

The Need for Adaptability in River Control Design to cope with Climate Change and other Flood Hazard Uncertainties

1. ABSTRACT

Monitoring the performance of a floodway or river is seen as an essential way of reassessing flood capacity. The initial design of most flood control schemes has relied upon limited information and included many uncertainties. These uncertainties include flood hydrology, channel hydraulics, aggradation, joint probability of high outlet levels and other parameters. Furthermore the New Zealand climate is changing, which presents a new uncertainty in defining the standard of flood control works into the future.

The paper reviews how the various uncertainties have affected assessing flood hazard standard for four case study rivers in Marlborough. Marlborough has a long history of flooding and river control works. The Marlborough District Council has an ongoing programme of review and upgrading of the river control works despite nearly 150 years of previous effort.

Adaptable design is identified as a sound way of dealing with climate change and the other uncertainties, with upgrading as and when monitoring and review of flood events shows it to be required. Adaptable design suggests that river control schemes should be designed so that they can be readily upgraded when further information comes to hand on the various uncertainties, including the uncertainty of climate change.

2 KEY WORDS

Adaptable design
Monitoring

Flood hazard standard
Uncertainty
Floodway capacity
Climate change

3. INTRODUCTION

3.1 BACKGROUND

Many areas of New Zealand (including Marlborough) have considerable flood hazard. Various river control schemes have been constructed to combat this flood hazard, starting from the time of European settlement in the middle of the 19th century.

A difficulty in constructing river control schemes is that there are no design codes for construction, nor specified factors of safety or margins of error. Furthermore the main "criteria" for river control design are specific for each river due to each river's unique characteristics. In this context "criteria" are the setting of the floodway width and the level to which stopbanks should be built; or the sizing of diversion channels; or the storage volume of detention dams etc. Flood hydrology and the channel hydraulics are the main factors controlling these criteria. In turn there are various parameters making up the hydrology and hydraulics.

The flood hydrology depends on parameters of the catchment size, rainfall intensity, and expected mathematical expression of storm frequency, antecedent conditions, soil and surface characteristics, slope, vegetation, snowmelt, seasonal factors, and human influences.

The channel hydraulics depends on the channel bed material, riparian and channel vegetation, channel irregularities and bends, bridges and other structures in the channel, debris in the channel and channel width.

The hydraulics may also be influenced by the flood level of the downstream receiving river (or sea) and the statistical probability that this level occurs at the same time as the river in question is in flood.

The channel hydraulics often changes substantially with time due to sediment deposition of the river bed or uncontrolled vegetation growth. Flood hydrology can also change in the future due to changes of the catchment, for example through urban development.

The probability and extent of a changing climate is another new factor clouding our understanding of flood hydrology.

Each of these parameters has a large degree of associated uncertainty in their assessment. The parameters are specific to each river. Numerous years of observation, study and analysis are required to reduce the uncertainty with regard to each parameter and in turn clarify the criteria for flood control design for any specific river.

It is virtually impossible for river control designers to have detailed information of the relevant parameters at initial construction stage. While initial design will be based on the best information available, a key aspect is that the river control scheme should be regularly monitoring for performance during flood events. A diligent ongoing monitoring programme may often overcome the lack of information at initial design.

This monitoring includes measuring flood size, reviewing flood frequency predictions, surveying bed level changes for aggradation, aerial photography of vegetation changes, and developing suitable computational hydraulic models calibrated on pegged flood levels from actual flood events. This monitoring is an ongoing challenge for river engineers working towards managing flood hazard.

The monitoring may then result in recommendations to upgrade the river control scheme so as to meet the design intentions. A vital corollary is that the original river control scheme design must be able to be readily upgraded as and when the monitoring demonstrates the need.

Economics also needs to be considered. A river may naturally cope with quite large floods, and the river control works may only needed to be increase the capacity of the channel by a small proportion of the total flood size. The size of the required river control works is the difference between the natural hazard free channel capacity and the calculated design flood criteria. Costs of a flood control scheme will be very sensitive to assessment of design criteria. If a conservative approach is taken regarding design uncertainties, this can result in an unacceptable increase in scheme costs. This is the opposite to many other engineering projects where the increase in capital costs of conservative design is usually relatively small.

Thus on economic grounds it is also desirable for a river control scheme not to be overly conservative in initial design provided that the scheme can be easily upgraded as and when monitoring shows the need.

A classic text on New Zealand river control (Acheson 1968) discusses many river control schemes but has limited comment regarding an overall design philosophy. A recent guideline (Ministry for the Environment 2010) focuses on making recommendations regarding climate change in the design of flood control schemes. This guideline however does not however discuss how to deal with the uncertainty of the other important parameters, nor how treating the other uncertainties should be interfaced with climate change.

3.2 CLIMATE CHANGE

Global warming is occurring and there is evidence over the last decade that the New Zealand climate is changing and with more change expected in the future (Ministry of the Environment 2008). Such changes will affect flood hazard and the adequacy of flood protection works. This changing climate will also modify the use of historical hydrological records to predict future flood events. In general it has

been suggested that storm rainfall and flood sizes will increase in proportion to the increased moisture that warmer air will hold. At this stage there is uncertainty as to how much future increases in temperature will be. Scientists have suggested a range of possible temperatures, but estimates will become more accurate as time progresses.

There is even more uncertainty with regard to how climate change will affect storm track. In some areas of New Zealand it is probable that changes in storm track will increase flood size and frequency, greater than simple temperature increase would indicate. In other areas of New Zealand storm track changes may reduce flood size and frequency. At this stage it is an unknown.

More information will come to hand as monitoring is carried out into the future. In this regard the climate change parameter is the same as other flood hazard parameters.

3.3 SCOPING OF FLOOD HAZARD UNCERTAINTIES

As discussed in 3.1 the design of a river control scheme requires examination of many hydrological and hydraulic parameters on an individual catchment basis. The degree of uncertainty of these various parameters may be greater than what is generally appreciated in comparison to climate change uncertainty.

