Climate Change Amongst Other Flood Hazard Uncertainties; Marlborough Case Studies

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ABSTRACT

Knowledge of the performance of a floodway or river is an ongoing challenge for engineers working towards managing flood hazard. Furthermore the New Zealand climate is changing, which presents a new uncertainty in defining the standard of flood control works into the future. Other uncertainties also cloud the ability to define both the existing and future flood hazard standards. These uncertainties include flood hydrology, channel hydraulics, aggradation, joint probability of high outlet levels and other parameters.

Marlborough has a long history of flooding and river control works. The Marlborough District Council still has a programme of monitoring and further upgrading of the river control works despite nearly 150 years of previous effort.

The paper scopes how the various uncertainties affect assessing flood hazard standard for four case study rivers. The new climate change uncertainty is considered in the context of comparison with these other uncertainties that are site specific for each river.

Monitoring and review of flood events is identified as a sound way of dealing with climate change and the other uncertainties, with upgrading as and when required. This supports the principle of adaptable design; 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.

KEYWORDS

Climate change, flood hazard standard, uncertainty, floodway capacity.

PRESENTER PROFILE

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1 INTRODUCTION

Knowledge of the performance of a floodway or river is an ongoing challenge for engineers and scientists working towards managing flood hazard – flood frequency analysis changes as historical flood estimates are revised and new events are assessed, bed levels change through aggradation/degradation, knowledge of hydraulic roughness develops as flood levels are monitored, and amongst other things the performance of each floodway is specific to variables like slope, ever-changing surrounding development, and a changing climate.

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.

The Marlborough District Council continues a programme of review and further upgrading of the river control works despite nearly 150 years of previous effort.

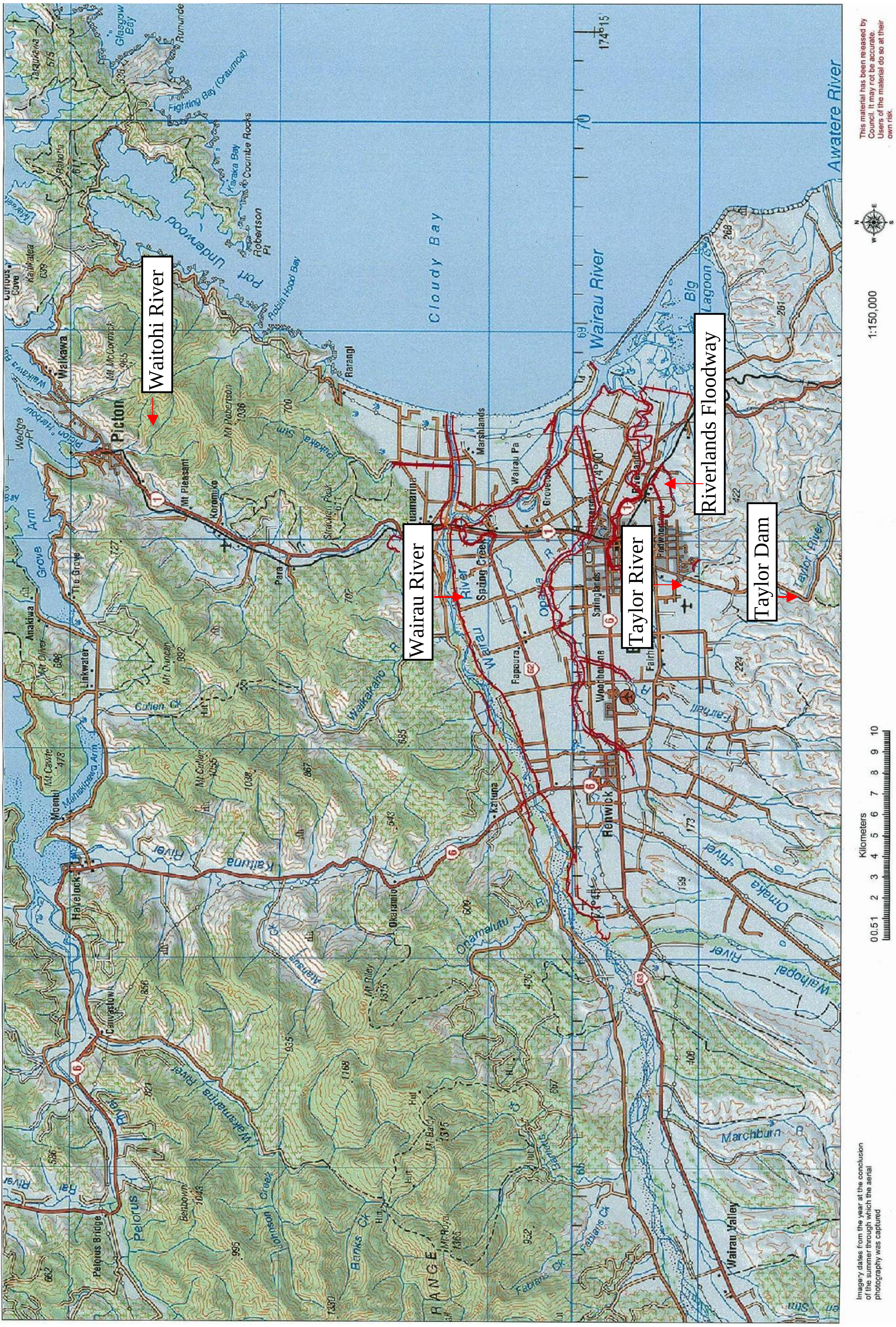
Global warming is occurring and there is evidence over the last decade that the New Zealand climate is changing. Such changes could affect flood hazard and the adequacy of flood protection works. It is timely therefore to scope Marlborough's river control standards in the light of this new uncertainty of probable climate change.

