Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

**TECHNICAL REPORT** Investigations and Monitoring Group

# Kowai River, Leithfield Beach and Amberley Beach flood investigation

Report No. R14/99

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**Report No. R14/99**
**ISBN 978-1-927314-87-6 (print)**
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Michelle Wild

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| | Name | Signature | Date |
|---|---|---|---|
| **Prepared by :** | *Michelle Wild*<br>*Hazards Analyst* | | *October 2014* |
| **Reviewed by :** | *Tony Oliver, Hazards Analyst*<br>*Brodie Young, Env. Science & Hazards Manager* | | *October 2014* |
| **Approved by:** | *Ken Taylor*<br>*Director Investigations & Monitoring* | | *October 2014* |

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PO Box 345
Christchurch 8140
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru 7940
Phone (03) 687 7800
Fax (03) 687 7808

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

# Executive summary

Flooding occurs on the Kowai River floodplain, and in the Leithfield Beach and Amberley Beach settlements, during prolonged periods of high intensity rainfall in the foothills and coastal catchments. In particular, local surface water runoff can cause considerable volumes of water to pass into the areas surrounding the Amberley Beach and Leithfield Beach settlements. In the case of Leithfield Beach, this flooding can also be exacerbated by overbank flows from the Kowai River.

This study of the Kowai River floodplain and Leithfield Beach and Amberley Beach settlements used a combined one and two dimensional hydraulic computer model to estimate flood extent, depths, and flood levels for the 50 year and 200 year Average Recurrence Interval (ARI) flood events. Floodplain topography for the model was derived from a detailed LiDAR survey flown in 2012. The model was calibrated using the July 2008 storm event which recorded a 95 $m^3/s$ (5-10 year ARI) peak flow on the Kowai River North Branch at Grays Road (Site 66101). Kowai River flood hydrographs for the July 2008 event were based on the Kowai North Branch at Grays Road flood hydrograph, while local flood water flows draining into the Leithfield Beach and Amberley Beach settlements was determined from local rainfall records. The 50 year and 200 year ARI rainfall events were derived by scaling the 2008 flood hydrographs and local 24-hour and 48-hour rainfall totals.

Several assumptions have been necessary when undertaking this modelling study. For example, the derivation of flood flows and tide levels, impact of human intervention to open lagoon outlets, and timing of high tides on the Kowai River mouth (and other outlets to the sea), have all been assessed and require assumptions to be made. There is also very limited calibration information in the way of measured water levels and no measured river and lagoon outlet flows (which can vary enormously due to tide levels, lagoon levels, and the resulting extent of scouring). Regular disturbances to some areas of the floodplain (e.g. due to quarrying), and antecedent conditions within the catchment, can also have a significant impact on river flows, lagoon and quarry ‘pond’ levels, and surface runoff. These results should therefore be interpreted and used with care.

It is hoped the floodplain mapping and predicted flood levels will assist land use planning within the area, and provide information on appropriate minimum floor levels for proposed buildings. The modelled **200 year** (and 50 year) ARI flood water levels for Amberley Beach and Leithfield Beach settlements have been determined to be **3.4 m** (3.2 m) and **3.8 m** (3.5 m) above mean sea level (Lyttelton 1937 Datum), respectively. These model results can also be used to determine 50 year and 200 year ARI flood levels for other locations within the model extent (e.g. Leithfield township).

This modelling study assumes that the large design flood events will be widespread causing both the Kowai River and local catchments to generate the design flood flows simultaneously; the sea level is also raised to incorporate an additional 0.4 m storm surge. Wave run-up and overtopping of the sand dunes at Amberley Beach and Leithfield Beach has not been included in this study.

**Note:** The model produced as part of this investigation has been constructed specifically to model flood events. Significant changes to the model configuration may be required to simulate less significant events or average flows.

*5 September 1974 - Looking north towards the Waipara River with Amberley Beach settlement on right.*

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# 1 Introduction

The Kowai River, together with the Amberley Beach and Leithfield Beach settlements, are located to the north of Christchurch in the Hurunui District and have a combined catchment and floodplain area of ~ 212 km$^2$ (Figure 1-1). Large flood events (including the floods of 1868, 1923, 1963, 2000 and 2008) can occur in this area when south-westerly or easterly weather systems produce prolonged periods of high intensity rainfall in the foothills and coastal catchments. During such flood events, State Highway 1 (SH1) can be overtopped, and large areas of farmland and the Amberley Beach and Leithfield Beach settlements can become inundated, restricting farming operations and flooding residential properties and access roads.

While Environment Canterbury has some information on the approximate extent and magnitude of historical flood events, there is no information on more extreme flood events. The investigations described in this report have therefore been undertaken to simulate the extent of flooding likely to occur for large flood events – in particular 50 year and 200 year average recurrence interval (ARI) flood events. This is achieved by using very detailed topographic data obtained from a LiDAR (aerial laser) survey, and a combined one and two-dimensional hydraulic computer model of the Kowai River and floodplain (which includes local runoff to the Amberley Beach and Leithfield Beach settlements).

Potential inundation areas, including depths of flooding and water levels, are required for land use planning purposes and the provision of minimum floor levels. At present, information is limited to that observed during historical flood events. The computational modelling discussed in this report provides inundation maps, flood depths and flood levels for the estimated 50 year and 200 year ARI events.

Chapter 11 of the Canterbury Regional Policy Statement includes a policy which requires new buildings in areas subject to inundation to have floor levels above the 200 year ARI flood level. The Building Code also states that housing and communal buildings should be designed and constructed in such a way that floor levels are above the 50 year ARI flood level. This floodplain investigation provides both 50 year and 200 year ARI flood levels for the Amberley Beach and Leithfield Beach settlements.

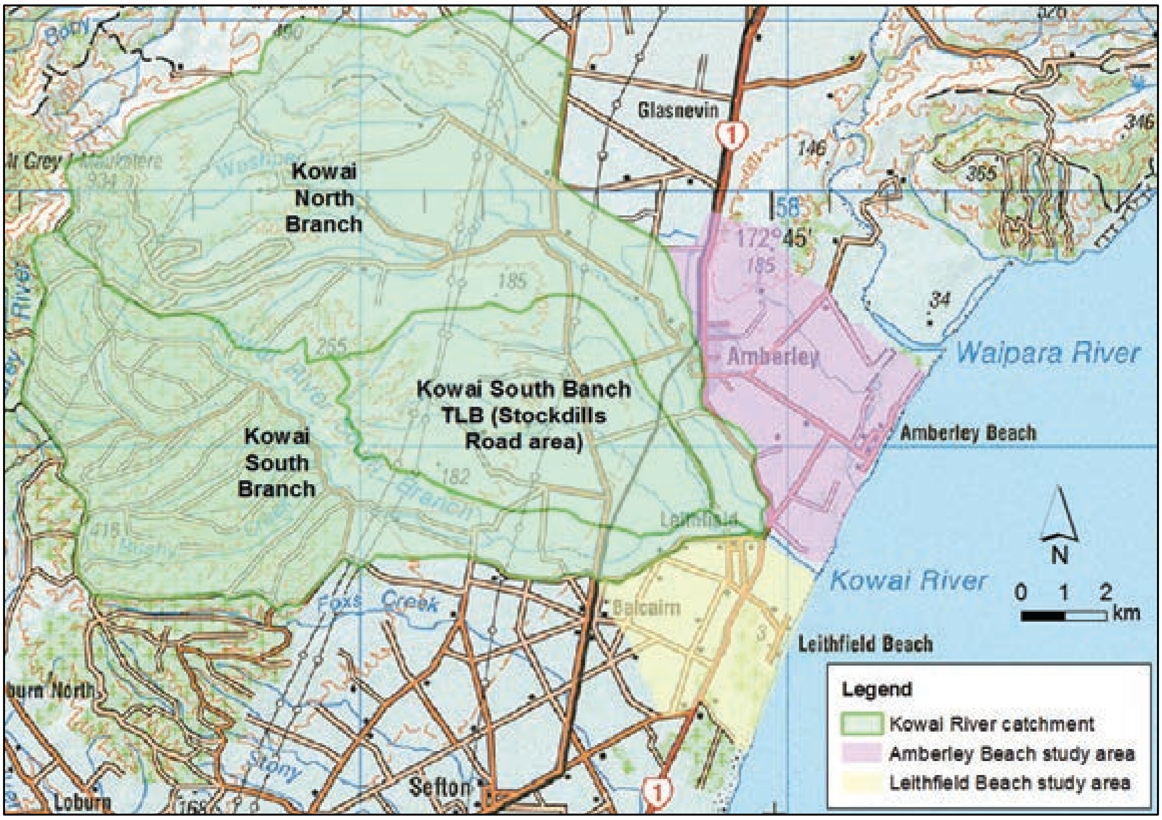



**Figure 1-1: Kowai River, Amberley Beach and Leithfield Beach location map**

# 2 Background

The study area for this flood investigation is shown in Figure 1-1. This includes the Kowai River, the Amberley Beach and Leithfield beach settlements, and along the coast from the Waipara River in the north to Ashworths Beach Road in the south (Figure 2-1).The modelled Kowai River North Branch extends from upstream of the Grays Road bridge (Amberley township) to the confluence with the Kowai River South Branch – modelled from upstream of the Balcairn-Amberley Road bridge to the sea.

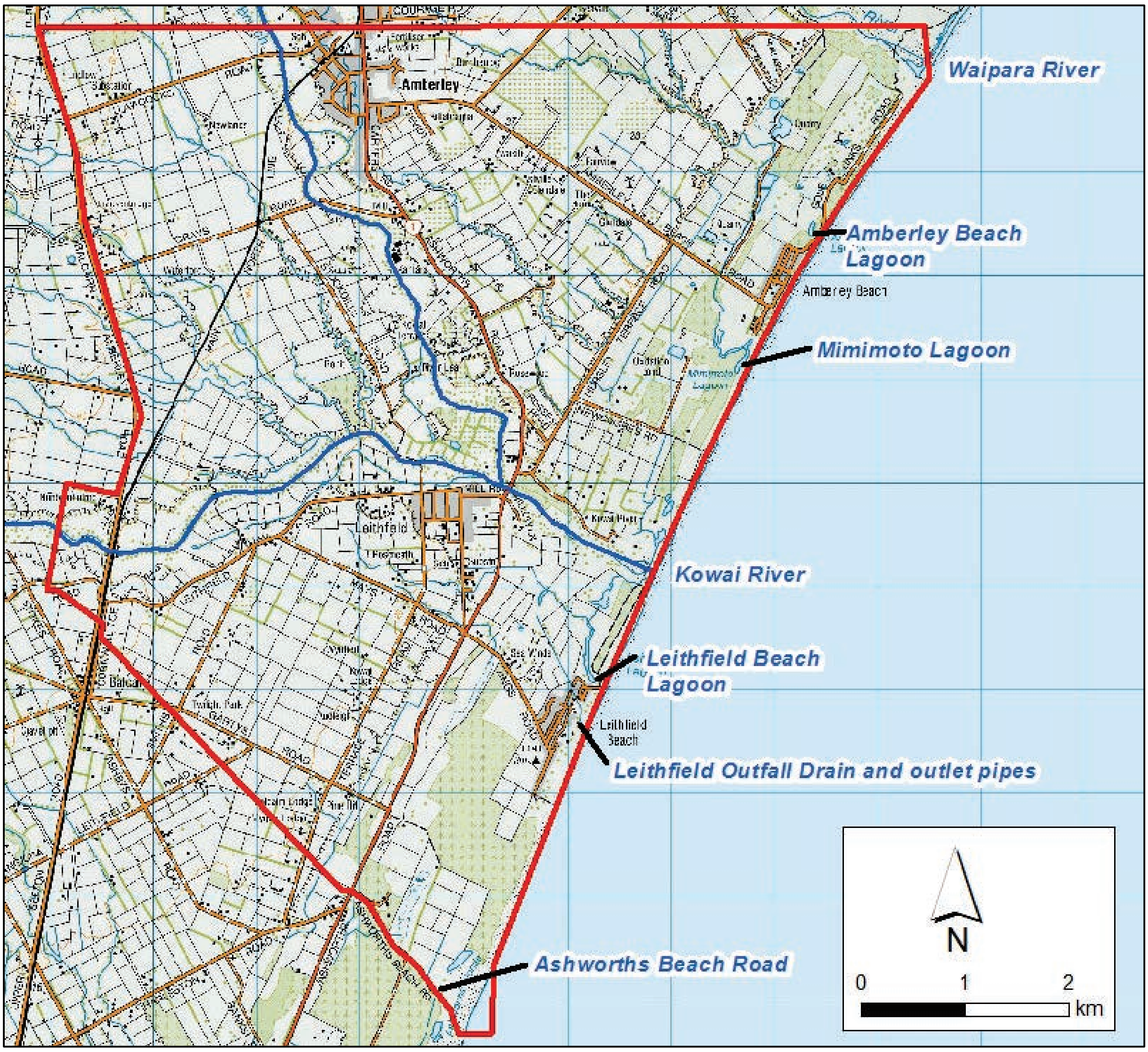



**Figure 2-1: Study area, including the location of Amberley Beach and Leithfield Beach lagoons and the Leithfield Outfall Drain and outlet pipes**

## 2.1 Kowai River, Amberley Beach and Leithfield Beach catchments

The Kowai River North and South Branches converge upstream of SH1 and flow out to the sea between the settlements of Amberley Beach and Leithfield Beach (Figure 1-1 and Figure 2-1). Local runoff and spring water within the Amberley Beach catchment drains to coastal lagoons to the north and south of Amberley Beach settlement (i.e. Amberley Beach Lagoon and Mimimoto Lagoon), while water from the Leithfield beach catchment drains to the Leithfield Beach Lagoon or out to sea via the Leithfield Outfall Drain and outlet pipes (Figure 2-1). The Kowai River, together with the Amberley Beach and Leithfield Beach settlements has a combined catchment and floodplain area of ~ 212 km$^2$.

The Kowai River has a catchment area of approximately 172 $km^2$, with the South Branch (including the Stockdills Road area) and North Branch contributing 91 $km^2$ and 81 $km^2$, respectively. The headwaters of the Kowai River North and South Branches (and upper tributaries) originate on the eastern and southern faces of Mt Grey/Maukatere, respectively – with the upper reaches of the South Branch flowing through Ashley Forest. Mt Grey/Maukatere consists of deformed bedded sandstone and mudstone, with weathered greywacke-clast conglomerate and gravel/sand river and fan alluvium 'blanketing' most of the upper catchment area. The elevated areas to the west of SH1/Hursley Terrace – which form the upper catchment areas for the Leithfield Beach and Amberley Beach settlements – consist of a gravel/sand/silt/clay river alluvium while the settlements are located on a mixture of active and stable dunes, backed by older beach and river deposits.

The catchment of the Kowai River and beach settlements is predominantly rural with large areas of pastureland used for dairy farming and dry stock. The headwaters of the Kowai River South Branch also contain large areas of exotic pine plantation (Canterbury Regional Council, 1993). The urban township of Amberley, with a population of 1575 (2013 Census), is located in the Kowai River catchment and quarry activities are also currently being undertaken in the Amberley Beach catchment area.

To the west of the coastal settlements of Amberley Beach and Leithfield Beach there is an elevated terrace with incised ephemeral streams which drain water towards the beach settlements. Average annual rainfall at Amberley township is around 650 to 700 mm with NIWA's High Intensity Rainfall Design System (HIRDS version 3) estimating 100 year ARI 24-hour and 48-hour rainfall totals of 189 mm and 211 mm, respectively (Table 3-4).

Leithfield Beach is a composite beach with a sandy foreshore and a sand and gravel seaward beach ridge (~ 3.5 to 4 m above mean sea level (msl)) backed by sand dunes that are ~ 5.5 m above msl (Todd, 2008). These sand dunes protect the Leithfield Beach settlement from sea water inundation due to wave run-up and storm surge.

Amberley Beach is also a mixed sand and gravel beach with a concave shaped beach profile (Flatman, 1998). The sand dunes/bund protecting the Amberley Beach settlement is ~ 5 m above msl - a height which is maintained by a beach re-nourishment program that was initiated in 1992 after large waves overtopped the dunes inundating several houses and causing the evacuation of the settlement (Todd, 2009). Lower sand dune heights immediately to the north and south of the North Amberley Lagoon outlet culverts make this area susceptible to overtopping by wave run-up at present.

The Amberley Beach and Leithfield Beach coastline is a high-energy wave environment with the largest wave heights tending to originate from the south (southerly storm swells) – particularly in winter between June and August (Flatman, 1998).The combination of sediment characteristics, wave height and the angle that the wave approaches the beach, determines the quantity of sediment being transported along the coastline at any given time. At times when sediment transport along the coast is higher it is more difficult to maintain any lagoon and drain outlet openings to the sea.

## 2.2 Historical flooding

The worst flooding in the study area has generally been associated with south-westerly or easterly weather systems, which affect the foothills and coastal catchments (e.g. flooding in 1868, 1923, 1963, 2000 and 2008). A brief summary of significant historic flood events is given in Table 2-1.

Areas of the Leithfield Beach settlement which were flooded in 1923 and 1936 have since been developed (Norton, 1959).

**Table 2-1: Summary of previous large flood events in the Kowai River, Amberley Beach and Leithfield Beach areas**

| Date | Extent of flooding | Source |
|---|---|---|
| 1868 | ' … almost the entire south Sefton plains from Kowai to the Ashley was covered" | Yetton *et al*. (2000) |
| 24 Mar 1902 | Largest flows in Kowai since 1868. At Leithfield the south branch broke through the embankment and flowed down the street and into houses. | Yetton *et al.* (2000) |
| 6-8 May 1923 | Rainfall was torrential – particularly in North Canterbury. Amberley recorded a total of 495mm rain (265mm in 16 hours). Kowai flooded Leithfield with water flowing along North Road and flooding several houses. Metal on road was scoured. Over a distance of 50 chains, three breaks were made through the sand-hills (to drain flood waters in Leithfield Beach area). | SCRCC (1957)<br>Yetton *et al.* (2000)<br>Norton (1959) |
| Nov 1924 | 2 inches of rain in 24-hours at Amberley. Kowai flowed through Leithfield township and flooded four houses. | SCRCC (1957) |
| 20-22 Feb 1936 | South-westerly rain storm – floods were most serious in North Canterbury. Kowai broke its bank resulting in large areas of farmland being flooded. | SCRCC (1957) |
| 18 Jul 1963 | The Kowai River bar was breached by a fresh on 4th July. By 14 July, when river was in light flood, a small bar had developed but this was rapidly breached with minimal flooding allowing major flood flows on 16 July to pass straight out to sea. Overflows occurred over the South Kowai right bank at two known locations (0.8km upstream of Leithfield Village – returned to main river by old stopbanks , and 0.6km downstream of SH1 – flowing into the lagoon and outlet drain), and over the left bank (0.9km downstream of SH1 – flooding about 10 acres). Bank erosion also outflanked the existing belt of willows. | Norton (1963). |
| 5 Sep 1974 | Ponding and flooding behind the Amberley Beach settlement. | Yetton *et al.* (2000) from Holmes (1996) |
| 19-20 Aug 2000 | The Kowai River eroded the Grays Road bridge approach and breached the true left bank (TLB) downstream of Leithfield township. The closed Kowai River mouth was washed out before the main flood peak arrived. There was also limited flooding at Leithfield Beach. | Yetton *et al.* (2000) |
| 31 Jul 2008 | See Section 3.3.1 | |
| Jun 2014 | The Kowai River North Branch washed out the Grays Road bridge approach and also breached the true left bank upstream of SH1 – forcing a traffic diversion. | |

## 2.3 Kowai River system

The Kowai River system has two main watercourses (i.e. the North and South Branches) that join immediately upstream of SH1. Figure 2-3 shows the location of the river rating districts that benefit from the river control systems described in Sections 2.3.1 and 2.3.2.

Flooding along the upper reaches of both branches of the Kowai River is generally confined by well-defined terraces. However, the terrace along the Kowai River South Branch reduces in elevation near (and downstream of) the Leithfield Road-Terrace Road intersection. Historically this has allowed flood flows to pass into the Leithfield township and onto the downstream floodplain, including the Leithfield Beach settlement and farmland. Some of the floodwater passes into the Leithfield Outfall Drain which, starting at Leithfield township, drains spring and local rainfall runoff to the sea at the Leithfield Beach settlement (Norton, 1959). Flood waters tend to favour this flow path along the Leithfield Outfall Drain as it is located “at the southern margin of the alluvial fan of the Kowai River” (Norton, 1959), at a lower elevation than the Kowai River.

As the Leithfield Outfall Drain outlet to the sea is restricted, flood water can pond in the Leithfield Beach settlement. The recent construction of the two outlet culverts, through the sand dunes, may alleviate flooding to a certain extent - although at present one of these culverts is blocked. Therefore, in large flood events flood waters may still pond behind the sand dune, potentially overtopping the sand dunes. Historically, “severe scouring” in the “very friable sandy soil” was also observed during flood events affecting the Leithfield beach settlement (Norton, 1959).

During periods of low flows in the Kowai River and/or significant sediment movement along the coast, a bar forms across the mouth of the river. While the mouth is closed water levels in the lagoon rise, eventually inundating land on both sides of the river - although stopbanks now prevent flooding of some farmland that was historically observed to flood on a regular basis. The Kowai River mouth (Figure 2-2) can be opened manually, by excavating a 2 m divot in the mouth bar, when lagoon water levels are 200 mm below the top of the stopbank on D Rowell’s property (2.4 m above msl), and still rising. The mouth bar will also open naturally if the mouth bar is breached by high lagoon water levels.

**Figure 2-2: Kowai River mouth – 13 March 1986**

The Kowai River mouth is part of a Department of Conservation (DOC) reserve. The Kowai River is also considered a wetland of ecological and representative importance and a site of riparian native bird habitat, as well as land of National Significance.

### 2.3.1 North Branch Kowai River

Prior to Environment Canterbury establishing the North Branch Kowai River Rating Area in 2009 (Figure 2-3), river control works in the Kowai River North Branch were limited to government-subsidised planting of trees (to provide protection against bank erosion), and the construction of small scale stopbanks (to reduce the occurrence of flooding on adjacent land). This work was completed in the 1970s and was overseen by the North Canterbury Catchment Board. However, on completion of the works there was no rating district in place, so maintenance of the trees and stopbanks became the responsibility of the adjacent landowners. This resulted in the effectiveness of the scheme being compromised over time by a "lack of coordinated maintenance" (CRC Asset Management Plan). The river channel became congested with willow trees, which exacerbated bank erosion and flooding when the July and August 2008 flood events occurred. As a result, the North Branch Kowai River Rating District was established – extending from Douglas Road, downstream to the confluence with the South Branch. Figure 2-4 shows the Kowai River North Branch around the Grays Road area in August 1986.


**Figure 2-3: Kowai River North and South Branch Rating Districts benefitting from River Control Systems**

The North Branch Kowai River Asset Management Plan states that the aim of the river control system is to maximise river flood capacity and minimise bank erosion by:

- Establishing a strongly vegetated buffer flanking the river fairway (continuous and at least 20 m wide).
- Clearing the river fairway of vegetative obstructions (maintaining a fairway width of 32 m to 56 m).
- Encouraging appropriate shingle extraction (maximising flood capacity and reducing channel edge erosion).

**Figure 2-4: Kowai River North Branch with Grays Road in foreground (11 August 1986)**

### 2.3.2 South Branch Kowai River

In 2003 the Kowai River (Leithfield) Rating Area was established to cover the Kowai River from the Balcairn-Amberley Road to ~ 500 m upstream of the coast (Figure 2-3).

The Kowai River Asset Management Plan states that the aim of the river control system is to maximise river flood capacity and minimise bank erosion by:

- Establishing a strongly vegetated buffer flanking the river fairway (continuous and at least 20 m wide).
- Clearing the river fairway of vegetative obstructions (maintaining a fairway width of 40 m to 70 m upstream of the North Branch confluence, and 70 m to 100 m downstream of the confluence).
- Encouraging appropriate shingle extraction (maximising flood capacity and reducing channel edge erosion).

An historic low stopbank located along part of the river true right bank (TRB), to reduce the risk of flooding at Leithfield township, has also been reconstructed.

Figure 2-5 shows the Kowai River South Branch near the Balcairn-Amberley Road during the June 2014 storm event.


**Figure 2-5: Kowai River South Branch looking east, downstream from the Balcairn-Amberley Road (10 June 2014)**

## 2.4 Amberley Beach lagoons and outlets

At Amberley Beach there are two lagoons adjacent to the ocean (Figure 2-1). The Amberley Beach or Northern Lagoon is located immediately to the north of the Amberley Beach settlement with the wetland area adjacent to the lagoon considered to be a Wetland of Ecological and Representative Importance (WERI), a Site of Special Wildlife Importance (SSWI), an important habitat for native birds and land of National Significance. Part of the wetland is also a Department of Conservation (DOC) reserve. Amberley Beach Lagoon drains both the wetland area, and the low-lying area to the west of Amberley Beach (Figure 2-6), via two 3 m wide by 3 m high culverts (Figure 2-7).

Mimimoto Lagoon and the adjacent wetland are located to the south of Amberley Beach (Figure 2-8), draining Eastern Drain and surrounding low-lying land via a cutting through the beach barrier (Figure 2-9). The Eastern Drain exits Hursley Terrace in the vicinity of the Amberley Northern Lagoon but travels south, towards Amberley Beach Road rather than draining to North Amberley Lagoon. The section of Eastern Drain from the twin culverts under Amberley Beach Road, downstream to Mimimoto Lagoon, currently also has reduced conveyance due to significant vegetation within the channel (Figure 2-10). The wetland area adjacent to Mimimoto Lagoon is classified as land of National Significance.

Both of the lagoons usually have their outlets to the ocean blocked by beach barriers, however Hurunui District Council has a resource consent which allows the lagoons to be manually opened (excavated) at a trigger level of 2.10 m above msl (500 mm below the lowest house floor level). Note that this trigger level is documented in the consent as 1.89 m above msl however this is assumed to be relative to a different datum. The trigger levels were set below the floor levels of homes in Amberley Beach to alleviate flooding at the settlement and surrounding land. However, openings may be delayed by coastal conditions (e.g. storm surge, high tide, etc.) or may result in sea water flowing back into the lagoons. Climate change (i.e. rising sea level) is also likely to have an impact on the ability to open the lagoon outlets in the future.

**Figure 2-6: Aerial photo of Amberley Beach (Northern) Lagoon – 11 August 1986**

**Figure 2-7: The new Amberley Beach (Northern) Lagoon outlet structure showing sea water passing back into the drained lagoon (Photo: Ross Harper)**

**Figure 2-8: Aerial photograph of Mimimoto Lagoon – 11 August 1986**

**Figure 2-9: Mimimoto Lagoon outlet draining to the south (Photo: Ross Harper)**

**Figure 2-10: Eastern Drain looking downstream from Amberley Beach Road at the twin culverts**

## 2.5 Leithfield Beach Lagoon, Outfall Drain and outlets

Leithfield Beach Lagoon is located immediately to the north of the Leithfield Beach settlement (Figure 2-11). The lagoon outlet to the sea is formed when a cutting is made through the beach barrier (either a manual cutting or overtopping of the sand dune system in very high water levels). The lagoon is also connected via a channel to another small lagoon to the north; a channel from this lagoon drains water to the lower reaches of the Kowai River. Leithfield Beach Lagoon is also considered to be a Wetland of Ecological and Representative Importance (WERI) and a Site of Special Wildlife Importance (SSWI).

The Leithfield Outfall Drain (Figure 2-11 and Figure 2-12) drains water from the upstream Leithfield township (and the adjacent farmland), via the northern end of the Leithfield Beach settlement, to the piped outlet (Figure 2-13 and Figure 2-14).

The piped outlet consists of two 1.4 m diameter concrete pipes approximately 90 m long – although one is currently blocked. These pipes were installed after flooding in July and August 2008 resulted in the Outfall Drain overtopping its' banks, exacerbating flooding in the northern end of the Leithfield Beach settlement (Pattle Delamore Partners Ltd, 2010). Prior to the construction of the outlet pipes water passed into the sea via a manual or natural cutting made through the sand dunes 10 to 15 times per year. The invert level of manually opened cuts for the Outfall Drain is approximately 1.6 m above msl (Todd, 2008).


**Figure 2-11: Aerial photography showing the location of the Leithfield Beach Lagoon and Leithfield Outfall drain and outlet pipe**

**Figure 2-12: Leithfield Outfall Drain passing through Leithfield Beach settlement**

**Figure 2-13: Leithfield Outfall Drain piped outlet to the sea - Inlet**

**Figure 2-14: Leithfield Outfall Drain piped outlet to the sea - Outlet**

Leithfield Beach Lagoon and Outfall Drain usually have their natural outlets to the ocean blocked by beach barriers which can now be manually opened (excavated) at trigger water levels of 2.16 m above msl and 2.40 m above msl, respectively. The trigger levels were set below the floor levels of homes in Leithfield Beach to alleviate flooding at the settlement and surrounding land. However, openings may be delayed by coastal conditions (e.g. storm surge, high tide, etc.) or may result in sea water flowing back into the lagoons. Climate change (i.e. rising sea level) is also likely to have an impact on the ability to open the lagoon outlets in the future.

## 2.6 Waipara River

The Waipara River has a catchment area of 726 $km^2$ with the Waipara River mouth and lagoon located immediately to the north of the Amberley Beach floodplain. Like the Kowai River, the river mouth closes to the sea during low flows. The river mouth generally opens when there are freshes in the Waipara River of 8-10 $m^3/s$ (http://www.waiparariver.org.nz/manage6.html, accessed August 2014).

For this study it has been assumed that the Waipara River mouth will be open during any flood events, and that water from the Waipara River will flow out to sea rather than pass onto the Amberley Beach floodplain.

## 2.7 Ashworths Ponds

Ashworths Ponds are the shallow lagoons/ponds located on the Leithfield Beach floodplain to the south of Leithfield Beach. They are adjacent to the Saltwater Creek/Ashley River lagoon area and are considered to be of high ecological importance. The sand dunes were observed in LiDAR topographical data to be lower in elevation in this area than further to the north.