Greater rainfall intensities due to climate change have been projected to increase by eight to 16 per cent over the next century due to climate change (Ministry for the Environment 2010). This results in an increase of 17 per cent in flood flows for the case study examples of the Leith, Hutt and Buller (middle of the road estimates).

In the author's experience, particularly with Marlborough rivers, the uncertainty involved with the other flood hazard parameters for river control schemes is usually greater, often in the order of 50 per cent and can be more. This will be discussed in detail later in this paper.

Case studies presented in this paper indicate that the climate change parameter is not of a greater scale than other river control design uncertainties, at least on our current monitoring and knowledge.

3.4 HYPOTHESIS

- That regular and detailed monitoring of the hydrological and hydraulic parameters is required to confirm that a river control scheme performance in flood events meets initial design intentions, and if not, to determine the need for upgrading works
- A key design philosophy for river control schemes is that their initial design should allow for upgrading to be readily carried out as and when new information indicates the need
- The parameter "climate change" could, and should, be incorporated as one of the hydrological parameters being monitored.

3.5 DISCUSSION

Marlborough has a long history of flooding. Blenheim is situated on the Wairau floodplain at the junction of several tributary rivers. Flood protection works have been carried out by various river boards from the 1860s onwards; however the early river works were so ineffective and flooding was so regular that the town was called the Beaver or Beavertown.

This ongoing flood hazard and the dynamics of the rivers prompts the Marlborough District Council to continue a programme of monitoring, review and further upgrading of the river control works despite nearly 150 years of previous effort.

The monitored uncertainties include: the ability to measure flood size and assign flood frequency distribution, the hydraulic performance of the river channel, the changes of performance due to riverbed aggradation and tree growth, the probable channel maintenance, the hydraulic model used for calculation, the adequacy of the survey information used in the computer model, changes to run-off characteristics of the catchment, and the joint probability of the main river flood flow coinciding with a tributary or high tide.

Each presented river control case study looks at the uncertainty with regard to background, flood hydrology, evidence of climate change, hydraulic assessments, upgrading works and conclusions.

The information herein is presented in a qualitative and at times simplified manner. All information presented is based on monitored data and many internal council reports, memoranda, consultant reports and data base information. Any one of a dozen different aspects could be presented in much more detail but that would detract from the thrust of the paper, let alone considerably increase its size. It is not considered worthwhile to reference the

many supporting documents, which are not at any rate easily available outside of Marlborough District Council. The previously mentioned hypothesis will be tested by examination on the various flood hazard uncertainties for four Marlborough river control case studies in the following section. The location of the case study rivers is shown in Figure 1.