Climate change is one of many uncertainties in assessment of flood hazard.

Other 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 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 are other parameters. The degrees of uncertainty of these other factors can be large, often considerably larger than the change in flood flow due to climate change.

A scoping exercise has been done on how to consider climate change effects within the context of these other uncertainties for four Marlborough rivers.

Marlborough District Council:
River Assets Atlas



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Imagery dates from the year at the conclusion of the summer through which the aerial photography was captured

2 Marlborough Case Studies

2.1 Case Study: Wairau River

2.1.1 Background, characteristics and flood standard policy

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 1 in 100 year return period event for the main rivers of the Wairau floodplain.”

2.1.2 Is there evidence that Wairau flood sizes may be changing due to a changing climate?

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 rainfalls on a NZ 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 NZ 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.

The below table lists peak Wairau flood sizes per decade that flood flows have been measured.

Decade	Year	Flood Size
1920s	1926	4,500 m^3/sec
1930s	1939	4,000 m^3/sec
1940s	1945	3,300 m^3/sec
1950s	1954	4,200 m^3/sec
1960s	1962	3,620 m^3/sec
1970s	1975	4,000 m^3/sec
1980s	1983	5,800 m^3/sec
1990s	1998	3,760 m^3/sec
2000s	2004	2,200 m^3/sec

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 3500 m^3/sec.

The last decade stands out as the only decade not having a significant flood.