**Figure 2-15: Ashworths Ponds with Saltwater Creek/Ashley River lagoon in the background**

## 2.8 Climate change

The impacts of future climate change on the Kowai River catchment and Amberley and Leithfield Beach settlements are complex and, at present, not fully known. Some of the likely changes that are relevant to this flood modelling study include:

Air temperature
It is widely accepted that in the 100 years from 1990 (1980-1999) to 2090 (2080-2099) the mean annual air temperature in Canterbury is likely to increase by ~ 2ºC (Mullan *et al.,* 2008). This increase in air temperature is likely to increase the rate of evaporation from the lagoon areas – although higher sea levels (and greater seepage) may counteract any slightly lower lagoon levels.

Rainfall
In general, rainfall varies more significantly spatially and temporally than temperature. For the Canterbury region average annual rainfall is expected to increase in the west (i.e. in the alpine areas), by up to 10% between 1990 and 2090, while in the east and north it is expected to decrease by over 5% in places during the same time period (Renwick *et al.,* 2010). In the Kowai River and Amberley and Leithfield Beach settlements the change in average annual rainfall is likely to be relatively small.

However, rising air temperatures are also likely to produce an increase in the intensity of extreme rainfalls since warmer air contains ~ 8% more moisture for each 1ºC increase in temperature (Mullan *et al.,* 2008). Mullan *et al.* (2008, Table 1, p 9) states with "moderate confidence" that the magnitude of change in extreme rainfall in New Zealand is likely to be within the range of "no change through to halving of heavy rainfall return period by 2040; no change through to fourfold reduction in return period by 2090" – with areas where average annual rainfall is predicted to increase being more susceptible to increases in rainfall intensity ((Mullan *et al.,* 2008). For the Kowai River catchment an increase in extreme rainfall intensity of 8% (in 50 years, 1990-2040) and 16% (in 100 years, 1990-2090) would be consistent with approximately doubling and quadrupling, respectively, the frequency of the rainfall event (Surman, 2013). This means that by 2040 a 100 year flood event may become a 50 year flood event, and by 2090 the same flood may be equivalent to a 20-30 year flood event (Surman, 2013).

Sea level

The current expectation is that in the 100 years from 1990 (1980-1999) to 2090 (2080-2099) there will be a *minimum* increase in sea level of 0.5 m, although consideration should also be given to a higher increase of at least 0.8 m over this time period (Ministry for the Environment, 2008). Small increases in sea level will most likely require more frequent openings of the lagoon outlets to the sea. These more frequent openings will be required as the outlet to the sea will tend to close earlier (i.e. at higher lagoon levels).

Other

In conjunction with sea level rise, it is expected that the beach/dune system will also be modified.

# 3 Methodology

Floodplain flows are often difficult to predict due to the multi-directional nature of the flows, the interaction between main river channel flows passing out of and then returning to the river, and also the difficulty in identifying flow paths where ground levels vary more gradually.

This floodplain investigation used a combined 1-d/2-d hydrodynamic computer model (Mike Flood) to simulate flood events and determine river and floodplain water levels, floodplain extent, floodplain flow patterns and flow velocities. The methodology included:

- Compilation of historical flood event information (Section 2.2)
- Estimation of flood hydrology/design flows (Section 3.1)
- Construction of a computational hydraulic model (Section 3.2)
- Calibration of the hydraulic model (Section 3.3)
- Modelling of 50 year ARI design flood event using the calibrated hydraulic model (Section 3.4)
- Modelling of 200 year ARI design flood event using the calibrated hydraulic model (Section 3.5)
- A sensitivity analysis (Section 3.6)

## 3.1 Flood hydrology

In the Mike 11 model flow hydrographs are used to input flood flows into the upstream limits of the Kowai River North and South Branches, while a tidal cycle/water level boundary is used to define the downstream Kowai River boundary at the coast. Additional inflows are input to the Mike 21 model grid to represent the Stockdill Road area (Figure 2-1), which is modelled as two smaller streams entering the Kowai South Branch, and local rainfall runoff from the twenty-nine smaller Amberley Beach and Leithfield Beach sub-catchments (Figure 3-4).

For this study the July 2008 flood event was considered to be a 'typical' flood event. This was partly out of necessity (as it is the only relatively large event that there is a flow record for), and partly because it was a recent event (and there have been only minor changes within the catchment since this time). For the July 2008 storm event the Kowai River North Branch had an estimated peak flow of 95 $m^3/s$ (5-10 year ARI) and Amberley at Railway Terrace recorded a 24 hour rainfall with ~ 20 year ARI. A summary of the methods used to derive the boundary conditions for the July 2008 calibration event, and the 50 and 200 year average recurrence interval (ARI) design flood events, is given below.

### 3.1.1 Kowai River flows

The Kowai River consists of a North Branch and South Branch that converge upstream of the SH1 road bridge at Leithfield township. Downstream of SH1 the Kowai River flows into the sea – although this opening is often closed, resulting in water accumulating behind the beach barrier.

The 1-d Mike 11 model for the Kowai River North branch extends 6 km upstream from the sea (i.e. upstream of the Grays Road bridge), and the South branch extends 6.5 km upstream from the sea (i.e. upstream of the Balcairn Amberley Road bridge). The Mike 11 model extent is shown in Figure C-1 and Figure C-2; here the modelled overflow from the 1-d Mike 11 Kowai River channel to the 2-d Mike 21 floodplain is represented by yellow lines. The Mike 21 modelled floodplain extent is shown in Figure 2-1.

*July 2008 calibration event*

Between 2006 and 2012 a water level/flow recorder was located on the Kowai River North Branch at Grays Road (Site 66101). During the time that the recorder was operating the July 2008 and August 2008 flood events occurred, with peak flows of 95 $m^3/s$ and 85 $m^3/s$, respectively. The larger July 2008 flood event has been used to 'calibrate' the model.

The Kowai North Branch at Grays Road (Site 66101) record provided the inflows for the North Branch, and the flow hydrographs for the Kowai South Branch and Stockdill Road area were derived by scaling the Kowai North Branch hydrograph by the relative catchment areas. Figure 3-1 shows the July 2008 measured and scaled flow hydrographs.

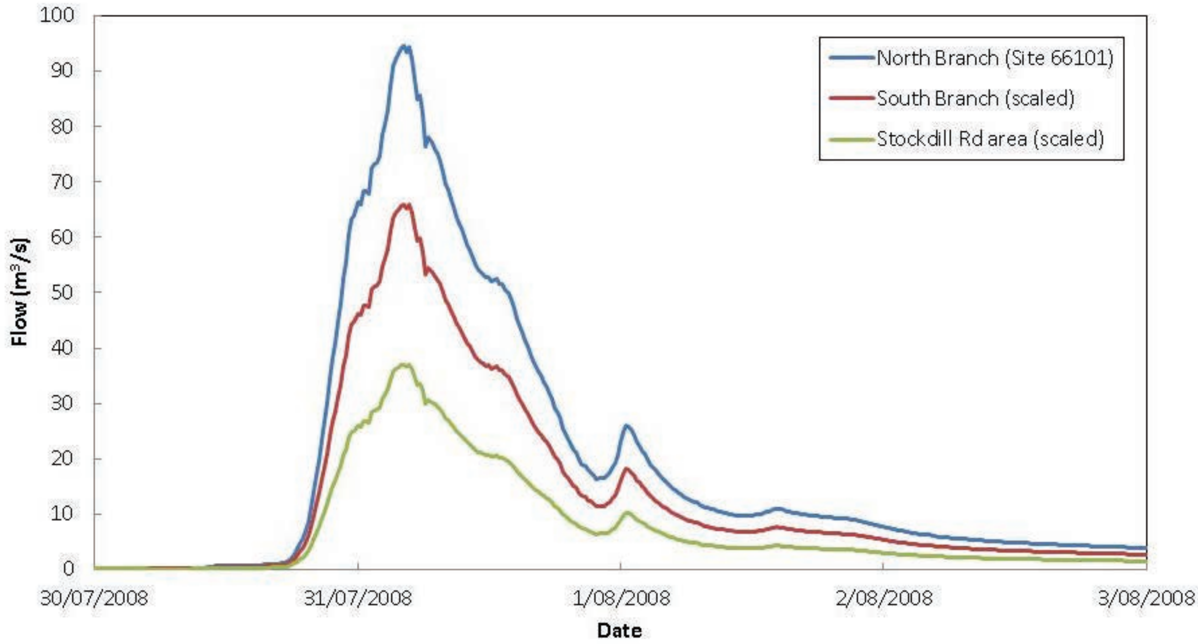



**Figure 3-1: Kowai River flow hydrographs – 30 July to 2 August 2008**

*Design flood events*

Due to the short length of the Kowai River North Branch record, it could not be used to generate design flows for large and infrequent flood events, such as 50 and 200 year ARI flood events.

Instead, Griffiths *et al.* (2011) provides a methodology to enable design flood peak estimates to be calculated specifically for rivers in the Canterbury region, where long flow records are not available. This Griffiths *et al.* (2011) regional flood estimation study updates the previous work of McKerchar and Pearson (1989). Estimated Kowai River design flood flows, derived using this methodology, are shown in Table 3-1 and Figure 3-2. Figure 3-2 also shows (dashed lines) the standard error of 16 to 30% associated with the design flows.

The factors used to derive the design peak flows are summarised in Table 3-1 where:

$$Mean\ annual\ flood\ (MAF) factor\ =\ \frac{Q_{MAF}}{A^{0.866}}$$

$$Flood\ frequency\ factor\quad q_{100} = \frac{Q_{100}}{Q_{MAF}}$$

To produce the Kowai River 50 year and 200 year ARI flow hydrographs, the July 2008 flow hydrograph for the Kowai River North Branch is multiplied by $Q_{design}$/94.5 m$^3$/s, where $Q_{design}$ is specified in Table 3-1. The Stockdill Road area inflow is also split evenly between two tributaries draining this area.

The regional flood estimation method (Table 3-1) indicates that for the Kowai River North Branch both the July and August 2008 flood events had a 5 to 10 year Average Recurrence Interval (ARI).

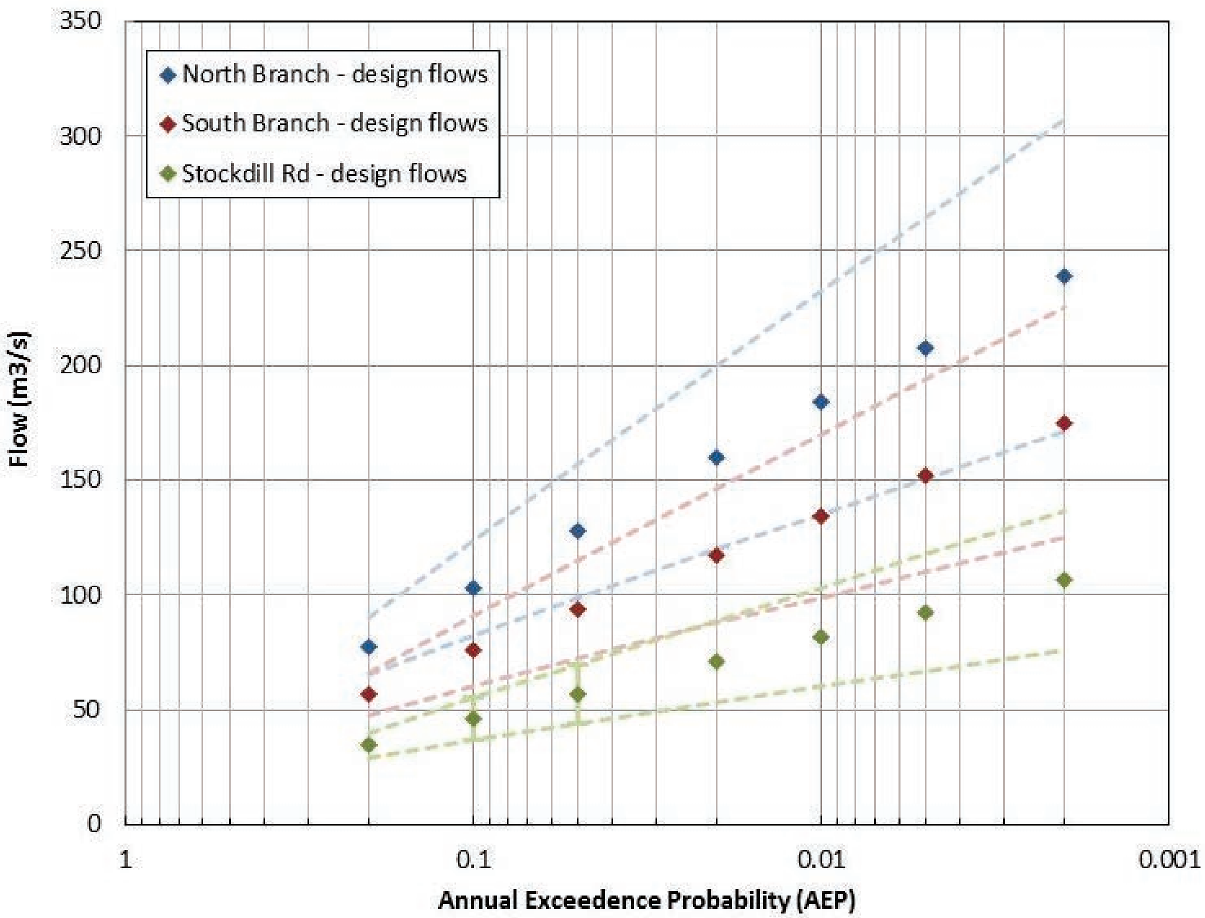



**Figure 3-2: Annual exceedence probability (AEP) for Kowai River inflows (standard error is shown as dashed lines)**

**Table 3-1: Kowai River flow data (including design flows and standard errors derived from Griffiths *et al.* (2011))**

| | | North Branch | South Branch | Stockdill Rd |
|---|---|---|---|---|
| Catchment area (km²) | | 81 | 58 | 33 |
| MAF Factor | | 1 | 1 | 1 |
| $q_{100}$ | | 4 | 4 | 4 |
| Mean Annual Flood, $Q_{MAF}$ (m³/s) | | 46 | 34 | 20 |
| *Design flows (m³/s)* | *Std error* | | | |
| 0.2 AEP (5 year ARI) | 16% | 78 | 57 | 35 |
| 0.1 AEP (10 year ARI) | 20% | 103 | 76 | 46 |
| 0.05 AEP (20 year ARI) | 23% | 128 | 94 | 57 |
| 0.02 AEP (50 year ARI) | 25% | 160 | 117 | 71 |
| 0.01 AEP (100 year ARI) | 26% | 184 | 135 | 82 |
| 0.005 AEP (200 year ARI) | 27% | 208 | 152 | 92 |
| 0.002 AEP (500 year ARI) | 28% | 239 | 175 | 106 |

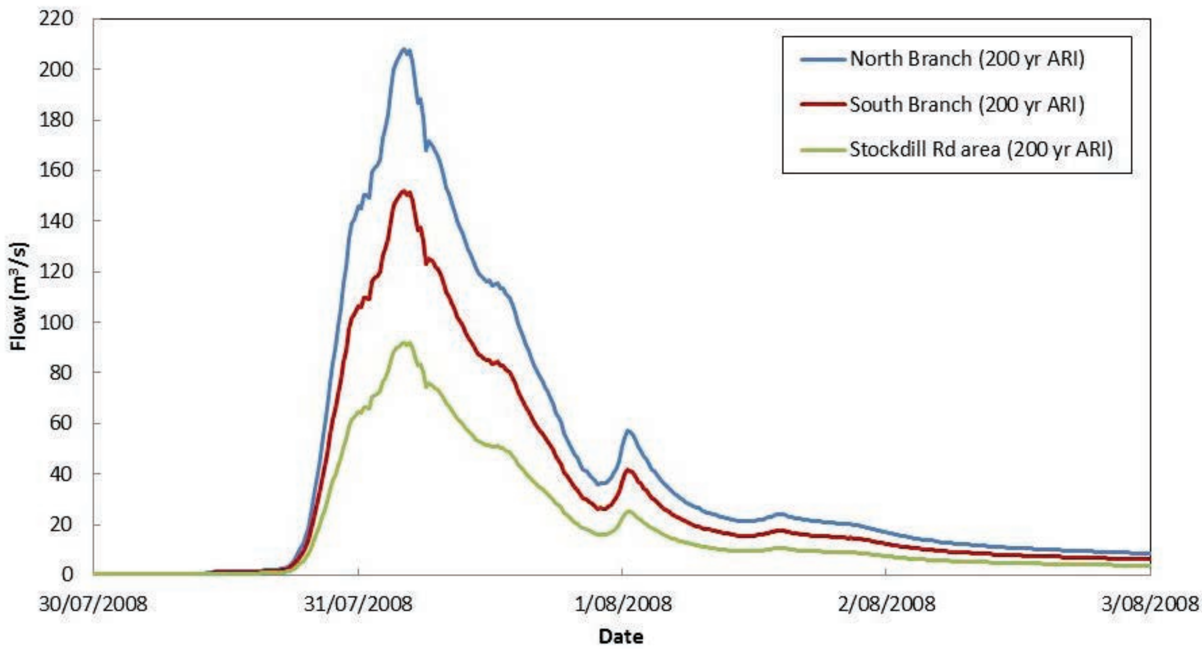



**Figure 3-3: Kowai River 200 year ARI flow hydrographs**

### 3.1.2 Amberley and Leithfield Beach settlement local inflows

Due to the undulating nature of the historic sand dunes surrounding the Amberley and Leithfield Beach settlements, it is likely that in some areas rainfall and local runoff will pond rather than flow towards the sea. There are also a relatively large number of smaller streams draining water from the more elevated hilly land to the west. It was therefore necessary to divide the Amberley Beach and Leithfield Beach study areas into a total of 29 smaller sub-catchments (Figure 3-4).

As these sub-catchments are relatively small (i.e. all are less than 3 $km^2$ excluding the 10.9 $km^2$ Eastern Drain sub-catchment), it was not considered suitable to use the Regional Flood Estimation (RFE) method used to derive the Kowai River design flows (Section 3.1.1). This is because the RFE method is based on much larger catchments. Instead, rainfall runoff modelling has been used to determine the flow contributions from each of the 29 sub-catchments, and the RFE method has only been used for comparative checks.

The Rainfall Runoff Editor in the Mike 11 modelling suite was used for the rainfall runoff modelling (i.e. to convert the rainfall falling on the sub-catchments into a flow accumulating within, and flowing out of, each sub-catchment).

The Mike11 Rainfall Runoff Editor (RRE) requires:

- at least one rainfall time series
- rainfall runoff parameters
- model run parameters

The rainfall time series, and resulting local sub-catchment flow time series, are described below for the July 2008 50 year ARI and 200 year ARI flood events. The rainfall runoff and model run parameters are summarised in Appendix A (Table A-1).

*July 2008 calibration event*

Pattle Delamore Partners Ltd (2008 and 2009) provides a summary of rainfall data recorded during the July 2008 flood event. The location of the rainfall gauges used for this study are shown in Figure 3-5, and Table 3-2 provides a summary of the rainfall totals measured during the calibration event.

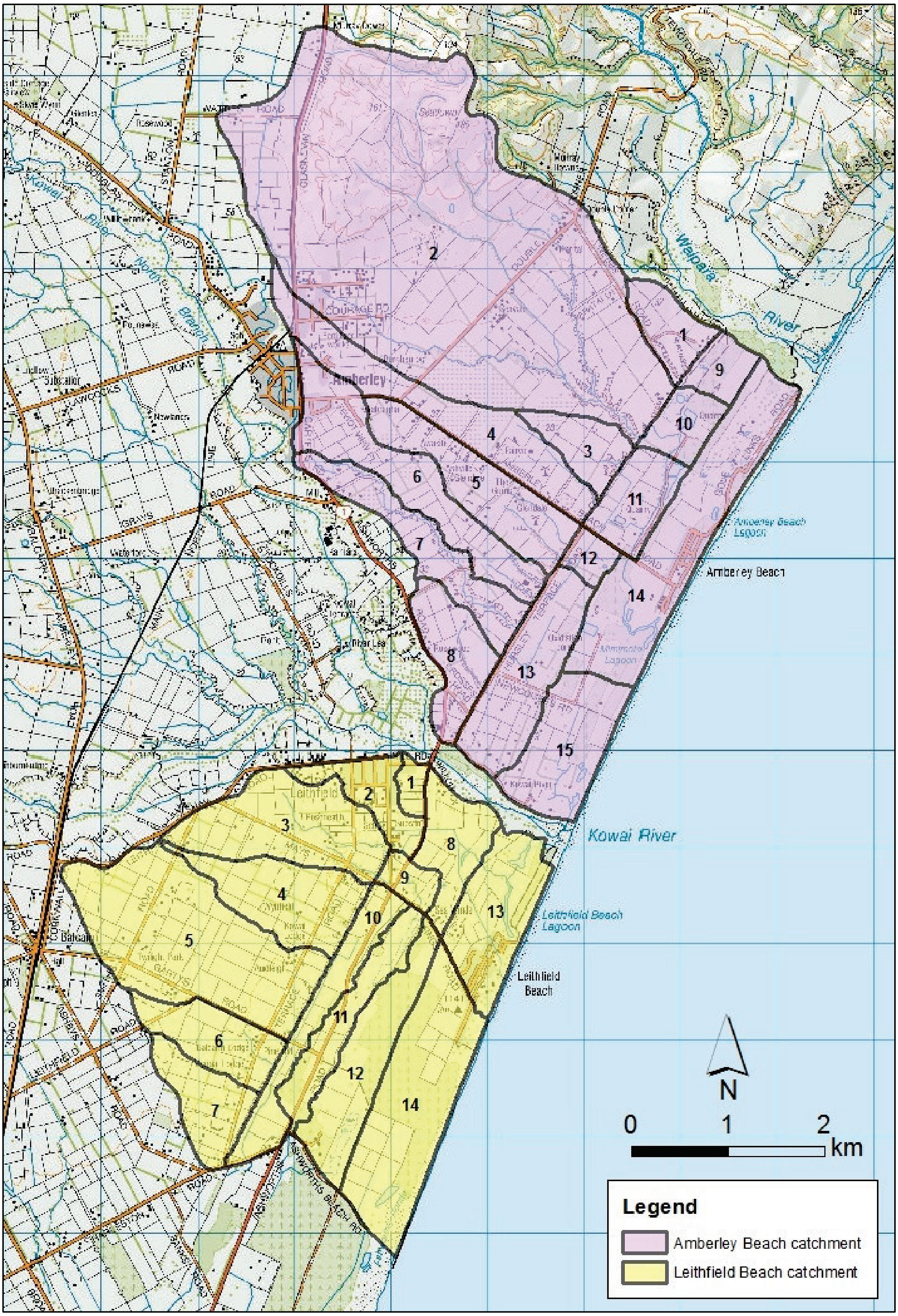



**Figure 3-4: Amberley and Leithfield Beach settlement sub-catchments**

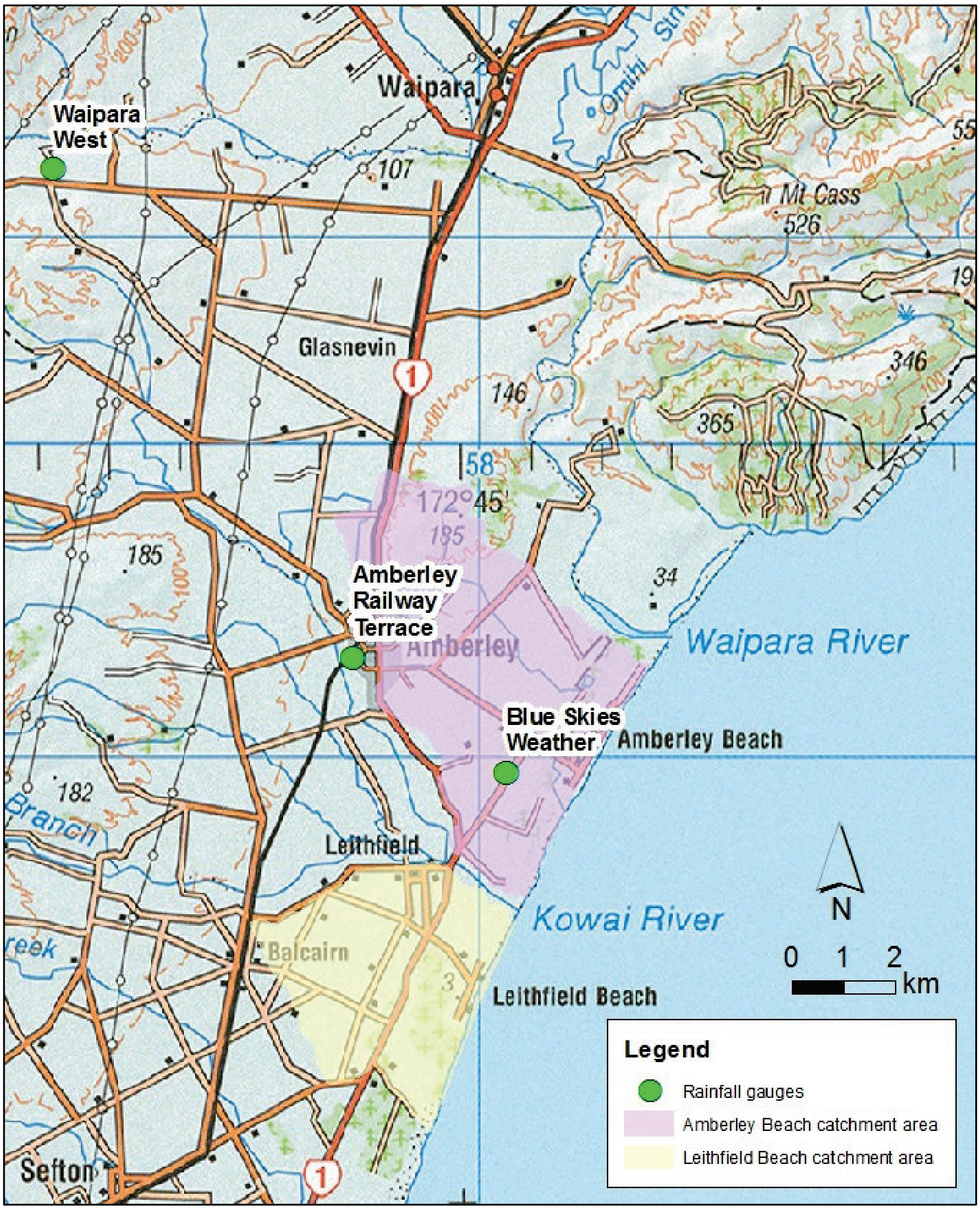



**Figure 3-5: Location of rainfall gauges**

**Table 3-2: Summary of rainfall gauges near the Amberley and Leithfield Beach settlements for the July 2008 calibration event**

| Site Name | Owner | Data type | July Monthly Total Rainfall (mm) | 31 July Total Rainfall (mm) | 1 August Total Rainfall (mm) |
|---|---|---|---|---|---|
| Waipara West | NIWA | 15 min | 151 | 86.6 | 9.2 |
| Amberley Railway Terrace | NIWA | Daily (9am) | 177 | 122.3 | 18.2 |
| Blue Skies – Hursley Terrace Road | Blue Skies Weather Ltd | Daily (noon) | 191 | N/A | N/A |

From Figure 3-5 it can be seen that the Blues Skies raingauge is the most appropriate raingauge to use for modelling rainfall runoff from the Amberley Beach and Leithfield Beach sub-catchments. To generate a July 2008 rainfall time series for the Amberley Beach and Leithfield Beach sub-catchments, the Waipara West 15 minute rainfall record (Figure 3-6) was scaled by the ratio of the daily rainfall total for the Amberley Railway Terrace gauge compared to the Waipara West Gauge (i.e. factor $R_{Amb}$, Table 3-3). This rainfall time series for the Amberley Railway Terrace rainfall gauge was then scaled by a factor of 1.08 (i.e. 191/177, which equals the Blue Skies/Amberley Railway Terrace monthly rainfall totals) to produce a rainfall time series for the Amberley Beach and Leithfield Beach sub-catchments (Figure 3-6). This derived rainfall time series was used in the Rainfall Runoff Editor, together with the rainfall runoff and model run parameters specified in Table A-1 (Appendix A), to generate the sub-catchment flows.

**Table 3-3: Daily rainfall totals and scaling factor $R_{Amb}$ for the July 2008 calibration event**

| Date | Time of measurement | Amberley at R/way Tce Daily Total Rainfall | Waipara West Daily Total Rainfall | Scale factor $R_{Amb}$ |
|---|---|---|---|---|
| 29/7/08 | 9am | 0 | 0 | 0 |
| 30/7/08 | 9am | 3.2 | 2.6 | 1.2 |
| 31/7/08 | 9am | 122.3 | 86.6 | 1.4 |
| 1/8/08 | 9am | 18.2 | 9.2 | 2.0 |
| 2/8/08 | 9am | 5.2 | 6 | 0.9 |
| 3/8/08 | 9am | 6.7 | 6.6 | 1.0 |
| 4/8/08 | 9am | 1.6 | 1.2 | 1.3 |

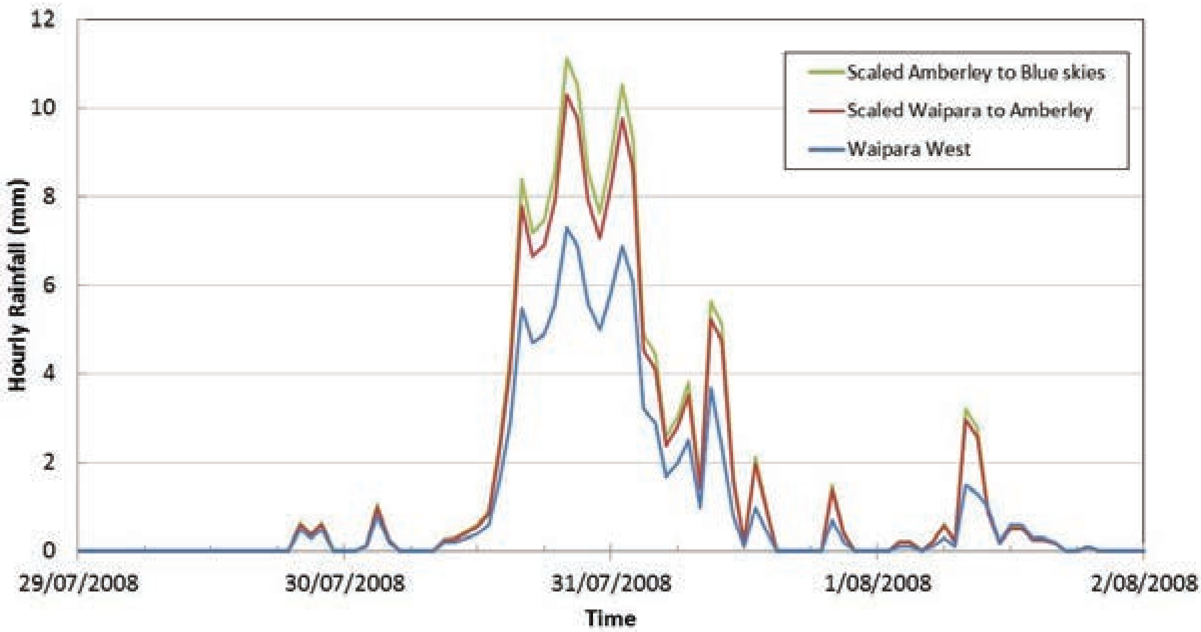



**Figure 3-6: Rainfall time series for the July 2008 flood event**

It can be seen from Table A-1 (Appendix A) that an end infiltration rate of 3 mm/hr has been specified in the rainfall runoff parameters. Although this may seem low for imperfectly drained and moderately drained silty loams (hilly, terrace catchment areas) and more so for well drained sandy loams/loams (flat areas near the coast), it is assumed that the antecedent conditions are likely to be relatively wet. It has also been observed, with recent flooding, that water tends to pond in some areas, rather than drain away immediately following a storm. This suggests that drainage in some areas is relatively poor.

