BULLER RIVER: HYDRAULIC MODELLING STUDY

July 2015

Hydraulic Modelling Study

LANDRIVERSEA CONSULTING

Report prepared for West Coast Regional Council
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1. INTRODUCTION

SCOPE OF STUDY

The West Coast Regional Council has commissioned Land River Sea Consulting to build a hydraulic model of the Buller River system, in order to identify the likely extent of flooding for a range of return period events, as well as to be able to use the model for investigating potential flood mitigation options.

This report outlines the background to the project, the methods used for constructing the model and presents the results and recommendations. Options assessed using the final model will be addressed in a separate report.

BACKGROUND

The town of Westport, is located on the north of the West Coast of the South Island of New Zealand. First settled around 950AD by the local Maori population with the first European settlers arriving in the early 1860's. The development of the port at the mouth of the Buller River since European arrival, has allowed industry to develop and a permanent population in the vicinity of 4000 people have settled in the town.

The main town centre is bordered by two waterways, the largest of these is the Buller River and the smaller of these is called the Orowaiti River. The Buller River drains an extensive catchment of approximately 6,380 km^2 including the catchments of Lakes Rotoiti and Rotoroa as well as several rivers draining the Southern Alps. The river has the largest estimated flood peak in New Zealand of 12,700 m^3/s in 1926, estimated at the Te Kuha gauging site (Soil Conservation and Rivers Control Council, 1957). The Orowaiti River has a much smaller catchment, however functions as a major overflow channel for the Buller River during flood events. The location of the Buller River and Orowaiti Stream catchments are shown in Figure 1-1.

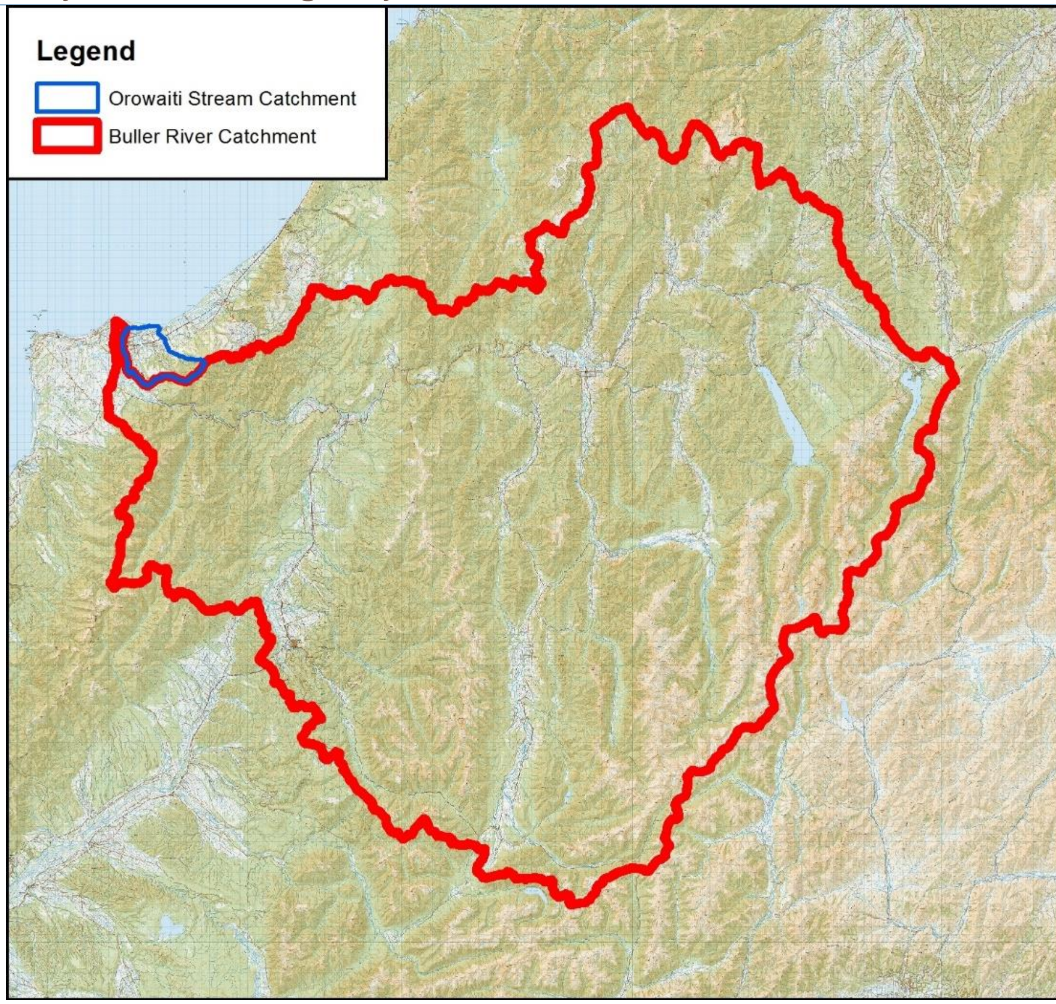

Figure 1-1 – Location and catchment boundary of the Buller River and Orowaiti Stream

FLOOD HISTORY

There have been a large number of floods in the Buller River since European Settlement. Reports on the three largest recorded floods have been included below and have been taken directly from the document "A Chronology of Flooding on the West Coast, South Island, New Zealand. (Benn, 1990)

8-9 February 1872

The highest flood in Eurpoean times occurred in the Buller River. On the 8th the river rose rapidly during the day and by nightfall was overflowing its banks. By the next morning the force of the current was deflected by Garden Island towards Westport. Stanley Wharf, the National Hotel, a large two storey building and a store were swept away. The river commenced to scour the bank at the rear of the protective works at the foot of Gladstone Street, and with alarming velocity the narrow strip of roadway and ground that the National Hotel was on, gave way. The river changed course and cut a new channel through the north spit, this making it an island. A slaughter house, a piggery, a skinyard and tools on the spit were completely washed away causing damage of approximately £400 (W.C.T. 10/02/1872) (ibid)

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4-5 November 1926

Westport experienced perhaps its most disastrous flood when the Buller River broke its banks and flooded practically the whole town. Hundreds were rendered temporarily homeless, and many lost all their belongings when flood waters entered their homes. At the peak of the flood the Buller River was within a metre of the top of the combing and at Te Kuha the discharge was estimated at 7645 cumecs from 6060 square kilometres, although it is now believed that the discharge must have been much greater as the peak was some feet higher than the May 1950 flood the peak flow of which was determined by an accurate slope-area determination.

The flood water lapped over the top of the caps of the Buller railway bridge at the height of the flood, and an enormous white pine 32m long got across Piers 11 and 12, knocking pier 12 22cm downstream. Pier 13 scoured out and sank 30 cm in the upstream side. The damage to public services amounted to £50,000. In the Murchison area, where 78mm of rain fell in twelve hours, serious damage occurred when the Longford Bridge over the Mangles River was washed away, and farmers suffered damage to farms through inundation and flood water. At Fern Flat the river rose 12.1m above normal, and the occupants of one home were forced to break a hole in the ceiling to escape the flood waters. At their confluence the Tutaki River peaked at 140 cumecs off 65 square kilometres. In the Reefton area some bridges were washed away and many roads were damaged. Buller county roads suffered damage amounting to £7,320 and the Murchison county damages totaled £11,480 (ibid).

An online search has also located several flood photos from the 1926 flood. Figure 1-2 shows a picture from the 1926 flood likely well after the peak of the flood and waters have begun to recede.

Figure 1-2 – Photograph of Westport Town centre after the 1926 flood event

28-31 August 1970

The Buller River rose to reach the top of the arch at Hawkes Crag but this was about 2.7m lower than the 1926 flood. At Berlins the water line was about 2.5 m below the level of the road which was also about 2.7m lower than 1926 (w.C.B. File 375). A discharge of 8497 cumecs flowed down the Buller at Te Kuha (W.C.B. data), and abuot 140 cumecs flowed down the Orowaiti overflow to the north of Westport. This overflow saved the town from serious damage. At Te Kuha the Buller rose 11m (W.C.B. File 375). Transport links to Westport were limited. The Upper and Lower Buller Gorges were cut by flood waters and slips, as was the Westport-Airport-Cape Fouldwind Road. The most serious problem in the district was the washout of the Waimea Bridge in the Karamea area, this isolating Karamea for some time (ibid).

Since the publication of the preceding text, the flood peak of the 1970 flood has now been refined to be 7568 m^3/s. Figure 1-3 shows a picture of flooding in Westport from the local newspaper. Further photos of this flood can be found in the document 'Westport flood mapping study progress report' (Duncan, 2003)

Figure 1-3 – Floodwaters in Westport during the 1970 flood event (Duncan, 2003)

PREVIOUS INVESTIGATIONS

The Buller River system has been investigated fairly extensively in recent history. Connell Wagner carried out a preliminary flood study (2000). That study discussed sediment transport within the river and included the construction of a MIKE 11 model of the river system. Whilst that study did estimate water levels for the main river for a range of flood events, the author emphasised that the conclusions were limited to the areas where cross section data exists.

In 2003, NIWA developed a 2-dimensional (2D) model of the river system (Duncan, et al., 2003) using a software package called Hydro2de. The model topography was made from a combination of ground survey, contour maps and photogrammetric imagery as well as a bathymetric survey of the river channel from Organs Island to the mouth which was carried out by jet boat (Duncan, et al., 2003). The model had a grid size of 7 m and was calibrated to the 1970 flood extent. It was found that it was not possible to calibrate the model by only adjusting roughness coefficients to the 1970 flood levels; calibration was finally achieved by introducing a significant amount of scour to the main channel.

In 2012, NIWA refined this model further using recently available LiDAR data. The grid size of the model was reduced to 4.8 m and the model was refined further to the 1970's event by introducing a larger degree of scour in the main channel again. Bed levels in the Orowaiti Channel were not surveyed and were assumed. Bed levels in the Orowaiti Lagoon were lowered to allow for a significant amount of scour immediately downstream from the main Orowaiti Bridge.

Flood maps were produced for design events and locations for potential stopbanks were determined in order to protect the town from significant flooding. It has recently been discovered however that the main railway trestle bridge on the Orowaiti Overflow path was not included in this model and was instead represented as a closed embankment. (Duncan per comms, 2015) This caused for significantly less water to travel down to the Orowaiti Lagoon and caused the flood maps to be in error.

2. MODEL BUILD

An integrated 1D/2D model of the Buller River and floodplain has been constructed using the MIKE Flood software package. MIKE Flood is an advanced, industry leading software package by the Danish Hydraulic Institute (DHI), and is used in a large number of major investigations in New Zealand as well as internationally.

There are three main components of the MIKE Flood model, these are the MIKE 11 model, the MIKE 21 model and the MIKE Flood Component, which essentially links these two models together.

The MIKE 11 model is essentially a representation of the main river channel and includes structures such as bridges and culverts. MIKE 11 solves the one dimensional (1D) St Venant equations and therefore assumes that the water is flowing in a line (ie 1 dimension). The assumptions necessary for these equations to be considered valid can be largely met within a confined river channel.

The MIKE 21 model is a representation of the adjacent floodplain. MIKE 21 solves the two dimensional (2D) Navier Stokes equations, which allow water to flow in both the x and y directions (ie 2D). These equations are considerably more time consuming to solve and therefore it is necessary to divide the floodplain up into a grid system. The finer the grid selected, the greater the run times will be.

The MIKE Flood component of the model dynamically links the MIKE 11 and MIKE 21 models together allowing water to spill from the river channel onto the floodplain and vice versa.

The integration of the 1D and 2D models allows for a more detailed representation of the river system, allowing for the effects from structures such as bridges to be more accurately represented in the model, which cannot be easily represented in a purely 2D model.

The model set up is detailed below.

MIKE 11 MODEL

NETWORK

The MIKE 11 network has been set up to represent the main Buller River channel as well as small sections of channel on the floodplain where structures such as bridges and culverts are located. The final section of the Orowaiti River has also been represented in MIKE 11, allowing for the 2D domain to be reduced and ultimately reducing run times and improving model stability.

Significant bridges have been represented within MIKE 11 using the bridge module. Five bridges are represented in the model using the bridge module. These bridges are the main Buller River Bridge, the main Orowaiti road bridge, main railway Embankment Bridge on Nine Mile Road as well as two bridges on Stephens Road under the railway tracks. Further details of the modelled bridges are included in Appendix A.

CROSS SECTIONS

A cross section survey was most recently carried out on the Buller River in March 2014 and has been used in the MIKE 11 model. Due to the spacing of the cross sections, it was necessary in certain locations to interpolate additional cross sections to ensure a reasonable representation of the river channel within the model. The location of surveyed cross sections as well as interpolated sections are shown in Figure 2-1 below.

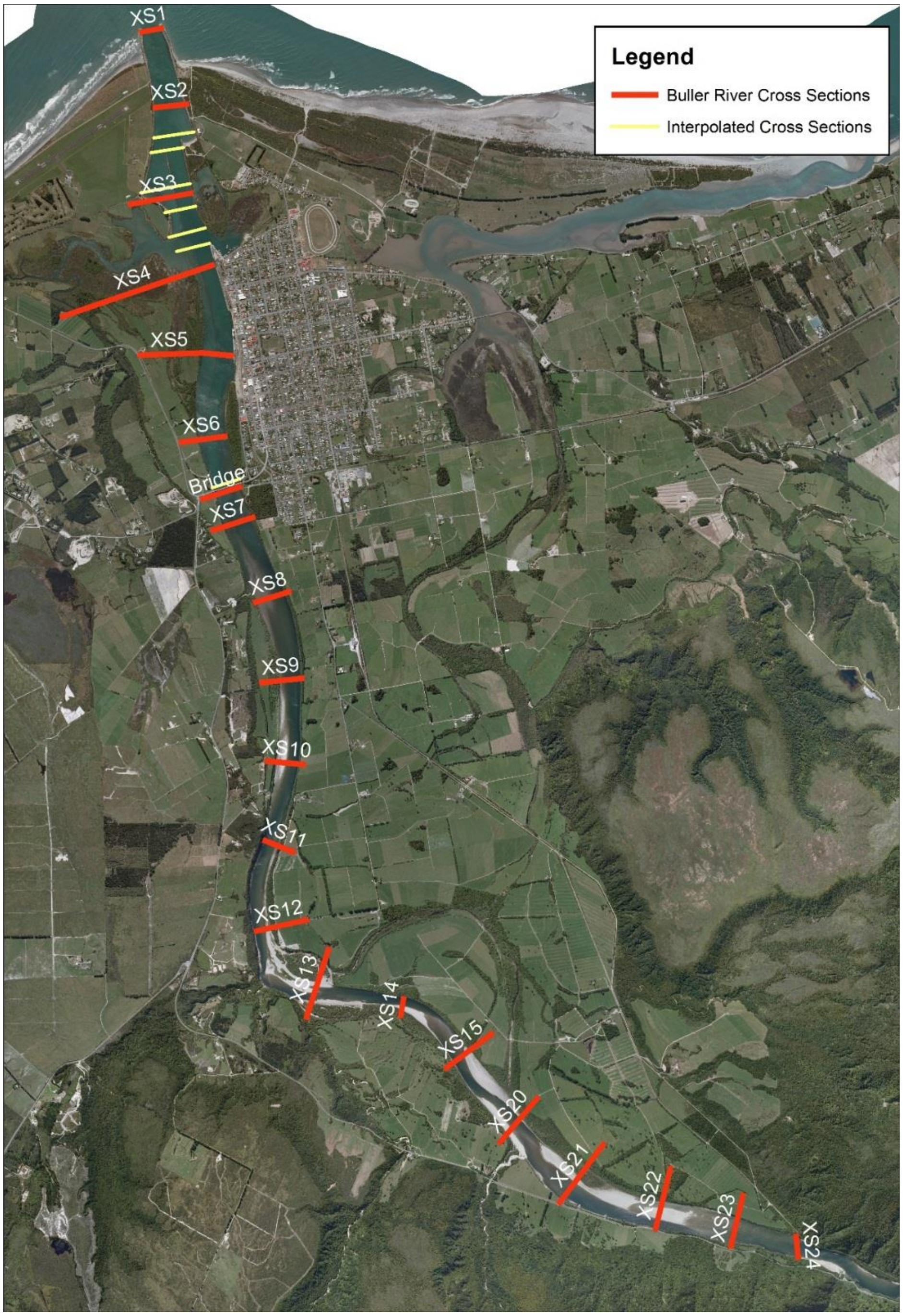

Figure 2-1 – Buller River modelled cross section locations

BED RESISTANCE

Bed resistance has been represented in the model as a Manning's 'n' value. Earlier work carried out by NIWA has included an investigation into sediment size distributions at a range of locations down the river (Duncan, et al., 2004). This information has been used to determine a suitable range of values for Manning's 'n' based on the rigid bed Griffith's formula (Flow Resistance in coarse bed rivers., 1981) as well as Strickler's formula. Final adopted values lie in the range of 0.028 to 0.033 based on calibration as detailed in Section 3 and closely match the values calculated with the Strickler's Formula.

The two 'rigid bed; formulae recommended by Griffiths are presented below:

Method 1: $\frac{1}{\sqrt{f}} = 1.33(\frac{R}{d_{50}})^{0.287}$

Method 2: $\frac{1}{\sqrt{f}} = 1.98log_{10}\left(\frac{R}{d_{50}}\right) + 0.76$

Where: f = Darcy-Weisbach friction factor

R = hydraulic radius

d_{50} = size for which 50% of the bed material is smaller

Strickler's formula is presented below:

$$n = \frac{1}{21.1} {d_{50}}^{1/6}$$

Table 1 – Buller River Mannings's 'n' values

Cross Section	Chainage	Method 1	Method 2	Strickler Formula	Adopted Manning's 'n'
25	0				0.028
24	668				0.028
23	1288				0.028
22	2015				0.028
21	2907	0.028	0.031	0.029	0.028
20	3713	0.038	0.038	0.034	0.031
15	4536	0.036	0.036	0.033	0.033
14	5302	0.034	0.034	0.03	0.033
13	6147				0.033
12	7066				0.032

11	7904				0.032
10	8677	0.029	0.032	0.03	0.033
9	9466				0.029
8	10267				0.029
7	11038	0.03	0.032	0.029	0.028
Bridge	11349				0.028
6	11861				0.029
5	12647				0.029
4	13496				0.029
3	14214				0.029
2	15058				0.029
1	15787				0.029

BOUNDARY CONDITIONS

Boundary conditions are necessary in locations where water enters or exits the model domain. The primary boundary conditions in the model are:

- At cross section 24 where water enters the model
- At cross section 1, where water exits the main river into the sea.
- At the mouth of the Orowaiti River, where water exits to the sea.