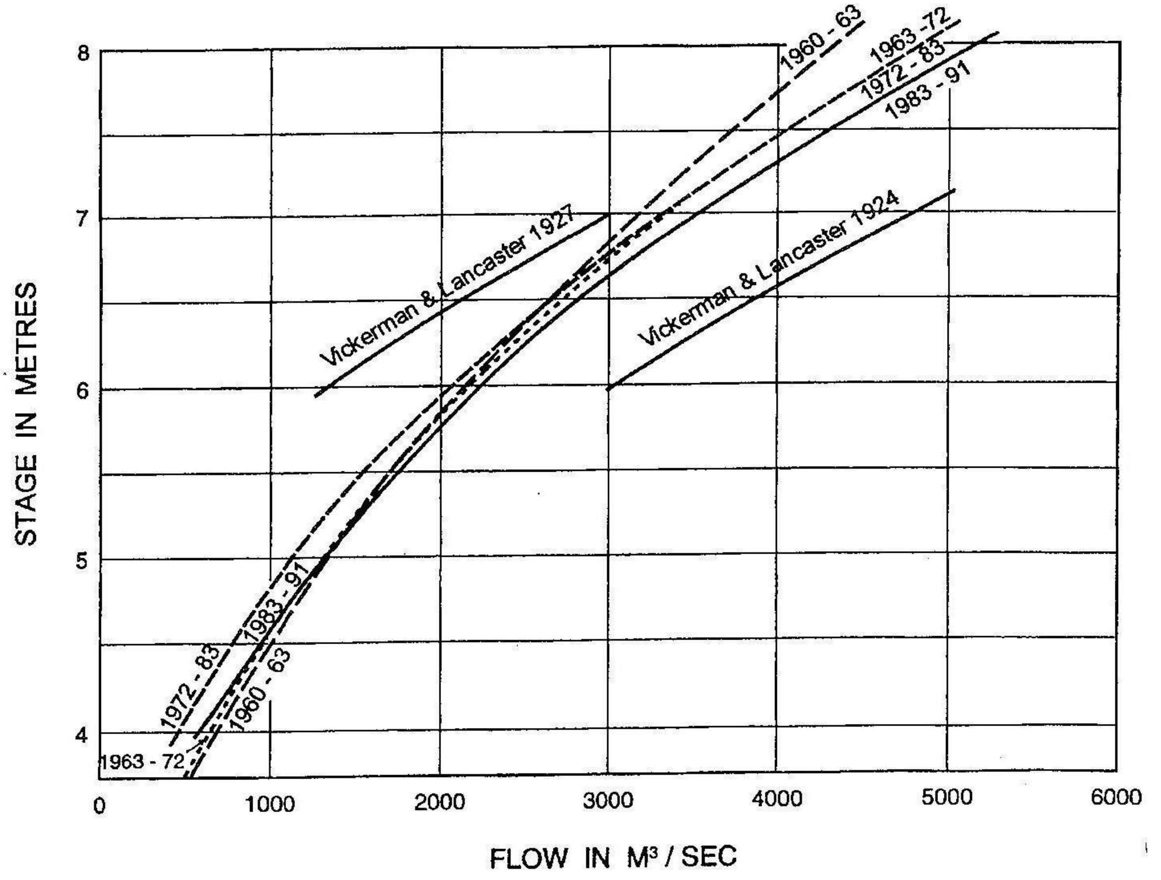
Thus, if anything, the records indicate that Wairau flood flows would be smaller under climate change than under earlier historical weather patterns. This may be due to change in frequency of storm track with a greater proportion of south westerlies from which Marlborough is very protected. It is of course premature to make conclusions based on only 10 years data.

2.1.3 Measurement of 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 m^3/sec at Tuamarina 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; being a reduction of 30% 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. These rating curves are shown on the below plot.



–Recommended flood stage-rating relationships for the Wairau at Tuamarina -

2.1.4 July 1983 flood

The July 1983 Wairau flood 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.

Wairau July 1983 flood at Tuamarina

Assessment of its size is a key parameter in flood hazard assessment and design of river control works.

However assessment of its size 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 was a size of 7,765 m^3/sec. This was reviewed down the following year to 7,000 m^3/sec.

A very detailed review was carried out in 1992 by new staff (Williman 1995) and the flood size reviewed down to 5,800 m^3/sec; this having an assessed return period of 150 years.

2.1.5 Floodway hydraulic assessment and capacity monitoring

At the time of the July 1983 flood, MCB staff had considered the capacity of the floodway to be 5,200 m^3/sec. This was based on manual calculations of the 1960s when the stopbanks had been upgraded.