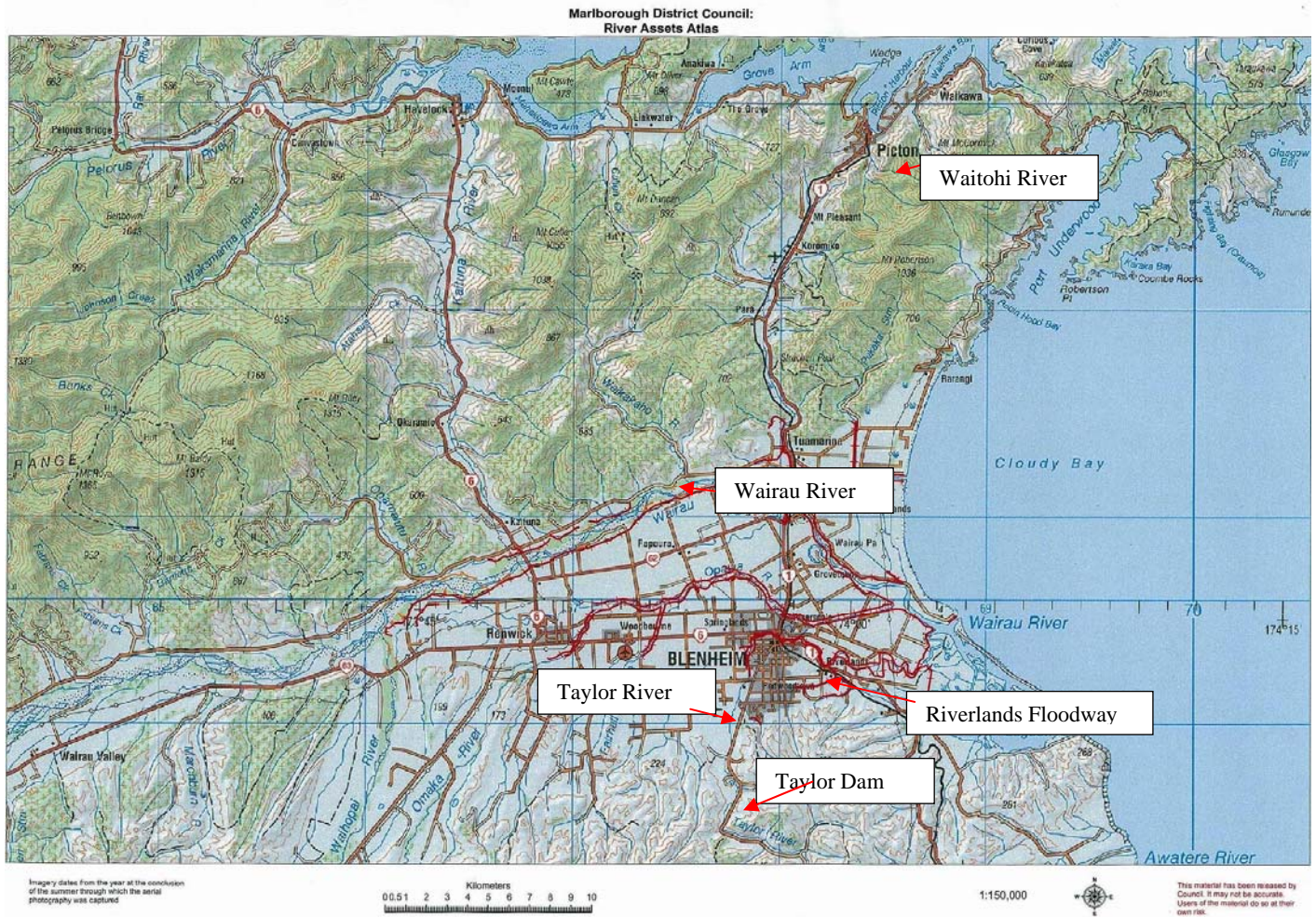


FIGURE 1: Location of Case Study Rivers

4 MARLBOROUGH CASE STUDIES

4.1 CASE STUDY: WAIRAU RIVER

4.1.1 Background

The braided Wairau River has flood flows amongst the largest and powerful in New Zealand; which poses a major flood threat to its fertile 20,000 hectare floodplain. Flood control works commenced in the 1860s at the start of Pakeha settlement.

After 60 years of fragmented river control the Wairau River Board was formed in 1921 to tackle control of the Wairau River in a comprehensive manner. The directions given to the incoming engineer included "The enlarging of the Wairau channel to a uniform discharging capacity that should be capable of carrying the largest flood hitherto observed with a reasonable margin of safety". (Wairau River Commission 1917).

Another three generations later the Marlborough District Council has tried to be more specific in its policies. The current Wairau/Awatere 1998 Resource Management Plan has the policy "To achieve a standard of protection for a flood size up to a one in 100 year return period event for the main rivers of the Wairau floodplain."

4.1.2 Flood hydrology

There have always been difficulties on measuring the size of large floods and the size of floods have also been reviewed at later dates. Thus for example in the large floods in 1923 and 1926 were initially estimated as 4,700, and 6,000 cubic metres per second (m^3/sec) at Tuamarina bridge based on a 1924 rating curve by Vickerman and Lancaster.

The flood rating curve was re-evaluated in 1927. The 1923 flood was downgraded to 3,200, and the 1926 flood as 4,200 m^3/sec ; these being a reduction of 30 per cent on the earlier estimates. The basis for either of these rating curves is unknown. It resulted in a change to the scope of planned river control works. The recent and more accurate rating curves for Wairau at Tuamarina

are intermediate between these two earlier rating curves.

The 1960 scheme design was for a flood size of 5,200 m^3/sec . This was based on estimates of flood flows over the previous 24 years, but with very little confirmatory gauging information. A water level recorder was established for the Wairau at the Tuamarina bridge in 1960. In 1993 the record from this site was an important information source for a very thorough review of Wairau flood hydrology (Williman 1995). This review also included information from all actual flood gauging, analysis of pegged channel flood levels, breakout flows, and bed level changes. The analysis also included the less reliable flood estimates going back to the 1920s.

The review paid particular attention to the July 1983 Wairau flood, which is the largest known flood since at least 1868. It caused stopbank overtopping, failure and flood breakout at four major locations and a dozen minor locations. The river and flood breakout at Tuamarina bridge is shown in Figure 2.

Assessment of 1983 flood size had proved difficult. This was because of uncertainty of the rating curve at high stages, and the difficulty of measuring flood breakouts. The immediate Catchment Board flood estimate in 1983 was a size of 7,765 m^3/sec . This was reviewed down the following year to 7,000 m^3/sec .

The detailed review in 1993 (Williman 1995) reassessed the flood size down to 5,800 m^3/sec ; this having an expected return period of 150 years. The review of all flood data concluded a 100 year average recurrence interval (ARI) flood to be 5,500 m^3/sec and this size was adopted for a scheme upgrade.

In 2010 preliminary analysis of the further 17 years of data from the Tuamarina recorder site indicates that the 100 year ARI flood size may have reduced by nine per cent to 5,100 m^3/sec . However the nominal scheme design has not been adjusted and remains at 5,500 m^3/sec .



FIGURE 2: Wairau at Tuamarina, July 1983 flood

4.1.3 Evidence of climate change

New Zealand average temperatures are changing, with the last decade of the 2000s the warmest on record. Warmer air can hold more water, so there can be heavier rainfall. The Ministry for the Environment (Ministry for the Environment 2008) recommends that allowance should be made for heavier rainfall on a New Zealand-wide basis.

The frequency of heavy rain depends also on storm track. Storm track may further increase the chance of heavy rain in some areas of New

Zealand, but decrease the chances in other areas. The Ministry for the Environment acknowledges this, but advises on applying to New Zealand as a whole as they do not have the evidence to support regional differences at this stage.

The last 10 years may provide some insight in to the impacts of a changing climate on Wairau River flood flows. Table 1 lists peak Wairau flood sizes; note that prior to 1960 the information is limited to estimated major floods.

Decade	Annual Average flood (2.33yr ARI) for decade	Maximum Flood for Decade
1920s	unknown	4,500 m ³ /sec
1930s	unknown	4,000 m ³ /sec
1940s	unknown	3,300 m ³ /sec
1950s	unknown	4,200 m ³ /sec
1960s	2,000 m ³ /sec	3,620 m ³ /sec
1970s	2,100 m ³ /sec	4,000 m ³ /sec
1980s	2,060 m ³ /sec	5,800 m ³ /sec
1990s	1940 m ³ /sec	3,760 m ³ /sec
2000s	1600 m ³ /sec	2,200 m ³ /sec

TABLE 1: Wairau River at Tuamarina flood size estimates

There is also historical information that there have been large damaging floods every decade from 1860 to 1920. Those floods were not measurable but are likely to have exceeded 3300 m³/sec.

The last decade stands out as a decade of lesser flood flows and not having a significant flood.