The derived flows for each sub-catchment are shown on Figure B-1 (Appendix B). This shows that the July 2008 maximum flow of ~ 16 $m^3/s$ from sub-catchment A2 (i.e. the largest Amberley Beach sub-catchment) is significantly larger than the flows from the adjacent, smaller Amberley Beach sub-catchments. It also indicates that over 40% of the local sub-catchment inflows to the Amberley Beach area may come from this one sub-catchment. Meanwhile, the smaller Leithfield Beach catchment area is likely to receive less inflow from local sub-catchment inflow that the Amberley Beach catchment.

To determine the sensitivity of the sub-catchment peak flows to infiltration rates, the end infiltration rate was decreased from 3 mm/hr to 1 mm/hr. This increased peak flows by ~ 35%. Similarly, when infiltration rates increased from 3 mm/hr to 5 mm/hr the peak flows decreased by ~ 35%.

*Design flood events*

To determine the 50 year ARI and 100 year ARI 24-hour and 48-hour rainfall totals for the Amberley Beach and Leithfield Beach catchments, NIWA's High Intensity Rainfall Design System (HIRDS version 3) was used. HIRDS is a web-based programme that can estimate rainfall frequency at any point in New Zealand (http://hirds.niwa.co.nz/, accessed 5 August 2014) for any storm event up to a 100 year ARI. The HIRDS results for the Amberley Railway Terrace rainfall gauge location (which gave the highest rainfall totals of the three rain gauge sites) are summarised in Table B-1.

To produce 200 year ARI rainfall totals, the HIRDS 100 year ARI rainfall totals for the Amberley Railway Terrace site were scaled using dimensionless rainfall depth factors ($P_{ARI}/P_M$). These factors were produced in a recent analysis of the frequency of high intensity rainfalls in Christchurch (Table 3.4, Griffiths *et. al,* 2009). The values of interest are shown below

$$\frac{P_{100}}{P_M} = 2.73 \qquad \frac{P_{200}}{P_M} = 3.09 \qquad \frac{P_{200}}{P_{100}} = 1.13$$

Where $P_{100}$ is the rainfall total for the 100 year ARI and $P_M$ is the median annual maximum rainfall.

This scaling factor of 1.13 was checked against the latest review of flood frequency for the Canterbury Region (Table 5-1, Griffiths *et. al,* 2011). Here $q_{100}$ is the dimensionless flood peak discharge for a 100 year ARI, $Q_{100}$ is the peak flow for a 100 year ARI, and $Q_M$ is the mean annual flood. This also gave a scaling factor of 1.13, as shown below.

$$q_{100} = \frac{Q_{100}}{Q_M} = 4.0 \qquad \frac{Q_{200}}{Q_M} = 4.52 \qquad \frac{Q_{200}}{Q_{100}} = 1.13$$

The 200 year ARI rainfall totals used for this study are therefore summarised in Table 3-4.

**Table 3-4: Summary of 24-hour and 48-hour design rainfall totals for the Amberley and Leithfield Beach catchments**

| Rainfall event | 50 year ARI ($P_{50}$) | 100 year ARI ($P_{100}$) | Scale factor ($P_{200}/P_{100}$) | 200 year ARI ($P_{200}$) |
|---|---|---|---|---|
| 24-hour | 160 mm | 189 mm | 1.13 | 214 mm |
| 48-hour | 178 mm | 211 mm | 1.13 | 239 mm |

As we have not experienced a 200 year ARI flood event it is difficult to ascertain the likely timing of local rainfall runoff peaks in relation to flood peaks travelling along the larger Kowai River watercourse. It was therefore considered appropriate to scale the July 2008 rainfall profile as we know that, when combined with scaled Kowai River flows from the July 2008 event, it should be fairly indicative of what could occur in larger events.

To enable the 24-hour (and 48-hour) design rainfall event to be simultaneously modelled, the July 2008 rainfall time series was scaled so that the 24-hour time period with the highest rain total (i.e. 30 July 2008 at noon to 31 July 2008 at noon) was scaled to match the 24-hour design rainfall. The following 24-hour period was then scaled so that the total rainfall for the 48-hour period matched the 48-hour design rainfall. Table 3-5 shows the derivation of the scaling factors and Figure 3-7 and Figure 3-8 show the resulting 50 year and 200 year ARI rainfall time series, respectively.

These derived rainfall time series were used in the Rainfall Runoff Editor, together with the rainfall runoff and model run parameters specified in Table A-1 (Appendix A), to generate the sub-catchment flows (Figure B-2, Appendix B for 200 year ARI). Figure 3-9 summarises the peak flows from each sub-catchment. This shows a peak flow of ~ 33 $m^3$/s from sub-catchment A2 (i.e. the largest Amberley Beach sub-catchment) for the 200 year ARI with most other sub-catchments having peak flows less than 5 $m^3$/s.

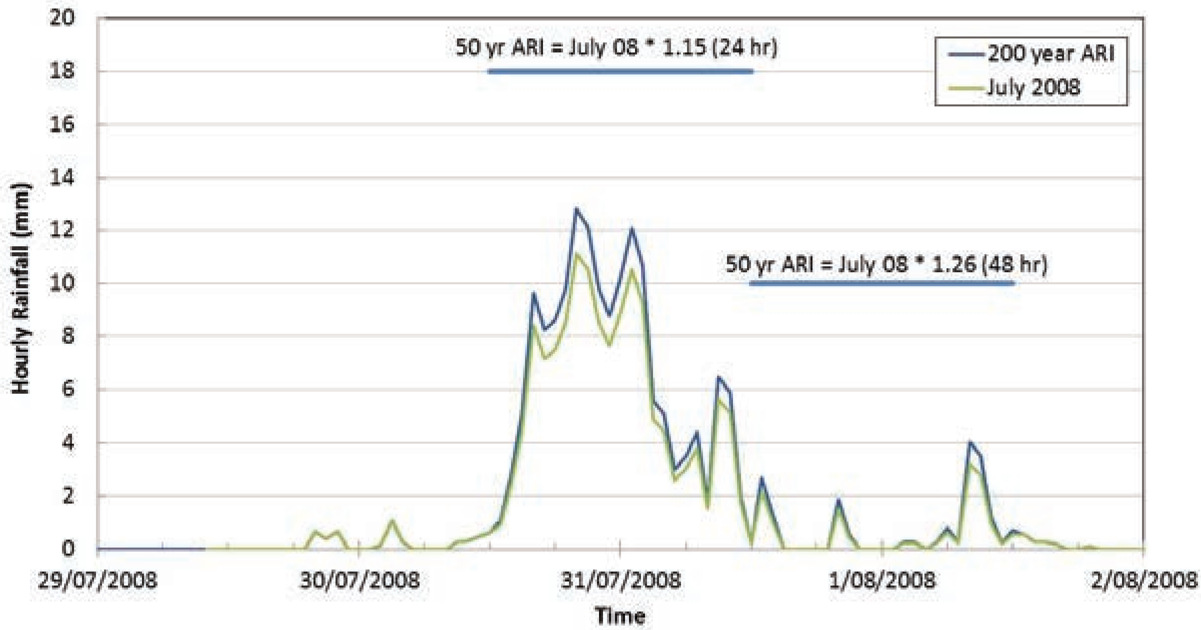



**Figure 3-7: Derived 50 year ARI rainfall time series**

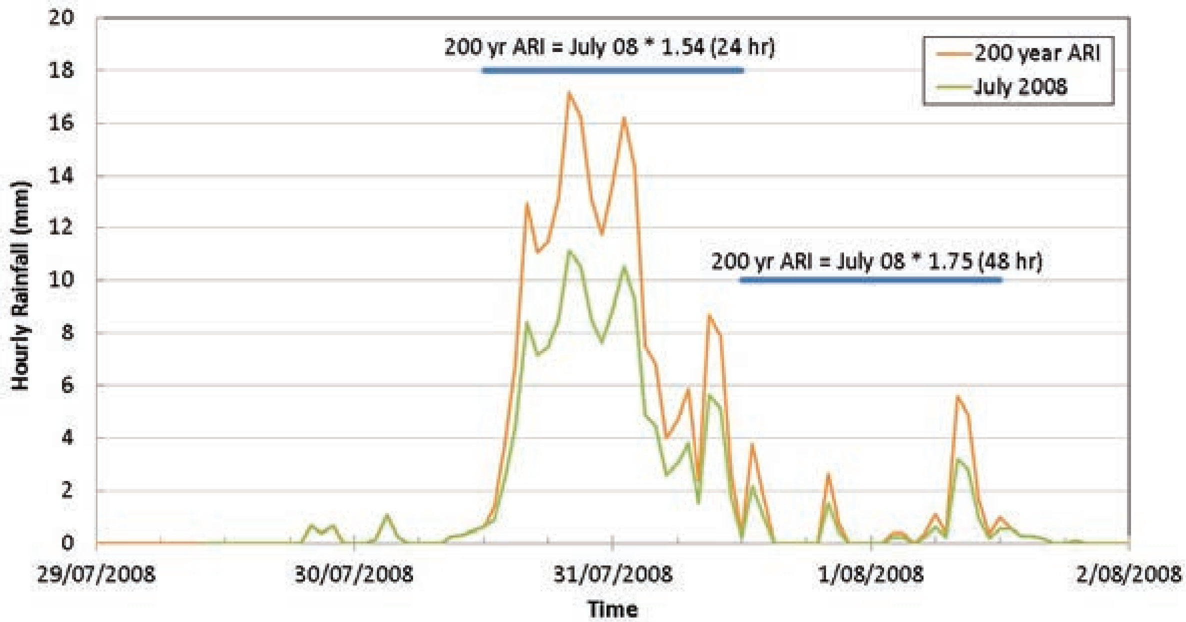



**Figure 3-8: Derived 200 year ARI rainfall time series**

**Table 3-5: Scaling of July 2008 rainfall profile to produce 50 year and 200 year ARI design rainfall**

| Rainfall event | 200 year ARI ($P_{200}$) | 50 year ARI ($P_{50}$) | July 2008 | 200 year ARI scale factor | 50 year ARI scale factor |
|---|---|---|---|---|---|
| 24-hour | 214 mm | 160 mm | 138.8 mm | 1.54 | 1.15 |
| 24 to 48 hours | 25 mm | 18 mm | 14.3 mm | 1.75 | 1.26 |
| 48-hour | 239 mm | 178 mm | 153.1 mm | - | - |

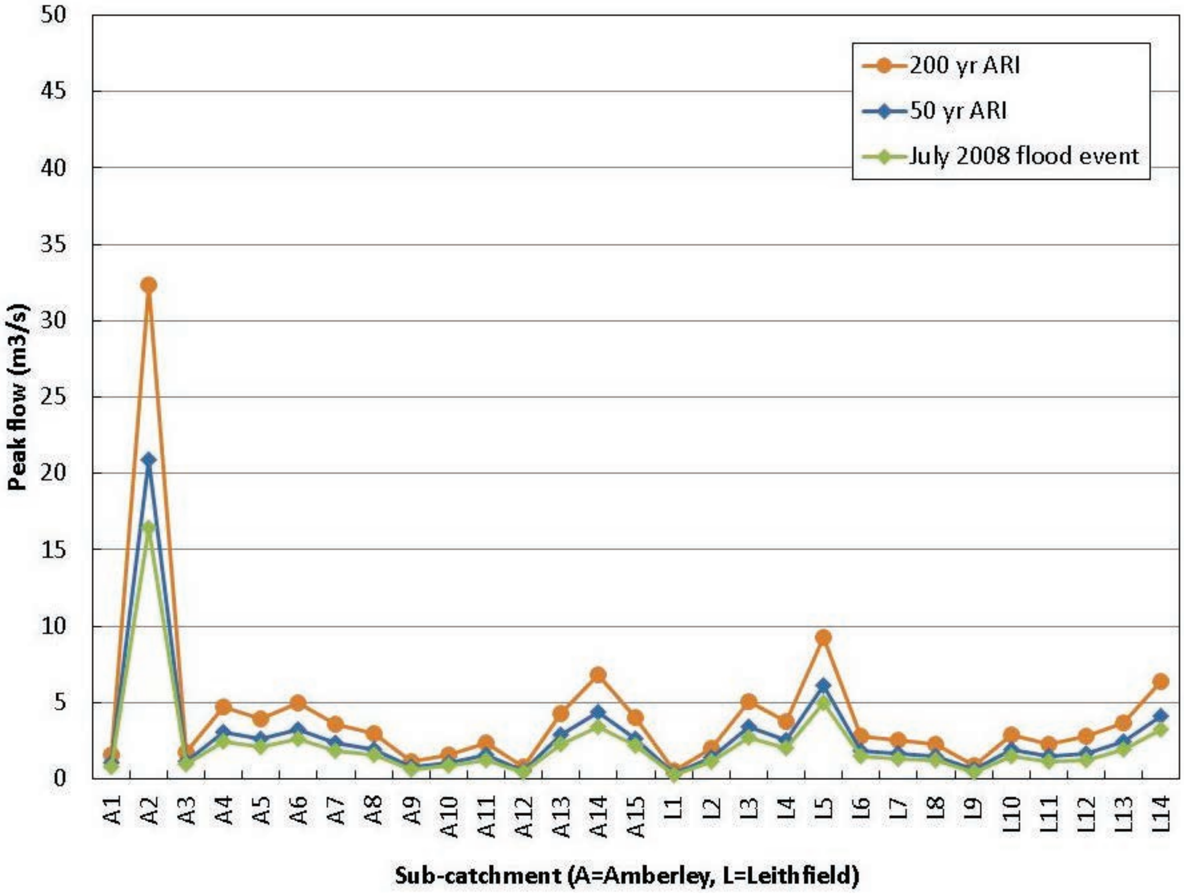



**Figure 3-9: Amberley and Leithfield Beach sub-catchment peak flows derived from Rainfall Runoff Editor for the July 2008, 50 year and 200 year ARI storm events**

*Sub-catchment design flow comparison*

The sub-catchment peak flows derived using the design rainfall and the Rainfall Runoff Editor (RRE) were compared to peak flows derived using the regional flood estimation (RFE) method which was used in Section 3.1.1 to generate 50 and 200 year ARI flood peak flows for the Kowai River. These RFE flood peaks (including standard error) are shown on Figure 3-10. Although the flood peaks generated using the RRE are lower, the peak flows are generally within the RFE method standard error. Since we do not have any flow data to calibrate the design flows to, a sensitivity test is included in the Mike FLOOD model 200 year ARI runs to determine the effect of increasing RRE-derived local sub-catchment inflows by 25% (Section3.6.2).

It should be noted that the rainfall runoff modelling has been based on scaling of the July 2008 rainfall time series to produce the 24 hour design rainfalls – rather than using a standardised rainfall profile. Storm durations less than a 24 hour design rainfall event have not been modelled as it was considered that, despite smaller higher rainfall intensity events potentially producing higher peak flows (in smaller sub-catchments), they would not contribute as large a total volume of water to the Amberley Beach and Leithfield Beach areas as longer duration storm events such as a 24 hour event. The 48 hour design rainfall was also considered less relevant as it was more likely that the outlets to the sea would be able to be opened in a longer duration event.

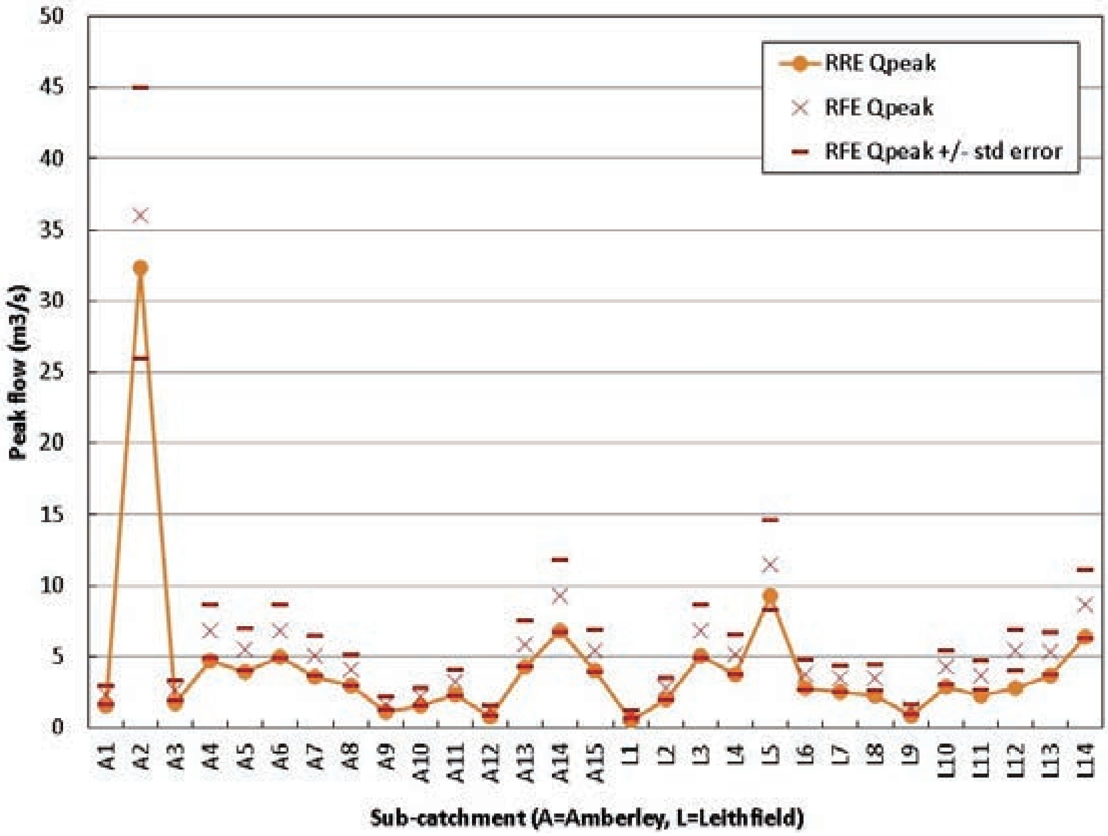



**Figure 3-10: Comparison of peak flows, derived using the Rainfall Runoff Editor (RRE) and RFE (Griffiths *et. al.,* 2011) methods, for the Amberley and Leithfield Beach sub-catchments**

### 3.1.3 Pegasus Bay sea levels

Sea level is a combination of tide level, storm surge and other sea level variability such as seiche, tidal residuals and other variations (Bell, 2011). The closest sea level recorder site to the Amberley Beach/Leithfield Beach area is located at Sumner Head (Site 66699). This site has been operating since June 1994, and is jointly funded by the National Institute of Water and Atmospheric Research (NIWA) and Environment Canterbury.

Using the NIWA tide forecaster (http://www.niwa.co.nz/services/online-services/tide-forecaster, accessed 31 July 2014) a tide forecast (time and height of high and low tides) can be derived for any location around the New Zealand coastline with an accuracy of 0.1 m (vertically) and 5-10 minutes relative to a mean level of sea (MLOS). High tides at Sumner tend to be 20 to 50 mm greater in magnitude, and approximately 7 minutes earlier, than those in the vicinity of Amberley Beach/Leithfield Beach.

*July 2008 calibration event*

To derive a sea level record for the July 2008 flood event, a sine curve was fitted to the 'averaged' low and high tide water level records generated by the NIWA tide forecaster for Sumner and Amberley Beach/Leithfield Beach (Figure 3-11, blue and black lines, respectively).

The difference between the Sumner recorded (red line) and derived sine curve (blue line) sea levels (i.e. light blue line) was then smoothed by averaging over 7 time steps (orange line). This 'residual' sea level was then added to the derived sine curve for Amberley Beach/Leithfield Beach (black line) to produce the 'smoothed' sea level record used in the model (green line).

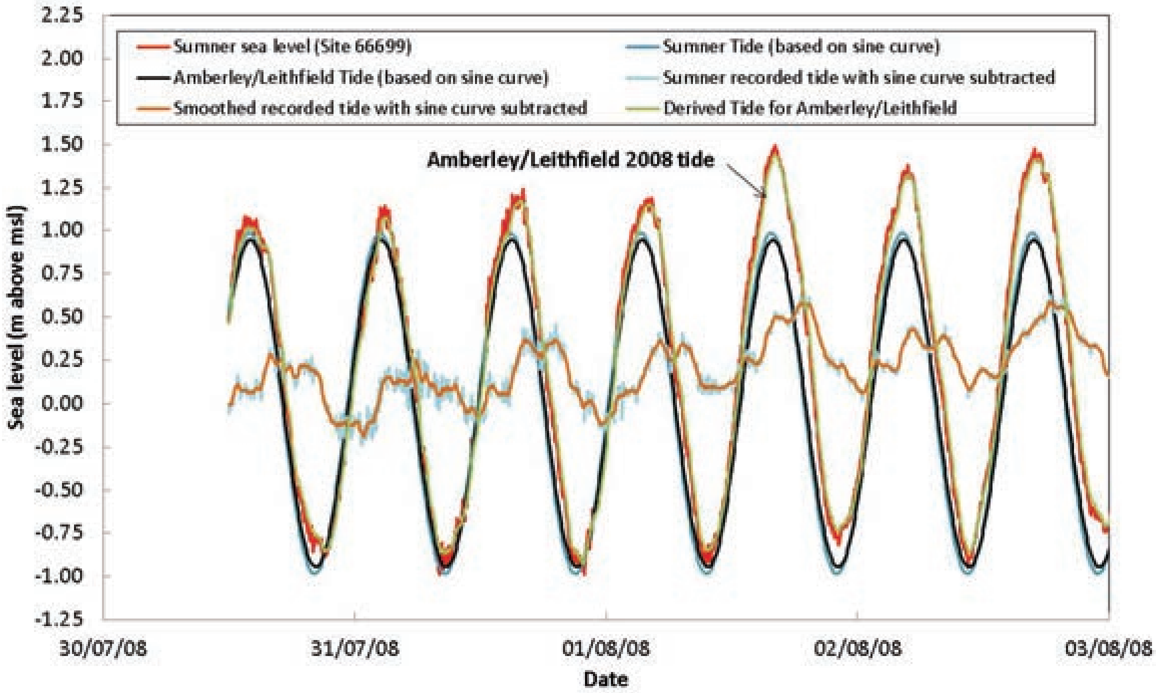



**Figure 3-11: Derivation of Amberley/Leithfield Beach tide for July 2008 flood event**

During the July 2008 storm event the highest tide level (excluding storm surge, etc) at Sumner was 1.10 m above the mean level of the sea (MLOS) or 1.24 m above msl on 31 July at 3:05pm. According to Bell (2011) this is considered to be a moderate ‘king tide’ since it was higher than the mean high water perigean-spring (MHWPS) level at Sumner Head which is 1.08 m above MLOS – a level only exceeded by 8% of all tides (Bell & Wild, 2006). Bell (2009) also shows that, during the 31 July 2008 storm event, storm surge was relatively insignificant at Sumner Head, indicating that high sea levels were largely due to the king tide rather than storm surge. However, it should be noted that storm surge was calculated at Sumner Head, and is also offshore (beyond the break zone), and does not include wave set-up and wave run-up at the shoreline at Amberley Beach and Leithfield Beach.

Design sea level

Despite storm surge being small during the 31 July 2008 storm event, in 2008 there were 15 separate storm surge events where storm surge height exceeded 0.20 mm - the largest storm surge of 0.42 m occurring on 16th February (Bell, 2009). This storm surge occurred when a deep low-pressure system travelled in an easterly direction over the central South Island. The low pressure system, with a barometric pressure of 987-992 hPa, “pulled a strong south-westerly wind flow up the east coast” (Bell, 2009, p 14). In Canterbury, these strong south-westerly winds tend to push water into the coast, increasing water levels further with wind set-up (Bell, 2009). It is worth also mentioning that the highest storm tide level (i.e. combination of high tide + storm surge + other sea level variability) did not occur at the same time as the largest storm surge in 2008. Instead, the highest storm tide level of 1.62 m above msl occurred on the 6 July 2008

Analysis of the Sumner Head sea level record between 1995 and 2010 (16 years inclusive) shows that the mean annual maximum storm surge is 0.37 m with a maximum storm surge of 0.49 m recorded on 6 October 2005 (Bell, 2011). Between 2004 and 2010 (7 years inclusive) the mean annual maximum storm tide level is 1.60 m above msl with a maximum storm tide level of 1.72 m above msl recorded on 4 January 2006.

For the 50 year and 200 year ARI design flood events the derived July 2008 moderate ‘king tide’ sea level time series for the Amberley Beach/Leithfield Beach area has been increased by 0.4 m to incorporate storm surge that could occur for a more significant low pressure weather system (Figure 3-12). This increases storm high tide levels to between 1.42 m above msl and 1.58 m above msl during the design storm event runs (Table 3-6).

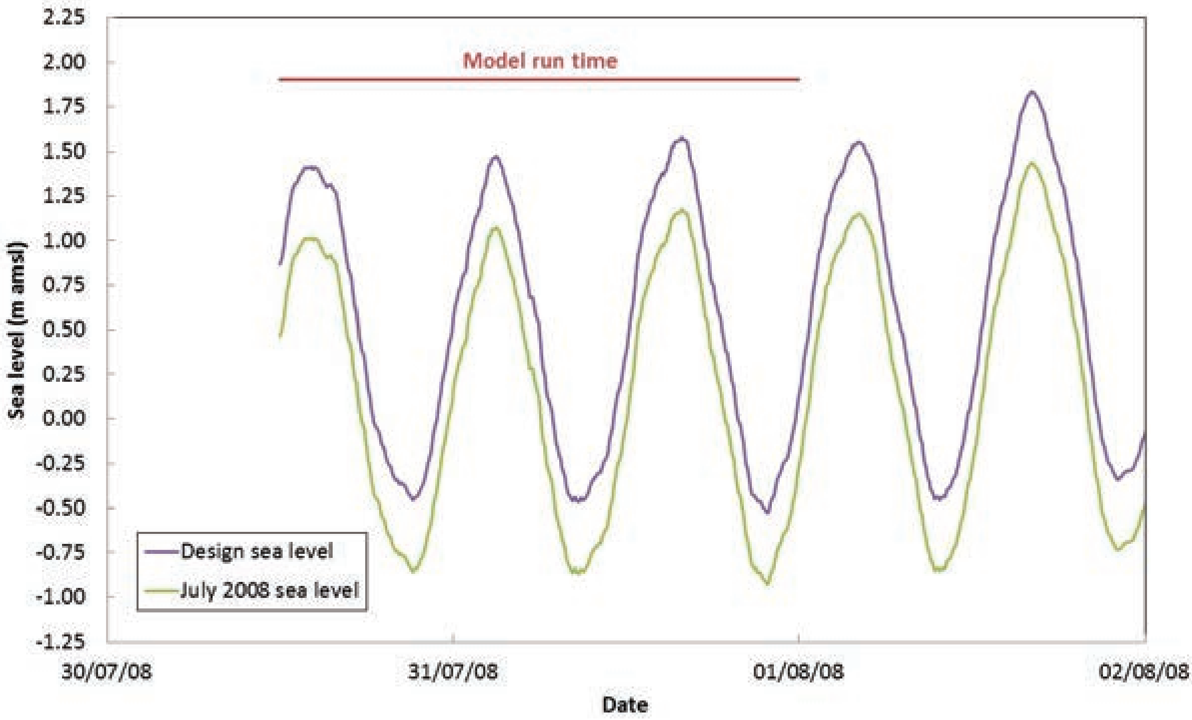



**Figure 3-12: July 2008 and design sea level time series for the Amberley Beach/Leithfield Beach area**

**Table 3-6: Summary of July 2008 and design high tide levels for Amberley Beach/Leithfield Beach**

| Date/Time | 2008 high tide level (m above msl) | Design high tide level (m above msl) |
|---|---|---|
| 30 July 2008 2:10pm | 1.02 | 1.42 |
| 31 July 2008 3:00am | 1.08 | 1.48 |
| 31 July 2008 3:50pm | 1.18 | 1.58 |
| 1 August 2008 4:10am | 1.15 | 1.55 |
| 1 August 2008 4:05pm | 1.44 | 1.84 |

## 3.2 Hydraulic model construction

The Mike Flood (DHI software) modelling package, combining one-dimensional (Mike 11) modelling for the main river channels, with two-dimensional (Mike 21) modelling for the floodplain, was used in this study. The Mike 11 and Mike 21 models are linked along the entire length of the Mike 11 model of the Kowai River North and South Branches to enable flood waters to move between the Kowai River main channel and the floodplain.