The detailed review of 1993 indicated that the safe capacity of the floodway was only 4,200 m^3/sec. This assessment was based on resurveys of the river channel and computer based hydraulic calculations calibrated against measured floods.

In 1983 the Wairau River channel was some 1,600 m^3/sec short of safely carrying the 5,800 m^3/sec – some 35% too small.

Of this

> 10% - was due to inaccurate flood estimation.
>
> 10% - was due to inaccurate calculation of river hydraulic performance.
>
> 15% - was due to channel aggradation over the 25 years since the stopbank upgrading in the 1960s.

There were also other factors causing flood breakout more readily than expected.

The SH 1 road bridge at Tuamarina was a constriction to the flow – the deck was too low and caused a raising of flood levels a further 0.6 m for the river reach upstream of the bridge.

Stopbanks – which were considered adequate pre-flood – in some places completely failed because the bank erosion protection works were but eroded away, or piping occurred.

2.1.6 Wairau case study conclusions

Historically (ie; 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%. 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 1992-94. This review used much better information and more rigorous analysis, and to an intended design standard of providing for a 1 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% in the next two generations. This is less than the other uncertainties. Indeed the most difficult uncertainty is considered to be the continuing aggradation of the Wairau River.

A freeboard of 0.8 metres on stopbank height has been allowed for the uncertainties, and this amply covers current estimates of 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.

2.2 Case Study; Taylor River 1960

2.2.1 Background, characteristics and flood standard policy

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 performance standard of the dam.

Reviews have therefore been regularly carried out, leading to upgrading work.

2.2.2 Is there evidence that Taylor flood sizes may be changing due to a changing climate?

The Taylor flood record for the last decade may be indicative of future flood conditions under climate change, as indicated by the table below.

Taylor River at Borough weir recorder – measured flood peaks

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

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 MfE proposal that flood flows here will increase with climate change.

2.2.3 Measurement of flood hydrology

There is now 50 years of record of Taylor River flows into the dam, which provides a very good estimate of flood flows into and out of the dam. However there are also some significant tributaries downstream of the dam which provides approx 40% of the design flow of the downstream Taylor floodway through Blenheim.

Information on flood sizes of the Taylor through Blenheim is less good, with no good 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.

2.2.4 Floodway hydraulic assessment and capacity monitoring

The capacity of the Taylor River floodway (2 km) through Blenheim joining the Lower Opawa floodway (16 km to the sea) is hydraulically very complex. Flood capacity was grossly overestimated by over 100% in the 1960 detention dam design.

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 1 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% of the floodway capacity; and provide short cut paths across the meander bends.

Extensive growths of overhanging willows bordered the channel up to the mid 1990s.

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. 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 on to 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 early guestimates.

A programme of berm shaping works and willow removal was embarked on from the early 1990s, and this has proved very effective as confirmed by the monitoring of the 2008 flood. 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.

Summary of Hydrology & Hydraulic monitoring and subsequent upgrades

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	535	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% of design intention. A programme of increasing floodway capacity of channel downstream of Blenheim embarked on.
2008	274	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.

2.2.5 Taylor River case study conclusions

Initial estimates of flood hydraulics and hydrology were grossly inaccurate at the flood scheme inception.

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 these reviews. This modification work has been easy to carry out because the original scheme design was very adaptable.

There is freeboard of 0.5 metres on stopbank height above calculated design flood level and this amply allows for the various uncertainties including current estimates of climate change.

2.3 CASE STUDY: RIVERLANDS CO-OP FLOODWAY

2.3.1 Background, characteristics and flood standard policy

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 outlets to the sea via the Wairau lagoons 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.

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 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.

2.3.2 Is there evidence that Riverlands flood sizes may be changing due to a changing climate?

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.

2.3.3 Measurement of flood hydrology

The initial scheme works were based on simple rainfall runoff formulae.