Thus, if anything, the records indicate that Wairau flood flows would be smaller under a changing climate compared to earlier historical weather patterns. This may be due to change in frequency of storm track with a greater proportion of climate change induced south-westerlies from which Marlborough is well protected. It is of course premature to make conclusions based on only 10 years data, and the nominal scheme design has not been revised downwards.

4.1.4 Hydraulic assessments

The 1960 Wairau river control scheme used manual calculations of floodway capacity to set floodway width and stopbank height for the 5,200m³/sec design flood. At the time of the July 1983 flood, the Marlborough Catchment Board staff had considered the capacity of the floodway to be of this size.

The detailed review of 1993 was based on resurveys of the river channel and used computer based hydraulic calculations calibrated against measured floods and pegged flood levels. This review recommended that the safe capacity of the floodway was only 4,200 m³/sec.

In 1983 the Wairau River channel was some 1,600 m³/sec short of safely carrying the 5,800 m³/sec flood – some 35 per cent too small. Broadly speaking, 10 per cent was due to under estimates of flood size, 10 per cent was due to over estimates of floodway hydraulic performance, and 15 per cent was

due to 20 years of channel aggradation reducing floodway capacity since 1960. There were also other factors causing flood breakout more readily than expected. The State Highway 1 road bridge at Tuamarina was a constriction to the flow – the deck was too low and caused a rising of flood levels a further 0.6 metres (m) for the river reach upstream of the bridge.

The hydraulics of the river also performed differently from what might have been expected because river training banks in some places completely eroded away resulting in a different flow pattern in this wide floodway.

4.1.5 Upgrading work

The 1993 review resulted in a programme of scheme upgrading works being approved. The main works consisted of stopbank raising, strategic gravel extraction, widening the active channel within the floodway, and training bank protection works.

This work could be readily carried primarily because the floodway was of generous width and was mostly reserve land vested in the Council.

4.1.6 Wairau case study conclusions

Historically (i.e. up till the mid 1990s) there has been considerable uncertainty in assessing the flood hazard standard of the Wairau floodway; and its standard was overestimated by the order of 35 per cent. This was due to uncertainty in measurement of flood flows, hydraulic analysis, and aggradation of the riverbed.

Upgrading of stopbanks was carried out in the late 1990s following a major review of design standard in 1993. This review used much better information and more rigorous analysis, and to an intended design standard of providing for a one in 100 year return period event.

Probable climate change is a new uncertainty. Current suggestions are that it could reduce flood flows; or conversely it increase them; and if an increase, by the order of 10 per cent in the next two generations. This is less than the other uncertainties. Indeed the most difficult uncertainty is considered to be possible continuing aggradation of the Wairau River.

A freeboard of 0.8 m on stopbank height has been allowed for the uncertainties. This equates to about 25 per cent of flood capacity and this amply covers current estimates of uncertainties including climate change.

Regular monitoring and review of the floodway system, especially after large floods, is seen as the most appropriate way of addressing flood standard uncertainties, including climate change.

4.2 CASE STUDY; TAYLOR RIVER 1960

4.2.1 Background

The Taylor River is a tributary (via the Lower Opawa) of the Wairau; and flowing through the heart of Blenheim it poses a direct flood threat to the town; although it is a much smaller river than the Wairau. Council has a formal policy that flood control works will to be a standard of a 100 year return period flood.

A flood detention dam was constructed in 1965 as a main flood control mechanism, though there is also stopbanked floodway through Blenheim and the lower Opawa River downstream. The design intention of the detention dam is to reduce the dam outflow to a flow less than the capacity of the river floodway downstream through Blenheim. The detention dam design is therefore very sensitive to assessments of flood hydrology and downstream channel capacity.

The main detention dam design parameters are its storage volume, and its outlet culvert size. There was very little available data on flood hydrology and channel hydraulics at initial dam design in 1960. The flow recorder was only established at the same time as the initial dam design. There was considerable uncertainty as to the dam's performance standard. Reviews have therefore been regularly carried out, leading to upgrading work.

4.2.2 Flood hydrology

The original Taylor dam detention dam design in 1960 was for a 100 year ARI flood of 505 m³/sec. A water level recorder was established for the Taylor at the Borough Weir just upstream of the dam site in 1960. Reviews of this monitored flood flow information were carried out in 1980, 1993, and 2002.

The detailed reassessment of 310 m³/sec for a 100 year ARI flood by the National Institute of Water & Atmospheric Research in 2002 is considered reliable and authoritative. Preliminary analysis of the further eight years of data to 2010 from the recorder site indicates that the 100 year ARI flood size may have reduced 15 per cent to 260 m³/sec. However the accepted dam design flow remains 310 m³/sec. There are also some significant tributaries downstream of the dam which may provide approx 40 per cent of the design flow of the downstream Taylor floodway through Blenheim.

Information on flood sizes of the Taylor through Blenheim is less good, with a poor recorder site. The tributaries do not have flow recorder sites; the size of these tributary flood flows has to be assessed by less accurate methods. There is also the issue of the timing of the flood flows in the tributaries with that of the main Taylor. In short there is still some uncertainty with regard to flood size estimation – but that uncertainty is likely to err on the safe size as

the contribution from the tributaries has been assumed to be coincident with the main Taylor.

4.2.3 Evidence of climate change

The Taylor flood record taken at the Borough weir just upstream of the dam for the last

decade may be indicative of future flood conditions under climate change, as indicated by Table 2. It can be seen that flood flows for this last decade are much smaller than for the previous four decades. Again this record is not in accord with the proposal that flood flows will increase with climate change.

Decade	Average Annual Flood (2.33 yr ARI) for decade	Maximum Flood for Decade
1960s	81 m ³ /sec	175 m ³ /sec
1970s	67 m ³ /sec	170 m ³ /sec
1980s	51 m ³ /sec	195 m ³ /sec
1990s	52 m ³ /sec	175 m ³ /sec
2000s	18 m ³ /sec	120 m ³ /sec

TABLE 2: Taylor River at Borough weir recorder – flood size estimates

4.2.4 Hydraulic assessments

The capacity of the Taylor River floodway – 2 kilometres (km) through Blenheim joining the Lower Opawa floodway (16 km to the sea) is

hydraulically very complex. Flood capacity was overestimated by over 100 per cent in the 1960 detention dam design.