FLOW INPUTS

Peak flow inputs for the 50 and 100 year flood events have been based on 2014 estimates made by NIWA (Duncan, et al., 2014). It should be noted that the peak flow estimates have increased in the order of 4.4% from previous estimates by McKerchar (2004) which were adopted in recent studies.

Ministry for the Environment (MfE) guidelines recommend allowing for the estimated effects of climate change when producing flood maps (Woods R, 2010). In order to incorporate climate change predictions into the modelling, design peak rainfall intensities have been increased based on the mid-range predictions (A1B Scenario). This scenario allows for an increase in average temperatures by 2°C by 2090 and allows for an increase in peak rainfall intensities by 16%. An estimate of the ratio between this increase in rainfall intensity and the corresponding increase in peak flow has been based on published results from NIWA's topnet model of the Buller Catchment (H. McMillan, 2012). This study reports that peak flows for a 50 year flood event are likely to increase by 9.12% under the A1B scenario up to 2090. It has been assumed that this ratio will remain consistent for the 100 year event. It should be noted that an increase in flow of only 9% in relation to an increase in rainfall intensity of 16% is very low compared to many other catchments in New Zealand. The reason for this has not been investigated as part of this study and the NIWA values have been adopted at face value.

Adopted peak flow rates are summarized in Table 2 below.

Table 2 – Summary of adopted peak design flows

Return Period	Peak Flow (m^3/s)
50 year	8920
50 year including climate change	9780
100 year	9750
100 year including climate change	10686

HYDROGRAPH SHAPE

Hydrograph shapes for the 50 and 100 year flood events have been based on those adopted in the 2010 NIWA modelling report and scaled to the new flow estimates. These hydrograph shapes were based on an average from the 5 largest events on record in the catchment (Duncan, et al., 2010). Input design hydrographs are presented below in Figure 2-2.

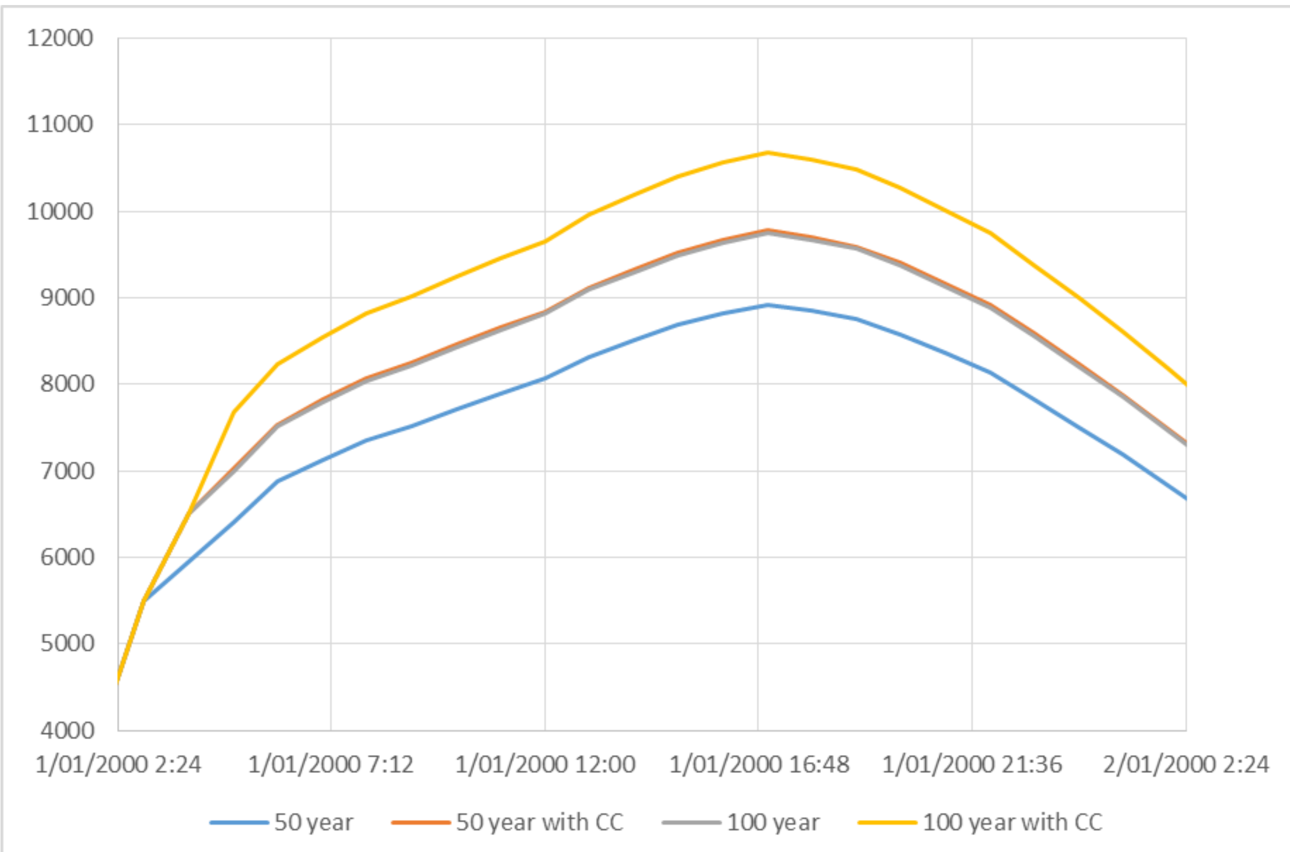

Figure 2-2 – Input Design Hydrographs

TIDE BOUNDARIES

Tidal levels have been based on levels in the tide charts downloaded from the Land Information New Zealand (LINZ) website (www.linz.govt.nz). Tide levels have been converted from the Westport chart datum into the Lyttleton Vertical Datum which is the datum of the model. The tidal profile has been taken from recorded data at the Buller Port level recorder and adjusted so that the peak level matched the desired peak tide level. The adopted design tide level has been based on the Mean High Water Spring (MHWS) which is defined as the tide level which is likely to be exceeded 10% of the time.

A joint probability analysis has been conducted by staff at NIWA using historical records from the Charleston Tide recorder and the Buller River 'Te Kuha' flow gauge in order to determine the joint probability between the river discharge and storm surge (Duncan, 2005). This analysis concluded that events greater than 2500 m^3/s in the Buller River showed significant correlation between peak river flow and storm surge elevation. The study concluded that for a 2% AEP (1 in 50 year) flood event occurring in winter, a concurrent storm surge of 0.59 +/- 0.22 m is likely.

Previous studies by NIWA (Duncan, et al., 2010) have demonstrated however that the combined probability however of a storm surge of 0.6m coinciding with a MHWS would be a very rare event. After discussions with Dr Michael Allis (Coastal Engineer, NIWA) it was decided that a storm surge component of 0.4m combined with a MHWS would be a suitable tidal condition for design scenarios.

MIKE 21 MODEL

DEM

A Digital Elevation Model of the ground levels has been created using a range of data sources, which include:

1. 2008 LiDAR
2. 2014 Bathymetric Survey
3. July 2014 ground survey (Chris J Coll Surveying)
4. NIWA DEM (2010 model)

Figure 2-3 shows the locations where each of the data sources has been obtained from. Areas not highlighted on the following Figure have been taken from the DEM produced by NIWA which is reportedly based on a combination of contour plans and ground survey. (Duncan, 2010)

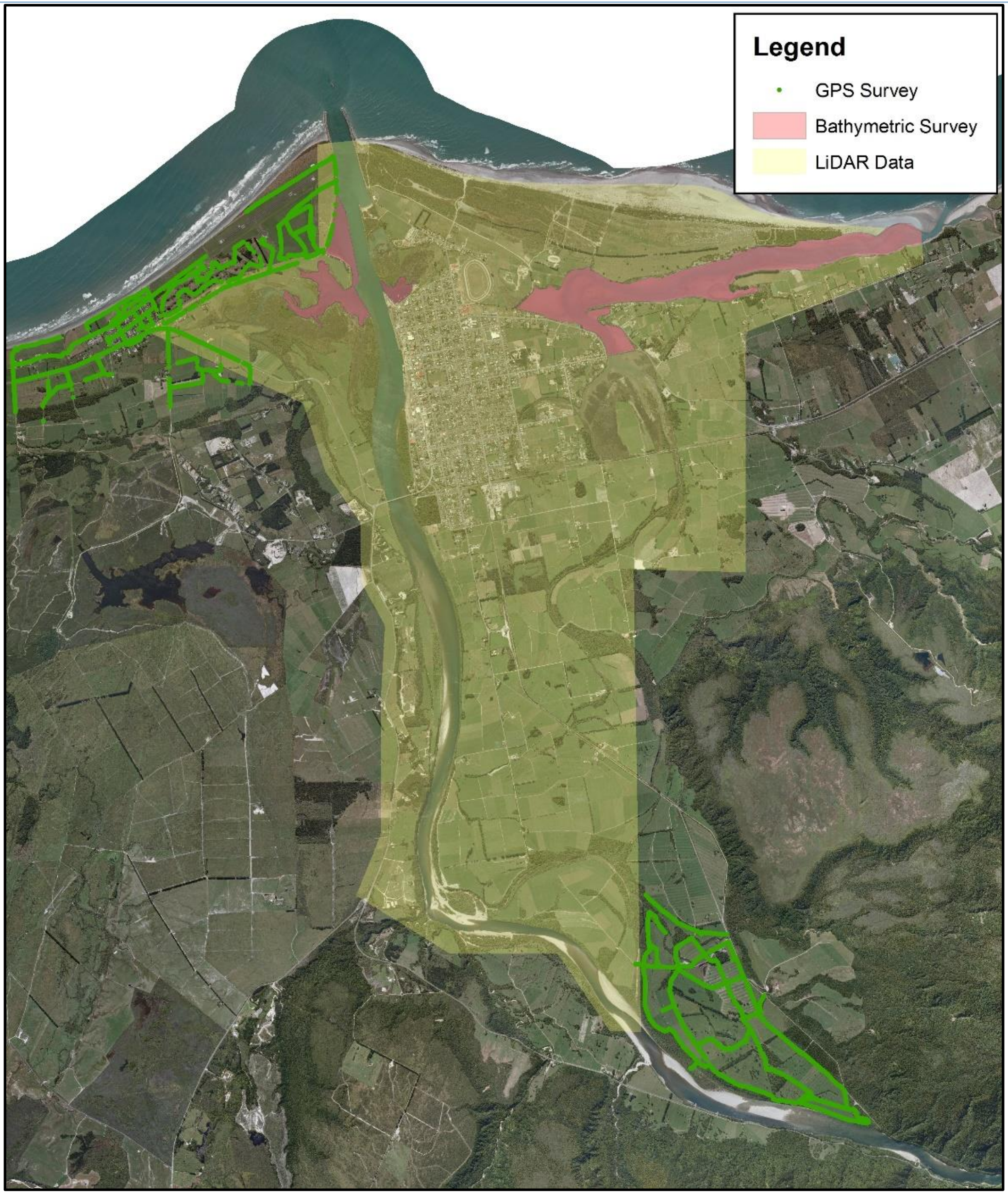

Figure 2-3 - Data sources for base terrain DEM used in the model

The LiDAR was compared with ground survey data in a range of locations on the flood plain. In general it was found that the LiDAR differed by 0.15 m from the ground survey downstream from the Buller River Bridge. Comparisons in areas upstream from this area did not show as noticeable a difference with the 2014 cross sections, however discussions with staff from Chris J Coll Surveyors has indicated that they have also carried out comparisons and found the shift to be fairly consistent. In order to rectify the difference between the data sets, the LiDAR values have been raised by 0.15 m to ensure they tie in with the provided ground survey data.

The size of the adopted grid impacts on the resolution of water levels as well as on model run times and size of result files. A grid size of 4.8 m has been adopted to remain consistent with the previous modelling carried out by NIWA, and is considered a reasonable compromise between the model resolution and model run times.

FLOODPLAIN RESISTANCE

Manning's 'n' values have been applied to the floodplain in order to account for the differences in resistance on the floodplain.

Table 3 outlines the Manning's 'n' values which have been used in this model.

Table 3 – Manning's 'n' values applied in model

Land Type	**Manning's 'n'**
Grass	0.035
Roads	0.015
Residential	0.125
Commercial/Industrial	0.1
Vegetation	0.08-0.12

MODEL PARAMETERS

Standard parameters have been applied in the model. A model timestep of 0.25 seconds has been selected, signifying that the model calculates a water level four times every second. This timestep was found to be necessary in order to remove minor instabilities at several of the structures in the model.

MIKE FLOOD LINKING

The primary linking of the 2D model to the 1D model is via a series of lateral links located on the banks of the Buller River. Lateral links allow the water level at a given location in the MIKE11 model to be transferred into the MIKE 21 model once the level exceeds the defined bank height at the link location. The location of the lateral links is shown in Figure 2-4 below.

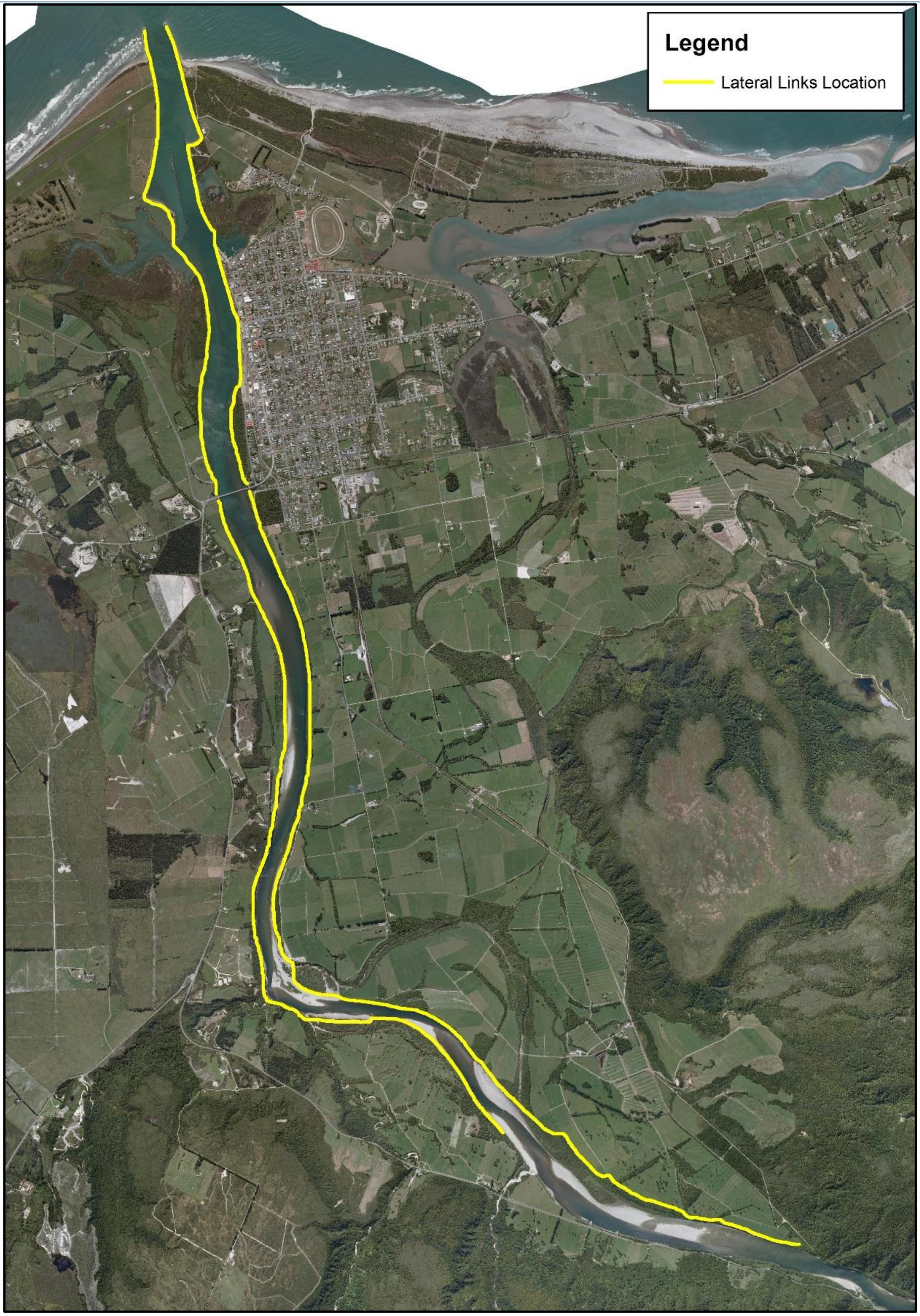

Figure 2-4 – Location of modelled lateral links

3. MODEL CALIBRATION

Previous models have relied on data from the 1970 flood event for model calibration. Whilst this was the best that could be done at the time, it can be problematic due to the fact that there are potentially a range of unknown changes to the river system and general catchment in recent years.

In July 2012, a significant flood event occurred within the catchment, the flood has a recorded peak flow of 7568 m^3/s at the Te Kuha gauge, equating to an estimated return period of 20 years. In order to assist with the model calibration process, information on the flooding was sourced from a range of sources.

AERIAL PHOTOGRAPHY

Aerial photos of the flood extent were taken by WCRC staff during the flood event. These are invaluable for model calibration. Figure 3-1 to Figure 3-13 show a range of aerial flood photos taken during the event.

Figure 3-1 – Flood level at Buller River Bridge

Figure 3-2 – Flooding on true left bank

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Figure 3-3 - Orowaiti Lagoon flooding

Figure 3-4 – Flooding in Westport Town

Figure 3-5– Orowaiti overflow flooding

Figure 3-6 – Flooding in the vicinity of Soapworks Road

Figure 3-7 – Flooding at Buller Bridge (Stuff, 2012)

Figure 3-8 - Flooding in local park (Stuff, 2012)

Figure 3-9 – Flooding at Martin's Bend (Stuff 2012)

Figure 3-10 – Peel Street flooding (Stuff, 2012)

Figure 3-11 – Flooding in Westport (Stuff, 2012)

Figure 3-12 – flooding (3 News, 2012)

Figure 3-13 – flooding (3 News, 2012)

SURVEYED WATER LEVELS

Survey levels of maximum water heights were also provided by Chris J Coll surveyors, these levels are invaluable in assisting with the calibration of a model. These levels are not precise should only be considered as a guide due to the fact that they are based on debris marks left in the location after the flood event as well as anecdotal comments from landowners after the flood event. Figure 3-14 shows the location of the surveyed water levels.