### 3.2.1 One dimensional river model (Mike 11)

The one-dimensional (Mike 11) model of the Kowai River extends from upstream of the Grays Road bridge (North Branch - cross section 93957, 6 km upstream from the sea) and upstream of Balcairn Amberley Road Bridge (South Branch – cross section 93510, 6.5 km upstream from the sea) downstream to the confluence of the North and South branches and downstream to the beach barrier at the coast. Cross-sections for the model have been generated, with an average spacing of 200 to 400 m, using 2012 LiDAR data flown during low Kowai River flows. The location of the cross sections is shown in Appendix C along with a table summarising the cross section information.

The 2012 LiDAR data covers the full extent of the Kowai River floodplain as well as the Amberley Beach and Leithfield Beach settlements. Despite the upper reaches of the Kowai River being relatively dry at the time of the 2012 LiDAR survey, the lagoon area near the coast does have a reasonable depth of ponded water. As there are no cross sections in this area the submerged bed levels have been assumed.

The LiDAR data has been compared to 7 points of known location and elevation (located on clear open ground) producing an average difference of -0.03 m with a standard deviation of 0.06 m for vertical accuracy. The digital terrain model (DTM) generated from the captured LiDAR data has a specified accuracy of ±0.3 m horizontally and ±0.15 m vertically (standard deviation) in clear, open, hard surface areas.

A Mannings ‘n’ number of 0.04 has been used for the open channel bed resistance. Variations in resistance, due to vegetation, have been accounted for by using relative resistances across each cross-section where required. Mannings ‘n’ values of up to 0.12 have been used for heavily vegetated berm areas (Table 3-7).

**Table 3-7: Summary of Mannings ‘n’ values used in the Kowai River Mike 11 model**

| Vegetation | Relative resistance | Mannings ‘n’ |
|---|---|---|
| Gravel-bed channel | 1.0 | 0.04 |
| Light scrub | 1.43 | 0.06 |
| Scrub | 1.8 | 0.07 |
| Dense scrub or trees | 3.1 | 0.12 |

Within the model extent for the Kowai River North Branch there is one road bridge (Grays Road). On the Kowai River South Branch there are also two road bridges (Balcairn Amberley Road and SH1), and one railway bridge (immediately downstream of the Balcairn Amberley Road bridge). These have been included to take into account head losses due to channel cross-section changes, submerged soffits, and pier losses.

As the Kowai River outlet to the sea is often closed – generally only opening due to high lagoon water levels – it is not possible to model the transition from closed to open outlet using a fixed structure. For the Kowai River it has been assumed the lagoon mouth opens naturally (or is opened manually) well before the peak of the flood passes. A 100 m wide fixed weir with an invert level of 0.5 m above msl has been used to pass the flood flows into the sea. To test the validity of the weir, the July 2008 flood was modelled with the weir replaced by a 50 m long channel with the same dimensions as the weir. Maximum water levels were approximately 0.04 m higher in the lagoon for the cross section model configuration. However, within 270 m of the lagoon outlet there was no difference in maximum water levels. Given that the differences were negligible, and the exact dimension of the Kowai River outlet varies in both size and location, it was considered simplest to model the outlet as a weir.

### 3.2.2 Two dimensional floodplain model (Mike 21)

*Floodplain topography*

To realistically model floodplain flows with any degree of accuracy, good topographic data (including features such as banks, terraces, overland flow channels, roads and railway embankments) is essential. For the Kowai River, Amberley Beach and Leithfield Beach floodplain this high resolution topographic data was obtained from a LiDAR survey (aerial laser scanning) flown in 2012. The detail provided by LiDAR data, including historic flow paths, can be seen in Figures D-1 and D-2 (Appendix D).

The specified accuracy of the 2012 LiDAR was a standard deviation of ±0.15 m vertically on clear, open, hard surface areas. However, this is likely to increase where there is rapidly changing levels (e.g. steeply sloping riverbanks). In some areas there are also sparse ground points, with considerably lower accuracy, due to cropping taking place. In these locations the number of LiDAR returns that penetrated through the crop to the ground was limited and some elevated levels appear to have been retained. This can result in recorded ground levels in some areas that are of the order of 0.5 m above actual ground level. As these areas are also likely to be assigned a relatively high surface resistance/floodplain roughness, floodplain flow paths need to be checked carefully to ensure there are no ‘artificial’ high areas modifying flow paths. As this study uses a model with a 5 m grid, and is focused on the overall extent of flooding within the floodplain rather than more detailed site-specific flooding, the impact of cropping anomalies has been only checked in areas where it appears that flow paths or flood water storage may have been impacted. However, for a more thorough site-specific flood assessment, a site visit may be required to confirm ground levels and check potential flow paths are schematised correctly.

Water levels and flows on the floodplain are resolved on a rectangular grid. The size of the grid is dependent on the level of detail required, model stability, and computational efficiency (i.e. computer capacity and speed). A 5 m grid was chosen for this study to allow for a reasonable degree of topographic detail while keeping the model run time to a maximum of ~ 2 days (depending on the extent of the floodplain that is submerged - a greater extent of inundation requires more calculations at each time step). Unfortunately the 5 m grid does have some limitations pertaining to representation of some features such as smaller drains. Where these drains are not able to be represented it is generally assumed that this is equivalent to the drain being either blocked or at full capacity due to local rainfall runoff, which is usually a reasonable assumption – especially for the larger and less frequent storm events.

As the floodplain contains many elevated topographic features capable of impeding flows (e.g. roads and stopbanks), the 5 m model grid was modified in places to use maximum elevations - rather than average elevations - to represent roads and stopbanks, and manually connecting the lower elevation grid cells (representing some of the more significant smaller waterways, e.g. Leithfield Outfall Drain) to ensure correct conveyance of flow. Because of the intensive drainage networks on the Kowai River, Amberley Beach and Leithfield Beach floodplain, there are also a large number of bridges/culverts at the road crossings and on private property. To ensure flood water flows were not incorrectly constricted, 16 culvert structures were included on the main waterways and drainage paths of the model floodplain (excluding the North Amberley Lagoon and Leithfield Outfall Drain culverts).

Checks were made with the detailed LiDAR data to ensure important topographic features (e.g. banks, terraces, roads and railways) were correctly represented in the 5 m grid, and that historic flow paths were correctly simulated.

*Floodplain roughness (surface resistance)*

Floodplain flows and depths are influenced by the hydraulic resistance of the ground cover and other obstructions, such as buildings and trees on the floodplain. Resistance values (i.e. Manning ‘n’ values) were assigned to the various surfaces of the floodplain by interpretation of aerial photographs and ground survey.

Initial model runs identified areas most likely to flood. Where vegetation was thick, or there were significant restrictions to the flow path (e.g. hedges, houses, etc), the Manning ‘n’ value was increased to 0.12 to increase the surface resistance. For the rest of the floodplain Manning ‘n’ was equal to 0.05 (Figure D-4, Appendix D).

If time and resources permitted, the roughness grid could be refined further to take into consideration smooth road surfaces and other variations in Manning M. Typically Manning ‘n’ values vary from 0.02 (roads) to over 0.15 (dense vegetation).

### 3.2.3 Mike Flood combined 1-d river and 2-d floodplain model

The one-dimensional (Mike 11) and two-dimensional (Mike 21) models are dynamically coupled together in the Mike flood module using lateral links. These lateral links allow flow to pass between the 1-d Mike 11 river channels (i.e. Kowai River North and South Branches) and the 2-d Mike 21 floodplain. Schematic maps of the model, including lateral links, are shown in Figures C-1 and C-2 (Appendix C).

To obtain the range of possible maximum water levels for the Amberley Beach and Leithfield Beach settlements a 'base' model, with the most likely scenarios for the 50 year and 200 year ARI events have been modelled along with several sensitivity tests which examine the sensitivity of the maximum water levels to various model input parameters for the 200 year ARI event.

Relatively high water levels are expected for the 50 year and 200 year ARI 'base' scenarios where all lagoon and drain outlets remain closed until after the flood event has passed (excluding the Kowai River which remains open for all model runs). Sensitivity tests, using the 200 year ARI event, model the impact of increases in flow, sea level rise and also the situation where all lagoon outlets and the Outfall Drain outlet (+ one or both of the Outfall Drain piped outlets) remain open for the duration of the flood event (i.e. flooding predicted in advance and seas favourable for openings to remain open).

For the scenarios where the outlets are opened, the following outlets to the sea are modelled:

- North Amberley Lagoon – 2 culverts (3 m by 3 m) with an invert level of 1.21 m above msl
- Mimimoto Lagoon – 10 m wide weir with an invert level of 0.5 m above msl
- North Leithfield Lagoon – 10 m wide weir with an invert level of 0.5 m above msl
- Leithfield Outfall drain – 6 m wide weir with an invert level of 1.6 m above msl
- Leithfield Outfall drain piped outlet – two 1.4 m diameter circular pipe with an invert level of 1.15 m above msl.

These outlets were modelled by linking the 2-d floodplain model grid to short 1-d channels with the outlet structures located along the channel, and the tide time series as the downstream boundary.

For all model scenarios flood water is also able to flow over the low sand dunes to the south of Leithfield Beach at Ashworths Ponds (immediately upstream of Ashworths Beach Road which is the southern limit of the model), or into the Waipara River (northern limit of model), if water levels reach high enough levels. It has been assumed that no water will pass over Ashworths Beach Road as the Ashley River and Saltwater Creek (to the South) are also likely to be in flood and may have elevated water levels in this area; meaning flow is more likely to pass over the low sand dunes. Another assumption is that the Waipara River does not overtop the true right bank and allow water to flow towards the Amberley Beach settlement.

## 3.3 Model calibration

To provide confidence in the model predictions, it is important to calibrate with historical flood events, where possible.

As the Kowai North Branch at Grays Road (Site 66101) water level/flow recorder was only operational for a relatively short period of time (2006 to 2012), the most significant observed flood events were those that occurred in 2008 on 31 July (94.5 $m^3/s$) and 25 August (84.7 $m^3/s$). As the 31 July 2008 flood event was the largest recorded event, it has been used to calibrate the model. This event is estimated to have a 5 to 10 year ARI on the Kowai River.

### 3.3.1 July 2008 storm event

On 31 July 2008 the east coast of the South Island – and in particular North Canterbury – experienced a large rainfall event. During this event the townships of Amberley and Leithfield, along with the Amberley Beach and Leithfield Beach settlements experienced widespread surface flooding. The Railway Terrace rainfall gauge recorded 24-hour and 48-hour rainfall totals of 122 mm and 141 mm, respectively (Table 3-2 and Table 3-3). This was equivalent to a rainfall event with a ~ 20 year ARI (based on HIRDS v3).

A large volume of flood water from Amberley (see PDP (2008) for further details), flowed via Eastern Drain and Dry Gully to the Amberley Beach settlement and surrounding farmland. Water that flowed over Hursley Terrace, as well as other local runoff, accumulated at the bottom end of Amberley Beach Road (PDP, 2008), as shown in Figure 3-16. The Eastern Drain also overtopped its banks and flooded the area around the Readymix quarry (Figure 3-18), before flowing eastwards over the access road into the wetland area (PDP, 2008).

No flooding from the Kowai River was observed at Leithfield township. Flooding appeared to be "largely due to a lack of conveyance capacity within the local stormwater network" (PDP, 2009). A more detailed description of the flooding that occurred in Leithfield township is provided in PDP (2009).

Flood water in the Kowai River did overtop the stopbank on the north bank of the Kowai River mouth at Dave Rowell's property (Figure 3-20); this stopbank has since been raised by approximately 600 mm. Additional floodwater from the Hursley Terrace area also drains into the area behind this stopbank. During high water levels in the Kowai River a flapgate in the stopbank prevented water flowing back into Dave Rowell's property.

At Leithfield Beach, flood waters from the North Leithfield Lagoon overflowed and breached the stopbank between the northern end of the settlement and the lagoon, with maximum water depths of approximately 0.75 m around the houses at the northern end of Elizabeth Square (PDP, 2009). The Leithfield Outfall Drain also overtopped its banks, contributing to the flooding (Figure 3-22).

PDP (2009) identifies quite distinct discoloured/ turbid water to the north of the Outfall Drain, which implies that the Kowai River was the most likely source of flooding in this area, as well as in the North Leithfield Lagoon (which spilled into the northern end of the Leithfield Beach settlement). Local residents confirmed that the Kowai River did flood the area to the south of the river (Figure 3-23), flowing into the North Leithfield Lagoon via flow reversal back up the channel that usually drains the North Leithfield Lagoon area to the Kowai River, and also historic flow paths over farmland – with only some of the south bank overflow being intercepted and diverted back into the Kowai River by an existing return bank (PDP, 2009). Flood waters further south (within the Leithfield Beach settlement) are less turbid and more likely to be sourced from local runoff (PDP, 2009).

Once the lagoon outlet to the sea was opened manually (since high water levels in the Kowai River prevented drainage towards the Kowai River), water levels rapidly dissipated over approximately 8 hours (PDP, 2009). PDP (2009) also note that at the time of the August 2008 flood event, the Kowai River had a "well-established flood channel through the lagoon to the sea from the July flood".

Aerial photographs of the flooding were taken on 31 July 2008 between 11am and 11:30am. At this time the Kowai River mouth (Figure 3-20 and Figure 3-23), Leithfield Outfall Drain (Figure 3-25) and Mimimoto Lagoon were all open with water flowing into the sea. However, North Amberley Lagoon was not opened until later in the day (4:30pm) according to a television news interview. Although flooding was still present at the time of the aerial photographs, the peak flood levels had most likely passed.

Despite limited available information, this flood was a relatively recent event and, as such, the river cross sections should be representative. For instance, aggradation/degradation within the river system should be relatively minimal, vegetation changes should be limited to the main water course (i.e. main changes are due to avulsion of the active braided channels), and stopbank profiles should be similar (although there have been some changes post-July 2008 including raising of the Kowai River stopbanks in the area immediately upstream of the outlet, and the construction of the Leithfield Outfall Drain piped outlet to the sea). The Mike Flood model inputs and modelling results for the July 2008 flood event are summarised below.

### 3.3.2 Model inputs

The Kowai River flows for the July 2008 flood event are described in Section 3.1.1. It is assumed that the Kowai River mouth opens prior to the flood event (e.g. due to a fresh before the main event or by manual opening). The river mouth opening is represented by a 100 m wide weir with an invert level of 0.5 m above msl.

Local inflows to the Amberley Beach and Leithfield Beach catchments are described in Section 3.1.2. These are derived from rainfall data converted into sub-catchment flow hydrographs.

The Sumner sea level record was used to generate a sea level record for the downstream boundary of the Kowai River, lagoon outlets and also at the southern limit of the model (south of Leithfield Beach) where the sand dunes can be overtopped at high water levels (Section3.1.3).

Initial lagoon levels were set relatively high at levels of 1.5 m above msl (Amberley Beach lagoons) and 2.0 m above msl (Leithfield Beach lagoons/outlet drains). These levels were similar to the lagoon levels measured in the LiDAR survey. However, it should be noted that the lagoon areas are relatively small and modelling results indicate that differences in initial lagoon levels are relatively insignificant.

The floodplain roughness grid used in the models is described in Section 3.2.2. For the July 2008 model run it was assumed that all outlets were closed. It is not known what time the Leithfield Outfall Drain outlet to the sea was opened, but it was observed to be open by ~ 11:30am on 31 July. By this time Mimimoto Lagoon was also open.

Note that the Leithfield outfall Drain piped outlet was not constructed at the time of this event.

### 3.3.3 Comparison of modelled and observed flood extent

The extent of inundation in the Amberley Beach and Leithfield beach area was captured by oblique aerial photographs flown on 31 July between 11am and 11:30am. This was most likely at a level lower than the peak level as television coverage showed a slightly greater flood extent.

The Mike FLOOD July 2008 calibration model was run for a 1.5 day time period covering the July 2008 flood event (i.e. from 30 July 2008 at 12:00pm until 1 August 2008 at 12:00am). Figure 3-13 shows the modelled water level elevation at 11am on 31 July 2008. Maximum water depths and extent of modelled floodplain inundation at the same time are shown on Figure 3-14 and Figure 3-15 shows the modelled water surface elevations in the lagoons during the flood event.

A comparison between the oblique aerial photographs and the modelled inundation (for 31 July at 11am) is shown in Figure 3-16 to Figure 3-26. The modelled areas of inundation compare well with areas shown on the aerial photographs – with some areas appearing to have the extent of inundation slightly under-estimated by the modelling (especially given that the Leithfield Outfall Drain and Mimimoto Lagoon had started draining water, while the model simulated all outlets remaining closed). The slightly lower modelled water levels could be due to local inflows being under-estimated (i.e. assuming too much infiltration into the ground).

For Amberley Beach it was noted that there is ~ 4 hours between the trigger level of 2.1 m above msl being reached and the water level at the lowest house reaching floor level (2.6 m above msl).

### 3.3.4 Summary

Taking into account the limited calibration information, and all of the assumptions and uncertainties that have been made, there is reasonable agreement between modelled and observed flood extents and water levels for the July 2008 flood event. However, it should be remembered that the modelling is based on the assumption that the Kowai North and South Branches have similar flood hydrograph shapes, and that local runoff has been correctly simulated (with limited calibration information this is difficult to ascertain).

It has also been assumed that the lagoon outlets and Leithfield Outfall Drain remain closed until approximately 11am on the 31 July.

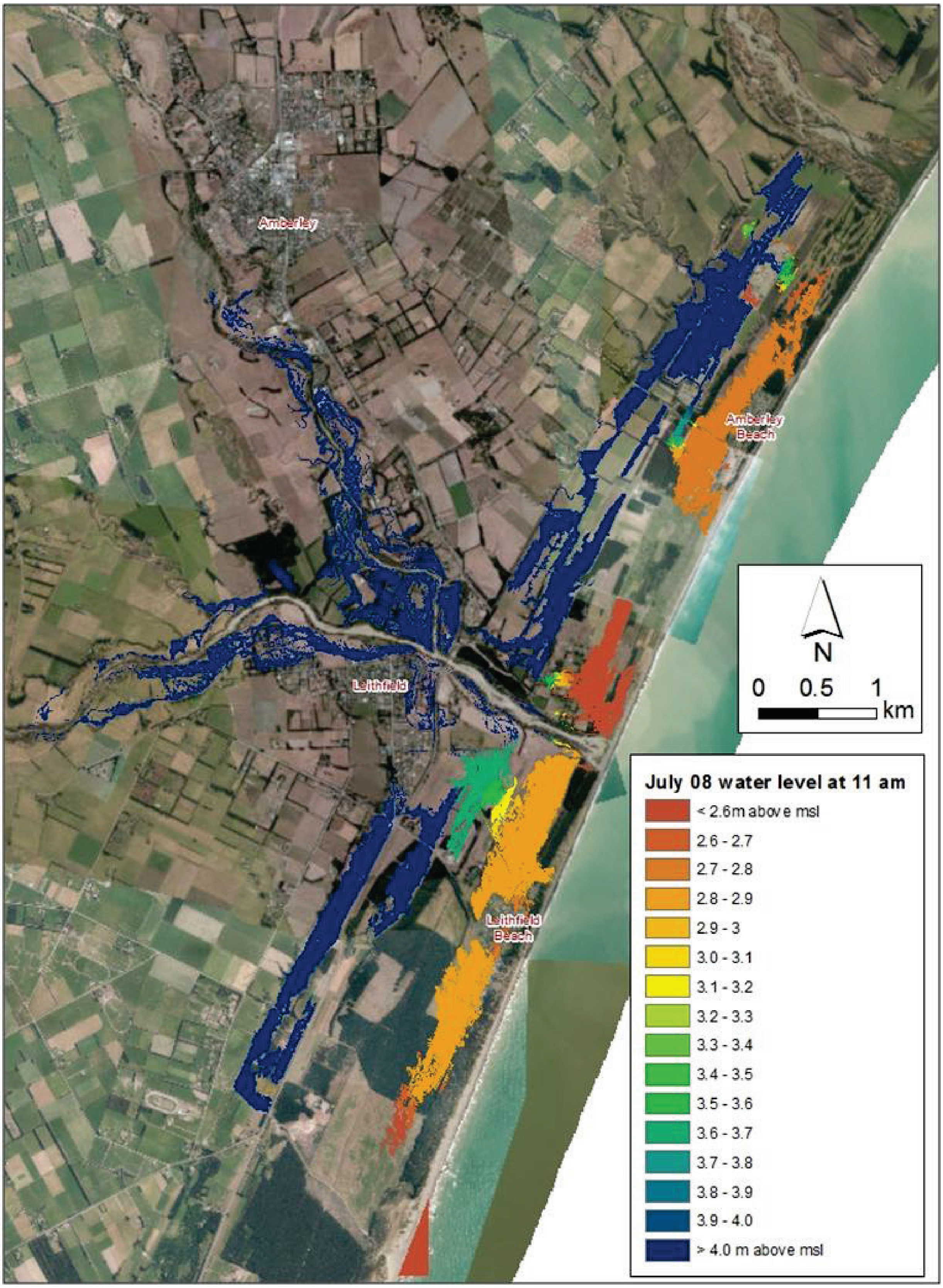



**Figure 3-13: Modelled water surface elevation – 31 July 2008 at 11am (lagoon outlets all closed)**

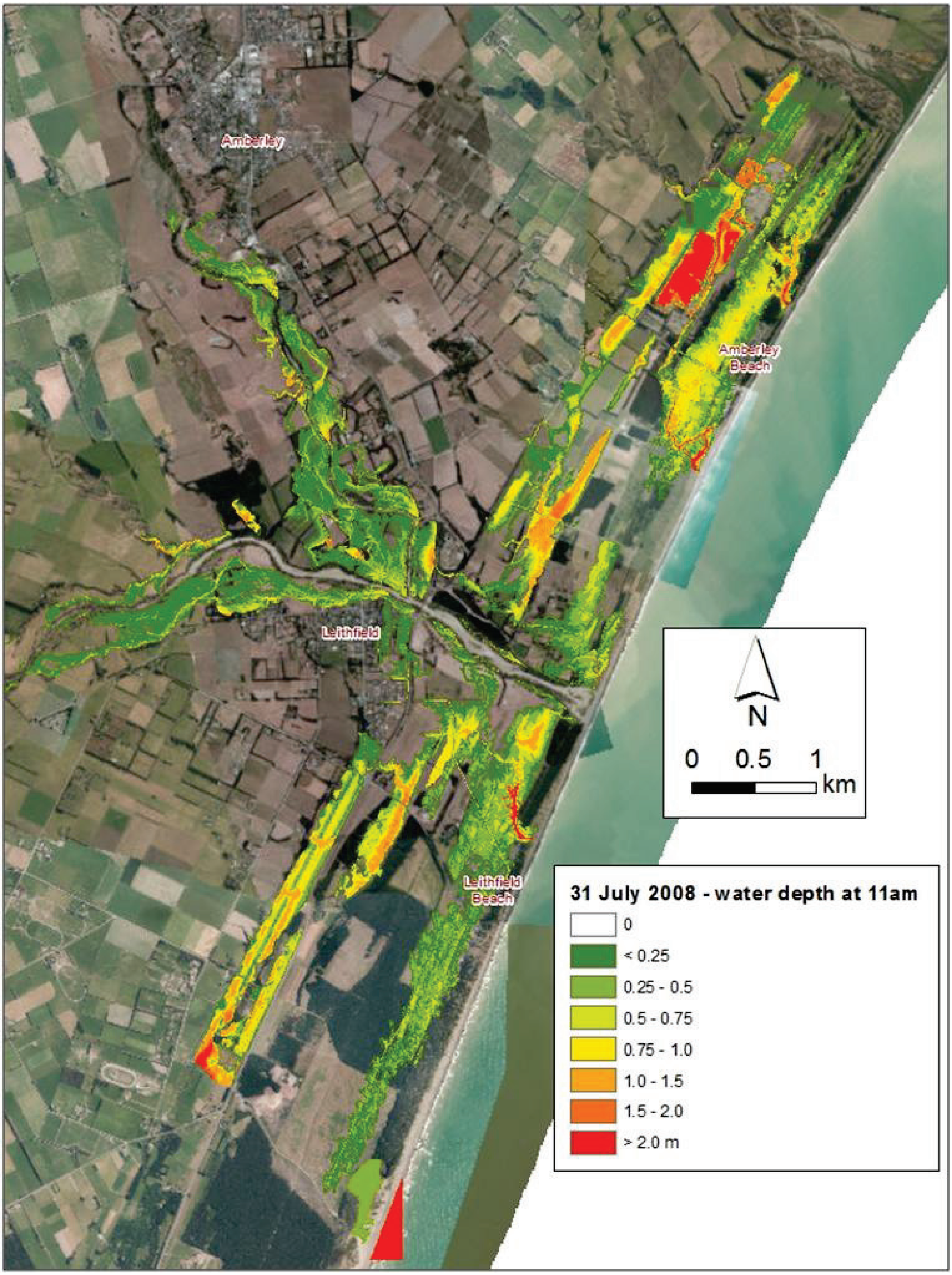



**Figure 3-14: Modelled water depth – 31 July 2008 at 11am (lagoon outlets all closed)**

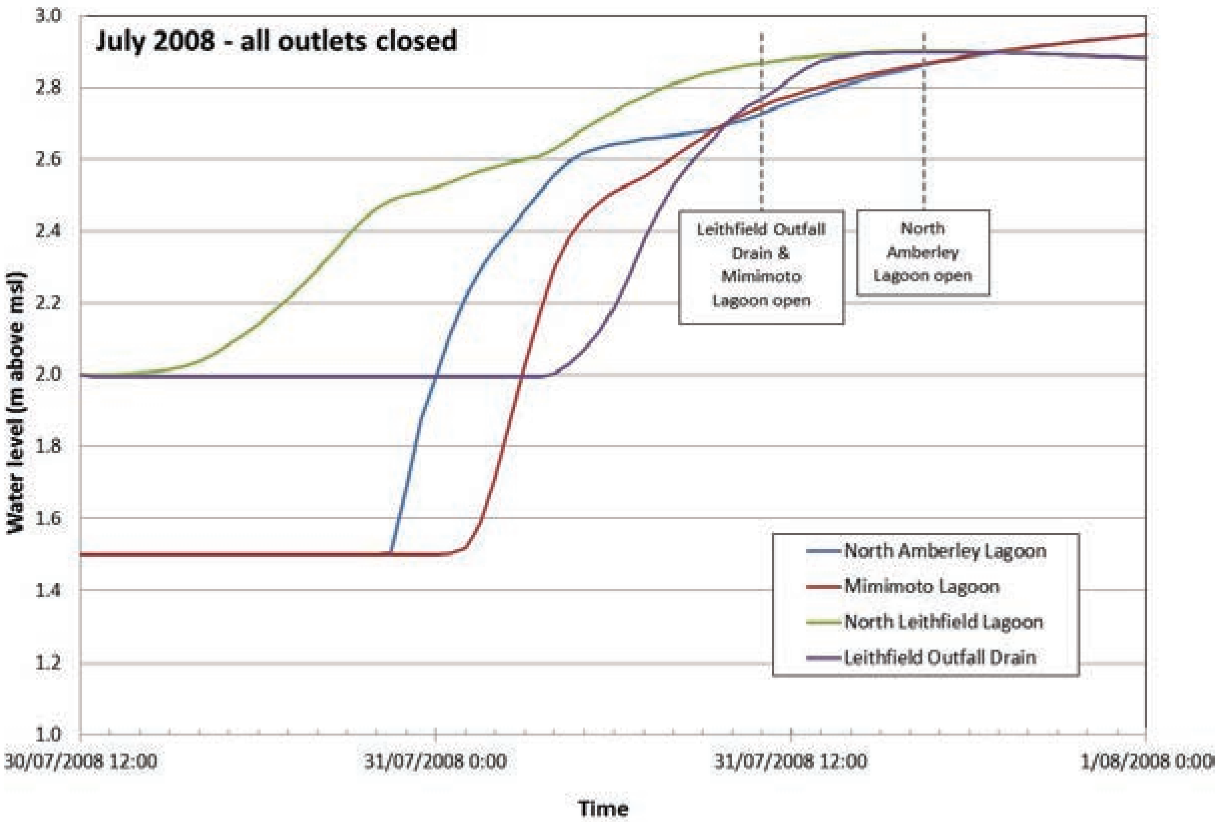



**Figure 3-15: Modelled water levels for the Amberley Beach and Leithfield Beach lagoons and Leithfield Outfall Drain assuming all outlets are closed – July 2008 flood event**