FIGURE 3: Complex channel and berm flow hydraulics of the Lower Opawa floodway in July 2008 flood

The Taylor/lower Opawa is tidal for the full 18 km, and its flood slope is only on a grade of one in 5000. The channel is a narrow deep and meandering. It is flanked by berms that slope

away from the bank edge to stopbanks set well back from the channel. In large floods the berms could provide up to 40 per cent of the floodway capacity; and provide short cut paths across the

meander bends. Furthermore extensive growths of overhanging willows bordered the channel up to the mid 1990s. This provides for very complex flood hydraulics. A photo of the stopbanked Lower Opawa floodway is shown in Figure 3. The floods of 1989, 1994, and 1996 were carefully monitored with regard to flood size and flood levels, and used to calibrate a Mike 11 model which treated berm flows as separate 'channels'. This monitoring clarified the hydraulic complexity and limited capacity of the floodway, and was the basis of a programme of upgrading work.

Overestimates of the floodway capacity arose from two aspects. The berms were not being adequately utilised because the berm topography restricted flow from the channel onto and off the berms. The hydraulic restriction of overhanging willows was not appreciated. Calibration of flood flows showed that Manning's "n" was typically 0.070 in flood flows – much higher than initial scheme design presumptions.

4.2.5 Upgrading works

Following the 1980 flood review the culvert outlet on the Taylor dam was throttled by simply bolting a steel orifice plate in the front of the culvert entry, thus reducing the outflow by 35per cent. The dam storage was still adequate to retain a flood volume in excess of a 100 year ARI.

A programme of berm shaping works and willow removal was embarked on from the early 1990s, and this has proved very effective at improving the floodway hydraulics. The computer model predicted improvements were confirmed by the monitoring of the 2008 flood levels. While good calibration was achieved, there is still some uncertainty about the accuracy of the model; though indications are that at design flood size the floodway may perform better than the model indicates. Table 3 provides a summary of the monitored assessments of the various hydrological and hydraulic parameters and resulting upgrading works over time.

Year	Estimated Detention Dam Inflow (100 year flood)	Estimated Dam Outflow plus Tributaries (100 year flood)	Estimated Channel Capacity Through Blenheim	Comment (The key design intention is for column 4 to equal or exceed column 3)
1960	505	255	280	Initial scheme design. Little data on flood size or downstream channel capacity of the Taylor/ Lower Opawa.
1965	425	235	200	Construction. Final dam design incorporated four years of data with a downward revision of flood size. Flood hazard protection standard not being met.
1981	270	183	158	Review of 20 years flow data and expected dam inflow revised down. As a result the dam outlet culvert was throttled to reduce dam outflow substantially. More field data resulted in downward revision of downstream channel capacity. Flood hazard protection still not being met.
1992	285	170	125	Detailed hydraulic review of channel capacity based on calibrating computer model with monitored field observations. Flood hazard protection standard now assessed as only 75 per cent of design intention. A programme of increasing floodway capacity of channel downstream of Blenheim embarked on.

Year	Estimated Detention Dam Inflow (100 year flood)	Estimated Dam Outflow plus Tributaries (100 year flood)	Estimated Channel Capacity Through Blenheim	Comment (The key design intention is for column 4 to equal or exceed column 3)
2002	310	170	170	Floodway downstream of Blenheim enlarged. Tested by July 2008 flood and found to be adequate. Flood hazard protection now to intended design standard.

TABLE 3: Summary of Hydrology and Hydraulic monitoring and upgrades

4.2.6 Taylor River case study conclusions

Initial estimates of flood hydraulics and hydrology were grossly inaccurate at the flood scheme inception, because of a lack of data. However there has been regular monitoring of the scheme performance. Further upgrading work to modify the initial design has been carried out as a result of this monitoring. This modification work has been easy to carry out because the original scheme design was very adaptable.

A freeboard of 0.5 m on stopbank height through Blenheim has been allowed for the uncertainties. This equates to about 25 per cent of flood capacity and this amply covers current estimates of uncertainties including climate change.

4.3 CASE STUDY: RIVERLANDS CO-OP FLOODWAY

4.3.1 Background

The Riverlands Co-op floodway is a very flat artificial channel on the lower edge of the Wairau floodplain and stopbanked for 10 km from Blenheim to the Wairau lagoons estuary.

It collects water from eight small streams totalling 16 km² of hill catchment. None of the streams have flow recorders on them, and nor is it feasible to have flow recorders on the main Co-op Floodway itself because of its considerable storage and tidal nature. It empties to the sea via the Wairau river estuary.

Estuary water levels are a substantial factor in the performance of the floodway, and the coincidence of high estuary levels with Riverlands flood flows impairs the hydraulic performance of the floodway. Estuary levels are determined by mixture of sea level, Wairau flow, and Wairau mouth efficiency.

Wairau flood flows are usually affected by different storm events than impact on Riverlands.

The Council has a formal policy that flood control works will to be a standard of a 100 year return period flood. The importance of it performing to standard has increased due to recent industrial development. Determination of the flood hazard standard has to deal with the considerable uncertainties in flood hydrology, flood hydraulics, and the joint probability of coincidence of Riverlands floods with high estuary levels due to Wairau floods, high tide and an inefficient mouth. This latter factor may be the largest of the uncertainties.

4.3.2 Flood hydrology

The initial scheme works were based on simple rainfall runoff formulae, with the only rainfall information being from a recorder on the edge of the catchment. The design flood peak size varies along the length of the floodway from 14 up to 40 m³/sec.