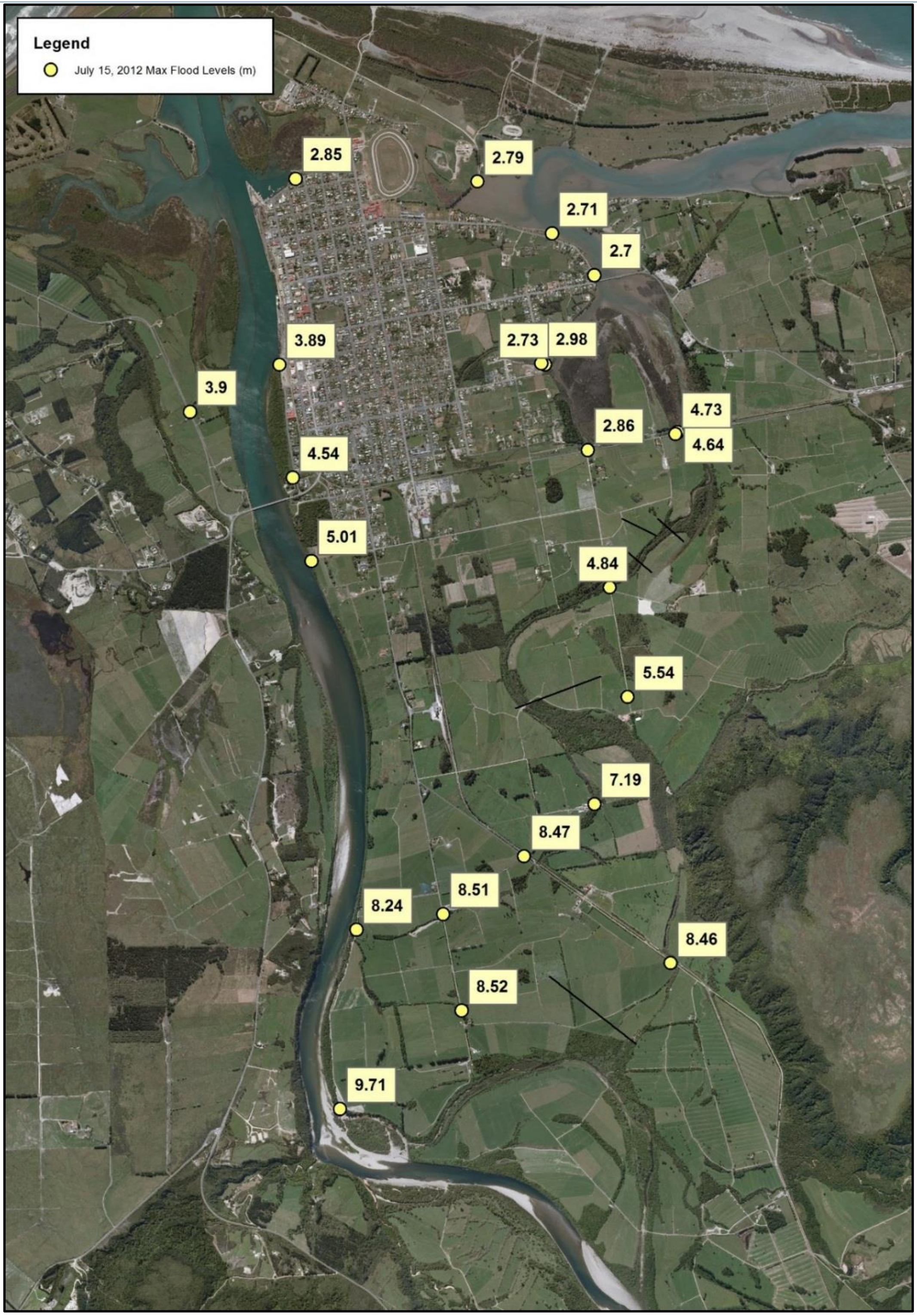

Figure 3-14 – Surveyed maximum flood levels from the July 15, 2012 flood event

SEA LEVEL DATA

Two sea level gauges were in operation in July 2012. The first of these is monitored by LINZ and is located at the Westport Harbour. This gauge has been tied into the local survey datum and provides actual levels.

It should be noted however that raw data from the gauge needs to be subtracted by 0.118m to provide actual levels due to a discrepancy found during calibration. The second gauge is the Charleston gauge which was operated by NIWA, however due to a lack of funding was discontinued at the end of July 2012. This gauge was never tied into any local datum so only provides relative levels.

Data was obtained from both gauges, however unfortunately the Westport gauge was not working properly from the 10th to the 18th of July and did not manage to record the sea level during the flood event of the 15th of July.

In order to make an assessment of the levels of the sea on the day, data from the NIWA operated tide gauge at Charleston were analysed. Data from the 18th to the 31st of July was plotted and compared to determine if there were any significant differences in behavior of sea level at the two sites. Examination of these plots shows that both gauges show a similar trend, however the Charleston gauge appears to be more open to interaction with waves at sea. Figure 3-15 shows a plot of the raw data from both data sets.

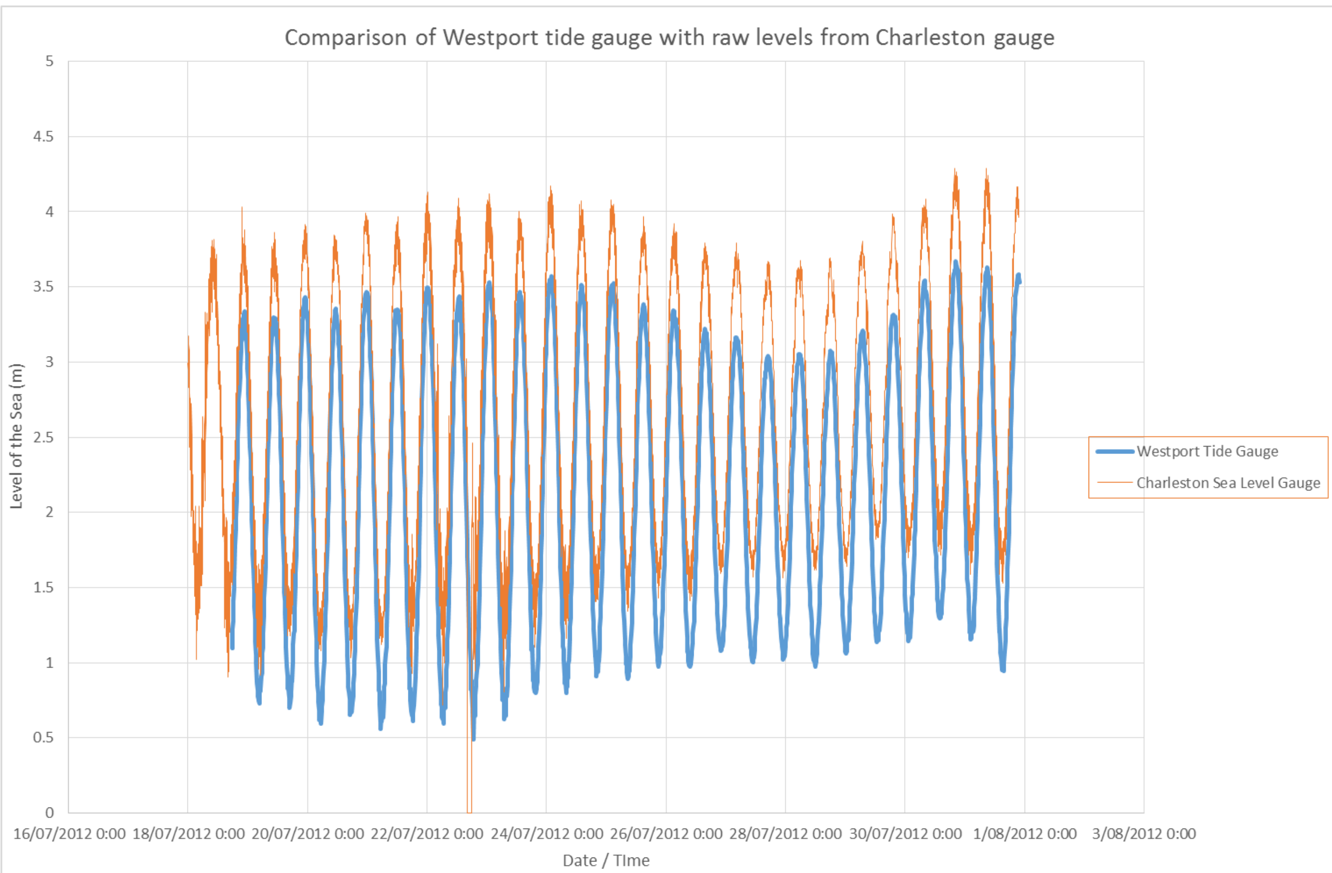

Figure 3-15 – Comparison of raw data from the Westport and Charleston sea level gauges

The mean sea level (m.s.l.) for both data sets was calculated over this time period and was found to differ by 0.5 m. The Charleston data was hence lowered by 0.5m to convert it to the same datum as the Westport tide data. A plot of the adjusted Charleston gauge data compared with the Westport gauge data is shown in Figure 3-16.

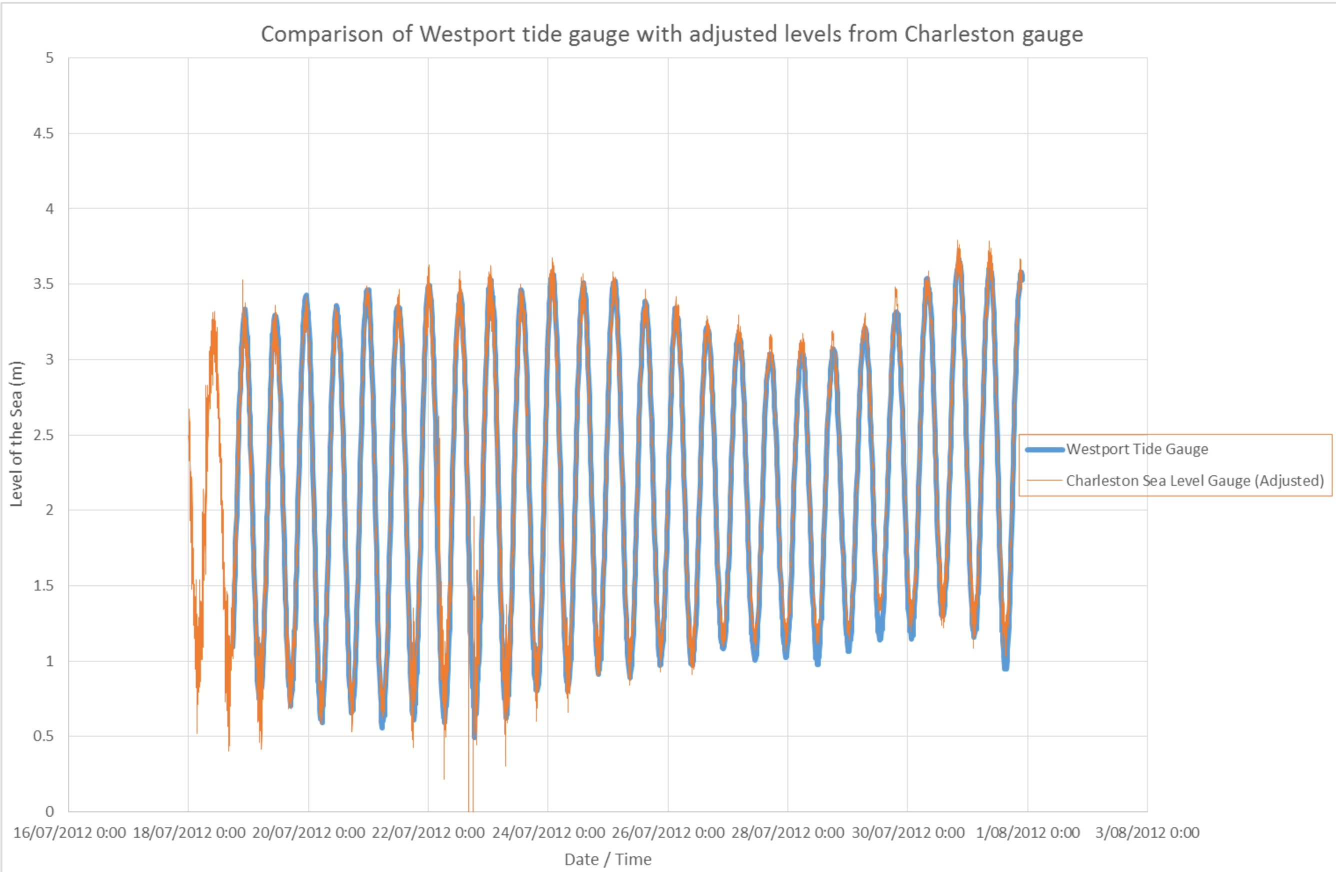

Figure 3-16 – Comparison of data from the Westport tide gauge with the adjusted levels from the Charleston sea level gauge

The electronic Westport gauge readings have reportedly been calibrated and found to over report by 0.118 m (Graham per comms, 2014). In order to convert levels from the Westport gauge to Lytletton m.s.l. levels need to be reduced by 0.118 m to put the levels in terms of the Wesport local chart datum and then reduced by a further 1.779 m which is the difference between the Lytlleton and Westport datums as reported by LINZ. The Lyttleton Vertical Datum is the datum which has been adopted in the model and is that which has been adopted by the Coll Survey as well as the LiDAR survey.

The recorded tide data from the Charleston gauge on the 15th of July 2012 was therefore adjusted according and adopted as the tide boundary for the model calibration. Figure 3-17 shows the final adopted tide boundary.

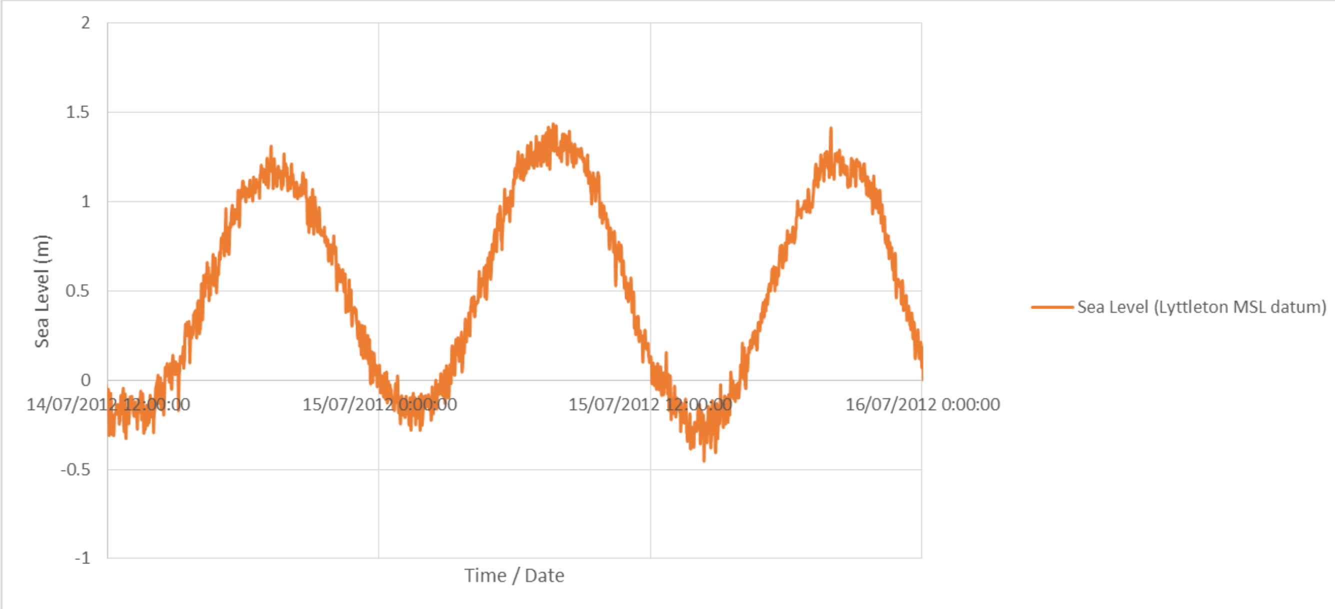

Figure 3-17 – Adopted sea level boundary for calibration run

Comparing the peak tide level with the predicted high tide level from the NIWA tide forecaster indicates that the recorded level of the sea is in the order of 0.25 m higher than the predicted level based on the tidal cycle alone. This gives a reasonable estimate of the storm surge component on the 15th of July.

CALIBRATION VARIABLES

The model was run using the recorded flows and tide levels from the 15th of July 2012 and the results were then compared to the observed levels and photography from the day. Model parameters such as the bed resistance were adjusted within reasonable limits in order to adjust the modelled water levels to more closely match observed levels. Parameters such as head loss coefficients were also adjusted at structures.+

LiDAR levels upstream of the Orowaiti Bridge were also lowered after a site visit and close inspection of the LiDAR data. It became apparent that the approximately 1m high dense reed grass was preventing the LiDAR from reaching the ground levels. Areas that are covered in dense reed grass have been lowered to approximately match the surrounding level of the mud. Figure 3-18 shows a photo of the area.

Preliminary results showed that the model was generally over predicting on the flood plain, in particular immediately downstream from the Orowaiti Bridge. Levels were generally too high in the main channel also, however to a lesser degree. These water levels were unable to be adjusted through lowering of resistance within reasonable bounds. Comparison of survey levels in the Orowaiti lagoon from 1999 with that in 2014 showed no significant difference in bed levels, and discussion with staff at both the Buller District Council and the West Coast Regional Council have suggested that bed levels are relatively static in the lagoon and did not lower by any noticeable amount after the flood event. This suggests that the flow gauge may be over estimating the flow during this event. All flow gauges in natural river systems have a significant level of uncertainty, in particular during large events, due to the fact that they are generally calibrated during relatively low flow events. Recent detailed investigations on the Wairau River located in the Marlborough District have shown that this gauge generally overpredicted in the order of 15% during flood flows (McMillan, et al., 2010)

Conversations with WCRC hydrology staff have determined that the flow gauge is calibrated several times a year to lower flows, however has never been calibrated during a significant flood event.

In order to attempt to improve the calibration of the model, reported flows from the Te Kuha gauge were scaled by a factor of 0.95. This reduction of flow is considered to be well within the expected bounds of error for the flow gauge.

Figure 3-18 – Reed grass preventing complete LiDAR penetration to ground level

CALIBRATION RESULTS

Differences between the peak flood levels are summarized in Table 4 for both the gauged flows as well as the flows scaled by a factor of 0.95 and are presented graphically in Figure 3-19 and **Error! Reference source not found.** below.

Table 4 - Comparison of modelled water levels with measured debris levels for the July 20, 2012 flood event.

