening of the lower floodway by 50m as well as a 70m wide inflatable rubber dam with a 158m fixed spillway to control flow into the floodway (Opus International Consultants, 2007). The Opus report was peer reviewed as part of the consent process (by Waterline Consultants Limited), and also by the Ministry of Civil Defence and Emergency Management (which engaged an independent consultant). It is highlighted that neither of these peer reviews included a detailed technical review of the hydraulic modelling and hydraulic design.

With the Central Government funding came a requirement for regular reporting on the progress of the scheme. In the July 2010 Progress Report to the Department of Internal Affairs (Bay of Plenty Regional Council, 2010), a five year programme was presented with $5.5M of floodway widening works to be undertaken from 2009/10 through to 2012/13. This was to be followed by the construction of the spillway control structure in 2013/14, estimated at the time to cost $1.9M. This was consistent with the costs and programme presented in the

2008/2009 Rivers and Drainage Asset Management Plan (Bay of Plenty Regional Council, 2009).

The key risks that were highlighted in this report were: the scope of the geotechnical works; landowner acceptance of proposed remedial works; compensation to landowners; and the completion of the SH2 Floodway Bridge by NZTA. The risk of inaccuracies in the hydraulic modelling or design of the floodway or spillway were not identified as risks at this stage in the project. At this point the Public Works Act was mentioned as a possible method for resolving landowner issues but this was considered a last resort.

In December 2010 a peer review of the hydraulic modelling and design of the floodway upgrade was undertaken by River Edge Consulting (2010). The peer review highlighted several areas of concern, namely the change to hydraulic radius as opposed to resistance radius from the previously calibrated model and the apparent lack of bridge contraction and expansion losses. The combined effects appeared to be an overestimate of the flows into the floodway but an underestimate of the flood levels within the upper reach of the floodway. The Opus hydraulic design report (Opus International Consultants, 2011) was issued as “Final” in February 2011 and acknowledges the items raised by the Wallace peer review but there appears to have been a lack of agreement on the resolution of the key issues.

Of importance to note is that River Edge Consulting was at this time undertaking floodplain mapping and modelling across the Rangitāiki - Tarawera Plains as part of the Floodplain Management Plans that were being developed. The modelling tool it was using included 2-dimensional (2-D) representation of the floodplain areas and 1-dimensional (1-D) representation of the main channel sections. The 2-D modelling approach is generally considered more accurate for representing complex flow paths across floodplains as it uses spatially extensive ground topography covering the entire floodplain as opposed to 1-D modelling which uses samples of the topography from surveyed cross sections. The 2-D modelling of floodplains had at this time (post 2010) become accepted best practice in New Zealand and had been used on floodplain investigations since 2005.

The June 2011 Progress Report to the Department of Internal Affairs (Bay of Plenty Regional Council, 2011) highlighted that there had been three notable floods in the Rangitāiki River (once in August 2010 and twice in January 2011) that had resulted in staff efforts being concentrated on repair works. The risk of increased scope for the widening works was again highlighted but the programme still showed two years of floodway widening works for 2011/12 and 2012/13 at a cost of more than $2.5M, followed by the completion of the project with the construction of the spillway in 2013/14.

Details of further works required for the widening works were now becoming apparent, with **seepage relief trenches** and wells, **wick drains** and significant toe-loading works now required to ensure the geotechnical stability of the system. Further to this, the upgrade of the low-level stopbanks protecting pastures from 5-year floods was now becoming a requirement of landowners in the lower reaches of the floodway. It is not clear to what degree these additional geotechnical works would have been needed if the wider floodway option had been pursued, with the resultant lower flood levels and lower stopbanks.

At this point it was also noted that there was "wide divergence of expectation relating to land compensation values". The Public Works Act was again mentioned, but highlighted as being costly and creating significant ill-feeling with the landowners and community.

On the basis of the issues noted above, the programme was pushed out by one year and the cost of the floodway widening works were increased by $0.7M. The estimated completion date with the construction of the spillway control structure was now 2014/15 (a one year delay from the original target completion date), while the cost had increased to $2.24M.

At around this time the upper floodway stopbank raising was inflated in the 2012-2022 Long Term Plan to $1.3M and programmed for completion in 2018/19. At this point it appears that the disagreements around the limitations of the Opus hydraulic modelling and design versus the River Edge Consulting modelling were still unresolved. On this basis, it seemed only relatively minor works were required to top-up the upper floodway stopbanks.

By the end of 2012 the programme and cost for the floodway works was re-evaluated and presented to a workshop (Bay of Plenty Regional Council, 2012b). The geotechnical issues had now escalated to an additional $4.5M above the original estimate of $5.5M (total now being $10M). It was recommended that the 2012/13 capital works were put on hold and carried forward to the 2013/14 year. At the 2012 workshop the floodway widening works were now estimated to be $2.7M for 2013/14, $3M for 2014/15 and $2.7M for 2015/16 with the spillway structure not being completed until 2016/17 (a three-year delay from the original target completion date).

The June 2014 Progress Report to the Department of the Prime Minister and Cabinet reported "very good" progress on the geotechnical strengthening works (Bay of Plenty Regional Council, 2014b). It also reported that previous delays relating to land compensation, land entry agreements and the scope of works, as well as geotechnical issues, had "been resolved". The cost of the geotechnical works had increased by another $1M to a total of $11M but they were scheduled to be completed in 2015/16 in parallel with the spillway control structure (a three-year delay from the original target completion date). The upper floodway stopbank raising was also specifically identified and had been scheduled for completion one year earlier than previously presented in the Long Term Plan (2016/17) for $1.3M.

This 2014 report also mentioned that a review of the spillway structure had been undertaken by River Edge Consulting in 2013 using 2-D modelling techniques which revealed that the consented rubber dam structure would not be adequate for getting the required discharge into the floodway. The consented design produced by Opus using a 1-D model was for a 70m wide rubber dam structure which assumed critical flow over the rubber dam and no downstream hydraulic effects. The River Edge Consulting review (River Edge Consulting Ltd, 2013a) demonstrated that the modular limit was exceeded and the flow was controlled by downstream water levels so that a rubber dam would need to be 180m long to direct the design flow of 190m^3/s into the floodway.

With this major issue identified, Pattle Delamore Partners (PDP) were commissioned to further investigate the details and cost of the longer rubber dam structure as well as consider other alternatives (Pattle Delamore Partners Ltd, 2014). It is acknowledged that one of the Panel Members (Kyle Christensen) was a Technical Director at PDP at this time and was the technical lead for the hydraulic design of the options being considered for the spillway options. This was disclosed to the Panel Chair prior to selection of the Panel and there is not considered to be any conflicts of interest in relation to undertaking this previous technical input.

The 2014 PDP report (Bay of Plenty Regional Council, 2014b) provided an updated cost estimate of $4.6M for the rubber dam as well as analysis of a tipping block spillway ($1.12M) and a lowered fixed crest spillway ($0.4M). The lowered fixed crest spillway was designed to begin spilling at a lower level (river flow = 500m^3/s) compared to the existing spillway that did not begin operating until the river flow reached 680m^3/s. Taking into account the costs of using the floodway in terms of damage to fences and pasture and lost production, and the benefits in terms of reduced flood risk, the lowered fixed crest spillway had a cost benefit ratio of 1.07 (Pattle Delamore Partners Ltd, 2014). The tipping block spillway had a benefit-cost ratio less than 1 (0.92) and the 180m long rubber dam had a benefit-cost ratio of 0.21 to 0.40, depending on how it was operated.

There seemed to be little justification for pursuing any option other than the lowered fixed crest spillway. However, there is a perception from some members of the community that control of the spillway is required to prevent more frequent than necessary operation of the floodway. In their view, if the floodway stopbanks are showing signs of geotechnical issues (such as heaving and piping) then the flow can be reduced and the flow directed to the main Rangitāiki channel.

These arguments would not appear to justify a $4.6M control structure that only has a 4% to 8% chance of operating in any given year (Pattle Delamore Partners Ltd, 2014), especially considering the well-known limitations of the main Rangitāiki stopbank system and the fact that $11M was being spent on upgrading the lower section of Reid's floodway so it could be used more effectively.

Furthermore, the complexity of operating a control gate system during a flood event and the decision making based on “increasing the risk to Edgecumbe” to “reduce the risk to the rural areas to the east” would appear problematic.

Notwithstanding the above, the June 2014 Progress Report to the Department of the Prime Minister and Cabinet stated that targeted stakeholder consultation was being undertaken on the spillway options and there was likely to be the need for a variation to the resource consent (Bay of Plenty Regional Council, 2014b). At the time of the June 2014 report the completion of the spillway was only two years behind schedule and was scheduled to be completed in 2015/16, with the upper floodway stopbank raising being undertaken the following year (2016/17).

By 30 October 2014 a report to the Regional Direction and Delivery Committee (Bay of Plenty Regional Council, 2014c) detailed that the programme for completion of the spillway had been pushed out to 2018/19, being five years behind schedule and three years later than the programme presented four months earlier in the Progress Report to the Department of the Prime Minister and Cabinet. The reason cited for the delay was that further options needed to be analysed to reduce the extent of top-ups of the upper floodway stopbanks. No specific cost was provided for the possible increased stopbank top-ups in the Tarboton (2014c) report.

It appears from the above that at this point there had been acceptance of the limitations of the original Opus design and modelling and that the outputs from the modelling by River Edge Consulting were now adopted as being the appropriate design. This is confirmed in email correspondence from the Regional Council to the Panel on 4 July 2017 (Bay of Plenty Regional Council email, 4 July 2017) which describes communications between the Opus modelling team, River Edge Consulting, and a previous Principal Engineering Hydrologist, Bay of Plenty Regional Council):

> “and in the end Opus conceded that their modelling had flaws. Consequently, [River Edge Consulting’s] modelling has been adopted”.

The adoption of this new hydraulic design profile had major consequences for the scope and extent of the upper floodway raising. Rather than being relatively minor “top-ups”, there was now significant stopbank raising required which had to be done prior to completion of the spillway. The scope of these works were included as part of the draft 2015-2025 Long Term Plan along with an updated programme and cost for completing the overall floodway works. The already planned Stage 3 widening work for $2.7M was scheduled for 2015/16 followed by three years of upper floodway stopbank raising with estimated costs of $3.4M in 2016/17, $2.2M in 2017/18 and $2.54M in 2018/19 (total $8.14M), finishing with the spillway upgrade for $1.74M in 2019/20.

The major delay in now finishing the project was the vastly expanded scope of the upper floodway stopbank raising, requiring three years and $8.14M to construct.

If more accurate modelling had been undertaken at the concept design stage it is possible that the wider lower floodway option would have been pursued and lessened the need for this significant upper floodway stopbank raising. Equally, a more precautionary design approach that recognised the value of lower flood levels in a challenging geotechnical environment could have also resulted in a wider lower floodway.

With the programme for completion of the floodway now pushed out to 2019/20, the Rangitāiki -Tarawera Rivers Scheme Liaison Group requested that the Regional Council staff make a submission on the draft Long Term Plan for the acceleration of the floodway and spillway works as they were unhappy with the further delays in completing the project. A *Deliberations Position Paper* was presented to the Regional Council (Bay of Plenty Regional Council, 2015c) which evaluated an option to accelerate the works by one year but resulted in a cost escalation of $1.46M. The cost escalation was attributed to requiring an additional, higher cost contractor to do the works ($0.68M), requiring external project management consultants ($0.44M) and a contingency of $0.3M. The Regional Council made a resolution at its meeting on 19 May 2015 (Bay of Plenty Regional Council, 2015d) to modify the programme as presented in the draft annual plan to allow for further consideration of options but to keep a completion date of 2019/2020.

The most recent (January 2017) assessment of the works to complete the Reid's Floodway upgrade is shown in Figure 31 below (Bay of Plenty Regional Council, 2017c). The Regional Council has also been undertaking preliminary scoping investigations on a number of options to reduce the extent of stopbank raising in the upper floodway. These options include a secondary outlet to the main Rangitāiki River upstream of Thornton Hall Road Bridge combined with controlled spilling upstream and downstream of SH2 as well as downstream of Thornton Road. The Panel acknowledges that further analysis and consideration of the feasibility of these options is required before the final plan for the works to complete the Reid's Floodway upgrade can be determined. This is discussed further in the Long Term Strategy section of this report.

It is highlighted that the works that are currently being investigated by the Regional Council are in-effect providing the same reduction in flood levels that could have been achieved if the lower floodway had been widened by 200m.

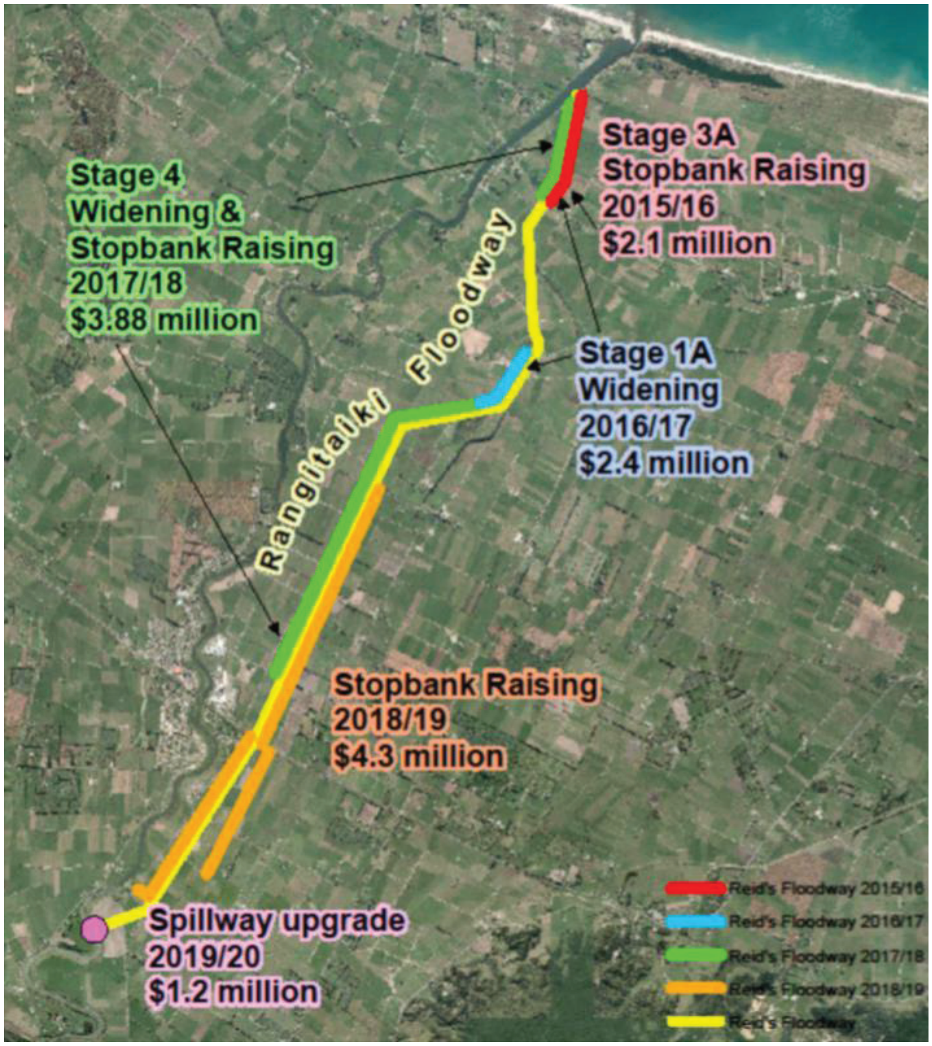


Figure 31: January 2017 assessment of works to complete Reid's Floodway upgrade (Source: Bay of Plenty Regional Council Presentation to RRSR Panel, 8 June 2017)

5.2.2.1 Summary of Delays to Floodway Upgrade

- The original target completion date was 2013/14, with $5.5M of floodway widening and a $1.9M control structure with minor upper floodway stopbank top-ups of $0.8M in 2018/19;
- Approximately a two-year delay was attributable to the 2010, 2011 and 2012 floods as well as protracted negotiations with landowners, plus increased geotechnical works cost escalation of $5.5M, raising the total cost to $11M for the floodway widening;

- Currently at least a one-year delay is attributable to design issues arising from the way the spillway structure was represented in the 1-D model used for the concept (consenting phase) design. A more accurate 2-D model has been used to develop the currently accepted design options which will likely require a new resource consent. The range of costs for the spillway structure is $0.4M for the fixed crest to $4.6M for the variable control gate;
- Approximately a three-year delay is attributable to the extent of floodway stopbank raising not being correctly quantified in the original design/consent in 2007-9 with an $7.2M cost escalation. This work is yet to be completed and scoping design is still being undertaken to try and minimise the extent of works. This is a major issue and would have very likely affected the overall design with regard to the extent of lower floodway widening. This was a hydraulic modelling issue, arising from the limitations of the 1-D representation of complex flow features (e.g. SH2 and McLean Rd skewed bends) in the concept (consenting phase) design compared with the subsequently accepted design based on a 2-D model output;
- The current target completion date is 2019/2020, with options still being considered for spill compartments to minimise or eliminate the need for $8M of stopbank raising as well as a yet to be confirmed or consented control structure costing between $0.4M and $4.6M.

The use of a designation (s166-186, Resource Management Act, 1991) or the Public Works Act 1981 at the outset of the project may have accelerated the programme, but it is acknowledged that this can create ill feeling amongst those directly affected. It can also be cost prohibitive with the requiring authority having to be prepared to purchase all the land covered by the designation.

It is considered that the delays directly attributable to landowner issues to date are relatively minor compared with the other technical issues. Similarly, the works required by the Regional Council relating to flood repairs following the 2010, 2011 and 2012 floods were reasonable and, although it has contributed somewhat to the delay, is not considered to be a fundamental issue.

The failure to complete the project, and the more than 100% cost escalation, are at least in part attributable to issues originating from the concept (consent phase) design:

- an overall philosophy that gave significant weight to concerns of landowners within and adjacent to the floodway rather than fundamental technical issues (geotechnical and hydraulic design);

- this philosophy also resulted in the inclusion in the project of a rubber dam spillway with questionable utility at the upper end of the floodway as well as lower floodway widening that was less than optimum from a technical perspective;
- the resulting narrower lower floodway option had insufficient allowance for geotechnical works (wick drains, toe drains etc.) to support stopbank construction in an environment well-known for being geotechnically challenging;
- limitations in the 1-D representation of the floodway in the concept (consent phase) design meant that the subsequent preliminary design using a 2-D model predicted that the narrower lower floodway option (now already constructed) generated higher than allowed for flood levels in the upper floodway. These higher flood levels would necessitate significant stopbank raising or significant offline spilling or further widening of the floodway;
- limitations in the 1-D representation of the rubber dam spillway in the consent phase) design meant that the subsequent preliminary design using a 2-D model predicted that the structure would have to be more than double the consented length;
- the design of key elements to allow completion of the Reid's Floodway upgrade is currently in an options/scoping phase with consideration being given to a second outlet to the main Rangitāiki River, controlled spilling upstream and downstream of SH2 and consideration of various options for the spillway at the entrance of the floodway;
- following the completion of the options/scoping phase it is likely that a new resource consent will be required along with negotiations with affected landowners to allow the works to be constructed.

If the floodway upgrade had been adequately and accurately scoped in 2007 with consideration of the possibility of significant geotechnical works in the lower floodway as well as significant upper floodway stopbank raising it is debatable whether the project would have proceeded in the form it has currently taken. It is possible that a greater degree of widening in the lower floodway would have reduced (or eliminated) the need for upper floodway stopbank raising, as well as the additional geotechnical work associated with the limited lower floodway widening that was undertaken.

Furthermore, there are fundamental issues in significantly raising the upper floodway stopbanks given the well-known issues with the underlying geology and this would not be generally considered current best practice. This is particularly so given the rural nature of the surrounding area of the upper floodway where there are relatively few constraints to the development of a wider, lower stopbank option or in fact lowering sections of the existing stopbanks to create designated offline spilling compartments. These alternative strategies are discussed further in Section 6 - Long-term strategy and design philosophies.

5.2.3 REID'S FLOODWAY PERFORMANCE DURING APRIL 2017 FLOOD

With the works to enlarge the floodway and improve the spillway not completed at the time of the April flood, the main Rangitāiki River had to take a higher proportion of the total flood flow. The Panel requested information regarding what the flow would have been in the main Rangitāiki River at Edgecumbe if the floodway works had been completed, assuming a lowered fixed crest spillway.

The College Road floodwall failed at about 08:30 on 6 April with a flow of approximately 670m^3/s in the main Rangitāiki River and a flow of approximately 10 to 20m^3/s just starting to spill into the upper end of the Floodway. The river level at College Road was approximately 6.19mRL at the point of failure. If the Reid's Floodway upgrades had been completed, with the lowered fixed crest spillway, the flow in the river at 08:30 on 6 April would have been reduced to 575 m^3/s and there would have been a flow of approximately 120m^3/s in the floodway.

This reduced volume of flow in the Rangitāiki River at College Road would have lowered water levels by approximately 0.45 m. This would have reduced the pressure on the College Road wall during the flood event. It is noted that the peak river level that would have occurred was equivalent to the level that occurred at around 06:15 on the day of the breach. Although the College Road wall handled this level without failing some two hours prior to the breach, the mechanisms that contributed to the breach are such that it is not simply related to the peak water level. The duration of elevated water levels and the subsequent degree of saturation within the stopbank and floodwall drainage system are also key factors that contribute to the overall stability of the wall and the likelihood of failure.

It is not possible to definitively conclude that if Reid's Floodway had been fully enlarged and operational then the College Road floodwall would not have failed but there certainly would have been less pressure on the wall during the flood event.

5.2.4 REID'S FLOODWAY RECOMMENDATIONS

The recommendations for the completion of Reid's Floodway are provided in Section 6 – Long-term strategy and design philosophies.

5.3 Evacuation planning

The evacuation element of emergency management is a key non-structural component of comprehensive flood risk management (Standards New Zealand, 2008). It is most often used for managing the residual risks associated with flood events that exceed the design limit of structural works, such as stopbanks. The effectiveness of an evacuation is closely linked with the ability to provide accurate and timely flood warnings often based on flood forecasting. The Flood Warning Manual (2016) states:

> "The objective (of the flood warning manual) is to mitigate the risk to life and property during a flood".

During the April 2017 event the advice from the Regional Council to Civil Defence to evacuate Edgecumbe was given approximately 20 minutes before the failure of the College Road Floodwall (see Appendix F). At the time this advice was given the Civil Defence controller "had already come to that conclusion" and there appeared to be self-directed as well as Fire Service assisted evacuations occurring around College Road. It is extremely fortunate that no one was seriously injured or killed as a result of the College Road floodwall failure. The fact that the wall failed only 20 minutes after the evacuation advice was given by the Regional Council raises some questions about the adequacy of planning for potential evacuations during major flood events.

5.3.1 BACKGROUND

As highlighted by the Regional Council *Flood Warning Manual* (Bay of Plenty Regional Council, 2016), the primary purpose of evacuation is to remove people (and livestock) from potentially life-threatening situations as well as minimising property damage by allowing people to take their most valued possessions with them. A study completed after the 1986 Georges River flood in Australia showed that flood aware households were able to reduce flood related losses by approximately $10,000 (inflation adjusted) per household with two people-hours of effort (New South Wales Government, 2005).

It is highlighted that evacuation plans are usually developed prior to flood events. They require detailed technical assessments to understand the likely performance limitations of assets for a flood of a particular size, as well as modelling and mapping exercises to identify the areas at risk. There is also a need to communicate the risks to affected communities and ensure that the method of warning (radio, sirens, text, etc.) is understood and accessible. The communication of warnings, co-ordination of the actual evacuation, and subsequent welfare requirements, involve collaboration between territorial authorities, Civil Defence and community organisations.

A second type of evacuation can also be considered in terms of an unexpected asset performance issue that arises during a flood event where an "**emergency evacuation**" is needed. This would typically be identified by asset monitoring during the event and would normally, depending on the type of issue, have a very limited lead time for the evacuation to be undertaken. This type of evacuation could also escalate to a "rescue" situation if it happens after the capacity of an asset has been exceeded. In this situation the area to be evacuated is already inundated with floodwater and the use of boats, helicopters or high wheel base vehicles is required due to self-evacuation not being possible. For the purposes of this report a distinction will be made between "**planned evacuations**" which are developed prior to a flood event and "emergency evacuations" which are initiated during the event without specific prior planning.

It is important to highlight that the scope of this review of the evacuation during the April 2017 flood is limited by the Review Terms of Reference to the point at which a recommendation of evacuation was provided to Civil Defence by the Regional Council. The actual evacuation and welfare of evacuees is the responsibility of other agencies, including Civil Defence, and Fire and Police Services. This the subject of a separate review.

The Regional Council responsibilities associated with evacuations are therefore limited to:

- understanding the performance limitations of the assets for which the Regional Council is responsible for (i.e. stopbanks);
- understanding the areas affected by the potential failure of these assets;
- identifying key (rainfall/river level) trigger levels for when an asset failure is possible;
- maintaining an accurate flood forecasting system that provides advanced warnings of when key trigger levels are likely to be exceeded;
- developing evacuation plans in conjunction with other organisations including Civil Defence and Whakatāne District Council;
- monitoring assets during flood events;
- monitoring and forecasting rainfall and river levels during flood events;
- frequent communication with Civil Defence during flood events to keep them informed of actual and forecast rainfall and river levels so that planned evacuations can be initiated when evacuation trigger levels are likely to be exceeded.

The above items are similarly reflected in the planning expectations for local CDEM Evacuation Plans on page 27 of the *Bay of Plenty Group Evacuation Plan 2014* (Bay of Plenty Civil Defence Emergency Management Group, 2014).

5.3.2 REGIONAL COUNCIL FLOOD WARNING MANUAL (JUNE 2016)

The Regional Council *Flood Warning Manual* (Bay of Plenty Regional Council, 2016) provides the basis for the emergency management procedures that the Regional Council follows during flood events. It provides a summary of roles and responsibilities, flood management tools, communications and then specific details of required actions for each catchment for which the Regional Council has a management responsibility (See Section 3.6).

5.3.2.1 Stopbank Levels of Service

Within the *Flood Warning Manual* there is a section for the Rangitāiki catchment that provides a description of the current (2014) levels of service for the stopbanks of the Rangitāiki River and Reid's Floodway. This information has been sourced from the *2014/2015 Rivers & Drainage Asset Management Plan* (Bay of Plenty Regional Council, 2015a).

The "nominal" levels of service and design flows for the respective reaches of the Rangitāiki River are provided below -

- Rangitāiki River – rural from SH30 to mouth 1% **AEP** (100 year) plus 300mm freeboard 780m^3/s at Te Teko;
- Rangitāiki River – urban (Te Teko, Edgecumbe, Thornton) 1% AEP (100 year) plus 600mm freeboard 780m^3/s at Te Teko;
- Rangitāiki Floodway 1% AEP (100 year) plus 300mm freeboard 190m^3/s (current capacity approximately 85 m^3/s) in floodway when 780m^3/s at Te Teko.

As reported in the *2014/2015 Rivers and Drainage Asset Management Plan* and the *Flood Warning Manual Plan*, none of the above reaches were assessed as meeting the identified design standard. It is understood that the primary reason for this conclusion is the non-completion of the Reid's Floodway upgrade (see Section 5.2 - Reid's Floodway). It is also understood from information provided to the Review Panel by the Regional Council that the reach of the Rangitāiki River through urban Te Teko has been upgraded so that it now meets the required design standard in terms of hydraulic capacity.

As noted previously, there are no specific evacuation or other emergency management provisions provided in the *Flood Warning Manual* in relation to the

Rangitāiki River being below the design standard until the completion of the Reid's Floodway upgrade. Given the Reid's Floodway upgrade was still at least six years away from completion at the time of writing of the *Flood Warning Manual* it would have seemed prudent and consistent with taking the recommended precautionary approach (Ministry for the Environment, 2010) to have some, at least temporary, evacuation measures in place for floods smaller than the design 100-year flood event. Following the completion of Reid's Floodway upgrade there could be consideration of a higher threshold or trigger level for evacuations.

5.3.3 WHAKATĀNE DISTRICT COUNCIL FLOOD RESPONSE PLAN (OCTOBER 2013)

Although evacuation triggers for the Rangitāiki River, and in particular the urban area of Edgecumbe, are not provided in the Regional Council *Flood Warning Manual* there are some provisions in the Whakatāne District Council's *Flood Response Plan* (Whakatāne District Council, 2013). Annex 1 of the *Flood Response Plan* provides "indicative warning levels" in terms of flood levels at the Rangitāiki River at Te Teko gauging station. The warning levels at the Te Teko gauging station are relative to stopbank crest levels for the main urban areas of Te Teko and Edgecumbe and are reported as 7.44m and 7.48m respectively.

Inspection of the Rangitāiki at Te Teko staff gauge prompter (page 46 Regional Council's *Flood Warning Manual*) show that the "indicative warning levels" of 7.44m and 7.48m for the Te Teko and Edgecumbe stopbank crests are more than 1m higher than the highest previously recorded flood level of 6.39m (July 2004 flood) and approximately 0.9m higher than the peak level measured during the April 2017 event (6.58m). They are also approximately 1.0m higher than the top end of the rating curve that existed for the Te Teko gauging station at the time of the April 2017 event.

The "indicative warning levels" provided in the Whakatāne District Council *Flood Response Plan* are not considered adequate because they appear to be too high and based solely on stopbank overtopping as an evacuation trigger. It is understood that the Regional Council reviewed the *Flood Response Plan* but did not raise any concerns with the adequacy of the "indicative warning levels" provided in the plan.

Further discussion on the possible reasons for the inadequacy of evacuation planning for the urban areas of the Rangitāiki Plains is provided in the following section.

5.3.4 THE NEED FOR EVACUATION PLANS

To provide further analysis of why there were inadequate evacuation plans in place for the urban areas adjacent to the Rangitāiki River, consideration is given to the flood modelling work undertaken by River Edge Consulting in 2011 (River Edge Consulting Ltd, 2011a; River Edge Consulting Ltd, 2011b). This modelling looked at events larger than the current design, including a 300-year return period flood of approximately 1000m^3/s. The modelling of this very large flood event did not show any substantial inundation of the urban areas of Edgecumbe and none at all around the College Road area.

The primary reason for the limited inundation of the urban area of Edgecumbe is the differential freeboard that is a fundamental design parameter of the Rangitāiki River stopbank system. In effect, the stopbanks around the urban areas of Edgecumbe as well as Te Teko and Thornton are built approximately 300mm higher than the stopbanks for the surrounding rural areas, including the Reid's Floodway stopbanks. This means that when floods larger than the design flood occur, floodwaters should spill out into the rural areas first in an attempt to reduce the likelihood of widespread flooding, disruption and damage in the urban areas.

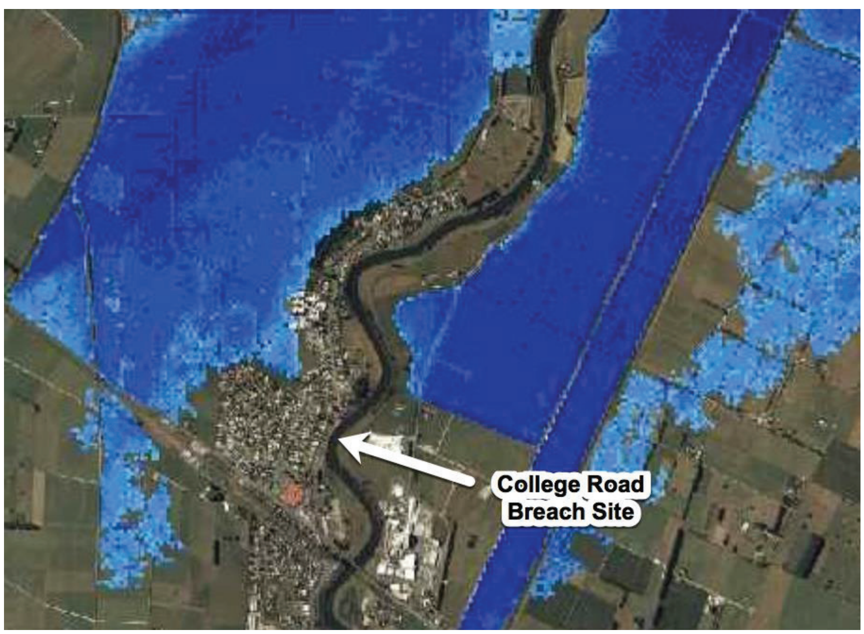


Figure 32: 300-year flood extent with no stopbank breaches (Source: River Edge Consulting Ltd, 2011b)

It must be highlighted that this flood modelling assumes that the stopbanks remain functional during these extreme events and that geotechnical failures have not occurred at lower levels resulting in breaches and flooding of other (urban) areas before the rural stopbanks begin overtopping.

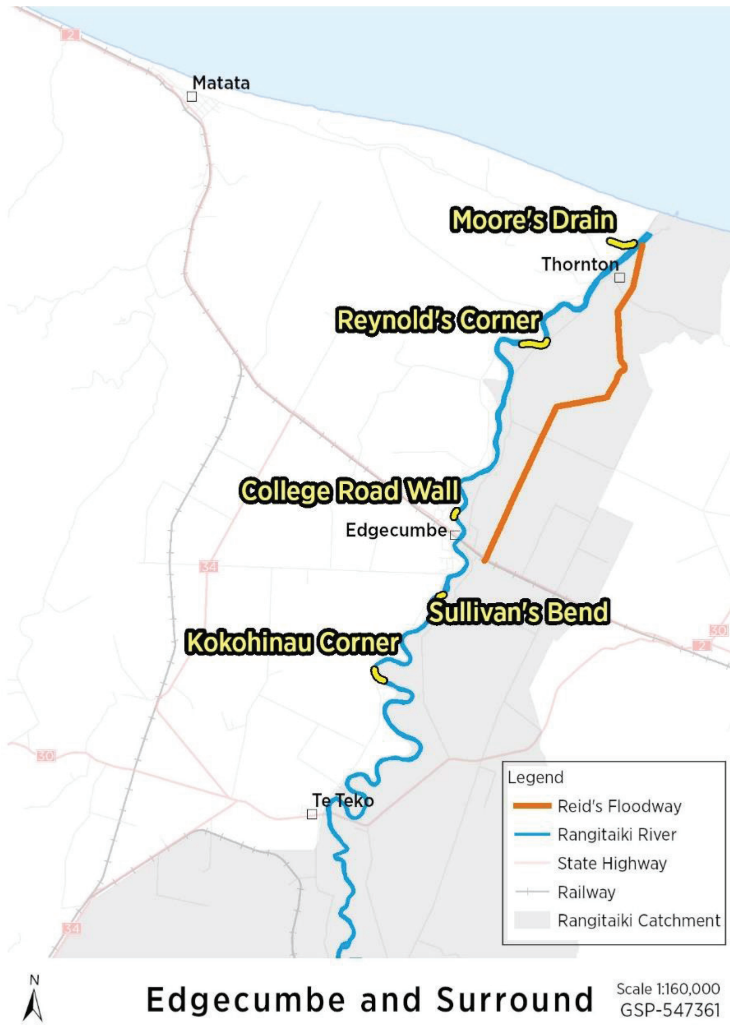


Figure 33: Edgecumbe area and critical structures related to the 2017 flood event (Source: Bay of Plenty Regional Council 2017)

The 2011 modelling did consider three breach locations on the Rangitāiki River; Moores Road and Reynold's Bend both downstream of Edgecumbe, as well as at Kokohinau upstream of Edgecumbe (see Figure 33). It is understood that the breach locations were identified based on past areas where there had been concerns around stopbank stability. Neither of the downstream breaches resulted in inundation of Edgecumbe but the theoretical Kokohinau breach would inundate a large part of the urban area of Edgecumbe (See Figure 34). It is interesting to note that the higher ground immediately adjacent to the river in Edgecumbe was not inundated, including the area at the College Road breach site.

Figure 34: 100-year flood (including climate change) with a breach in the Rangitāiki River stopbank at Kokohinau (Source: River Edge Consulting Ltd, 2011a)

It is also common to select breach sites for analysis where there will be the highest consequences of failure (for example, in close proximity to urban areas). This would suggest that prior consideration of a breach scenario of the left (western) stopbank downstream of the SH2 Bridge at Edgecumbe would have been prudent. Notwithstanding the above, there are no evacuation provisions provided in the *Flood Warning Manual* for managing the residual risk of a breach of the left (western) stopbank of the Rangitāiki River at Kokohinau, or any other downstream location, for <u>any size</u> of flood event. The evacuation provisions provided in the *Flood Response Plan* (Whakatāne District Council, 2013) for the urban area of Edgecumbe appear to be solely based on a stopbank crest overtopping threshold which is less relevant than other failure modes (i.e. geotechnical) due to the differential (higher) freeboard provided for in the stopbanks protecting Edgecumbe.

Further to the above discussion on the level of service with regard to hydraulic (flood flow) capacity, there must also be consideration of possible geotechnical failure mechanisms, especially with the well-known issues related to the underlying geology (peat, ash, faulting etc) and the fact that there have been a number of geotechnical failures of the Rangitāiki River stopbanks in the past.

This is particularly relevant for the current situation where Reid's Floodway is not operating at its intended design capacity and the main Rangitāiki River is having to take up to an additional 100m^3/s (17%) of flood flow which equates to around an additional 400–500mm in terms of flood levels. These elevated water levels in the Rangitāiki River have significant implications for the geotechnical performance of the stopbanks. It is acknowledged that a significant amount of strengthening and drainage work has been done over the past decade on the Rangitāiki stopbanks. It is, however, considered that there should have been sufficient concern regarding the stability of the stopbanks, particularly without Reid's Floodway being fully operational, to have an urban evacuation plan in place for a flood smaller than the design 100-year flood event.

5.3.4.1 Planned Evacuations

For the Rangitāiki catchment the flood warning procedures in terms of planned evacuations in the *Flood Warning Manual* (Bay of Plenty Regional Council, 2016) include; issuing warnings to farmers grazing the stopbanks on the lower Rangitāiki River and Reid's Floodway as well as advising Whakatāne District Council of road closures for Hydro Road, McCracken Road, McLeans Road, and, in the event of extreme flows down the floodway, Thornton Hall Road. The *Flood Response Plan* (Whakatāne District Council, 2013) also provides "indicative warning levels" relating to the likely overtopping of stopbank crest levels at Te Teko and Edgecumbe.

The first warning level to farmers for stock relocation is given when the Rangitāiki River is predicted to reach 2.6m (165m^3/s) at the Te Teko gauge. The warning for the likely operation of Reid's Floodway and the resulting road closures is given when the level is predicted to reach 5.85m (540m^3/s) at Te Teko. This is somewhat below the current estimate of when the floodway will commence operation, a level > 6.5m at Te Teko (680m^3/s). The "indicative warning level" for potential overtopping of the stopbanks within Edgecumbe is 7.48 m provided in the *Flood Response Plan* (Whakatāne District Council, 2013). Based on extrapolation of the current rating curve at the Te Teko gauging station this level would have required a flow of approximately 1000m^3/s being around a 300-year return period flood event.

As highlighted above, it would have seemed prudent to provide for planned evacuations for floods smaller than the design 100-year flood event for the period prior to the completion of Reid's Floodway, with the possibility of a higher threshold following the completion of Reid's Floodway or other upgrading works.

5.3.5 APRIL 2017 EVENT

Given the river levels that trigger "planned evacuations", as specified in the *Flood Response Plan* (Whakatāne District Council, 2013) the residents of Edgecumbe were effectively dependent on "emergency evacuations" which were based on monitoring the performance of stopbank and floodwall assets during the event. This is considered a relatively high risk approach as it requires detailed physical monitoring of potentially risky structures throughout the event and then a very rapid and likely ad-hoc evacuation or emergency mitigation works if issues are identified. It is suggested that this is not consistent with the precautionary approach as recommended by the Ministry for the Environment in their 2010 guide, *Preparing for Future Flooding* (2010).

Without the "planned evacuation" thresholds specified in the *Flood Response Plan* being exceeded (or forecasted to be exceeded) it is unreasonable to expect the Regional Council Flood Managers to have recommended ad-hoc evacuations to Civil Defence and Whakatāne District Council any earlier than was done so during the event. The lack of planning for possible stopbank breaches at river levels below the crest level of the Rangitāiki River stopbanks is a notable gap that the Regional Council needs to work with the Whakatāne District Council and Civil Defence to resolve.

5.3.6 SUMMARY

Overall, it is considered that there should have been "planned evacuations" in place for the urban areas of the Rangitāiki Plains with trigger levels set lower than the stopbank crests and more specifically for events smaller than the design 100-year flood. This is in recognition of the fact that the lower Rangitāiki River system was not up to the intended 100-year design capacity as identified in the *Flood Warning Manual* and *2014/2015 Asset Management Plan*. There was also an elevated risk of geotechnical failures in the main Rangitāiki River channel due to it taking a greater proportion of flow compared to the situation with Reid's Floodway completed.

There could have been prior consideration of a breach scenario at College Road because of the high consequences of failure resulting from a breach of the stopbank at this location. It is, however, concluded that the Regional Council Flood Managers made the correct decisions during the April 2017 flood event based on the information they had at the time. It is considered unrealistic to expect that earlier evacuations would have been recommended to Whakatāne District Council and Civil Defence without pre-determined evacuation plans and exceedance of specified trigger levels.

5.3.7 EVACUATION PLANNING RECOMMENDATIONS

u. Evacuation plans need to be developed to manage the risk of stopbank failures. This will require the evaluation of the "safe" capacity for both overtopping and geotechnical failure modes and planned evacuations for flood events which exceed the assessed "safe" capacity.

v. Consideration should be given to variable river level trigger thresholds where the residual risk of geotechnical failures is being managed through evacuation plans. This is in recognition of the importance of antecedent groundwater conditions as well as the duration of elevated river levels in the development of geotechnical failure mechanisms.

w. Specific consideration needs to be given where large capital works upgrades, such as Reid's Floodway and Spillway, are not yet completed and operational.

x. The development of an evacuation plan for Edgecumbe is something to be urgently completed by the Regional Council, Civil Defence and the Whakatāne District Council working together.

6. Long-term strategy and design philosophies

It is important to consider the longer-term management of the Rangitāiki catchment from the perspective of both the past and current design philosophies and strategies. This is to provide the context of how the past strategies and designs have shaped the system as it exists today and how current strategies can be put into action to create the river system that is desired for the future.

6.1 Historic river control strategy/design philosophy in New Zealand

The location and general arrangement of the key Rangitāiki River flood management assets (that is, stopbanks and Reid's Floodway) were set in place in the late 1960s through the work of the Bay of Plenty Catchment Commission. At that time the overall design was very much guided by the philosophies as presented in *River Control and Drainage in New Zealand* (Acheson, 1968). There was generally a focus on the confinement of river systems, particularly aggrading gravel bed rivers, in an attempt to "flush" sediment through to the coast as well as maximising the areas of "protected land". The Government subsidies of the time were often as high as two to one. This reflected the additional productive value of the largely agricultural land and the return on investment that could be achieved for the national economy.

It is generally now accepted that the degree of confinement that was achieved was not sufficient to keep sediment entrained and that this practice in some cases amplified **aggradation** (for example, the North Ashburton River, the Waiho River). Notwithstanding this, the overall investment in river schemes across the country is generally considered to have been successful in terms of providing for national economic growth.