Flood levels from a large flood in summer 2002 were carefully monitored, from which estimates were made of flood peak sizes. As the storage in the channel buffers the flood peak this means that assessment had to be made of the whole flood hydrograph and not just the peak; and assessments needed also to be made of the timing of the floods of the different tributaries.

Another flood in winter 2008 showed that the flood hydrograph could be longer and less peaky than the earlier summer flood had indicated.

4.3.3 Evidence of climate change

There are no flow recorder or rainfall records for the catchment. It is known that large floods occurred in 1966, 1980, 2002 and 2008 – and there are aerial photographs of these events. This evidence is too vague to draw any inferences.

4.3.4 Hydraulic assessments

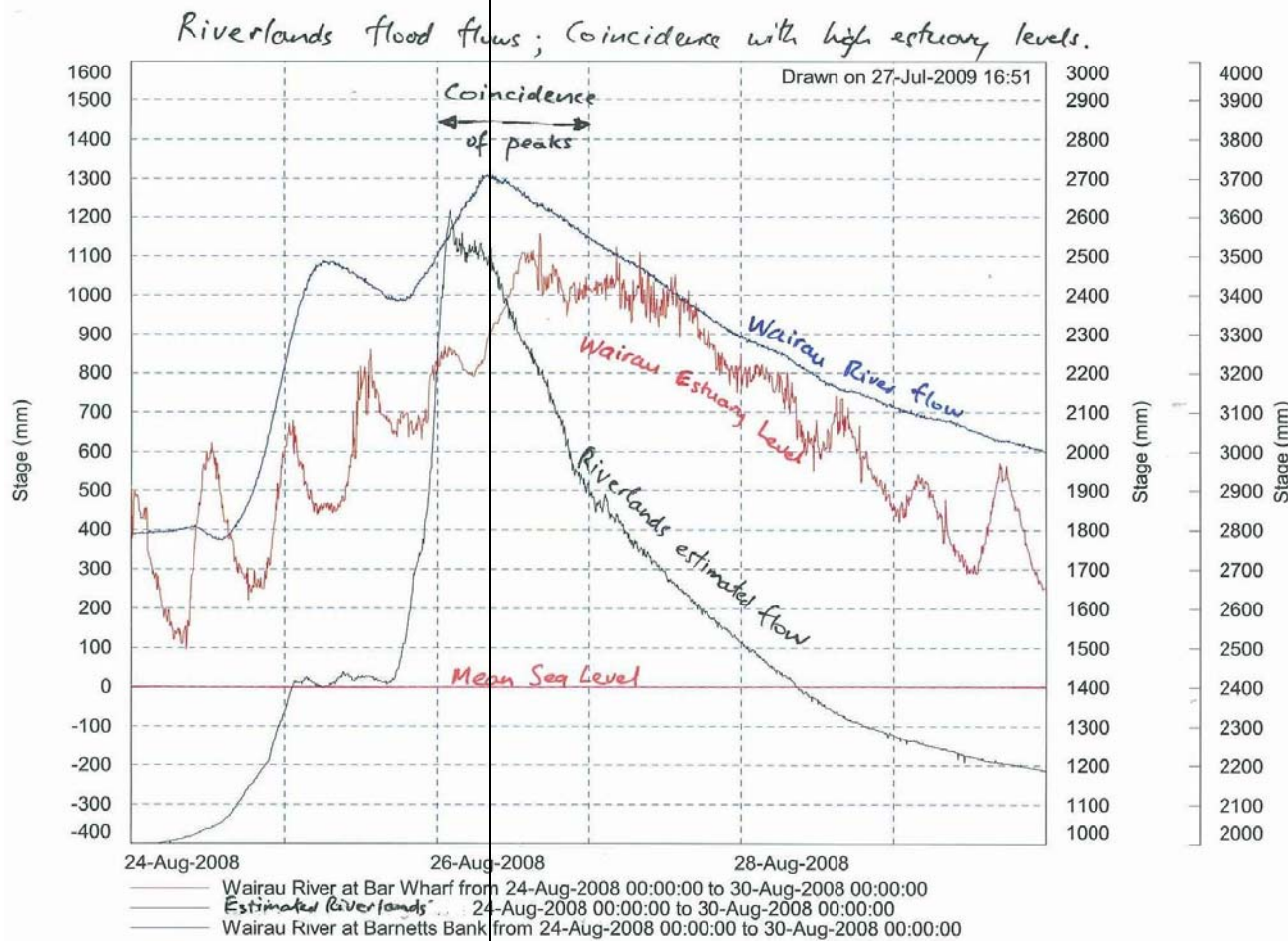
A detailed Mike 11 hydraulic model was set up based on the 2002 monitored information. This showed that the floodway was not large enough in some locations and as a result upgrading work was initiated.

In a flood event in August 2008 the stopbanks were

observations the size of the flood event was considered no greater than a 10 year return period event.

The main reason for the poor performance of the floodway was due to high estuary levels persisting for over 2 days. This was caused by coincidence of the Riverlands flood with a Wairau flood, an inefficient river mouth to the sea, and high tide.

This is shown in Figure 4.



unexpectedly close to overtopping. From general

FIGURE 4: Riverlands Co-op flood flows, coincidence with high Wairau Estuary levels

4.3.5 Upgrading works

Following the monitored 2002 flood a programme of channel widening and raising stopbanks was carried out over various reaches of the floodway. Fortunately this channel widening was carried out prior to proposals for intensive development on both sides of the

channel – which would have precluded later widening.

Following the 2008 flood the existing rock guide bank at the Wairau estuary mouth to the sea was lengthened to provide a new outlet to the sea. This outlet is hydraulically more efficient this being of considerable benefit to the

Riverlands Co-op floodway as well as the Wairau river and tributary drains.

This has reduced the likelihood of a Riverlands flood coinciding with high Wairau estuary levels.