	Difference from recorded Debris Levels (m)	
PointID	**95% Flow**	**100% Flow**
FL1	-0.37	-0.25
FL2	-0.46	-0.35
FL5	-0.16	0.01
FL6	0.10	0.33
FL7	-0.24	-0.05
FL8	-0.30	-0.10
FL9	-0.09	0.00
FL10	0.07	0.15
FL11	-0.66	-0.49
FL21	-0.20	-0.09
FL22	0.12	0.25
FL23	-0.11	0.02
FL24	-0.21	-0.05
FL25	-0.05	0.19
FL26	-0.04	0.20
FL27	-0.05	0.20
FL28	0.12	0.25
FL29	-0.14	0.01
FL30	0.08	0.15
FL31	-0.19	-0.01
Post FL1	0.10	0.23
Pump Station	-0.03	0.08
Absolute Average Error	**0.18**	**0.16**

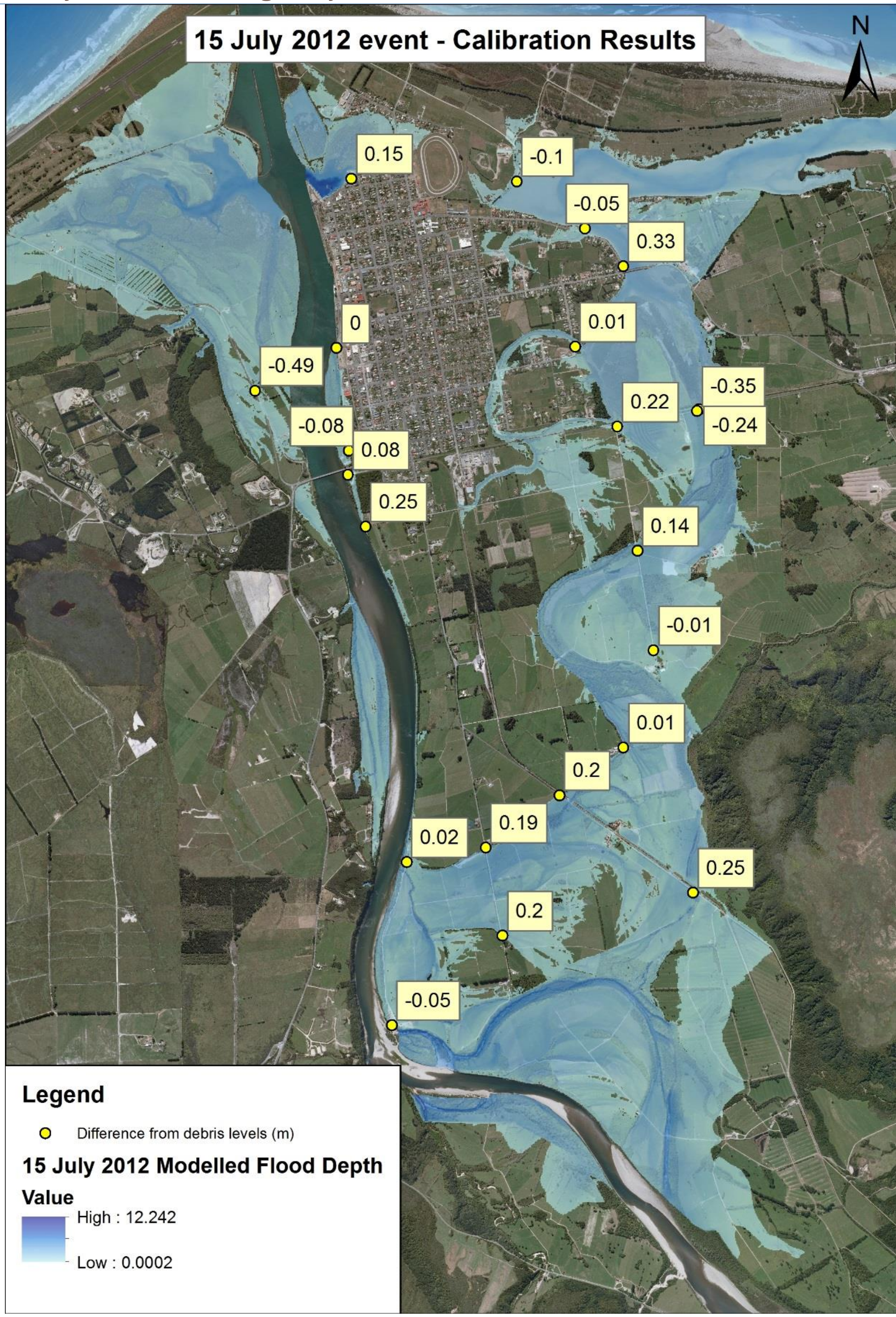

Figure 3-19 – Comparison of modelled water levels with measured debris levels for the July 15, 2012 flood event.

3D visualisations of the modelled flood extents were produced in GIS in order to compare with the aerial photography on the day in order to provide a further verification of the results.

Figure 3-20 – Comparison of calibration results with aerial photography at the Buller Bridge

Figure 3-21 - Comparison of calibration results with aerial photography upstream of the Buller River mouth

Figure 3-22 - Comparison of calibration results with aerial photography at Stephens Road

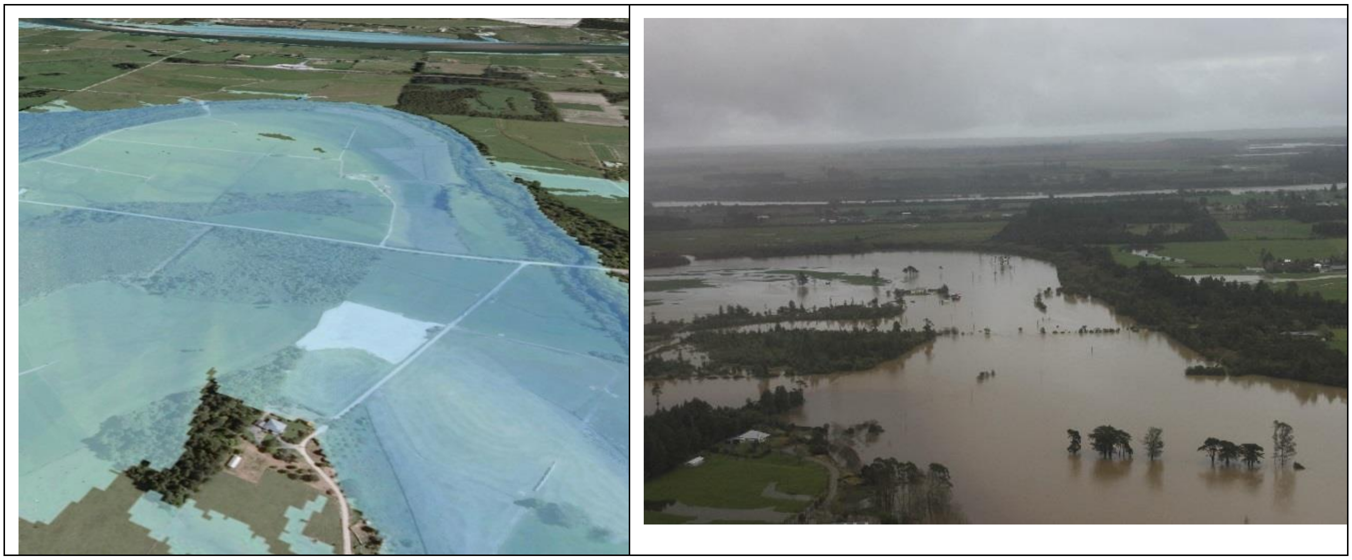

Figure 3-23 - Comparison of calibration results with aerial photography at Soapwoks Road

Figure 3-24 - Comparison of calibration results with aerial photography at Organs Island

4. DESIGN RUNS

Design maps have been produced for 50 year and 100 year rainfall events both with and without the predicted effects of climate change. The design runs have differed from the calibration runs in the following ways.

Three separate design scenarios have been presented in this report, differing only by the degree of blockage on the Buller River and Nine Mile Road Bridge. For the purpose of this report this blockage scenarios have been labelled as no blockage, medium blockage and high blockage. They have been represented in the model as follows:

No Blockage: This scenario assumes that no significant amount of debris builds up on any of the bridge piers.

Medium Blockage: This scenario allows for a moderate degree of blockage on the Buller River and Nine Mile Road Bridges. This scenario simulates the Buller River waterway being blocked by a further 10% and the level of the bridge soffit has been lowered by 0.5m, it also allows for a 5% blockage of the Nine Mile Road Bridge.

High Blockage: This scenario simulates a more significant degree of blockage on the Buller River and Nine Mile Road Bridges. This scenario simulates the Buller River waterway being blocked by further 15% and the level of the bridge soffit has been lowered by 0.75m. It also allows for a 10% blockage of the Nine Mile Road Bridge.

NB: During the 1926 Flood it has been recorded that a 32m long tree truck got stuck across two of the piers)

In all simulation the sand spit at the mouth of the Orowaiti River has been removed assuming that the flows are sufficient to remove this. Historical photos provide evidence that this gets partially blown out after increased flows in the Orowaiti River. The effect of likely scour at the mouth of Orowaiti has been replicated from the NIWA model (Duncan, et al., 2010). Sensitivity test have shown that this will only have a minor effect on flood levels, however has been included for consistency.

DESIGN FLOOD EXTENTS

The following figures present the design flood extents for the 50 and 100 year rainfall events with and without the predicted future effects of climate change.

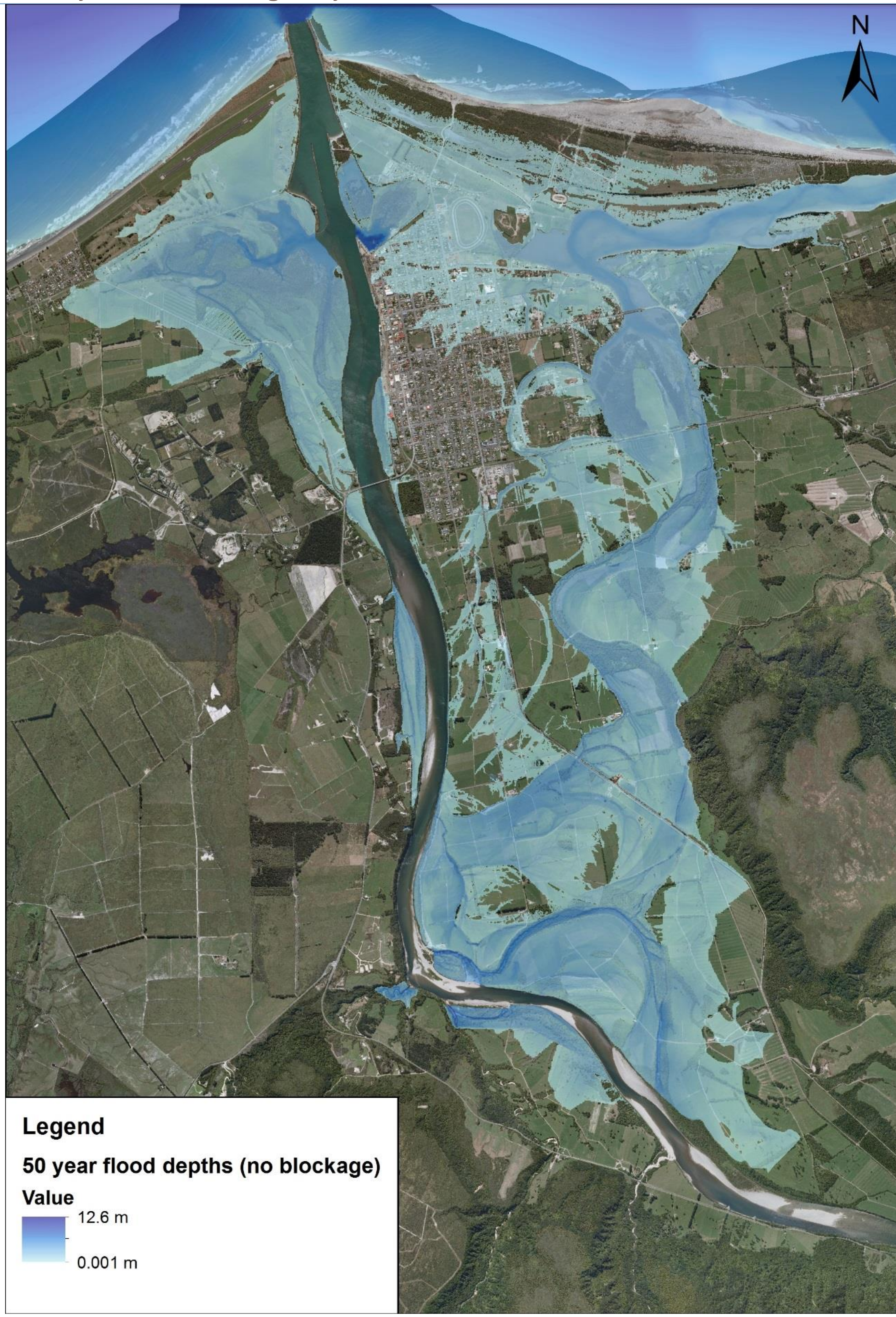

Figure 4-1 – 50 year design flood extent for the current climate - no blockage scenario

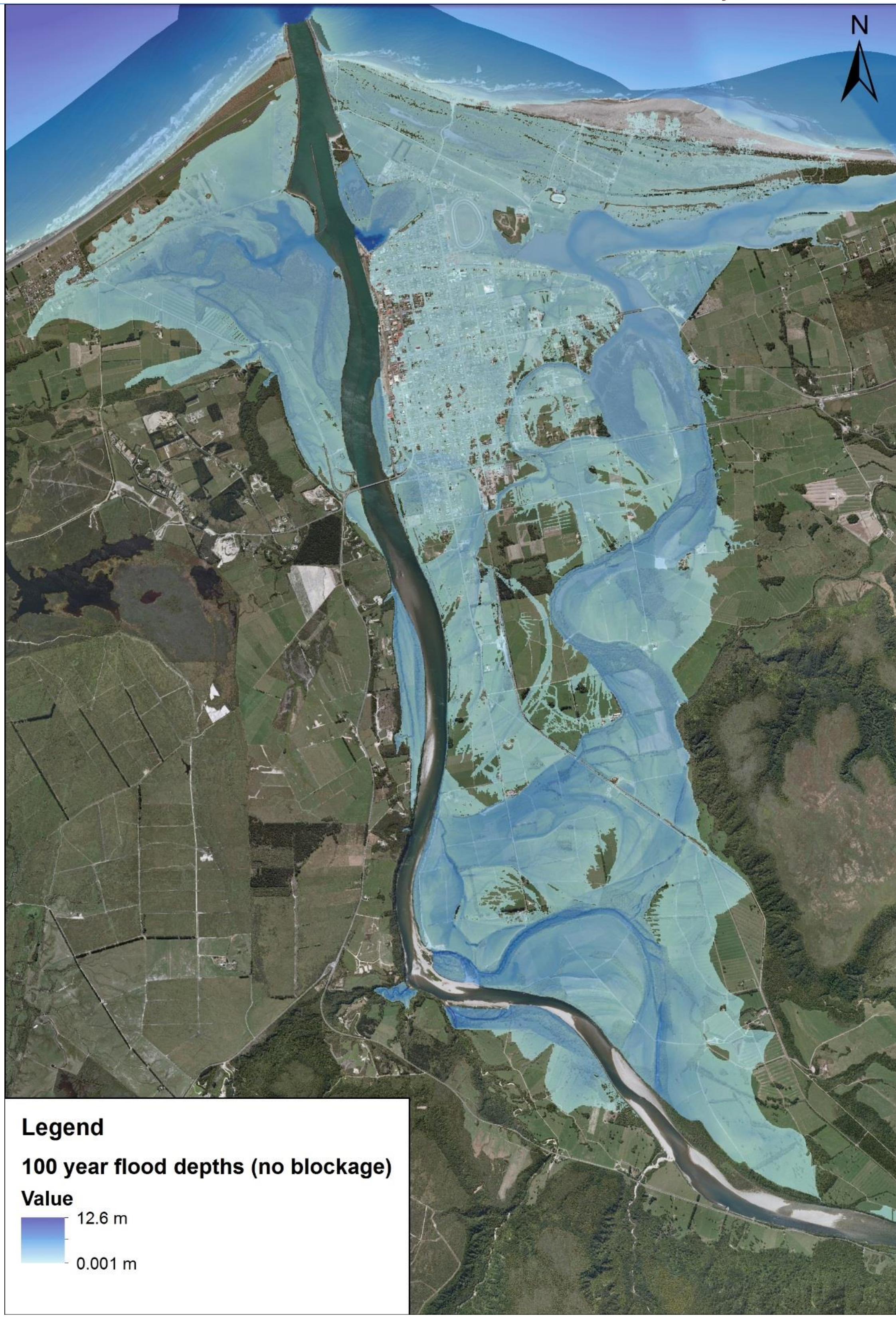

Figure 4-2 - 100 year design flood extent for the current climate - no blockage scenario

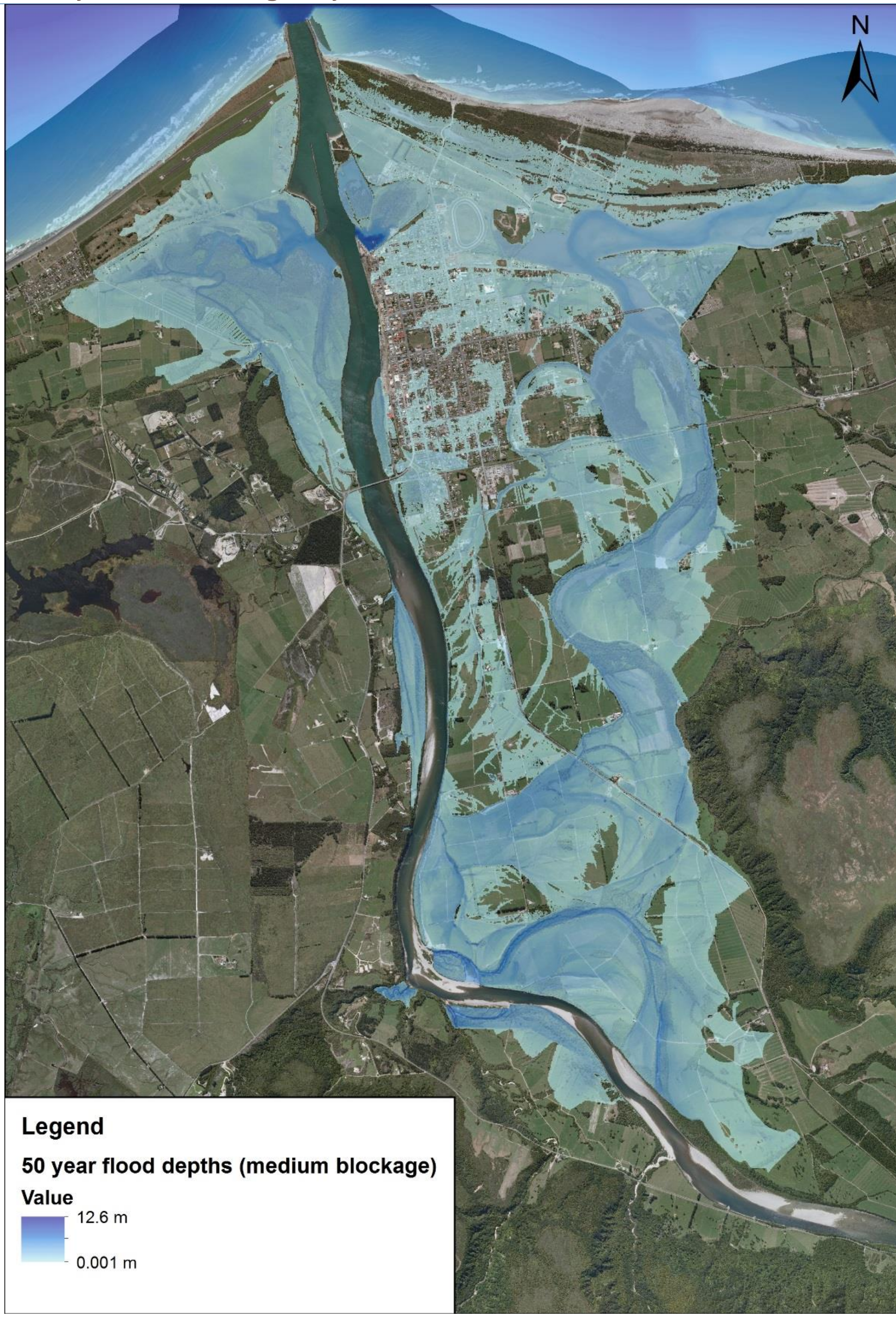

Figure 4-3 – 50 year design flood extent for the current climate - medium blockage scenario