These river schemes exist across New Zealand. Over the past decade it has become more apparent that a wide-ranging review of their ongoing sustainability is needed as climate change, water quality, cultural values and the desire for access to rivers come to the forefront in public policy and best practice. An ad-hoc, piecemeal, patch-up of assets that were constructed over 50 years ago, and that are limited by the current location of these assets, is unlikely to provide a sustainable long term solution. If there is a reluctance to consider relocating these existing stopbanks further away from the river there will inevitably be the need for higher stopbanks to manage larger future, climate change influenced, floods.

This increased confinement will increase the hazard (depth and velocity) within these rivers during floods and also lead to higher consequences of stopbank failures.

There is currently a lack of centralised policy, legislation or funding to support solving these issues. Within NZS 9401:2008[7] there is a specific outcome of "Allowing rivers to revert to their natural behaviour is an option for consideration" (Standards New Zealand, 2008) but these types of options are often prohibitively expensive to implement. Without wider funding it is generally considered difficult to develop longer term solutions providing flooding and erosion management while also offering wider value to the whole community and country in terms of cultural and recreational resources that are underpinned by improved water quality and terrestrial biodiversity.

These fundamental issues are important to consider in terms of the constraints under which the Rangitāiki River has been managed in the past, as well as the future aspirational visions for the river and catchment.

6.1.1 1968 RANGITĀIKI RIVER COMMISSION

Under the guiding philosophies of river engineering and management in New Zealand in the 1960s, the Rangitāiki River Commission created an overall plan for the Rangitāiki River that confined much of the river system with stopbanks located very close to the main river channel.

Within the middle reaches of the Rangitāiki River through Galatea, the confinement philosophy described in the scheme report was as follows:

> "under the scheme it is proposed to stabilise the shingle fans and confine the flow by planting and stopbanking and to develop an adequate floodway" (Rangitāiki River Commission, 1968).

This confinement in the middle reaches through Galatea will have likely provided some immediate benefit to adjacent landowners and to the protection of roading infrastructure. But it is likely that it has also lessened the travel time and increased the downstream flood peak due to areas of the floodplain being cut-off. The effects of this will have somewhat been mitigated by the storage provided in Matahina Dam, but it is worth noting the possible effects of this confinement when considering the longer-term future strategies discussed below.

In the lower reaches of the Rangitāiki River (downstream of the Matahina Dam) the stopbanked section of the river was confined within a somewhat nominal 30

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foot (10m) set back from the river bank edge to the base of the stopbanks if space permitted (Rangitāiki River Commission, 1968). It is noted that in the lowest reaches of the river, near the river mouth, the main channel was in fact widened by up to 300 feet (100m) to improve the capacity. In addition, the stopbanks were located 30 feet (10m) further back from this newly widened main channel section.

It is of particular note that in the lowest reaches of the Rangitāiki River the County Road needed to be realigned three **chains** (60m) further away from the river bank to allow for the newly constructed channel and stopbank (Rangitāiki River Commission, 1968). There were also a small number of houses and farm buildings that were moved to make way for the new river channel and stopbank.

Notwithstanding the above design decisions to move property and infrastructure in the lowest reaches, once the Commission came to considering College Road at Edgecumbe it stated:

> "The main road through Edgecumbe passes close to the river bank here and there is not sufficient room to construct a stopbank. It is proposed to build a concrete wall 4 ft. to 5 ft. (1.2 to 1.5 m) high over a length of 5 chains (100m)".

The design alignment for the College Road floodwall as proposed in the 1968 is shown in Figure 35 below.

The Rangitāiki River Commission also developed the concept for Reid's Floodway including the specific design of a higher capacity spillway inflow with a restricted downstream outlet through a narrow (50m wide) 4km reach of the lower channel. It is also noted that the overall design of the stopbanks was to provide two feet (600mm) freeboard in urban areas and one foot (300mm) in rural areas.

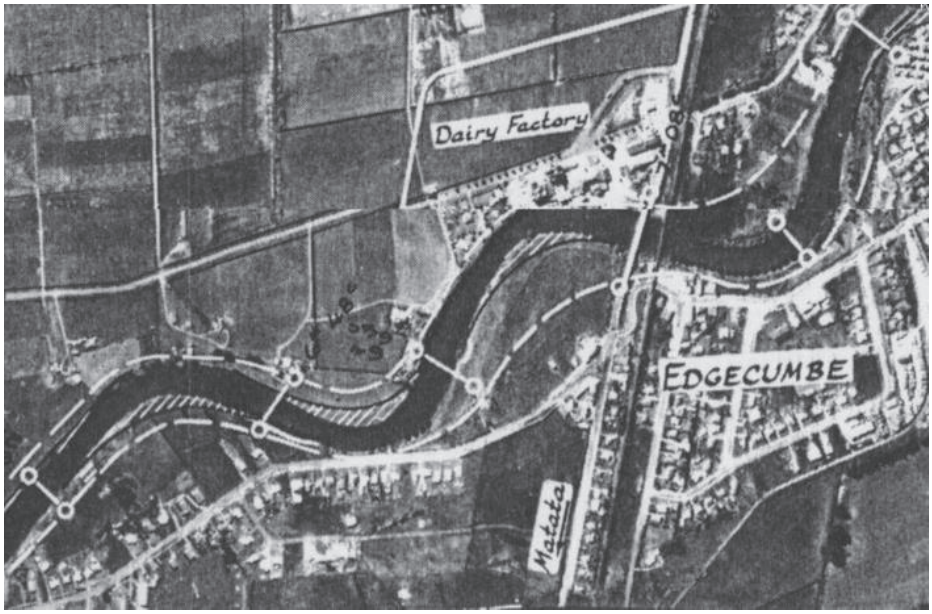

Figure 35: College Road in Edgecumbe (Source: 1968 Rangitāiki River Commission Volume 4 Plan No. R400)

It is very evident that the key strategic decisions regarding the location and relative height of stopbanks, and the construction of concrete floodwalls and floodways, especially for the lower Rangitāiki Plains, were made at this time. It is the legacy of these past decisions that have significantly affected the scheme as it is today and the cost and feasibility of implementing the future strategies that are presented below.

6.2 Evolving shift in philosophy in the 1980s

It was in 1986, with the publication of "*Creating Flood Disasters*" by the National Water and Soil Conservation Authority (Ericksen, 1986), that a paradigm shift began in the overall philosophy of floodplain management in New Zealand, especially with regard to the construction of stopbanks. The concept of stopbanks encouraging the intensification of floodplain development and, therefore, an increase in the value of assets at risk on the floodplain, which then led to even higher stopbanks and further development, has played out across New Zealand as well as in almost every other country across the world.

The realisation around the potential increased risks associated with higher and higher stopbanks led to the re-evaluation of methods, especially the position and height of stopbanks and was the start of the "Making Room for Rivers" concept which is now generally agreed to be best practice.

The Netherlands are considered to be leading the way in the implementation of this concept driven by the extreme flood risks that are evident in their country. Some further information on the work they have already completed can be found at - https://www.ruimtevoorderivier.nl/english/.

The idea of "Making Room for Rivers" is based around reducing flood levels and velocities by having a wider river corridor that can utilise floodplain attenuation and controlled compartment spilling and storage to more safely manage flood risk. The idea is fundamentally based around restoring the natural functioning of river floodplains whilst working around the constraints that exist due to floodplain development.

A key aspect of making these programmes successful is achieving multi-functionality so that when these areas are not being used to store or convey flood waters they can be used for cultural wellbeing, agriculture, wetlands, recreation, ecological reserves and any other uses that the community values. The key barriers to the implementation of this philosophy in the New Zealand context is the legacy of "protection" provided by narrowed river systems, private property rights and, predominantly, the very high cost. It would generally only be considered feasible if the value provided by the other functions, which are often difficult to value in dollar terms, is included in the overall assessment and funding from the wider community is used to support these developments.

The above discussion is particularly relevant for the following sections of the report on the modern philosophy as it is generally accepted that "Making Room for Rivers" is best practice, but it is acknowledged as being difficult to implement with the current barriers that exist, especially regarding the cost for smaller rural communities.

6.3 Post-2004 strategy

Following the 2004 flood on the Rangitāiki Plains a thorough review was undertaken and recommendations were presented for upgrades to the main Rangitāiki River stopbanks as well as Reid's Floodway (Opus International Consultants, 2007). The general philosophy of the upgrades was around strengthening the existing stopbanks on the main Rangitāiki River to reduce the risk of geotechnical failures and increasing the capacity of the Reid's Floodway by widening the lower sections of the Floodway. At this stage there was also minor stopbank "topping up" which is further described in Section 4.3 – The College Road floodwall.

This general philosophy was sound in that it was generally trying to best utilise existing assets and the constrained reaches of the lower Reid's Floodway were being widened to increase capacity. However, the degree of widening that was finally recommended was less than optimal in terms of reducing flood levels and geotechnical risks. The design philosophy that was presented in the Opus 2009 resource consent was based around undertaking the minimum amount of widening of the lower floodway so that the current 100-year design flood could be just accommodated by the existing floodway banks (Bay of Plenty Regional Council, 2017a).

This philosophy appeared to be driven by minimising the need for land compensation or acquisition in the lower reaches where the widening was proposed rather than seeking to achieve lower flood levels to minimise geotechnical risk and provide some future capacity for climate change.

It is acknowledged that some widening is better than none at all, but the decision to not widen the lower reaches of Reid's Floodway to be at least as wide as the 200m upper section has now been shown to have significant consequences in terms of managing flood levels in the upper reaches of the floodway as discussed in detail in Section 5.2 – Reid's Floodway.

6.4 Current strategy and philosophy

The present thinking around longer term management of the Rangitāiki River is described in a number of documents and the following are considered the most up to date and relevant:

- *Te Ara Whanui O Rangitāiki – Pathways of the Rangitāiki* (Rangitāiki River Forum, 2015);
- Rangitāiki Tarawera Floodplain Management Strategy, Stage 2 (River Edge Consulting Ltd, 2013b);
- Various "Optioneering" Reports emanating from the River Scheme Sustainability Project.

The Rangitāiki River Forum's River Document – *Te Ara Whanui o Rangitāiki – Pathways of the Rangitāiki* (Rangitāiki River Forum, 2015) provides a valuable overarching vision for the future health and community connection to the Rangitāiki River. It describes eight objectives with specific actions that will contribute to achieving those objectives. All of these objectives are intrinsically linked with management of the river and wider catchment. In particular, *Objective 7 – Naturalness of the river and the landscape of the Rangitāiki catchment* - is significant for this discussion. There are six contributing actions identified as being required to work towards achieving this objective. All of these actions identify the Regional Council as being the lead organisation.

These key actions include: developing a 100-year strategy for sustainable management of the rivers and drainage schemes including managing flood risk;

exploring alternative options for riverbank management; and installing eco-passages and removing or adapting structures within the river system to minimise effects. A great deal of work has been undertaken by the Regional Council to consider the best strategies for management of the Rangitāiki River and, in particular, the longer term sustainable management of flood risk.

The Stage 2 *Rangitāiki-Tarawera Floodplain Management Strategy* (River Edge Consulting Ltd, 2013b) provides a comprehensive analysis and recommendations for the full spectrum of structural and non-structural floodplain management options. This report specifically considers the "Making Room for the River" concept in a number of different forms including reinstating the use of historical distributory channels including a remnant channel at Te Teko, Awaiti Stream and the Old Rangitāiki Channel. None of these options individually provided any significant reduction in flood flows, but collectively and combined with other options they could lead to incremental improvements in flood risk reduction, along with improved cultural and ecological value.

Specific consideration was also given to stopbank retreat, but it was highlighted that the highest ground was in fact immediately adjacent to the perched main river channel so that moving stopbanks further back may not provide any meaningful reduction in overall stopbank height. It would still, however, provide reduced risk from hydraulic erosion by the river, lessening the need for continued maintenance of hard rock lines on the river edges. It was also noted in this report that there was a "range of impediments" that meant that stopbank retreat would not be achievable in the short to medium term. It is acknowledged that costs associated with property purchases and relocating infrastructure could be a significant barrier if it was solely dependent on funding from the local community.

The most promising option that was presented with regard to the structural flood management works was the possibility of using offline storage from Reid's Floodway or the main Rangitāiki River. This concept of controlled, compartment flooding is a significant feature of the "Making Room for the River" works that have been completed in the Netherlands in recent years.

This idea was followed through with further investigation and modelling by AECOM in *Rangitāiki Spillway Optimisation* (AECOM Consulting Services, 2015). An area between the Rangitāiki River and Reid's Floodway was identified (See Figure 36) as a possible spill compartment area providing total storage of 7.4Mm^3 at a cost of $4.76M

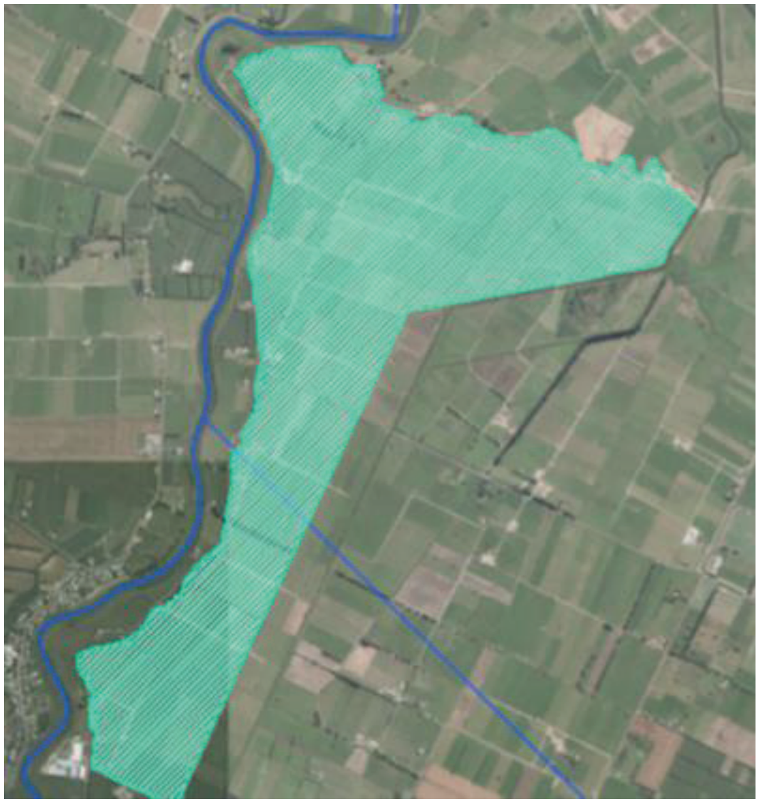

Figure 36: Possible Flood Spilling Compartment between Rangitāiki River and Reid's Floodway (Source: AECOM Consulting Services, 2015)

In addition to this area, another area to the east of Reid's Floodway, as well as a large area south west of Edgecumbe, were identified and modelled as possible offline storage areas. The AECOM report also assessed the benefits of various Matahina Dam operating protocols as well as the possibility of a Galatea basin aquifer recharge option and the effect of upper catchment conversions from forest to pasture. The recommendations included providing defined bunded offline storage on the lower floodplain as well as further investigations into the Galatea aquifer recharge project.

The Review Panel has been informed that the Regional Council is currently undertaking further work to assess the feasibility of a range of spilling compartment options upstream and downstream of SH2 on Reid's Floodway combined with a possible additional outlet to the Rangitāiki River upstream of the Thornton Hall Road Bridge.

In 2017, AECOM completed an initial feasibility study of a combined irrigation and flood storage project in the Upper Rangitāiki River (AECOM New Zealand Ltd., 2017). The most promising option was a combined system on the Galatea Plains, but it came at a significant cost of $39M.

Overall the strategic assessments and visions for the Rangitāiki River and catchment are considered to be in line with best practice and encompass a wide range of options from upper catchment storage through to "Making Room for the River" in the lower plains, particularly with controlled spill into flood compartments. How these strategic assessment are currently translated into actual implementation through the Long Term Plan and Long Term Infrastructure Plan are discussed below.

6.5 Currently proposed short-term (1-5 years) actions

With the above context of best practice around "Making Room for Rivers", and specifically identified floodplain spill compartments, it is surprising that the current long term plan provides for over $8M of stopbank raising in the upper reach of Reid's Floodway adjacent to areas specifically identified as possible spill compartments. Significant stopbank raising and further confinement of floodwaters would seem to be a poor option given the well-known difficulties with the underlying geology of the Rangitāiki plains.

The Review Panel has been informed that the Regional Council is currently considering alternatives that will reduce or eliminate the need for the significant stopbank raising that is currently allowed for in the long term plan. It is acknowledged that these options require the use of private property and the Regional Council should consider the full range of tools available, including designations (s166-186 RMA, 1991), the Public Works Act 1981 and publicly notified resource consents (for Regional Council consents), to ensure the best solution for the overall management of flood risk for the whole community is achieved.

The above also applies to the implementation of the Spillway solution at the entrance to Reid's Floodway. The Panel considers that the lower fixed crest spillway is the most practical and cost effective option to pursue and the planning tools noted above should also be considered for accelerating the completion of this part of the project.

It is also noted that within the *2015-2045 Infrastructure Strategy Plan* there appears to be a number of items that represent "stopbank top-ups" to manage the effects of climate change (Bay of Plenty Regional Council, 2014a). It has been suggested to the Panel by the Regional Council engineering team that these are merely placeholders and that the work being done through the River Scheme Sustainability workstreams will better define what other options may be possible.

On a specific technical matter, it is noted that the current design flood flows have been determined by analysis of the rated flow record from the Rangitāiki River at Te Teko. It is acknowledged that previous reports have assumed that the effects of Matahina Dam on large flows has been minimal and that the Te Teko record can be used to determine the flood frequency. With the April 2017 flood being significantly reduced by the operation of Matahina Dam, it is considered necessary to re-evaluate the validity of using the Te Teko record as the basis of the design flood for the lower Rangitāiki River.

It is also highlighted that there has been a drawdown operating protocol since the construction of Matahina Dam and it is quite possible that the large number of floods at the middle and lower end of the annual maxima series may have been affected to some degree. This could affect the extrapolation of the frequency distribution to the lower frequency (larger) floods.

To derive calculated Matahina inflows would require detailed information about historic lake levels and dam (spillway and machine) discharges. It is not known how readily available this information is. It is also noted that the shape, and therefore volume, of the hydrograph will become a critical part of the analysis along with assumptions on how this is routed through the dam to determine downstream design flows for various scenarios.

6.6 Long-term strategy recommendations

y. The Regional Council should give high priority to developing and implementing long term sustainable flood risk management solutions for the Rangitāiki Plains to manage the effects of climate change as well as providing ecological and cultural value to the wider community.

z. The stopbank raising for both banks of the upper reach of Reid's Floodway allowed for in the current (2015-25) long term plan would appear to be a poor option given the well-known geotechnical complexities of the underlying geology. It is also considered that stopbank raising is not aligned with the visions and objectives of the Rangitāiki River Document or generally accepted best practice.

aa. The work the Regional Council is currently undertaking to examine the feasibility of spill compartments and an additional outlet from Reid's Floodway as well as a lower fixed crest for Reid's Spillway should be pursued using all of the tools available including designations (s166-186 RMA, 1991), and if necessary the Public Works Act 1981.

bb. The flood hydrology of the Rangitāiki River needs to be updated to include the April 2017 event. It is recommended that a "naturalised" annual maxima flood series is developed that uses estimated Matahina Lake inflows rather than flows at Te Teko as its basis.

7. Community engagement

How councils engage with their communities in the development of flood management solutions, and the understanding of communities of the risk posed by flood hazards is an important component of NZS 9401:2008 *Managing Flood Risk*[8] (see Appendix E). This next section identifies how the Regional Council has engaged with the community from the formulation of policy, through to implementation, management and maintenance.

7.1 Policy, plan and strategy development

The RMA sets out processes whereby a Council must consult with its community when developing statutory documents such as the Regional Policy Statement and Plans. These are generally "minimum" processes, which councils usually supplement with engagement with communities of interest prior to formal submission and hearing processes commencing. Good practice guides can be found in the *Quality Planning Website* (Quality Planning Website, n.d.)

Councils are obliged to set out how they will engage with communities in decision-making under the Local Government Act. The Regional Council gives effect to this through its *Significance and Engagement Policy*. Appended to this policy is a *Community Engagement Guide* that identifies the different forms of engagement used to be. These range from "inform", through "consult", "involve", "collaborate" to "empower" (Bay of Plenty Regional Council, 2014d).

The descriptions of these different processes are as follows (note that the italics have been added by the writer for clarity):

> **Inform**: One-way communication providing balanced and objective information, to assist understanding *by the community* about something that is going to happen or has happened.
>
> **Consult**: Two-way communications designed to obtain public feedback about ideas on rationale, alternatives and proposals to inform *Council* decision making.
>
> **Involve:** Participatory process designed to help identify issues and views *held by the community*, to ensure that concerns and aspirations are understood and considered prior to decision making.

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> **Collaborate**: Working together *with the community or other agencies* to develop understanding of all issues and interests, to work out alternatives and identify preferred solutions.
>
> **Empower**: The final decision making is in the hands of the public. Under the LGA 2002, Councillors are elected to make decisions on behalf of their constituents.

Relevant examples of the different processes include:

- Annual Reports and Civil Defence preparedness are examples where Council has kept the community *informed*;
- "Living with Risk" project, which was a project that *involved* different segments of the community as part of developing up Change 2 (Natural Hazards) to the Regional Policy Statement;
- The Rangitāiki River Forum, where the Council has a duty to take a *collaborative* approach.

The guide also sets out that the Council will engage at different levels within the community depending on how the community is affected by or is interested in the decisions. These range from the use of one-way tools for informing the community (such as websites, flyers, signage, social media), through increasing engagement as the level of involvement increases.

7.1.1 HOW COMMUNITY ENGAGEMENT HAS BEEN IMPLEMENTED IN POLICY AND PLAN DEVELOPMENT

There does not appear to have been any direct engagement with the Edgecumbe community in the development of core statutory documents, policies or frameworks other than through representative groups: however this is standard practice unless Council had a view that there was a particular reason that a greater depth of engagement was required. That there are no particular policies, planning overlays, or specific strategies for the Edgecumbe township indicates that the Council may not have perceived that the Edgecumbe township faced any undue risk.

A view was expressed in discussions that some interactions with representative liaison groups have not been particularly effective either in influencing the Council's direction or disseminating views back to the community. The Review Panel has noted that the terms of reference for the Rangitāiki-Tarawera Rivers Scheme Liaison Group have recently been reviewed to improve representation and effectiveness (including a name change to the Rangitāiki-Tarawera Rivers Scheme Advisory Group).

The Panel understands that brochures have been developed by the Regional Council as part of the Rivers Schedule Sustainability Project that may have alerted the community to the long term need to take a different approach to flood risk management, rather than relying on increasing stopbank heights. The Panel understands these have been prepared, but not yet been disseminated.

7.2 Community engagement in development of flood protection measures

During the options development and subsequent consenting processes for the *Edgecumbe Rangitāiki Plains Flood Mitigation Works* (prepared for Whakatāne District Council by Opus, 2009*)* communities were engaged through more specific processes, including drop-in days, frequent newsletters, and subsequent follow ups particularly around rating issues. A range of landowners and stakeholders also met on a one-on-one basis with the project to clarify any matters and address concerns. These stakeholders included directly affected property owners, iwi representatives, other community groups and impacted organisations. Staff have advised that newsletters ceased around 2009 apparently following feedback that they were no longer necessary, and communication with the Edgecumbe community since appears to have been at the generic general public level. More detailed communication continued through representative forums and groups such as the Rangitāiki Liaison Group, and Federated Farmers, and more recently through the Rangitāiki River Forum.

As highlighted in Section 5.2 – Reid's Floodway, there was little direct communication from the Regional Council to the community about changes and delays to the project.

It was apparent during conversations with the Edgecumbe community during the drop-in session for the Review (and it is to be noted that this is a very small sub-set of the community) that there is a very low awareness reported of flooding risk and the hazards that this posed. This was particularly evident with more recent residents. The community had no awareness of any formal evacuation procedures.

It has been reported in the media that there was high underinsurance and numbers of households that were not insured. It is difficult to form a view whether there would have been a different approach from the community had there been more awareness of flood risk on the basis of information used as a basis for this review.

As noted in Section 6.5, it is apparent that the Regional Council is now considering a broader range of options for Reid's floodway, and that either new resource consents or variations to existing consents, and possibly notices of requirement (commonly referred to as designations) may be required if these options are to be pursued. It is the view of the Review Panel that the full community with an interest in the broader Rangitāiki Plains flood protection works should be engaged both as these options develop, and through any formal decision processes (such as resource consents). This is to ensure that the community both has an input into future works, and is kept informed of the risks and benefits of any choices made that will affect it.

7.3 Community engagement recommendations

cc. Engagement of the full community (including Edgecumbe township) should be undertaken when considering further options for Reid's Floodway. This should include full notification of any notices of requirement and/ or application for resource consent.

8. Overall conclusions

The essential features of the existing Rangitāiki River Flood Scheme have been in place since the early 1970s. Since that time there have been considerable repairs, improvements and upgrades of the scheme. Twice this century, in 2004 and 2017, the scheme has been tested by large floods with flows exceeding 700m^3/s. On both occasions it failed that test, despite the flood levels below the Matahina Dam being within the intended design criteria of the scheme. This year's flood level below the dam was not significantly different in size from that in 2004. But, because it occurred in Edgecumbe, its consequences in human terms were much larger.

Any such scheme is only as strong as its weakest point. If the 2004 flood had not occurred upstream of Edgecumbe, it may have occurred in another point downstream, possibly along College Road somewhere close to this year's flood.

The Review Panel has carefully examined the Bay of Plenty Regional Council's frameworks, policies, and processes for identifying and managing natural hazard events, such as floods. While there are areas where improvements can be made, our conclusion is that, overall, these frameworks, policies, and processes are good. We have made a number of recommendations for their improvement.

It is a different matter when we turned our attention to the implementation of those frameworks, policies and processes. Neither the natural hazard approach nor, more importantly in the context of the 2017 flood, the planned improvements to the Rangitāiki River Flood Scheme have been fully implemented. In particular, the incomplete state of Reid's Floodway and Spillway may have been significant in terms of what happened.

The delay in completing both the Floodway and the Spillway meant that far less water was diverted out of the river than would have occurred had it been completed. This, therefore, substantially increased the peak flows in the river downstream of the Spillway. The failure of the floodwall at College Road occurred before the peak flow even reached that part of the river. It is possible that the failure would not have occurred had Reid's Floodway and Spillway been completed.

It must be emphasised that this is far from a certainty. In any case, the Panel's analysis of the plans for both the Spillway and the Floodway suggest flaws in the planned designs. It seems to the Panel that the widening of the Floodway to 200 metres should have been planned to occur over its whole length, rather than narrowing significantly towards its outlet.

As a consequence of the decision not to do so, expensive further works are currently planned or under consideration in order to achieve the same outcome to that a fully widened floodway in the lower reaches would have provided.

The design for a variably controlled Spillway is also questionable, especially as its purpose may put Edgecumbe at unnecessary risk. An urgent review of the remaining planned works needs to be undertaken and the preferred options proceeded with as soon as possible, if necessary using designations and publicly notified resource consent applications.

The reasons for the floodwall failing at College Road are complex. They relate less to the design of the concrete wall itself and more to the fact that water found its way through the material beneath the wall. This caused water pressure to rise in the ground underneath the wall. The pressure may have been increased as a result of the water being confined by the concrete walkway laid a few years ago. What is certain is that the pressure increased to the point so that the cribwall sheared off at its base and moved inland.

Without the support of the cribwall the concrete wall sections at that point slid outwards with catastrophic consequences. It must be emphasised that, even without the presence of the pad, a similar kind of progressive failure could have occurred. The possible means by which the water was able to find its way through are canvassed in detail in the report. The Panel considered an alternative explanation for the build-up of the water pressure proposed by the Bay of Plenty Regional Council but decided, on balance, to stand by its original conclusions as to the most likely sequence of events. It is recognised, however, that certainty in this matter is not possible.

There are, in fact, many “what-ifs” about the event. If, as is possible, the contractor who was on site at the time of the breach had had more time to load sufficient material on top of and in front of the pad it might not have lifted and the cribwall might not have given way. This extra time might have been gained if the Regional Council had had better information about the river flows above Lake Matahina or if there had been some differences in the management of the lake levels. Neither of these is anything more than a low possibility. There is no reason to believe that any of those involved at the time did anything less than their best.

The fact remains that the completion of Reid’s Floodway and Spillway are still some way off. Indeed, the Panel recognises that its recommendation to review their design may somewhat increase that delay unless, at the same time, funding priorities are changed and the design review is undertaken urgently.

The Panel is concerned that there has been insufficient attention paid to the risks faced by the Edgecumbe community while the Rangitāiki River scheme was being upgraded. This is reflected in the fact that there are no plans for precautionary evacuation in the event that certain trigger points are reached in terms of anticipated river flows. It needs to be emphasised that such an evacuation protects life, not property.

It also appears from the Panel's community engagement that many of the residents of Edgecumbe, for whatever reasons, were insufficiently aware of the risks of serious flooding in the township. At planning stages the Regional and District Councils engage in structured processes of consultation as required under the Local Government Act. But this sort of approach does not seem to extend to ensuring ongoing awareness in the community of the risks associated with living in a low-lying floodplain.

Looking at the longer term, the Panel has concluded that the historic framework which has governed the development of the Rangitāiki River Control Scheme is at or near the end of its useful life. Frameworks now being more widely adopted look towards allowing greater room for rivers to move. This change is underlined by the near-certainty that climate change is leading to more severe and more frequent extreme weather events of the sort that occurred in April this year.

Already, the Regional Council and associated bodies, such as the Rangitāiki River Forum, have been thinking about what this means for the future shape of living with and by the Rangitāiki River. The Panel notes that a changed approach reflects wider community attitudes and interests and cannot expect to be funded on the current basis. Nevertheless, the Panel hopes that this report will assist in moving further and faster in a new direction.

Appendices

8.1 Appendix A: About the Reviewers

Sir Michael Cullen – Chair, spokesperson, member of the Eastern Bay of Plenty community

Sir Michael Cullen KNZM (MA, PhD) is a former New Zealand Deputy Prime Minister.

While in government he held several ministerial portfolios including Minister of Finance, Attorney-General, Minister in charge of Treaty of Waitangi Negotiations and Deputy Prime Minister.

Since retiring from Parliament in 2009, Sir Michael has served as Deputy Chair and Chair of the New Zealand Post Board. He was appointed to the Constitutional Advisory Panel in 2011. He is the chief negotiator for Ngāti Tuwharetoa and is the advisor for a number of other Iwi. He also recently undertook the Independent Review of Intelligence and Security (tabled in Parliament in March 2016) with Dame Patricia Reddy DNZM.

Kyle Christensen, Water Resources Engineer – Panel member, technical expert

Kyle is an independent consultant with over 17 years' experience in River and Stormwater Engineering. He has a Bachelor of Natural Resources Engineering as well as a Masters of Engineering specialising in the interaction of river control works and morphological processes in river systems.

Key affiliations: Chartered Professional Engineer; Professional Member of and practice area assessor for Institution of Professional Engineers New Zealand (IPENZ); and Chairman IPENZ/Water NZ Rivers Group.

Key areas of expertise: River and stormwater engineering; numerical modelling of hydrology, hydraulics and sediment transport; detailed design of river control works and hydraulic structures; operational flood response; and design review and failure diagnosis of flood and erosion protection works.

Charlie Price, Geotechnical Engineer – Panel member, technical expert

Charlie Price is a geotechnical/civil engineer with over 40 years' experience working on the investigation, design, supervision and contract management of major construction works for dams, hydroelectric power, water supply, mining, and subsea developments.

Key affiliations: Chartered Professional Engineer; Fellow of Institution of Professional Engineers New Zealand (IPENZ), International Professional Engineer; and Chairman NZ Geotechnical Society.

Key areas of expertise: Geotechnical engineering; ground investigation; earthquake geotechnical engineering; and investigation, design, supervision and contract management of major construction works for dams, hydroelectric power, water supply, and mining developments.

Charlie Price is employed by MWH New Zealand Limited, now part of Stantec.

8.2 Appendix B: Rangitāiki River Scheme Review Terms of Reference

Terms of Reference:

Rangitāiki River Scheme Review – April 2017 flood event

Background

The Bay of Plenty region was inundated with rain and severe weather from ex-Tropical Cyclone Debbie from 3 to 6 April 2017. Although the whole of the region was affected, the eastern Bay of Plenty felt the most significant impact.

The Whakatāne State of Local Emergency was declared on 6 April 2017 in response to the flooding caused by the significant rain from ex-Tropical Cyclone Debbie. The high rainfall resulted in all rivers in the region reaching warning levels with the some rivers reaching potentially record levels. A breach of the Rangitāiki River stopbank at College Road in Edgecumbe occurred on the morning of 6 April 2017, which resulted in widespread flooding of properties and the evacuation of people from the town. The breach at College Road was sealed late on the night of 7 April 2017 with further work undertaken during the day on 8 April 2017.

A region-wide State of Local Emergency was declared on 11 April 2017 in anticipation of the imminent impact of ex-Tropical Cyclone Cook, superseding the Whakatāne State of Local Emergency that was already in place. Ex-Tropical Cyclone Cook affected the region through the evening and night of Thursday 13 April 2017.

The region-wide State of Local Emergency was lifted on 14 April 2017, with a Whakatāne State of Local Emergency being re-declared at the same time for the next seven days. This came to an end at 12 midday on 21 April 2017, at which point the recovery phase commenced.

The Bay of Plenty Regional Council manages river and drainage schemes across the Bay of Plenty for the benefit of the community. The breached stopbank in Edgecumbe is part of the infrastructure assets that make up the Rangitāiki-Tarawera Rivers Scheme. The Scheme provides stopbanks, channel edge stability works and some drainage and flood pumping services to the township of Edgecumbe and the Rangitāiki, Galatea and Waiohau Plains. The Matahina and Aniwhenua hydro-electric power stations, and their associated hydro lakes, are located on the Rangitāiki River, upstream of Edgecumbe. Each year Bay of Plenty Regional Council spends more than $3 million maintaining the Rangitāiki-Tarawera Rivers Scheme and over the last ten years has spent around $30million on capital works. Expenditure on the Scheme is funded primarily from targeted rates (80 percent) on property owners within the Scheme area.

There has been a major impact on people and property from the breach of the stopbank at College Road, Edgecumbe. The entire Edgecumbe township was evacuated as many urban and rural properties became inundated. In the days following the breach some residents were able to return to their homes. However, at the beginning of May 2017, there were 16 damaged properties that had been assessed as severely damaged and around 250 lesser damaged properties that had been assessed as habitable with repairs.

The Bay of Plenty Regional Council recognises and appreciates that many people in the community are looking for answers – understandably asking how this breach could happen and what could have been done to prevent it. On 10 April 2017 The Chairman announced this independent review on the infrastructure and the circumstances that led to the breach of the stopbank and associated flooding through Edgecumbe on 6 April 2017. It is a technical review that will focus on the Regional Council's responsibilities.

Purpose of and Audience for these Terms of Reference

The Bay of Plenty Regional Council (BOPRC) wishes to record its intentions in relation to the independent review. This Terms of Reference is a public document intended for those members and organisations of the Bay of Plenty community affected by the flood event, as well as stakeholders more generally, including relevant government ministers. It sets out the task of the independent review panel.

Purpose of the Review

The purpose of this review is to understand the circumstances that led to the breach of the Rangitāiki River stopbank at College Road, Edgecumbe, and the resulting flooding through the town on 6 April 2017.

Governance and Leadership of the Review

BOPRC has initiated and commissioned this independent review and is the approver of the Terms of Reference.

The review will be led by Sir Michael Cullen who will chair a panel of experts. This will ensure the review is an independent, impartial, arms-length assessment of BOPRC infrastructure and activity.

Review Scope

The scope of the review has two interlinked parts:

1. The operation of the Rangitāiki River Scheme assets, including design, engineering, maintenance and management, that BOPRC manages on behalf of the community;

2. Implementation of the flood management role[9] that BOPRC delivered during the ex-Tropical Cyclone Debbie event up until the breach and in response to that breach.

The Panel will report its findings on the circumstances that led to the breach and will make recommendations it considers fit on matters within the review scope, including recommendations relating to future actions that the Regional Council might take.

Exclusions

The review has been commissioned by the BOPRC to cover matters it is responsible for. It is not intended to cover district council roles and responsibilities, including but not limited to:

- The effectiveness of the local Civil Defence Emergency Management response, including the timing and notification of evacuations; and

- The establishment and implementation of the recovery phase of the flood event.

The following matters are also outside the scope of the review:

- The Civil Defence Emergency Management Bay of Plenty Group role in and response to the event; and

- The appropriateness and effectiveness of the terms and conditions of the respective resource consents for the dams, hydro-electric power stations and spillways on the Rangitāiki River upstream of Edgecumbe, their monitoring (other than in respect of flood management) and the processes by which the consents were granted under the Resource Management Act 1991.

[9] This includes management of water through the dams on the Rangitāiki River, upstream of Edgecumbe.

Review Panel

The Panel will be comprised of three members:

- Sir Michael Cullen – Chair, spokesperson, member of the eastern Bay of Plenty community.

- Kyle Christensen, Water Resources Engineer – Panel member, technical expert.

  Key affiliations: Chartered Professional Engineer; Professional Member of and practice area assessor for Institution of Professional Engineers New Zealand (IPENZ); and Chairman IPENZ/Water NZ Rivers Group.

  Key areas of expertise: River and stormwater engineering; numerical modelling of hydrology, hydraulics and sediment transport; detailed design of river control works and hydraulic structures; operational flood response; and design review and failure diagnosis of flood and erosion protection works.

  Kyle Christensen is an independent consultant.

- Charlie Price, Geotechnical Engineer – Panel member, technical expert.

  Key affiliations: Chartered Professional Engineer; Fellow of Institution of Professional Engineers New Zealand (IPENZ), International Professional Engineer; and Chairman NZ Geotechnical Society.

  Key areas of expertise: Geotechnical engineering; ground investigation; earthquake geotechnical engineering; and investigation, design, supervision and contract management of major construction works for dams, hydro-electric power, water supply, and mining developments.

  Charlie Price is employed by MWH New Zealand Limited.

The Panel will be advised by an independent Legal Advisor. It may request advice from other subject matter experts during the course of the review.

The Panel will be supported by a Secretariat.

Public Opportunity to Provide Information, Input and Feedback

The Panel will ensure that all members of the community affected by, and all stakeholders with an interest in, the flood event that resulted from the breach of the Rangitāiki River Scheme stopbank on 6 April 2017 are given the opportunity to provide information, input and feedback. The Panel shall accept written input and feedback and will also provide an opportunity for verbal input and feedback to be provided. It will initiate meetings with community and stakeholder groups that it identifies as well as groups identified by BOPRC to the Panel.

BOPRC will provide full disclosure to the Panel of all the information it holds. It will also provide the Panel with full access to any relevant staff. In order to be effective, it is expected that the Panel will receive information and hear from, organisations outside of BOPRC.

Timeframes

The Panel should provide its final report to BOPRC by or on 31 July 2017.

Reporting Sequence

The Panel is to provide its report, including its findings and recommendations, to BOPRC in writing no later than the date specified in this Terms of Reference. Any delays in meeting this date are to be agreed with the Chairman of the BOPRC.

The Panel must provide a draft report to BOPRC for a factual check only. The Panel shall allow BOPRC ten working days to undertake this factual check, giving a minimum of five working days notice of the delivery date of the draft report.

The Panel's report will be made public. BOPRC may receive and consider the outputs of the review in confidence, prior to their public release, to enable it to prepare and provide an initial response to the Panel's findings and recommendations.

Enquiries

All enquires relating to providing input to the review should be directed to the review Secretariat in the first instance. Contact information will be publicly available and will also be available on the review website: www.rrsr.org.nz .

Any enquires to BOPRC should be directed to Mat Taylor, General Manager Corporate Performance, by phone 0800 884 880 or email mat.taylor@boprc.govt.nz .

Approval

These Terms of Reference were approved by resolution of the Bay of Plenty Regional Council on:

Date 18 May 2017

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Doug Leeder, Chairman BOPRC

These Terms of Reference were accepted by the review Panel on:

Date ______________________________

____
Hon Sir Michael Cullen, Panel Chair

8.3 Appendix C: Glossary

One-in-100 year flood	A one in 100-year flood event has a 1% (one in 100) chance of being equalled or exceeded in any one year. On average, this is expected to occur once in 100 years, based on past flood records, though in reality it could happen at any time.
One-in-200 year flood	A one in 200-year flood event has a 0.5% (one in 200) chance of being equalled or exceeded in any one year. On average, this is expected to occur once in 200 years, based on past flood records, though in reality it could happen at any time.
Aggradation	Increases to the level (height) of a river bed or floodplain due to natural deposition of sediment sourced from the upstream river channel and catchment.
Annual exceedance probability (AEP)	Expressed as a percentage, it gives the chances of a flood of that size or larger occurring in any given year. It is equal to the inverse of the "return period" that is also used to describe flood probability. For instance: • A "1% AEP flood" means a flood with a 1% or 1 in 100 chance of occurring in any given year. This is equal to a "100-year return period flood event". On average, this is expected to occur once in 100 years, based on past flood records, though in reality it could happen at any time. • A "5% AEP flood" means a flood with a 5% or 1 in 20 chance of occurring in any given year. This is equal to a "20-year return period flood event".
Annual Plan	A forward-looking publication. It contains changes from the Long-Term Plan for that year, as well as key financial information.
Borehole	A hole bored or drilled in the ground
Catchment	The boundaries of a river system based on the area that will capture rainfall that contributes to that river system.
Chain	A historic unit of British origin equal to length of 66 feet
Construction joint	An intentional joint built in to concrete work.
Control gate	A mechanical device that can be operated to change its height or degree to which it is open for the purpose of controlling the flow through or over a structure.
Conveyance system	The drainage facilities which collect, contain, and provide for the flow of surface water and urban runoff from the highest points on the land down to a receiving water.