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 to be longer and less peaky than the earlier summer flood had indicated.

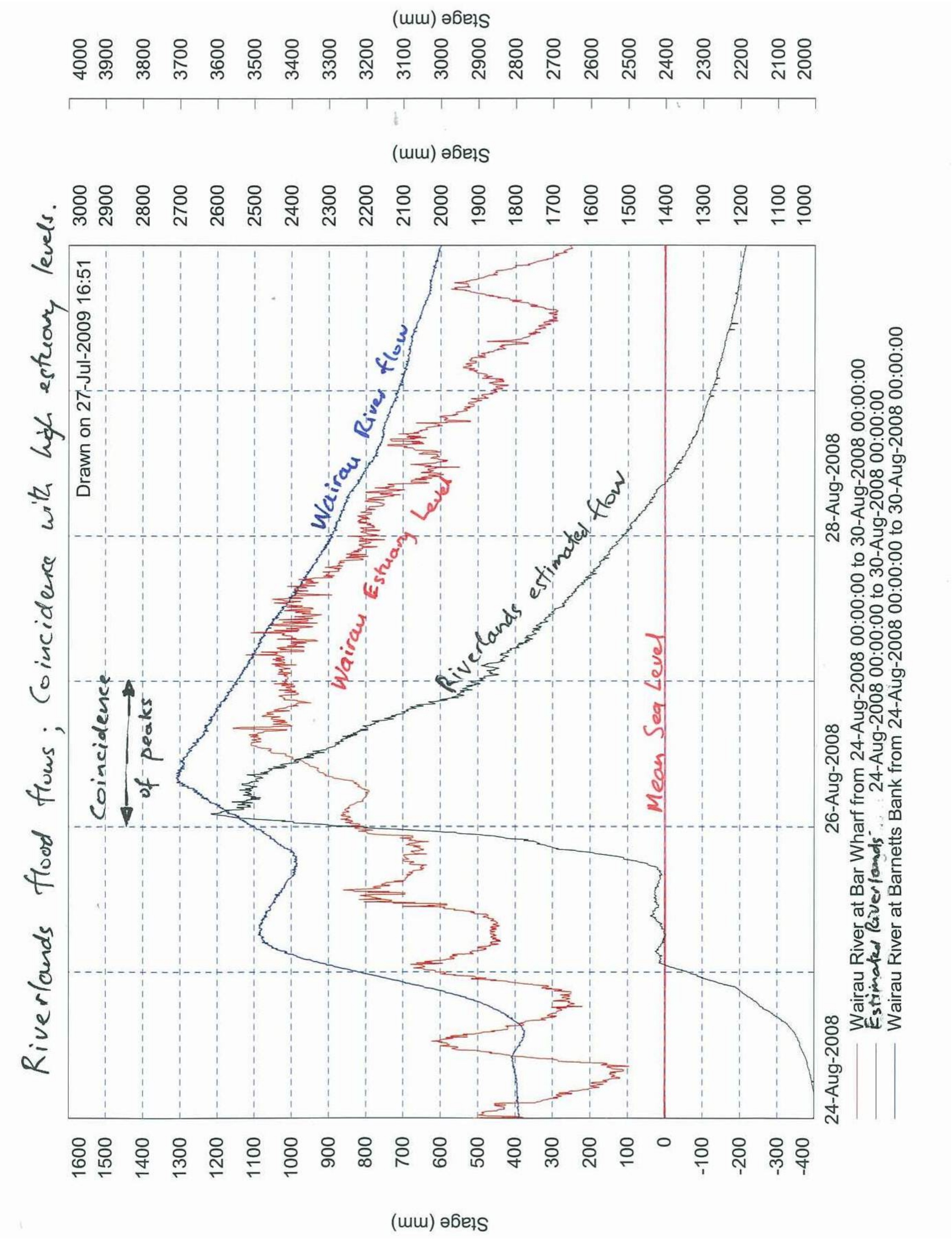
2.3.4 Floodway hydraulic assessment and capacity monitoring

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 of increasing channel size and raising stopbanks was carried out over various reaches of the floodway.