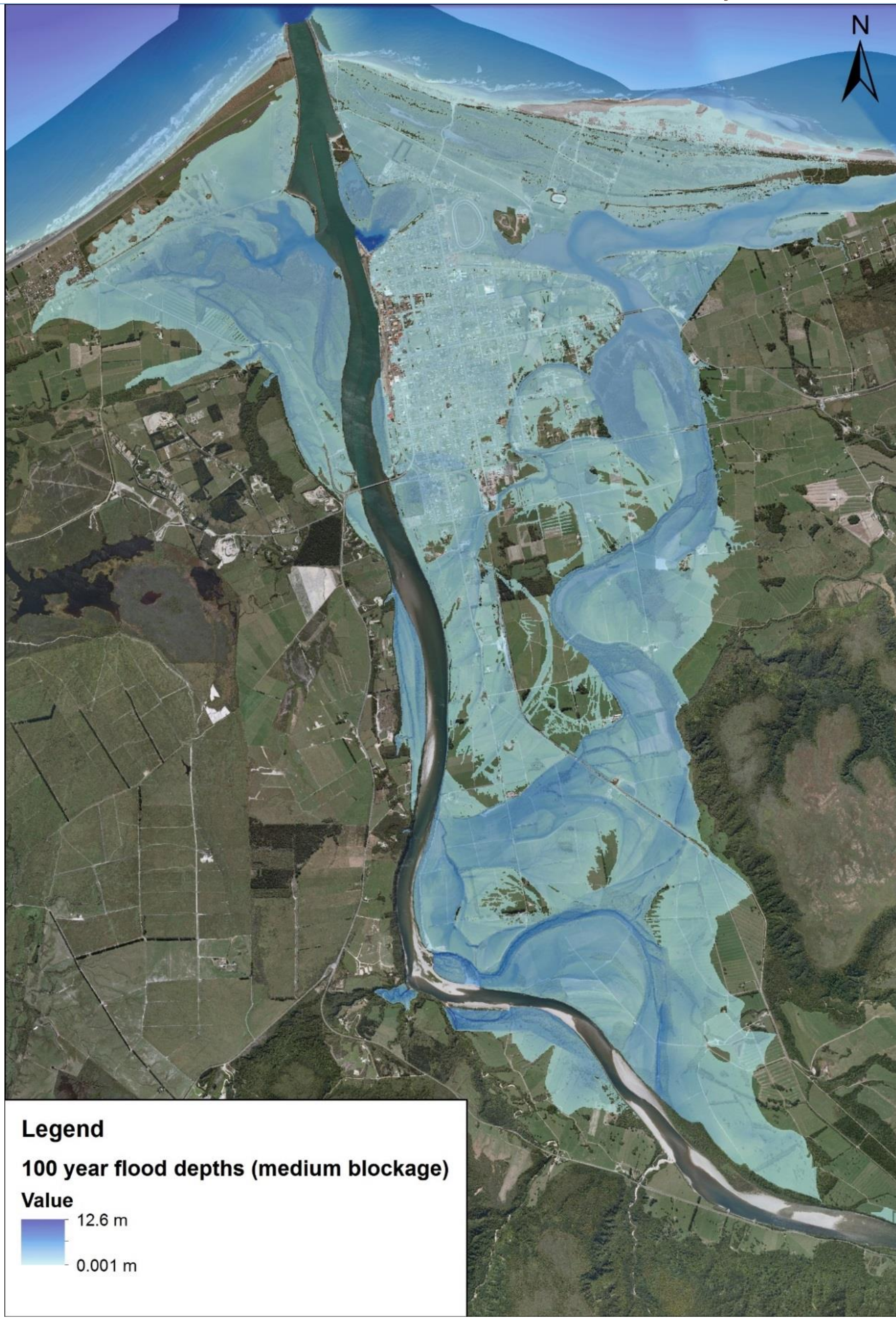

Figure 4-4 – 100 year design flood extent for the current climate (medium blockage scenario)

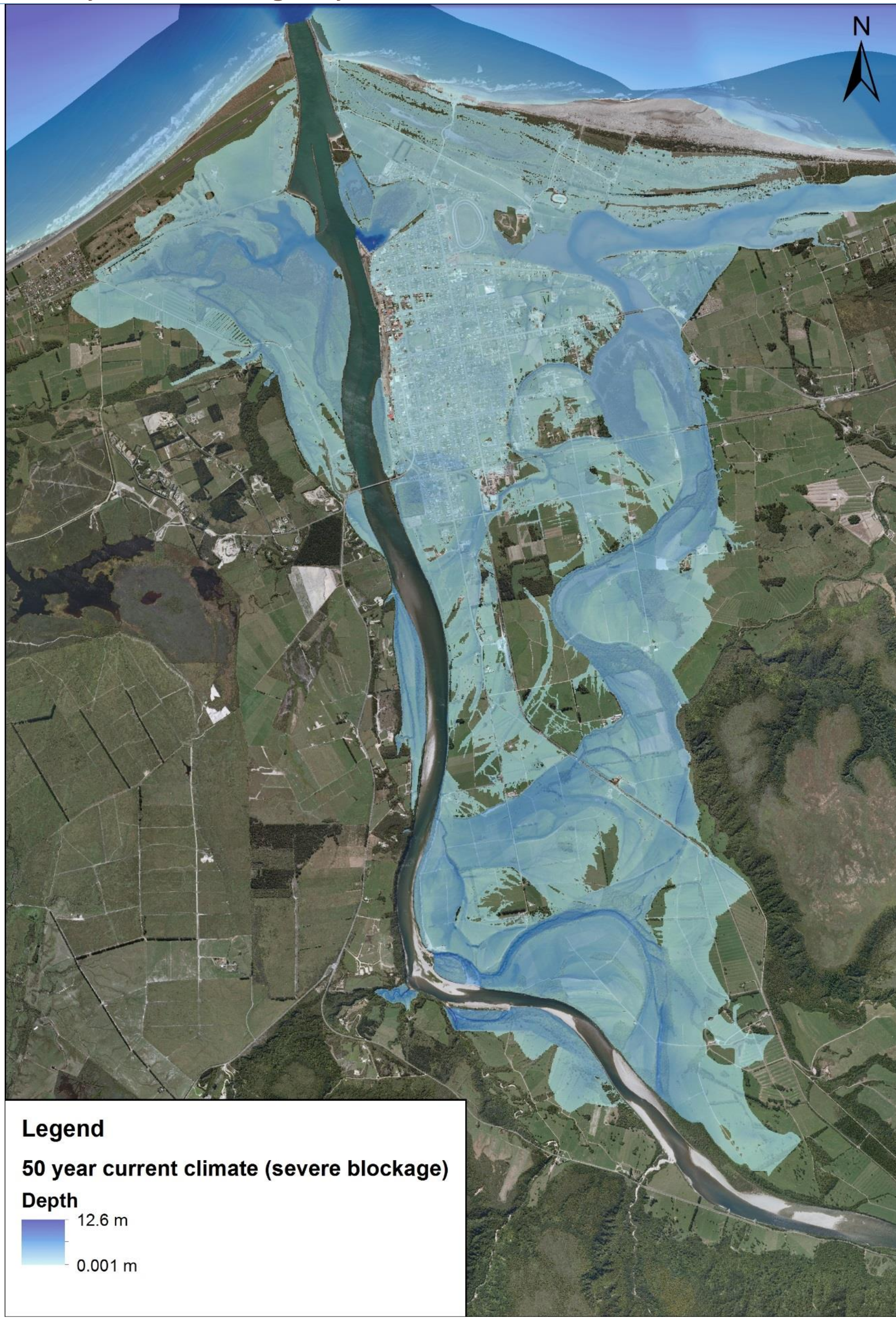

Figure 4-5 - 50 year design flood extent for the current climate (severe blockage scenario)

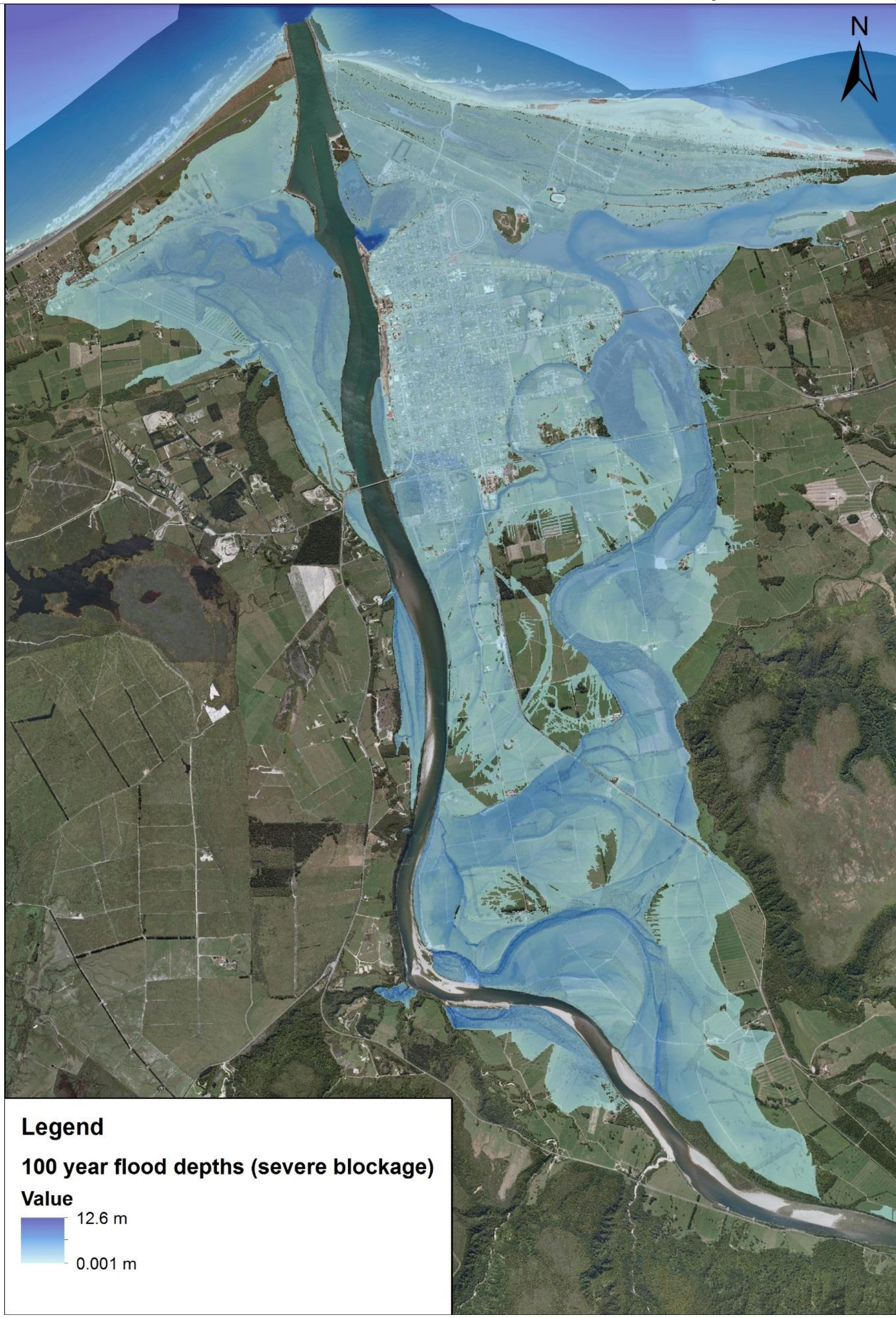

Figure 4-6 - 100 year design flood extent for the current climate (severe blockage scenario)

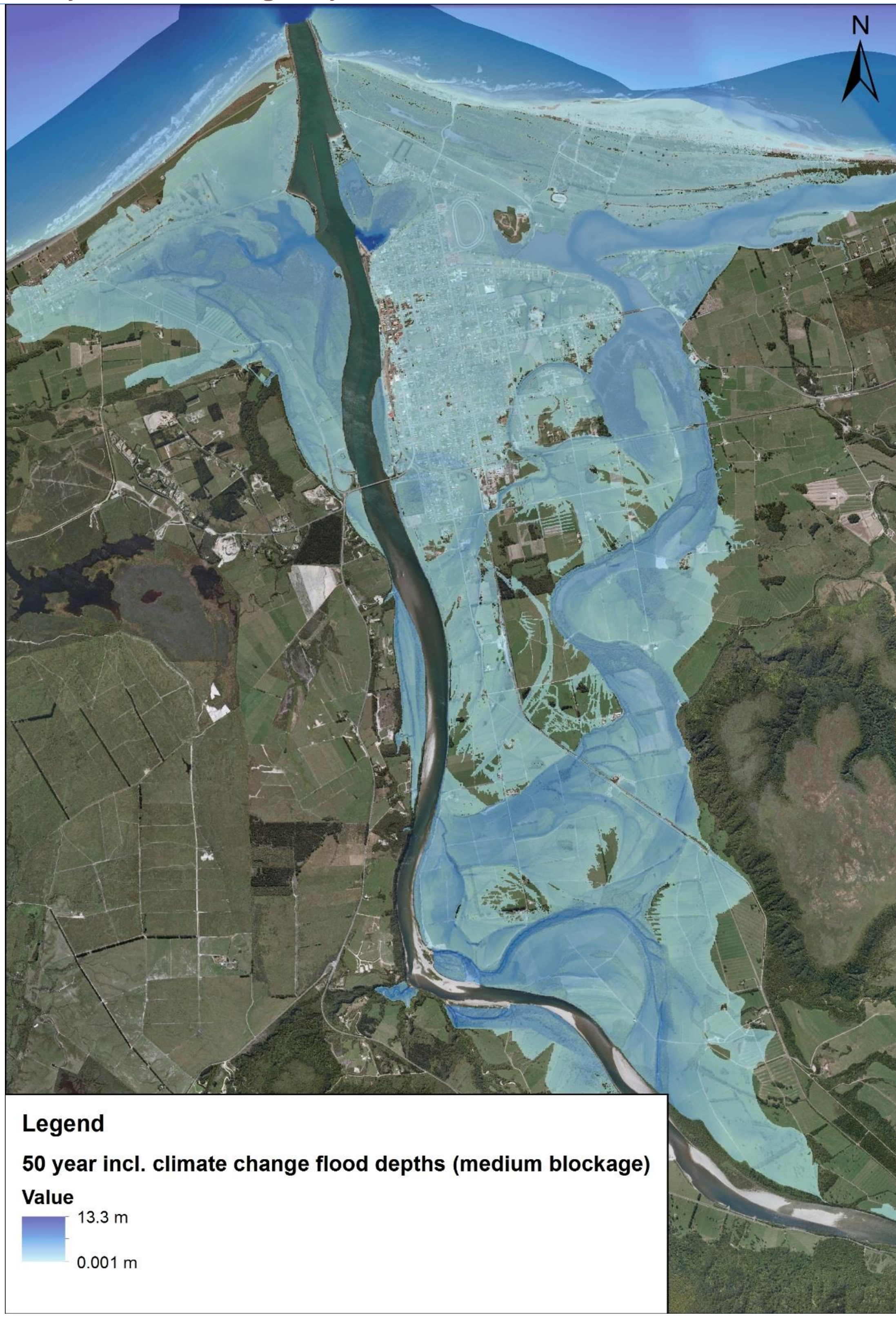

Figure 4-7 – 50 year design flood extent including predicted future effects of climate change (16% increase in peak rainfall intensity and sea level rise of 0.7m)