Cribwall	A wall constructed of a grillage of interlocking header and stretcher units laid at right angles to each other. The header and stretcher units may be timber or reinforced concrete.
Cumecs	A unit of measurement for the flow of water, equal to one cubic metre per second ($1m^3/s$).
Cusecs	A unit of flow equal to one cubic foot per second.
Cutoff	A wall of impervious material installed beneath a stopbank or floodwall to reduce seepage
Cutoff drain	A drain designed to intercept and control sub-surface water flows.
Drainage Board	Organisation responsible for managing drainage prior to formation of the Bay of Plenty Regional Council in 1989.
Drainage metal	Typically processed free-draining rock of uniform grading (size).
Drainage schemes	Areas provided with land drainage by a network of canals, drains, pump stations and other assets.
Emergency evacuation	Temporary but rapid removal of people from building or disaster (or threatened) area as a rescue or precautionary measure.
Expansion joints	A joint between two parts of a structure permitting expansion without structural damage.
Factors of safety	The ratio of the resistance provided by a structure to the forces attempting to disturb it
Floodbanks	*See stopbank.*
Flood control schemes	A historic term (circa 1960-70s) used to describe the assets or works used to control rivers.
Flood forecasting model	A technique which uses the known characteristics of a river basin to predict the timing, discharge, and height of flood peaks resulting from measured rainfall and sometimes measure river flow, usually with the objective of warning populations who may be endangered by the flood.
Flood protection scheme	A more modern term used for describing assets or works used to control rivers. *See also Flood control scheme.*
Floodway	A channel built to take the floodwaters of a river.
Freeboard	An allowance to account for uncertainty in hydrological and hydraulic modelling.
Geofabric	A strong synthetic fabric used in ground engineering that stabilises loose soil and prevents erosion.
Ground Penetrating Radar (GPR)	A technique using radar waves to indirectly identify underground objects, soil layers and voids

Heave	Lifting of ground due to the pressure of upwards flow of water
Homogeneous	A material which has consistent properties throughout
Hydraulic gradient	The change in total hydraulic head between two points, divided by the length of flow path between the points. *See hydraulic head.*
Hydraulic Head or Head	The elevation of a water body above a particular datum level (known point). Specifically, the energy possessed by a unit of water at any particular point. The higher the water level or hydraulic head, the more energy the water at a specific location has.
Lake level optimisation	Making full use of the storage available in a lake (reservoir) to minimise the peak outflow. Requires accurate information on inflows and precise control of outflows.
Land Information Memorandum (LIM)	A report prepared by the District Council providing information from its records on matters affecting the land and any buildings on a particular property.
Long Term Plan	Outlines the long-term direction of the Council and includes information on all our major projects, activities and programmes for the next ten years and how they will be paid for. Reviewed every three years.
M^3/s	Cubic metre per second. *See cumecs.*
Membrane	A thin pliable sheet of material forming a barrier or lining.
Operating range (Matahina)	The range of levels which a lake or reservoir is managed within.
Overtopping	To flow over the top of (a structure).
Permeability	The ability of a substance to allow another substance to pass through it, especially the ability of porous rock, sediment, or soil to transmit fluid through pores and cracks.
Piping	A process whereby seepage from the ground surface carries with it fine particles of soil. The void created by the loss of soil particles moves progressively back through the ground along the seepage path, creating a 'pipe' in the ground.
Planned evacuation	An evacuation which is based on pre-determined rainfall or riverflow trigger points, an identified area or population, an agreed and understood warning method, identified safe egress routes, identified and equipped welfare centres.
Pore water pressure	The pressure of groundwater in a soil.
Reduced level (RL)	Calculated elevation in relation to a particular datum (known point).
Regional Policy Statement (RPS)	Sets out the framework and priorities for resource management in the region. The Resource Management Act 1991 requires all regional councils to produce an RPS for their region and renew it every 10 years.

Rip rap	Graded, quarried, rock placed in an interlocking fashion as protection against erosion.
River berm	The area between the top of the river bank and the river side of a stopbank or other constraining feature.
River bank crest	The highest point
Scheme or River Scheme	See *flood control scheme*.
Sediment flushing	The scouring out of deposited sediment from reservoirs typically through the use of low-level outlets in dams to lower water levels, thereby increasing the flow velocities in the reservoir.
Seepage	The movement of water through the ground.
Seepage relief trench	A subsurface trench drain designed to intercept and control sub-surface water flows
Silts	Fine sand, soil, or mud which is carried along by a river.
Soil saturation	A condition in which all the voids (pores) between soil particles in the ground are filled with water.
Spatial coverage	Geographical area where data was collected, a place which is the subject of a collection, or a location which is the focus on an activity.
Spillway	A structure constructed in a hydroelectric dam or at the upstream end of floodway or other conveyance structure to provide a safe path for floodwaters to flow downstream.
Stopbank	An elongated artificially constructed embankment which acts to constrain river levels.
Stratification	The arrangement of sedimentary rocks in distinct layers (strata), each layer representing the sediment deposited over a specific period
Subsidence	The gradual caving in, sinking or settlement of an area of land.
Toe	The outermost base of a structure.
Toe drain	A drain which carries seepage away from a water retaining structure.
Toe load	Placement of bulk fill at or on the toe of a structure.
Topping up	Placement of fill to raise isolated low points (in a stopbank).
Trial pit	A pit or trench dug to investigate the soil.
Tributaries	A river or stream flowing into a larger river or lake.
Wick drains	An artificial vertical drain installed in soft compressible soil to provide a drainage path to allow pore water pressure to escape.

8.4 Appendix D: Roles and responsibilities for natural hazard management

No one agency is responsible for natural hazard management in New Zealand. Rather, natural hazard management responsibilities extend to a wide range of organisations. However, local authorities play a pivotal role at the local community level.

Natural Hazards: Roles and Responsibilities

Ministry of Civil Defence and Emergency Management (MCDEM)	To support the functions of the Director of CDEM in overseeing that arrangements are in place nationally to manage hazards across the 4Rs in the event of a civil defence emergency. This involves promoting for, advising on and monitoring the integration and coordination of policies, planning, procedures and resources across agencies at both the national and local levels (CDEM Act 2002).
Regional councils	Control the use of land for the purpose of the avoidance or mitigation of natural hazards (s30 RMA 1991). Section 62(1)(i) of the RMA requires a **regional policy statement** to specify objectives, policies and methods relating to the avoidance and mitigation of natural hazards. In accordance with s62(2) of the RMA, if a regional council does not set out responsibilities for functions relating to natural hazards, then the regional council retains the primary responsibility.
Territorial authorities	Control the effects of the use of land for the avoidance or mitigation of natural hazards (s31 RMA 1991). Territorial authorities are also given the authority to control subdivision under s31(2) and have discretion under 106 to refuse a subdivision consent where the land is subject to hazards, or the subsequent use of the land will exacerbate the hazard.

Natural Hazards: Roles and Responsibilities continued

Emergency management officers	Carry out specific initiatives and ensure that procedures are in place at the local level for hazard and emergency management (CDEM Act 2002).
Civil Defence and Emergency Management Groups	Based on regional boundaries, they comprise representatives from local councils, emergency services, health boards and other organisations that are involved with emergency management (s12-24 CDEM Act 2002).
Engineering Lifelines Groups	A voluntary group of organisations with representatives from territorial authorities and major utility and transportation sector organisations. These voluntary organisations support their members in meeting their obligations with respect to networks providing the basic necessities of life and services essential to limiting the extent of an emergency. Engineering lifeline groups are co-ordinated at the national level by the National Lifeline Engineering Committee.

Natural hazard management activities undertaken by regional and territorial authorities

Regional councils (hazard identification)	Territorial authorities (hazard management)
Assess hazards of regional-level significance Providing direction through provisions in regional plans Implement, maintain and monitor warning systems Conduct research into hazard threats Provide education and information Provide information on site-specific and localised natural hazards Undertake works and services at a regional level (e.g. stopbank repair) Maintain a 'regional natural hazards register' Administer and update group civil defence emergency management plans	Assess hazard risks of district-level significance Control the location of, or requirements for, engineering or other solutions for development in hazard-prone areas through provisions in district plans Undertake works and services at the district level (e.g. hazard mitigation works) Provide education and information Provide information on site-specific and localised natural hazards Control development and activities in hazard-prone areas through their district plans and resource consents Prepare hazard management plans (e.g. flood management plans, contingency plans) Control stormwater discharges (through involvement in land-use planning and the control of building development) Ensure infrastructure is sited and designed to cope with hazards events (e.g. through asset management plans and provisions in district plans) Maintain a 'district natural hazards register'

Regional Councils have a number of tools at their disposal to discharge their responsibilities. They include the planning regime under the RMA, delivery of works and services (such as flood protection schemes), bylaws to protect flood and drainage assets, warning systems, education and information, and emergency management functions.

Regional Councils have a particular duty, through their regional policy statements, to set out responsibilities for natural hazard management with territorial local authorities.

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Regional Councils have a particular duty, through their regional policy statements, to set out responsibilities for natural hazard management with territorial local authorities.

Source: Extract from the Quality Planning Website (Quality Planning Website, n.d.) *(administered by Ministry for the Environment in conjunction with the New Zealand Planning Institute, Resource Management Law Association, New Zealand Institute of Surveyors, Local Government New Zealand and New Zealand Institute of Architects)*

8.5 Appendix E: The evaluation using NZS 9401:2008 Managing Flood Risk

NZS 9401:2008 outcome and associated categories	Chapters in the report addressing this outcome
1. Engaging communities and stakeholders This will be seen through the following: **a.** Communities and stakeholders are involved in formulating flood risk management solutions; **b.** Flood risk management decisions are a shared responsibility of individuals and their local and central governments to ensure the transfer of risk is minimised; **c.** Individual responsibility for managing personal risk is enhanced; **d.** Public and private interests are balanced; **e.** Roles and responsibilities of stakeholders are clear and agreed; **f.** A comprehensive risk communications strategy is in place and actively managed.	The legal and planning framework for flood hazard management (page 22) Could the breach have been avoided? (page 72) *Note: Evacuation planning in particular (page 105)* Community engagement (page 125)
2. Understanding Natural Systems and Catchment Processes This will be seen through the following: **g.** Natural river and catchment processes as these affect flood risk management are understood by all those affected;	The legal and planning framework for flood hazard management (page 22) Could the breach have been avoided? (page 72) *Note: Operation of Matahina*

NZS 9401:2008 outcome and associated categories	Chapters in the report addressing this outcome
h. Systematic assessments of catchments form the basis for catchment-based management of flood risk; **i.** Allowing rivers to revert to their natural behaviour is an option for consideration.	*Dam and Reid's Floodway in particular (page 72 & 89)* Long-term strategy and design philosophies (page 115)
3. Understanding the Interaction of Natural and Social Systems This will be seen through the following: **j.** Decisions on flood risk management are made within the wider context of natural and social systems; **k.** Catchment-based management strategies integrate consideration of environmental, economic, social, and cultural dimensions to provide the best approach to assessing risk associated with floodplain management planning; **l.** Adaptive management is an integral component of flood risk management.	The legal and planning framework for flood hazard management (page 22) Could the breach have been avoided? *Note: Operation of Matahina Dam and Reid's Floodway in particular (page 72 & 89)* Long-term strategy and design philosophies (page 115)
4. Decision Making at the Local Level This will be seen through the following: **m.** Each solution is based on how communities and stakeholders seek to manage flood risks in terms of their interests, the affordability of the risk management solution, and the nature of the risks at the sites being considered.	The legal and planning framework for flood hazard management (page 22) Long-term strategy and design philosophies (page 115) Community Engagement (page 125)

NZS 9401:2008 outcome and associated categories	Chapters in the report addressing this outcome
5. All Possible Forms and Levels of Management This will be seen through the following: **n.** Data and information, appropriate methodologies, and best practice guidance are available and used; **o.** A long-term risk assessment of flood management solutions is essential; **p.** All options to reduce or mitigate flood risk are considered. These should be risk-based; **q.** Impacts and cumulative effects are assessed; **r.** Outcomes that enhance aquatic, land, and coastal environments are considered; **s.** The performance of the flood risk management system is monitored and actively managed.	The legal and planning framework for flood hazard management (page 22) Could the breach have been avoided? (page 72) *Note: Matahina Dam and Reid's Floodway in particular (Page 72 & 89)* Long-term strategy and design philosophies (page 115) Community Engagement (page 125
6. Residual Risk This will be seen through the following: **t.** Residual risks are identified and addressed; **u.** The impacts of extreme events are considered as residual risks; **v.** Routine risk analyses are necessary to ensure that residual risk management remains appropriate.	The legal and planning framework for flood hazard management (page 22) Could the breach have been avoided? (page 72) *Note: Evacuation planning in particular (page 105)* Community Engagement (page 125)

8.6 Appendix F: 2017 Rangitāiki Flood Event - Log

This log is drawn from the substantial amount of information provided by a wide range of sources. Much of it is from the written logs that Trustpower and the Regional Council have submitted as a definitive record. These have been supplemented by people's recollections of the events. Comments and assessments made throughout this report rely upon the actions and observations submitted to the review. The Review Panel is mindful that other actions and communications may well have been carried out but not recorded in the stress of the event.

Date	Time	Event
31st March 2017	18:00	Matahina level started reducing
Monday 3rd April		
3 April	09:53	Flood forecast – MetService issues first severe weather watch
3 April	10:00	Flood forecast - automatic advisory data flood greater than 300m^3/s predicted
3 April	13:59	Flood forecast – MetService issue severe weather watch
3 April	14:20	Communications between Trustpower and Regional Council on flood event starts. Discussion on lowering dam to lower level
3 April	16:18	Flood forecast – MetService issue severe weather watch
3 April	18:00	Major flood forecast – automatic advisory data greater than 500m^3/s predicted
3 April	20:37	Flood forecast – MetService issue severe weather watch
Tuesday 4th April		
4 April	06:00	Flood forecast – Automatic advisory data and Regional Council modelling flood greater than 500m^3/s predicted
4 April	07:40	Telephone conversation between council and Trustpower regarding lowering of lake levels
4 April	08:36	Regional Council advise Trustpower to lower to 71.6mRL by midday tomorrow (Wednesday) Note: no record of this target from Trustpower
4 April	08:40	Regional Council meeting of Flood Managers/ Flood Forecasters – agree to continue to lower dam level at 0.1m/hr
4 April	09:49	Flood forecast – MetService issues first severe weather warning
4 April	11:37	Regional Council call to Duty Forecaster at MetService to confirm which of their forecast models is the more accurate. Duty Forecaster advised a "band of intense rain is expected along a line from "Rotorua to south of Opotiki" where up to 300mm of rain will fall up to mid-night"

Date	Time	Event
4 April	11:44	Flood forecast – MetService issues severe weather warning
4 April	12:00	Flood forecast – Automatic advisory data and Regional Council modelling flood less than 500m^3/s predicted
4 April	14:47	Update from Trustpower - discharging at 157.5m^3/s. Increased from 140m^3/s at 11:00
4 April	15:45	Regional Council Flood Team meeting: • Confirmed level trending down. Aiming for 71.6 midday tomorrow. Cannot ask for lower yet as forecast <500m^3/s peak. • Discussed lowering Aniwaniwa for desilting
4 April	16:04	Regional Council issued spill warning to landowners downstream of Matahina Dam
4 April	16:20	Telephone conversation Regional Council: Trustpower • Aim for 71.6m by midday tomorrow (5th); • Regional Council have issued spill warning in advance (at 16:04); • Asked to contact pager before spilling. Note: disagreement on expectations to use spilling
4 April	18:00	Flood forecast – Automatic advisory data and Regional Council modelling flood greater than 500m^3/s predicted
4 April	20:20	Flood forecast – MetService issues severe weather warning
Wednesday 5th April		
5 April	Wednesday morning	MetService Duty Forecaster considered that the amount was not replicated in the other two models and was probably an "outlier" but that we should act accordingly
5 April	Early morning	Major Flood Forecast – automatic advisory data and Regional Council modelling flood 700-800m^3/s predicted
5 April	01:00	Trustpower reduced outflows 00:00-02:00. Inflows increased 00:00-06:00 from 127m^3/s to 207m^3/s. Regional Council report this resulted in Matahina dam rising 300mm
5 April	06:29	Regional Council radio broadcast request warning for Eastern BOP Rivers. Includes Rangitāiki River and notes that controlled spilling has started from Matahina Dam
5 April	07:30	Trustpower report telephone conversation with Regional Council questioning lack of progress overnight on lake level. Discussion lead by council regarding need for storage in dam and requested to aim for total outflow of 350m^3/s and lake level of 71.6mRL by 16:00 5th April. Note: mismatch with Regional Council reporting
5 April	08:00	Regional Council report no contact from Trustpower. Noticed on Hydrotel that dam level has risen since 01:00. Note: mismatch with Trustpower reporting (conversation at 07:30).

Date	Time	Event
		Flood Manager responsibilities split across Rangitāiki-Tarawera scheme and all other river systems
5 April	08:20	Regional Council report contacting Trustpower as they did not spill overnight. Advised them new 500m^3/s peak. Need to aim for 71.6m at midday. Currently 72.7m. Note: mismatch between Trustpower and Regional Council expectations
5 April	08:30	Matahina spillway gates 1 and 3 gradually opened to 2.1m to achieve target outflow of an additional 200m^3/s
5 April	09:18	Confirmatory e-mail from Regional Council Flood Manager regarding 07:30 telephone conversation. Spill gradually increased via two spillway gates to achieve total flow of 350m^3/s. Note: mismatch with Regional Council – no mention of 07:30 call
5 April	09:20	Regional Council agreed need to discharge 350m^3/s
5 April	09:20	Flood Room activated (operates until 17:00 Saturday 8 April)
5 April	09:51	Regional Council email Trustpower to spill at 350m^3/s and that 71.6m must be reached before 16:00 – when 500m^3/s forecast
5 April	10:05	Flood forecast – MetService issues severe weather warning
5 April	10:10	Phone call Regional Council and Trustpower: disagreement on agreed targets for 4-5 April and that the dam rose
5 April	10:30	Trustpower Generator 1 tripped (automatically shut down) due to a stator earth fault. Isolation Applied to allow testing of generator. A temporary dip in total outflow (water flow) for ~30minutes occurred while spillway gates adjusted to maintain overall outflow, inflows to the lake continued to rise. (G1 out of service for ~24 hours for isolation, test and de-isolation)
5 April	11:20	Trustpower confirm outflow is at 350m^3/s now (email). Regional Council Flood Manager advised that forecast peak then is 800m^3/s and with operation of dam storage could reduce this to 560m^3/s. Floodway operation threshold forecast at 22:00
5 April	11:24	Trustpower report further telephone conversation Regional Council reviewing prediction(s), 500m^3/s at 19:00 tonight peaking 800m^3/s ~08:00 Thursday. Lake outflows will be managed to ensure reasonably constant rate of decline. Confirmed via e-mail from Trustpower to Regional Council. Target: 71.6m at 19:00 tonight. Current lake level 72.38mRL. Note: mismatch with Trustpower and Regional Council expectations
5 April	11:30	Regional Council report conference call for Regional Council and Trustpower. They agree to do as directed by the Flood Manager. Regional Council report sending email to Trustpower to have dam at 71.6m by 16:00.

Date	Time	Event
		Note: mismatch with Trustpower and Regional Council expectations
5 April	13:32	Confirmatory e-mail from Regional Council following telephone discussion and new targets. Comment from Flood Manager "looks real good" Target volunteered by Trustpower: 71.6m around 19:00
5 April	15:30	Regional Council Flood Room Briefing: • Spillway (Reid's Floodway) could be in operation by 03:00 (Thursday); • Issue warning and arrange road closures on Hydro, McCracken, McClean Roads. Forecast now 951m^3/s. Regional Council agree need to release 550m^3/s
5 April	15:32	Trustpower update to Regional Council: current level 72.0m, 500m^3/s forecast 22:00, must get to 76.1m before then (22:00)
5 April	16:00	Major Flood Forecast - automatic advisory data and Regional Council modelling flood greater than 900m^3/s predicted
5 April	16:21	Regional Council send flooding warning to downstream landowners about road closures due to Reid's Floodway/ Canal to be in operation
5 April	16:30	Trustpower report conference call with Regional Council reviewing predictions, confirming flood manager and use of communications channels Note: mismatch of teleconference times
5 April	17:00	Regional Council advise Whakatāne District Council Emergency Operations Centre (EOC) that Reid's Floodway/ Canal will likely need to be operated
5 April	17:17	Regional Council radio broadcast request: Reid's Floodway and Canal likely to start operating.
5 April	17:35	Regional Council report teleconference with Trustpower: • Noted "adverse forecast" - dam inflows may reach 950m^3/s by 10:00 6 April; • Agree target outflows of 550m^3/s; • Agreed approach is to drive lake down hard, and capture peak inflows; • Regional Council give approval to drop lake below 71.6mRL (to 70.0mRL). Regional Council report wish to get from 71.6 – 71.0m. Changes not implemented until after 20:00. Actual Lake level ~71.79mRL. Note: mismatch in expectations on getting close to 71.0 and in teleconference times
5 April	18:00	Confirmatory e-mail from Regional Council to Trustpower following 17:35 telephone discussion confirming strategy and targets
5 April	19:32	Pioneer received call from Regional Council Flood Manager A. Advised Aniwaniwa was down 2.0m and holding satisfactorily. Regional Council Flood Manager asked if flood storage was available. Advised Regional Council in no position to offer flood storage.

Date	Time	Event
		Note: mismatch regarding storage available at Aniwaniwa
5 April	19:45	Regional Council called Pioneer to hold Aniwaniwa level. Advised only 1.0m able to be filled. Note: mismatch regarding storage available at Aniwaniwa
5 April	20:00	Regional Council Flood Room staff change
5 April	20:05	Owners of Aniwaniwa indicated that Aniwaniwa is not available for storage
5 April	20:27	Flood Forecast - MetService issues severe weather warning
5 April	20:30	Regional Council contact Trustpower. At 550m^3/s. Will hold and discuss after next modelling run
5 April	21:05	Rangitāiki at Waiohau Bridge = 550m^3/s. Dam level at 71.6m
5 April	22:00 Approx.	Lake Matahina starts filling
5 April	22:15	Regional Council provide directive to Trustpower to increase outflows to 600m^3/s immediately
5 April	22:32	Confirmatory e-mail from Regional Council instructing total outflow to 600m^3/s immediately and continue to keep dam at or below 71.6m. Total outflow 600m^3/s, keep dam at 71.6m or below
5 April	22:44	Confirmatory e-mail to Regional Council confirming 600m^3/s
5 April	23:50	Directive to Trustpower to increase outflows to 650m^3/s. Confirmed via email
5 April	23:58	Confirmatory e-mail from Regional Council instructing total outflow to 650m^3/s immediately. Total outflow 650m^3/s
Thursday 6th April		
6 April	00:40	Discussion and agreement at Regional Council to call and email Trustpower to increase outflow to 710m^3/s. This is the optimised fill outflow. Lake needs to be monitored against fill profile
6 April	01:33	College Road floodwall inspected: • No obvious signs of seepage.
6 April	01:43	Laws Bend Stopbank inspected: • River level is approximately 2m below stopbank crest; • No obvious signs of seepage; • Water on the road at the bend – appears to be surface flooding as there is no sign of water movement at all.
6 April	01:44	Flood Forecaster advised fill profile based on 700m^3/s
6 April	01:55	Thornton Boat Ramp inspected: • River level is up to road level; • General surface flooding water around toilets coming across road to meet the river level.

Date	Time	Event
6 April	02:05	Grieg Road Floodwall inspected: • River Level is approximately 1.2m below top of floodwall; • No obvious signs of seepage.
6 April	05:27	College Road Floodwall inspected: • No obvious signs of seepage
6 April	06:06	Regional Council advise Whakatāne District Council EOC that Reid's Floodway is being used as a spillway. Upon inspection, this is not seen
6 April	07:00-07:30	Regional Council local reportedly seen on stopbank. Residents questioned whether community should evacuate. His advice – pack bag and let neighbours know. Local tested bank with prod and water poured out. Requested residents to call if it turned murky (residents thought it was already brown). Left in hurry. Community start to self-evacuate. Fire brigade and police observed onsite at stopbank. Fire brigade had been instructed to stop traffic – believed this due to vibrations putting wall at risk. Rangitāiki River starts to flow into Reid's Floodway approx. 07:15
6 April	07:30-07:45	Regional Council contractor arrives at Edgecumbe Regional Council yard on standby for flood response. Observations and calls on water flowing through the cribwall at College Road floodwall, including: • Local resident visited Regional Council Works Manager regarding seepage at the wall (approx. 07:30-07:45); • Regional Council contractor told of several phone calls about the floodwall leaking water. He goes to the wall; • Fire Service personnel out and about looking at various sites. Phone call made to local Fire Station that the stopbank "was leaking". First truck directed to College Road wall.
6 April	07:45-08:00	At floodwall: • First fire truck arrives 07:51; • Regional Council arrive (contractor, works coordinator, works manager) and make observes clear water seeping through the cribwall and some seepage through the wall joints. Observe 'soft spot' at the southern end of wall on grass verge above the cribwall; • Regional Council decide to undertake mitigation works (**toe load**) and inform Flood Room. River detail: • River height approx. 500 to 600mm below top of wall; • Rangitāiki inflows 800-850m^3/s; • Outflows from Matahina at 710m^3/s.
6 April	08:00—08:15	At wall: • Second fire truck arrives at 08:06; • Fire officers decide to advise police and residents in College Road between Rata St and the Library to consider evacuation; • Additional fire service support requested for evacuation;

Date	Time	Event
		• Fire service requested to remove handrail for start of mitigation works Note: conflicting reports on who made this request In Regional Council Flood Room: • Staff change at 08:00; • At 08:10 Flood manager advises Civil Defence Controller at EOC to start evacuation of Edgecumbe, outflows from Matahina cannot be lowered; • EOC note evacuation already underway; • At 08:08 call from 105 College Road re extensive seepage and heave reported in back lawn. Overlay provided by Regional Council; • Approx 08:00, call from resident to check if Reid's Floodway is working.
6 April	08:15-08:30	At floodwall • Fire Service remove handrails; • Truck with digger arrives for mitigation works on wall (toe loading). In Regional Council Flood Room • Additional communications from residents on a stopbank breach and that the rubber seals in concrete wall are leaking at 97 College Road (a different section of wall).
6 April	08:30	College Road floodwall breaches. See Section 4.2 – the breach for observations
6 April	08:35	Resident walking near the breach of the wall shared the following comments: At wall 5 minutes before. Left to respond to call from police to open hall for evacuees. As he returned to bank, returned, breach occurred. Went from ankle deep to waist deep in 3-4 minutes
6 April	09:05	Telephone call with Trustpower and Regional Council Flood Room to maintain spill at 710m^3/s
6 April	09:30	Regional Council Flood Room decide to lower Reid's Floodway spillway crest to reduce pressure on Edgecumbe
6 April	09:40	Regional Council Flood Room agreed to increase outflow to 780m^3/s
6 April	09:50	Regional Council advised Trustpower to go to 780m^3/s. All three present agreed. Was kept at 780m^3/s for 4 hours; meant forecast inflow of 950m^3/s absorbed without dam level going beyond top of range
6 April	10:15	Hydrotel flow at Te Teko 781.5m^3/s
6 April	10:15	Confirmatory e-mail from Trustpower to Regional Council Flood Room confirming 780m^3/s
6 April	10:40	Regional Council Flood Room discussion with Aniwaniwa Dam owner (Pioneer Energy). Aniwaniwa will not provide storage as dam is not set up to manage and control elevated lake levels.
6 April	11:00	Matahina outflow 780m^3/s RL = 6.483m (100yr flood) Rating curve = 775m^3/s. Calibrates well

Date	Time	Event
6 April	11:20	Regional Council commence lowering of Reid's Floodway spillway crest
6 April	12:40	Whakatāne District Council declared State of Emergency
6 April	13:05	Gauged Rangitāiki and Waiohau = 735m^3/s
6 April	13:20	Flood Forecaster advised can go to 670m^3/s. Decided to reduce to 700m^3/s
6 April	13:21	Regional Council Flood Room advise Trustpower to reduce discharge to 700m^3/s
6 April	14:15	Update received from Nova Energy (Aniwaniwa Dam) level control since 07:30 in accordance with their Flood Management Plan. Advised 766m^3/s gauged and Waiohau.
6 April	14:15	Regional Council Flood Room call Trustpower. Discussed refilling of dam. Agreed review at 17:00 Note: mismatch of records
6 April	15:15	Trustpower conference call with Regional Council Flood Room. Lake rising at 0.15m/hr 12hr to peak level Note: mismatch of records
6 April	16:54	Regional Council Flood Room send extensive email to Trustpower about Recession Filling
6 April	17:10	Trustpower conference call with Regional Council Flood Room, inflows receding
6 April	21:20	Regional Council Flood Room send confirmatory e-mail to Trustpower. Total outflow to 700m^3/s from 650m^3/s
6 April	23:55	Regional Council Flood Room send confirmatory e-mail to Trustpower. Total outflow to 590m^3/s from 650m^3/s

8.7 Appendix G: Aniwhenua (Aniwaniwa) Draw Down Plan

Guidelines for the Drawdown of Lake Aniwhenua During High Inflows, and the Subsequent Refilling of the Reservoir.

Reservoir inflows referred to throughout are true inflows.

The following guidelines for the drawdown of Lake Aniwhenua in controlled stages resulting from high reservoir inflows, or impending high inflows, is intended to: -

- Reduce the effects of flooding down-stream of the Aniwhenua Power Station by using the reservoir as a buffer against rapidly changing inflows.
- Scour sediment deposits at the head of Lake Aniwhenua into deeper water and increase channel depths by increasing the water velocity through the reservoir.
- Facilitate the flow of water into the reservoir proper in the vicinity of Rabbit Bridge through increased channel depths.

The staged drawdown and refill levels below should be used as a guide only as each scenario will depend on, but is not limited to, the rate of change in inflows, the duration or predicted duration of the increased inflows, and the extent of flooding both upstream and downstream of Lake Aniwhenua.

Operational issues such as canal water level rate of change, and the relationship between headpond and penstock water levels to generation, must also to be considered and continually monitored throughout the drawdown operation.

Operations and management of station outflows must at all times comply with Water Right conditions.

Calculation of true inflows:
Flows between around $30m^3/s$ to $75m^3/s$ can be derived from the equation: -

$f(Q_{BoPE}) = 1.568\,Q_{BoPE} - 1.468m^3/s$ (Refer to Aniwhenua Reservoir Inflow Prediction by Tonkin & Taylor, February 2002).

Where: $f(Q_{BoPE})$ is the total inflow to the reservoir including the Pokairoa and Pahekeheke Streams.

Q_{BoPE} is the flow at the BoPE Rangitaiki River Gauge.

Alternatively, or for inflows outside the $30m^3/s$ to $75m^3/s$ range, true reservoir inflows can be derived from the calculation: -

Reservoir Inflow = Total Reservoir Outflows (From the NIWA River Gauge at Aniwhenua Power Station) + Flow to or from Reservoir Storage.

Where: The flow to or from storage is the difference in the reservoir volumes (Refer Appendix 8.1) at the lake levels before and after the measuring period, divided by the measuring period in seconds.

Reservoir Drawdown:
Lake drawdown must not exceed the drawdown rate of 300mm per hour.

Example of Lake drawdown levels at varying reservoir inflows. (Refer to included graph)

⇒ For inflows up to $80m^3/s$	Normal Operation:	146.80m to 146.60m
⇒ For inflows between $80m^3/s$* and $90m^3/s$	Maintain lake to:	146.60m
⇒ For inflows between $90m^3/s$ and $120m^3/s$	Progressive drawdown from:	146.60m to 146.20m
⇒ For inflows between $120m^3/s$ and $170m^3/s$**	Progressive drawdown from:	146.20m to 145.80m
⇒ For inflows between $170m^3/s$ and $230m^3/s$	Progressive drawdown from:	145.80m to 145.40m
⇒ For inflows between $230m^3/s$ and $330m^3/s$	Progressive drawdown from:	145.40m to 144.90m
⇒ For inflows greater than $330m^3/s$	At discretion of the Generation Eng:	144.90m to 144.10m

Notes on Reservoir Drawdown:

* Lake drawdown to 146.60m may commence at lower inflows than that indicated depending on the rate, or predicted rate, of change in inflows together with the perceived extent of the flood.

Ideally the reservoir drawdown to 146.60m should be achieved through generation before the need for spillage arises.

** The Generation Engineer must be advised before lake levels are drawn down below 146.10m.

Farmers with farms bordering Lake Aniwhenua are to be advised if drawdown is to proceed below 146.10m. Refer to emergency contact details in section 2 of this manual.

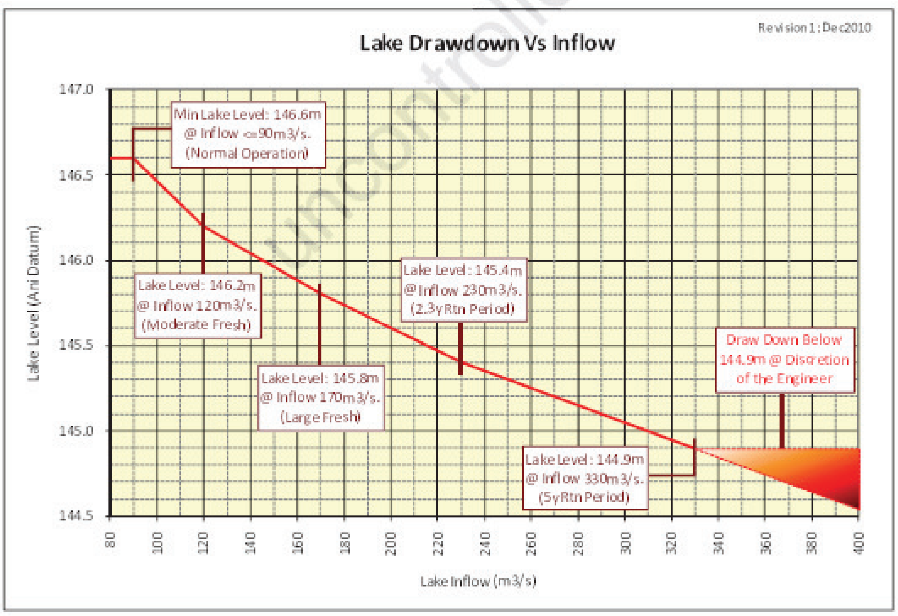
Refilling the Reservoir:

Example of Lake refill levels at varying reservoir inflows. (Refer to included graph)

⇒ For inflows of 330m^3/s or greater	At discretion of the Generation Eng:	144.10m to 144.90m
⇒ For inflows between 330m^3/s and 230m^3/s	Progressive refill from:	144.90m to 145.40m
⇒ For inflows between 230m^3/s and 170m^3/s	Progressive refill from:	145.40m to 145.80m
⇒ For inflows between 170m^3/s and 120m^3/s	Progressive refill from:	145.80m to 146.20m
⇒ For inflows between 120m^3/s and 90m^3/s	Progressive refill from:	146.20m to 146.60m
⇒ For inflows less than 90m^3/s***	Refill for normal operation:	146.60m to 146.80m

Notes on Reservoir Refill:

***Commencement for refilling the reservoir for normal operation is largely dependant on the rate of decline in inflows and may vary from the 90m^3/s flow indicated.



8.8 Appendix H: About the community input received

8.8.1 OVERVIEW OF COMMUNITY INPUT

A large volume of invaluable information and observations have been provided to the Rangitāiki River Scheme Review to support the development of this report. This information came from many parts of the community with all contributors acknowledged below.

The information provided varied from background documents about the Scheme, dam and Council frameworks to handwritten letters, photos, detailed timelines of events leading up to the breach on 6 April and individuals experiences through the flood event. In addition, people offered questions that would be helpful to address through the review.

Where possible the material received has reflected in the report, however information about the 2017 flood event was often based on recollections, experiences and events while under pressure. As a result, some information was conflicting. We have done our best to reconcile this wherever possible. In many cases, these conflicts have been related to events that are not material to understanding the circumstances (and causes) that led to the breach of the Rangitāiki River stopbank at College Road, and so have not been specified in detail in the report.

8.8.2 ACKNOWLEDGEMENTS

The Rangitāiki River Scheme Review panel would like to thank the following groups and organisations for taking the time to meet the Review lead or full Panel of experts. These discussions were an important source of information and guidance to support the review in understanding the circumstances that led to the breach of the Rangitāiki River stopbank at College Road in Edgecumbe.

- Bay of Plenty Regional Council, current and former staff and contractors, in particular the Rivers and Drainage Engineering Team
- Federated Farmers Whakatāne Branch representatives
- Marianne O'Halloran, IceGeo
- Peter Askey, Opus International Consultants Ltd
- Peter Mulvihill, Pioneer Energy
- Fire Chief Officer Adrian Massey, New Zealand Fire Service
- Ngāti Awa
- Rangitāiki River Forum, iwi members
- Rangitāiki Tarawera Rivers Scheme Liaison Group
- Trustpower
- Whakatāne District Council
- Opus International Consultants Ltd

The Review Panel would like to share condolences with the Rivers & Drainage Team from the Regional Council who unexpectedly lost a valued and a long-serving team member in July.

The Review Panel greatly appreciated support provided by the chairperson, Charelle Stevenson, and the other members of the Rangitāiki-Edgecumbe Community Board. In particular, the Community Board facilitated a drop-in session for community members to meet with the Review in early June.

The Review Panel would like to thank the following members of the community for taking the time to engage with the Review and provide questions, comments, information and stories to support the review in understanding the circumstances that led to the breach of the Rangitāiki River stopbank at College Road in Edgecumbe.

Alasdair Abernethy
Gerard van Beek
Mike Van Beek
Graeme Bourk
Garry Bryson
Liz Bryson
Kylie Carpenter
Seinna Carrington
Robin Cheung
Philip Coffin
Maureen Coffin
Reuben Cohen
Deborah Cohen
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John Davis
Platt Dell
Jade Elliot
Steven Evans
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Celia Gee
James Platt Gow
Peter Green
David Hansen
Roddy Howe
John Kearns
Ashley Kerei
Mary Kerei
John Lamont
Clive MacIndoe
Fred Mansell
Pare Mansell
Tiipene Marr
Bernie McCracken
Jacquie McPherson
Rod McPherson
Russell Milne
Dianne Milne
Robert Morris
Helen Morris
Bernadine Ngaheu
Ross Ogle
Louw Oliver
Russell Orr
Dave Pettinger
Paul Quinn
Mikko Rannali
Alison Rannali
Joe Richards
Vicki Richards
Brian Riddiford
Len Rika
Roberta Rika
Karyn Rogers
Graham Rough
Christine Scott
Andy Scott
Phil Silvester
Eunice Silvester
Andrew Skeet
Graham Smeaton
Adrian Spackman
John Stothers
Harry Street
Damon Tahu
Neville Thompson
Judy Turner
Shelly Wilson
Kevin Winters

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Update of scientific information for the Arrow catchment: 2012-2017

July 2017

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Otago Regional Council

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1. Introduction

The Otago Regional Council (ORC) has continued to measure flows in the Arrow River since the publication of the report “Management flows for aquatic ecosystems in the Arrow River” (Kitto 2012). This report presents an updated hydrological analysis for the Arrow River using data collected from the Cornwall Street flow site, including analyses to estimate naturalised flows for several seasons as well as updated instream habitat analysis.

The Arrow River (catchment area: 236 km²) is located in Central Otago. Its headwaters are in the Harris Mountains, and in the lower reaches it is bordered by the Crown Range; it flows in a south-east direction, joining the Kawarau River near the township of Arrowtown. The climate is typical of Central Otago being characterised by cold winters and warm, dry summers.

The upper reaches of the Arrow catchment are relatively unmodified with predominately steep tussock-covered mountain slopes. The catchment descends abruptly with dramatic landforms and ice-carved landscapes. In the mid to lower reaches there is a contrast of rocky bluffs and tussock; the vegetation changes from tall tussock to short tussock, exotic grasses, sweet briar and grey shrub-lands as you move down the catchment.

Arrow River forms an integral part of the picturesque setting of today’s Arrowtown. There are numerous bike and walking trails that follow the river margins and there are several recreational parks where local people and a large number of tourists sit and paddle in the waters of the Arrow River. The clean and clear nature of the river bed and inanga/pale green coloured pools add as much to the tranquillity of Arrowtown as the autumn seasonal tones of the deciduous trees that frame the township.

The river formed part of the 1860 Central Otago Gold Rush and provided a rich vein of gold for the many European and Chinese that settled in the area. At the peak of this period 1,500 miners occupied the banks of the river. (http://www.arrowtown.com/our-town/then-now/) and gold is still found in the river. Many of the historic dwellings that were established during the early history form part of today’s Arrowtown.

Maori referred to the Arrow River as Haihainui (big scratches) possibly reflecting the plant community, which was dominated by Matagouri, *Dracophyllum and Aciphylla* species. Summer seasonal hunts were undertaken collecting native birds such as weka. In addition they also gathered pounamu (greenstone) in the Wakatipu area; although it’s unclear whether any pounamu was found within the Arrow River catchment.

There are 22 existing surface water takes in the Arrow River catchment, with a total allocation of 2.25 m^3/s, although the measured usage does not exceed 1 m^3/s and the average take is about 0.55 m^3/s.

The objective of this report is to present the findings of further investigations in the hydrology, ecology, and irrigation practices of the Arrow catchment since the publication of the “Management flows for aquatic ecosystems in the Arrow River” (2012).

This report summarises the results of the work undertaken since 2012 and discusses the implications for the minimum flow process in the Arrow River catchment.

. This information includes the following:

- hydrology and existing water allocation in Arrow River
- aquatic values of Arrow River
- presentation, analysis and interpretation of the results of instream habitat modelling flows to maintain aquatic ecological values in the Arrow River

2. Rainfall patterns and naturalised flows in the Arrow catchment

2.1. Rainfall statistics

The climate of the Arrow catchment is consistent with other parts of Central Otago with cold winters and hot and dry summers. The catchment is affected by westerly weather systems that spill over the Southern Alps.

There are three rainfall stations located in the immediate vicinity of the Arrow catchment (Figure 2-1). The gauges are located at Queenstown Aero AWS (34 years to 2017), the Shotover at Peat's Hut (20 years to 2017), and Matukituki at West Wanaka (19 years to 2017).

Rainfall at Queenstown Aero Automatic Weather Station (AWS) does not have a strong seasonal distribution as shown in Figure 2-2. The rain gauges at Peat's Hut shows higher rainfall compared with Queenstown Aero AWS, likely due to the Peat's Hut site being more affected by westerly air flows bringing heavy spill-over rain over the Southern Alps. Matukituki at West Wanaka also generally has higher monthly rainfall totals than those at Queenstown Aero AWS. February, March, and April appear to be the months where all sites consistently receive lowest monthly rainfalls.

Annual rainfall statistics for Queenstown Aero AWS, Shotover at Peat's Hut, and Matukituki at West Wanaka are summarised in Table 2-1. The Shotover at Peat's Hut (923 mm) has the highest mean rainfall, while Queenstown Aero AWS has the lowest recorded rainfall of all the sites, with 569 mm recorded in 2005. Matukituki at West Wanaka had the highest maximum annual rainfall of these three rainfall sites with 1199 mm recorded in 2004.

The rainfall distribution map (Figure 2-3) shows that the highest annual rainfall totals occur in the headwaters of the catchment where there is spill-over rain from westerly storms. Rainfall decreases from north to south where annual rainfalls are in the range of 700 – 750 mm. The mean annual rainfall calculated for Queenstown was 733 mm; 939 mm for the Shotover at Peat's Hut and 918 mm for the Matukituki at West Wanaka. The long-term mean annual rainfall for the Arrow River catchment (Figure 2-3) is calculated as 701 mm.