**Figure 3-16: Amberley Beach - 31 July 2008 (looking east, Amberley Beach Road on right)**

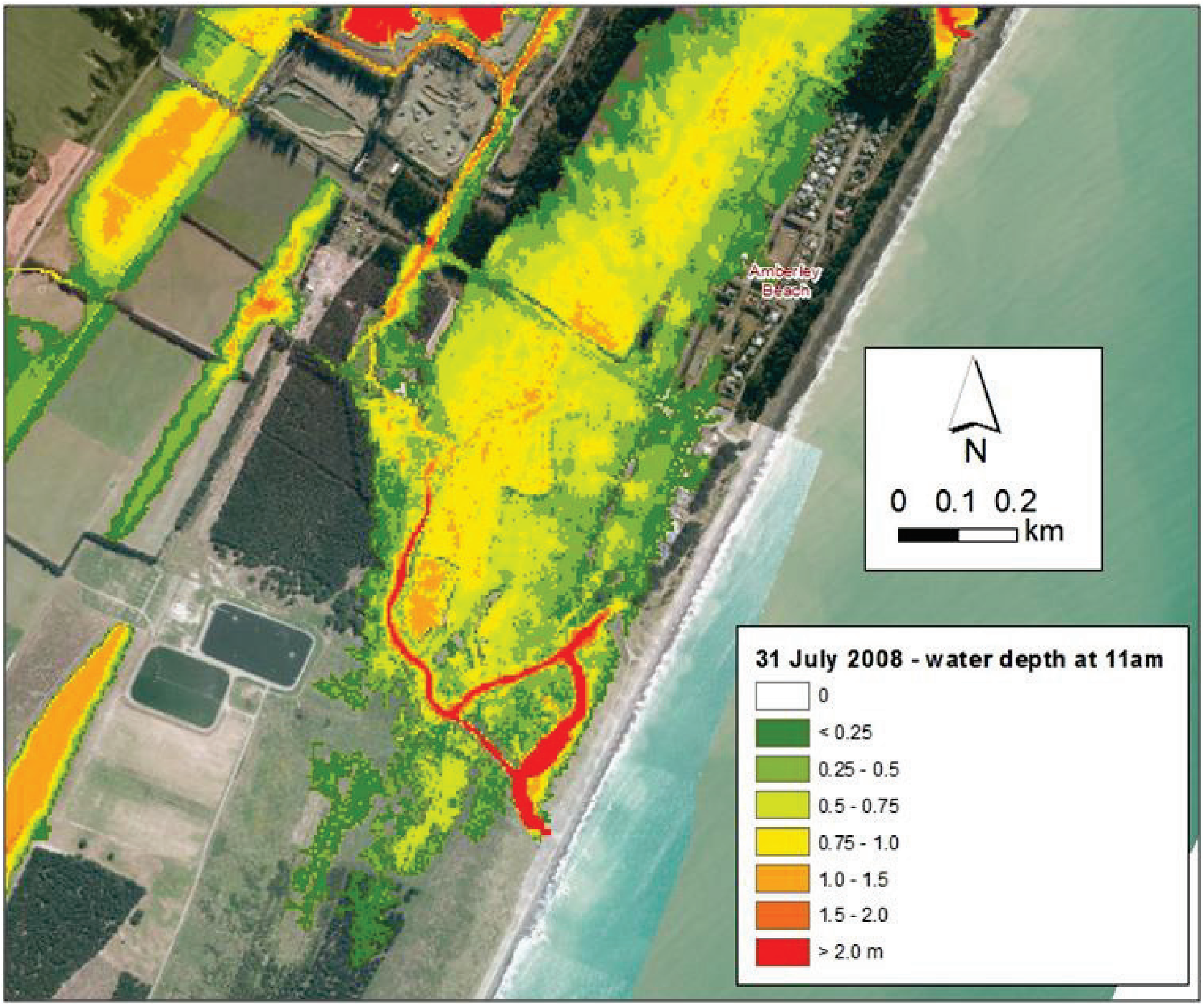



**Figure 3-17: Modelled maximum water depth at Amberley Beach Road on- 11am 31 July 2008**


**Figure 3-18: Amberley Beach – 31 July 2008 (looking east toward Readymix quarry)**

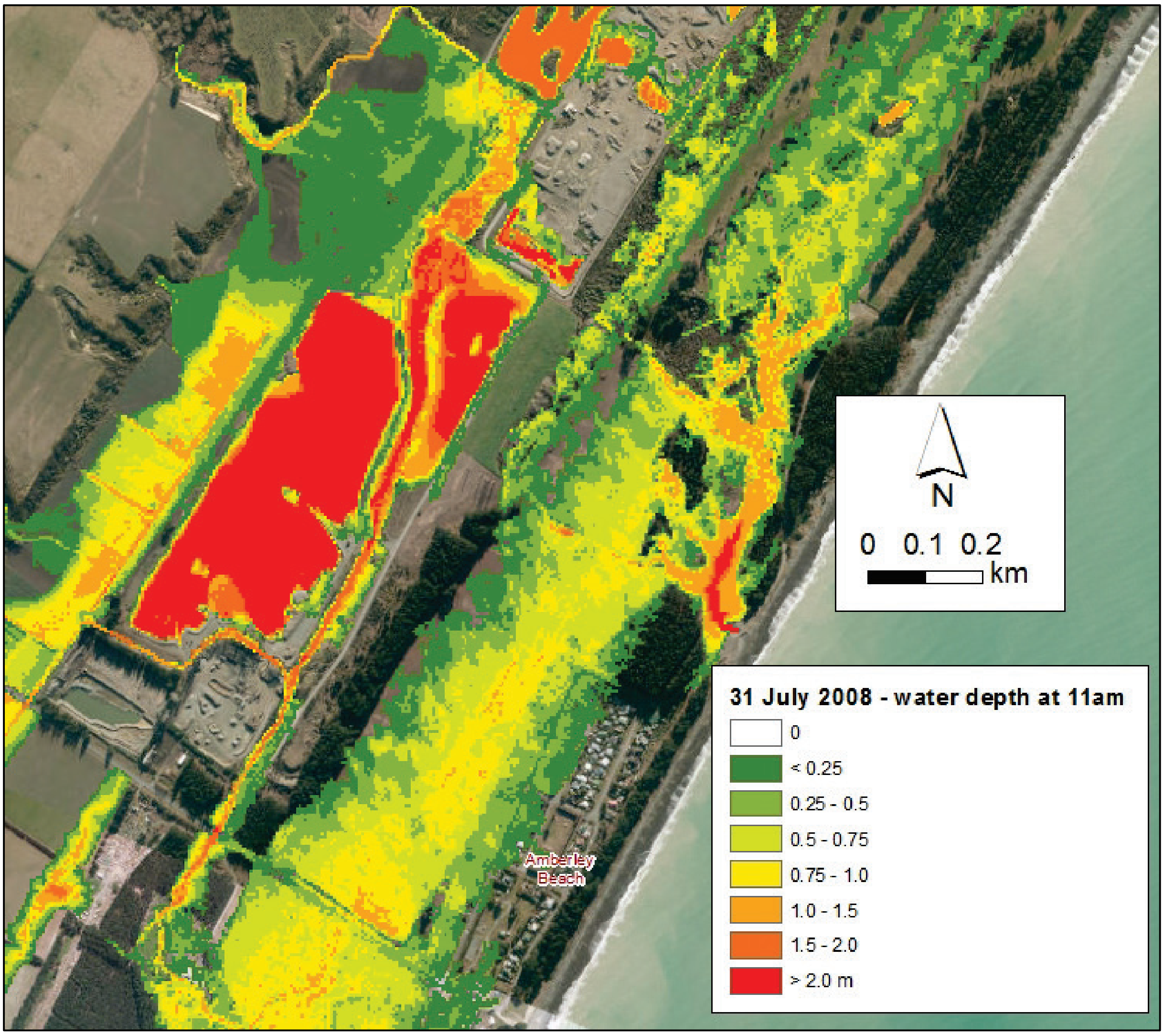



**Figure 3-19: Modelled water depth at Amberley Beach Readymix Quarry – 11am 31 July 2008**


**Figure 3-20: Kowai River mouth and north bank – 31 July 2008 (looking SW)**

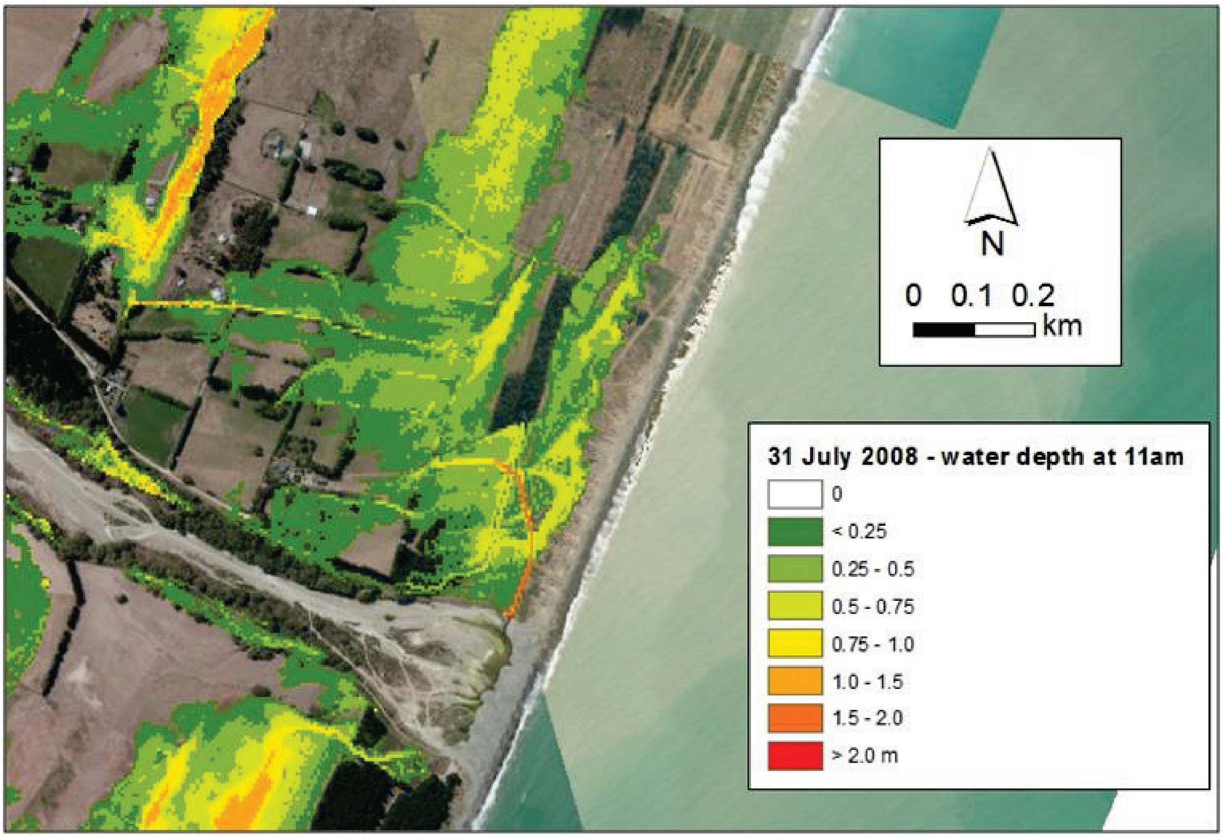



**Figure 3-21: Modelled water depth at Kowai River mouth and north bank – 11am 31 July 2008**

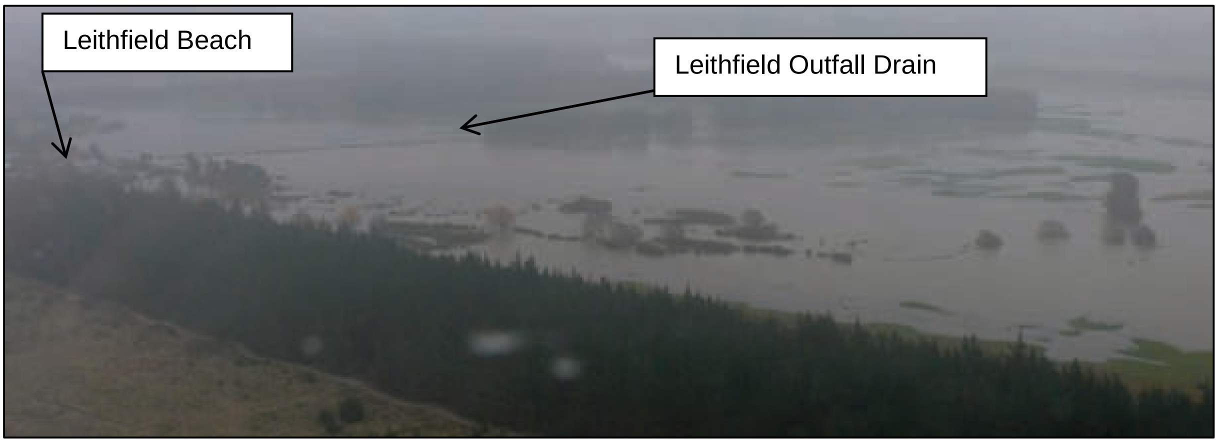



**Figure 3-22: Area between Leithfield Beach and the Kowai River – 31 July 2008 (looking SW)**


**Figure 3-23: Kowai River mouth and south bank – 31 July 2008 (looking NW)**

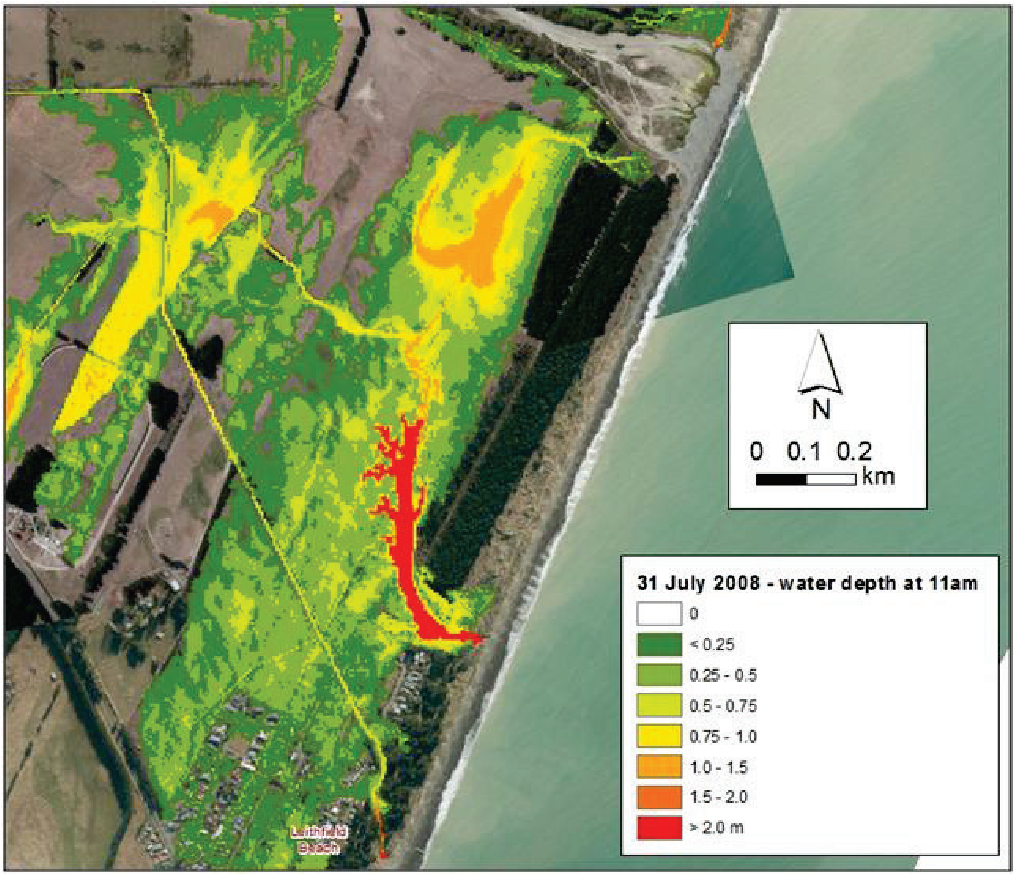



**Figure 3-24: Modelled Kowai River mouth and south bank water depth – 11am 31 July 2008**


**Figure 3-25: Flood inundation at Leithfield Beach – 31 July 2008 at 11:31am (looking east)**

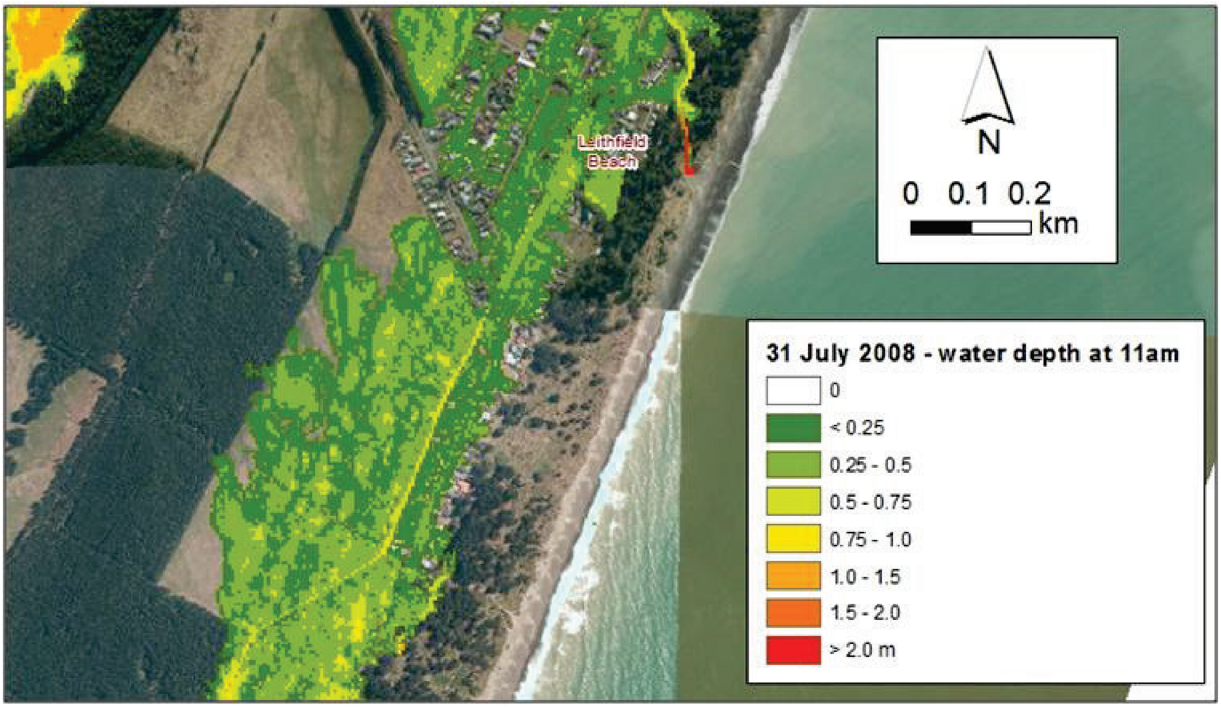



**Figure 3-26: Modelled Leithfield Beach water depth – 11am 31 July 2008**

## 3.4 Modelling of the 50 year ARI design flood event

The 50 year Average Recurrence Interval (ARI) or 2% Annual Exceedance Probability (AEP) flood event has been modelled for land use planning and flood mitigation purposes.

The 50 year ARI design storm event was simulated over a 1.5 day period. The model had a 2 second time step, to ensure stability, and results were saved every 30 minutes over the full storm event. Computer run times for each simulation were quite long (i.e. up to ~ 1.5 days).

The model inputs are summarised in Section 3.4.1 and the model results are shown in Section 3.4.2.

### 3.4.1 Model inputs

The Kowai River flows for the 50 year ARI design flood event are described in Section 3.1.1. It is assumed that the Kowai River mouth opens prior to the flood event (e.g. due to a fresh before the main event or by manual opening).

Local inflows to the Amberley Beach and Leithfield Beach catchments are described in Section 3.1.2. These are derived from rainfall data converted into sub-catchment flow hydrographs using the Rainfall Runoff Editor (RRE).

The Sumner sea level record was used to generate a sea level record for the downstream boundary of the Kowai River, lagoon outlets and also at the southern limit of the model (south of Leithfield Beach) where the sand dunes can be overtopped at high water levels (Section 3.1.3). To account for additional storm surge that is likely during a large 50 year ARI storm event, 0.4 m was added to the derived sea level record. Should a higher sea level be used, it is likely that the combined probability of, for example, a 50 year ARI Kowai River flow and a 50 year ARI sea level will combine to produce a flood event with an ARI greater than a 50 year design flood.

Initial lagoon levels were set relatively high at levels of 1.5 m above msl (Amberley Beach lagoons) and 2.0 m above msl (Leithfield Beach lagoon/Outfall Drain). The floodplain roughness grid used in the models is described in Section 3.2.2.

For the 50 year ARI model runs it was assumed that the most extreme maximum water levels would occur if all the lagoon outlets (and Leithfield Outfall Drain piped outlet) remained closed for the duration of the storm.

### 3.4.2 Model results

The 50 year ARI estimated maximum water levels (m above msl), assuming all outlets to the sea (from the two beach settlements) are closed, are shown in Figure 3-27 and the maximum water depths are shown in Figure 3-28.

The Amberley Beach and Leithfield Beach water levels for the 50 year ARI ‘base’ model are shown in Figure 3-29 and Figure 3-30, respectively. These figures show the relatively short time between trigger levels being reached and inundation of the lowest existing properties starting to occur. There is also only about 10 to 12 hours between trigger levels being reached and peak water levels being reached.

Note that averaging of the topography to produce the 5 m grid for the floodplain tends to remove many of the smaller drains; this is likely to be similar to having them in the model but blocked; flow in the smaller drains is assumed to be relatively small compared to the total floodplain flow. Human intervention, in the form of manual opening of the Kowai River mouth and Amberley Beach and Leithfield Beach lagoons, can also have an impact on maximum water levels.

The various factors that can have an impact on the maximum water levels at Amberley Beach and Leithfield Beach are discussed in Section 3.6 with regard to the 200 year ARI flood event.

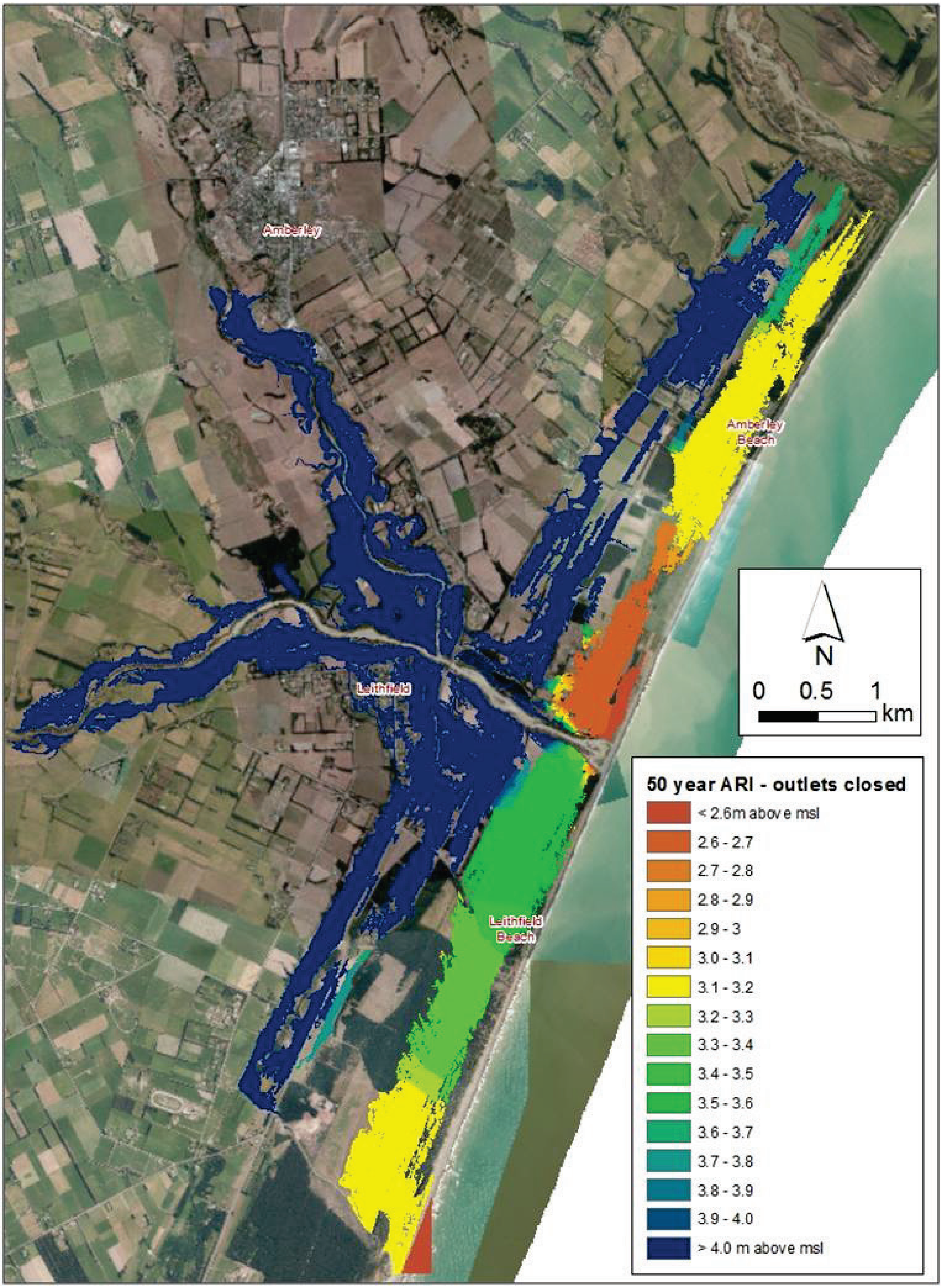



**Figure 3-27: Maximum water elevations (m above msl) for the Kowai River, Amberley Beach and Leithfield Beach floodplain 50 year ARI event (lagoon outlets closed except for Kowai River mouth)**

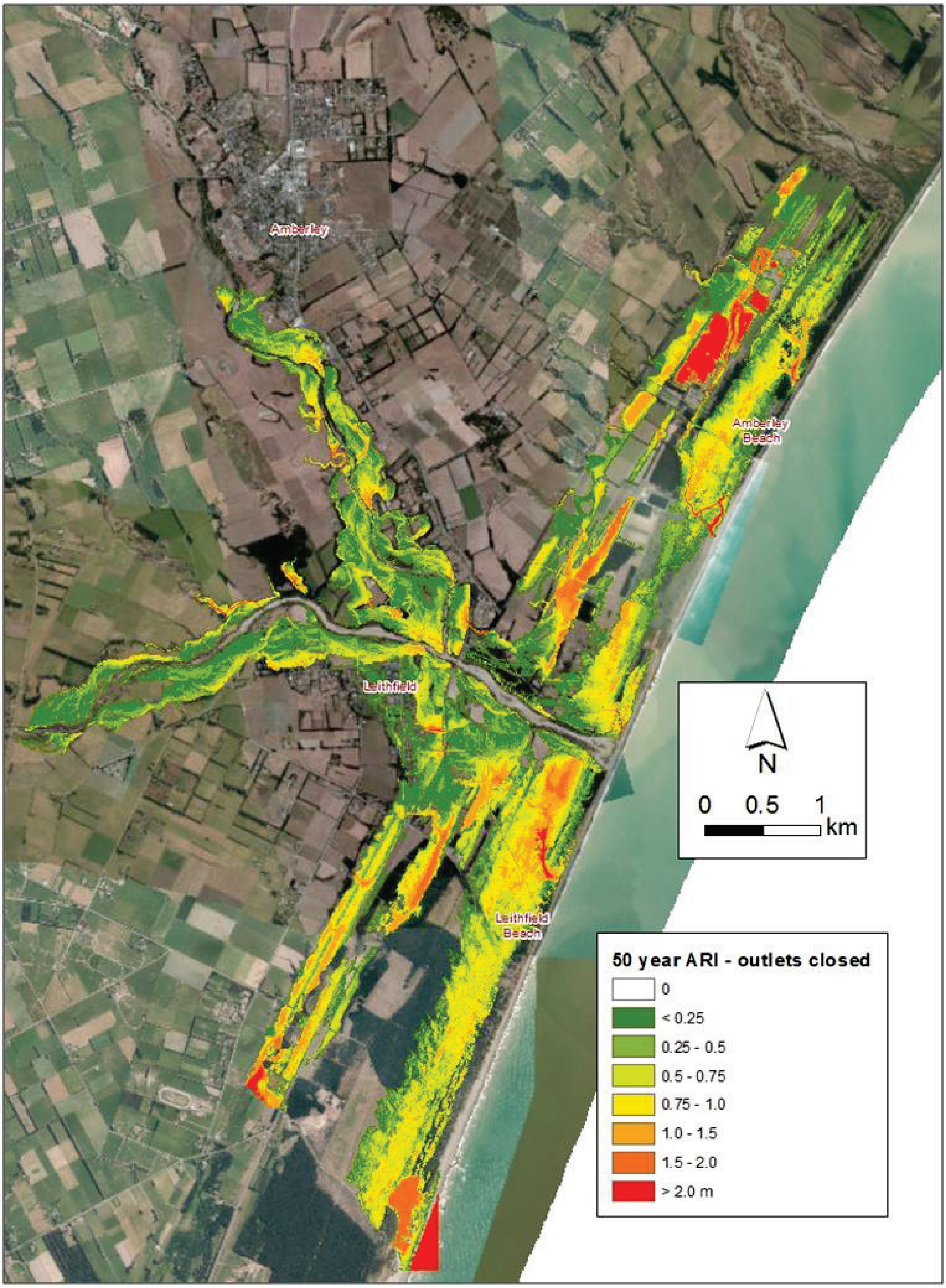



**Figure 3-28: Maximum water depths (m) for the Kowai River, Amberley Beach and Leithfield Beach floodplain 50 year ARI event (lagoon outlets closed except for the Kowai River mouth)**