The benefit of this is demonstrated by a small flood in Feb 2009. Estuary levels were 0.5 m lower during this Riverlands flood and limited to the few hours of high tide, as shown in Figure 6.



FIGURE 5: Wairau River mouth Jan 2009, cutting newmouth through bar, extending rock guide bank and cutting off old mouth.

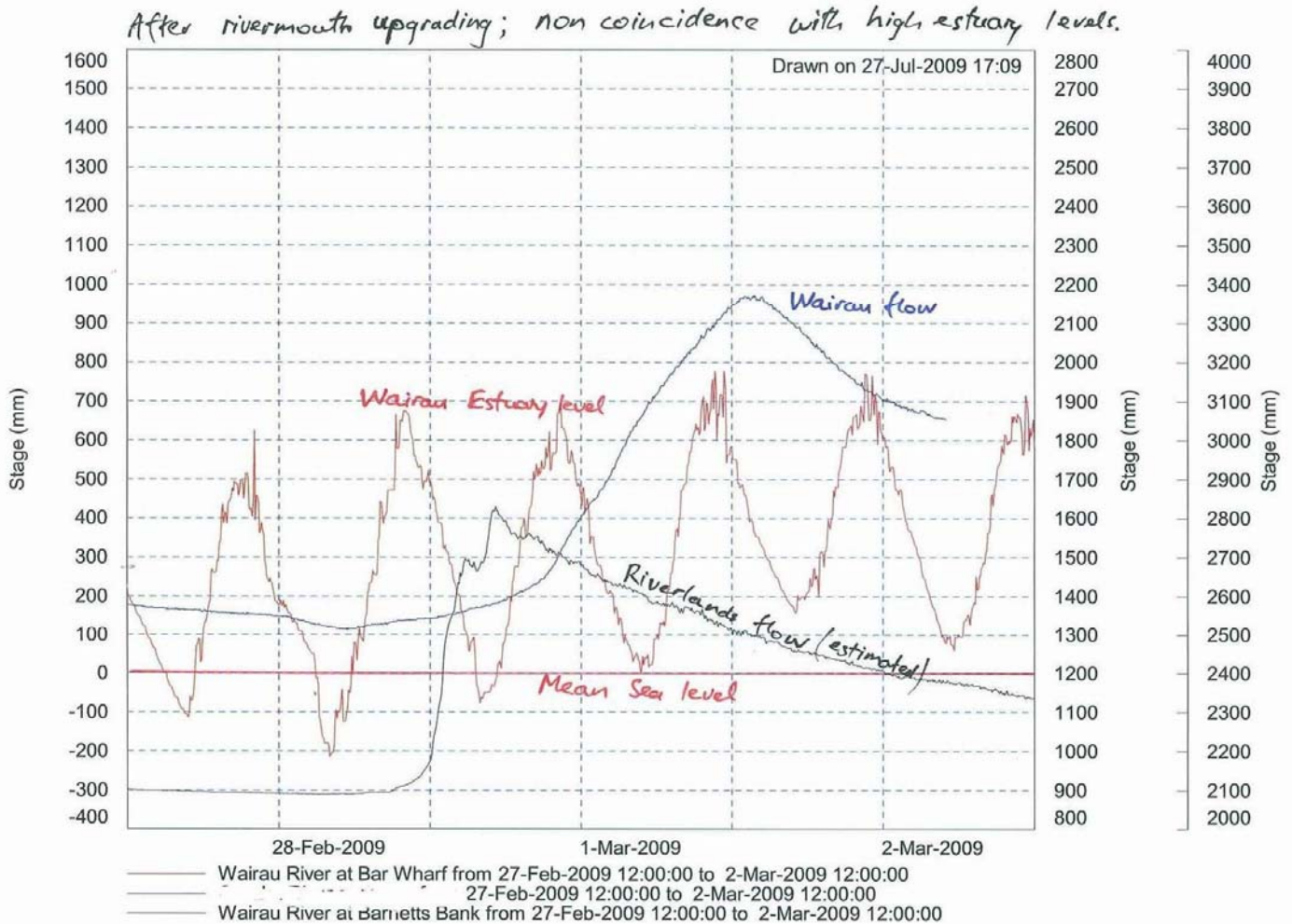


FIGURE 6: Riverlands Co-op Floodway flows; non-coincidence with Wairau Estuary levels

4.3.6 Riverlands Co-Op floodway case study conclusions

There is difficulty in defining the flood standard of the Riverlands Co-op Floodway due to the large uncertainties in many parameters. As far as can be estimated the upgraded floodway (and improved sea outlet) is capable of handling any flood that has been observed to occur in the last 50 years. The uncertainty in all the various parameters is greater than our current estimates of flood flow uncertainty due to climate change.

The possibility of a flood in the Riverlands floodway coinciding with high (Wairau) estuary levels may be the biggest uncertainty. This has been reduced by the recent river works to improve the efficiency of the Wairau estuary mouth outlet into the sea. In effect this has

countered 50 years worth of estimated climate change induced sea level rise.

Monitoring of flood events, with subsequent analysis and floodway upgrading has been an important part of ensuring that flood hazard standards are being met.

4.4 CASE STUDY; WAITOHI RIVER PICTON

4.4.1 Background

Picton is built on the small Waitohi floodplain at the base of a small steep hill catchment. Up to 1970 only minimal flood control works were needed or constructed.

The Harbour Board built a 350 m long large triple culvert in 1970 to allow wharves to be built over the former river estuary. There was

very limited information on which to assess Waitohi flood size at the time.

The culvert was not large enough for the floods of 1998, 2004 and 2008. The water backed up behind the culvert and flooded the industrial area of Picton. There is no secondary overflow

path, and water can build up behind the culvert flooding an eight hectare area of town by up to 1.5 m.



FIGURE 7: Picton February 2004, Industrial area flooded due to inadequate size of culvert under wharves

The Marlborough District Council has inherited both harbour and river control responsibilities since 1992.