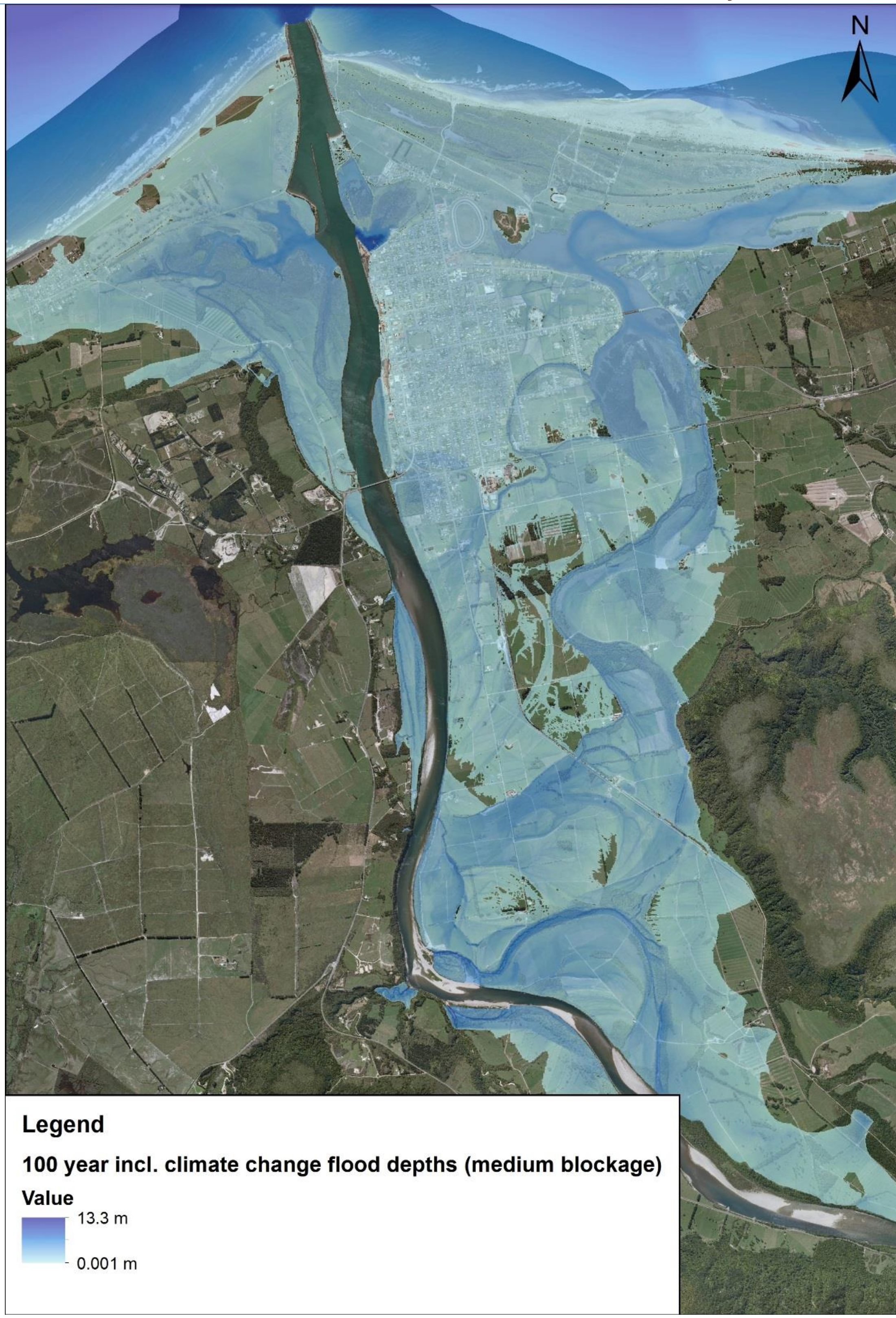

Figure 4-8 - 100 year design flood extent including predicted future effects of climate change (16% increase in peak rainfall intensity and sea level rise of 0.7m)

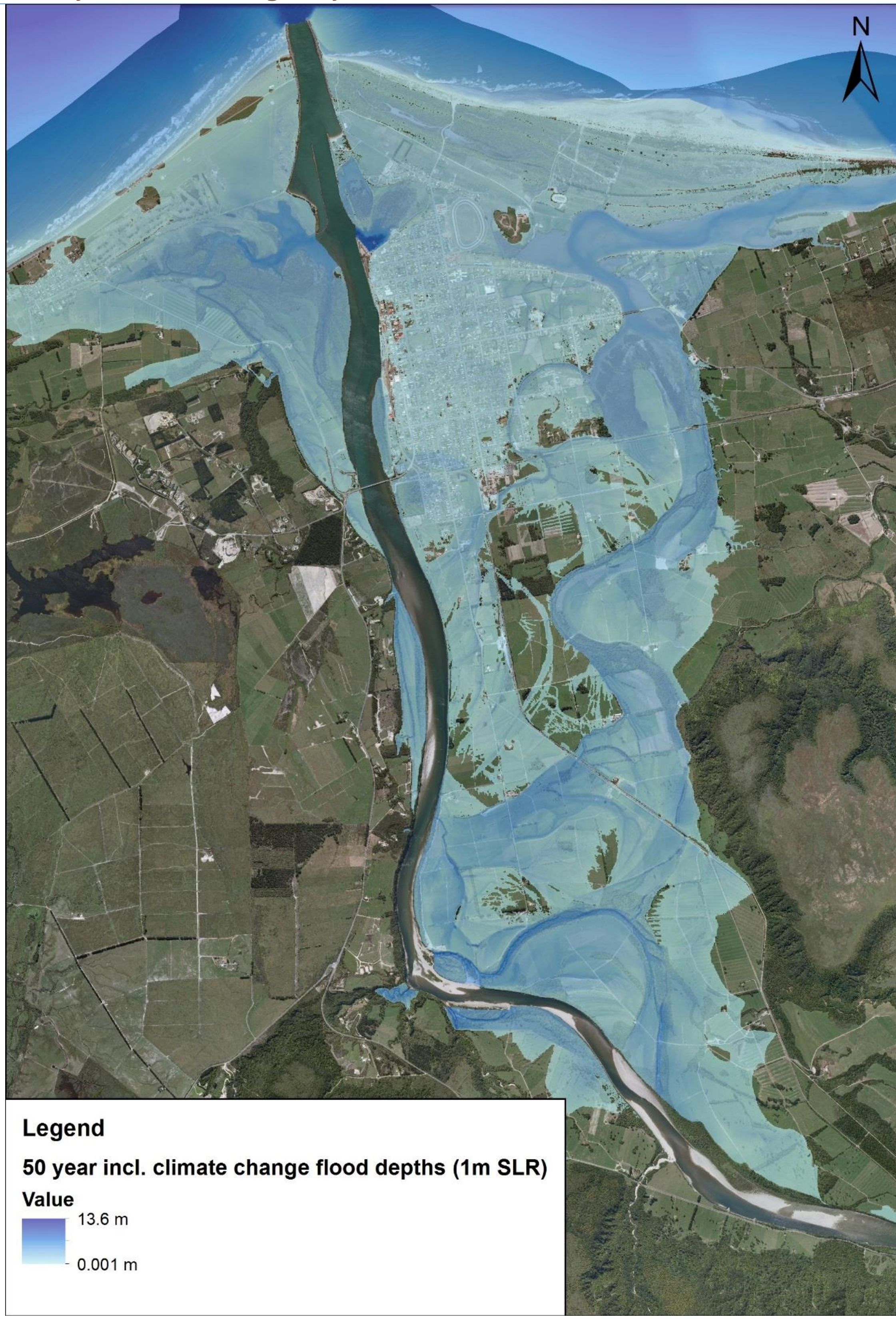

Figure 4-9 - 50 year design flood extent including predicted future effects of climate change (16% increase in peak rainfall intensity and sea level rise of 1m)

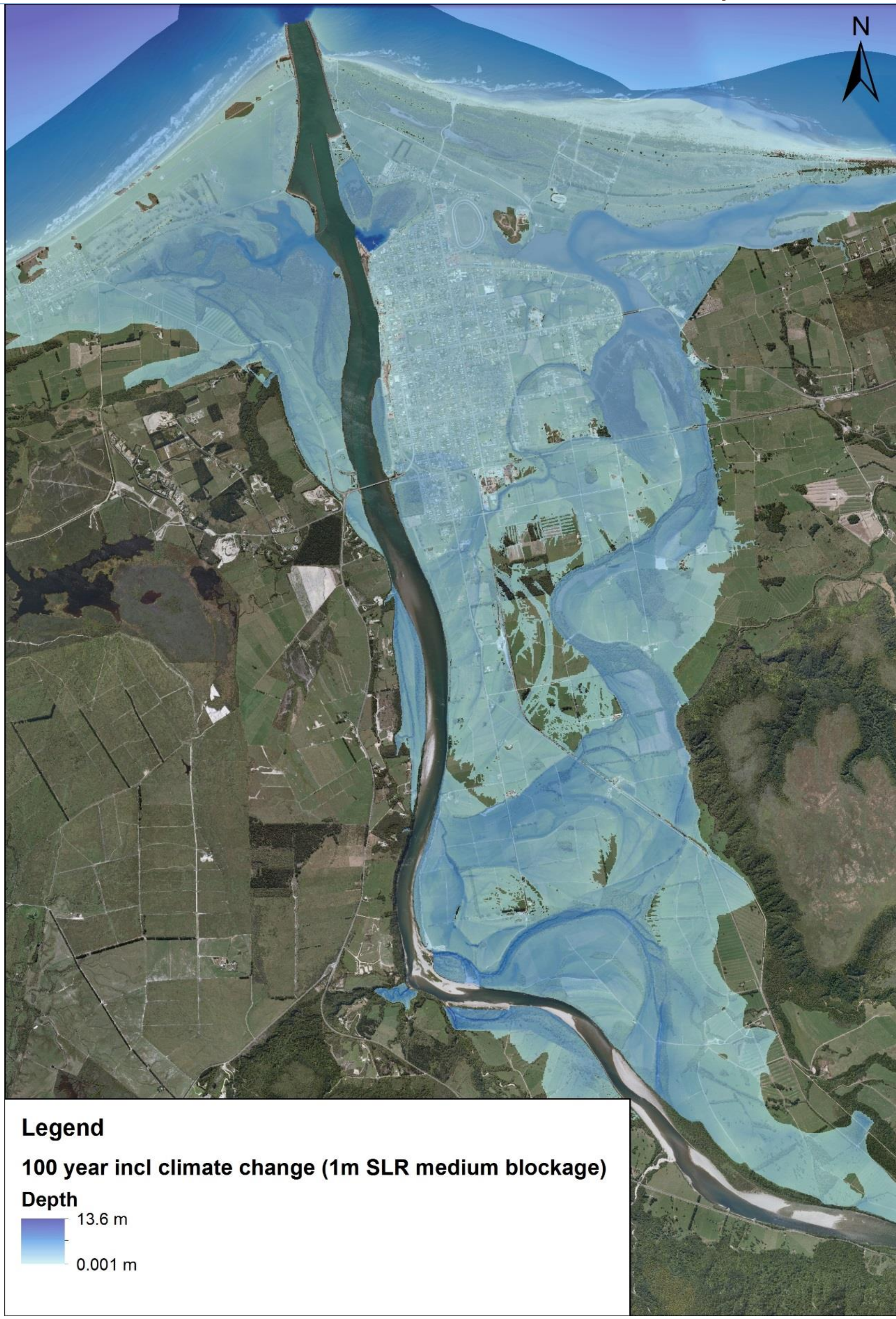

Figure 4-10 - 100 year design flood extent including predicted future effects of climate change (16% increase in peak rainfall intensity and sea level rise of 1m)

5. DAMAGES ASSESSMENT

An assessment of the potential damages for the design floods has been carried out using NIWA's Riskscape programme. More information about Risckape can be found at https://riskscape.niwa.co.nz/

The damages were calculated based on the peak depth and velocity outputs from the models. The scenarios have assumed that the flooding occurs during the day and there was no effective flood warning system in place.

Table 5 – Estimated damages for design scenarios

	Estimated Damages ($Million)		
Scenario	**No Blockage**	**Medium Blockage**	**Significant blockage of Buller and Orowaiti Trestle Bridge**
50 year current climate	28	38	135
50 year including climate change (0.7m SLR)		154	
50 year including climate change (1m SLR)		180	
100 year current climate	89	114	203
100 year including climate change (0.7m SLR)		291	
100 year including climate change (1m SLR)		306	

6. DISCUSSIONS

Comparison with 2010 NIWA modelling

The NIWA modelling did not consider any potential blockage scenarios and therefore in order to compare the results, the no blockage scenarios need to be used. The NIWA modelling results are presented for comparison in Appendix B. Comparisons of the current 50 year and 100 year flood extents with those presented in the NIWA report (Duncan, et al., 2010) indicate that the current modelling predicts a different degree of flooding than that in the previous report. The main difference appears to be that the current modelling shows significantly more water passing down the Orowaiti overflow and into the Orowaiti River.

The principal reason for these differences is due to the fact that the main railway trestle bridge on the Orowaiti overflow was unintentionally fully blocked in all NIWA modelling since 2010. This has caused the NIWA model to inundate Westport from above the town rather than allow floodwaters to enter the Orowaiti Lagoon and flood Westport from the Orowaiti Lagoon as occurs in this recent modelling (Duncan per comms, 2015).

Further rational for the discrepancies in flood extents can be explained due to the following differences in the models.

- Detailed checks on the LiDAR dataset with detailed ground survey data has found that values on the floodplain have been found to be 0.15 m higher than the survey data. In order to rectify this the LIDAR data was lowered by 0.15 m. This has the effect of increasing the volume of water that will spill from the main river onto the floodplain.
- Flood frequency estimates have increased the flow estimates for the 50 and 100 year flood events by approximately 4%. This greater volume of water increases the extent and depth of flooding.
- Modelled tide levels are greater than those used in the NIWA modelling. The NIWA modelling report (Duncan, et al., 2010) has presented what they consider to be a 50 and 100 year probability inundation event. The NIWA modelling has looked at the combined probability of tide and flow in order to create the appropriate inundation extent. As a result of this modelled river flows were less than the expected 50 and 100 year flow and adopted tide levels were less than the MHWS. Current modelling has modelled the estimated 50 and 100 year flood flows coupled with tide levels corresponding to a MHWS as well as a storm tide component of 0.4 m as detailed in Section 2. Further discussion on the rational for the adopted tide levels is included below.
- Bed levels in the Buller River and Orowaiti Lagoon were reduced significantly in order to allow for the effects of scour in the NIWA modelling. Bed levels have not been reduced in the current model for a number of reasons which are discussed in more detail below.
- It was found that the LiDAR was unable to penetrate the dense reed grass upstream of the Orowaiti Bridge. The LiDAR was modified in this location to allow water to flow through the reed grass.

Tide levels

Tidal ranges vary daily and depend on a number of factors. Tidal ranges are primarily effected by the local bathymetry and the influence of the moon. Low pressure weather systems and storm surges can also raise the level of the sea.

A number of terms have been developed in order to discuss the level of the sea and are summarized below. These definitions have been taken from the Land Information New Zealand website. (http://www.linz.govt.nz/sea/tides/introduction-tides/definitions-tidal-terms)

Mean Sea Level (MSL)

The average level of the sea surface over a long period or the average level which would exist in the absence of tides.

Mean High Water Springs (MHWS) & Mean Low Water Springs (MLWS)

The average of the levels of each pair of successive high waters, and of each pair of successive low waters, during that period of about 24 hours in each semi-lunation (approximately every 14 days), when the range of the tide is greatest (Spring Range).

Highest & Lowest Astronomical Tide (HAT & LAT)

The highest and lowest tidal levels which can be predicted to occur under average meteorological conditions over 18 years. Modern chart datums are set at the approximate level of Lowest Astronomical Tide (LAT) and Tide Tables list the predicted height of tide above Chart Datum. It should be noted that water level may fall below the level of LAT if abnormal meteorological conditions are experienced.

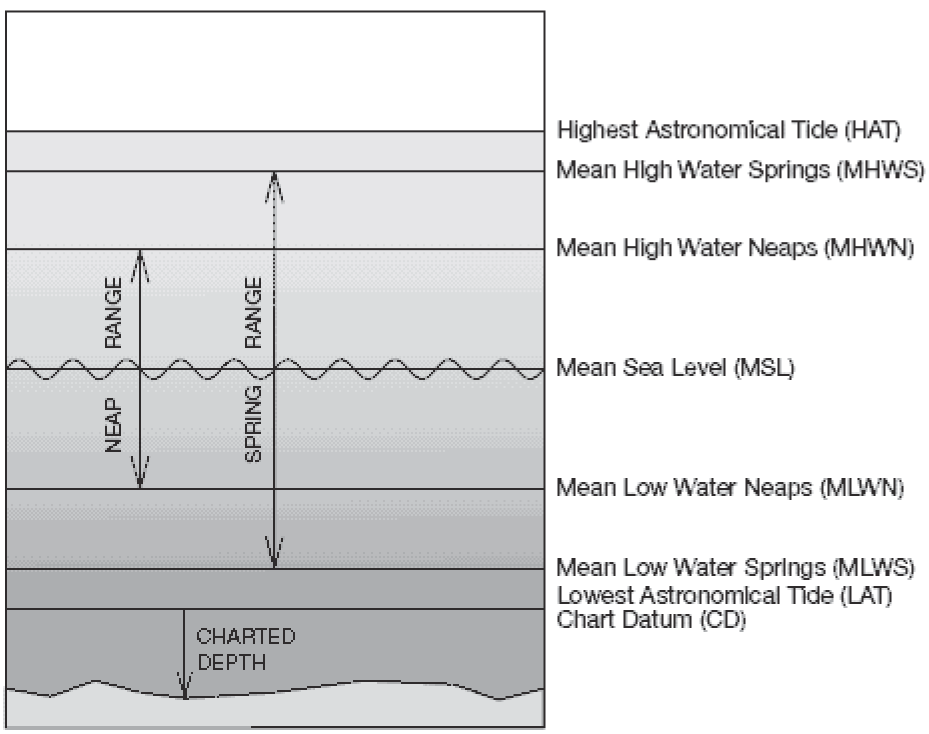

Figure 6-1 – Diagram of natural variations in tide ranges (http://www.linz.govt.nz/sea/tides/introduction-tides/definitions-tidal-terms)

In order to compare these various tide levels with the likely range of tide levels in Westport, the predicted tide levels for 2015 have been plotted using data from the NIWA online tide forecaster and have been compared with various tide levels in Figure 6-2 below. It should be noted that the tide levels do not have any allowance for storm surge or wave component and would therefore be raised further during a storm event.