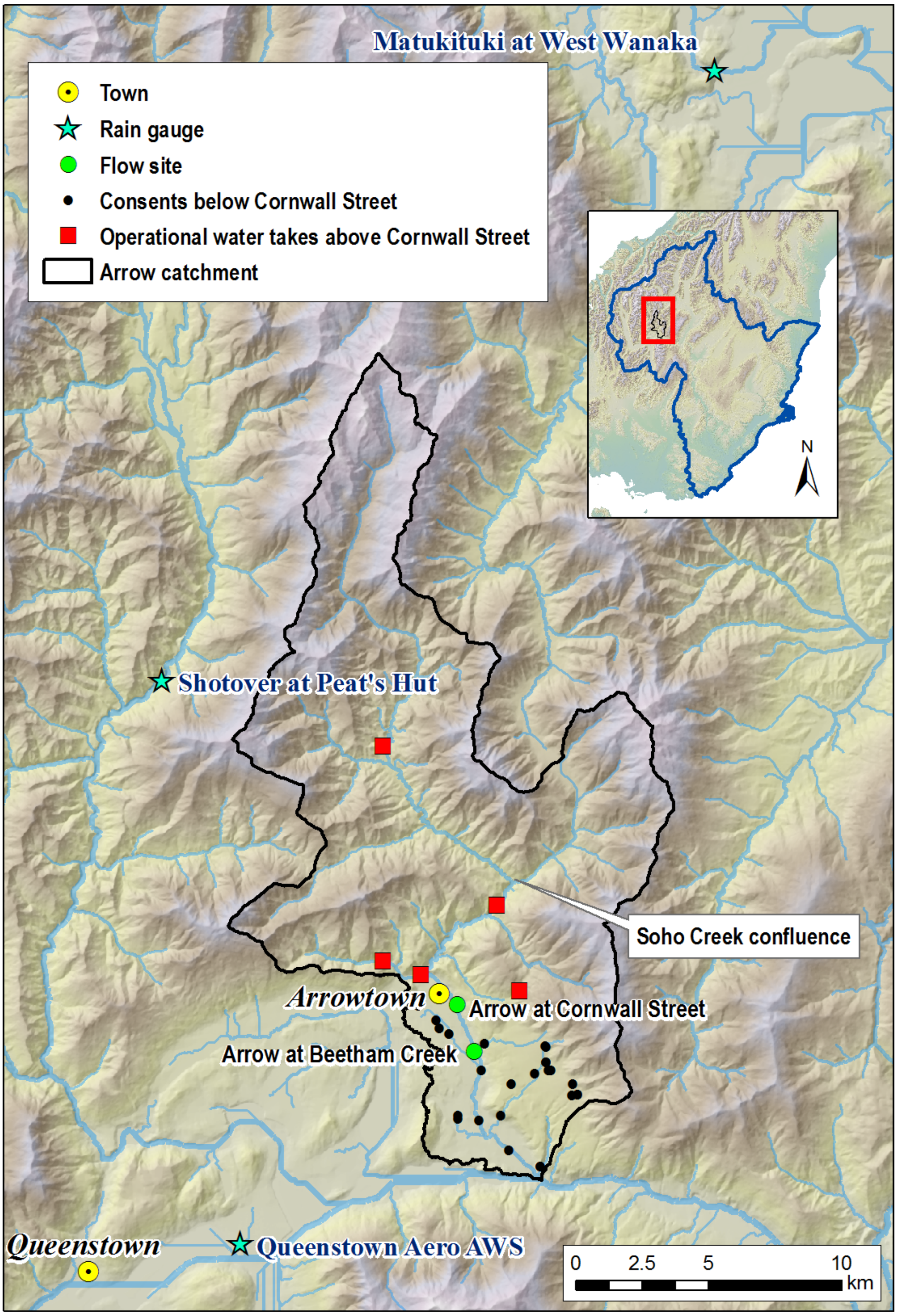

Figure 2-1 The flow recorders, water takes in the Arrow catchment, and the nearby rain gauges (Source: Otago Regional Council)

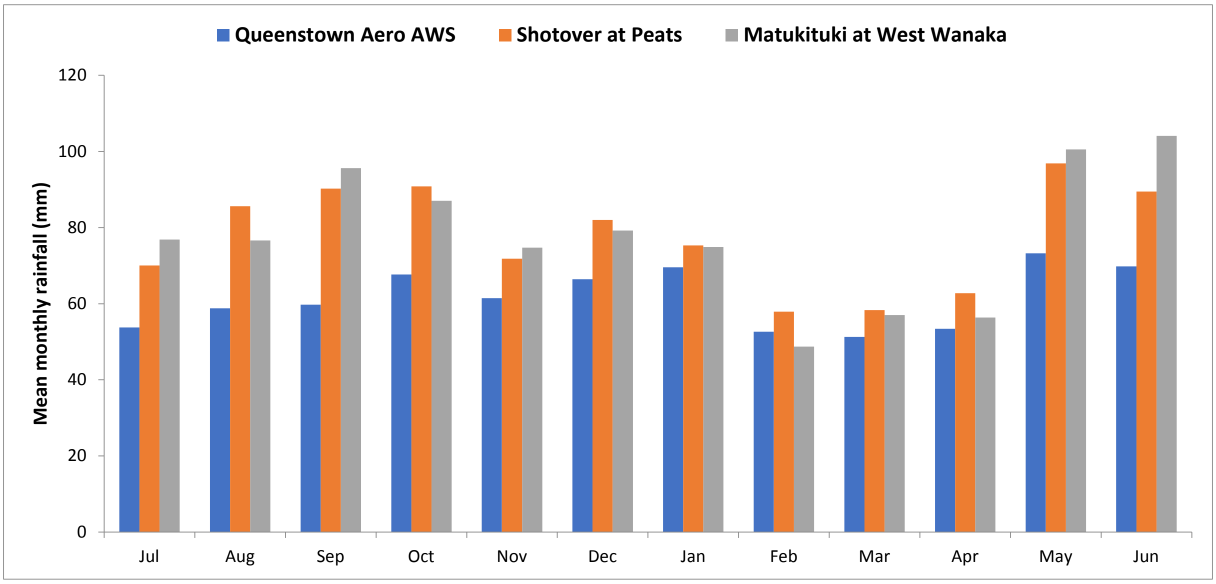

Figure 2-2 **Average monthly rainfall totals for the rainfall sites at Queenstown Aero AWS (NIWA), Shotover at Peat's Hut(ORC), and Matukituki at West Wanaka (ORC)**

Table 2-1 **Summary of annual rainfall statistics for Queenstown Aero AWS, the Shotover at Peat's Hut, and Matukituki at West Wanaka**

	Queenstown Aero AWS (Nov 1982-May 2017)	Shotover at Peat's Hut (Jan 1997-Apr 2010)	Matukituki at West Wanaka (Feb 1998-Apr 2017)
Min (mm)	569	691	682
Mean (mm)	733	939	918
Max (mm)	1077	1130	1199
Years of record	34	20	19

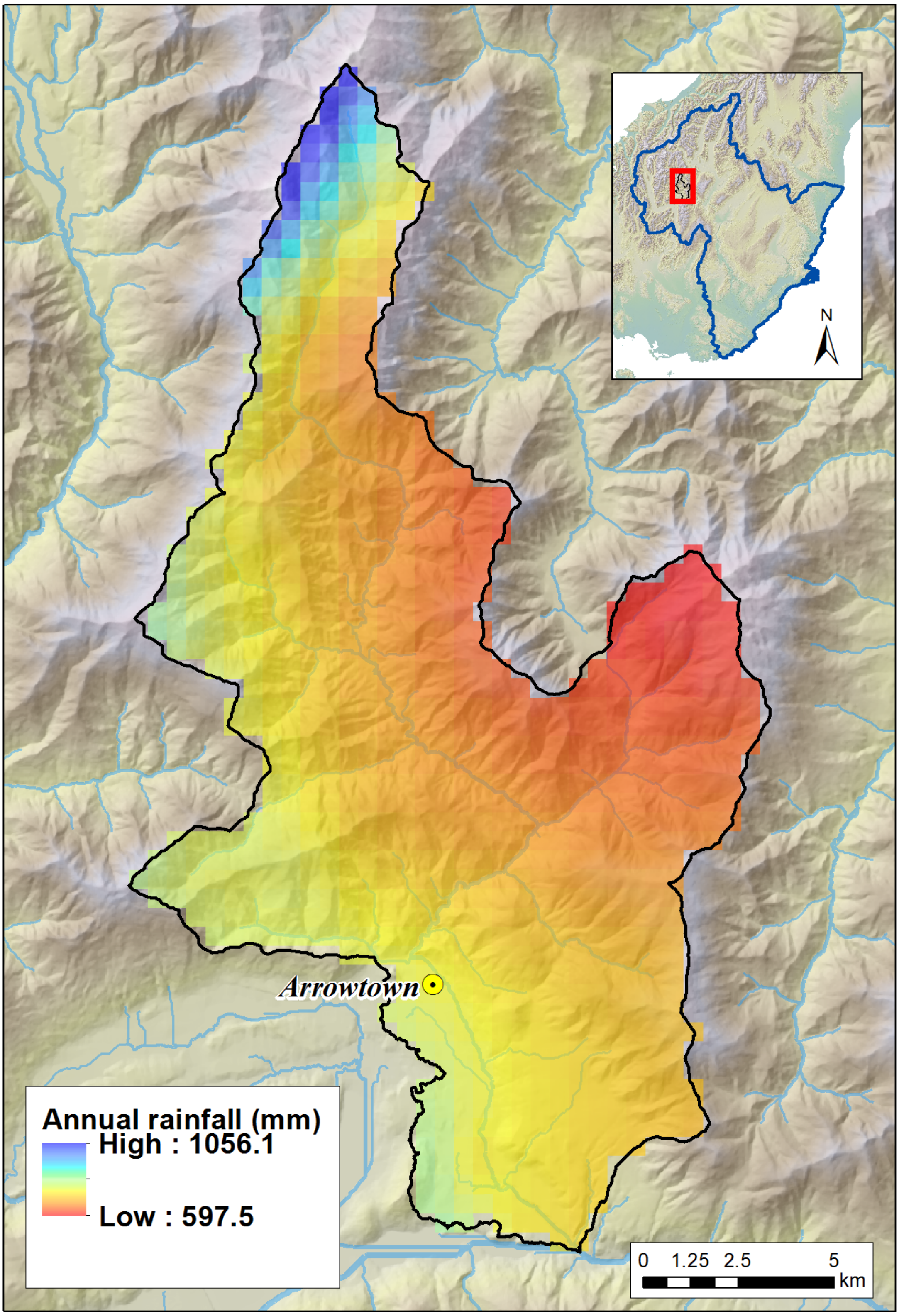

Figure 2-3 Long term rainfall distribution for the Arrow River catchment (Tait, etc., 2006)

2.2. Naturalised flows in the Arrow River at Cornwall Street

This section details the methods applied to derive the naturalised flows for the Arrow River at the Cornwall Street flow site. Flow descriptions include comparisons of flow statistics summarised from the measured and estimated naturalised flows at Cornwall Street including the estimated naturalised 7-day mean low flow (7dMLF).

2.2.1. Methods

The Ministry of Works established a flow site on the Arrow River upstream of Beetham Creek in April 1981 and removed the site in January 1994. The site is 2 km downstream from the ORC Arrow at Cornwall Street stage recorder and has a catchment area that is 7.5% larger, yet the measured 7dMALF is 0.88 m^3/s from the 12-year record (16/4/1981 – 23/1/1994) compared to the measured 7dMALF at Cornwall Street from a 7-year record (30/12/2010 – 9/10/2017) of 1.026 m^3/s. Table 2-2 lists the comparison of the basic flow statistics from the two sites.

Table 2-2 The flow statistics for all the available measured flow sites within the Arrow River catchment

Flow site	Availability (daily time series)	7dMALF (m^3/s), Jul - Jun	7dMALF (m^3/s), Oct - Apr	Minimum (m^3/s)	Median (m^3/s)	Mean (m^3/s)	Maximum (m^3/s)
Arrow at Beetham Creek	16/4/1980 - 23/1/1994	0.88	0.88	0.136	2.72	3.44	46.11
Arrow at Cornwall street d/s	30/12/2010 – 9/10/2017	1.03	1.03	0.631	2.80	3.49	63.09

The differences between the flow statistics for these two sites could be explained by differences in the water takes from the river which are unknown for all but the last 4 years of the Cornwall Street record (the Beetham Street site is downstream of the Arrow Irrigation Company off-take), or they could be explained by different weather conditions during the two periods of record.

A flow recorder was established in the Arrow River at Cornwall Street in December 2010. Since the water take time series data is available for takes above the Cornwall Street site, the flow at this site can be naturalised by totalling the measured flows and all consumptive water takes upstream; i.e., naturalised flows at Arrow at Cornwall Street = measured flows at Arrow at Cornwall Street + All upstream water takes.

The water takes for the area between Cornwall Street and the outlet of the Arrow catchment are not considered in this study due to availability lack of flow estimates for this part of the river as well as measured water use time series listed in Table 2-3. That is to say, the naturalised flows at the outlet of the Arrow catchment cannot be estimated by the method of totalling all water take above the outlet and its measured flows as the flows at the outlet are not available. Similarly, water use data were not available for the Beetham Creek flow site (Apr 1981 – Jan 1994), which makes it impossible to use any flow information from Beetham Creek to estimate naturalised flows. Therefore, in this study, we have chosen to develop naturalised time-series based on data from the Cornwall Street site as we have concurrent water use data for much of the record period.

2.2.2. Data

Table 2-3 lists the time series data used for deriving the naturalised flows for the Arrow River at Cornwall Street, while

Table 2-4 lists the seven-day low flow (7dLF) for each irrigation season (Oct - Apr) for all the available flow records at Arrow at Cornwall Street.

Table 2-3 The available flow data and water metering time series used to naturalised the flows at Arrow River at Cornwall Street in this study

Consent No. and flow site	Water meter number	Data type	Data availability	Max rate of take (l/s)
WR1440AR	WM0667	Consumptive primary water take	9/10/2013 – 20/10/2017	1389
95696	WM0733	Consumptive primary water take	4/6/2015 – 20/10/2017	83.33
2007.049	WM0458 and WM0459	Consumptive primary water take	13/6/2010 – 20/10/2017	108
Arrow River at Cornwall Street		Measured flow	30/12/2010 – 9/10/2017	

Note: Consent number 2003.670 is non-consumptive; Consent number 2007.410 is not used (Queenstown Lake District Council (QLDC) advised in 2016: There has never been a draw of water from Bush Creek under this 2007.410 consent, however QLDC retains this one in case of an emergency).

Table 2-4 The 7dLFs for each irrigation season across the whole flow records at Arrow at Cornwall Street

Season start	Season end	7dLF	Gap (day)	Minimum (m^3/s)	Median (m^3/s)	Average (m^3/s)	Maximum (m^3/s)
30/12/2010	30/04/2011	1.65	1	1.47	2.14	2.50	12.87
1/10/2011	30/04/2012	0.86	NA	0.83	2.18	3.25	22.13
1/10/2012	30/04/2013	1.07	NA	1.05	2.57	3.42	13.17
1/10/2013	30/04/2014	1.09	NA	1.06	2.39	3.20	16.52
1/10/2014	30/04/2015	1.06	NA	1.01	1.92	2.75	18.8
1/10/2015	30/04/2016	0.702	NA	0.631	1.29	1.99	6.62
1/10/2016	30/04/2017	1.37	15	1.33	3.28	3.84	12.9
1/10/2017	9/10/2017	4.03	NA	3.81	4.17	4.14	4.64

Figure 2-4 illustrates the entire measured water take and flow time series at Arrow at Cornwall Street mentioned in Table 2-3.

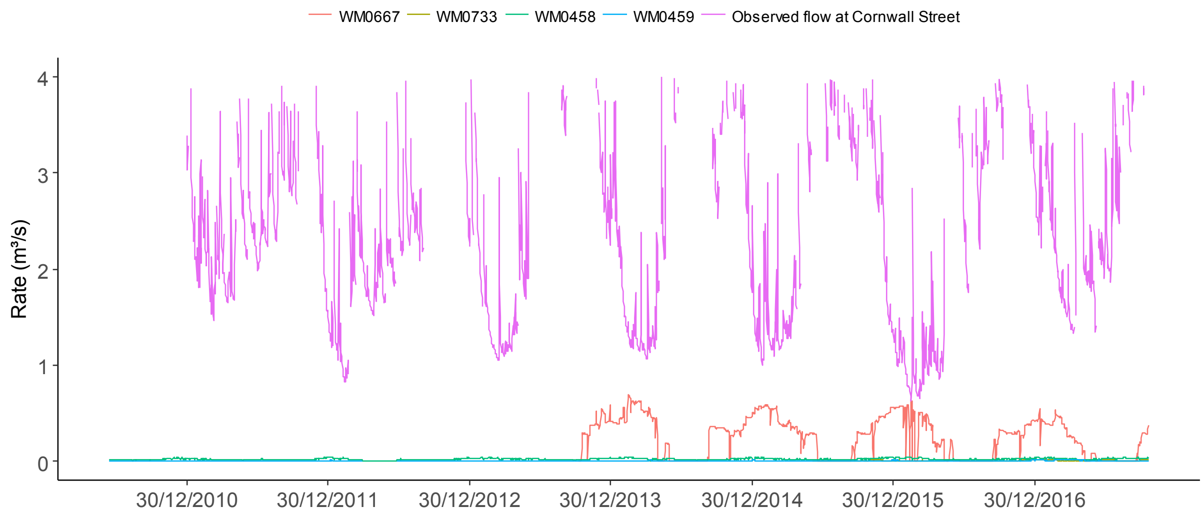

Figure 2-4 The overplot of all the measured water take time series and the flow time series at Cornwall Street mentioned in Table 2-3 and 2-4

2.2.3. Total water take above Arrow at Cornwall Street

Based on the water metering data listed in Table 2-3, the total water take above Cornwall Street can be derived. Figure 2-5 shows the monthly average percentages of consented water takes for Consent No's 2007.049, 95696, and WR1440AR across the water metering period. Figure 2-6 illustrates the monthly average rate of total take and the average ratio of the measured total take to the total consented take above the Arrow at Cornwall Street.

Figure 2-5 and Figure 2-6 confirm that the quantity of the water taken for the three consents is well below their respective consented maximum rates of take. Consent No. 95696 has a very short period of water metering data in comparison to the remaining two water takes (Table 2-3), with only two years of water take data available for this take; using two years of data would severely limit the usable flow data recorded at Cornwall Street.

By examining the available water take metering data for Consent No. 95696, the maximum daily rate of take for this consent is 23.8 l/s, which is well below its consented allocation limit (83.33 l/s). To expand the length of the estimated naturalised flow time series by the proposed method described above (Section 2.2.1), the daily average rate of take for Consent No. 95696 between 9/10/2013 and 3/6/2015 can be assumed to be from zero (lower level) to 20 l/s (upper level). Using this assumed range of usage (i.e. 0-20 l/s) allows an additional two years of flow data at Cornwall Street to be utilised to naturalise flows, giving a total of four years from 9/10/2013 to 20/10/2017 to be used in the analysis of naturalising flows in the Arrow River.

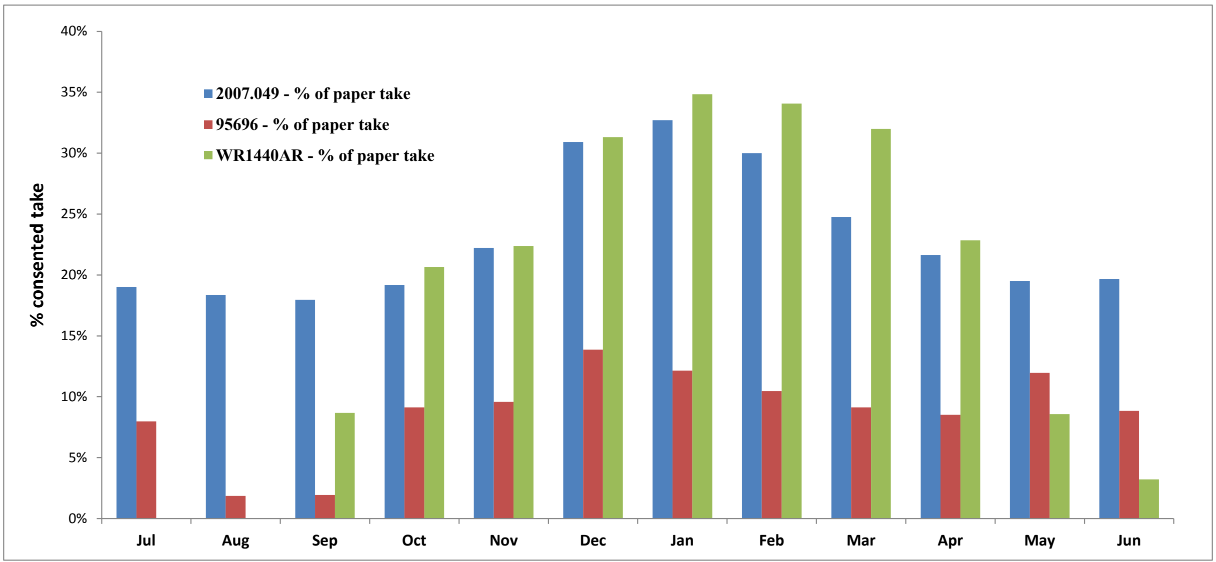

Figure 2-5 **The percentages of water takes for 2007.049, 95696, and WR1440AR across the available actual water take data**

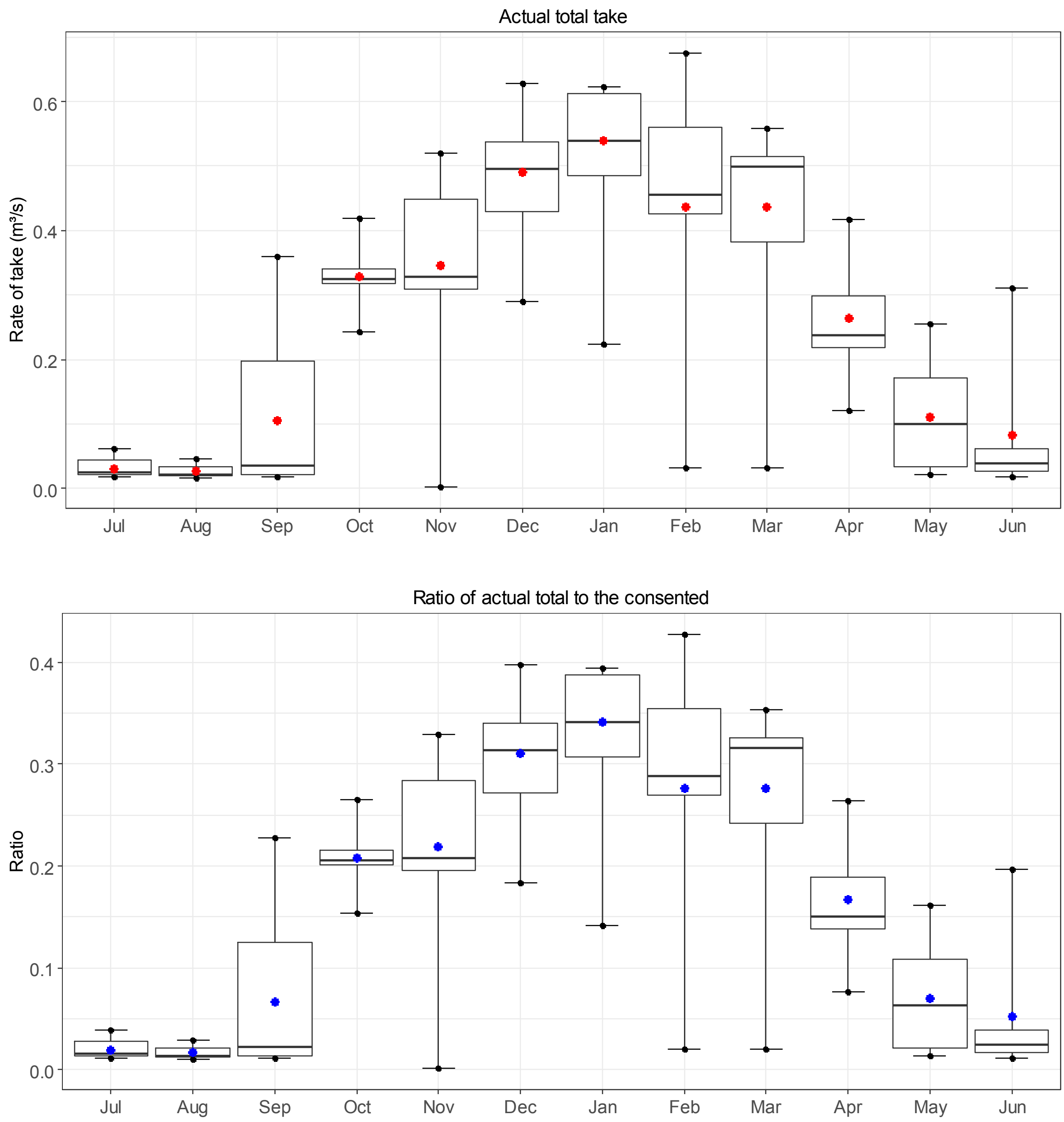

Figure 2-6 **The monthly average rate of measured take and ratio of the measured to the total consented take above the Arrow at Cornwall Street between 9/10/2013 and 20/10/2017**

2.2.4. Naturalised low-flow statistics of the Arrow River

A major objective of this study is to provide an understanding of the flows required to maintain the instream values and natural character of the Arrow River. Understanding the low flow hydrology of the Arrow River is an essential step in achieving this objective.

As mentioned in Section 2.2.1, naturalised flows at Arrow at Cornwall Street can be calculated by adding the upstream total water take to its measured flows. Flow naturalisation at the Arrow River at Cornwall Street is a reasonably straightforward task in comparison to many other waterways within Otago. The limiting factor in undertaking the analysis to naturalise the surface flows in the Arrow catchment is that the data set is restricted to a four-year period; this is due to having only four years of water take data available (including the two-year extended water take data for Consent 95696, details in Section 2.2.3). This limitation means that four of seven years of hydrological information collected at Cornwall Street can be utilised.

Table 2-5 compares the low-flow statistics between the measured and derived naturalised flows at Arrow at Cornwall Street. The analysis indicates that the estimated average naturalised 7-day mean low flow (7dMLF) between 2013 and 2017 was in the range of 1.43 ~ 1.44 m^3/s. This range is due to the assumptions of water use for Consent No. 95696.

Table 2-6 lists the flow statistics during winter months (May-Sep) for both measured and estimated naturalised flow records at flow site at Cornwall Street.

Table 2-5 The comparisons of 7dLFs between the measured and klnaturalised flows for each irrigation season for the flow site at Cornwall Street

Low-flow season	Measured flow at Cornwall Street		Naturalised flow at Cornwall Street	
	7dLF (m³/s)	Mean daily (m³/s)	7dLF (m³/s)	Mean daily (m³/s)
Oct 2010 – Apr 2011	1.65	2.50	Not available	Not available
Oct 2011 – Apr 2012	0.87	3.25	Not available	Not available
Oct 2012 – Apr 2013	1.07	3.42	Not available	Not available
Oct 2013 – Apr 2014	1.09	3.20	1.64 ~ 1.66	3.58 ~ 3.60
Oct 2014 – Apr 2015	1.06	2.75	1.60 ~ 1.62	3.19 ~ 3.21
Oct 2015 – Apr 2016	0.70	1.99	0.83	2.42
Oct 2016 – Apr 2017	1.37	3.84	1.65	4.23
7dMALF (Oct – Apr)	**1.12**		**1.43 ~ 1.44**	

The low-flow statistics for October 2015 through to April 2016 are much lower in comparison to other low-flow seasons. This is due to the dry weather conditions that occurred during Oct 2015 – Apr 2016.

Table 2-7 lists the rainfall totals during these low-flow seasons for the nearby rain gauges (with respective rainfall total during an average irrigation season) and the possible weather conditions categorised by the Standardised Precipitation Index (SPI).

Table 2-6 The comparisons of 7dLFs between the measured and derived naturalised flows for each winter season (May - Sep) for the flow site at Cornwall Street

Winter months	Measured flow at Cornwall Street		Naturalised flow at Cornwall Street	
	7dLF (m^3/s)	Mean daily (m^3/s)	7dLF (m^3/s)	Mean daily (m^3/s)
May 2011 – Sep 2011	2.04	2.66	Not available	Not available
May 2012 – Sep 2012	1.69	2.43	Not available	Not available
May 2013 – Sep 2013	1.83	4.36	Not available	Not available
May 2014 – Sep 2014	2.27	4.01	2.33 ~ 2.35	4.98 ~ 5.00
May 2015 – Sep 2015	3.03	4.16	3.31 ~ 3.33	4.82 ~ 4.82
May 2016 – Sep 2016	1.02	3.37	1.24	3.56
May 2016 – Sep 2017	1.61	2.73	1.72	3.53
7dMALF (May – Sep)	**1.87**		**2.13 ~ 2.16**	

Note: The 7dLF for season May 2014 – Sep 2014 is not involved in the 7dMALF (May – Sep) calculation, as it has a 72-day data gap.

As

Table 2-6 shows, the 7dMALF for the measured flows at Cornwall Street during the winter months (May - Sep) is 1.87 m^3/s, compared to the 7dMALF for the derived naturalised flows of 2.13 ~ 2.161 m^3/s. The lower flows occurred during the early May 2016 for these winter months.

Table 2-7 The rainfall totals during the low-flow seasons between 2010 and 2017 for the nearby rain gauges at the Shotover at Peats Hut, Queenstown Aero AWS, and Matukituki at West Wanaka with the weather conditions categorised by the Standardised Precipitation Index (SPI)

Low-flow season	Shotover at Peats Hut, with an average rainfall of 499 mm (Oct-Apr)		Queenstown Aero AWS, with an average rainfall of 422 mm (Oct-Apr)		Matukituki at West Wanaka, with an average rainfall of 478 mm (Oct-Apr)	
	Rain (mm)	SPI category	Rain (mm)	SPI category	Rain (mm)	SPI category
Oct 2010 – Apr 2011	519	Normal	452	Normal	533	Normal
Oct 2011 – Apr 2012	526	Normal	388	Normal	444	Normal
Oct 2012 – Apr 2013	584	Moderately wet	390	Normal	492	Normal
Oct 2013 – Apr 2014	501	Normal	383	Normal	438	Normal
Oct 2014 – Apr 2015	503	Normal	467	Normal	432	Normal
Oct 2015 – Apr 2016	392	Severely dry	299	Severely dry	280	Extremely dry
Oct 2016 – Apr 2017	575	Moderately wet	448	Normal	503	Normal

Table 2-7 shows that there was much less rainfall received during the October 2015 – April 2016 period (compared to the respective average rainfall total during a normal low-flow season), which is consistent with the very low flows observed at Cornwall Street over this same period. Based on the calculated SPI values for these three gauges (SPI values of -1.829 at Shotover at Peats, -1.664 at Queenstown Aero AWS, and -2.740 at Matukituki at West Wanaka), the rainfall total (during 15/16 low-flow season) is an 1 in 20 to 30-year event (Standardized precipitation index user guide, 2012).

Water temperature

Water temperature is a fundamental factor affecting all aspects of stream systems. It can directly affect fish populations by influencing survival, growth, spawning, egg development and migration. It can also affect fish populations indirectly, through effects on physicochemical conditions and food supplies (Olsen *et al*., 2012).

Of all the fish in the Arrow catchment, brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) are likely to be the most sensitive to high water temperatures. Their thermal requirements are relatively well understood, and Todd *et al*. (2008) calculated acute and chronic thermal criteria for both of these species. The objective of acute criteria is to protect species from the lethal effects of short-lived high temperatures. In this case, acute criteria are applied as the highest two-hour average water temperature measured within any 24-hour period (Todd *et al*., 2008). In contrast, the intent of chronic criteria is to protect species from sub-lethal effects of prolonged periods of elevated temperatures. In this study, chronic criteria are expressed as the maximum weekly average temperature (Todd *et al*., 2008). Most native fish species with available thermal tolerance data are more tolerant of high temperatures than trout (Olsen *et al.* 2012).

Limited water temperature data were available for the Arrow River – with just over 3 months of water temperature data from between 30 December 2010 and 4 April 2011 (Figure 2-7). Water temperatures over this period were well within the thermal tolerances of brown and rainbow trout, with peak temperatures well within acute criteria for both brown and rainbow trout (Figure 2-7).

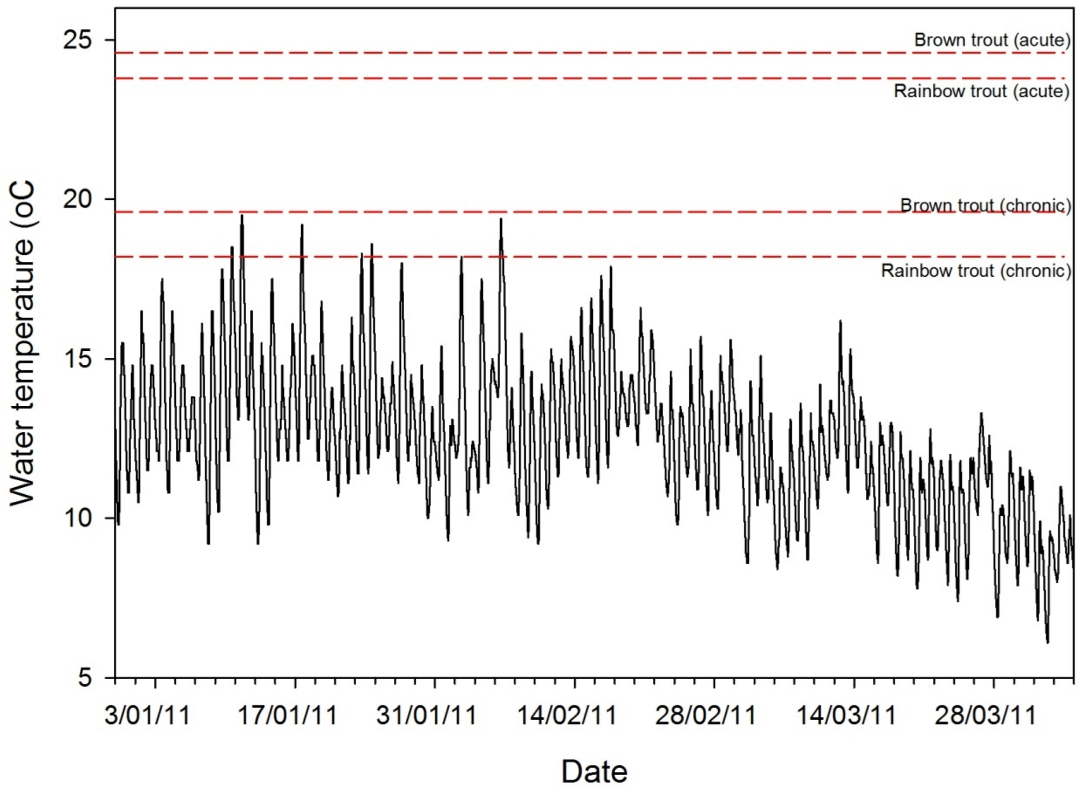

Figure 2-7 Water temperature from the Arrow River at the Cornwall Street flow site.

3. Aquatic ecosystem values of the Arrow River

Schedule 1A of the Regional Plan: Water for Otago (RPW) outlines the natural and human use values of Otago's surface water bodies. The Arrow River is identified as having the following values:

- gravel and sand bed composition of importance to resident biota
- access within the main-stem of a catchment through to the sea or a lake unimpeded by artificial means, such as weirs, and culverts
- presence of significant areas for fish spawning and development of juvenile fish,
- absence of aquatic pest plants identified in the Pest Plant Management Strategy for the Otago region
- significant presence of trout
- a high degree of naturalness above 900 m a.s.l.

The Soho Creek catchment, which is a sub-catchment of the Arrow catchment is also, identified Schedule 1A of the Regional Plan: Water for Otago with the following values:

- Weed free
- Presence of a rare macro-invertebrate

3.1. Native fish

There is a single record of the presence of an indigenous fish species documented within the Arrow catchment (Figure 3-1); this fish is commonly known as koaro (*Galaxias brevipinnis*). The location of this record is situated near the confluence of the main-stem of the Arrow River and Soho Creek five kilometres upstream of Arrowtown. Whether this species occupies other parts of the catchment is unknown, however if it does, then it appears that koaro abundance is potentially very low. Koaro is listed as "At Risk, Declining" in the most recent threat classification (Goodman *et al.,* 2014).

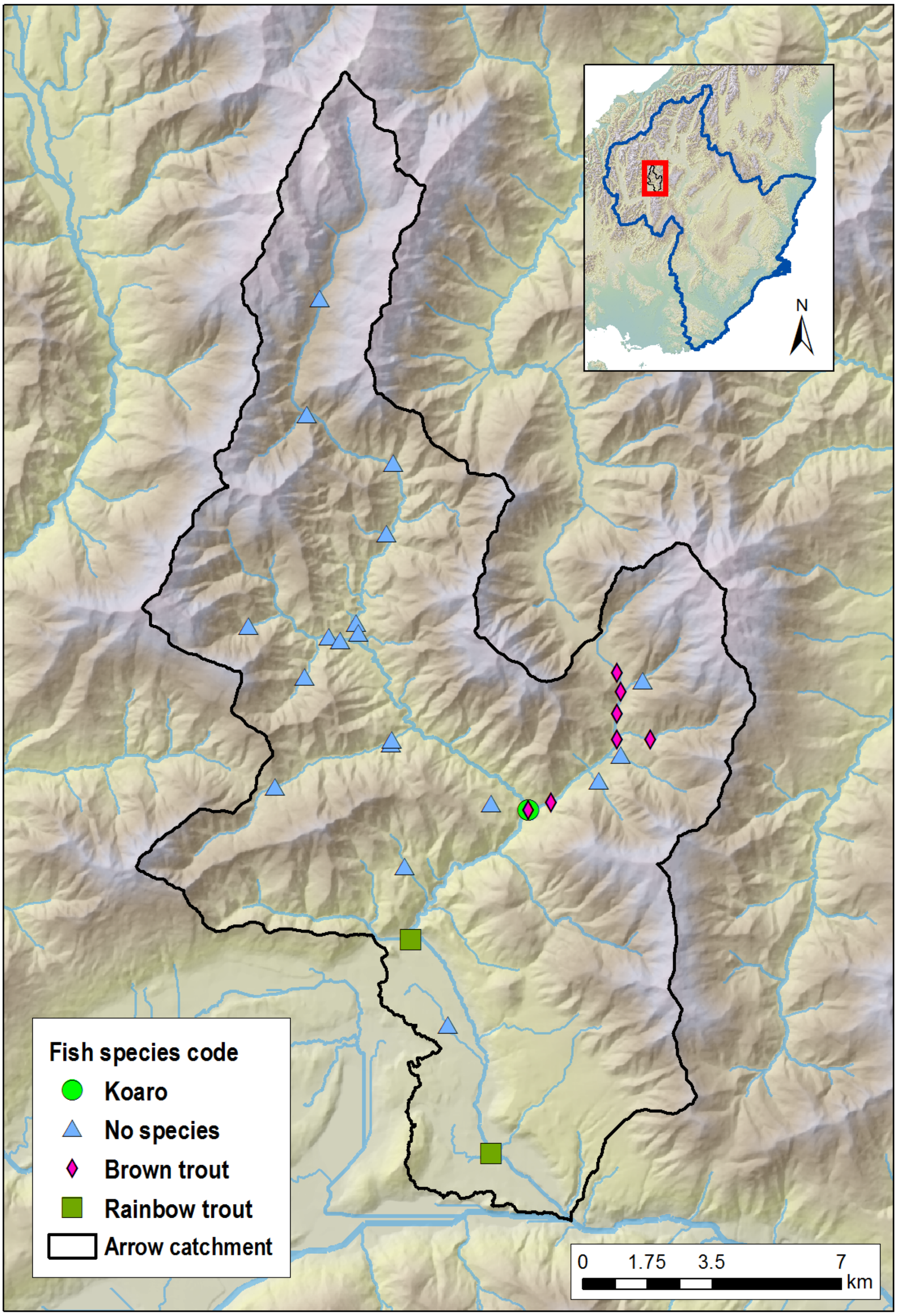

Figure 3-1 Location of fish records in the Arrow River (NZFFD)

Although not recorded from the Arrow River it is probable that longfin eels were once present. The construction of Roxburgh and Clyde Dams has blocked both up and downstream passage to and from the sea. Sea migration for eels is an obligatory part of their lifecycle. Although there are trap and transfer programmes being operated at Roxburgh Dam, eel numbers in the Upper Clutha catchment, (above Roxburgh Dam) have declined markedly overtime. Commercial eel fishing may have contributed to the decline; however construction of Roxburgh and Clyde Dams has accelerated the loss by preventing recruitment of young eels.

Roxburgh Dam was constructed in 1956 and the construction of the Clyde Dam was started in 1982 and finally filled in 1993. Therefore, eel passage to and from the Central Otago Lakes has been prevented for the past 61 years.

3.2. Sports fish

The Arrow River supports a locally significant sports-fish fishery (Otago Fish & Game Council, 2015). Although local angler use has declined over time; usage by overseas anglers has only been considered in the most recent national angler survey (Unwin 2016). Table 3-1**Error! Reference source not found.** presents angler effort on the Arrow River, recorded during National Angler Surveys conducted in 1994/95, 2001/2002, 2007/08 and 2014/15. Overall angler usage is relatively low, with anglers targeting the early part of the fishing season taking advantage of the occasional trophy sized trout. It's probable that these fish have remained in the river after spawning and will, over time, move out of the catchment. There is still however a small resident population of both brown and rainbow trout that remain within the catchment. These trout do obtain a catchable length and consequently do provide some angling value.

Fish survey records retrieved from the New Zealand Freshwater Fish Database indicates that no fish species have been recorded in the Arrow River above its confluence with Soho Creek (Figure 3-1). Below the confluence brown trout are scattered throughout the lower catchment. There is a healthy resident population of brown trout located within Soho Creek, whereas rainbow trout appear to have a restricted distribution within the catchment, being more confined to the lower reaches of the Arrow River, downstream of the gorge.

Table 3-1 Angler effort on the Arrow River based on the National Angler Survey (Unwin, 2016).

Source	Angler usage (angler days ± SE)			
	1994/95	**2001/02**	**2007/08**	**2014/15**
NZ resident	210 ± 120		350 ± 160	160 ± 100
Overseas				250 ± 240
Total	210 ± 120		350 ± 160	**410 ± 260**

3.3. Summary of aquatic ecosystem values

There is limited diversity of fish species in the Arrow catchment, with three fish species being recorded. Two sports-fish both the rainbow and brown trout and the native fish koaro have been recorded. Such low fish diversity could be a combination of several factors including detrimental impacts of historic mining practices combined with the difficulty of recruitment from outside the catchment; due to the boisterous nature of the flows of the Kawarau River and the presence of dams on the Clutha River.

Angler's surveys indicate that angler use for the Arrow catchment is relatively low and there has been a decline in local use of the river (Table 3-2).

Table 3-2 Assessment of instream habitat values in the Arrow River, with recommended levels of habitat retention (based on the approach of Jowett & Hayes, 2004).

Instream value	Fishery or conservation value	Recommended % habitat retention
Brown trout - adult	Locally significant†	70
Brown trout - juvenile	Locally significant†	70
Brown trout - spawning (May-August)	Locally significant†	70
Longfin eel	Declining‡	80
Koaro	Declining‡	80

† Based on the assessment in Otago Fish & Game Council (2015).

‡ Based on Goodman *et al.* (2014).

4. Instream habitat modelling

Instream habitat assessments were conducted for two reaches of the Arrow River by Jowett (2004): an upper reach near Eight Mile Hut just downstream of Macetown and a lower reach between the SH6 Bridge and the confluence with the Kawarau River. The instream habitat modelling presented in this report is based on the lower survey reach.

4.1. Instream habitat modelling

Instream habitat modelling can be used to consider the effects of changes in flow on instream values, such as physical habitat, water temperature, water quality and sediment processes. The strength of instream habitat modelling lies in its ability to quantify the loss of habitat caused by changes in the flow regime, which helps to evaluate alternative flow proposals. However, for an assessment to be credible, it is essential to consider all factors that may affect the organism(s) of interest, such as food, shelter and living space, and to select appropriate habitat-suitability curves. Habitat modelling does not take a number of other factors into consideration, including the disturbance and mortality caused by flooding and biological interactions (such as predation), which can have a significant influence on the distribution of aquatic species.