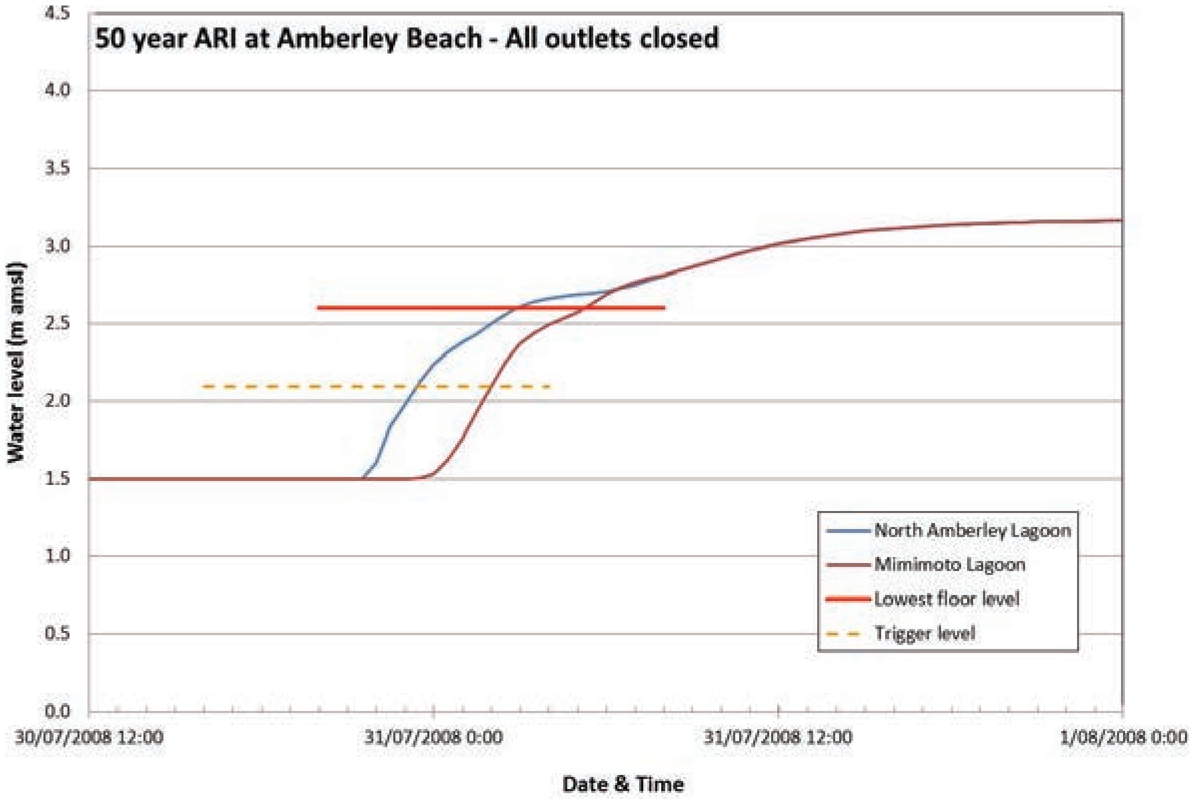



**Figure 3-29: Amberley Beach lagoon water levels (m above msl) during a 50 year ARI event with lagoon outlets closed**

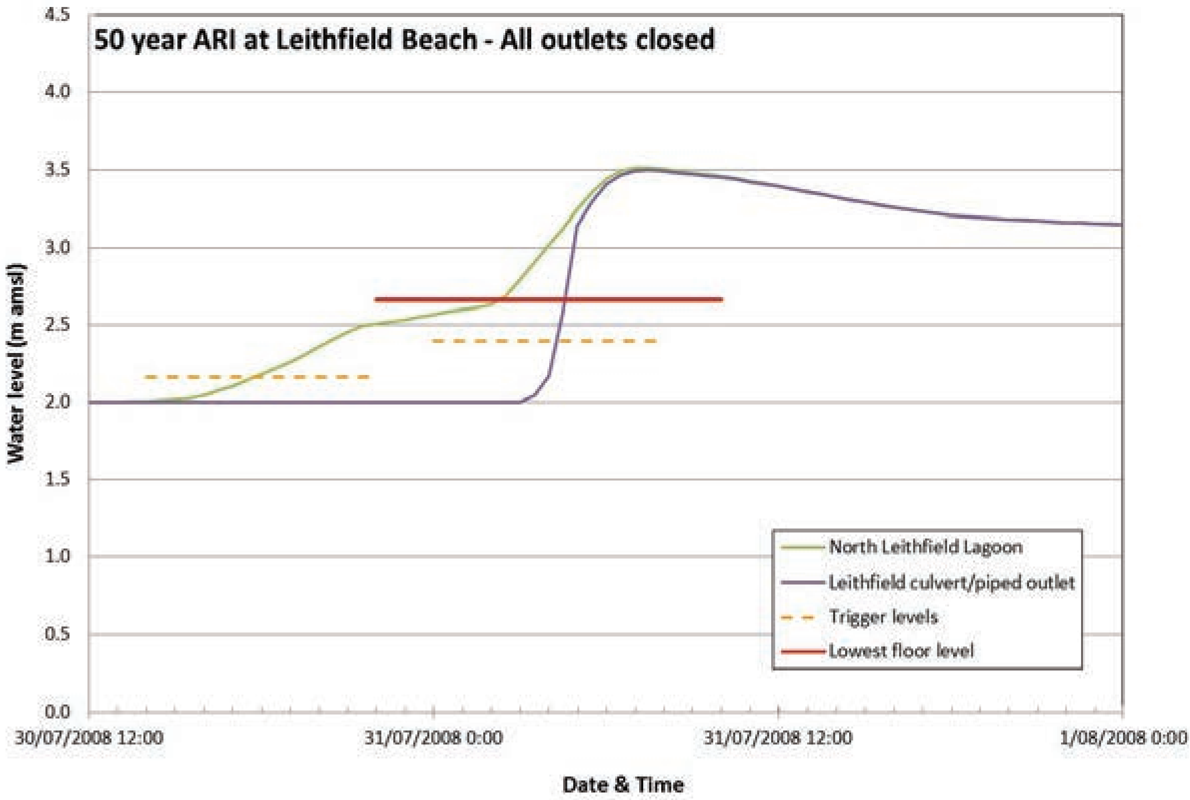



**Figure 3-30: Leithfield Beach lagoon water levels (m above msl) during a 50 year ARI event with lagoon outlets closed**

## 3.5 Modelling of the 200 year ARI design flood event

The 200 year Average Recurrence Interval (ARI) or 0.5% Annual Exceedance Probability (AEP) flood event has been modelled for land use planning and flood mitigation purposes.

The 200 year ARI design storm event was simulated over a 1.5 day period. The model had a 2 second time step, to ensure stability, and results were saved every 30 minutes over the full storm event. Computer run times for each simulation were quite long (i.e. up to ~ 2 days).

The model inputs are summarised in Section 3.5.1 and the model results are shown in Section 3.5.2.

### 3.5.1 Model inputs

The Kowai River flows for the 200 year ARI design flood event are described in Section 3.1.1. It is assumed that the Kowai River mouth opens prior to the flood event (e.g. due to a fresh before the main event or by manual opening).

Local inflows to the Amberley Beach and Leithfield Beach catchments are described in Section 3.1.2. These are derived from rainfall data converted into sub-catchment flow hydrographs using the Rainfall Runoff Editor (RRE). A comparison with the regional flood estimation (RFE) method showed that peak flows from the Amberley Beach and Leithfield Beach sub-catchments were higher using the RFE method. However, the flows peaks were generally still within the standard error. To be conservative a sensitivity run was completed with 25% additional flow added to all local inflow time series (Section 3.6.2).

The Sumner sea level record was used to generate a sea level record for the downstream boundary of the Kowai River, lagoon outlets and also at the southern limit of the model (south of Leithfield Beach) where the sand dunes can be overtopped at high water levels (Section 3.1.3). To account for additional storm surge that is likely during a large 200 year ARI storm event, 0.4 m was added to the derived sea level record. Should a higher sea level be used, it is likely that the combined probability of, for example, a 200 year ARI Kowai River flow and a 200 year ARI sea level will combine to produce a flood event with an ARI greater than a 200 year ARI.

Initial lagoon levels were set relatively high at levels of 1.5 m above msl (Amberley Beach lagoons) and 2.0 m above msl (Leithfield Beach lagoon/Outfall Drain). The floodplain roughness grid used in the models is described in Section 3.2.2.

For the 200 year ARI model runs it was assumed that the most extreme maximum water levels would occur if all the lagoon outlets (and Leithfield Outfall Drain piped outlet) remained closed for the duration of the storm.

Sensitivity runs are modelled in Section 3.6 to assess the effect on Amberley Beach and Leithfield Beach flood water levels of various scenarios including: all outlets being fully open for the full extent of the flood event (Section 3.6.1), local sub-catchment inflows increasing by 25% (Section 3.6.2), Kowai River flows increasing by 25% (Section 3.6.3), and sea level rise of 0.5 m (Section 3.6.4). A 1 m rise in sea level has not been modelled as it was considered unrealistic using the current model configuration (e.g. sand dune heights and the shoreline are likely to change significantly).

### 3.5.2 Model results

The 200 year ARI estimated maximum water levels (m above msl), assuming all lagoon outlets to the sea (from the two beach settlements) are closed, are shown in Figure 3-31 and the maximum water depths are shown in Figure 3-32.

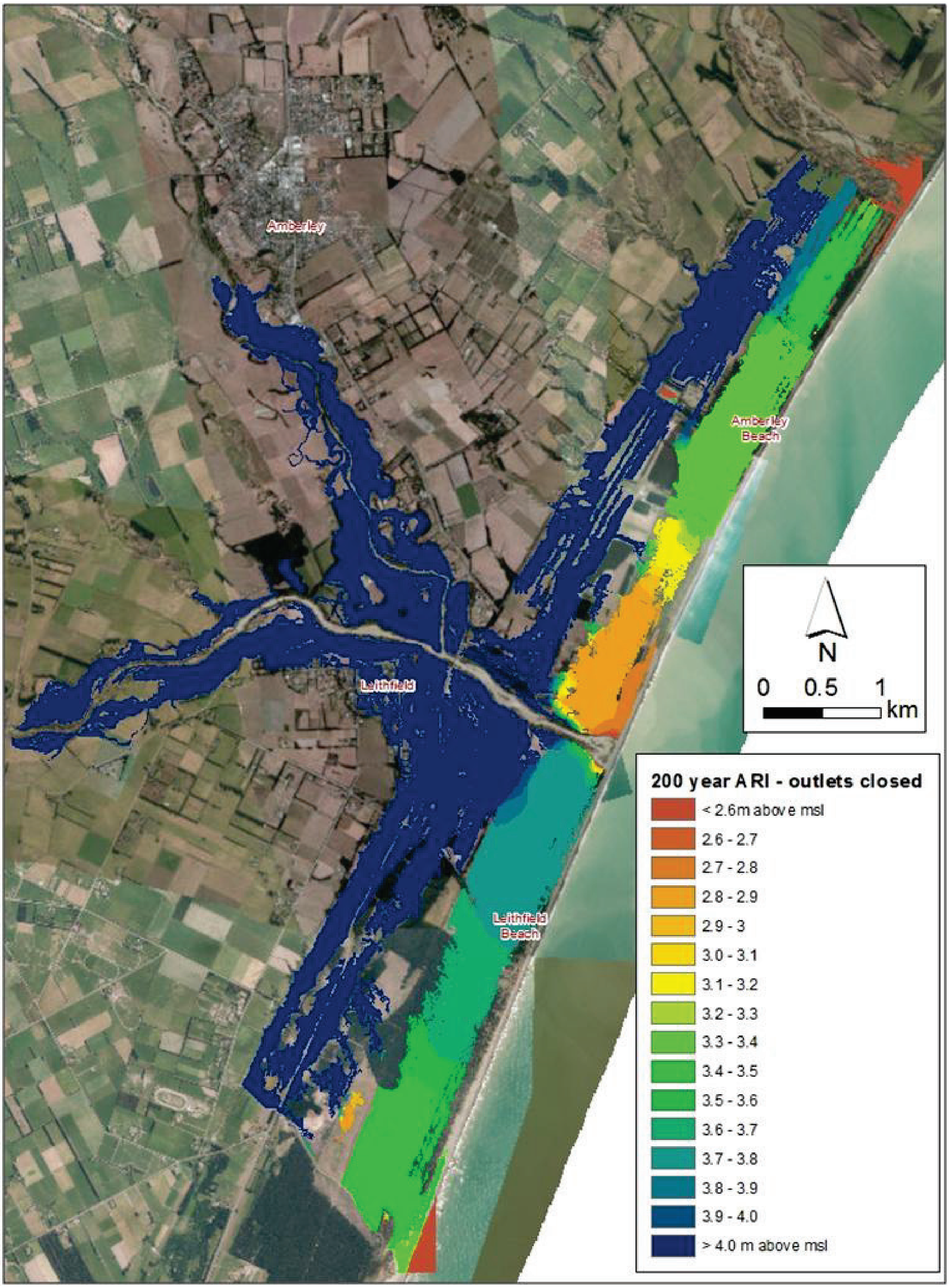



**Figure 3-31: Maximum water elevations (m above msl) for the Kowai River, Amberley Beach and Leithfield Beach floodplain 200 year ARI event (lagoon outlets closed except Kowai River mouth)**

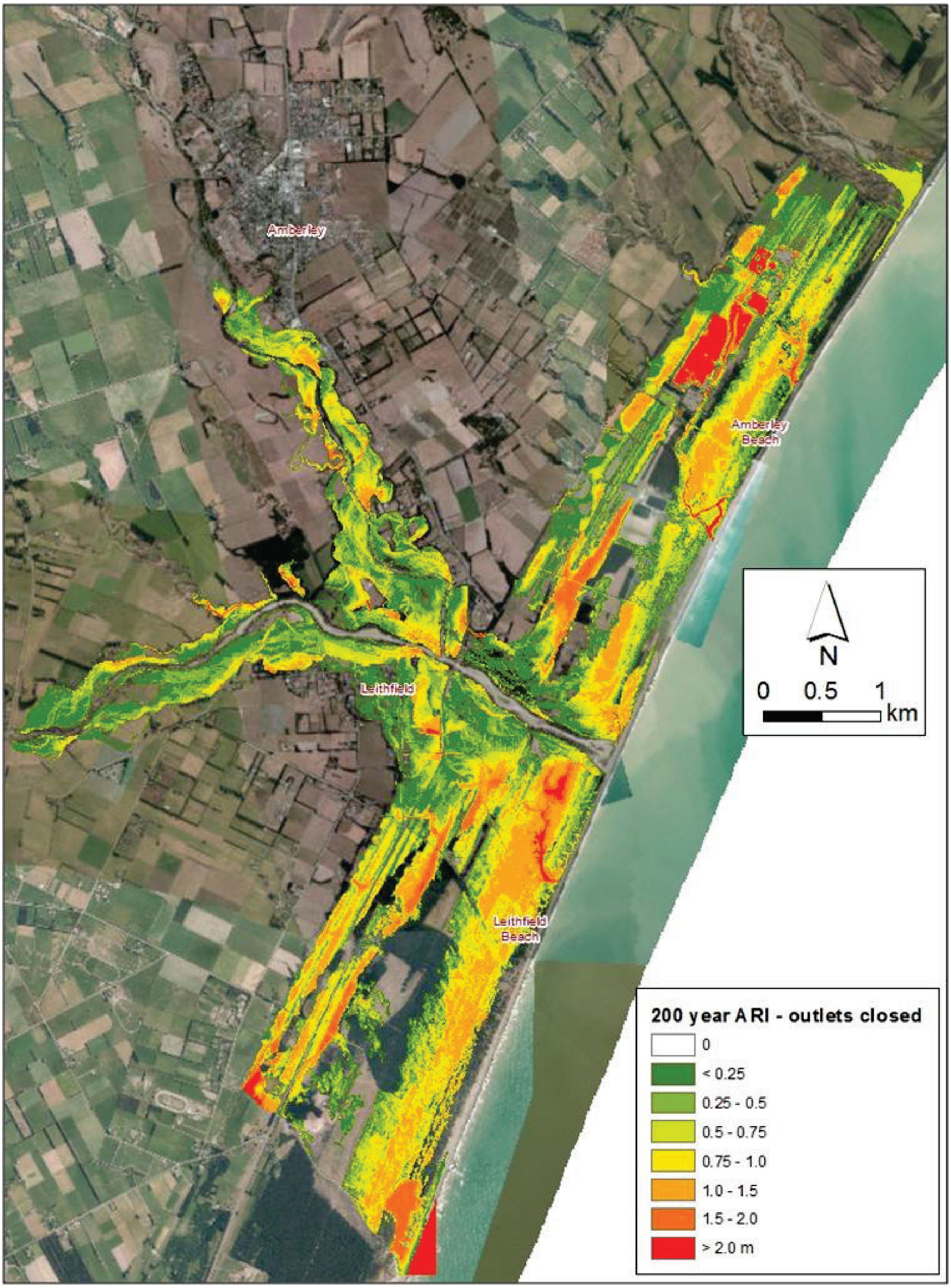



**Figure 3-32: Maximum water depths (m) for the Kowai River, Amberley Beach and Leithfield Beach floodplain 200 year ARI event (lagoon outlets closed except Kowai River mouth)**

The Amberley Beach and Leithfield Beach water levels for the 200 year ARI model are shown in Figure 3-33 and Figure 3-34, respectively. These figures show the relatively short time between trigger levels being reached and inundation of the lowest existing properties starting to occur. There is also only about 10 to 12 hours between trigger levels being reached and peak water levels being reached.

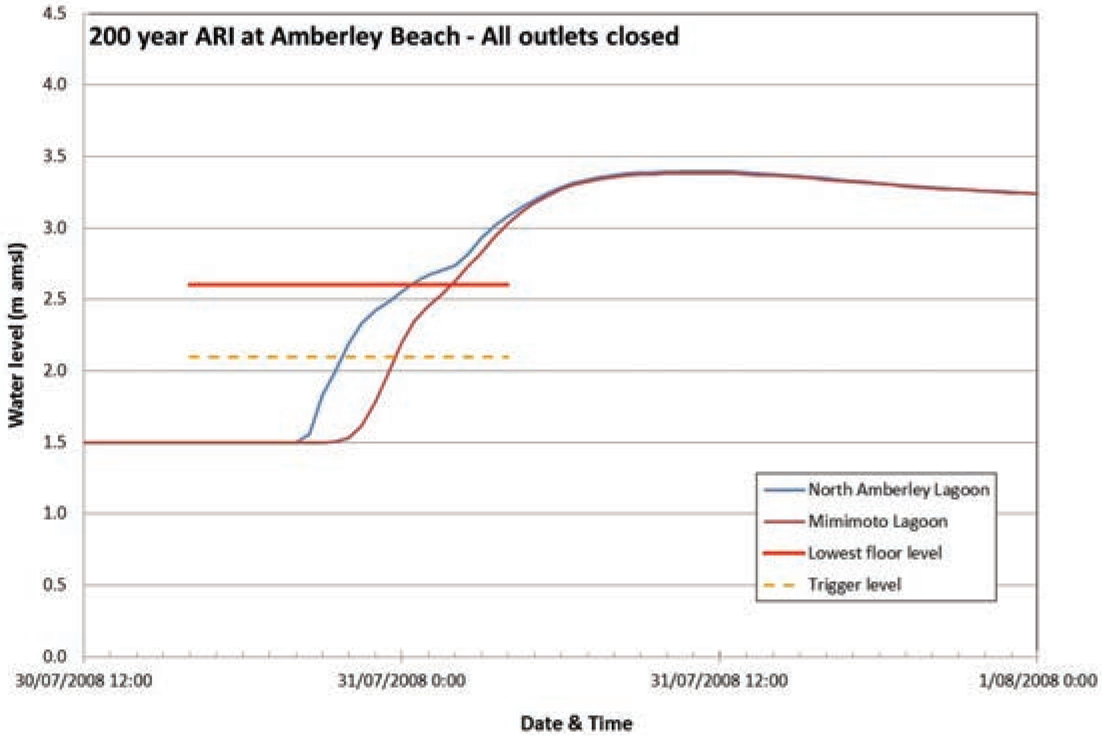



**Figure 3-33: Amberley Beach lagoon water levels (m above msl) during a 200 year ARI event with lagoon outlets closed**

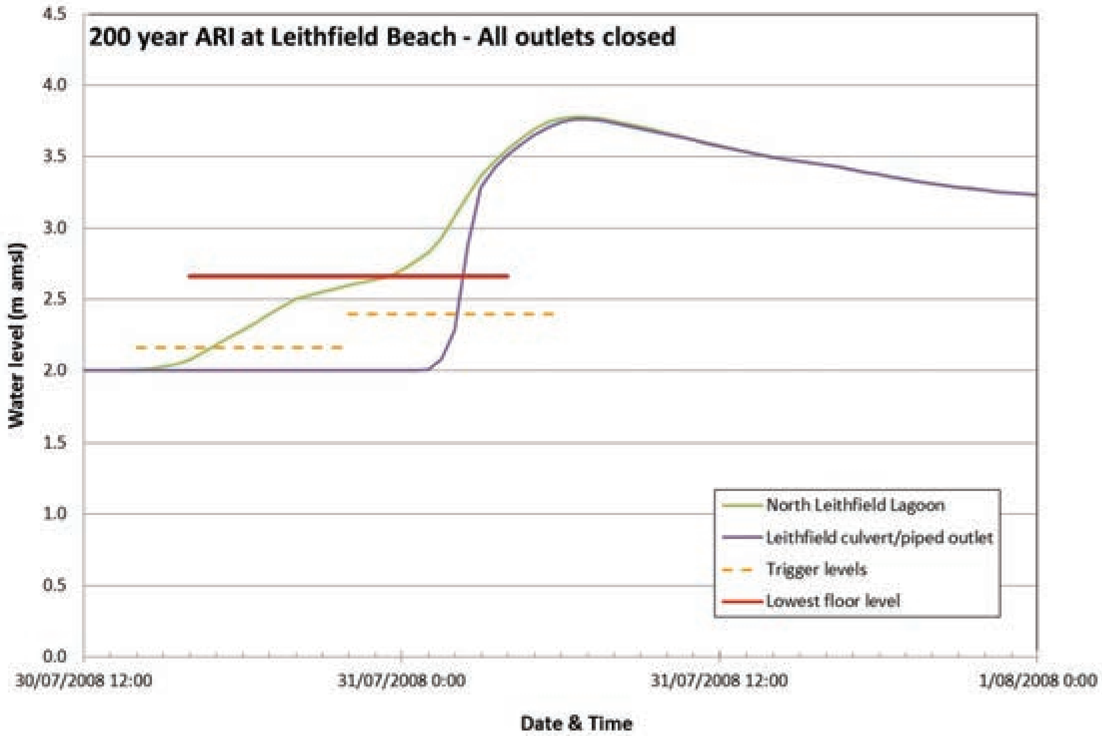



**Figure 3-34: Leithfield Beach lagoon water levels (m above msl) during a 200 year ARI event with lagoon outlets closed**

Note that averaging of the topography to produce the 5 m grid for the floodplain tends to remove many of the smaller drains; this is likely to be similar to having them in the model but blocked; flow in the smaller drains is assumed to be relatively small compared to the total floodplain flow. Human intervention, in the form of manual opening of the Kowai River mouth and Amberley Beach and Leithfield Beach lagoons, can also have an impact on maximum water levels.

The various factors that can have an impact on the maximum water levels at Amberley Beach and Leithfield Beach are discussed in Section 3.6.

## 3.6 Model sensitivity analysis for 200 year ARI design flood event

Several scenarios were modelled to determine the sensitivity of various model parameters and assumptions, as well as to determine the potential impact of climate change. Scenarios modelled are summarised below for the 200 year ARI flood event.

### 3.6.1 Lagoon outlets to sea remain open for the duration of the flood event

Hurunui District Council has a resource consent that allows the lagoons (including Leithfield Outfall Drain) to be manually opened to the sea; the driving force for this being that it will help to alleviate flooding for the existing properties in the Amberley Beach and Leithfield beach settlements during flood events.

This scenario has not been used as our ‘base’ model as there are some concerns about the practicalities of opening the lagoons in a large storm event, especially given the relatively short time period between the trigger levels being reached and the floodwater levels peaking. For example, if the trigger level is reached during darkness and/or when there are large ocean waves it may not be possible to excavate the openings. A newspaper article (Appendix E) outlines some issues that may lead to delays in opening the lagoons (i.e. availability of a digger and sea conditions).

Despite these concerns, a sensitivity test was completed assuming that all openings were excavated prior to the storm arriving, and also assuming that sea conditions do not cause them to close. One of the Leithfield Outfall Drain outlet pipes was also assumed to be operating (current situation).

Figure 3-35 shows the modelled water levels for the various lagoons (and Outfall Drain). Mimimoto Lagoon has low water levels, which is likely to be due to the channel capacity upstream of the lagoon being less than the modelled outlet capacity. This means the outlet water level is able to be drawn down effectively near the outlet to the sea but floodwater is restricted further upstream.

Figure 3-36 shows that there is a considerable flow passing out to the sea via the North Leithfield Lagoon (~ 60 $m^3/s$). This outflow is larger than the other outlet flows as it is supplemented by large volumes of Kowai River flows. This elevates the level in the North Leithfield Lagoon to around 3.5 m above msl, providing a considerable water level difference between the lagoon and the sea level (and hence considerable outlfows to the sea). North Amberley Lagoon, Mimimoto Lagoon and the Leithfield Outfall Drain (combination of one piped outlet and an excavated opening) are estimated to have relatively similar peak outflows (~ 15 $m^3/s$).

Table 3-8 indicates that if the outlets are all open for a 200 year ARI flood event, peak water levels would potentially be reduced at Amberley Beach and Leithfield Beach by 0.5 m and 0.25 m, respectively.

As we have based our modelling on the July 2008 storm event, the modelling does simulate high tide and the Kowai River flood peak both occurring around 5am on 31 July 2008. Should the timing of the high tide, in relation to the Kowai River flood peak, differ then maximum water levels may be lower. Modelling has not been completed to check the impact of the timing of the high tide as the situation modelled was considered conservative (but realistic).

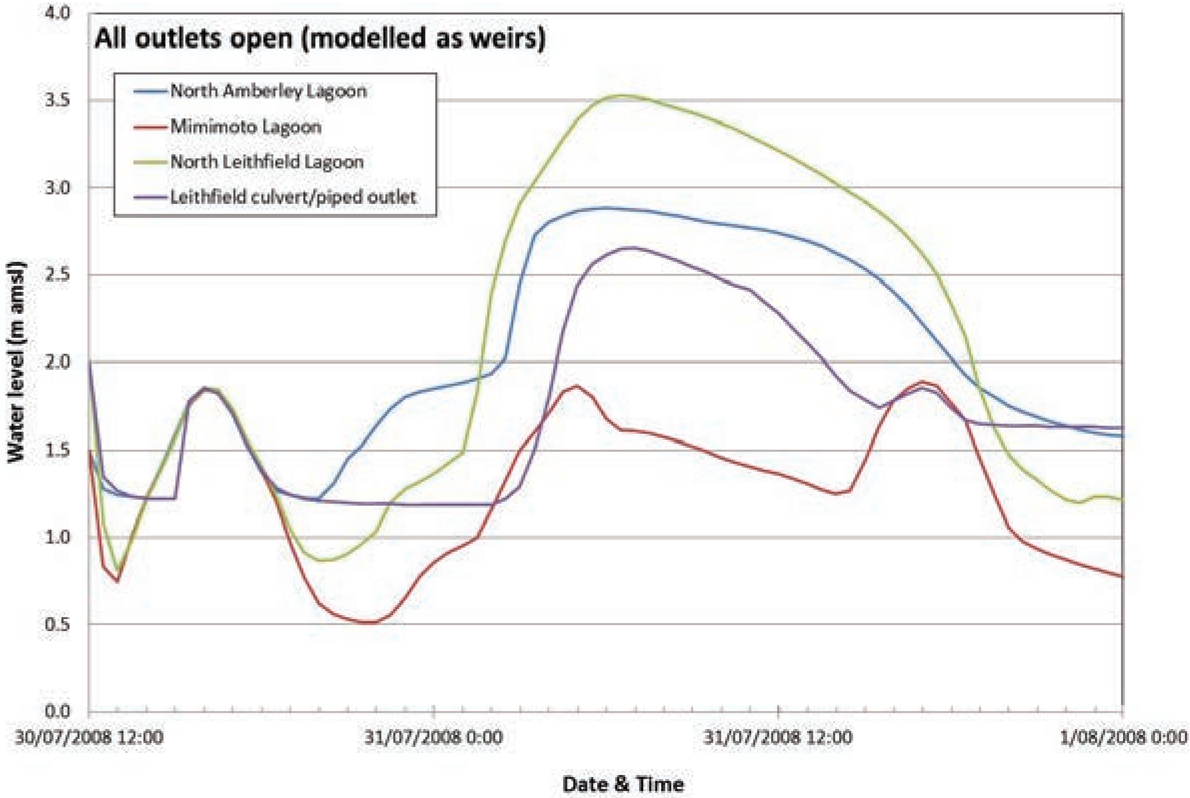



**Figure 3-35: Lagoon and Outfall Drain water levels (m above msl) during a 200 year ARI event with outlets open**

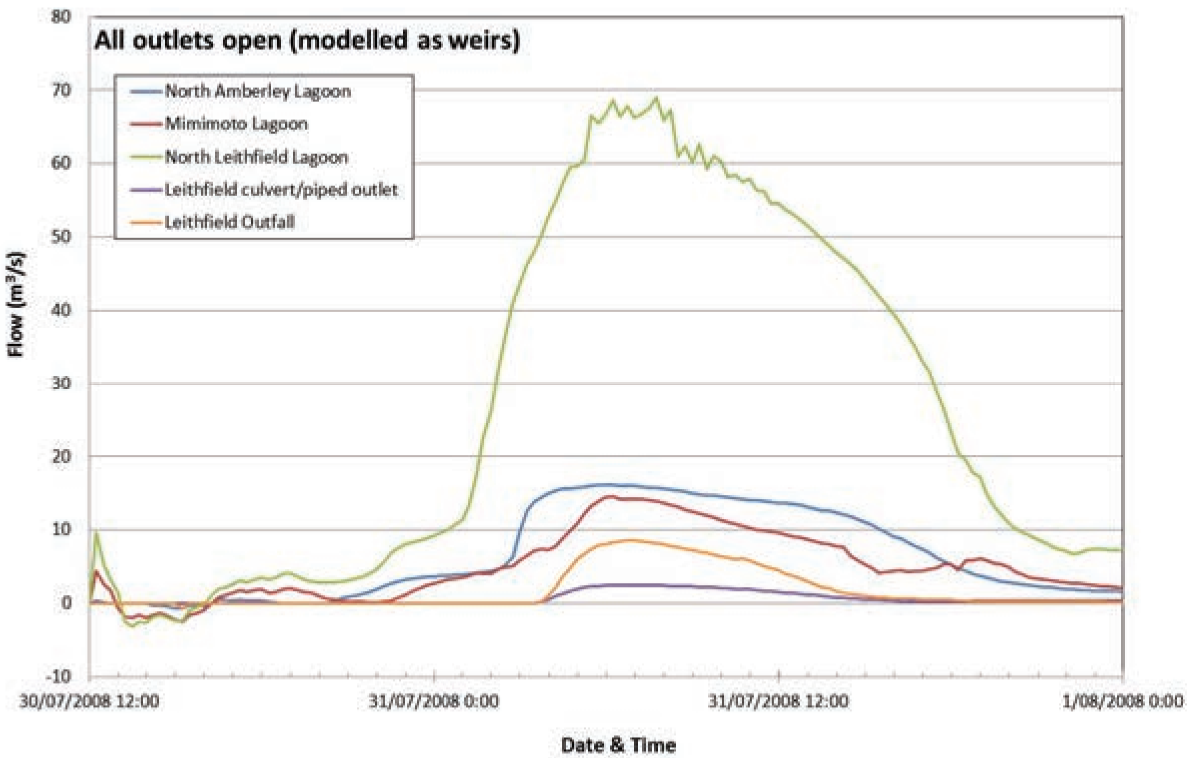



**Figure 3-36: Lagoon, Outfall Drain and piped outlet flows ($m^3/s$) during a 200 year ARI event with outlets open**

**Table 3-8: Modelled maximum water levels for Amberley Beach and Leithfield Beach**

| Run | Description | Lagoon outlets[1] | Water level (m above msl) | |
|---|---|---|---|---|
| | | | Amberley Beach | Leithfield Beach |
| | Lowest floor level | | 2.6 | 2.66 |
| | Typical ground level | | 2.4 – 2.8 | 2.4 – 2.8 |
| | <u>July 2008 flood event</u> | | | |
| | Actual July 2008 (maximum) | | ≥2.85 | ≥2.8 |
| | Model calibration (at 11 am) | Closed | 2.8 | 2.9 |
| | <u>50 year ARI flood event</u> | | | |
| | 'Base' model | Closed | 3.2 | 3.5 |
| | <u>200 year ARI flood event</u> | | | |
| 1 | 'Base' model | Closed | 3.4 | 3.8 |
| 2 | All Amberley Beach and Leithfield Beach outlets open | Open | 2.9 | 3.55 |
| 3 | Run 1 with local inflow increased by 25% | Closed | 3.5 | 3.8 |
| 4 | Run 1 with Kowai River flow increased by 25% | Closed | 3.4 | 4.0 |
| 5a | Run 1 with 0.5 m of sea level rise | Closed | 3.4 | 3.8 |
| 5b | Run 2 with 0.5 m of sea level rise | Open | 2.9 | 3.6 |

[1] Includes Leithfield Outfall Drain and one (of the 2) piped outlets. Kowai River mouth remains open for all runs.