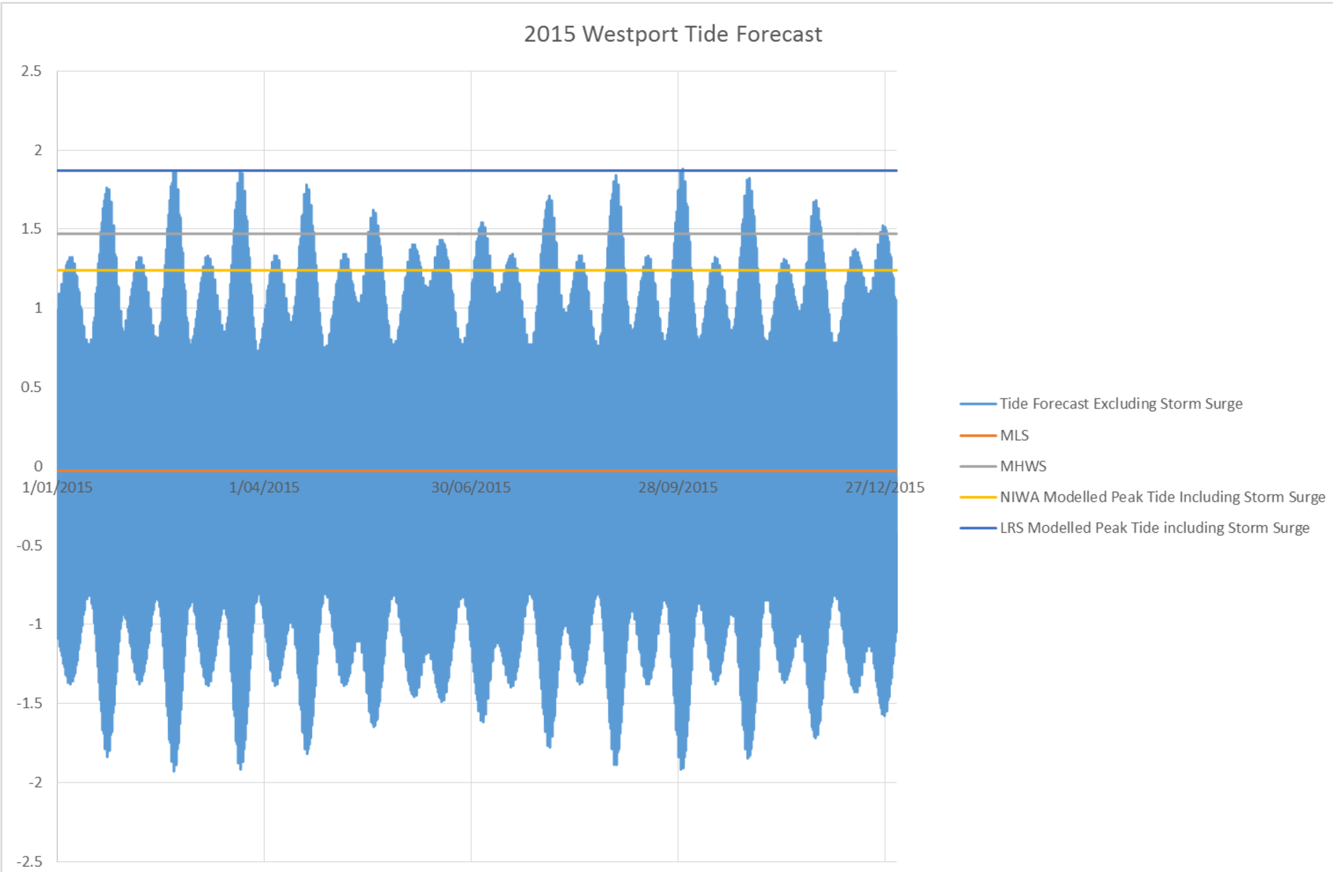

Figure 6-2 –2015 forecast tide levels compared with referenced tide levels

It can be seen in Figure 6-2 that the tidal range is quite large in Westport with the difference between the lowest and highest tides being close to four metres in 2015. Due to the fact that a large proportion of Westport is in the vicinity of the coast, it is considered essential that an appropriate tidal boundary condition is selected.

Storm Surge Joint Probability

Joint probability analysis of combined storm surge and river floods based on recorded sea levels at the Charleston recorder has been carried out previously by NIWA. It was concluded that for a flood event in the Buller River during winter months a storm surge of 0.59m +/- 0.22 m is considered probable (Duncan, 2005). The combined probability however of a MHWS coinciding with a 0.6m storm surge is considered to be very low however. For the sake of this modelling exercise the design tide levels peak at a level of MHWS + 0.4m to account for likely storm surge component. These tide assumptions have been discussed with Dr Michael Allis (Coastal Engineer, NIWA) and are considered to be appropriate (Allis, 2015). Another reason for not lowering these tide levels further is due to the fact that the storm surge component doesn't take into account wave action and run-up either, making it even more difficult for flood waters to exit at the sea.

Bed Scour

Previous modelling carried out by NIWA has allowed for the main bed of the Buller River to be lowered in the order of 1.5 m in order to account for the effects of scour. The NIWA modelling also lowered the level of the Orowaiti Lagoon in the vicinity of the main bridge by approximately 3m from current surveyed levels in order to assist with the calibration of the model.

The calibration achieved in this most recent calibration exercise was considered to be good without allowing for any scour. Without physical evidence that significant scour of the river will actually occur, or will have the effect of lowering flood levels it was not considered appropriate to lower bed levels due to the successful calibration without any account for scour.

Studies in the Manawatu River, which is also a gravel bed river that experiences bed mobilization during flood events, have shown that during large flood events, the increasing friction due to the mobilization of the bed has actually caused water levels to rise rather than lower as may be expected intuitively with the lowering bed. Work by Williams and Wallace (2006) for Horizons Regional Council found that resistance values needed to be increased to calibrate increasing flows for the Manawatu River.

Typically, in the case of the Manawatu River, Mannings 'n' values used to calibrate a 70 year flood (2004) were about 0.004 higher than those needed to calibrate a 20 year flood (1992), which in turn needed to be about 0.004 higher than those used to calibrate a 2 year flood (1988).

7. REFERENCES

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APPENDIX A – DETAILS OF MODELLED BRIDGES

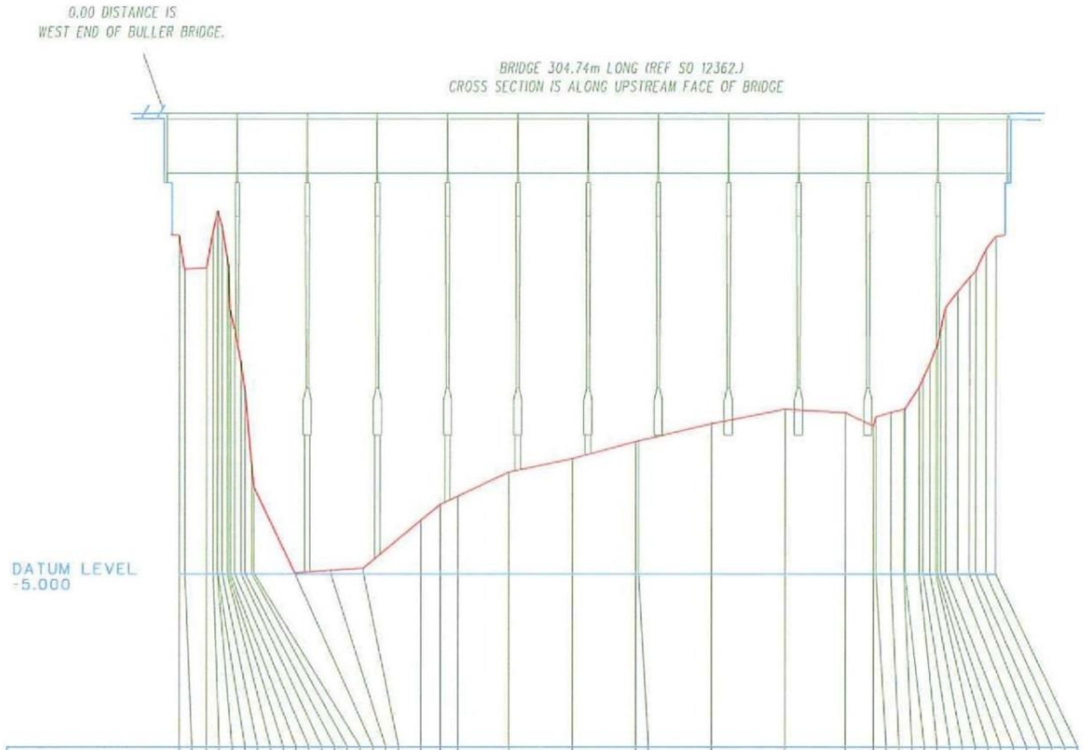
BULLER RIVER BRIDGE

Dimensions of the Buller River Bridge were taken from the drawing provided by Chris J Coll Surveyors.

The following dimensions have been adopted in the model

- Soffit = 6.5m
- Overflow = 8.1m
- Pier Width = 1.64 to 0.83m
- Average Width = 1.25m
- Number of piers = 11
- Opening Width = 304m
- Blockage = 13.75/304 = 0.045

A drawing of the bridge as provided by Chris J Coll Surveyors in presented on the following page.

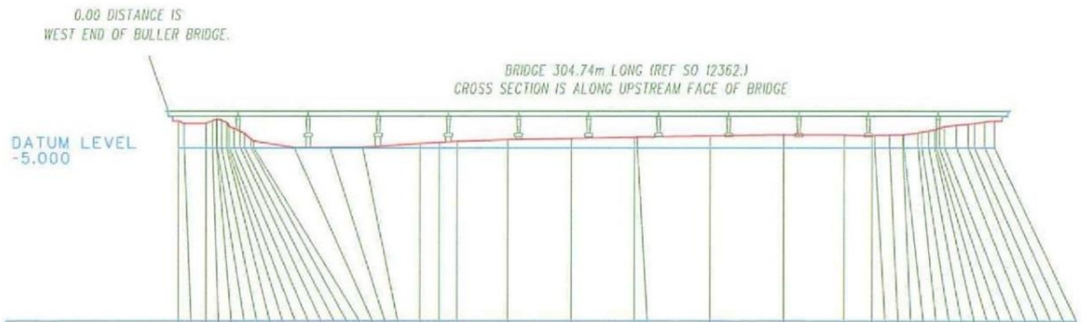


DISTANCE	GROUND LEVEL
3.79	4.75
5.78	3.76
13.72	3.82
16.12	4.83
17.53	5.36
17.81	5.46
19.38	5.02
21.20	4.16
21.75	3.90
22.33	2.59
23.91	2.05
26.14	1.13
27.62	0.31
30.09	-1.82
30.88	-2.50
45.61	-4.97
58.57	-4.89
70.42	-4.83
91.16	-3.45
98.11	-2.99
104.47	-2.75
122.80	-2.06
145.78	-1.67
168.60	-1.18
169.55	-1.16
196.03	-0.67
222.43	-0.25
244.39	-0.36
254.70	-0.73
255.52	-0.47
260.86	-0.34
265.67	-0.25
266.04	-0.24
271.23	0.36
272.65	0.63
275.13	1.07
277.35	1.49
277.92	1.60
279.06	2.05
280.89	2.69
285.23	3.14
289.51	3.54
291.75	3.73
295.54	4.36
299.03	4.73

LONGITUDINAL SECTION   CENTRE LINE FILE : XSECBRDG   START CHAINAGE : 3.790
END CHAINAGE : 299.029   HORIZONTAL SCALE 1 : 1250 (A1)   VERTICAL SCALE 1 : 100 (A1)

NOTE

CROSS SECTION AT DISTORTED/EXAGGERATED SCALE TO MATCH STANDARD CROSS SECTIONS ON OTHER SHEETS.



DISTANCE	GROUND LEVEL
3.79	4.75
5.78	3.78
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23.91	2.05
26.14	1.13
27.62	0.31
30.09	-1.82
30.88	-2.50
45.61	-4.97
58.57	-4.89
70.42	-4.83
91.16	-3.45
98.11	-2.99
104.47	-2.75
122.80	-2.06
145.78	-1.67
168.60	-1.18
169.55	-1.16
196.03	-0.67
222.43	-0.25
244.39	-0.36
254.70	-0.73
255.52	-0.47
260.86	-0.34
265.67	-0.25
266.04	-0.24
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277.92	1.60
279.06	2.05
280.89	2.69
285.23	3.14
289.51	3.54
291.75	3.73
295.54	4.36
299.03	4.73

LONGITUDINAL SECTION   CENTRE LINE FILE : XSECBRDG   START CHAINAGE : 3.790
END CHAINAGE : 299.029   HORIZONTAL SCALE 1 : 1250 (A1)   VERTICAL SCALE 1 : 1250 (A1)

NOTE

CROSS SECTION AT NATURAL (NOT DISTORTED) SCALE

Prepared for:
WEST COAST REGIONAL COUNCIL

0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150mm

BULLER RIVER AND OROWAITI RIVER CROSS-SECTIONS JULY 1999

LEVEL DATUM NOTE.
ALL LEVELS ARE IN TERMS OF M.S.L LYTTELTON BASED ON IT BULLER BRIDGE R.L. 8.309m

C J COLL
Regd Land Surveyor, Resource Management Consultant
19 BROUGHAM STREET PO BOX 204 WESTPORT

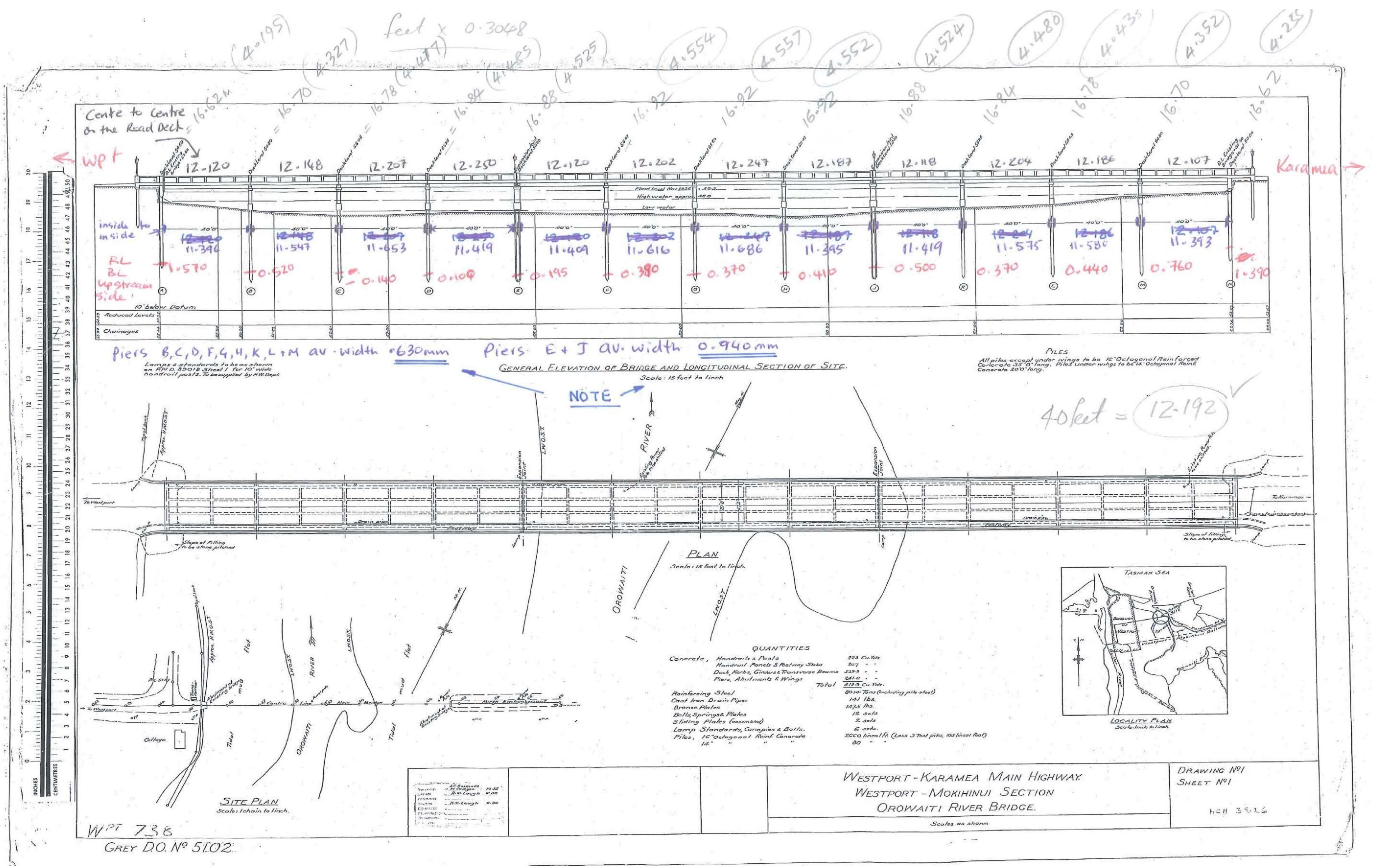
DRAWN	WARREN AND CHRIS	CHECKED	CHRIS	A1 SCALES	SHEET 1
DATE	JULY--AUGUST 1999	REV.		AS SHOWN	SERIES 1 OF 1
					REF XSECBRDG.GCI

OROWAITI RIVER STATE HIGHWAY BRIDGE

An historic drawing of this bridge has been provided however in order to confirm bridge dimensions and levels the bridge details were surveyed on request by Chris J Coll Surveyors.