Instream habitat modelling requires detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat methods is that a given species cannot exist without a suitable physical habitat (Jowett & Wilding, 2003). However, if there is physical habitat available for that species, it may or may not be present in a survey reach, depending on other factors not directly related to flow or to flow-related factors that have operated in the past (e.g., floods). In other words, habitat methods can be used to set the outer envelope of suitable living conditions for the target biota (Jowett, 2005).

Instream habitat is expressed as Reach Area Weighted Suitability (RAWS), a measure of the total area of suitable habitat per metre of stream length. It is expressed as square metres per metre (m^2/m). The reach-averaged Combined Suitability Index (CSI) is another metric and is a measure of the average habitat quality provided at a particular flow. CSI is useful when considering the effects of changes in flow regime on periphyton where it is the percentage cover across the riverbed that is of interest, rather than the overall population response (such as for fish).

4.2. Habitat suitability curves

Habitat suitability curves (HSC) for a range of organisms present in the Arrow catchment were modelled (Table 4-1) to understand the full range of potential effects of flow regime changes in the Arrow catchment – from changes in the cover and type of periphyton, to changes in the availability of macroinvertebrate prey, to changes in the habitat. It should be noted that the HSC used in these analyses may differ from those presented in the original report, as the analyses were re-run using the most up to date habitat modelling curves.

Table 4-1 Habitat suitability curves used in instream habitat modelling in the Arrow catchment.

Group	HSC name	HSC source
Periphyton	Cyanobacteria	Ex Heath *et al.* (2013)
	Diatoms	Unpublished NIWA data
	Didymo (Waitaki)	Jowett
	Long filamentous	Unpublished NIWA data
	Short filamentous	Unpublished NIWA data
Macro-invertebrates	Food producing	Waters (1976)
	Cased caddis fly (*Pycnocentrodes*)	Jowett *et al.* (1991)
	Mayfly nymphs (*Deleatidium*)	Jowett *et al*. (1991)
	Net-spinning caddis fly (*Aoteapsyche*)	Jowett *et al.* (1991)
Fish	Brown trout adult	Hayes & Jowett (1994)
	Brown trout spawning	Shirvell & Dungey (1983)
	Brown trout Juvenile	Jowett & Richardson (2008)
	Juvenile trout	Wilding *et al.* (2014)
	Adult trout	Wilding *et al.* (2014)
	Rainbow trout spawning	Jowett *et al.* (1996)

4.2.1. Periphyton

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters and can include a range of different types and forms. Periphyton is an integral part of many stream food webs; it captures energy from the sun and converts it, via photosynthesis, to energy sources available to macroinvertebrates, which feed on it. These, in turn, are fed on by other invertebrates and fish. However, periphyton can form nuisance blooms that can detrimentally affect other instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality.

The analyses presented in this report consider HSC for five classes of periphyton: cyanobacteria, diatoms, didymo (*Didymosphenia geminata*, an invasive non-native diatom), short filamentous algae and long filamentous algae (Figure 4-1). These periphyton classes were included in these analyses to consider how changes in flow may affect periphyton cover and composition, and the potential impacts on other instream values.

Cyanobacteria were included because some types may produce toxins that pose a health risk to humans and animals. These include toxins that affect the nervous system (neurotoxins), liver (hepatotoxins), and dermatotoxins that can cause severe irritation of the skin.

The presence of potentially toxic cyanobacteria is undesirable as it can affect the suitability of a waterway for drinking, recreation (swimming), dogs, stock drinking water and food-gathering (by affecting palatability or through accumulation of toxins in organs such as the liver). Cyanobacteria-produced neurotoxins have been implicated in the deaths of numerous dogs in New Zealand (Hamill, 2001; Wood et al., 2007).

Native diatoms are generally considered a desirable component of the periphyton community, while didymo is an invasive, non-native diatom that can form dense, extensive mats (Figure 4-1c) that can affect recreational and ecosystem values, as well as water use (ORC, 2007; Larned et al., 2007).

Filamentous algae, and in particular long filamentous algae, can form nuisance blooms during periods of stable flows and under nutrient conditions. Such blooms can affect a range of instream values, including aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality.

Figure 4-1 **Periphyton types considered in these analyses: a) benthic cyanobacteria (*Phormidium*), b) native diatoms, c) underwater photograph showing an extensive growth of didymo in the Hawea River and d) long and short filamentous algae (and cyanobacteria).**

4.2.2. Macroinvertebrates

Macroinvertebrates are an important part of stream food webs, linking primary producers (periphyton and terrestrial leaf litter) to higher trophic levels (fish and birds), and were included in these analyses to consider how changes in flow in the modelled reaches may affect food availability for fish and birds. HSC for “food producing habitat” (conditions representative of the most productive habitats in rivers) and four widespread and common macroinvertebrate taxa were included in this analysis.

Figure 4-2 **Macroinvertebrate taxa considered in these analyses: a) a nymph of the common mayfly (*Deleatidium*), b) a larva of the net-spinning caddis fly (*Aoteapsyche*) and c) larvae of the sandy-cased caddis fly (*Pycnocentrodes*).**

4.2.3. Native fish

HSC are available for koaro and longfin eels. However, the habitat suitability curves available for koaro (Richardson & Jowett, 1995) were not included in these analyses, as they were based on data from steep cascade habitat in the Onekaka River (Golden Bay) and their applicability to the type of habitat present in the Arrow River is uncertain.

Habitat is not currently the main factor affecting the distribution and abundance of longfin eels in the Arrow catchment. Recruitment of longfin eels to the upper Clutha and Kawarau catchments is low due to the presence of Roxburgh and Clyde Dams.

4.2.4. Sports fish

Both brown and rainbow trout are found in the Arrow catchment. Several HSC for different life stages of brown trout and for adult rainbow trout were included in these analyses to consider how changes in flow in the modelled reaches will affect habitat availability for sports fish.

4.3. Approaches to flow setting

There are a number of approaches to determining the appropriate flows to achieve management objectives. A simple approach is to identify the flow that provides the maximum (or optimum) habitat for a particular species. However, providing such flows is often unrealistic for flow-demanding species, as optimum habitat may occur at a flow well in excess of those commonly experienced. As a result, this approach is usually only applied when optimum habitat occurs at flows below the 7-d MALF.

Another common approach is to identify the "tipping point", the flow below which the rate of habitat decline accelerates as flows reduce, often incorrectly referred to as the inflection point. A disadvantage of this approach is that it can be difficult to identify the exact point at which this occurs, and assessments can differ between practitioners.

Probably the most common, transparent and defensible method is to calculate the amount of habitat retained relative to some baseline flow. For fish species, this baseline flow is usually the naturalised 7-d MALF.

4.4. Physical characteristics

The hydraulic component of instream habitat modelling made predictions about how water depth, channel width and water velocity will change with changes in flow (Figure 4-3). The most notable pattern is that there is a gradual decline in channel width and depth with declining flows down to 100 l/s, below which width and depth drop rapidly. Water velocity is predicted to reduce rapidly with declining flows.

4.5. Periphyton

The main purpose of considering periphyton is to understand how changes in flow are likely to affect how much of the river bed is covered by its growth, and the relative contribution of the different types of periphyton to the overall community. Given this, it is the percentage of the wetted channel covered by periphyton, not the total area of suitable habitat that is of interest. For this reason, the habitat suitability index (reach-averaged CSI) was used instead of weighted usable area (RAWS) in instream habitat analyses for periphyton.

Flow was predicted to have little effect on habitat quality for cyanobacteria (*Phormidium*) with a decline in habitat quality for both species predicted below 0.5 m^3/s (Figure 4-4). Habitat quality for didymo was predicted to increase with flow up to 900 l/s before declining gradually with flow above 1200 l/s. Habitat quality for native diatoms was predicted to increase with flow up to 1500 l/s, before declining at higher flows. Habitat quality for short filamentous algae was predicted to increase with increasing flows to 600 l/s before declining at higher flows, while habitat quality for long filamentous algae was predicted to be highest in the absence of flow and to decline across the modelled flow range.

This analysis suggests that when flows are less than 755 l/s in the lower Arrow there is a significantly higher risk of proliferation of long filamentous algae, compared with naturalised flows, and this risk is predicted to rise further as flows drop below this value, with habitat quality for long filamentous algae at 600 l/s predicted to be approximately twice that at the naturalised MALF (Table 4-2).

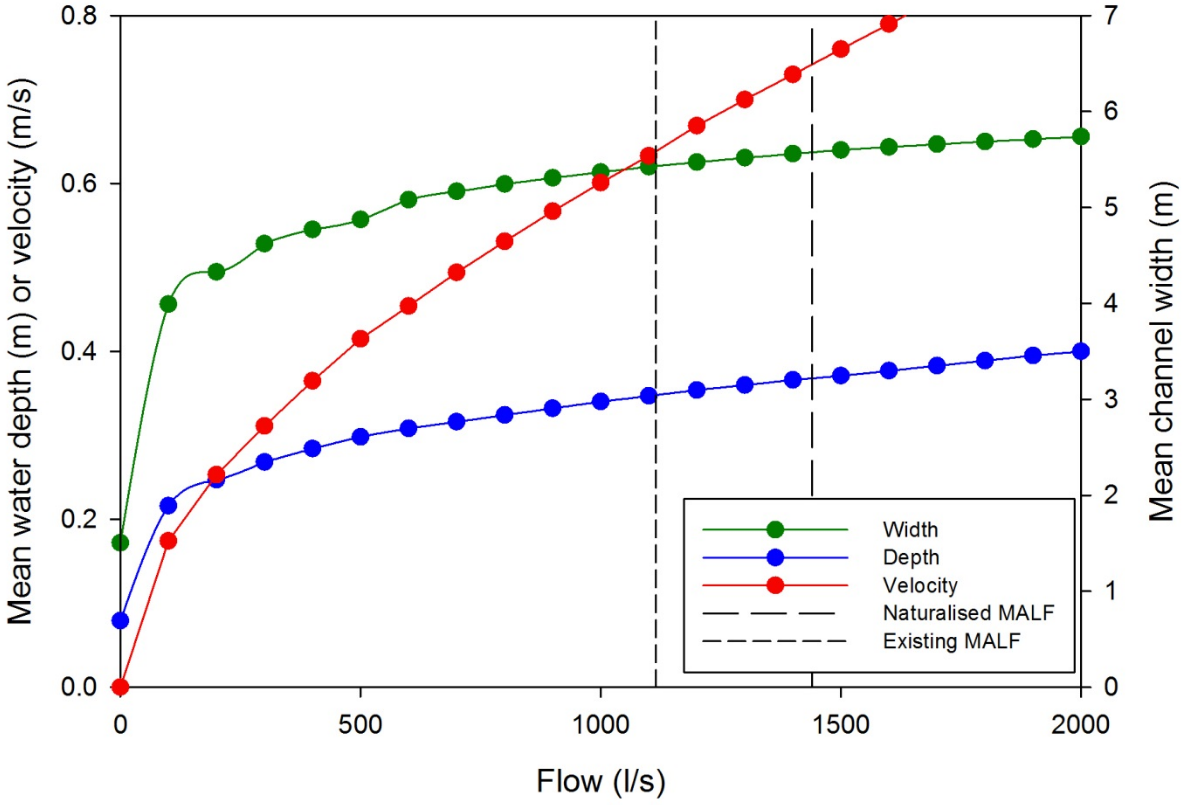

Figure 4-3 **Changes in mean channel width, mean water depth and mean water velocity with changes in flow in the lower Arrow River.**

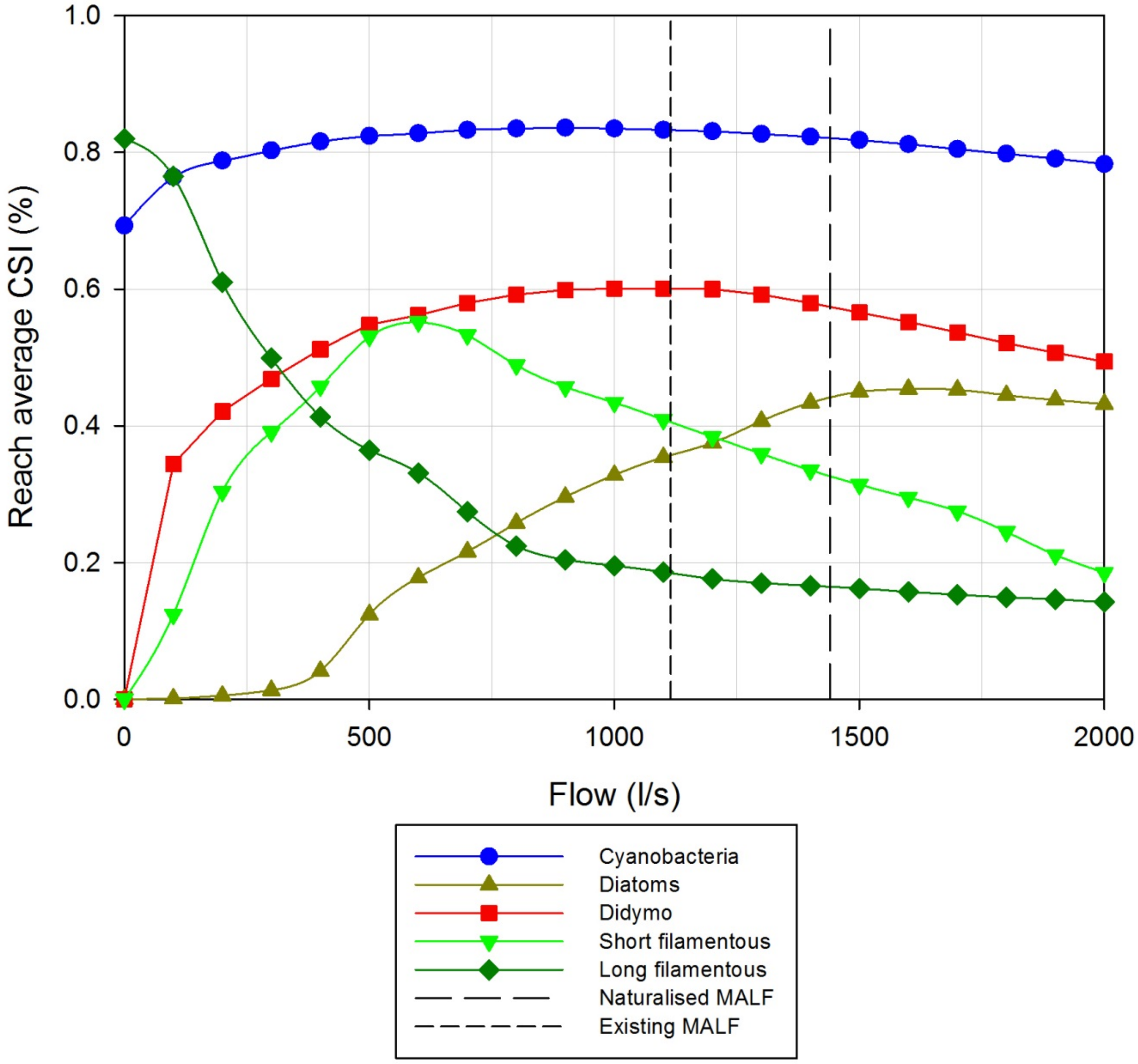

Figure 4-4 **Variation in instream habitat quality (reach-averaged CSI) for periphyton classes relative to flow in the lower Arrow River.**

Table 4-2 Flow requirements for periphyton habitat in the lower Arrow River. Flows required for the various habitat retention values are given relative to naturalised flows (i.e., flows predicted in the absence of any abstraction).

Species	Optimum flow (l/s)	Flow below which habitat rapidly increases (l/s)	Flow at which % habitat retention occurs (l/s)		
			150%	200%	300%
Cyanobacteria	900	-	-	-	-
Diatoms	1,600	-	-	-	-
Didymo	1,000	-	-	-	-
Short filamentous	600	-	798	-	-
Long filamentous	0	800	755	604	404

4.6. Macroinvertebrates

Food producing habitat is predicted to increase with increasing flow to 900 l/s, above which habitat is predicted to decline (Figure 4-5). Habitat for net-spinning caddis fly larvae was predicted to increase with increasing flow across the modelled flow range. Habitat for the common mayfly *Deleatidium* is predicted to increase with increasing flow up to 1300 l/s, above which habitat is predicted to decline. Habitat for the cased caddis *Pycnocentrodes* was predicted to rise with increasing flows, reaching a peak at 700 l/s, above which habitat was predicted to gradually decline. For most of the macroinvertebrate species modelled, habitat was predicted to decline rapidly as flows dropped below 500 l/s.

Flows of 350-400 l/s were predicted to retain 80% of the food producing (392 l/s) and *Deleatidium* (362 l/s) habitat available in the lower Arrow River relative to naturalised flows (Table 4-3). The flow requirements for 80% habitat of the other species considered varied widely, from 232 l/s for the cased caddis fly *Pycnocentrodes* and 1,030 l/s for the net-spinning caddis fly *Aoteapsyche*.

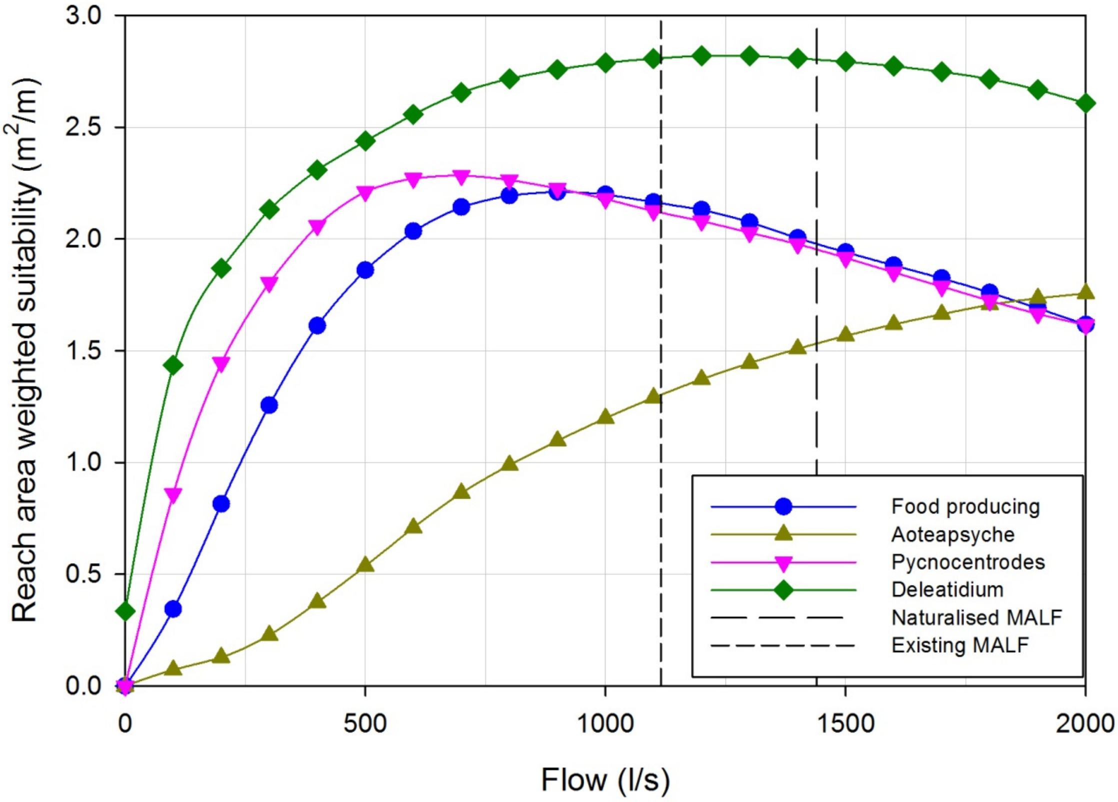

Figure 4-5 **Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the lower Arrow River.**

Table 4-3 **Flow requirements for macroinvertebrate habitat in the lower Arrow River. Flows required for the various habitat retention values are given relative to naturalised flows (i.e., flows predicted in the absence of any abstraction).**

Species	Optimum flow (l/s)	Flow below which habitat rapidly declines (l/s)	Flow at which % habitat retention occurs (l/s)			
			60%	70%	80%	90%
Food producing	900	600	285	336	392	468
Mayfly nymphs *(Deleatidium)*	1,200	300	157	235	362	570
Net-spinning caddis fly *(Aoteapsyche)*	>2,000	-	745	878	1,030	1,208
Cased caddis fly (*Pycnocentrodes*)	700	400	153	186	232	287

4.7. Sports fish

Habitat for adult brown trout was predicted to increase with flows to 600 l/s, before declining above flows of 800 l/s, while adult trout (rainbow and brown trout) habitat was predicted to increase with flow to 1,600 l/s before slowly dropping with increasing flows by the HSC of Wilding *et al.* (2014) (Figure 4-6). Habitat for juvenile brown and rainbow trout was also predicted to increase with flows to 500 l/s before dropping gradually at flows above 900 l/s. Predicted spawning habitat increased rapidly with increasing flows to reach an optimum at 400 l/s for brown trout and 600 l/s for rainbow trout, with the amount of suitable habitat predicted to decline when flows were above the optimum for each species.

A flow of 231 l/s was predicted to retain 70% of the adult brown trout habitat compared with naturalised flows in the lower Arrow River, and flows of 198 l/s retained 70% of the juvenile trout habitat available compared with naturalised flows (Table 4-4).

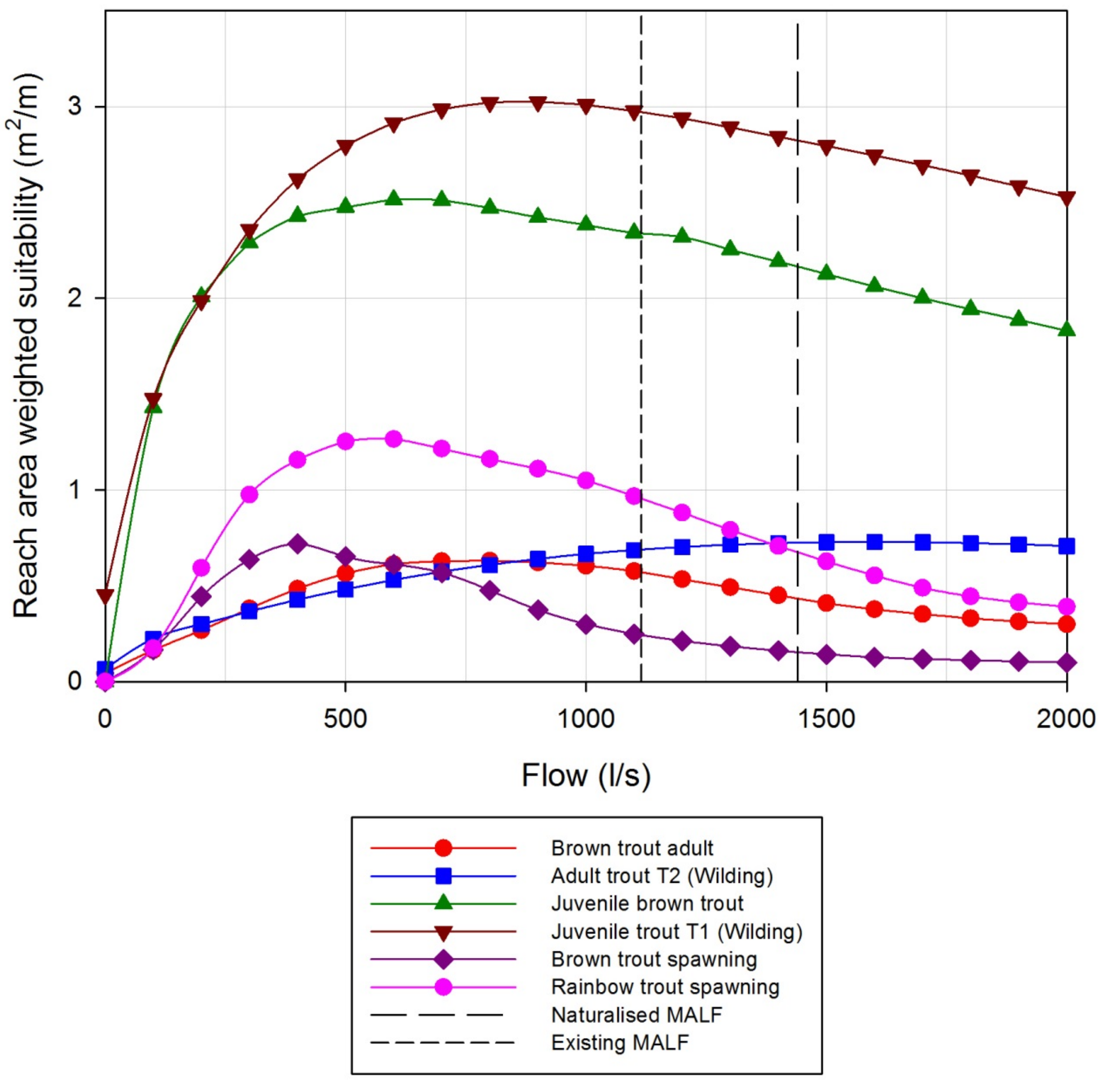

Figure 4-6 **Variation in instream habitat of trout relative to flow in the lower Arrow River.**

Table 4-4 Flow requirements for trout habitat in the lower Arrow River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of all abstraction). Habitat retention levels for spawning are relative to naturalised mean annual winter (May-September) low flows.

Species	Optimum flow (l/s)	Flow below which habitat rapidly declines (l/s)	Flow at which % habitat retention occurs (l/s)		
			70%	80%	90%
Brown trout adult	800	500	231	270	309
Adult trout (Wilding T2)	1,600	-	553	717	945
Juvenile brown trout	600	300	115	152	190
Juvenile trout (Wilding T1)	900	500	198	273	369
Brown trout spawning (May-Sep)	400	300	44	50	56
Rainbow trout spawning (Jul-Nov)	600	400	127	136	146

4.8. Effects of existing flows

Water users in the Arrow River are not currently subject to a minimum flow and the river is significantly over-allocated, at least in terms of consented maximum instantaneous rate of take, although actual use is significantly less than the consented use. The measured 7dMALF of the Arrow River retains appropriate levels of habitat (

Table 4-5). However, it should be kept in mind that the measured 7dMALF represents average low flow conditions, not the low flows experienced in exceptionally dry years.

Table 4-5 Habitat retention in the lower Arrow River under the existing 7dMALF relative to the naturalised 7dMALF.

Group	HSC name	% retention under existing 7dMALF compared with naturalised 7dMALF
Periphyton	Cyanobacteria	101%
	Diatoms	105%
	Didymo (Waitaki)	112%
	Long filamentous	124%
	Short filamentous	81%
Macro-invertebrates	Food producing	109%
	Cased caddis fly (*Pycnocentrodes*)	100%
	Mayfly nymphs *(Deleatidium)*	85%
	Net-spinning caddis fly (*Aoteapsyche*)	109%
Fish	Brown trout adult	131%
	Adult trout T2	95%
	Brown trout spawning	158%
	Brown trout Juvenile	108%
	Juvenile trout T1	105%
	Rainbow trout spawning	141%

4.9. Summary of instream habitat assessments

Appropriate objectives for the management of the aquatic ecosystems of the Arrow River include maintaining the locally-significant trout fishery and to protect its life-supporting capacity including macroinvertebrate populations and limiting the risk of periphyton proliferation. The flow requirements for key values of the lower Arrow River are presented in Table 4-6. It is likely that any minimum flow would have minimal effect on winter flows, given that demand for water is expected to be low in winter.

Table 4-6 Flow requirements to maintain the values of the Arrow River based on the instream habitat model of Jowett (2004).

Instream value	Season	Fishery or conservation value	Recomm. % habitat retention	Flow to maintain suggested habitat retention (l/s)	Flow below which habitat rapidly declines (l/s)	Optimum flow (l/s)
Adult trout	All year	Locally significant†	70%	553	-	1,600
Juvenile trout	All year	Locally significant†	70%	198	500	900
Brown trout - spawning (May-August)	Winter	Locally significant†	70%	44	400	600
Rainbow trout - spawning (May-August)	All year	Locally significant†	70%	127	400	600
Food producing	All year	Life supporting capacity	70%	392	600	900
Long filamentous algae	Summer	Nuisance	<150%	>755	800	-

† Based on the assessment in Otago Fish & Game Council (2015).

5. Conclusions: Flow requirements for aquatic ecosystems in the Arrow catchment

The original Otago Regional Council water resources report (Kitto, 2012) relied on flow statistics generated from comparing flows between the Cardrona River (Mount Barker) and Cornwall Street (Arrow River).There is now sufficient flow information from Cornwall Street recorder to allow flows to be naturalised, albeit the flow records are of relatively short length.

Under the Water Plan, rivers will have minimum flows set to provide for the maintenance of aquatic ecosystems and natural character under low-flow conditions. Similarly, residual flows can be imposed on resource consents for water takes from tributary streams for the same reasons. The purpose of this report is to update the previous report and provide information on the Arrow catchment that assists in setting minimum flows, including the values present in the catchment, the existing use of water resources and the flows required to maintain instream habitat, based on habitat modelling.

There are 22 existing surface water takes in the Arrow catchment, with a total allocation of 2.25 m^3/s although the actual usage is likely to be less than half this, especially at low flows. There is a reasonably high level of water allocation, and a long history of water use and flow alteration primarily due to a single water take. The hydrology of many waterways throughout Otago is complex; however in comparison the hydrology of the Arrow catchment is reasonably straight-forward.

Naturalised low-flow statistics were estimated by adding water take data upstream of the Cornwall Street recorder to flows at this site. There are three operational water takes above the recorder (WR1440AR, 95696, and 2007.049) as shown in Figure 2-1; with water take data being recorded for at least the past four years. This has meant that three years of flow data recorded at Cornwall Street were unable to be used when naturalising flows. Table 5-1 shows the comparison of the 7-day mean low flows (7dMLFs) during the low-flow seasons for Arrow at Beetham and at Cornwall Street.

Table 5-1 The comparison of the 7-day mean low flows (7dMLFs) during the irrigation seasons for Arrow at Beetham and at Cornwall Street

Site location	Data type (availability)	7dMLF (m^3/s)
Arrow at Beetham Creek	Actual (16/4/1981 – 23/1/1994)	0.88
Arrow at Cornwall Street	Actual (30/12/2010 – 9/10/2017)	1.03
Arrow at Cornwall Street	Naturalised (9/10/2013 – 9/10/2017)	1.43 ~ 1.44

The Arrow River supports a locally important trout fishery; many overseas anglers take advantage of early fishing season conditions. Fishing is limited to sections of the Arrow catchment downstream of the Soho Creek confluence. The catchment contains both rainbow and brown trout, with brown trout being the primary sportsfish targeted by anglers.

One indigenous fish is present in the Arrow catchment, the koaro, which is a migratory galaxiid. There is a single record of this species within the Arrow catchment, which suggests that their distribution is somewhat limited. The koaro is listed as “At Risk, Declining” in the most recent threat classification (Goodman *et al* 2014)

Appropriate aquatic ecosystem management objectives for the Arrow catchment are to maintain the locally important sports fishery, protect macroinvertebrate communities and maintain natural character by limiting the risk of proliferation of long filamentous algae.

The results of updated instream habitat modelling for the lower Arrow River presented in this report will be used to inform the development of management options by allowing the comparison of the potential effects of different options on instream values.

6. Glossary

Catchment

The area of land drained by a river or body of water.

Existing flows

The flows observed in a river under current water usage and with current water storage and transport.

Habitat suitability curves (HSC)

Representations of the suitability of different water depths, velocities and substrate types for a particular species or life stage of a species. Values vary from 0 (not suitable) to ideal (1). HSC are used in instream habitat modelling to predict the amount of suitable habitat for a species/life stage.

Instream habitat modelling

An instream habitat model is used to assess the relationship between flow and available physical habitat for fish and invertebrates.

Irrigation

The artificial application of water to the soil, usually to assist with the growing of crops and pasture.

Mean flow

The average flow of a watercourse (i.e., the total volume of water measured divided by the number of sampling intervals).

Minimum flow

The flow below which the holder of any resource consent to take water must cease taking water from that river.

Natural flows

The flows that occur in a river in the absence of any water takes or any other flow modification.

Naturalised flows

Synthetic flows created to simulate the natural flows of a river by removing the effect of water takes or other flow modifications.

Reach

A specific section of a stream or river.

River

A continually or intermittently flowing body of fresh water that includes a stream and modified watercourse, but does not include any artificial watercourse (such as an irrigation canal, water-supply race, farm drainage canal or canal for the supply of water for electricity power generation).

Seven-day low flow

The lowest seven-day low flow in any year is determined by calculating the average flow over seven consecutive days for every seven-consecutive-day period in the year, and then choosing the lowest of these averages.

Seven-day Mean Annual Low Flow (7dMALF)

The average of the lowest seven-day low flow for each year of record. Most MALF values reported here are calculated using flows from the irrigation season (October–April) only. This is to avoid the effect of winter low flows that may occur due to water being “locked up” in snow and ice in the upper catchment. However, if significant winter low flows do not occur, estimates of 7dMALF calculated using data from the full hydrological year or from the irrigation season should be very similar.

Taking

The process of abstracting water for any purpose and for any period of time.

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Update of scientific information ~~on~~ for the Cardrona catchment: 2011-2017

September 2017

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1. Introduction

The Otago Regional Council (ORC) has continued to measure flows in the Cardrona River since the publication of the report: "Integrated Water Resource Management for the Cardrona River" (Dale & Rekker 2011). This report presents updated hydrological analyses for the Cardrona River at the Mt. Barker hydrological site, including naturalised flows for 30 years as well as an updated instream habitat analysis based on this updated hydrological information.

The Cardrona River (catchment area: 337 km^2) has its headwaters in the Crown Range; it flows for 40 kilometres in a north-westerly direction, joining the Clutha River near the township of Albert Town. The Cardrona River flows through alluvial flats bordered by the Crown Range to the west and the Pisa and Criffel Ranges to the east. The river descends steeply from an elevation of 1200 metres to 300 metres at the confluence with the Clutha/Mata-au River.

The majority of the higher catchment is tussock and low production grassland while the lower catchment supports high producing exotic pasture. Sheep and beef farming on tussock dominate the catchment, with the high producing grasslands in the lower catchment supporting some deer farming (ORC 2011).

The climate of the Cardrona catchment is characterised as continental due to its distance from the moderating influence of the ocean (ORC 2016). Two distinct climate zones are spanned by the Cardrona; the lower catchment has a 'cool dry' climate whereas the upper reaches and high country has a 'cool wet' climate. The cool climate of the valley results in a short growing season.

Above Mt. Barker, the Cardrona Valley still has a degree of historic (undeveloped) atmosphere despite thousands of tourists passing through while traveling from Wanaka and Queenstown. Much of the atmosphere can be attributed to the Cardrona Hotel established in 1863. The hotel supported the many European and Chinese miners that once settled in the area as part of the 1860's Central Otago Gold Rush.

At its peak in the early 1870's the resident population reached 1000 with predominance of Chinese miners, who worked over claims abandoned by Europeans. Mine dredging started in the 1890's and continued through to the twentieth century (Middleton 2006). In recent years, urban development has spread up the valley, with the Wanaka Township now occupying what was once farm land past Orchard Road.

There are 25 existing surface water-takes in the Cardrona River catchment, with a total allocation of an approximately 2.0 m^3/s, although the measured usage is considerably lower.

This report summarises the results and upgrades of the work undertaken since 2011 and discusses the implications for the minimum flow process in the Cardrona River catchment.

This information includes the following:

- hydrology and existing water allocation in the Cardrona River,
- aquatic in-stream values of the Cardrona River,

- presentation, analysis and interpretation of the results of instream flow and habitat modelling to maintain aquatic ecological values in the Cardrona River.

This report supersedes the findings of the previous surface water section in the report: "Integrated Water resource management for the Cardrona River" (2011). An additional assessment of the groundwater component of this study is being undertaken separately to this report.

2. Climate and Rainfall

The Cardrona River catchment consists of a steep river valley at an elevation of between 300 m at the confluence with the Clutha/Mata-Au River and 1200 m at the top of its headwaters in the Crown Range. Figure 2-1 shows the Cardrona catchment, including temperature, flow and rainfall monitoring sites.

Topography plays a large role in the rainfall distribution over the Cardrona catchment, with high rainfall in western, mountainous parts of the catchment and much lower rainfall in the lower elevation middle and lower parts of the catchment (Figure 2-2). The mean annual rainfall along the western edge of the Cardrona catchment is between 650and 750 mm, while the annual rainfall in the middle and lower parts of the catchment between Ballantyne Road and the confluence with the Clutha River is a relatively low 550 mm. The long-term mean annual rainfall for the Cardrona catchment is 634 mm.

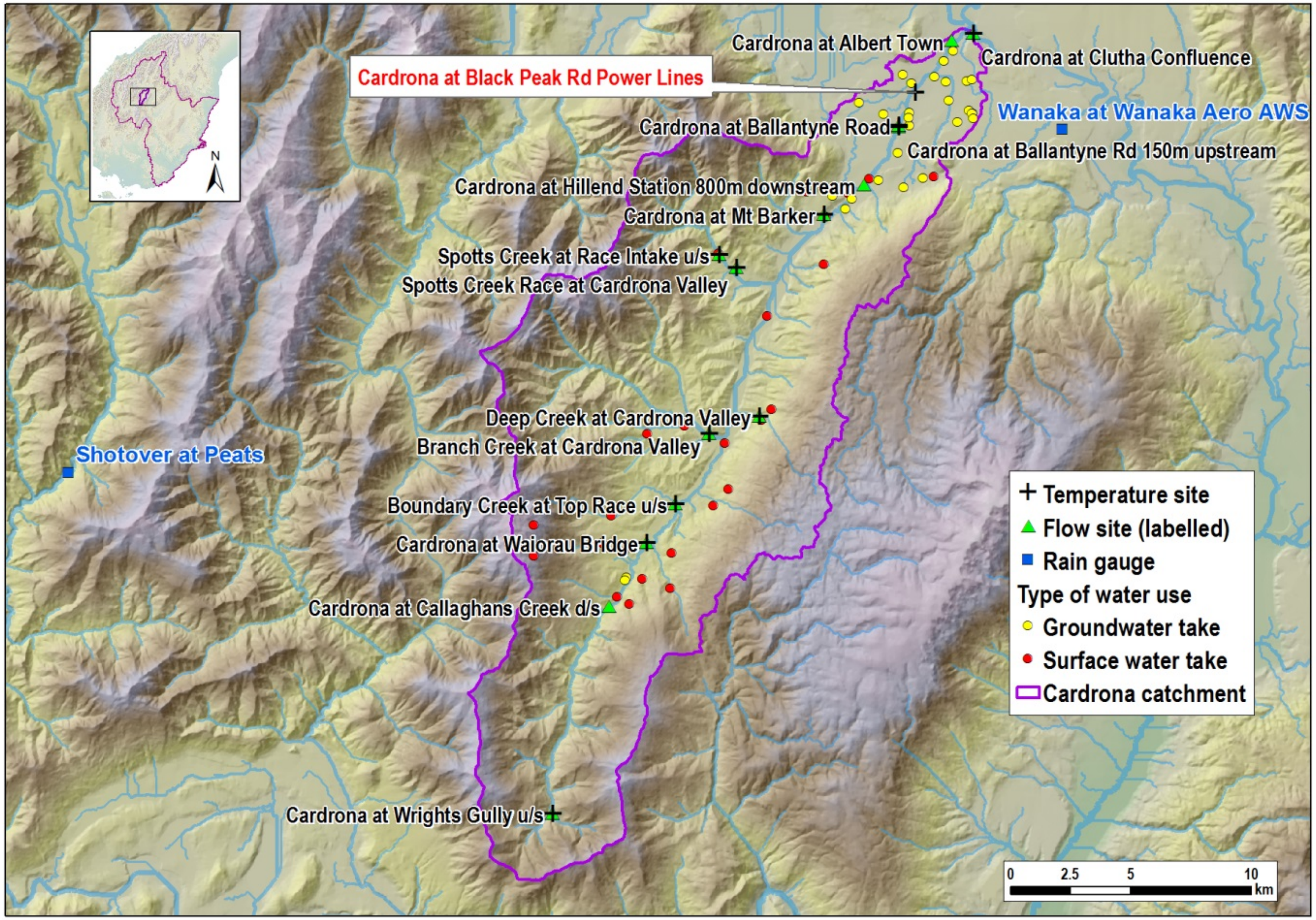

Figure 2-1 **The Cardrona catchment and the nearby temperature, flow and rain gaugesites.**

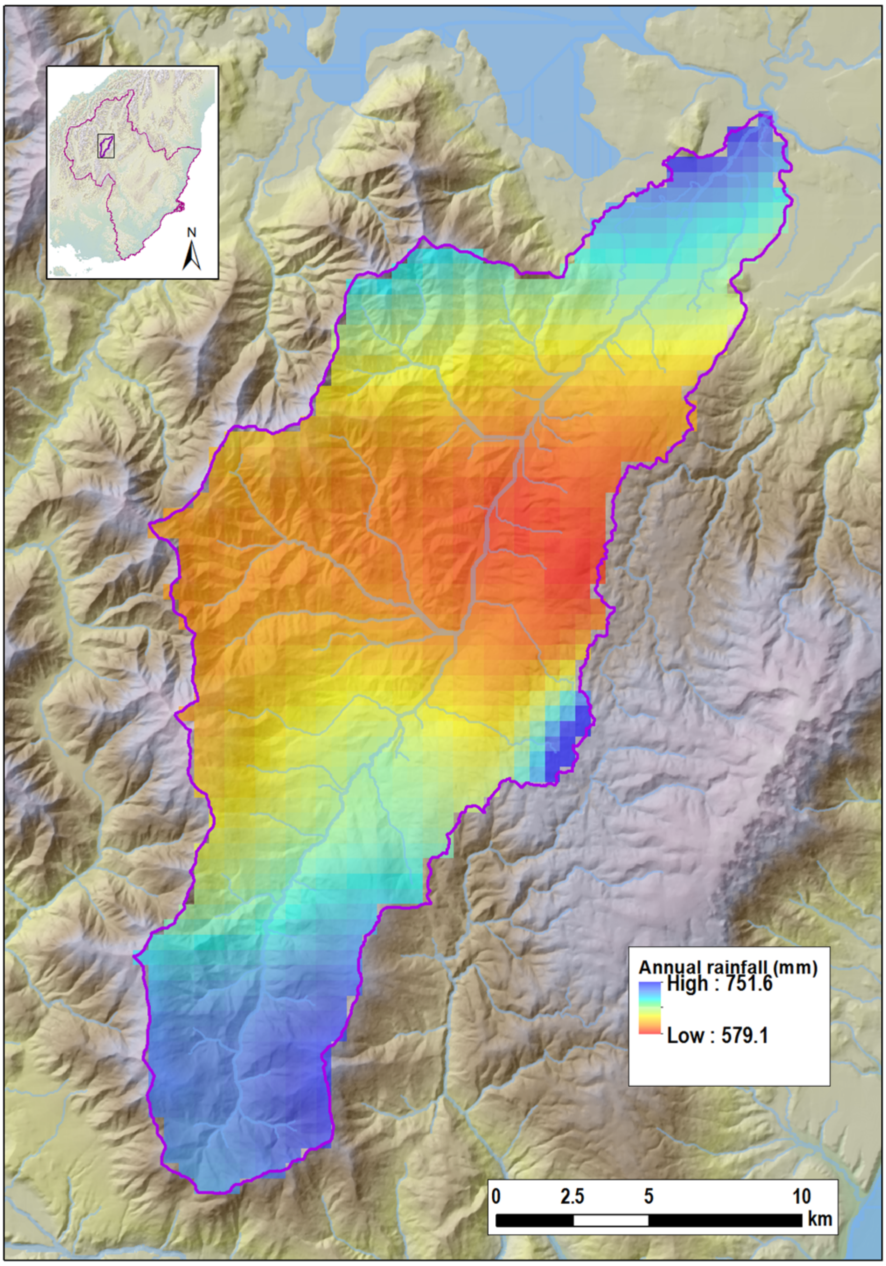

Figure 2-2 **The annual rainfall distribution around the Cardrona catchment (Tait, et al., 2006)**

Commented [DO1]: Lake Wanaka needs to be added to this figure

3. River Hydrology

Hydrological monitoring in the Cardrona catchment has included a permanent flow recorder at Mt. Barker (1976 to present) and thirteen temporary flow recorders that have been located at the Clutha River/Mata-Au confluence, Albert Town, Ballantyne Road, Hillend Station, Spotts Creek, Deep Creek, Branch Creek, Boundary Creek, Waiorau Bridge, Callaghans Creek confluence and Wrights Gully confluence (Figure 2-1).