### 3.6.2 Local sub-catchment inflows increased by 25%

Figure 3-10 shows that there is considerable uncertainty associated with deriving local inflows. As the RFE method gave higher peak local catchment flows a model run was completed with the local inflows to all 29 sub-catchments increased by 25%. This also provides an indication of the predicted impact of climate change on storm rainfall.

Table 3-8 shows that increasing local inflows by 25% increases Amberley Beach peak water levels by ~ 0.1 m but has a negligible effect on Leithfield Beach peak water levels. This is likely to be mainly due to the larger sub-catchment area draining water to Amberley Beach (in particular the large Eastern Drain sub-catchment).

### 3.6.3 Kowai River inflows increased by 25%

Figure 3-2 shows that there is considerable uncertainty associated with deriving river flows using the regional flood estimation (RFE) method (Griffiths *et al.,* 2011). However, when there is little or no flow information this is the best method available. Given that climate change is generally expected to increase peak runoff by 16-20% over the next century a model run was completed with the Kowai River flows increased by 25%.

Table 3-8 shows that, for the 200 year ARI flood event, increasing the Kowai river flows by 25% has a negligible effect on Amberley Beach peak water levels but increases Leithfield Beach peak water levels by 0.2 m. This is likely to be mainly due to the larger volume of water passing out of the Kowai River channel onto the floodplain - which drains towards Leithfield Beach.

### 3.6.4 Sea level increased by 0.5 m

It is not currently known how increasing sea level will directly impact on the Kowai River, Amberley Beach and Leithfield Beach coastal areas. To provide some initial information it was assumed that in the next 50 years the mean sea level may increase by 0.5 m. To model this scenario the design sea level time series had water levels increased by 0.5 m.

The model was run for the following two scenarios:

a) All Amberley Beach and Leithfield Beach lagoon outlets closed for the duration of the flood event. The Kowai River outlet had the outlet weir invert raised by 0.5 m to 1.0 m above msl.

b) All Amberley Beach and Leithfield Beach lagoon outlets open for the duration of the flood event. For the lagoon outlets that are opened manually, the cuts modelled as fixed crest weirs with invert levels of 0.5 m above msl (i.e. Mimimoto Lagoon and North Leithfield Lagoon plus the Kowai River) had their invert levels increased to 1.0 m above msl.

It was assumed that the sand dunes were not overtopped – although the low area in the sand dunes at Ashworths Ponds (southern limit of the model where overtopping occurs at high water levels) was not modified. Water was also still able to flow into the Waipara River at high water levels (i.e. the effect of higher sea levels on the Waipara River were not considered).

Table 3-8 shows that when sea level increases by 0.5 m, and the Amberley Beach and Letihfield Beach lagoon outlets remain closed, there is no significant difference in maximum water levels at the Amberley Beach and Leithfield Beach settlements. However, this does not mean there are not increases in maximum water levels at other locations. For example, Figure 3-37 shows that when all the outlets are closed (excluding the Kowai River mouth) maximum water levels to the north of the Kowai River increase by ~ 0.2 m over quite a large area of land.

When sea level increases by 0.5 m, and the Amberley Beach and Leithfield Beach lagoon outlets remain open for the full flood event, there is no significant difference in maximum Amberley Beach settlement water levels, and a small (0.05 m) increase in maximum water levels at Leithfield Beach settlement – when compared to the same situation (outlets open) with no sea level rise. Sea level rise of 0.5 m increases the maximum water levels to the north of the Kowai River by up to 0.2 m (over quite a large area south of Mimimoto Lagoon), and to the south of the Kowai River from ~ 0.05 m (Leithfield Beach settlement) to ~ 0.1 m (from Kings Road south to Ashworths Pond).

It should also be emphasised that the effects of wave run-up, resulting in overtopping the sand dunes, has not been included in this study. This is likely to have a more significant effect at higher sea levels.

### 3.6.5 Other parameters to consider

Other model parameters that could have an impact on maximum flood water levels are described below. Modelling these parameters was considered a lower priority (given the time constraints of this work) as they are likely to have a smaller impact on maximum water levels, or can be partially examined through other sensitivity tests. For example, increasing the Kowai River peak flows will cause more water to pass onto the floodplain; increasing channel roughness would also cause additional flow over the floodplain. Other parameters to consider include:

*1. River channel roughness*

The Kowai River Mike Flood model has channel roughness values as specified in Table 3-7. Since floodplain flow from the Kowai River occurs when water overtops the Mike 11/Mike 21 cross section banks, the volume of flood water entering the floodplain is reliant on the correct roughness values being used to represent the river system (i.e. water levels along the river will increase if Manning 'n' roughness increases).

2. *Floodplain roughness*

Floodplain roughness values used to represent the Kowai River, Amberley Beach and Leithfield Beach floodplain are described in Section 3.2.2 and shown on Figure D-4. As the Amberley Beach and Leithfield Beach floodplain area is relatively flat, and flow velocities are generally low, adjusting Manning 'n' roughness is likely to have relatively little effect on maximum water levels in the Amberley Beach and Leithfield Beach floodplain area.

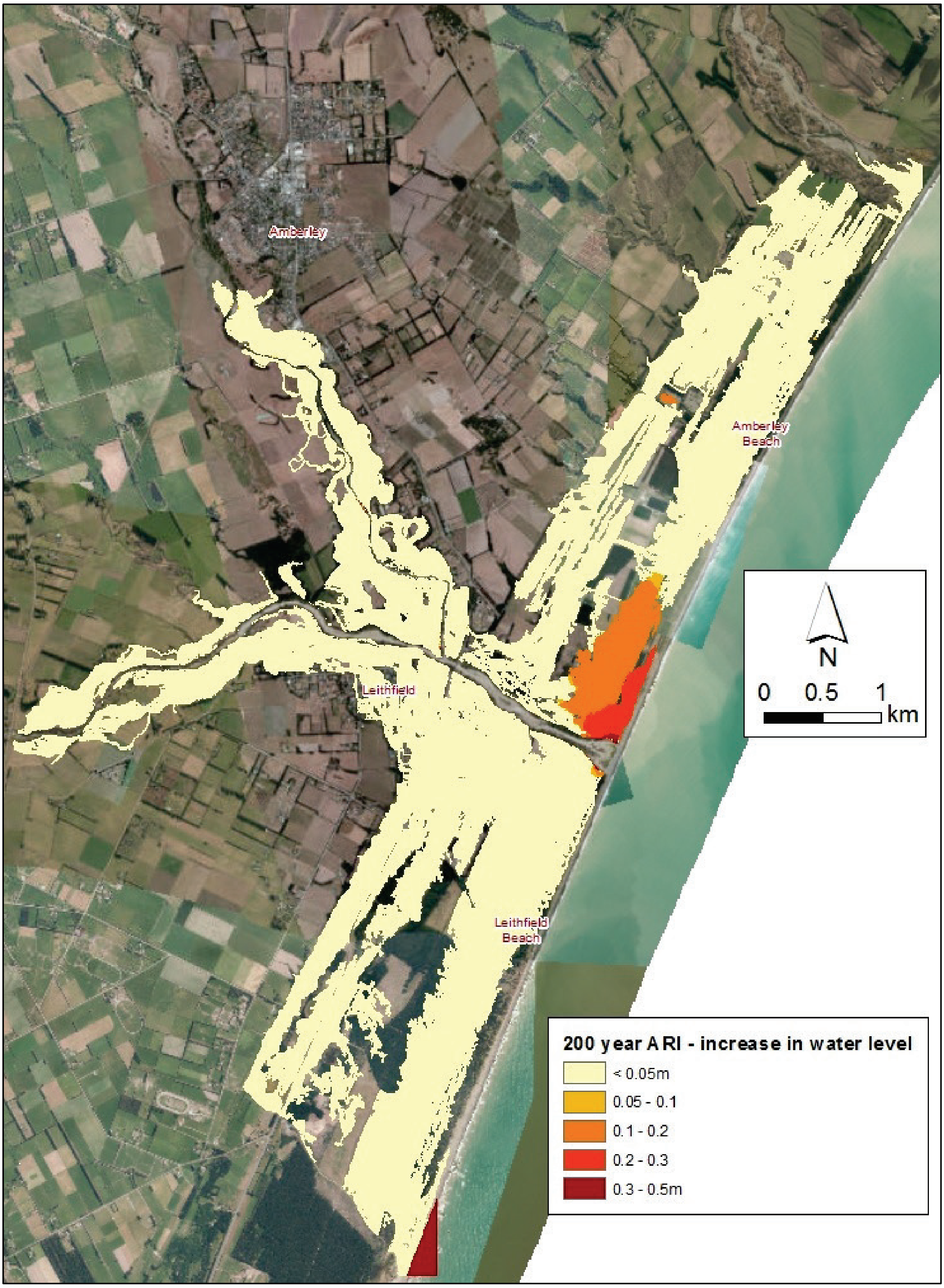



**Figure 3-37: Increase in maximum water levels for 200 year ARI event with 0.5 m of sea level rise (lagoon outlets closed except Kowai River mouth)**

# 4 Discussion

The results from this study contain several sources of uncertainty due to the nature of hydraulic modelling and the quality of the available model input data - with both tending to be simplified compared to what is actually occurring in the 'real world'. Despite these uncertainties and assumptions, hydraulic modelling is still a powerful tool for simulating floodplain inundation and flood flow paths, and is especially useful for comparing various scenarios that may occur during a flood event. A summary of the uncertainties and assumptions made in this study are given below.

### 4.1.1 Sources of uncertainty in hydraulic modelling

Hydraulic modelling has numerous sources of uncertainty that need to be taken into consideration when interpreting flood inundation maps derived from the model results. Bales and Wagner (2009) outline some of the uncertainties associated with 1-d hydraulic modelling using LiDAR data. These uncertainties are also relevant for this modelling study where uncertainties include model inputs (e.g. flow hydrographs, sea levels, roughness values and energy loss parameters), topographic data (e.g. LiDAR data, cross section data) and hydraulic model assumptions (e.g. simplification of equations by depth-averaging, as well as averaging topography and flow behaviour over a 5 m grid cell for computational efficiency). For this modelling study there is also considerable uncertainty associated with how the Kowai River mouth and Amberley Beach and Leithfield Beach lagoon outlets are managed.

### 4.1.2 Summary of model assumptions

To simulate flood inundation in the Amberley Beach and Leithfield Beach settlement areas, it has been necessary to make several assumptions. These are outlined below.

- The ground levels in the model are based on 2012 LiDAR data and do not include some proposed changes (e.g. possible flow diversions from the: upper Eastern Drain catchment to Kowai River, Eastern Drain via a swale to the Amberley Beach Lagoon, and Dry Gully system downstream of Hursley Terrace Road via a swale to Mimimoto Lagoon). However, it does incorporate the recently raised stopbanks on the true left bank at the Kowai River lagoon in the model bathymetry (this stopbank has been lowered in the model bathymetry for the July 2008 calibration model, which was prior to the stopbank being raised).
- Local sub-catchment boundaries for the Amberley Beach and Leithfield Beach settlements have been determined by a combination of site visits, LiDAR and topographic maps. Some drainage paths may not be fully accounted for in the model as only the more significant culverts have been included in the model. It is assumed that many smaller pipes are likely to be overwhelmed or blocked during large events.
- At the southern limit of the model, where flood water from the Leithfield area overtops the natural beach sand dune system, it is assumed that the dunes are simply overtopped rather than forming a more defined and incised opening like the lagoon outlets at Amberley Beach, Leithfield Beach and the Kowai River mouth. This was considered to be a conservative assumption.
- Seepage between the sea and the lagoon/beach settlement areas has not been included.
- Wave run-up is not included in this study. However, it is known that a combination of storm surge and wave run-up have previously caused sea water to flow over the Amberley Beach dunes and into the Amberley Beach settlement (e.g. 27 August 1992). Yetton *et al*. (2000) estimate that for a 24-hour storm with a wave height of 6.5 m the beach ridge could be overtopped passing 127,000 $m^3$ of sea water into the Amberley Beach Settlement (i.e. causing flood depths of 0.5 to 1 m).
- At the start of the model runs it is assumed that all lagoon outlets are closed (or have just been opened). Initial water levels in the various lagoons and the Outfall Drain have been assumed (as described in Section 3.5.1).
- The Kowai River mouth is assumed to be open before the Kowai River flood peak arrives.
- As no data is available to calibrate the local inflows, infiltration rates and roughness values have been assumed. The July 2008 rainfall time series is also assumed to be a typical storm profile for a large event. A sensitivity run has been completed with local inflows increased by

25% to assess the sensitivity of the beach settlements to changes in local inflows (i.e. taking the uncertainty in infiltration rates, etc, into consideration). However, other rainfall profiles have not been examined.
- No allowance has been made for additional inflows to the Amberley Beach and Leithfield Beach floodplain from the Waipara River (to the north) or Ashley River/Saltwater Creek (to the south).

Modelling results provided in this report should only be interpreted and used by those who are familiar with all aspects of the modelling.

### 4.1.3 Main findings

This modelling study has shown that, during a large storm event (with the lagoon outlets closed), the maximum water levels at Amberley Beach are largely dependent on the magnitude of the local inflows from the sub-catchments – in particular the Eastern Drain which has the largest sub-catchment area.

Leithfield Beach also has to contend with potentially significant overbank flows from the Kowai River, which tend to flow towards the Leithfield Beach settlement. It was also noted for the 200 year ARI that, when the North Leithfield Lagoon outlet was open, the peak outflows from the Kowai River decreased slightly, and additional flow passed through the lagoon outlet instead. Opening the lagoon outlets was therefore more effective for the Amberley Beach settlement where maximum water levels could be reduced by up to 0.5 m (compared to 0.25 m at Leithfield Beach) for the 200 year ARI.

The effects of 0.5 m of sea level rise are negligible for Amberley Beach when the lagoon outlets are closed. However, this does rely on there being no wave run-up and overtopping of the sand dunes (which has not been modelled). The impact of 0.5 m of sea level rise appears to be reduced for Leithfield Beach due to the higher Kowai River water levels flowing to the north of the river. Flood waters at Leithfield Beach settlement also tend to flow over Kings Road and travel towards Ashworths Ponds – resulting in higher maximum water levels in the area between Kings Road and Ashworths Road for the 0.5 m sea level rise scenario.

The maximum water levels summarised in Table 3-8 indicate that the 200 year ARI maximum water levels for Amberley Beach are likely to be between 2.9 m and 3.5 m above mean sea level, and for Leithfield Beach they are likely to be between 3.6 m and 4.0 m above mean sea level. Given the short time period over which water levels increase during a storm event, and the uncertainty over the ability of the outlets to be opened during adverse sea conditions, it was considered reasonable to assume that the outlets remain closed. The modelling therefore produces 200 year ARI maximum water levels for Amberley Beach of 3.4 m ± 0.1 m above msl, and Leithfield beach of 3.8 m ± 0.2 m above msl.

### 4.1.4 Recommendations

Despite a 200 year ARI flood event being considered to be a large and infrequent event, over a 70 year period it is estimated that there is a 33% chance of an event of this magnitude occurring (Table F-1, Appendix F).

**Modelled 200 year ARI flood water levels for Amberley Beach and Leithfield Beach settlements are 3.4 m and 3.8 m above mean sea level (Lyttelton 1937 Datum), respectively. It is recommended that building floor levels have an additional freeboard of 400 mm added to these flood water levels.**

These flood water levels are based on the assumption that the flood event will be widespread causing both the Kowai River and local catchments to generate 200 year ARI flood flows. The sea level is also raised to incorporate an additional 0.4 m storm surge but wave run-up and overtopping of the sand dunes at Amberley Beach and Leithfield Beach has not been included. A freeboard of 400 mm allows for uncertainties in modelling assumptions as well as physical allowances such as wind setup and vehicle bow waves.

There are several additional sensitivity tests that could be undertaken to confirm that the information in this report provides a robust and reasonable estimate of the 200 year ARI. These include:

- Testing the model for a range of design rainfall time series and rainfall runoff parameters. This would provide a range of local inflow scenarios.
- Undertaking a probability analysis to take into consideration the joint probability of various design inflows and design sea levels (i.e. maximum tide levels –including timing of high tide - and storm surge).
- Examining the impact of climate change further (e.g. including impact on Waipara River to north and the low sand dune area at the southern limit of the model).

# 5 Acknowledgments

The following Environment Canterbury staff have reviewed this report and provided valuable input to this study:

- Nick Griffiths (Hazards Analyst) – determined Amberley and Leithfield Beach sub-catchment areas, reviewed modelling results and provided archived images and background information on historical flooding within the Kowai River and Amberley/Leithfield Beach settlement areas.

- Tony Oliver (Principal Hazards Analyst) – peer reviewed modelling methodology, model configuration and report.

- Richard Holmes (Hazards Analyst) - reviewed modelling results (based on his long association with investigating historical flooding within the Hurunui District).

- Tony Gray (Team Leader Hydrological Archives) - provided hydrometric data used in this study.

- Renay Weir (Planner) - obtained historic flooding photographs from Hurunui District Council.

External assistance was also provided by:

- Kathy Walter (NIWA) - provided hydrometric data used in this study.

- Local residents – provided local knowledge of area and photographs.

# 6 Glossary

**Aggradation:** Deposition of shingle in river, raising the river bed level.

**Annual exceedance probability (AEP):** The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example if a peak flood discharge of 500 $m^3/s$ has an AEP of 5%, it means there is a 5% chance (i.e. a chance of one-in-twenty) of a peak flood discharge of 500 $m^3/s$ or larger occurring in any one year. AEP is the inverse of return period, expressed as a percentage.

**Average Recurrence Interval (ARI):** The average time period between floods, equivalent to or exceeding a given magnitude. For example, a 100 year ARI flood has a magnitude expected to be equalled or exceeded on an average of once every 100 years. Such a flood has a 1% chance of being equalled or exceeded in any given year, i.e. 1% AEP and is often used interchangeably with "return period" or "flood frequency".

**Catchment:** The land area draining through the main stream and tributaries to a particular site.

**Discharge:** The rate of flow of water measured in terms of volume per unit time, e.g. cubic metres per second.

**Fairway:** The open (ideally vegetation-free) area of the riverbed that carries the majority of any flood flow. There is often a maintenance program in place for clearance of vegetation such as willows, gorse and broom from the fairways.

**Floodplain:** The area of relatively flat land, which is inundated by floodwaters from the upper catchment up to the probable maximum flood event.

**Floor level***:* The top surface of the ground floor of a building (prior to the installation of any covering).

**LiDAR (Light Detection and Ranging) data:** Data acquired using a laser scanner mounted on an aircraft. The scanner measures the ground level at approximately one point every square metre. These data points are used to generate very accurate and high resolution digital elevation maps which enable subtle topographic features to be identified.

# 7 References


Bales, J.D. and Wagner, C.R. (2009). Sources of uncertainty in flood inundation maps. Journal of Flood Risk Management, Volume 2, Issue 2, p 139-147.

Bell, R.G. (2009). Sumner Head Sea-Level Station: Annual Report for 2008. NIWA Client report HAM2009-147. Prepared for Environment Canterbury. October 2009.

Bell, R.G. (2011). Sumner Head Sea-Level Station: Annual Report for 2009-2010. NIWA Client report HAM2011-051. Prepared for Environment Canterbury. June 2011.

Bell, R.G.; Wild, M.A. (2006). Sumner Head Sea-Level Station: Annual Report for 2005. NIWA Client report HAM2006-100. Prepared for Environment Canterbury.

Canterbury Regional Council. (1993). Issues and Options for the Management of Water Resources in the Waipara Region. Report 93(7). May 1993.

Flatman, M. (1998). Amberley Beach: Coastal Environment. Canterbury Regional Council Report No. CRC U98/04. February 1998.

Griffiths, G.; McKerchar, A.; Pearson, C. (2011). Review of flood frequency in the Canterbury region. Environment Canterbury Technical Report R11/50. August 2011.

Griffiths, G.; Pearson, C.; McKerchar, A. (2009). Review of the frequency of high intensity rainfall in Christchurch. NIWA Client report CHC2009-139. Prepared for Christchurch City Council and Environment Canterbury. September 2009.

McKerchar, A.I.; Pearson, C.P. (1989). Flood frequency in New Zealand. Hydrology Centre Publication 20, Christchurch, New Zealand. 87p.

Ministry for the Environment. (2008). Coastal hazards and climate change. A guidance manual for local government. 2nd edition. Revised by Ramsay, D, and Bell, R. (NIWA). Prepared for Ministry for the Environment.

Mullan, B.; Wratt, D.; Dean, S.; Hollis, M.; Allan, S.; Williams, T.; Kenny, G.; MfE. (2008). Climate change effects and impacts assessment: A guidance manual for local government in New Zealand. Report prepared for Ministry for the Environment, 2nd Edition, xviii + 149 p.

Norton, A.C. (1959). Kowai River Flood Control Scheme – Leithfield, Economic Report, Appendix B. Prepared for the North Canterbury Catchment Board. October 1959.

Pattle Delamore Partners Ltd. (2008). Flood management for Amberley and Amberley Beach. Prepared for Hurunui District Council. December 2008.

Pattle Delamore Partners Ltd. (2009). Flood management for Leithfield and Leithfield Beach – Second draft. Prepared for Hurunui District Council. September 2009.

Pattle Delamore Partners Ltd. (2010). Assessment of Environmental Effects for the Lagoon/Drain Mouth Openings for Flood Mitigation. Prepared for Hurunui District Council. March 2010.

Pennington, M. and Melanson, J. (2008). Amberley Floods – July and August 2008.

Todd, D. J. (2008). Evidence of Derek John Todd – Application CRC0081872, CRC081875, CRC081876, CRC081879, and CRC081880 by Hurunui District Council to undertake works in the bed of a river, Coastal Hazard Zone and Coastal Marine Area (CMA) to dam and divert Leithfield Stream and to discharge water and contaminants into the CMA. December 2008.

Todd, D. (2009). Amberley Beach renourishment maintenance program. Prepared for Hurunui District Council, August 2009.

The Soil Conservation and Rivers Control Council (SCRCC). (1957). Floods in New Zealand 1920-53. Published by The Soil Conservation and Rivers Control Council, Wellington, New Zealand.

Yetton, M.D.; McCahon, I.F.; Owens, I.; Todd, D. (2000). Hurunui District Engineering Lifelines Project – Natural Hazards Assessment. Environment Canterbury Report Number U00/73. November 2000.

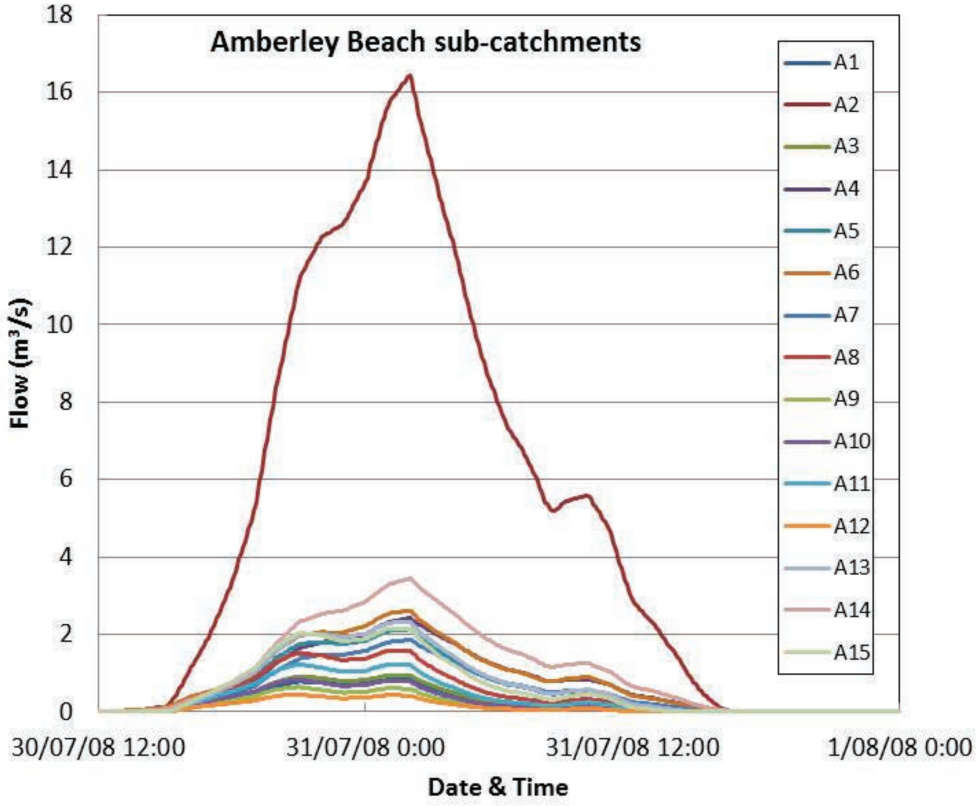
# Appendix A: Mike11 Rainfall Runoff parameters

**Table A-1: Summary of Mike 11 Rainfall Runoff parameters**

| Amberley sub-catchment rainfall runoff parameters | | | | | |
|---|---|---|---|---|---|
| Sub-catchment | Area (km2) | Length (km) | Slope (m/km) | % Impervious | % Impervious |
| 1 | 0.47 | 1.15 | 4 | 1 | 99 |
| 2 | 10.9 | 5.7 | 13 | 1 | 99 |
| 3 | 0.53 | 1.2 | 6 | 0 | 100 |
| 4 | 1.6 | 4.1 | 6.25 | 2 | 98 |
| 5 | 1.3 | 2.4 | 7 | 1 | 99 |
| 6 | 1.6 | 3.65 | 6.2 | 8 | 92 |
| 7 | 1.2 | 3.0 | 5.8 | 1 | 99 |
| 8 | 0.89 | 1.3 | 6.25 | 1 | 99 |
| 9 | 0.33 | 0.40 | 2 | 0 | 100 |
| 10 | 0.44 | 0.45 | 2 | 1 | 99 |
| 11 | 0.68 | 0.60 | 2 | 1 | 99 |
| 12 | 0.23 | 0.40 | 2 | 2 | 98 |
| 13 | 1.4 | 1.15 | 2 | 1 | 99 |
| 14 | 2.3 | 1.75 | 2 | 3 | 97 |
| 15 | 1.2 | 0.80 | 2 | 0 | 100 |
| Leithfield sub-catchment rainfall runoff parameters | | | | | |
| 1 | 0.16 | 0.80 | 5.8 | 4 | 96 |
| 2 | 0.57 | 1.7 | 6.0 | 25 | 75 |
| 3 | 1.6 | 2.4 | 8.5 | 1 | 99 |
| 4 | 1.2 | 2.2 | 10.5 | 1 | 99 |
| 5 | 2.9 | 2.9 | 10.0 | 1 | 99 |
| 6 | 0.82 | 1.7 | 11.3 | 1 | 99 |
| 7 | 0.74 | 1.4 | 10.3 | 1 | 99 |
| 8 | 0.75 | 1.7 | 2.4 | 0 | 100 |
| 9 | 0.25 | 0.7 | 5.0 | 4 | 96 |
| 10 | 0.93 | 1.5 | 2.0 | 1 | 99 |
| 11 | 0.79 | 2.6 | 2.0 | 1 | 99 |
| 12 | 1.2 | 2.8 | 0.5 | 0 | 100 |
| 13 | 1.2 | 1.1 | 0.6 | 8 | 92 |
| 14 | 2.1 | 1.4 | 0.8 | 1 | 99 |

| | Pervious surface | Impervious surface |
|---|---|---|
| Wetting (mm) | 0.05 | 0.05 |
| Storage (mm) | 1 | 0.6 |
| Manning number ($m^{1/3}/s$) | 20 | 70 |
| Start infiltration rate (mm/hr) | 4 | |
| End infiltration rate (mm/hr) | 3 | |
| Exponent (hertz) | 0.0015 | |
| Inverse Horton's equation (hertz) | 3e-005 | |