These stopbanks were unexpectedly close to overtopping in a flood event in August 2008. The size of the flood event was less 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 on the below plot.



2.3.5 River mouth guide bank to increase efficiency

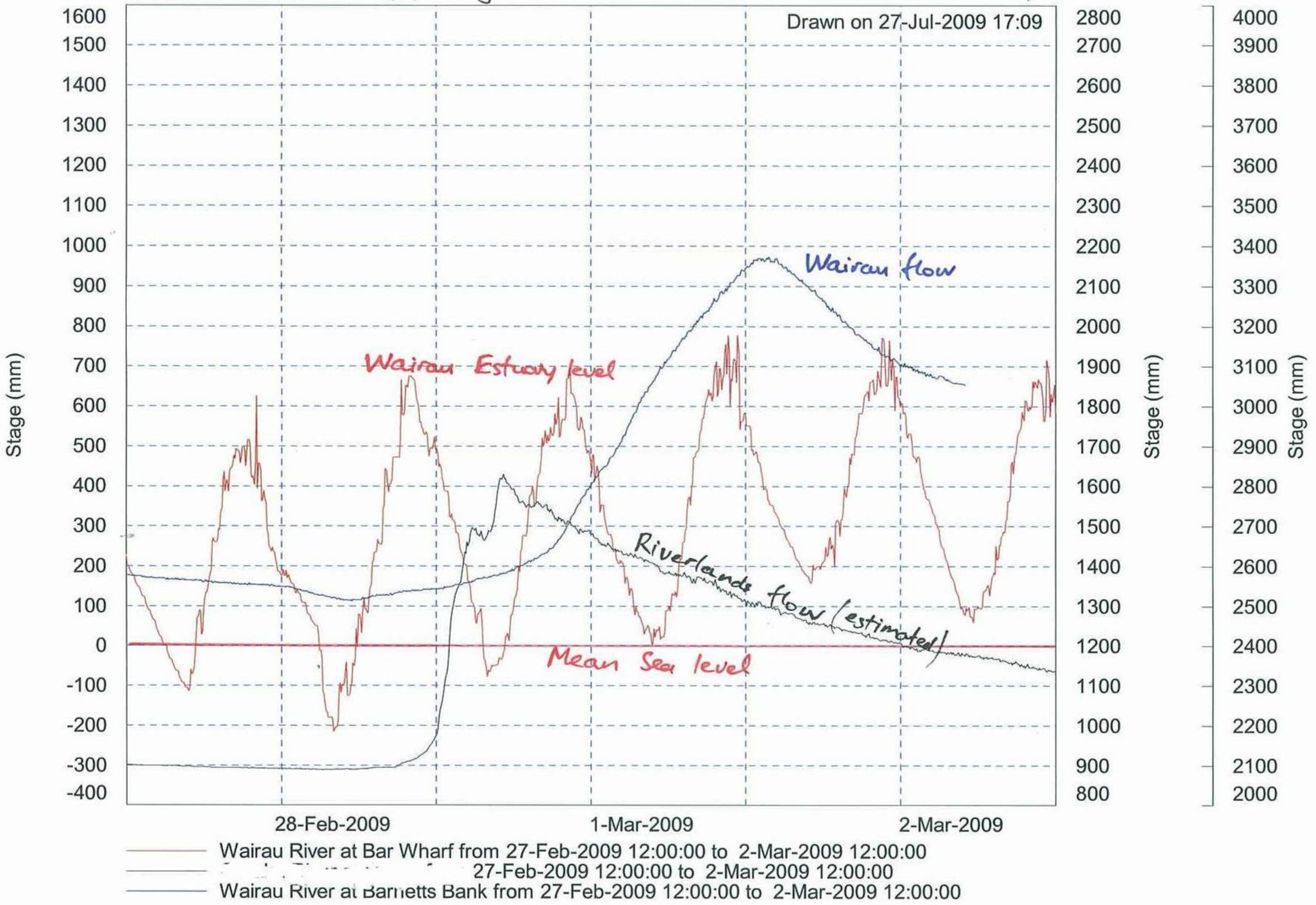
Subsequent to the flood in Jan 2009 Council upgraded the existing rock guide bank at Wairau river mouth to improve the efficiency of the outlet to the sea.