The three upper flow recorders (Waiorau Bridge, Callaghans Creek confluence and Wrights Gully confluence) were installed as part of a water resource study of the upper Cardrona catchment. Waiorau Bridge recorder was established in 2008 and removed 9 months later; the Callaghans Creek recorder was installed in 2008 and removed 14 months later and the Wrights Gully site was established in 2009 and removed 16 months later. These short-term recorders were not used in this study, which focuses on the hydrology of the lower catchment.

Commented [DO2]: When?

Commented [XL3]: The following sentences give the details when they were setup.

Currently, the Callaghans Creek flow recorder has been reinstalled as a reference flow site, capturing the natural flows for the upper catchment. The historic flow site located at Albert Town (Sep 1978 – Jan 2002) was managed by NIWA. Flows of the two newly-installed recorders (Dec 2016) at Ballantyne Road (150 m upstream) and Hillend Station, along with the water-take data, are used for estimating the surface water loss/gain along the Cardrona River between the two locations. Flow recorders installed at Deep Creek, Branch Creek, Spotts Creek and Boundary Creek record natural flows as there are no water-takes above these recorders. The flow recorder at Cardrona at Clutha Confluence was initiated in 2008 for monitoring the water level, and it became a permanent SOE water level recorder ~~for~~ since March 2014.

Commented [DO4]: No mention of Clutha confluence site?

3.1. Naturalised seven-day mean annual low flow (7dMALF) for the Cardrona River at Mt. Barker

Figure 2-1 shows the flows of the Cardrona River at Mt. Barker are modified by upstream water-takes. To understand the natural character of the Cardrona River, an estimate of what the river flow would have been like prior to any water abstractions is needed. This section details the flow naturalisation process at Mt. Barker.

3.1.1. Data

Table 3-1 ~~and Table 3-2~~ lists the flow data used ~~in~~ to estimate ~~the flow~~ naturalised flows ~~ation~~ for the Cardrona River at Mt. Barker, while Table 3-2 ~~and the~~summarises the availability of water-take time series data for water takes upstream of ~~above~~ Mt. Barker.

Table 3-1 **Flow data used to naturalise flows for the Cardrona at Mt. Barker~~The available flow time series for this study~~**

Flow site	Type of flow time series	Start	End

Lindis at Lindis Peak	Assumed natural	25/09/1976	21/03/2017
Cardrona at Mt. Barker	Modified by water-take during irrigation seasons (Oct – Apr, inclusive), flows during Jun-Aug are assumed natural	3/12/1976	4/05/2017

Table 3-2 Water-take time series data for water takes located in the Cardrona catchment upstream of the at Mt. Barker flow site~~The consent information above Mt. Barker~~

Site name	Consent ID	Max rate of take (l/s)	Start	End	Length (year)	Gap (day)
WM0325	2003.293.V1	8.33	19/10/2016	18/07/2017	0.7	0
WM0553	97199.V1	50	22/02/2014	18/07/2017	3.4	0
WM0555	RM12.259.01	13.9	3/11/2012	30/03/2017	4.4	0
WM0562	RM14.155.01 & RM14.161.01	27.77	22/10/2014	18/07/2017	2.7	0
WM0570	99151.V3	5	2/05/2007	18/07/2017	10.2	0
WM0571	99151B.V2	5	11/03/2007	18/07/2017	10.4	0
WM0577	99356	55.55	6/12/2013	18/07/2017	3.6	3
WM0629	RM12.254.01	24	22/01/2013	18/07/2017	4.5	0
WM0630	RM12.255.01	10	23/10/2014	18/07/2017	2.7	0
WM0638	RM12.473.01	28	3/09/2014	17/07/2017	2.9	0
WM0639	RM12.512.02	35.5	16/11/2013	29/06/2016	2.6	0
WM0726	2009.191.V1 & 2009.435.V1	45	5/05/2015	18/07/2017	2.2	0
WM0827	2005.493.V1	5.8	2/06/2011	30/07/2014	3.2	298
WM0832	2005.604.V1	0.35	1/06/2011	30/07/2014	3.2	207
WM0865	2006.377.V1	2.08	25/12/2007	15/08/2016	8.6	564
WM1002	99339.V1	56	2/01/2010	29/08/2016	6.7	0
WM1080	RM12.258.01	146	2/07/2015	17/07/2017	2.0	49
WM1102	99356	55.55	2/07/2015	28/06/2017	2.0	0
WM1184	95677.V1, 98058 & 99129	97.2	16/04/2016	18/07/2017	1.3	0
WM1233	98494	27.77	11/03/2007	18/07/2017	10.4	0
WM1239	99357 & 99358	152.774	12/12/2015	29/06/2017	1.5	0
WM1256	95677.V1 & 99129	83.32	21/09/2016	18/07/2017	0.8	0
WM1316	RM12.438.01	16.8	20/12/2016	18/07/2017	0.6	0
No meter	93390	41.66				
No meter	98181	5				

Due to the relatively short records of water use, ~~the~~ long-term naturalised flows at Mt. Barker cannot be estimated by totalling all measured upstream water abstractions and observed flows, thus alternative methods must be used. These are outlined in the following sections.

3.1.2. Estimating long-term naturalised low flow statistics

Flows in the Lindis River at Lindis Peak are almost natural, as there are very few takes upstream of this site (Figure 3-1). In addition, the Lindis Peak site has a sufficiently long record of flow data, which would result in a more reliable estimate of its ~~Seven~~seven-day Mean Annual Low Flow (7dMALF). Winter flows (June, July and August) are assumed to be natural as no irrigation is expected during this period. Therefore, flows during June-August between Lindis Peak and Mt. Barker have been analysed to establish a relationship between the flows of the two sites (with focus on low flows).

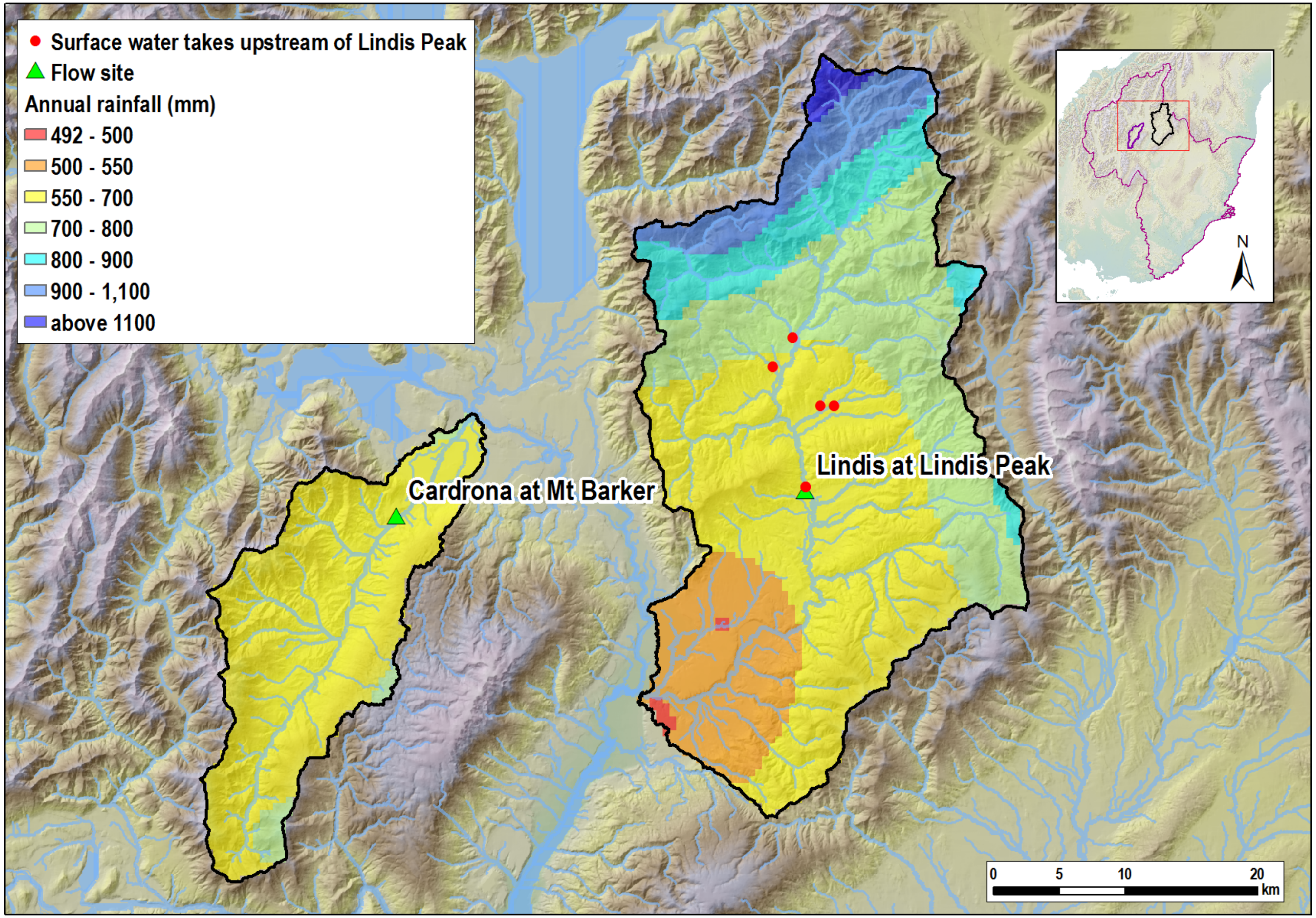

Figure 3-1 **The relative locations of the two flow recorders – Lindis at Lindis Peak and Cardrona at Mt Barker with long-term annual rainfall distribution (Tait et al., 2006)**

3.1.3. Relationship based on seven-day moving averages (7dMA) of low flow events

1. 7dMA flow time series for Lindis Peak and Mt. Barker were calculated.

2. Eighty-one independent flow events[1] (with focus on low flows) were identified during the June – August period and the minimum 7dMAs at Lindis Peak and Mt. Barker for each flow event were identified.

3. The lag time between the minimum flows of Lindis Peak and Mt. Barker was estimated. Figure 3-2(a) shows the relationships based on all eighty-one 7dMA low-flow events and Figure 3-2(b) shows the relationship based on the selected thirty 7dMA flow events with a lag time of 280-480 minutes, which constitutes the prevailing lag time between flows at the two sites.

Commented [DO5]: Not really an appropriate format for a formal report

To develop a relationship between flows atof the Lindis River at Lindis Peak and the Cardrona River at Mount Barker flow site, 7dMA flow time series for Lindis Peak and Mt. Barker were calculated. Eighty-one independent flow events[2] (with focus on low flows) were identified during the June – August period and the minimum 7dMAs at Lindis Peak and Mt. Barker for each flow event were identified. The lag time between the minimum flows of Lindis Peak and Mt. Barker was estimated. Figure 3-2(a) shows the relationships based on all eighty-one 7dMA low-flow events and Figure 3-2(b) shows the relationship based on the selected thirty 7dMA flow events with a lag time of 280-480 minutes, which constitutes the prevailing lag time between flows at the two sites.

Commented [DO6]: How?

[1] As for the selection of the low flows from Lindis at Lindis Peak between June and August, there is possibility of a sudden flow drop with fluctuation for several days during these winter months. Most likely, this would be the case of low flows under an extremely cold weather condition. For this analysis, the described low flows in these cases were ignored.

[2] As for the selection of the low flows from Lindis at Lindis Peak between June and August, there is possibility of a sudden flow drop with fluctuation for several days during these winter months. Most likely, this would be the case of low flows under an extremely cold weather condition. For this analysis, the described low flows in these cases were ignored.

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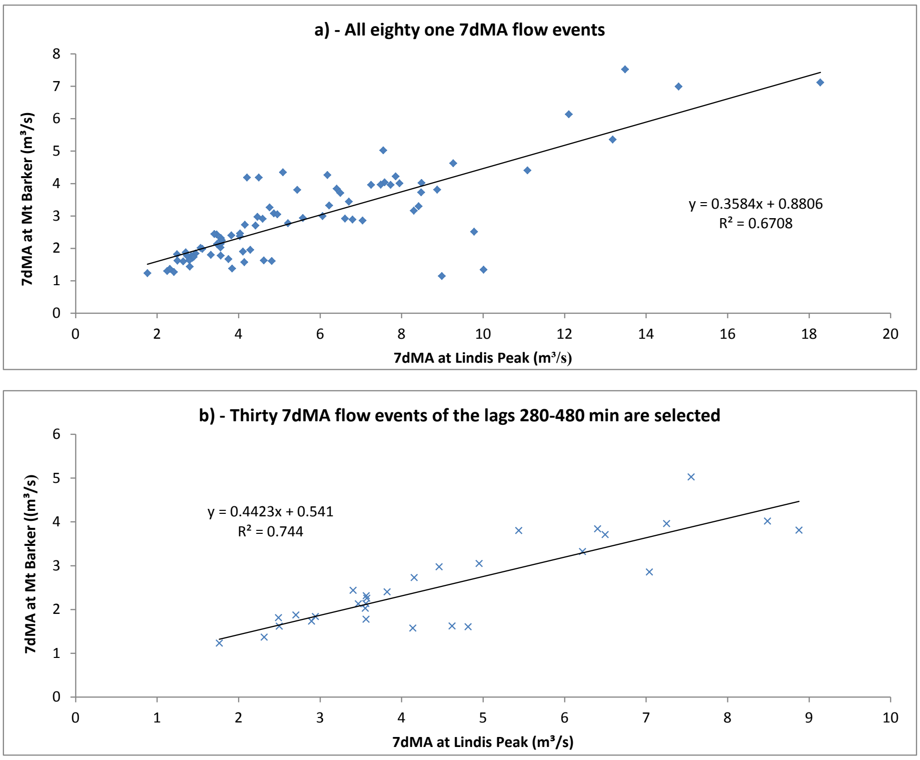

Figure 3-2 **The relationships from (a) all eighty-one minimum 7dMAs and (b) selected thirty minimum 7dMAs with lag time of 280-480 minutes**

When compared with Figure 3-2 (a), Figure 3-2(b) shows a better relationship for the low 7dMA. Based on this relationship, the naturalised 7dMALF at Mt. Barker was calculated as 1.18 m³/s (naturalised 7dMALF at Lindis Peak is 1.45 m³/s).

3.2. Naturalised flow time series for the Cardrona River at Mt. Barker

Commented [DO7]: I wonder whether a lot of the technical, detailed information should be moved to an appendix.

3.2.1. Building a relationship between daily flow time series of Lindis Peak and Mt. Barker

Selected flows (from flow events which exclude flows during recession periods after rainfall events, and focuses on low flows) for Lindis Peak and Mt. Barker ~~have been~~were analysed. A relationship ~~has been~~ was established, with a focus on low flows. Table 3-3 shows basic flow statistics for ~~the flow sites of~~ Cardrona at Mt Barker and Lindis at Lindis Peak. Most of the chosen flow events ~~are~~ were lower than the average flows for their corresponding flow sites. However, flows above the mean flow ~~(up to 4.87 m³/s for Mt Barker)~~ were also included so that this relationship is ~~also~~ applicable to flows up to ~~this range of~~

Commented [DO8]: Defined how?

~~flows~~54.873 m³/s at Mt Barker ~~when producing naturalised flows for the Cardrona River at Mt Barker~~.

~~Figure 3-3 shows the~~There was a strong relationship (R^2 = 0.9097) between the~~se~~ paired daily flows during the corresponding flow events at both sites (Figure 3-3). As shown in Figure 3-3, this relationship is only applicable for the flows at Mt. Barker between 1 ~~.1~~ and 4.873~~4.875~~ m³/s, as this is the flow range for Cardrona at Mt Barker for all the selected paired daily flows for this relation.

> **Commented [DO9]:** I think we can comfortably extrapolate a bit so that these are round numbers

Table 3-3 The basic flow statistics for the recorded daily flows at Cardrona a Mt Barker and Lindis at Lindis Peak

Flow site	Availability	Minimum (m³/s)	Maximum (m³/s)	Median (m³/s)	Mean (m³/s)
Cardrona at Mt Barker	3/12/1976 - 3/5/2017	0.310	77.4	2.34	3.1
Lindis at Lindis Peak	25/9/1976 - 21/3/2017	0.672	223	4.15	6.02

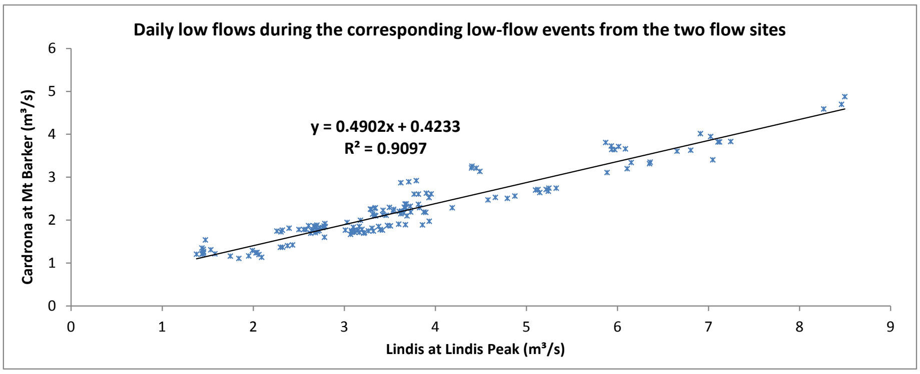

Figure 3-3 The relationship between Mt Barker and Lindis Peak selected daily flows during selected flow events with focus on low flows

Daily flows above ~~4.875~~4.873 m³/s at Mt. Barker were assumed to be natural as high flows are usually associated with rainfall events, and ~~during rainfall~~ such events are assumed to ~~mitigate~~ reduce the need for irrigation. Thus, when measured flows are greater than ~~4.875~~4.873 m³/s, flows at Mt Barker were considered to more accurately describe natural flows than flows correlated with those at Lindis Peak.

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3.2.2. Using water-take data to refine the naturalised flow time series

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As mentioned in Section 3.1.1, the naturalised flow at Mt Barker cannot be estimated by summing all measured upstream water abstractions and observed flows due to the short period of time for which water abstraction records are available, and their lower quality when considering periods shorter than monthly. However, the water abstraction data can be used as the boundary conditions for the estimation of long-term naturalised flow time series ~~estimation~~. This is done by estimating the monthly average rate of take for each take ~~is summarised~~ from its available measured water abstractions, and then calculating the monthly 'average' total take above Mt Barker ~~is calculated~~by summing these values for all takes above the Mt Barker flow site. This calculated total monthly take is assumed to apply to the periods with no available ~~measured~~ measurements of the rate of abstraction ~~available~~ across the flow records for Mt Barker. The details are presented in this section.

Commented [DO11]: I'm not sure what this means

Commented [DO12]: Not sure what this means either. Needs to be written for a non-specialist audience

Measured total water-take and consented allocations upstream of Mt. Barker were analysed and ~~are~~ used along with measured flows at Mt. Barker to refine and improve the quality of ~~its~~ the naturalised flows calculated ~~-~~for this site~~naturalised flows~~. This included two thresholds for the naturalised flows during irrigation seasons:

1. The lower threshold for the naturalised flows at Mt. Barker is the sum of its observed flows, F, and the measured water-takes (expressed as percentage of the total consented allocation above Mt. Barker WT of 0.998 m^3/s, i.e., %·WT). This lower threshold (LT) can be expressed as:
   LT = F + %·WT

2. Naturalised flows at Mt. Barker should not be higher than the sum of its observed flows F and the total consented takes WT (when applicable), and this is used as an upper threshold:

   UT = F + WT

The next step is to estimate how much water is used above Mt. Barker on average. Average ratios of monthly measured total water-take to the total consented allocations above Mt. Barker were estimated from the available water use data listed in Table 3-2 as percentages (%), as shown in Table 3-4.

Table 3-4 **~~The m~~Monthly average ratios (as percentages %) of the measured total take to the total consented during irrigation seasons from September to May**

Month	Average ratio (%) of the measured to the consented
Jan	22.1%
Feb	21.9%
Mar	24.6%
Apr	14.7%
May	6.9%
Sep	9.9%
Oct	14.1%
Nov	15.1%
Dec	20.3%

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In summary, the following steps are followed to generate the estimated naturalised daily flow time series at Mt. Barker:

1. The observed daily flows during winter "June – August" ($F_{Jun-Aug}$) at Mt. Barker are assumed natural.

2. As for the measured flows during other months (September – May), if measured flows are above 4.873 m³/s, they are assumed natural and labelled as (**$F_{Sep-May}$>4.873**)

3. Measured flows below 4.873 m³/s during Sept – May are labelled as (**$F_{Sep-May}$≤4.873**), the modelled naturalised flows at Mt. Barker were calculated by the relationship presented in Figure 3-3. i.e., (***Flow@Lindis Peak**$_{Sep-May}$*, labelled as ***LP***) **× *0.4902* + *0.4233*** when the ***Flow@Lindis Peak**$_{Sep-May}$* is available (i.e., no data gaps). If ***Flow@Lindis Peak**$_{Sep-May}$* is not available, the lower threshold ***LT*** (**$F_{Sep-May}$** + ***%·WT***) will be used. The calculated flows from both conditions in this step are labelled as **$MF_{Sep-May}$** and it can be expressed as:

$$MF_{Sep-May} = \begin{cases} LP \times 0.4902 + 0.4233, & LP \text{ is available} \\ LT, & LP \text{ is a gap} \end{cases}$$

4. Compare **$MF_{Sep-May}$** with the lower threshold ***LT*** (**$F_{Sep-May}$** + ***%·WT***) and ***UT*** (**$F_{Sep-May}$** + ***WT***). The naturalised flows at Mt. Barker during Sep – May, **$NF_{Sep-May}$** can be conceptually calculated as:

$$NF_{Sep-May} = \begin{cases} LT, & MF_{Sep-May} < LT \\ MF_{Sep-May}, & LT \leq MF_{Sep-May} \leq UT \\ UT, & MF_{Sep-May} > UT \end{cases}$$

Therefore, the estimated naturalised daily flow time series at Mt. Barker NF are the union of the following:

***NF* =** Union of **$F_{Jun-Aug}$, $F_{Sep-May}$>4.873,** and **$NF_{Sep-May}$**

3.2.3. Limitations which restricted the use of water-takes to produce naturalised flows at Mt. Barker

1 There are no overlapping periods for the available water use time series. Therefore, it wais not impossible to estimate the measured total water-take time series above Mt. Barker. The average monthly total water-take was applied instead.

2 The aAvailable water-take time series are very short for most water-takes. Only 18% of water-takes have available records of more than 5 years, and no records are available for more than 10.4 years. In addition, the quality of the available daily take values is poor, but these values can be averaged across a month to obtain a more reliable record of abstraction. Thus, a regression formula had to be used to estimate the long record of the naturalised flows at Mt. Barker based on the natural flows at

Lindis Peak. Measured water-takes were then used to revise and improve the synthesized naturalised flows.

3.2.4. Naturalised flow statistics

Table 3-5 lists basic flow statistics summarised from both observed and estimated naturalised daily flow time series at Mt. Barker (available from 3/12/1976 to 3/5/2017). The low-flow frequency analysis was carried out by testing the goodness of fit for the three selected distributions, i.e., Gumbel, GEV, and GPareto. Based on goodness of fit tests, the low-flow frequency analysis from GEV distribution was used. Table 3-6 shows the daily flows at three different return periods (2, 5, and 10 years). This low-flow frequency analysis, provides a better understanding of low-flow regime for the Cardrona River and could assist in setting minimum flows for protection of instream habitats.

Table 3-5 The basic flow statistics summarised from both naturalised and observed flows at Mt. Barker

	Flow statistics (m^3/s)					
	Minimum	Median	Mean	7dMALF (Jul – Jun)	7dMALF (Oct – Apr)	7dMALF (May – Sep)
Naturalised flows	0.753	2.62	3.32	1.18	1.17	1.68
Observed flows	0.310	2.34	3.1	0.840	0.85	1.54

Table 3-6 The low flow frequency analysis for both naturalised and observed flows at Mt. Barker

	2-year low flow (m^3/s)[3]	5-year low flow (m^3/s)	10-year low flow (m^3/s)
Naturalised flows	1.09	0.921	0.846
Observed flows	0.877	0.63	0.528

The low-flow frequency analysis was based on the naturalised daily flow time series at Mt. Barker. The low flows in Table 3-5 are expected to be lower if a finer temporal resolution is used (e.g., hourly).

Figure 3-4 shows flow duration curves for both naturalised and observed daily flow time series across the irrigation seasons (Oct – Apr, inclusive) at Mt. Barker, along with their corresponding 7dMALFs.

[3] 2-year low flow (m^3/s) is the low flow at a 1 in 2 chance or a 50 percent chance of occurring in any given year.

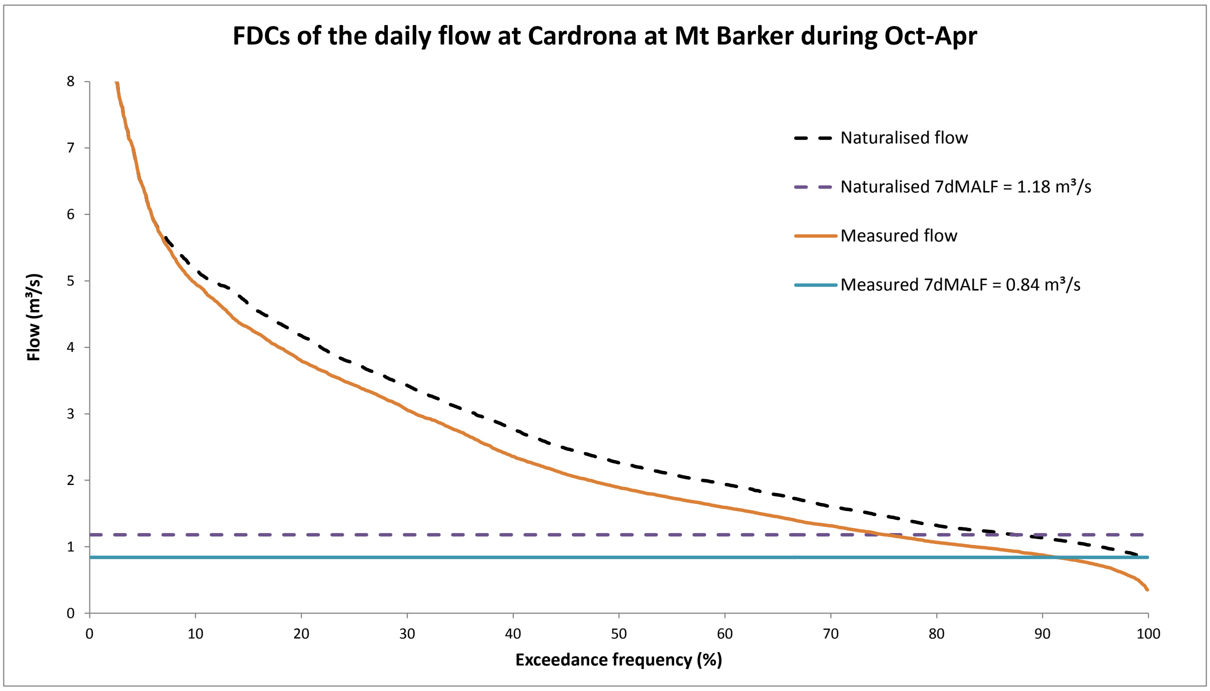

Figure 3-4 **Flow duration curves of the daily flow at Mt. Barker during the irrigation season (October-April).**

Figure 3-4 shows on average, for 91% and 87% of the time the observed and naturalised daily average flows are above their respective 7dMALFs.

Figure 3-5 shows monthly average naturalised flows start receding in November and continue to do so through to the end of April, then start recovering again in May onwards. The February – April period is where flows are lowest with February being marginally drier than any other month.

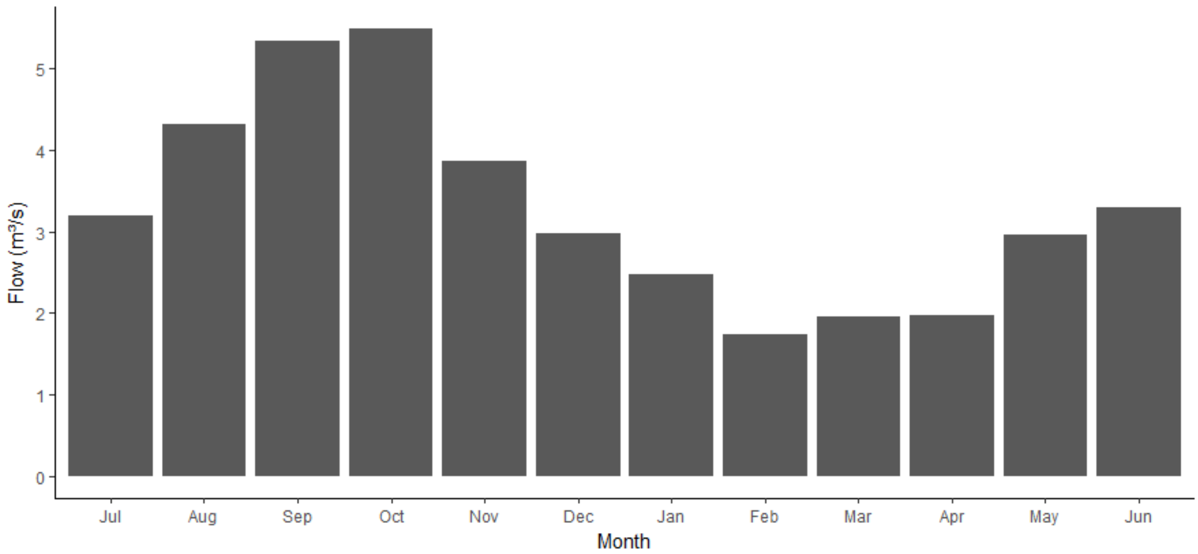

Figure 3-5 **Naturalised monthly average flows at Mt. Barker**

Table 3-7 presents the number of days and maximum consecutive number of days when the naturalised flows at Mt Barker were below its 7dMALF of 1.18 m³/s for the period of October – April from 2000 to 2017. On average, there have been 35.5 days and 13.6 maximum consecutive days when the flows were below the 7dMALF, respectively.presents the number of consecutive days when naturalised flows at Mt Barker were belowthe naturalised 7dMALF. On average, there will 13.6 maximum consecutive days when flows are below the 7dMALF of 1.18 m³/s and 35.5 days total.

Commented [DO13]: Total in a season?

Table 3-7 **The maximum consecutive number of days where flows are below; <1.18 (Mt Barker) The No. of days and maximum consecutive No. of days when the naturalised flows at Mt Barker were below 1.18 m³/s for the period of October – April between 2000 and 2017**

Period October – April	No. of days when flows are were < below 1.18 m³/s	Maximum consecutive No. of days when flows were below 1.18 m³/s
2000 – 01	26	9
2001 – 02	15	11
2002 – 03	14	10
2003 – 04	3	3
2004 – 05	0	0
2005 – 06	100	39
2006 – 07	53	17
2007 – 08	72	35
2008 – 09	1	1
2009 – 10	76	30
2010 – 11	0	0
2011 – 12	0	0
2012 – 13	25	9
2013 – 14	49	16
2014 – 15	55	17
2015 – 16	105	28
2016 – 17	10	6
Average No. days	35.5	13.6

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3.3. Surface water loss/gain for Mt. Barker- Hillend-Ballantyne Road

Flow connectivity is considered to be a key component of the natural character in a water way. Therefore, it is critical to understand whether the waterway dries naturally or due to water abstraction. As a result, a major objective of this study is to provide an understanding of surface and groundwater flow interactions to determine if the Cardrona River dries naturally and, if so, at what flows drying occurs.

The Cardrona River can be separated into three main sections: a neutral reach upstream of Mt. Barker; a losing reach, in which surface water is lost to ground between Mt. Barker and State Highway 6; and gaining reach in which surface flows are recharged from groundwater from State Highway 6 to the confluence with the Clutha River (Dale & Rekker 2011) (Figure 3-6).

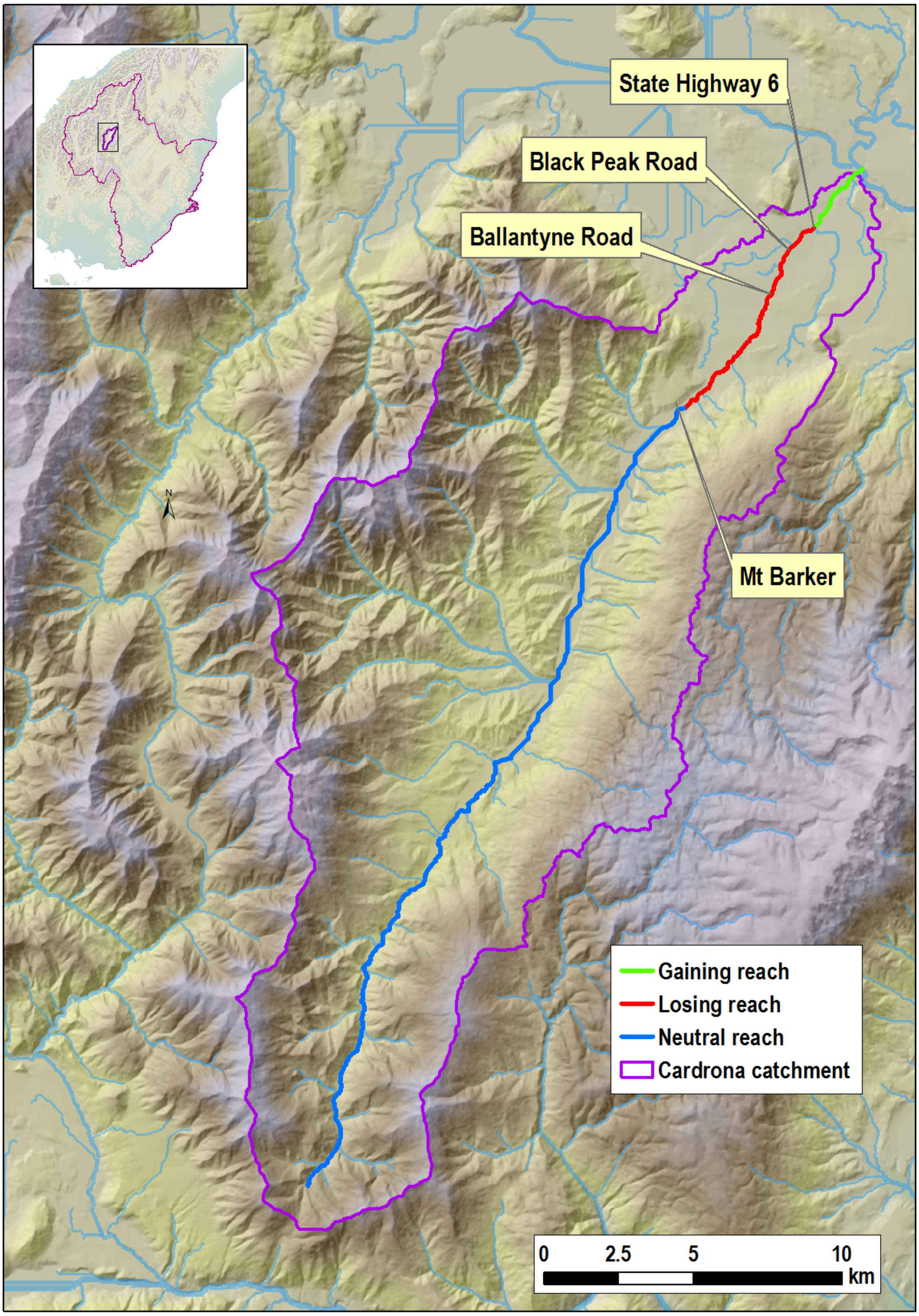

Figure 3-6 **Location the three different hydrological reaches in the Cardrona River**

3.3.1. Total water abstraction between Mt Barker and Ballantyne Road

Information was gathered from the permanent flow recorder site at Mt. Barker and a temporarily established flow recorder at Ballantyne Road which collected data from mid-December 2016 to May 2017. There are five abstraction points (listed in Table 3-8) located between the Mt. Barker and Ballantyne Road. These water-takes (99478, 97199.V1, 98370, 2001.A03, and RM14.345.01) were used to determine the amount of water lost to ground between the Mt. Barker and Ballantyne Road flow recorders.

Table 3-8 Summary of water takes between Mt Barker and Ballantyne Road

Site name	Consent ID	Start	End	Type	Maximum rate of take (l/s)
WM0583	99478	4/12/2012	17/07/2017	Surface take	250
WM0712	97199.V1 & 98370	8/05/2015	17/07/2017	Surface take	561.1
No meters[4]	96552, 96553 & 97129			Surface take	194.37
WM0203	2001.A03	6/11/2011	21/11/2016	Groundwater take	2.8
WM0987	RM14.345.01	19/01/2008	2/03/2015	Groundwater take	38

Based on water metering data, the total measured water-take data between Mt. Barker and Ballantyne Road can be derived and added to the flow at Ballantyne road to allow a calculation of loss to ground water (e.g. Flow at Mt. Barker – [Irrigation take between Mt. Barker and Ballantyne Rd + Flow at Ballantyne Rd] = Water loss). Figure 3-7 shows a box plot of the measured monthly rate of take along the Cardrona River between Mt Barker and Ballantyne Road during Feb 2014 – Jun 2017.

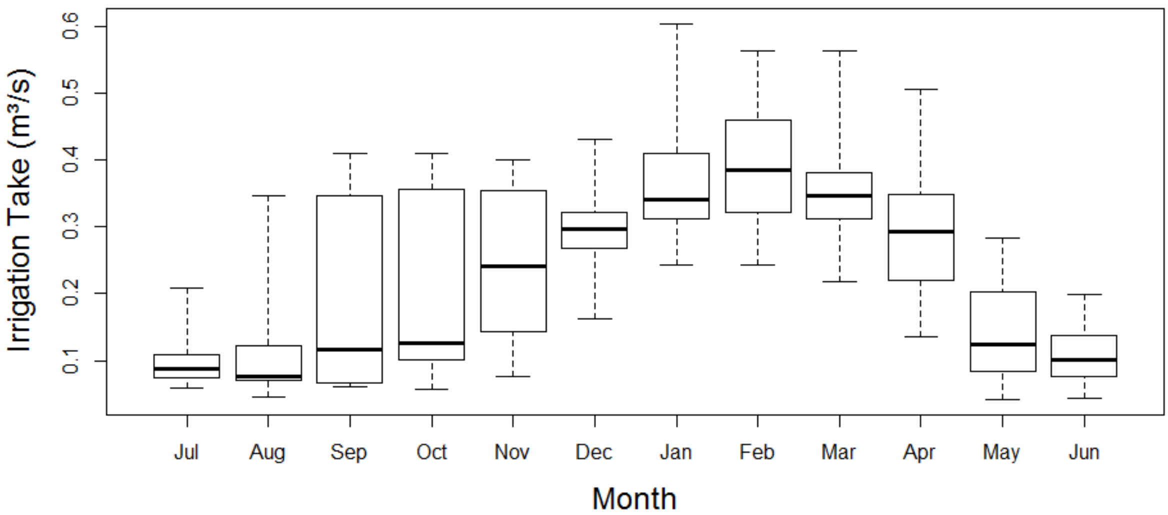

Figure 3-7 The box plot of the measured monthly rate of take along the Cardrona River between Mt Barker and Ballantyne Road (Figure 3-6) during Feb 2014 – Jun 2017.

[4] For the consents with no water meters being installed, the irrigators suggest that a consistent rate of 42 l/s is applied for a normal irrigation season.

3.3.2. Estimating losses to ground water

The relationship between flow at Mt. Barker and groundwater loss between Mt. Barker and Ballantyne Road was fitted with a quadratic relationship to account for potential saturation (Figure 3-8) and a maximum rate of loss to ground. When at or below naturalised 7dMALF, ground water loss between Mt Barker and Ballantyne Road ranges from approximately 0.52 m^3/s to 0.77 m^3/s (Figure 3-8). Above the naturalised 7dMALF, more water is lost to ground, but, as flows increase further, the rate of loss eventually starts to decrease resulting in a U-shaped curve. This U-shaped relationship likely occurs due to either groundwater saturation or a maximum rate of loss to ground. If groundwater is saturated or flows exceed this rate, surface flow would likely occur. The range of loss from Ballantyne Road to Black Peak Road powerlines is difficult to quantify as the amount of loss is dependent on the surface flows at Mt Barker.