Council has no formal policy on required flood standard, but there is an implied minimum desirable flood standard of a 50-year return period under the Building Act, otherwise planning restrictions need to be imposed on an area that is used and zoned for industrial development. A 100-year return period standard would be preferred, if achievable.

4.4.2 Flood hydrology

There is no flow recorder on the Waitohi River. Detailed rainfall records have only been collected for 15 years, and even then only on the edge of the catchment.

Following the very large 2004 flood a review of the flood hydrology was carried out from

examining flow records from a variety of flow and rainfall information within the region. This review indicated credible estimates for a 100 year ARI flood range from 77 to 121 m³/sec.

4.4.3 Evidence of climate change

For the 28 years following the construction of the culvert and wharves in 1970 there is no record of flooding being caused by the inadequate capacity of that culvert. However since 1998 there have been three floods in which flooding has occurred and the lack of culvert capacity was a factor. This implies that flood sizes may well be increasing due to climate change.

The weather pattern that causes flooding here can be quite different from that affecting the Wairau or Taylor.

Predicted sea level rise will also have a direct effect on increasing flood hazard.

4.4.4 Hydraulic assessments

The 2004 review also examined hydraulic performance and concluded that the safe capacity of the wharf culverts to be 65 m³/sec; despite a stated 1970 design intention of 80 m³/sec by the consultant engineers for the Harbour Board.

Even the calculated 65 m³/sec could be considered on the optimistic side as included only 0.1 m of freeboard.

4.4.5 Upgrading works

It is now very expensive to enlarge this culvert that has railway and port infrastructure built over it. Ownership of the culvert and responsibility for funding its upgrading is muddled; though clearly the Marlborough District Council now has to play a lead role. Improving the culvert inlet is assessed to increase hydraulic capacity to 70 m³/sec (eight per cent increase) at an estimated cost of \$400,000 and Council has approved this expenditure out of a general infrastructure budget.

Further increases to hydraulic performance are proportionally much more expensive. An increase to 85 m³/sec (30 per cent increase) is

5 SUMMARY AND CONCLUSIONS

In the background paragraph 3.4 a hypothesis was put forward regarding river control scheme monitoring, scheme adaptability, and incorporating climate change as one of many variables; and for this to be tested against four Marlborough case studies.

Monitoring:

Over the last 20 years there has been a strong focus on monitoring flood hazard parameters and the performance of Marlborough floodways and controlled rivers. This has been aided by the recent improvements of computer software.

The monitoring has shown a considerable difference in actual monitored results than the original scheme designs had presumed, due to the fact that there was limited data available at scheme design.

estimated at \$6 million. Higher standards would cost much more. There is not a clear funding source for such expenditure.

4.4.6 Waitohi case study conclusions

Works carried out on the Waitohi River were under size because they were based on inaccurate assessments of flood hydrology and hydraulics. Furthermore a minimal margin of error (freeboard) was allowed for. It has created an undesirable flood hazard to an intensively developed industrial area. Climate change is expected to worsen the situation.

The design of the works was such it is now very difficult and expensive to upgrade; i.e. the scheme design was not adaptable.

A key issue now is affordability.

Improvements to the culvert may have to be done to what is affordable rather than to a standard, and the affected land may have to be rezoned. Council has embarked on a staged upgrade, but only the first stage has approved funding.

Not only is it physically difficult to upgrade the culvert, but there is no ready source of funding.

The parameters examined included riverbed aggradation, effect of vegetation on hydraulic performance, the complex hydraulics of wide floodways with incised channels, measurement of actual flood sizes, flood frequency extrapolations, and the probability of high flood outlet levels with a flood. There will be some continuing uncertainty in many of these parameters into the future and monitoring will continue to be desirable.

This confirms the hypothesis "That regular and detailed monitoring of the hydrological and hydraulic parameters is required to confirm that a river control scheme performance in flood events meets initial design intentions, and if not, to determine the need for upgrading works".

Scheme adaptability

Three of the case studies presented had initial scheme designs that could be readily upgraded to deal with the required revisions. Upgrading

work has been carried out to upgrade to the initial scheme design intentions.

The fourth scheme was a concrete culvert of fixed capacity under subsequently developed land, and results in flood hazard for high value upstream land. It cannot be readily upgraded. This presents a problem. Options of what can be done are now limited by affordability.

This confirms the hypothesis “A key design philosophy for river control schemes is that their initial design should allow for upgrading to be readily carried out as and when new information indicates the need”.

Climate change

Climate change is another hydrological uncertainty. The uncertainty of climate change can be addressed within this context of adaptable design, and subsequent monitoring over time. The argument presented here is that there it should be treated the same as, and together with, the other hydrological and hydraulic uncertainties for Marlborough rivers. And this could be true for other areas of New Zealand too.

On current knowledge climate change is a lesser factor than other uncertainties for Marlborough rivers, and for some rivers may be reducing the required flood capacity. There is no need for immediate increasing of flood capacity of these rivers on the basis of a postulated general New Zealand flood increase due to climate change.

Monitoring of rainfall and flood events into the future will provide more information on climate change. Having river control schemes adaptively designed so that they can be readily upgraded is seen as a good way of dealing with the uncertainty of climate change. This applies irrespective of whether climate change is increasing flood flows, or conversely is not increasing flood flows.

This confirms the hypothesis “That the parameter ‘climate change’ could, and should, be incorporated as one of the hydrological parameters being monitored”.

Postscript comment

The Wairau River Board directions of 1921 to include “a reasonable margin of safety” to allow for uncertainties is still apt for today, including the uncertainty of climate change. Our challenge is to define what a reasonable “margin of safety” (usually freeboard) should be so as to allow for the various uncertainties including a changing climate. Such assessments of freeboard should be river specific and tailored to the knowledge of all the uncertainties for that river, and the ability to upgrade the scheme in the future.

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Author Profile

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