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

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

Wairau River mouth Jan 2009, cutting new mouth through bar, and blocking old mouth

After rivermouth upgrading; non coincidence with high estuary levels.



2.3.6 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. The uncertainty in all these 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.

2.4 Case Study; Waitohi River Picton

2.4.1 Background, characteristics and flood standard policy

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 metre long large triple culvert in 1970 to allow to 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 area of 8 ha by up to 1.5 metres.

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 development. A 100 year return period standard would be preferred, if achievable.

2.4.2 Is there evidence that Waitohi flood sizes may be changing due to a changing climate?

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.

2.4.3 Measurement of flood hydrology

There is no flow recorder on the Waitohi River; and detailed rainfall records have only been collected for 15 years.

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 return period flood range from 77 to 121 m^3/sec.

2.4.4 Floodway hydraulic assessment and capacity monitoring

The 2004 review also examined hydraulic performance and concluded that the safe capacity of the wharf culverts to be 65 m^3/sec; despite a stated 1970 design intention of 80 m^3/sec by the consultant engineers for the Harbour Board.

Even the calculated 65 m^3/sec could be considered on the optimistic side as it presumed minimal margin of error or freeboard. Closed culverts are less good at providing a margin of error (freeboard) than open channels.

It is now very expensive to enlarge this culvert that has railway and port infrastructure built over it. The estimated cost to upgrade the culverts to 70 m^3/sec (8% increase) is $400,000 and to 85 m^3/sec (30% increase) is $6 million. Higher standards would cost much more.

2.4.5 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 ie; the design was not adaptable.

A key issue is affordability.

Ownership of the culvert and responsibility for funding its upgrading is also muddled; though clearly the Marlborough District Council now has to play a lead role.

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.

3. CONCLUSIONS

- There are many uncertainties in assessing flood hazard standards for Marlborough rivers and floodways. Knowledge of the performance of a river or floodway requires detailed monitoring in flood events so as to better quantify these uncertainties and assess the standard of flood hazard being provided for.
- Climate change is one more uncertainty, and is a lesser factor than other uncertainties – on our current knowledge. Furthermore on our current knowledge many Marlborough river flood flows may be reduced by climate change, rather than increased.
- All these uncertainties change with time, either because the river physically changes, or because our knowledge of the uncertainties improves, as with climate change.
- Continuing regular monitoring is a very good way to quantify these uncertainties over time, including that of climate change.
- River control schemes should then be upgraded as and when required to combat the assessed change to the flood hazard.
- This approach has worked successfully for three of the four case studies looked at, because the original scheme designs were adaptable and could be readily upgraded. There was also a clear funding source for the review and upgrading these three case study rivers.
- The fourth case study had a design that is not easily upgradable, nor a clear funding source for upgrading work. This is a problem, and one that will be made worse by climate change. Options of what can be done are now limited by affordability.
- The Wairau River Board directions of 1921 to include “a reasonable margin of safety” to allow for uncertainties is still apt for today. Our challenge is to define what a reasonable “margin of safety” (usually freeboard) should be to allow for the various uncertainties. Such assessments of freeboard should be river specific and tailored to the knowledge of uncertainties for that river, and the ability to upgrade the scheme in the future.
- Climate change uncertainty should be addressed within this context of adaptable design, subsequent monitoring over time and tailored safety margins.

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