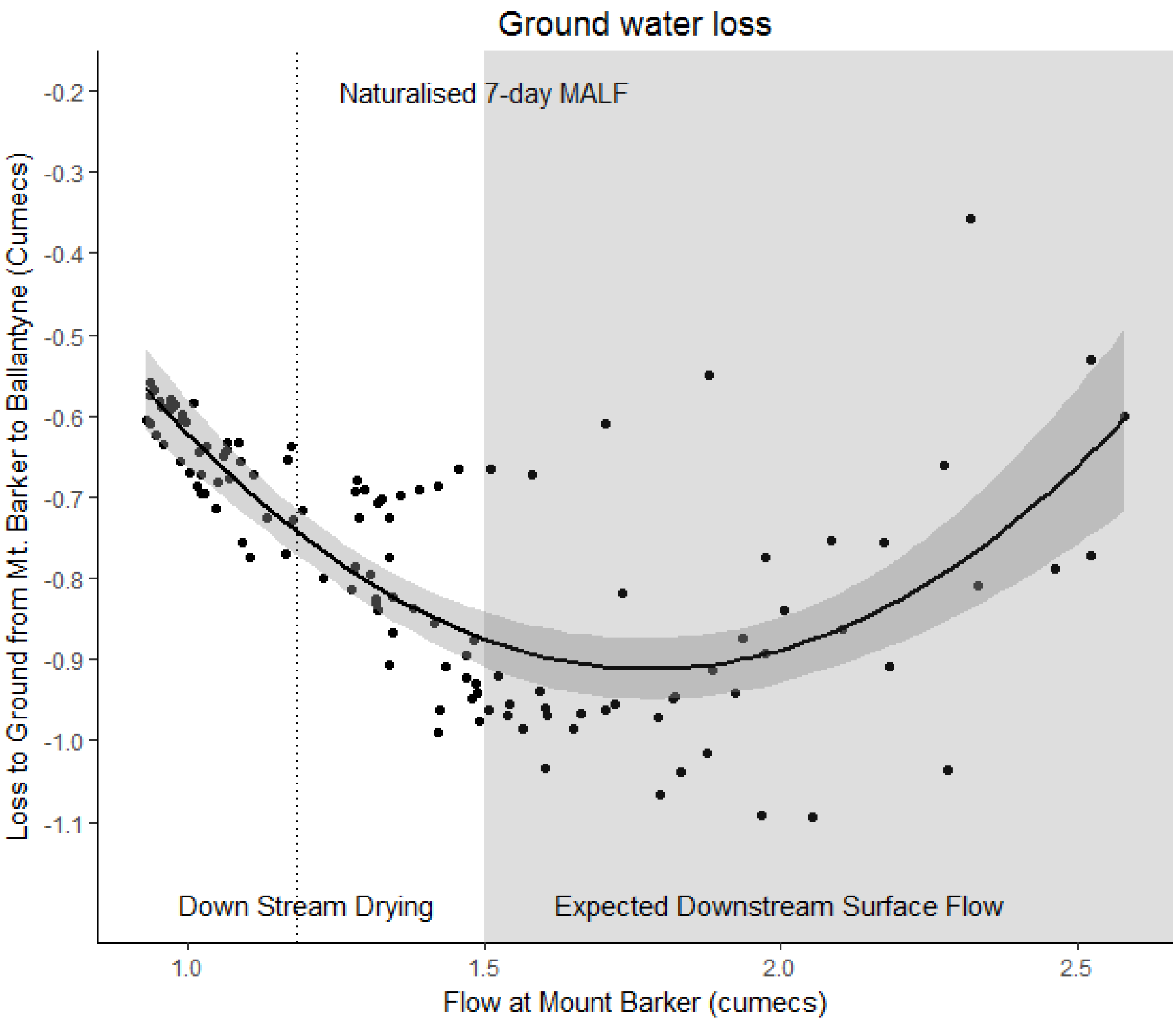

Figure 3-8 **Quadratic model fit of the relationship between flow at Mt. Barker and groundwater loss from Mt. Barker to Ballantyne Road with a shaded (grey) 99% confidence interval and naturalised minimum flow. Shaded expected downstream flow regions are based upon the inflection point of groundwater loss. When flow values exceed this point (1.5 cumecs), downstream surface connectivity is more likely to be maintained.**

Water temperature loggers were deployed between Mt Barker and the Clutha confluence to determine if sections of this reach went dry. A relatively small diurnal temperature range (e.g., ~10-25 °C) is characteristic of flowing water and a relatively large diurnal temperature range (e.g., ~5-45 °C) indicates water is not flowing and the reach is dry. Temperature data suggests that the river was flowing at Mt. Barker, Ballantyne Road and the Clutha confluence year-round while the Black Peak Road Power Lines site had periods of drying from January through to the end of March (

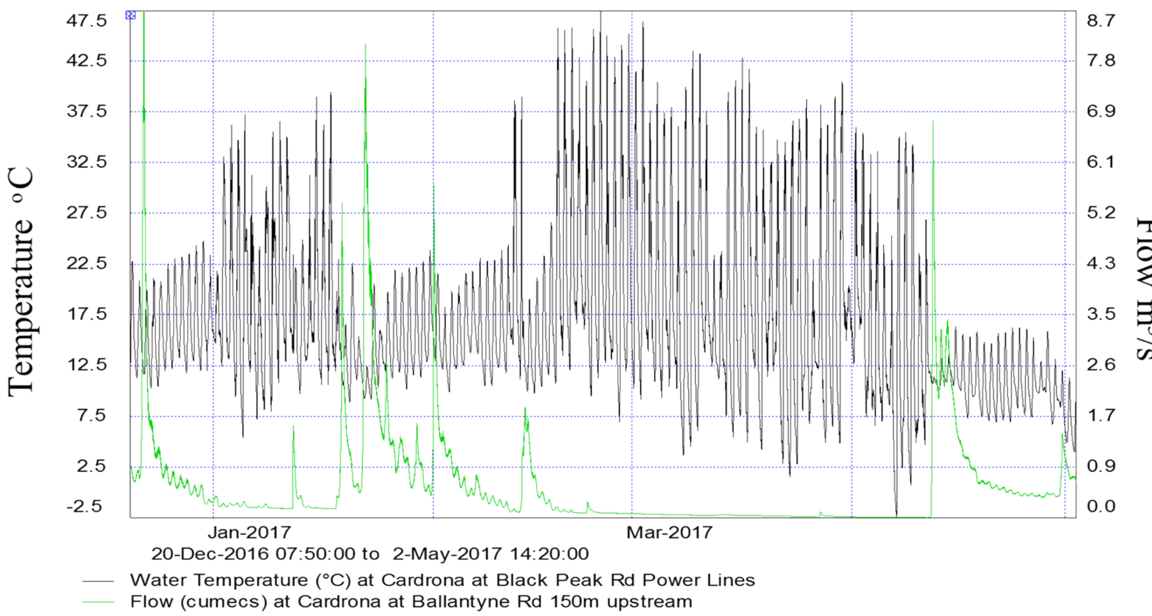

Figure 3-10 Surface flows at Ballantyne Road and temperature at Black Peak Road powerlines). The Black Peak Rd. Power Lines site was likely dry for at least 43 days and up to 69 days in the 2017 irrigation season. Temperature at this site does not show a gradual increase as seen in other catchments such as the Manuherikia (Olsen et al., 2016) but instead shows one of two states, either a relatively stable temperature, like that of Mt. Barker (Figure 3-9), or a drying reach with large temperature ranges. This suggests drying occurs relatively rapidly.

There were three high flow events on the 19th, 22nd and 31st of January. These flows peaked at 5.38 m^3/s, 8.09 m^3/s and 5.69 m^3/s respectively. These high flow events may have provided connectivity in the lower reach but for relatively short duration (Figure 3-10). Field observations made at the time when flows were at 1.2 m^3/s (13th Feb 2017) confirmed there were no surface flows.

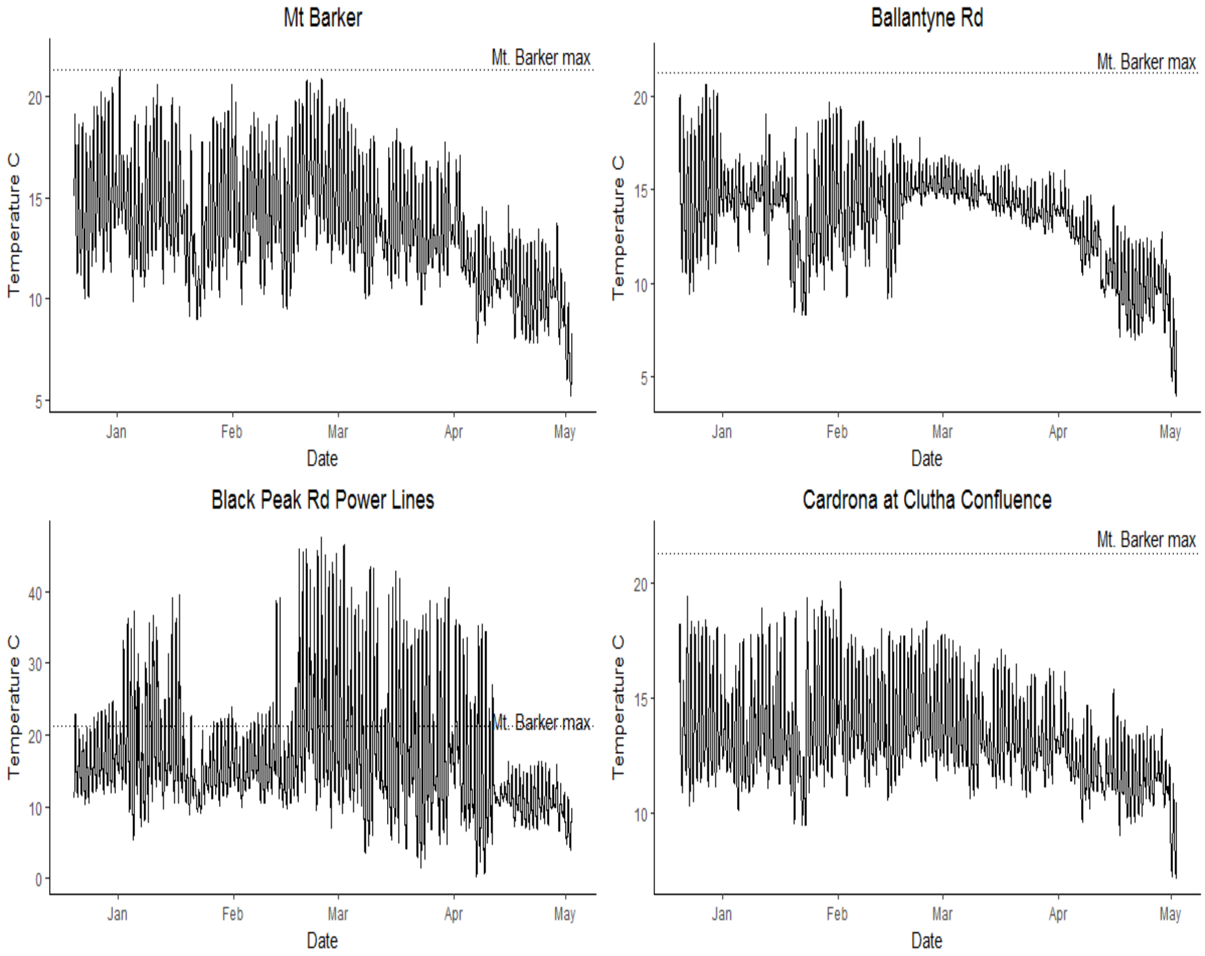

Figure 3-9: **Temperature graphs for four sites along the Cardrona River. Mt. Barker maintained flow and had a maximum daily temperature of 21.3 °C. Black Peak (note the greater y-axis scale) routinely exceeds this temperature by more than 10 °C suggesting a dry reach**

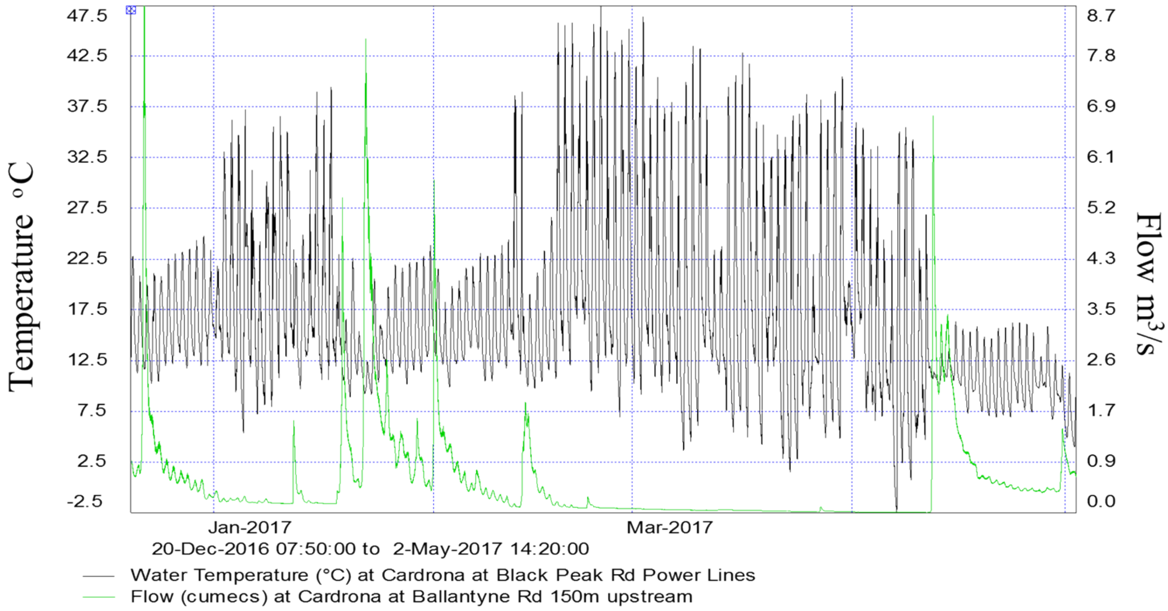

Figure 3-10 Surface flows at Ballantyne Road and temperature at Black Peak Road powerlines

To determine if the model in Figure 3-8 was meaningful in the context of downstream drying, the temperature of downstream sites was used as a proxy measure to determine if downstream reaches maintain surface connectivity at various flows. The relationship between flow at Mt. Barker and temperature range (

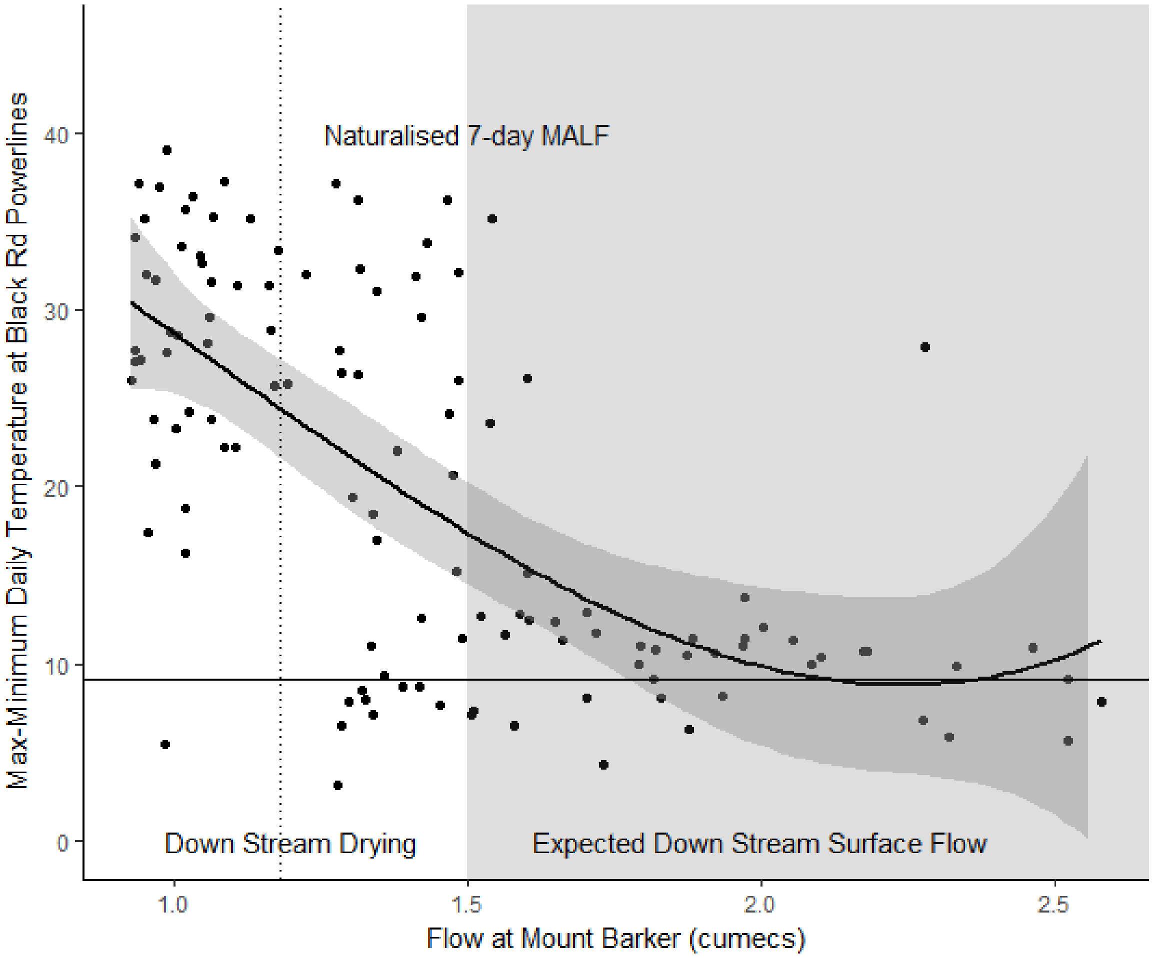

Figure 3-11) at the Black Peak Rd. Power Lines shows when flows are below the range of the critical value (approximately 1.5 m³/s) identified in Figure 3-8, temperature ranges have relatively high values whereas when flows are above 1.5 m³/s temperature ranges are much less indicating the temperature logger likely remained submerged. Both drying and wetted temperature ranges are present from approximately 0.75 m³/s to 1.75 m³/s. This suggests surface flow may occur in downstream reaches when flows are less than 1.5 m³/s if conditions, such as groundwater level, allow. Above 1.75 m³/s, nearly all temperature ranges indicate surface flow. However, whether these flows maintain surface flow beyond the Black Peak Rd. Power Lines site to the Clutha confluence is unknown based on current data.

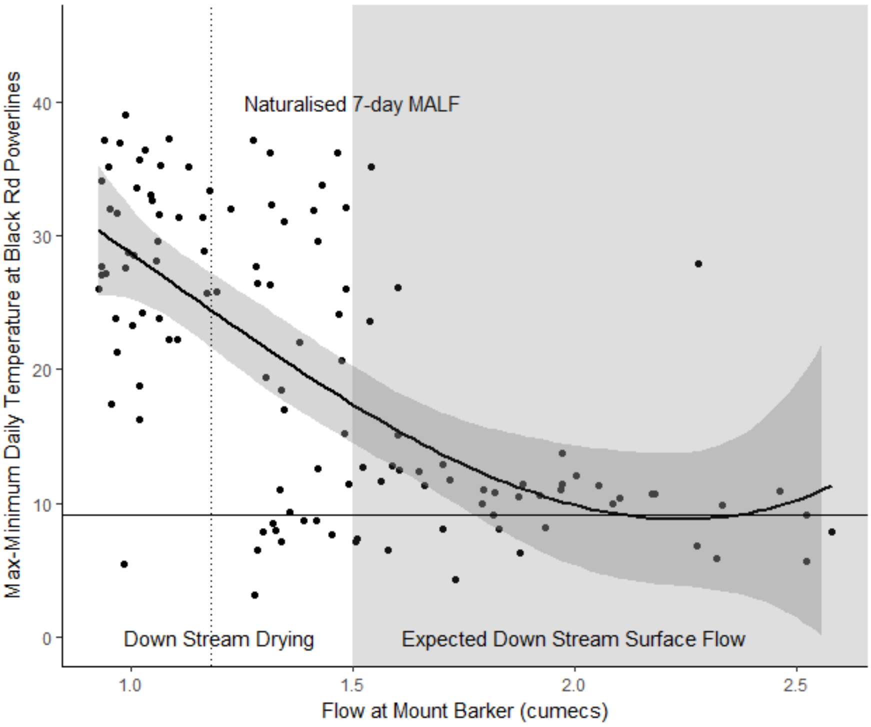

Figure 3-11 **Temperature range (daily maximum-daily minimum) at Black Peak Rd power lines and flow at Mt. Barker with 95% confidence interval. The shaded rectangle represents flows at which downstream connectivity is likely to occur based estimates from Figure 3-8**

Flow losses in the Cardrona River from Ballantyne Road to State Highway 6 were further established using ground-based surveys and aerial photography/satellite imagery. The analysis included xx aerial photographs and/or satellite images of the reach immediately downstream of the Ballantyne Road flow recorder obtained from various sources (Otago Regional Council, Google Earthpro). Ground-based surveys involved marking drying reaches on five separate occasions from 5th January 2017 to 17th March 2017 using a hand-held GPS unit. These GPS points were imported to ArcGIS and the length of each section was determined.

Commented [MD14]: You need a number here.

To determine the length of the drying sections in the Cardrona River in relation to flows at Mt. Barker the following calculation was used: flows at Mt. Barker flow recorder minus measured water-take equals flow below the lowest point of take (Figure 3-12).

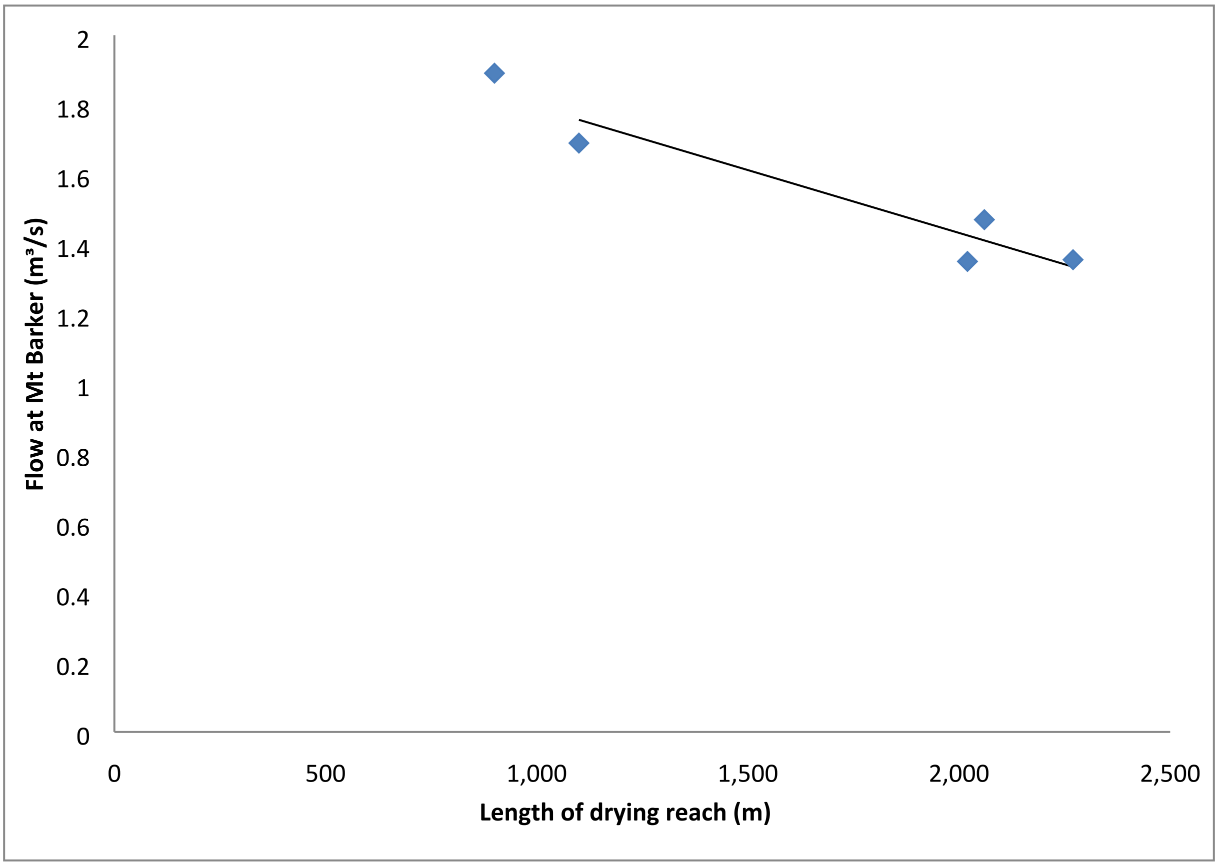

Figure 3-12 **Length of dry river bed in the Cardrona River in relation to actual flows at Mt. Barker minus water-take data**

The river consistently dries at Black Peak Rd Power Lines and recedes from this point upstream. The extent and the frequency of the drying reach are determined by surface flows and the interaction with ground water.

On the 5th January 2017, a 1,100-metre section of the Cardrona River was dry. At this time, the measured flow at Mt. Barker was 1.41 m^3/s; minus measured water abstraction which equates to a surface flow of 1.09 m^3/s entering the losing reach (Figure 3-12). The longest drying reach was 2,270 m recorded during the period 1st – 17th March. The dry reach extended from the power lines upstream to 30 metres above the Ballantyne Road Bridge. During this period, flows below the lowest point of take were 0.725 – 0.634 m^3/s. The highest flow at Mount Barker where a drying reach was observed was 1.78 m^3/s on 13th February 2017, when 900 m of river had no surface flows. This suggests drying flows are likely to occur when flows are below 1.5 m^3/s but may occur when flows are as high, or higher than, 1.78 m^3/s.

Figure 3-13 shows the flow duration curves for both naturalised and observed daily flow time series across the irrigation seasons (Oct – Apr, inclusive) at Mt. Barker, along with their corresponding 7dMALFs and threshold flows of 1.5 and 1.7 m^3/s when a dry reach is likely to occur.

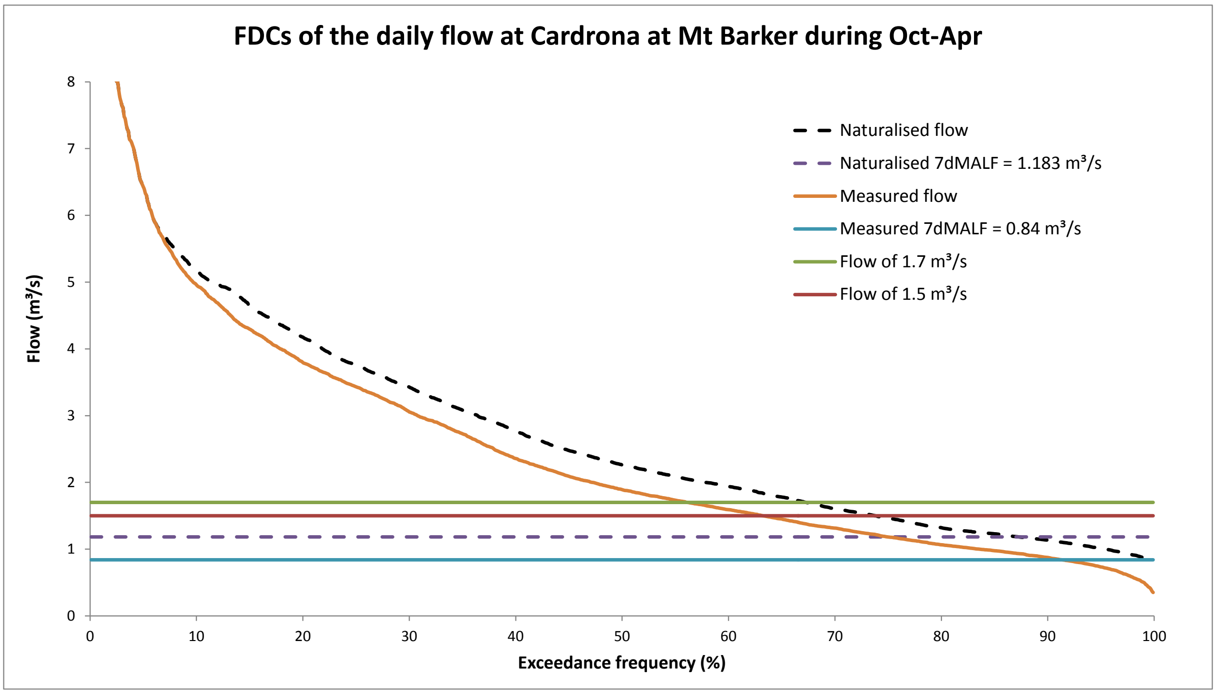

Figure 3-13 **Flow duration curves of the daily flow at Mt. Barker during the irrigation season (October-April).**

Figure 3-13, shows on average, for 91% and 87% of the time the observed and naturalised daily average flows are above their respective 7dMALFs. Naturalised flows are expected to be above 1.5 m^3/s and 1.7 m^3/s for 74 % and 67% of the time.

Table 3-9 presents the number of consecutive days when naturalised flows at Mt Barker were below three different flow rates. On average, there will 13.6 maximum consecutive days when flows are below 1.18 m^3/s; 31.8 maximum consecutive days/year when flows are below 1.5 m^3/s and 39.1 maximum consecutive days/year when flows are below 1.7 m^3/s.

From October to April and when flows are below 1.18 m^3/s we are likely to observe 35.5 days/year when flows are likely to be less than this. When flows are below 1.5 m^3/s and 1.7 m^3/s then, the number of days when flows will be less than this are 64.9 and 78.1, respectively.

Table 3-9 The maximum consecutive number of days where flows are below; <1.183 m³/s; < 1.5 m³/s; <1.7 m³/s (Mt Barker)

Period October – April	No. of days when flows are < 1.183 m³/s	Maximum consecutive No. of days < 1.183 m³/s	No. of days when flows are < 1.5 m³/s	Maximum consecutive No. of days < 1.5 m³/s	No. of days when flows are < 1.7m³/s	Maximum consecutive No. of days < 1.7 m³/s
2000 – 01	26	9	64	32	64	32
2001 – 02	15	11	40	35	54	36
2002 – 03	14	10	77	28	87	34
2003 – 04	3	3	28	13	50	23
2004 – 05	0	0	0	0	0	0
2005 - 06	100	39	132	66	151	86
2006 – 07	53	17	79	40	89	47
2007 – 08	72	35	94	38	107	38
2008 – 09	1	1	28	10	55	27
2009 – 10	76	30	89	58	96	71
2010 – 11	0	0	10	7	14	14
2011 – 12	0	0	41	13	72	18
2012 – 13	25	9	69	37	83	42
2013 – 14	49	16	67	34	76	34
2014 – 15	55	17	96	48	112	49
2015 – 16	105	28	139	66	143	66
2016 - 17	10	6	51	15	75	48
Average No. days	35.5	13.6	64.9	31.8	78.1	39.1

3.4. Summary

The measured total take in the Cardrona River is highest in the December-March irrigation period, with an average of 0.54 m³/s being abstracted. This period aligns with seasonal low flows. In addition to abstraction, a further portion of surface flow is lost to ground between Mt. Barker and Ballantyne Rd when flows at Mt. Barker are at or below 1.5 m³/s. When at or below 7dMALF, this loss to ground ranges from 0.52 m³/s to 0.77 m³/s totalling in a 62-92% loss of the measured 7dMALF in this reach and 44-65% of loss of the naturalised 7dMALF in this reach alone.

The loss of surface flows continues within the reach from Ballantyne Road to Black Peak Road power lines. It is difficult to quantify the maximum rate of loss in this reach as it is dependent on surface flows at Mt Barker, groundwater levels and saturation. However, the range of loss that was observed varied from 0.01 m³/s – 1.2 m³/s. Temperatures downstream of Ballantyne Road show drying reaches occur when flows are at, or slightly above, 1.5 m³/s at Mt Barker. Observations show up to 2,270 metres of river bed was dry when surface flows were 1.36 m³/s at Mt. Barker and again 800 metres of river bed was dry when surface flows at Mt. Barker were 1.78 m³/s.

Flows start receding in November and continue to do so through the end of April, before increasing again in May onwards. The February – April period is where flows are lowest with February being marginally drier than any other month.

The flow duration curves are summarised in Table 3-9 where the naturalised 7dMALF at Mt Barker is 1.18 m^3/s and likely to occur, on average, every 1.5 years. Flows of 1.5 m^3/s are likely to occur annually. In a typical season there will be a maximum of 13.6 consecutive days when flows are <1.18 m^3/s; a maximum of 31.8 consecutive days when flows are <1.5 m^3/s and a maximum of 39.1 consecutive days when flows are <1.7 m^3/s. On average there is likely to be 35.5 days, 64.9 days and 78.1 days per year when flows are less than the naturalised flows of 1.18 m^3/s, and threshold values of 1.5 m^3/s and 1.7 m^3/s respectively. These durations will be longer with the current flow regime.

Groundwater levels influence flow continuity during the period of October – April in the reach between Ballantyne Road and Black Peak Road Power Lines. The results of this study suggest surface reaches of the Cardrona River downstream of Ballantyne Road are expected to dry naturally in most years, even under naturalised conditions, due to losses to groundwater or the hyporheic zone.

4. Water temperature

Water temperature is a fundamental factor affecting all aspects of stream systems. It can directly affect fish populations by influencing survival, growth, spawning, egg development and migration. It can also affect fish populations indirectly, through effects on physicochemical conditions and food supplies (Olsen *et al.*, 2012).

Of all the fish in the Cardrona catchment, brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) are likely to be the most sensitive to high water temperatures. Their thermal requirements are relatively well understood, and Todd *et al.* (2008) calculated acute and chronic thermal criteria for both of these species. The objective of acute criteria is to protect species from the lethal effects of short-lived high temperatures. In this case, acute criteria are applied as the highest two-hour average water temperature measured within any 24-hour period (Todd *et al.*, 2008). In contrast, the intent of chronic criteria is to protect species from sub-lethal effects of prolonged periods of elevated temperatures. In this study, chronic criteria are expressed as the maximum weekly average temperature (Todd *et al.*, 2008). Most native fish species with available thermal tolerance data are more tolerant of high temperatures than trout (Olsen *et al.* 2012).

Water temperatures, recorded every five minutes, between Mt. Barker and Ballantyne Road suggest flow was maintained throughout the irrigation season. All temperatures are well within the acute and chronic thermal ranges of both brown and rainbow trout (Figure 4-1). This suggests that trout mortality in these reaches is unlikely to increase solely due to temperature. Drying reaches, as discussed in the previous section, are likely to pose a greater challenge to trout. Native species present in the main stem of the Cardrona River, such as longfin eel and bully species have a higher thermal tolerance than trout and therefore are unlikely to be negatively affected by temperature (Olsen *et al.* 2012).

4.1. Mt. Barker to Ballantyne Road

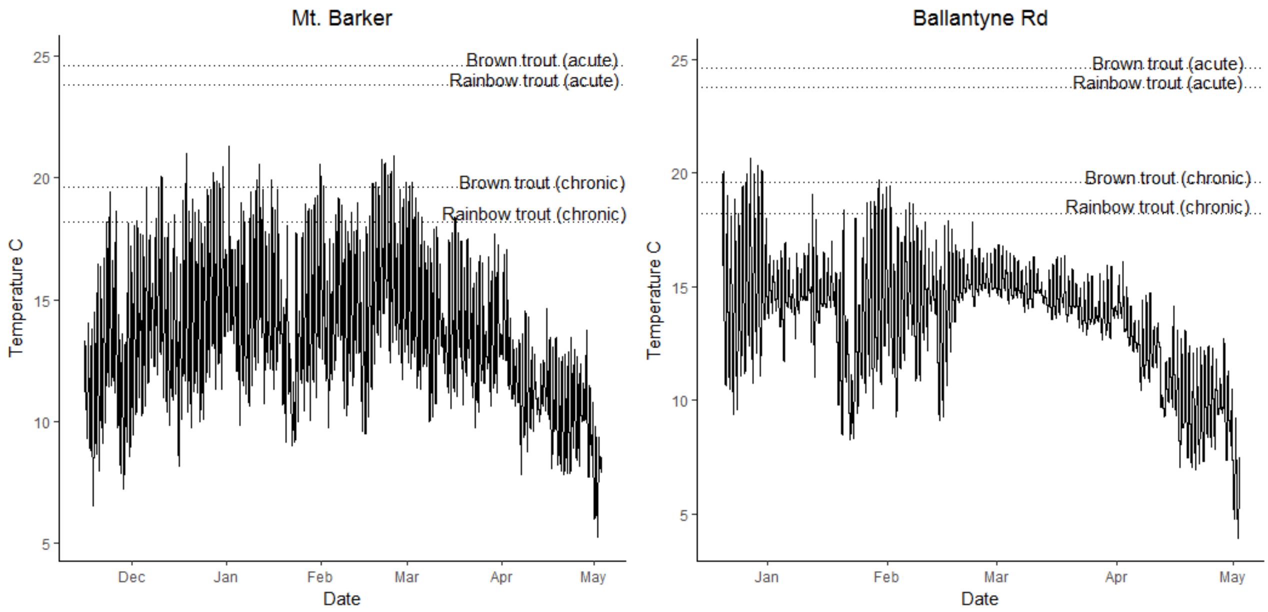

Figure 4-1: Water temperature for the 2016-2017 irrigation season at Mt. Barker and Ballantyne Rd with chronic and acute temperatures for both brown and rainbow trout

5. Aquatic ecosystem values of the Cardrona River

Schedule 1A of the Regional Plan: Water for Otago (RPW) outlines the natural and human use values of Otago's surface water bodies. The Cardrona River is identified as having the following values:

- Boulder, gravel and sand bed composition of importance to resident biota,
- presence of significant areas for fish spawning and development of juvenile trout,
- absence of aquatic pest plants identified in the Pest Plant Management Strategy for the Otago region,
- significant presence of trout,
- significant presence of eels,
- presence of indigenous fish species threatened with extinction,
- A high degree of naturalness above 900 m a.s.l.

5.1. Native fish

Native fish recorded from the catchment have included longfin eel, Clutha flathead galaxias (*Galaxias* sp. D), koaro, common and upland bully (NZFFD). The significant presence of Clutha flathead galaxias is listed as a value of the catchment in Schedule 1A of the RPW.

Clutha flathead galaxias are classified as 'nationally critical' (the highest threat classification in the New Zealand threat classification system; Townsend *et al.* 2008) in the most recent assessment of the conservation status of freshwater fish in New Zealand, while longfin eel and koaro were classified as 'declining' (Goodman *et al.* 2014). Upland bullies are classified as 'not threatened' (Goodman *et al.* 2014).

Clutha flathead galaxias are restricted to remote headwater tributaries of the Cardrona, likely due to the presence of trout and potentially koaro. Koaro require a lake or ocean environment to successfully reproduce. Due to the establishment of Lake Dunstan downstream, koaro are now able to inhabit the Cardrona and may be further extirpating Clutha flathead galaxias, as koaro are known to be piscivorous and potentially adversely affect non-migratory galaxiids, through competition and potentially predation. Koaro, also known as the climbing galaxiid, can climb vertical surfaces and thus conventional barriers used to stop trout movement are unlikely to stop koaro.

It is probable that longfin eels would also be present in the Cardrona catchment if it were not for the presence of Roxburgh and Clyde Dams, which block upstream passage from the sea. Although a trap and transfer programme is operated at Roxburgh Dam, eel numbers in the upper Clutha catchment, (above Roxburgh Dam) have declined markedly since its construction. Commercial eel fishing has contributed to the decline in the overall numbers; however, construction of Roxburgh and Clyde Dams has accelerated the loss by preventing natural recruitment of young eels.

5.2. Sports fish

The Cardrona River supports a locally important sport fishery (Otago Fish & Game Council 2015). Angler use has increased over time and it has become more popular with fishing guides. Table 5-1 presents angler effort on the Cardrona River, recorded during National Angler Surveys conducted in 1994/95, 2007/08 and 2014/15. Overall angler usage is relatively low, with anglers targeting the early part of the fishing season, with 95% (Unwin, 2016) of angling effort being undertaken in the period from October to November, taking advantage of the adult sized trout. It's probable that these fish have remained in the river after spawning and will, overtime, move out of the catchment prior to December. However, there is a resident population of both brown and rainbow trout that remain within the catchment. These trout rarely obtain a catchable length and consequently provide little value to anglers.

Table 5-1: Angler effort on the Cardrona River based on the National Angler Survey (Unwin, 2016)

Source	Angler usage (angler days±SE)			
	1994/95	2001/02	2007/08	2014/15
NZ resident	30±30		30±30	200±+180

The Cardrona River provides juvenile recruitment for both the rainbow and brown trout fishery of the Upper Clutha system. The upper Clutha River sports fishery is nationally significant (Otago Fish & Game Council 2015).

Spawning of rainbow trout generally occurs within the Cardona River from late August to November but the key period is between October to November (pers. comm. Cliff Halford, Otago Fish and Game). Rainbows spawn throughout the catchment with densities of redds being higher in the upper catchment; the Branch Burn is known as a particularly significant spawning stream.

Brown trout spawn earlier than rainbow trout with the key spawning period being May to June. Brown trout redds have been observed throughout the catchment with the majority of spawning above Mt. Barker.

There is also a single record of brook char *(Salvelinus fontinalis)* which was observed 1991. There have been no observations of this species subsequently.

5.3. Summary of aquatic ecosystem values

The Cardrona River is a locally important brown and rainbow trout fishery based on the most recent angling survey. However, it also contributes to the recruitment of the nationally significant fishery in the upper Clutha River (Otago Fish & Game Council 2015). Koaro, longfin eel, upland bully, common bully and Clutha flathead galaxias comprise the native fish community. Clutha flathead galaxias is nationally critically endangered while koaro and longfin eel are both declining. Clutha flathead galaxias, are found within the reach of the main stem affected by flow alteration but are limited by presence of trout and potentially koaro, as opposed to habitat, and thus are not included in the instream habitat assessment. The values of the Cardrona River, and recommended level of habitat retention relative to the naturalised 7dMALF, are summarised in Table 5-2.

Table 5-2: Assessment of instream habitat values in the Cardrona River, with recommended levels of habitat retention (based on the approach of Jowett & Hayes, 2004). The % habtiat retention is expressed relative to the habitat at the naturalised 7dMALF.

Instream value	Fishery or conservation value	Recommended % habitat retention
Brown trout - adult	Locally significant†	70
Brown trout - juvenile	Locally significant†, recruitment to upper Clutha River*	90
Brown trout - spawning (May-August)	Locally significant†, recruitment to upper Clutha River*	90
Longfin eel	Declining‡	80
Koaro	Declining‡	80
Upland bully	Low	60

† Based on the assessment in Otago Fish & Game Council (2015).

* The fishery of the upper Clutha is assessed as being nationally significant (Otago Fish & Game Council 2015).

‡ Based on Goodman *et al.* (2014).

6. Instream habitat modelling

Instream habitat assessments were conducted for a single reach of the Cardrona River by ORC (2001). The study reach covered a 2 km reach downstream from Chinaman Gully, immediately upstream of the Mt. Barker flow recorder site. This reach is representative of much of the main-stem of the Cardrona River upstream of the Mt. Barker flow recorder.

6.1. Instream habitat modelling

Instream habitat modelling can be used to consider the effects of changes in flow on instream values, such as physical habitat, water temperature, water quality and sediment processes. The strength of instream habitat modelling lies in its ability to quantify the loss of habitat caused by changes in the flow regime, which helps to evaluate alternative flow proposals. However, for an assessment to be credible, it is essential to consider all factors that may affect the organism(s) of interest, such as food, shelter and living space, and to select appropriate habitat-suitability curves. Habitat modelling does not take a number of other factors into consideration, including the disturbance and mortality caused by flooding and biological interactions (such as predation), which can have a significant influence on the distribution of aquatic species.

Instream habitat modelling requires detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat methods is that a given species cannot exist without a suitable physical habitat (Jowett & Wilding, 2003). However, if there is physical habitat available for that species, it may or may not be present in a survey reach, depending on other factors not directly related to flow or to flow-related factors that have operated in the past (e.g., floods). In other words, habitat methods can be used to set the outer envelope of suitable living conditions for the target biota (Jowett, 2005).

Instream habitat is expressed as Reach Area Weighted Suitability (RAWS), a measure of the total area of suitable habitat per metre of stream length. It is expressed as square metres per metre (m^2/m). The reach-averaged Combined Suitability Index (CSI) is another metric and is a measure of the average habitat quality provided at a particular flow. CSI is useful when considering the effects of changes in flow regime on periphyton where it is the percentage cover across the riverbed that is of interest, rather than the overall availability of habitat (such as for fish).

6.2. Habitat suitability curves

Habitat suitability curves (HSC) for a range of organisms present in the Cardrona catchment were modelled (Table 6-1) to understand the full range of potential effects of flow regime changes in the Cardrona catchment – from changes in the cover and type of periphyton, to changes in the availability of macroinvertebrate prey, and to changes in the habitat for native fish and trout. It should be noted that the HSC used in these analyses may differ from those presented in the original reports, as the analyses were re-run using the most up to date HSC.