- Bridge Top Level = 4.2 at edges to 4.6 in center
- Soffit Level = 3.5 to 3.75
- Number of Piers = 13
- 11 piers = 0.63 m
- 2 Piers = 0.94 m
- Opening Distance = 146.1 m
- Blockage = 8.18/146.1 = 0.056

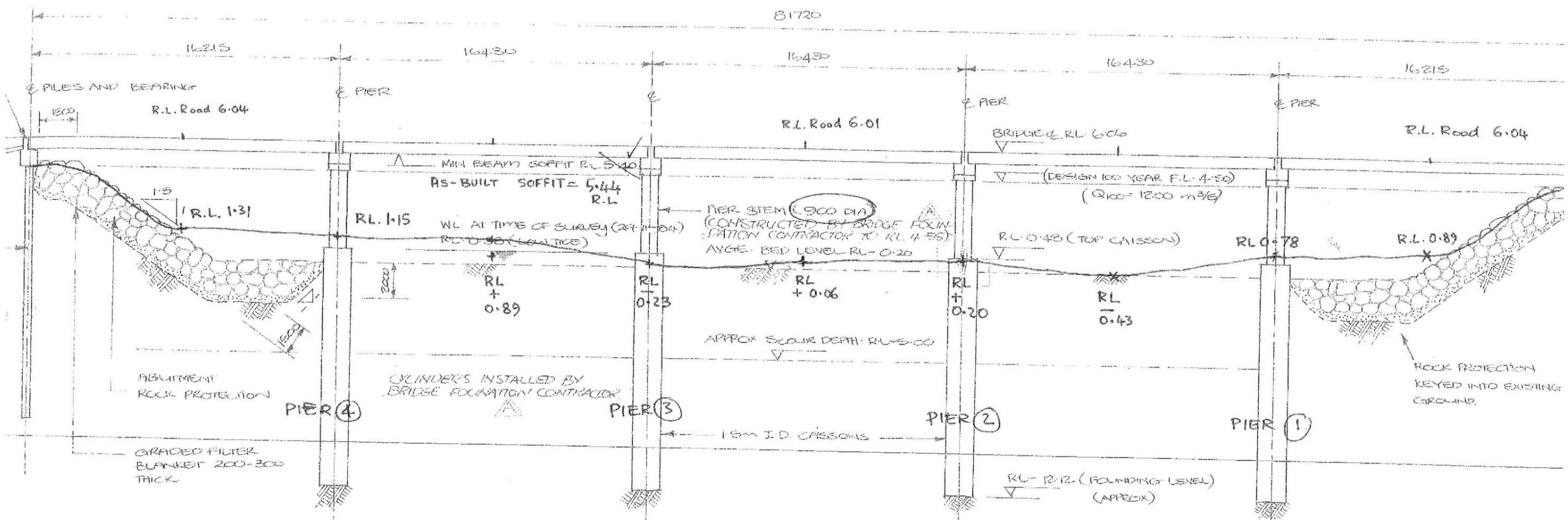
The original bridge drawing is presented below, annotated by hand with the up to date dimensions.



feet × 0.3048
Centre to Centre on the Road Deck
16.62M 16.70 16.78 16.84 16.88 16.92 16.92 16.92 16.88 16.84 16.78 16.70 16.62
4.195 4.327 4.417 4.485 4.525 4.554 4.557 4.552 4.524 4.480 4.435 4.352 4.235
wpt
Karamea
12.120 12.148 12.207 12.250 12.120 12.202 12.247 12.187 12.118 12.204 12.186 12.107
inside to inside
11.396 11.547 11.653 11.419 11.409 11.616 11.686 11.395 11.419 11.575 11.580 11.393
RL BL upstream side
1.570 0.520 0.140 0.100 0.195 0.380 0.370 0.410 0.500 0.370 0.440 0.760 1.390
Flood level Nov 1926
Highwater
Low water
10' below Datum
Reduced Levels
Chainages
Piers B, C, D, F, G, H, K, L + M av. width 630mm
Piers E + J av. width 0.940mm
Lamps & standards to be as shown on P.W.D. 35018 Sheet 1 for 10' wide handrail posts. To be supplied by P.W. Dept.
GENERAL ELEVATION OF BRIDGE AND LONGITUDINAL SECTION OF SITE.
Scale: 15 feet to 1 inch
NOTE
PILES
All piles except under wings to be 16" Octagonal Reinforced Concrete 35'0" long. Piles under wings to be 14" Octagonal Reinf. Concrete 20'0" long.
40 feet = 12.192
RIVER
OROWAITI
Expansion Joint
L.W.O.S.T.
To Westport
To Karamea
Footway
Slope of Filling to be stone pitched
PLAN
Scale: 15 feet to 1 inch
TASMAN SEA
LOCALITY PLAN
QUANTITIES
Concrete, Handrails & Posts 223 Cu. Yds.
Handrail Panels & Footway Slabs 207
Deck, Kerbs, Girders & Transverse Beams 329.9
Piers, Abutments & Wings 241.0
Total 818.9 Cu. Yds.
Reinforcing Steel 80.14 Tons (excluding pile steel)
Cast Iron Drain Pipes 141 lbs.
Bronze Plates 1475 lbs.
Bolts, Springs & Plates 12 sets
Sliding Plates (assembled) 2 sets
Lamp Standards, Canopies & Bolts. 6 sets.
Piles, 16" Octagonal Reinf. Concrete 2560 lineal ft. (Less 3 Test piles, 105 lineal feet)
14" " " " 80
Tidal
mud
flat
Cottage
SITE PLAN
Scale: 1 chain to 1 inch
WESTPORT - KARAMEA MAIN HIGHWAY.
WESTPORT - MOKIHINUI SECTION
OROWAITI RIVER BRIDGE.
Scales as shown
DRAWING Nº1
SHEET Nº1
WPT 738
GREY D.O. Nº 5102

STEPHENS ROAD - SCOTT'S BRIDGE

- Soffit – 5.44
- Road Level – 6.01
- Number of Piers =4
- Pier Width = 0.9
- Opening Width = 81.2m
- Blockage = 3.6/81.2 = 0.044



BRIDGE ELEVATION – LOOKING DOWNSTREAM SCALE 1:200

OROWAITI BRIDGE : STEPHENS ROAD

Bed Levels August 2014 and "SOFFIT" Levels

R.L's in terms of M.S.L. Lytellton Datum

C.J. Gall Regd. Surveyor
Westport
31/07/14.

Distance Units: Metres

Point ID	North	East	Elevation	Code	Group	Description
EastAbut	5375781.19	1486401.68	6.06	BRDG	BRIDGE	BRIDGE CL
Pier1	5375778.20	1486385.66	6.03	BRDG	BRIDGE	BRIDGE CL
Pier2	5375775.12	1486369.56	6.00	BRDG	BRIDGE	BRIDGE CL
Pier3	5375772.12	1486353.40	6.02	BRDG	BRIDGE	BRIDGE CL
Pier4	5375769.19	1486337.23	6.05	BRDG	BRIDGE	BRIDGE CL
WestAbut	5375766.14	1486321.27	6.06	BRDG	BRIDGE	BRIDGE CL

INITIAL	F.B.	4/6	
		INITIALS	DATE
	SURV.		
	DGN.		11-2-85

(JOB # 2864)

BULLER COUNTY COUNCIL

NINE MILE ROAD BRIDGE (RAIL BRIDGE 110)

Details of this bridge were provided by staff at Buller District Council. No drawing was available.

- Bridge Top Level = 10
- Soffit Level = 9.5 (Estimated)
- Pier Width = 0.28-0.35 (average 0.315)
- Number of Piers = 28
- Opening Distance = 180 m
- Blockage = 8.96/180 = 0.05

APPENDIX B – PREVIOUS STUDY FLOOD EXTENTS FOR COMPARISON

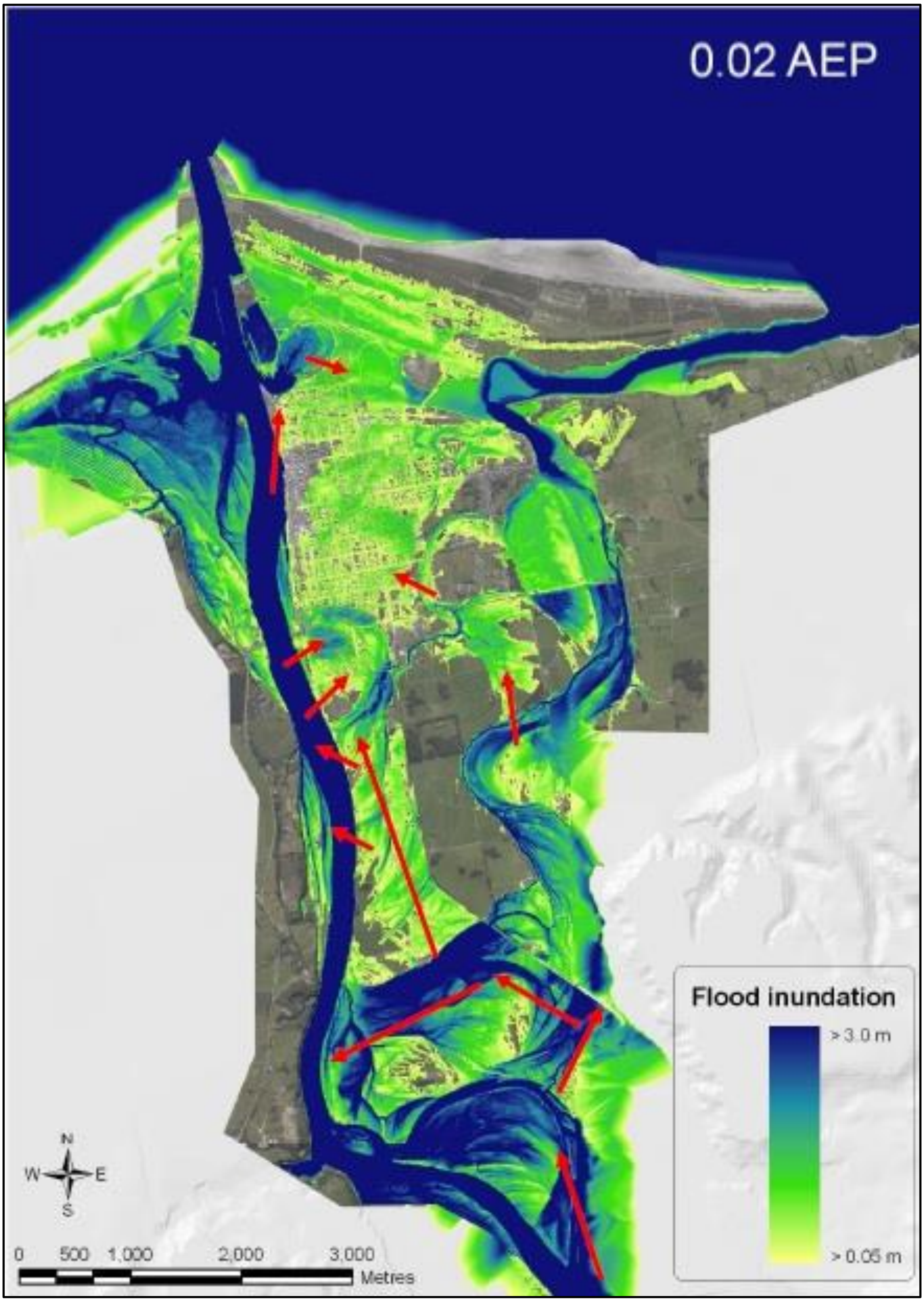


Figure 0-1 – 50 year (0.02AEP) floodspread from the 2010 NIWA study (Duncan, et al., 2010)

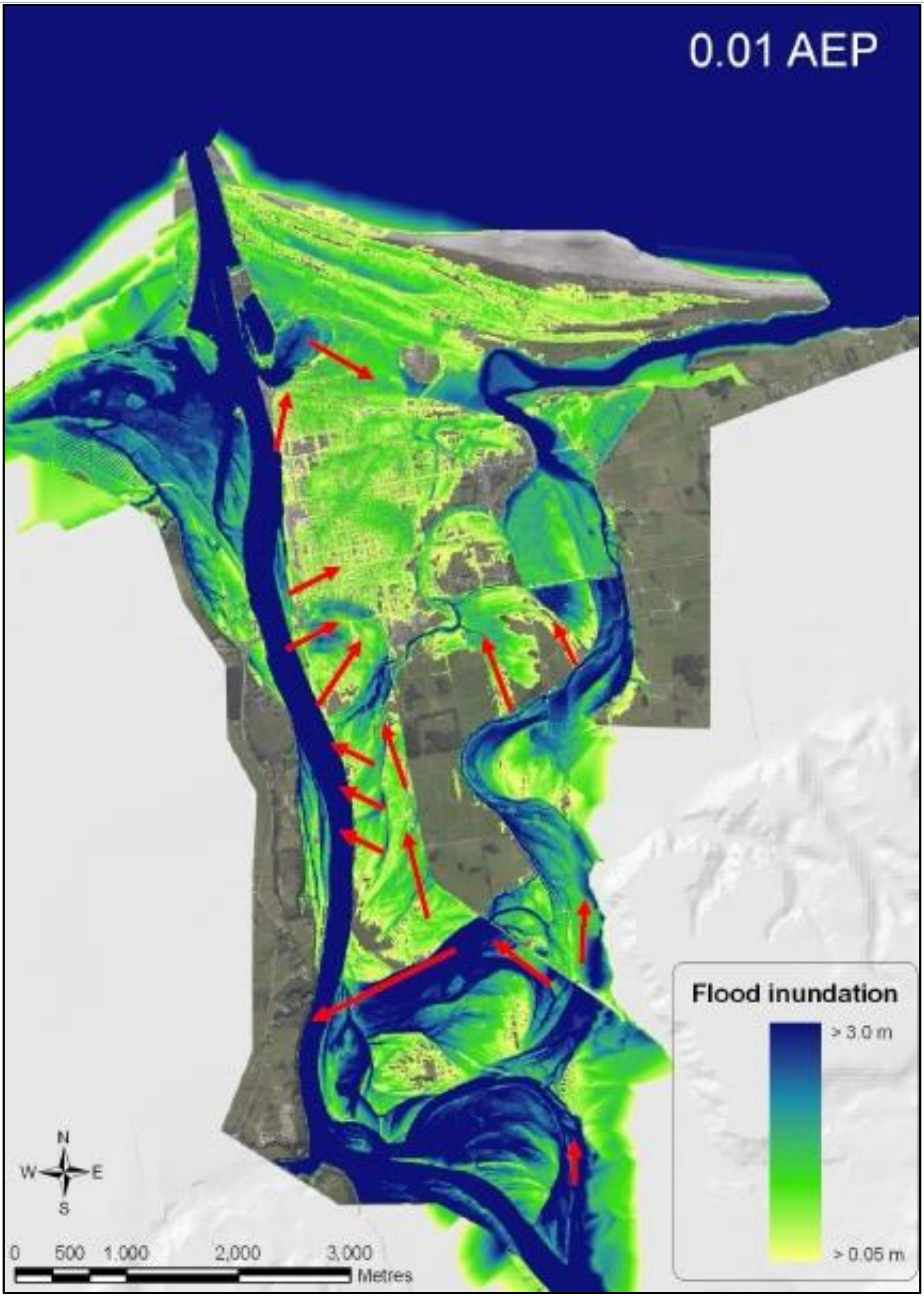


Figure 0-2 - 100 year (0.01AEP) floodspread from the 2010 NIWA study (Duncan, et al., 2010)

Hi Matt,

Thanks for your email and instructions.

I've been over the latest version of the report and the model files. My comments are as follows:

Buller River Modelling Report July 2015.docx

I've made various track-changes comments on the document. I'll forward a link later this evening. to the track-change copy of the report with these comments.

Thank you – these have been incorporated into my final report

My main comment is in regard to the calibration and the inference that calibration using 95% of recorded flows gives better results than using 100% of recorded flows. I'm not convinced, although I note that this wouldn't change your design flow results.

I have removed this section from the report, as this was more applicable to an earlier version of the report. The latest, most detailed version of the model calibrates well with 100% flows and therefore there is no longer any need to reduce the flows for the model calibration.

There are a number of spelling/grammatical things to fix – I'm sure you are aware of that and so I haven't pointed these out.

Model files

Nine Mile Rail Bridge

I see that you have put more detail in the Nine Mile Rail bridge cross-section. Although I'm not familiar with the layout (aerial photos and topo dfs2 not detailed enough to tell), and I note that your records say the bridge is 180m wide, I don't think I would have made the cross-section and standard links so wide – I would probably restrict this to the stream channel, ie 20-30m wide. Is it the road rather than the rail that restricts the flow? Also, the dfs2 either side is such that in effect the waterway wouldn't flow until WL > 6.6m RL, so there is in effect an additional degree of blockage you would not have intended. I'm not sure how significant this is, but I do note that you talk in your report about the differences between NIWA's and your results being in part due to how that bridge cross-section allows flow into either Westport or Orowaiti Lagoon.

I have kept the entire channel in the model so that the soffit and bridge piers can be simulated using the MIKE11 bridge module. When on site, it is clear that the lie of the land is similar to that used in the DEM and therefore should accurately represent the flow dynamics through this structure ie there is a dip under the bridge. The differences with the NIWA modelling were due to this bridge being accidentally completely closed in the NIWA model..ie no water could flow through the bridge.

Lower River cross-sections

I know we had some discussions on this previously and the complications that the training walls present.

One thing I note is that the training wall seems to be at about RL 1m. This wall ties into the left bank at around interpolated xs3c. So as the tide drops below 1m, there is no longer any physical connection in the left embayment between xs 4 and xs 3b for instance – but the model does assume that there is, ie that the left embayment contributes to the overall conveyance. At high flows this may not be such an issue, depending on the level of accuracy required, although I think it would still have some impact on results.

This might also be an issue for the training wall between xs 4 and the bridge in low flow situations – although I know that we aren't interested in that here.

There could be some expansion losses eg around xs2a. With the 1-d representation, in lieu of having such losses in the model, there could be a case for increasing roughness instead?

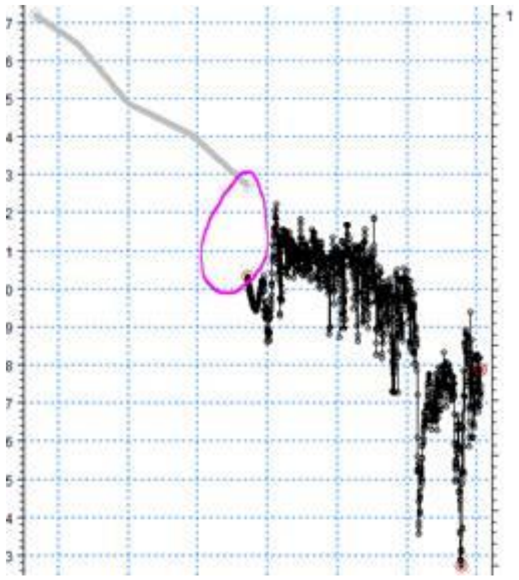
I note though that from your results, most of the overland flow in Westport arrives from further upstream, and as there is a reasonable slope on the main river channel, the model schemetisation in this lower reach is not really going to affect your conclusions.

At the least, I'd qualify your report to note that there are limitations in the model schemetisation in this lower reach (ie d/s of bridge) and that In an ideal world, you'd have more bathymetric survey over this area of the model, and calibration data. Recommend to client that this be collected in the future?

I have qualified the results as suggested, however I believe these will have more of an effect on low flow events rather than high as you point out.

Other model comments

Any reason why RB link 668 is M11 rather than M21 controlled? Also note that there is a large step in the lat link spill level at 3713 as a result.



The land upstream from here is M11 controlled due to the fact that the LiDAR did not continue this high upstream. There is a high bank running parallel to the river which has been picked up in the cross section survey and hence I have used that level as the spill level. The steep drop can be explained by a side channel entering the Buller River in this location. Unfortunately the survey in this area does not pick the topography well and could be improved in the future using LiDAR or Structure From Motion.

Momentum factor for standard links - I take your point about how this has only been reduced for previously troublesome links – but might want to do an additional run now to confirm this has no significant impact . Stephens Rd/rail ridge is one I would look at. Might also reconsider the Railway Embankment Bridge in light of comments above.

I have rerun the model with these altered and found that it had no significant impact on the overall model results.

Bathymetric survey – jump at end of the Orowaiti Lagoon – I agree that this is not important for most cases, but in low tide it might be – you've looked at tides going down to approx -0.5m. So maybe only 300mm deep at that point, then next cell is drop of 2.5m. You could have made assumptions re the transition from end of

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the bathy survey to the off-shore bathy (not sure where that is from) – eg interpolate over a number of cells. Of course the actual bathymetry through the throat and over the bar is unknown/forever changing, so there will always need to be assumptions.

I have rerun the model with this section of the bathymetry smoothed and found that it had no significant impact on the overall model results.

Conclusions

Overall the model looks well set-up and appropriate. I would suggest however that you consider the above points to satisfy yourself that the model results and your conclusions are not sensitive to the approximations you have made. Also, as per the comments I've shown as track-changes in your report, a reconsideration of the reduction in calibration flows might be in order, or at further justification for reducing it.

I trust these comments are helpful. Please get in touch if you wish to discuss.

Kind regards

Phil