Table 6-1: Habitat suitability curves used in instream habitat modelling in the Cardrona catchment.

Group	HSC name	HSC source
Periphyton	Cyanobacteria	Ex Heath *et al.* (2013)
	Diatoms	Unpublished NIWA data
	Didymo (Waitaki)	Jowett
	Long filamentous	Unpublished NIWA data
	Short filamentous	Unpublished NIWA data
Macro-invertebrates	Food producing	Waters (1976)
	Cased caddis fly (*Pycnocentrodes*)	Jowett *et al.* (1994)
	Mayfly nymphs (*Deleatidium*)	Jowett *et al.* (1994)
	Mayfly nymphs (*Deleatidium*) (Rainy)	Shearer *et al.* (2015)
	Net-spinning caddis fly (*Aoteapsyche*)	Jowett *et al.* (1994)
Fish	Brown trout adult	Hayes & Jowett (1994)
	Brown trout spawning	Shirvell & Dungey (1983)
	Brown trout Juvenile	Jowett & Richardson (2008)
	Juvenile trout T1	Wilding *et al.* (2014)
	Rainbow trout spawning	Jowett *et al.* (1996)

6.2.1. Periphyton

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters and can include a range of different types and forms. Periphyton is an integral part of many stream food webs; it captures energy from the sun and converts it, via photosynthesis, to energy sources available to macroinvertebrates, which feed on it. These, in turn, are fed on by other invertebrates and fish. However, periphyton can form nuisance blooms that can detrimentally affect other instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water-takes (irrigation, stock/drinking water and industrial) and water quality.

The analyses presented in this report consider HSC for five classes of periphyton: cyanobacteria, diatoms, didymo (*Didymosphenia geminata*, an invasive non-native diatom), short filamentous algae and long filamentous algae (Figure 6-1). These periphyton classes were included in these analyses to consider how changes in flow may affect periphyton cover and composition, and the potential impacts on other instream values.

Cyanobacteria were included because some types may produce toxins that pose a health risk to humans and animals. These include toxins that affect the nervous system (neurotoxins), liver (hepatotoxins), and dermatotoxins that can cause severe irritation of the skin.

The presence of potentially toxic cyanobacteria is undesirable as it can affect the suitability of a waterway for drinking, recreation (swimming), dogs, stock drinking water and food-gathering (by affecting palatability or through accumulation of toxins in organs such as the liver). Cyanobacteria-produced neurotoxins have been implicated in the deaths of numerous dogs in New Zealand (Hamill, 2001; Wood *et al.*, 2007).

Native diatoms are generally considered a desirable component of the periphyton community, while didymo is an invasive, non-native diatom that can form dense, extensive mats (Figure 6-1) that can affect recreational and ecosystem values, as well as water use (ORC, 2007; Larned *et al.*, 2007).

Filamentous algae, and in particular long filamentous algae, can form nuisance blooms during periods of stable flows and under nutrient conditions. Such blooms can affect a range of instream values, including aesthetics, biodiversity, recreation (swimming and angling), water-takes (irrigation, stock/drinking water and industrial) and water quality.

Figure 6-1 **Periphyton types considered in these analyses: a) benthic cyanobacteria (*Phormidium*), b) native diatoms, c) underwater photograph showing an extensive growth of didymo in the Hawea River and d) long and short filamentous algae (and cyanobacteria).**

6.2.2. Macroinvertebrates

Macroinvertebrates are an important part of stream food webs, linking primary producers (periphyton and terrestrial leaf litter) to higher trophic levels (fish and birds), and were included in these analyses to consider how changes in flow in the modelled reaches may affect food availability for fish and birds. HSC for "food producing habitat" (conditions representative of the most productive habitats in rivers) and four widespread and common macroinvertebrate taxa were included in this analysis. Two HSC were run for the mayfly *Deleatidium*: one was produced using data from large rivers (Jowett *et al.* 1994), the other from a small river in Nelson (Rainy River; Shearer *et al.* 2015).

Figure 6-2 Macroinvertebrate taxa considered in these analyses: a) a nymph of the common mayfly (Deleatidium), b) a larva of the net-spinning caddis fly (Aoteapsyche) and c) larvae of the sandy-cased caddis fly (Pycnocentrodes).

6.2.3. Native fish

HSC are available for flathead galaxias, koaro and longfin eels. However, the habitat suitability curves available for koaro (Richardson & Jowett, 1995) were not included in these analyses, as they were based on data from steep cascade habitat in the Onekaka River (Golden Bay) and their applicability to the type of habitat present in the Cardrona River is uncertain.

Clutha flathead galaxias (*Galaxias* sp. D) are present in the Cardrona catchment, although numbers in the main stem are low, likely as a result of interactions with trout. It is likely that habitat is not the main factor currently affecting the distribution and abundance of Clutha flathead galaxias in the main stem of the Cardrona, but rather it is the presence of trout that is the main driver determining the presence and/or abundance of Clutha flathead galaxias in the Cardrona River. For this reason, habitat-flow relationships for Clutha flathead galaxias are not presented.

Habitat is also not currently the main factor affecting the distribution and abundance of longfin eels in the Cardrona catchment. Recruitment of longfin eels to the upper Clutha and Kawarau catchments is low due to the presence of Roxburgh and Clyde Dams.

6.2.4. Sports fish

Both brown and rainbow trout are found in the Cardrona catchment. Several HSC for different life stages of brown trout and for adult rainbow trout were included in these analyses to consider how changes in flow in the modelled reaches will affect habitat availability for sports fish.

6.3. Approaches to flow setting

There are a number of approaches to determining the appropriate flows to achieve management objectives. A simple approach is to identify the flow that provides the maximum (or optimum) habitat for a particular species. However, providing such flows is often unrealistic for flow-demanding species, as optimum habitat may occur at a flow well in excess of those commonly experienced. As a result, this approach is usually only applied when optimum habitat occurs at flows below the 7dMALF.

Another common approach is to identify the "tipping point", the flow below which the rate of habitat decline accelerates as flows reduce, often incorrectly referred to as the inflection point. A disadvantage of this approach is that it can be difficult to identify the exact point at which this occurs, and assessments can differ between practitioners.

Probably the most common, transparent and defensible method is to calculate the amount of habitat retained relative to some baseline flow. For fish species, this baseline flow is usually the naturalised 7dMALF.

6.4. Physical characteristics

The hydraulic component of instream habitat modelling made predictions about how water depth, channel width and water velocity will change with changes in flow (Figure 6-3). The most notable pattern is that there is a gradual decline in channel width, water velocity and depth with declining flows down to 0.40 m^3/s below which width and depth begin to drop more rapidly (Figure 6-3).

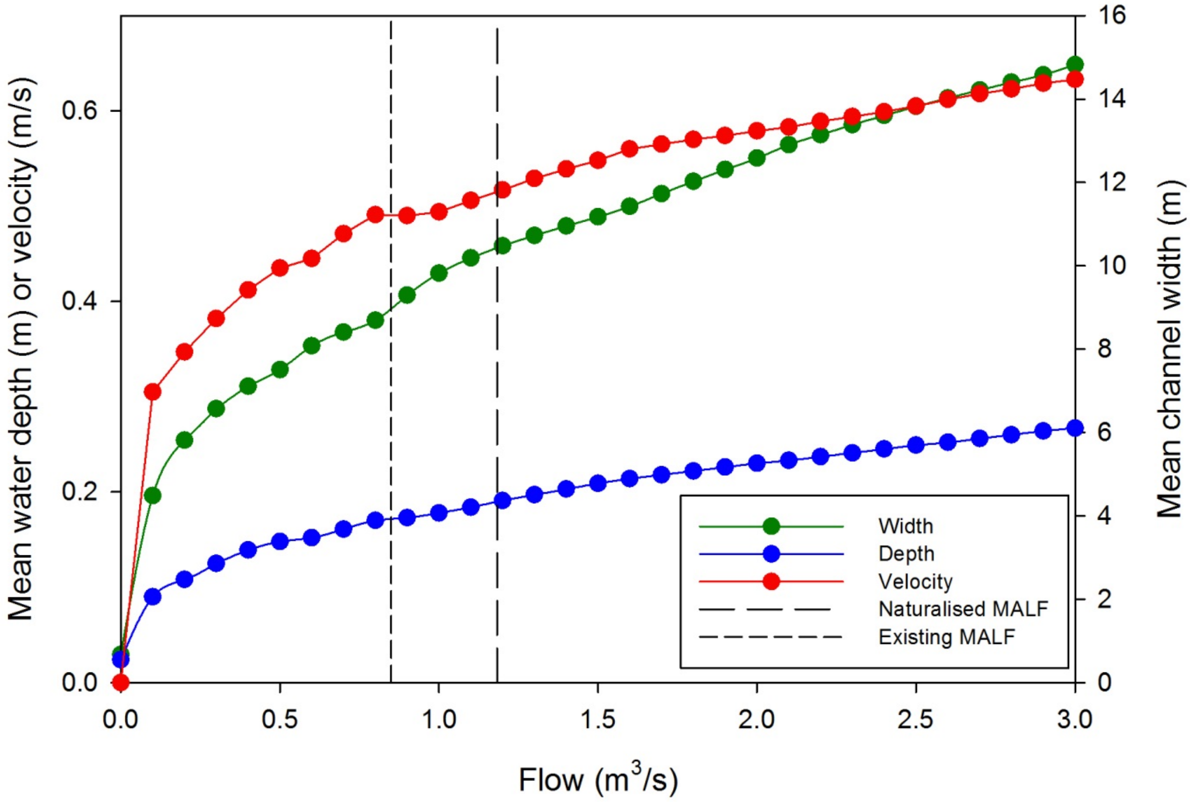

Figure 6-3 **Changes in mean channel width, wetted perimeter, mean water depth and mean water velocity with changes in flow in the Cardrona River.**

6.5. Periphyton

The main purpose of considering periphyton is to understand how changes in flow are likely to affect how much of the river bed is covered by periphyton, and the relative contribution of the different types of periphyton to the overall community. Given this, it is the percentage of the wetted channel covered by periphyton, not the total area of suitable habitat that is of interest. For this reason, the habitat suitability index (reach-averaged CSI) was used instead of weighted usable area (RAWS) in instream habitat analyses for periphyton.

Flow was predicted to have little effect on habitat quality for cyanobacteria (*Phormidium*) with habitat quality predicted to decline below 0.2 m^3/s (Figure 6-4). Flow was predicted to have little effect on habitat quality for didymo at flows between 0.5 m^3/s and 2 m^3/s, although habitat quality for didymo was predicted to decline as flows reduced below 0.5 m^3/s, or rose above 2.0 m^3/s (Figure 6-4). Habitat quality for native diatoms was predicted to increase with flow up to 2.0 m^3/s and remained constant at flows of between 2.0 m^3/s and 3.0 m^3/s (Figure 6-4). Habitat quality for short filamentous algae was predicted to increase with increasing flows to 0.5 m^3/s before declining as flows rose above 0.8 m^3/s, while habitat quality for long filamentous algae was predicted to be highest in the absence of flow and to decline as flows dropped to 0.7 m^3/s, with little change in habitat quality for long filamentous algae at higher flows (Figure 6-4).

This analysis suggests that when flows are less than 0.433 m^3/s in the Cardrona there is a significantly higher risk of proliferation of long filamentous algae, compared with the habitat available at the naturalised7dMALF, and this risk is predicted to rise further as flows drop below this value, with habitat quality for long filamentous algae at 0.26 m^3/s predicted to be approximately twice that at the naturalised 7dMALF (Table 6-2).

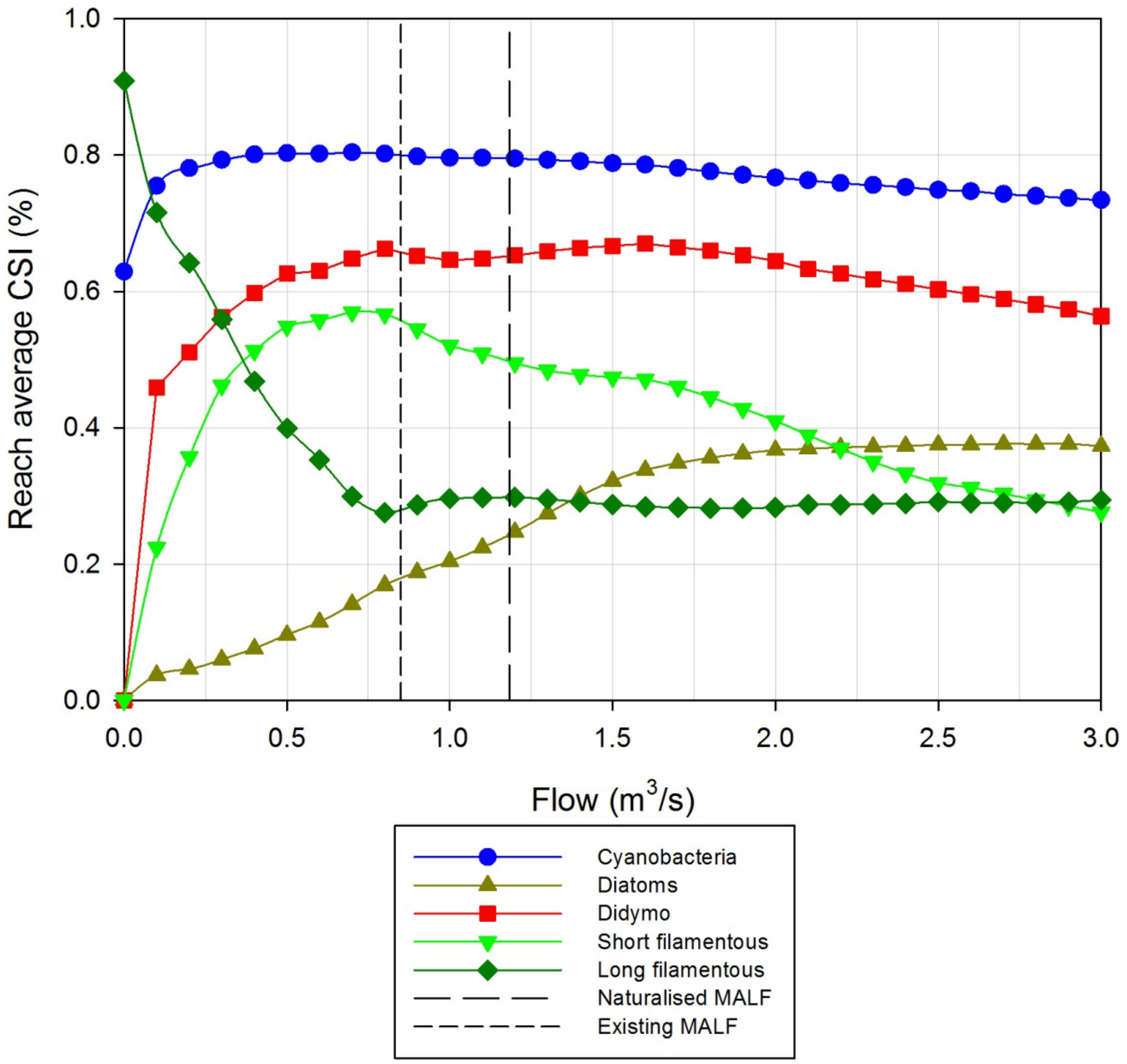

Figure 6-4 **Variation in instream habitat quality (reach-averaged CSI) for periphyton classes relative to flow in the Cardrona River. The long dash line represents the naturalised MALF.**

Table 6-2 Flow requirements for periphyton habitat in the Cardrona River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF.

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly increases (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			150%	200%	300%
Cyanobacteria	-	-	-	-	-
Diatoms	>2	-	-	-	-
Didymo	-	-	-	-	-
Short filamentous	0.70 -0.80	-	-	-	-
Long filamentous	0	0.80	0.433	0.258	0.009

6.6. Macroinvertebrates

Food producing habitat is predicted to increase with increasing flow to 2.1 m^3/s, above which habitat is predicted to decline (Figure 6-5). Habitat for net-spinning caddis fly larvae was predicted to increase with increasing flow across the modelled flow range (Figure 6-5). The habitat for the common mayfly *Deleatidium* is predicted to increase with increasing flow across the modelled flow range by the Jowett *et al.* (1994) HSC, while the small-river HSC of Shearer *et al.* (2015) predicted that habitat for *Deleatidium* would increase rapidly with increasing flows up to 0.7 m^3/s, after which habitat was predicted to rise more slowly with increasing flows up to 1.3 m^3/s and was then relatively consistent up to 3 m^3/s (Figure 6-5). Of these two sets of HSC, those of Jowett *et al.* (1994) are more conservative than those of Shearer *et al.* (2015). Habitat for the cased caddis *Pycnocentrodes* was predicted to rise with increasing flows, reaching a peak at 1.3 m^3/s, above which habitat was predicted to relatively consistent (Figure 6-5).

Flows of 0.7-0.8 m^3/s were predicted to retain 80% of the food producing (0.8 m^3/s) and *Pycnocentrodes* (0.711 m^3/s) habitat available in the lower Cardrona River relative to the habitat at the naturalised 7dMALF (Table 6-3). The flow requirement of the other species considered varied widely, from 0.595 m^3/s for the cased caddis fly *Pycnocentrodes* and 0.951 m^3/s for the net-spinning caddis fly *Aoteapsyche* (Table 6-3).

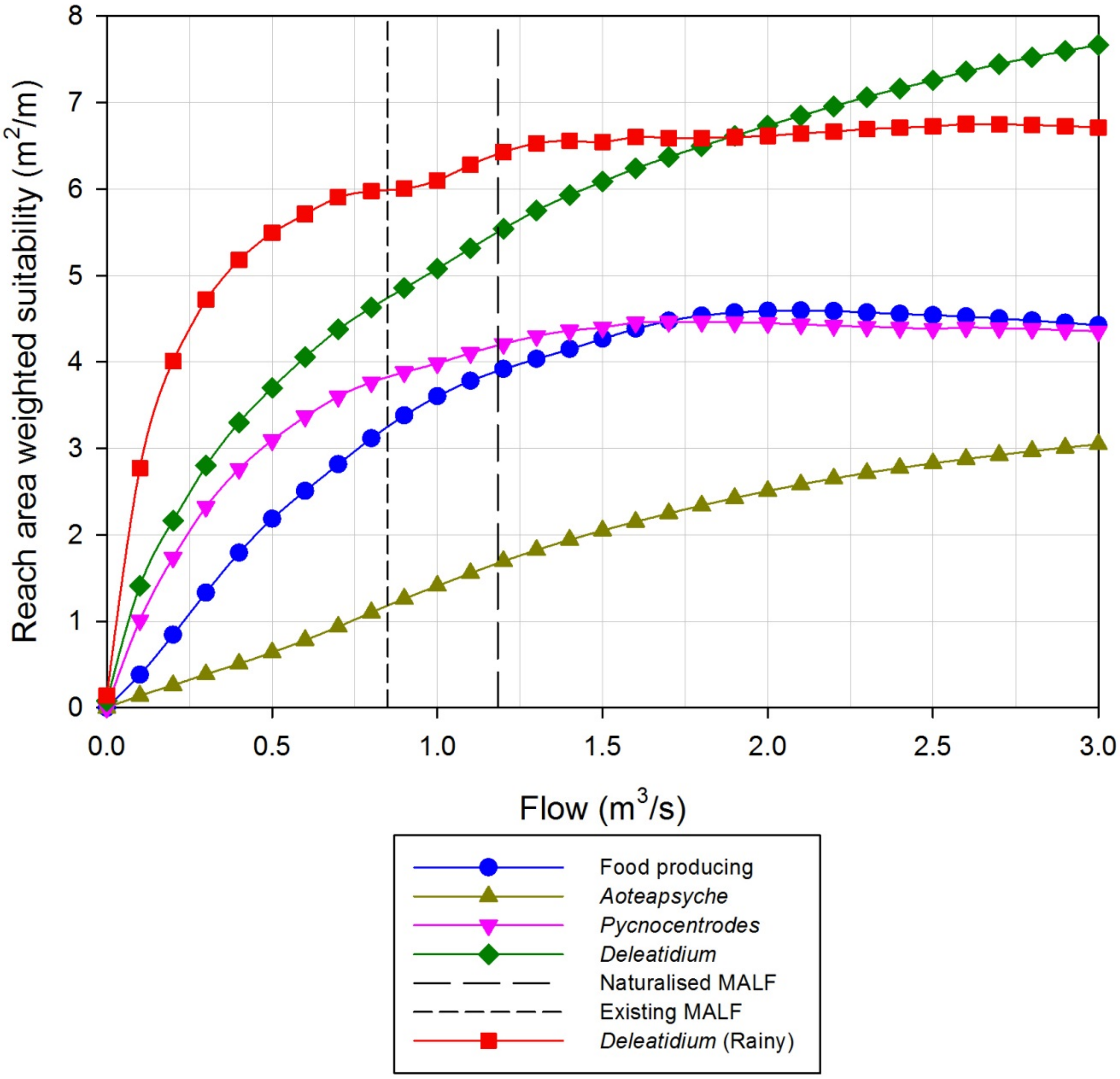

Figure 6-5 **Variation in instream habitat for common macroinvertebrates relative to flow in the survey reach of the Cardrona River. The long dashed line represents the naturalised MALF.**

Table 6-3 Flow requirements for macroinvertebrate habitat in the Cardrona River. Flows required for the various habitat retention values are given relative to the naturalised 7dMALF (i.e., flows predicted in the absence of any abstraction).

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)			
			60%	70%	80%	90%
Food producing	2.1	-	0.547	0.671	0.800	0.956
Mayfly nymphs *(Deleatidium)*	>3.0	-	0.401	0.542	0.711	0.944
Mayfly nymphs *(Deleatidium)* Rainy R	2.6	0.700	0.186	0.266	0.387	0.627
Net-spinning caddis fly *(Aoteapsyche)*	>3.0	-	0.740	0.843	0.951	1.07
Cased caddis fly (*Pycnocentrodes*)	1.750	-	0.344	0.452	0.595	0.806

6.7. Sports fish

Habitat for adult brown trout was predicted to increase with flows to 1 m^3/s, but remain relatively constant between flows of 1-3 m^3/s, while the adult trout (both brown and rainbow trout) curve of Wilding *et al.* (2014) predicted that habitat would increase with increasing flows across the modelled flow range (Figure 6-6). Habitat for juvenile brown and rainbow trout was also predicted to increase with flows across the modelled flow range, although the rate of increase was greatest up to 1 m^3/s (Figure 6-6). In contrast, the juvenile brown trout HSC of Jowett & Richardson (2008) predicted that habitat for juvenile brown trout would peak at a flow of 1.6 m^3/s before declining at higher flows (Figure 6-6). Predicted brown trout spawning habitat increased rapidly with increasing flows to reach an optimum at 0.5 m^3/s before declining as flows rise to 1.3 m^3/s before rising again with rising flows up to 2.9 m^3/s (Figure 6-6).

Flows of between 0.661 m^3/s (Hayes & Jowett 1994) and 0.789 m^3/s (Wilding *et al.* 2014, T1) were predicted to retain 70% of the adult trout habitat compared with habitat available at the naturalised 7dMALF in the lower Cardrona River, and flows of between 0.79m^3/s (Jowett & Richardson 2008) and 1.04 m^3/s (Wilding *et al.* 2014) were predicted to retain 90% of the juvenile trout habitat available compared with habitat available at the naturalised 7dMALF (Table 6-4).

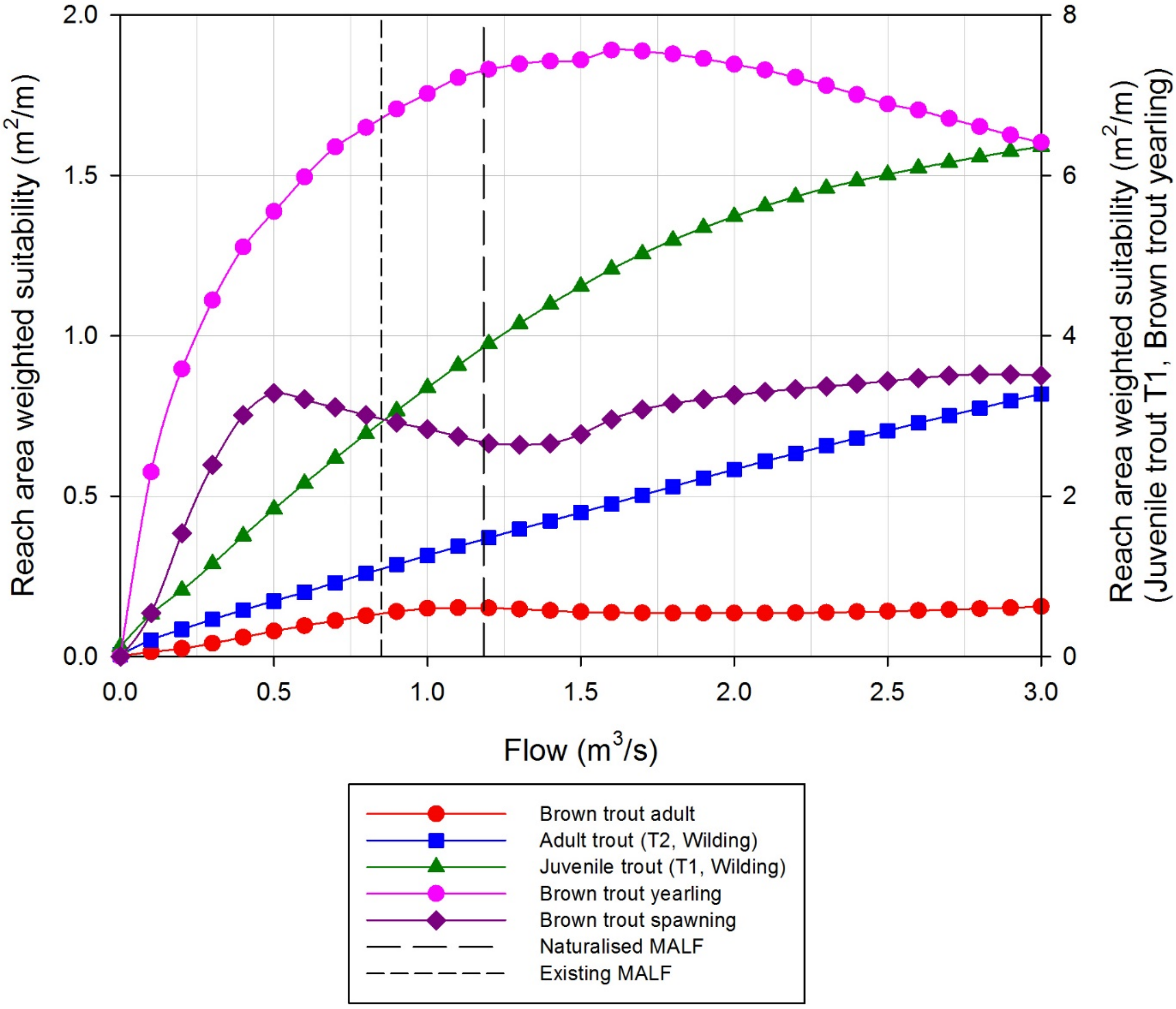

Figure 6-6 **Variation in instream habitat of various life stages of brown trout and rainbow trout relative to flow in the Cardrona River. The long dashed line represents the naturalised MALF.**

Table 6-4 **Flow requirements for trout habitat in the Cardrona River. Flows required for the various habitat retention values are given relative to the habitat available at the naturalised 7dMALF (i.e., flows predicted in the absence of all abstraction). Habitat retention levels for spawning are relative to naturalised mean annual winter (May-September) low flows.**

Species	Optimum flow (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Flow at which % habitat retention occurs (m^3/s)		
			70%	80%	90%
Brown trout adult (Hayes & Jowett)	>3	1	0.661	0.76	0.87
Adult trout (T2, Wilding)	>3	-	0.789	0.919	1.05
Brown trout juvenile	1.6	0.7	0.401	0.568	0.79
Juvenile trout (Wilding T1)	>3	1.7	0.775	0.906	1.04
Brown trout spawning (May-Sep)	0.5	0.4	0.22	0.248	0.277

6.8. Effects of existing flows

Water users in the Cardrona River are not currently subject to a minimum flow and the river is significantly over-allocated, at least in terms of consented maximum instantaneous rate of take, although measured use is significantly less than the consented use. The existing 7dMALF of the Cardrona River retains appropriate levels of habitat within the modelled reach (Table 6-5). However, it should be kept in mind that the existing 7dMALF represents average low flow conditions, not the low flows experienced in exceptionally dry years.

Table 6-5 Habitat retention in the Cardrona River under the existing 7dMALF relative to the naturalised 7dMALF

Group	HSC name	% retention under existing 7dMALF compared with naturalised 7dMALF
Periphyton	Cyanobacteria	101%
	Diatoms	80%
	Didymo (Waitaki)	101%
	Long filamentous	95%
	Short filamentous	109%
Macro-invertebrates	Food producing	83%
	Mayfly nymphs *(Deleatidium)*	86%
	Mayfly nymphs *(Deleatidium)* Rainy	94%
	Net-spinning caddis fly (*Aoteapsyche*)	71%
	Cased caddis fly (*Pycnocentrodes*)	91%
Fish	Brown trout adult	88%
	Adult trout (T2, Wilding)	75%
	Rainbow trout feeding	82%
	Brown trout Juvenile	92%
	Juvenile trout (T1, Wilding)	76%
	Brown trout spawning	111%

6.9. Summary of instream habitat assessments

The Cardrona River dries naturally within the reach from Ballantyne Road and Black Peak Road power lines. Therefore, the following conclusion is for the reach of the river above Mt Barker.

Appropriate objectives for the management of the aquatic ecosystems of the Cardrona River include maintaining the locally-significant trout fishery and to protect its life-supporting capacity including macroinvertebrate populations and limiting the risk of periphyton proliferation. In addition, the Cardrona River contributes to the recruitment of the nationally significant fishery in the upper Clutha River (Otago Fish & Game Council 2015).

A flow of 1 m^3/s in the Cardrona would provide 90% habitat retention (relative to the natural 7dMALF) for adult and juvenile trout, as well as providing excellent amounts of habitat for macroinvertebrates and keeping the risk of periphyton proliferation at a level similar to that at present (Table 6-6). In comparison, a flow of 0.9 m^3/s in the Cardrona would provide 80% habitat retention (relative to the natural 7dMALF) for adult and juvenile trout, whilst also providing excellent amounts of habitat for macroinvertebrates and keeping the risk of periphyton proliferation at a level similar to that at present (Table 6-6).

Flows of 0.9 m^3/s or 1 m^3/s are predicted to maintain existing trout spawning habitat. However, given that demand for water is expected to be low in winter, it is likely that any minimum flow would have minimal effect on winter flows (Table 6-6).

Table 6-6 Flow requirements to maintain the values of the Cardrona River based on the instream habitat model of Jowett & Wilding (2003)

Instream value	Season	Fishery or conservation value	Recomm. % habitat retention	Flow to maintain suggested habitat retention (m^3/s)	Flow below which habitat rapidly declines (m^3/s)	Optimum flow (m^3/s)
Adult trout - adult	All year	Locally significant†	70%	0.789	-	>3
Juvenile trout	All year	Locally significant†	90%	1.04	1.7	>3
Brown trout - spawning (May-Sep)	Winter	Locally significant†	90%	0.277	0.4	-
Food producing	All year	Life supporting capacity	70%	0.671	-	2.1
Long filamentous algae	Summer	Nuisance	<150%	>0.433	0.8	-

† Based on the assessment in Otago Fish & Game Council (2015).

7. Conclusions: Flow requirements for aquatic ecosystems in the Cardrona catchment

Under the Water Plan, rivers will have minimum flows set to provide for the maintenance of aquatic ecosystems and natural character under low-flow conditions. Similarly, residual flows can be imposed on resource consents for water-takes from tributary streams for the same reasons. The purpose of this report is to update the previous Cardrona report and provide information on the Cardrona catchment that assists in setting minimum flows including the existing use of water resources, the values present in the catchment, and the flows required to maintain instream habitat, based on instream habitat modelling.

There are three distinct hydrological reaches in the Cardrona River; the upper reach from the headwaters to Mt. Barker is a neutral reach, a losing reach from Mt. Barker to State Highway 6 and a gaining reach from this point downstream to the confluence with the Clutha River.

Twenty-five existing surface water-takes are present in the Cardrona catchment, with a total allocation of approximately 2.0 m^3/s although the measured usage is considerably lower than this, especially at low flows. There is a reasonably high level of water allocation, and a long history of water use and flow alteration.

Naturalised low-flow statistics were estimated by building a relationship between the Mt. Barker flow site and the Lindis Peak flow site. Analysis was conducted comparing the relationship between to the two sites at low flows from the same event low flow event. Results indicate a strong correlation between the two sites, (R^2=0.9097).

Table 7-1 provides the findings of this analysis which indicates that the measured 7dMALF at Mt. Barker was 0.84 m^3/s whereas the naturalised 7dMALF was 1.18 m^3/s.

Table 7-1 The basic flow statistics summarised for both naturalised and measured flows at Mt. Barker

Mt. Barker	Minimum flow (m^3/s)	Median flow (m^3/s)	Mean (m^3/s)	7dMALF (m^3/s)
Naturalised flows	0.753	2.62	3.32	1.18
Observed flows	0.310	2.34	3.1	0.84

In a typical year, flows are at their lowest from January through to the end of April (Figure 3-5), with February marginally the month where flows are at the lowest. The flow duration curves (Figure 3-4) indicate that on average, 91% and 87% of time the observed and naturalised daily average flows are above their respective 7dMALFs at Mt. Barker. When flow parameters are 1.5 m^3/s and 1.7 m^3/s respectively then naturalised flows were shown to be exceeded for 74 % and 67% of the time meaning a dry reach is likely to be present.

The low flow frequency time series analysis (Table 3-6) show there is a 1 in 2, or 50%, chance of naturalised flow of 1.1 m^3/s occurring in a given year; 1/5 (20%) chance of flows 0.92 m^3/s occurring in a given year, and 1/10 (10%) chance of flows of 0.85 m^3/s occurring in a given year.

The findings of this study established a relationship between the loss of surface flows to groundwater between Mt. Barker and Ballantyne Road. When flows were at or below 7dMALF of 1.18 m³/s at Mt Barker, the loss to ground water between Mt Barker and Ballantyne Road ranged from approximately 0.52 m³/s to 0.77 m³/s (Figure 3-8). There was no consistent relationship between the losses to groundwater with the increase in surface flows above 1.18 m³/s. The rate of loss to groundwater is highly dependent on groundwater level and other ground water related factors which cannot be addressed by this study.

The river consistently dries at Black Peak Road Power Lines and recedes from this point upstream generally to Ballantyne Road. The extent and the frequency of the drying reach are determined by high or low surface flows and losses to ground. The surface loss within this reach ranged between 0.01 m³/s and 1.2 m³/s. Water temperature data collected during the 2016–17 period from Black Peak Road Power Lines site indicated that surface flows ceased for 43–69 days. Temperature data shows that flow connectivity was likely when flows were at or above 1.5 m³/s (

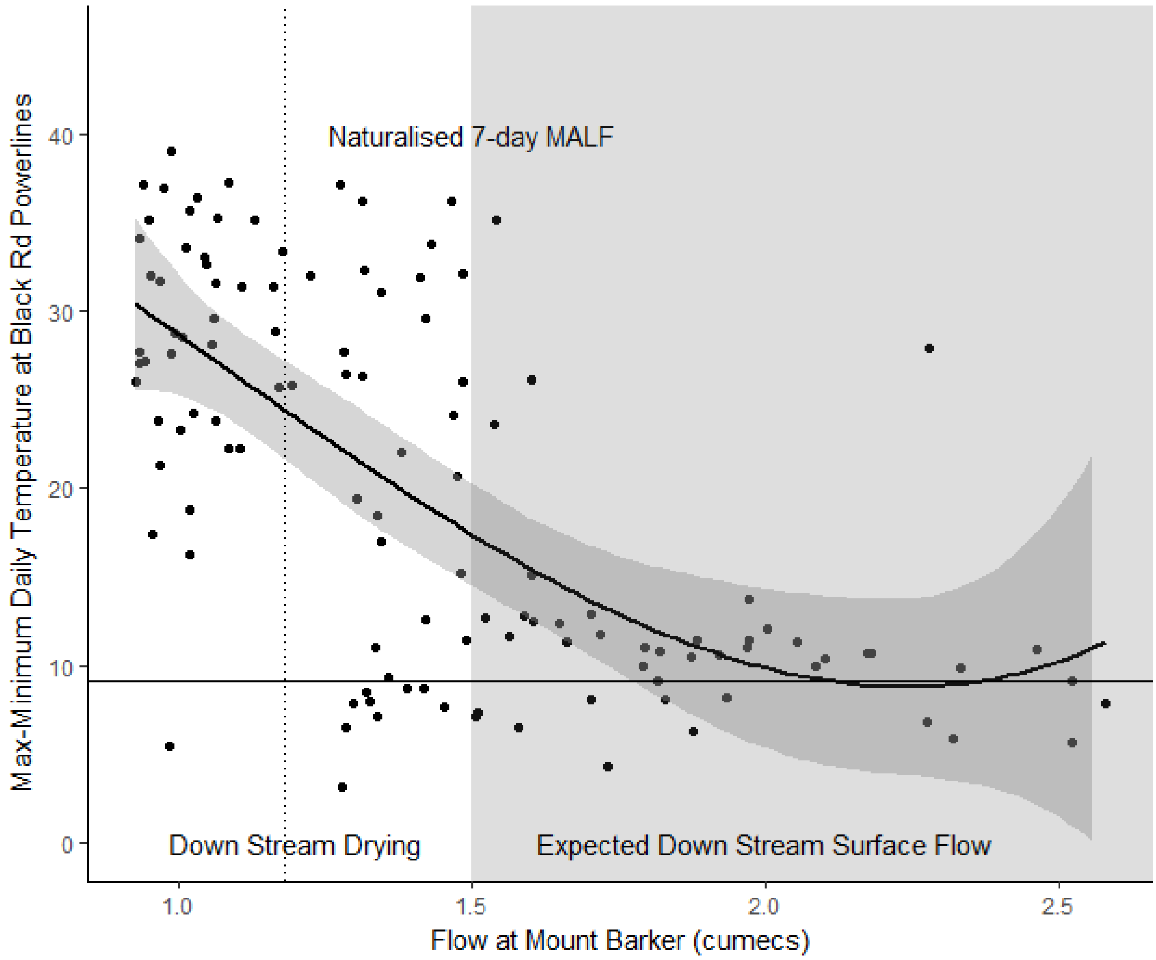

Figure 3-11). However, the measured distance of the drying reach suggested that flow disconnection can occur even when flows were as high as1.78 m³/s. The flow where disconnection occurs is influenced by groundwater levels and therefore is variable. However, based on this study, the best estimate of when flow disconnection likely to occur is 1.5 m³/s, which is much higher than the naturalised 7dMALF of 1.18 m³/s.

Flow connectivity is considered to be a key component of the natural character in a water way. Therefore, it is critical to understand whether the waterway dries naturally or due to water abstraction. The data gathered during the summer of 2016-17, indicates that the Cardrona River would go dry naturally between Ballantyne Road and State Highway 6. Flow continuity will cease at times during the October to April period within the naturalised flow range of 1.18 m^3/s (7dMALF) to 1.5 m^3/s. In a typical summer, the river will be dry for 35.5 days (max. 13.6 consecutive days) and when flows are below 1.18 m^3/s and 64.9 days (31.8 maximum consecutive days) when flows are below 1.5 m^3/s (Table 3-9). These drying periods are likely to be even longer under the current flow regime.

There are five native fish species recorded in the Cardrona catchment. Clutha flathead galaxias is classified as "nationally critical", the highest threat classification available (Goodman *et al.*, 2014). The galaxiid still persists in isolated pockets within the main-stem and occasionally in a small number of tributaries but, overall, it has disappeared from much of its historic range within the Cardrona catchment. Koaro and longfin eels are also present in the catchment and are listed as "At Risk and Declining" in the most recent threat classification (Goodman *et al.*, 2014). Longfin eels have not appeared in a survey since 1992, whereas koaro numbers have increased since the formation of Lake Dunstan. There two species from the bully, common and upland neither of these two species are threatened.

In addition, koura and freshwater mussels have been recorded in several tributaries (NZFFD) but there is doubt whether they actually are present; they have a threat classification of "at risk, declining" (Granger *et al.*, 2014).

The Cardrona River supports a locally important brown and rainbow trout fishery, with the majority of the angling effort occurring in the early part of the season (Unwin, 2016). Adult rainbow and brown trout spawn throughout the Cardrona catchment with the majority of spawning activity occurring above Mt. Barker.

Table 6.6 provides flow requirements to maintain instream values that are located above Mt Barker, based on the instream habitat model of Jowett et al. (2004). Modelling recommends that a flow of 1 m^3/s would provide 90% habitat retention (relative to the natural 7dMALF) for adult and juvenile trout, as well as providing excellent amounts of habitat for macroinvertebrates and keeping the risk of periphyton proliferation at a level similar to that of current conditions. Flows of 0.9 m^3/s or 1 m^3/s are predicted to maintain existing trout spawning habitat.

This report shows the Cardrona dries naturally. A loss of connectivity has implications for fish passage, particularly during the out-migration season of juvenile salmonids (November-December). As the river likely dries naturally from December-January onwards; the setting of two minimum flow thresholds could be considered. A higher minimum flow threshold for the period leading into January which recognises the need to maintain fish passage through the critical drying reaches for as long as possible and second minimum flow beginning in January that recognises that in a typical year, the reach of river below Ballantyne Road will dry naturally.

8. Glossary

Catchment

The area of land drained by a river or body of water.

Existing flows

The flows observed in a river under current water usage and with current water storage and transport.

Habitat suitability curves (HSC)

Representations of the suitability of different water depths, velocities and substrate types for a particular species or life stage of a species. Values vary from 0 (not suitable) to ideal (1). HSC are used in instream habitat modelling to predict the amount of suitable habitat for a species/life stage.

Instream habitat modelling

An instream habitat model is used to assess the relationship between flow and available physical habitat for fish and invertebrates.

Irrigation

The artificial application of water to the soil, usually to assist with the growing of crops and pasture.

Mean flow

The average flow of a watercourse (i.e., the total volume of water measured divided by the number of sampling intervals).

Minimum flow

The flow below which the holder of any resource consent to take water must cease taking water from that river.

Natural flows

The flows that occur in a river in the absence of any water-takes or any other flow modification.

Naturalised flows

Synthetic flows created to simulate the natural flows of a river by removing the effect of water-takes or other flow modifications.

Reach

A specific section of a stream or river.

River

A continually or intermittently flowing body of fresh water that includes a stream and modified watercourse, but does not include any artificial watercourse (such as an irrigation canal, water-supply race, farm drainage canal or canal for the supply of water for electricity power generation).

Seven-day low flow

The lowest seven-day low flow in any year is determined by calculating the average flow over seven consecutive days for every seven-consecutive-day period in the year, and then choosing the lowest of these averages.

Seven-day Mean Annual Low Flow (7-d MALF)

The average of the lowest seven-day low flow for each year of record. Most MALF values reported here are calculated using flows from the irrigation season (October–April) only. This is to avoid the effect of winter low flows that may occur due to water being "locked up" in snow and ice in the upper catchment. However, if significant winter low flows do not occur, estimates of 7-d MALF calculated using data from the full hydrological year or from the irrigation season should be very similar.

Taking

The process of abstracting water for any purpose and for any period of time.

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