# Appendix B: Mike11 Rainfall Runoff inflows



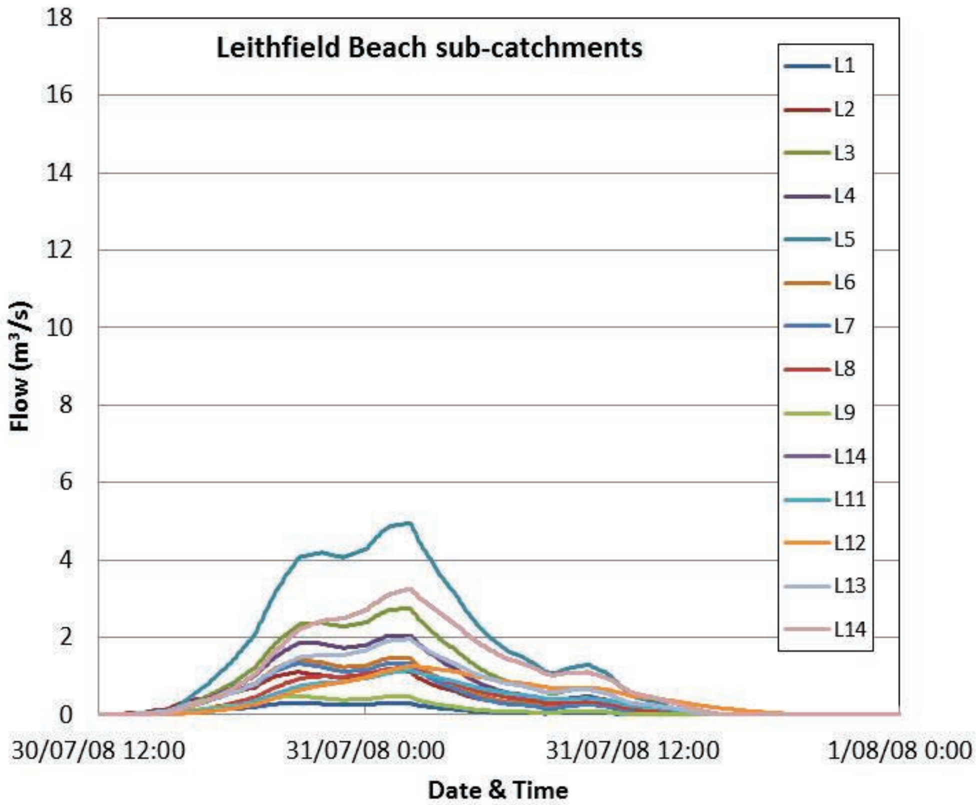




**Figure B-1: July 2008 calibration event local inflows**

**Table B-1: Output from HIRDS (v3) for Amberley Railway Terrace rainfall gauge location**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High Intensity Rainfall System V3 | | | | | | | | | | | |
| | | | | | | | | | | | |
| Depth-Duration-Frequency results (produced on Wednesday 18th of June 2014) | | | | | | | | | | | |
| Sitename: Amberley Railway tce | | | | | | | | | | | |
| Coordinate system: NZMG | | | | | | | | | | | |
| Easting: 2487550 | | | | | | | | | | | |
| Northing: 5783525 | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| Rainfall depths (mm) | | | | | | | | | | | |
| | | | | | Duration | | | | | | |
| ARI (y) | aep | 10m | 20m | 30m | 60m | 2h | 6h | 12h | 24h | 48h | 72h |
| | | | | | | | | | | | |
| 1.58 | 0.633 | 3.5 | 5.3 | 6.7 | 10.1 | 15 | 28 | 41.7 | 61.9 | 69.2 | 73.8 |
| 2 | 0.5 | 3.9 | 5.8 | 7.4 | 11.1 | 16.5 | 30.8 | 45.6 | 67.7 | 75.7 | 80.7 |
| 5 | 0.2 | 5.2 | 7.8 | 9.9 | 15 | 22.1 | 40.9 | 60.4 | 89.2 | 99.6 | 106.3 |
| 10 | 0.1 | 6.3 | 9.5 | 12.1 | 18.2 | 26.8 | 49.5 | 72.7 | 107 | 119.5 | 127.5 |
| 20 | 0.05 | 7.7 | 11.5 | 14.6 | 22.1 | 32.3 | 59.3 | 86.9 | 127.4 | 142.3 | 151.8 |
| 30 | 0.033 | 8.5 | 12.9 | 16.3 | 24.6 | 36 | 65.8 | 96.3 | 140.9 | 157.4 | 167.9 |
| 40 | 0.025 | 9.2 | 13.9 | 17.6 | 26.6 | 38.8 | 70.8 | 103.5 | 151.2 | 168.9 | 180.2 |
| 50 | 0.02 | 9.8 | 14.7 | 18.7 | 28.2 | 41.2 | 75 | 109.4 | 159.7 | 178.4 | 190.3 |
| 60 | 0.017 | 10.3 | 15.5 | 19.7 | 29.6 | 43.2 | 78.5 | 114.5 | 167 | 186.6 | 199 |
| 80 | 0.012 | 11.1 | 16.7 | 21.2 | 32 | 46.6 | 84.5 | 123.1 | 179.2 | 200.2 | 213.5 |
| 100 | 0.01 | 11.8 | 17.7 | 22.5 | 33.9 | 49.4 | 89.4 | 130.1 | 189.2 | 211.4 | 225.5 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| Coefficients | | | | | | | | | | | |
| c1 | c2 | c3 | d1 | d2 | d3 | e | f | | | | |
| 0.0002 | -0.0068 | 0 | 0.5901 | 0.5719 | 0.1596 | 0.2642 | 2.3089 | | | | |
| | | | | | | | | | | | |
| Standard errors (mm) | | | | | | | | | | | |
| | | | | | Duration | | | | | | |
| ARI (y) | aep | 10m | 20m | 30m | 60m | 2h | 6h | 12h | 24h | 48h | 72h |
| | | | | | | | | | | | |
| 1.58 | 0.633 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.6 | 1.7 | 1.7 |
| 2 | 0.5 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.3 | 1.5 | 1.7 | 1.8 | 1.9 |
| 5 | 0.2 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.5 | 2 | 2.6 | 2.8 | 3 |
| 10 | 0.1 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.9 | 2.6 | 3.9 | 4.3 | 4.6 |
| 20 | 0.05 | 1.2 | 1.3 | 1.4 | 1.6 | 1.6 | 2.6 | 3.7 | 6.1 | 6.7 | 7.2 |
| 30 | 0.033 | 1.2 | 1.4 | 1.5 | 1.9 | 1.9 | 3.1 | 4.6 | 7.8 | 8.7 | 9.3 |
| 40 | 0.025 | 1.3 | 1.5 | 1.7 | 2.1 | 2.1 | 3.6 | 5.3 | 9.2 | 10.3 | 11 |
| 50 | 0.02 | 1.3 | 1.5 | 1.8 | 2.3 | 2.2 | 3.9 | 5.9 | 10.5 | 11.7 | 12.5 |
| 60 | 0.017 | 1.4 | 1.6 | 1.9 | 2.5 | 2.4 | 4.3 | 6.5 | 11.7 | 13 | 13.9 |
| 80 | 0.012 | 1.5 | 1.8 | 2.2 | 2.9 | 2.7 | 4.9 | 7.4 | 13.7 | 15.2 | 16.3 |
| 100 | 0.01 | 1.5 | 1.9 | 2.4 | 3.2 | 3 | 5.4 | 8.2 | 15.4 | 17.1 | 18.3 |

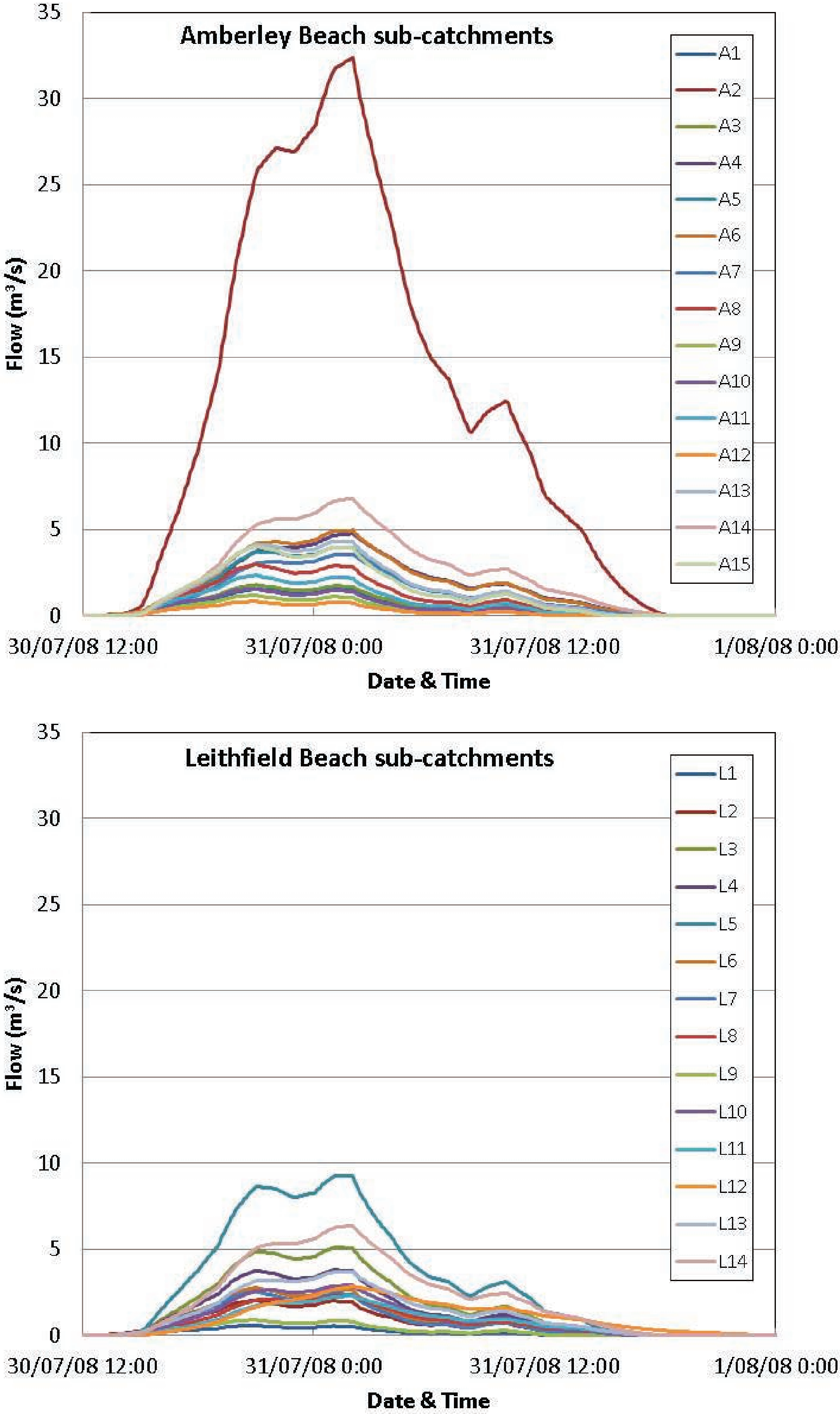



**Figure B-2: 200 year ARI event local inflows**

# Appendix C: Model cross section locations

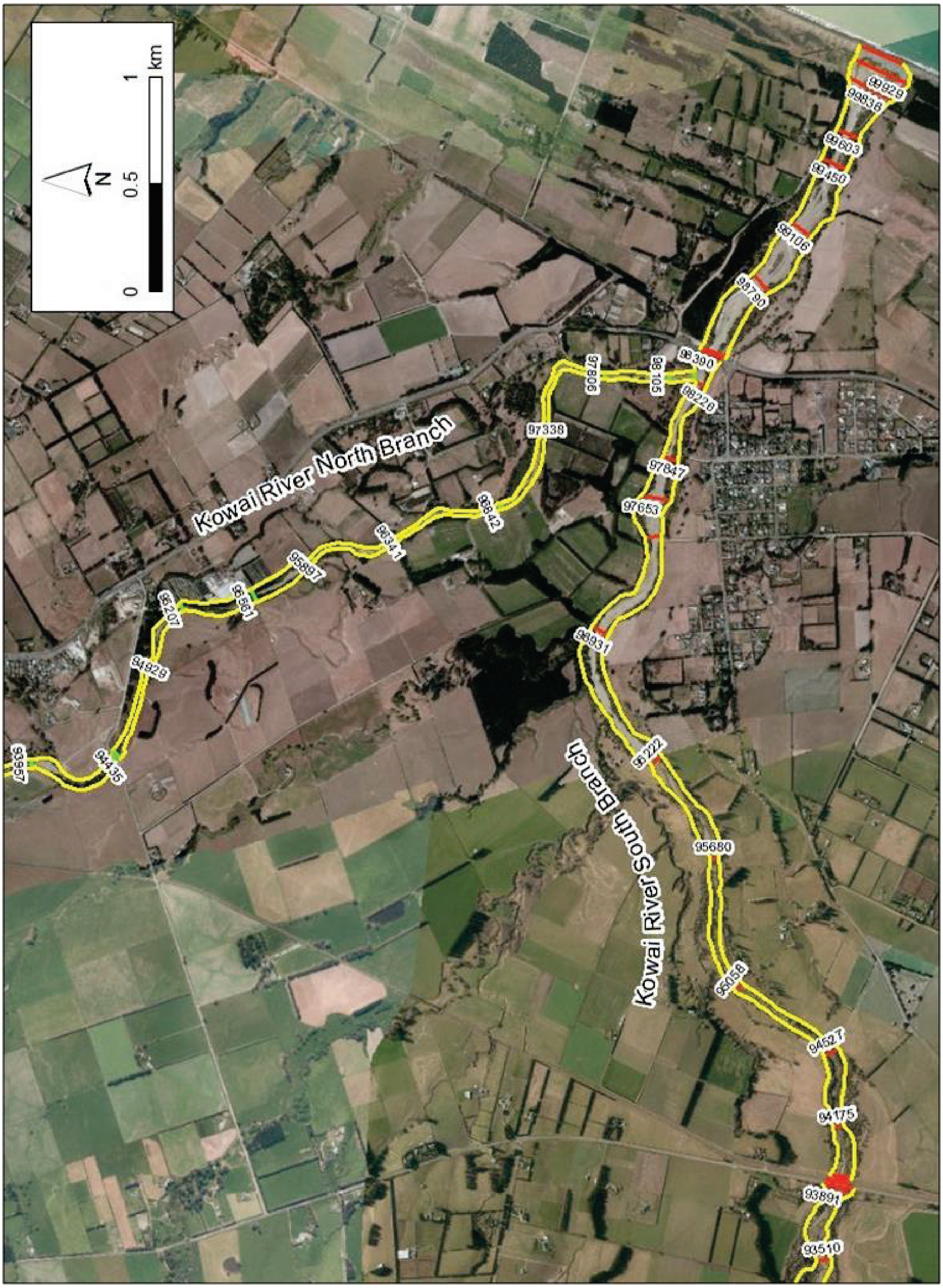



**Figure C-1:** **Location of Kowai River Mike Flood model cross sections**

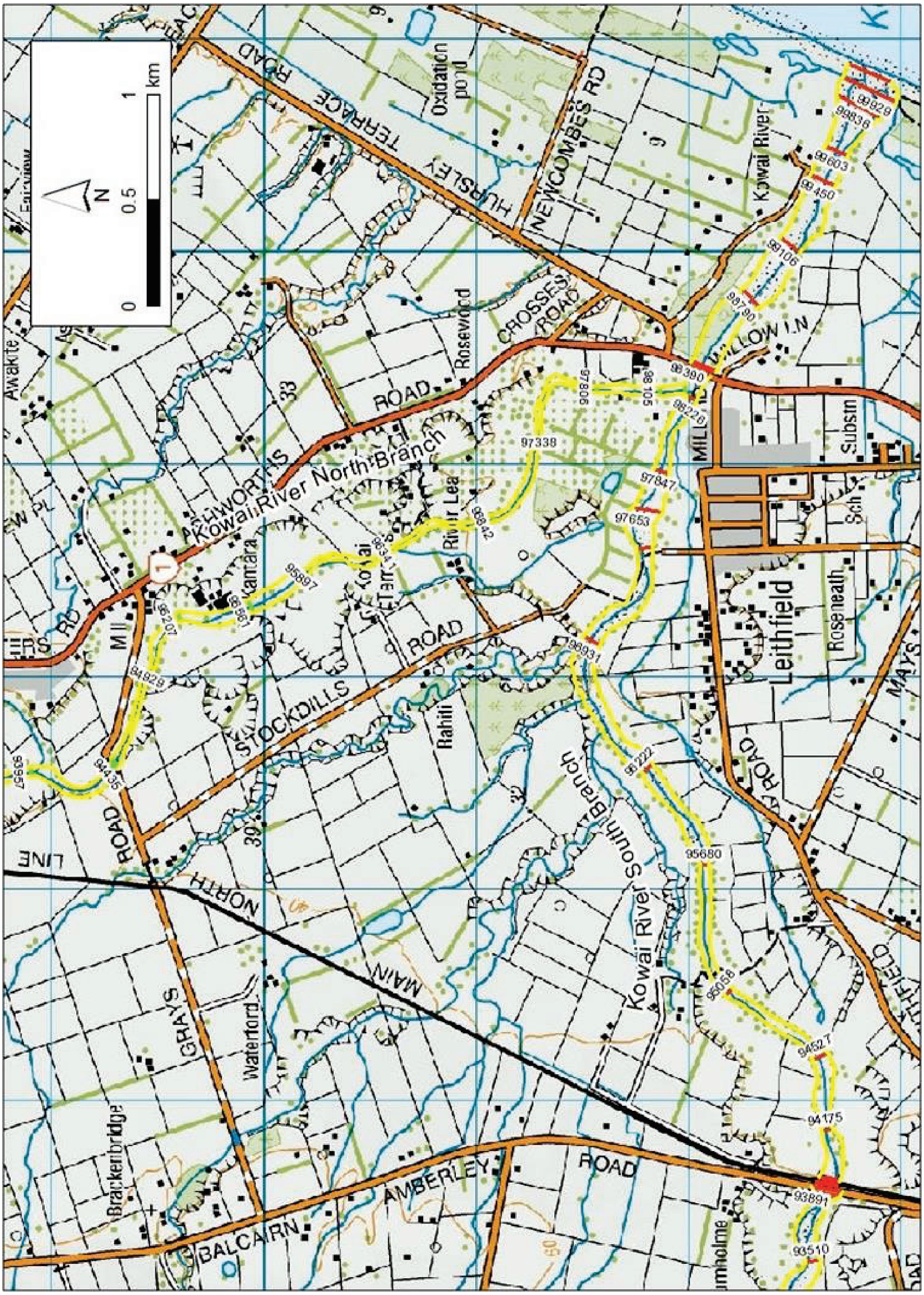



Figure C-2: Location of Kowai River Mike Flood model cross sections

**Table C-1: Summary of Mike 11 cross section information**

| Mike 11 chainage | Data source | Survey date | Location/Description |
|---|---|---|---|
| Kowai River North Branch | | | |
| 93957 | LiDAR | 2012 | Upstream model limit |
| 94410 | LiDAR | 2012 | |
| 94420 | LiDAR | 2012 | |
| 94428 | | | Grays Road bridge |
| 94435 | LiDAR | 2012 | |
| 94443 | LiDAR | 2012 | |
| 94929 | LiDAR | 2012 | |
| 95207 | LiDAR | 2012 | |
| 95561 | LiDAR | 2012 | |
| 95897 | LiDAR | 2012 | |
| 96341 | LiDAR | 2012 | |
| 96842 | LiDAR | 2012 | |
| 97338 | LiDAR | 2012 | |
| 97806 | LiDAR | 2012 | |
| 98105 | LiDAR | 2012 | |
| 98226 | LiDAR | 2012 | Confluence with Kowai South Branch |
| Kowai River South Branch | | | |
| 93510 | LiDAR | 2012 | Upstream model limit |
| 93870 | LiDAR | 2012 | |
| 93891 | LiDAR | 2012 | |
| 93898 | | | Road bridge |
| 93911 | LiDAR | 2012 | |
| 93916 | LiDAR | 2012 | |
| 93924 | | | Rail bridge |
| 93936 | LiDAR | 2012 | |
| 93945 | LiDAR | 2012 | |
| 94175 | LiDAR | 2012 | |
| 94527 | LiDAR | 2012 | |
| 95058 | LiDAR | 2012 | |
| 95680 | LiDAR | 2012 | |
| 96222 | LiDAR | 2012 | |
| 96931 | LiDAR | 2012 | |
| 97470 | LiDAR | 2012 | |
| 97653 | LiDAR | 2012 | |
| 97847 | LiDAR | 2012 | |
| 98226 | LiDAR | 2012 | Confluence with Kowai North Branch |
| 98235 | LiDAR | 2012 | |
| 98305 | LiDAR | 2012 | |
| 98360 | LiDAR | 2012 | |
| 98368 | LiDAR | 2012 | SH1 road bridge |
| 98380 | LiDAR | 2012 | |
| 98390 | LiDAR | 2012 | |
| 98790 | LiDAR | 2012 | |
| 99106 | LiDAR | 2012 | |
| 99450 | LiDAR | 2012 | |
| 99603 | LiDAR | 2012 | |
| 99836 | LiDAR | 2012 | |
| 99929 | LiDAR | 2012 | |
| 99980 | LiDAR | 2012 | |
| 99990 | LiDAR | 2012 | Kowai River mouth (100 m wide weir, crest level 0.50 m above msl |
| 100000 | LiDAR | 2012 | Pegasus Bay sea level boundary |

| Mike 11 chainage | Data source | Survey date | Location/Description |
|---|---|---|---|
| North Amberley Lagoon | | | |
| 100 | | | |
| 104 | | | |
| 105 | | | Outlet = two 3m by 3m culverts, invert level = 1.21 m above msl |
| 106 | | | |
| 110 | | | |
| 150 | | | Pegasus Bay sea level boundary |
| Mimimoto Lagoon | | | |
| 100 | | | |
| 104 | | | |
| 105 | | | Outlet = 10 m wide weir, crest level = 0.5 m above msl |
| 106 | | | |
| 110 | | | |
| 150 | | | Pegasus Bay sea level boundary |
| North Leithfield Lagoon | | | |
| 100 | | | |
| 104 | | | |
| 105 | | | Outlet = 10 m wide weir, crest level = 0.5 m above msl |
| 106 | | | |
| 110 | | | |
| 150 | | | Pegasus Bay sea level boundary |
| Leithfield Outfall Drain outlet | | | |
| 100 | | | |
| 104 | | | |
| 105 | | | Outlet = 6 m wide weir, crest level = 1.6 m above msl |
| 106 | | | |
| 110 | | | |
| 150 | | | Pegasus Bay sea level boundary |
| Leithfield Outfall Drain piped outlet | | | |
| 100 | | | |
| 104 | | | |
| 105 | | | Outlet = two 90 m long, 1.4 m diameter culverts, invert level = 1.15 m above msl. |
| 206 | | | |
| 210 | | | Pegasus Bay sea level boundary |

# Appendix D: Kowai River, Amberley Beach and Leithfield Beach maps

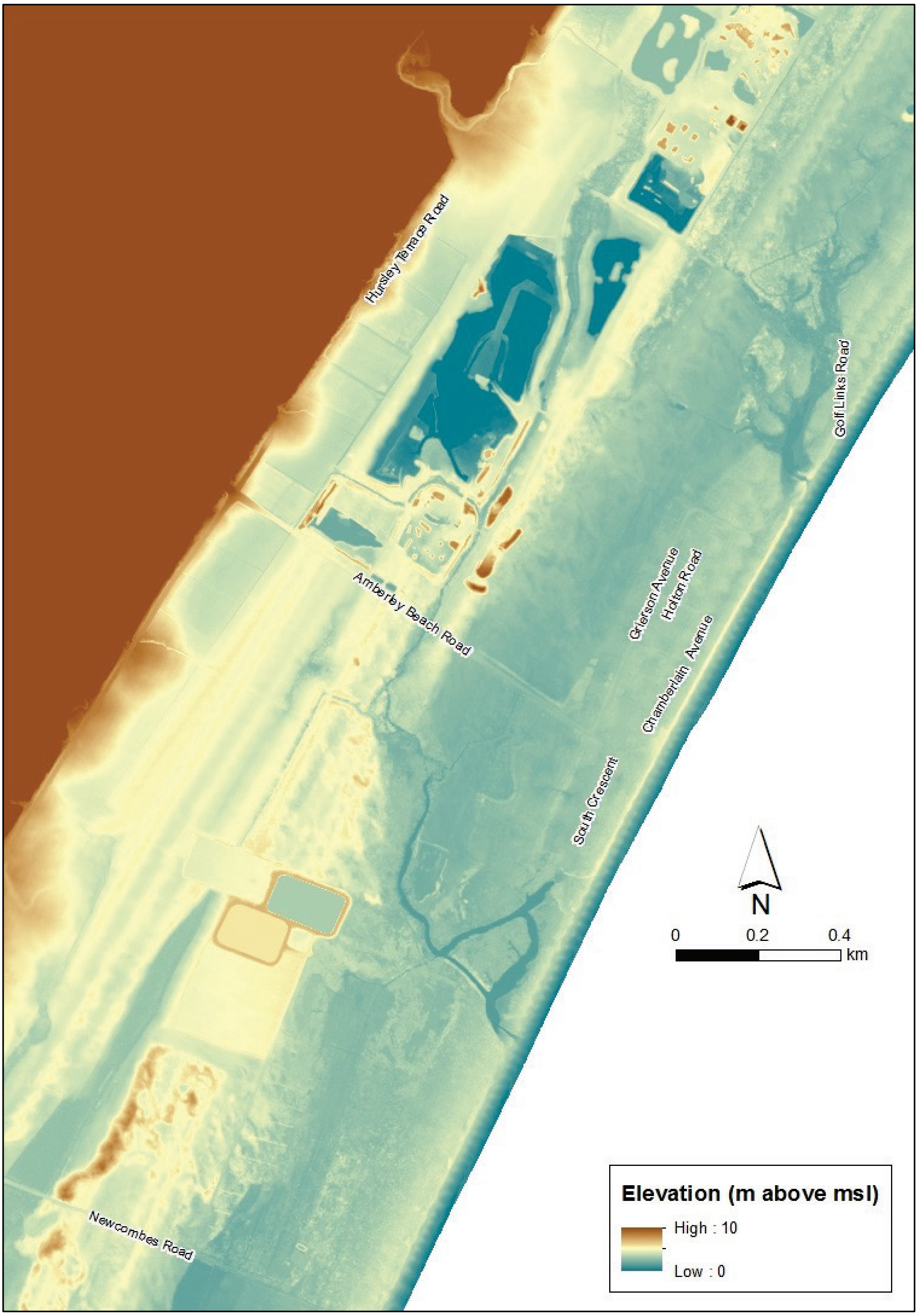



**Figure D-1: Amberley Beach area LiDAR map**

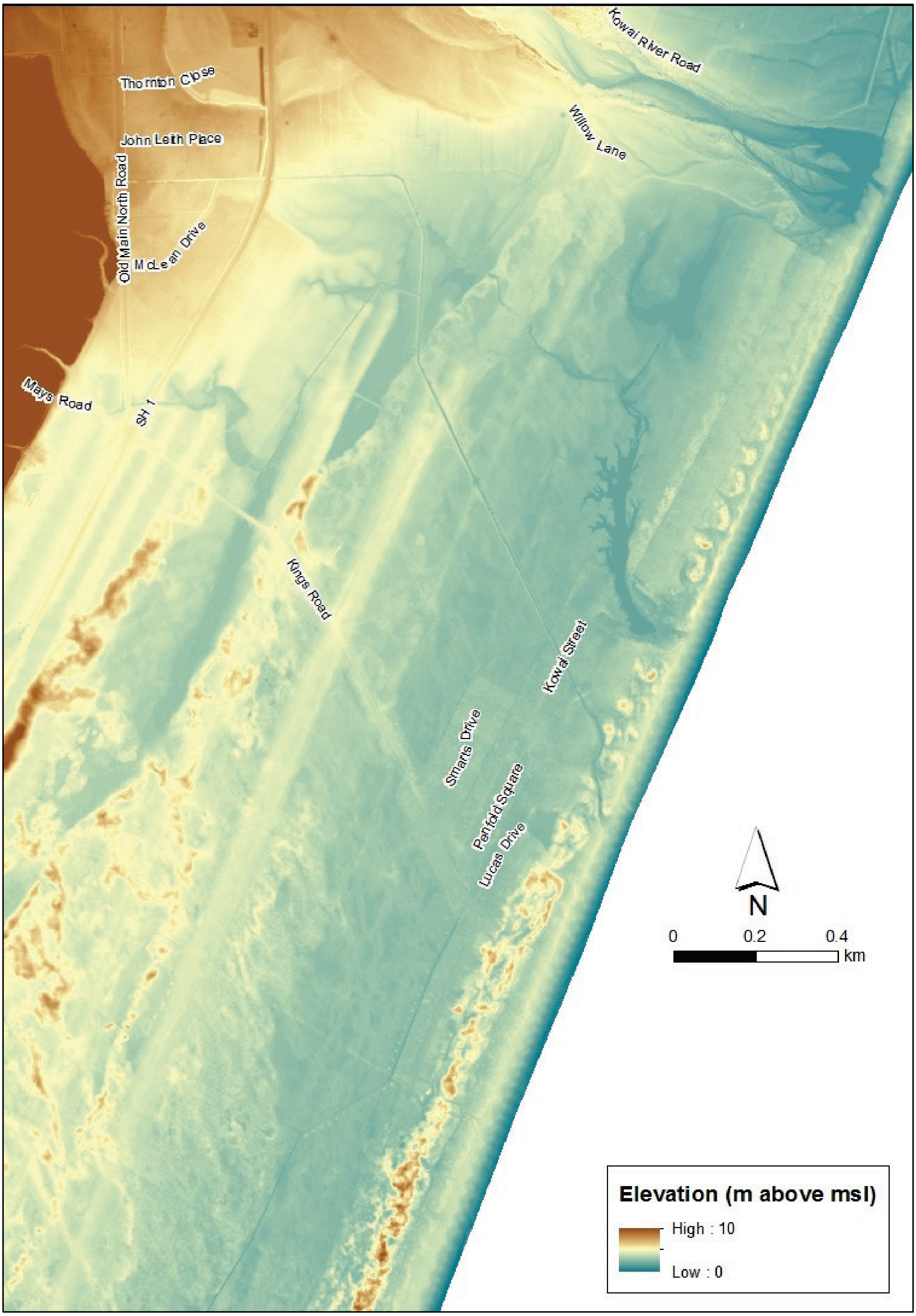



**Figure D-2: Leithfield Beach area LiDAR map**

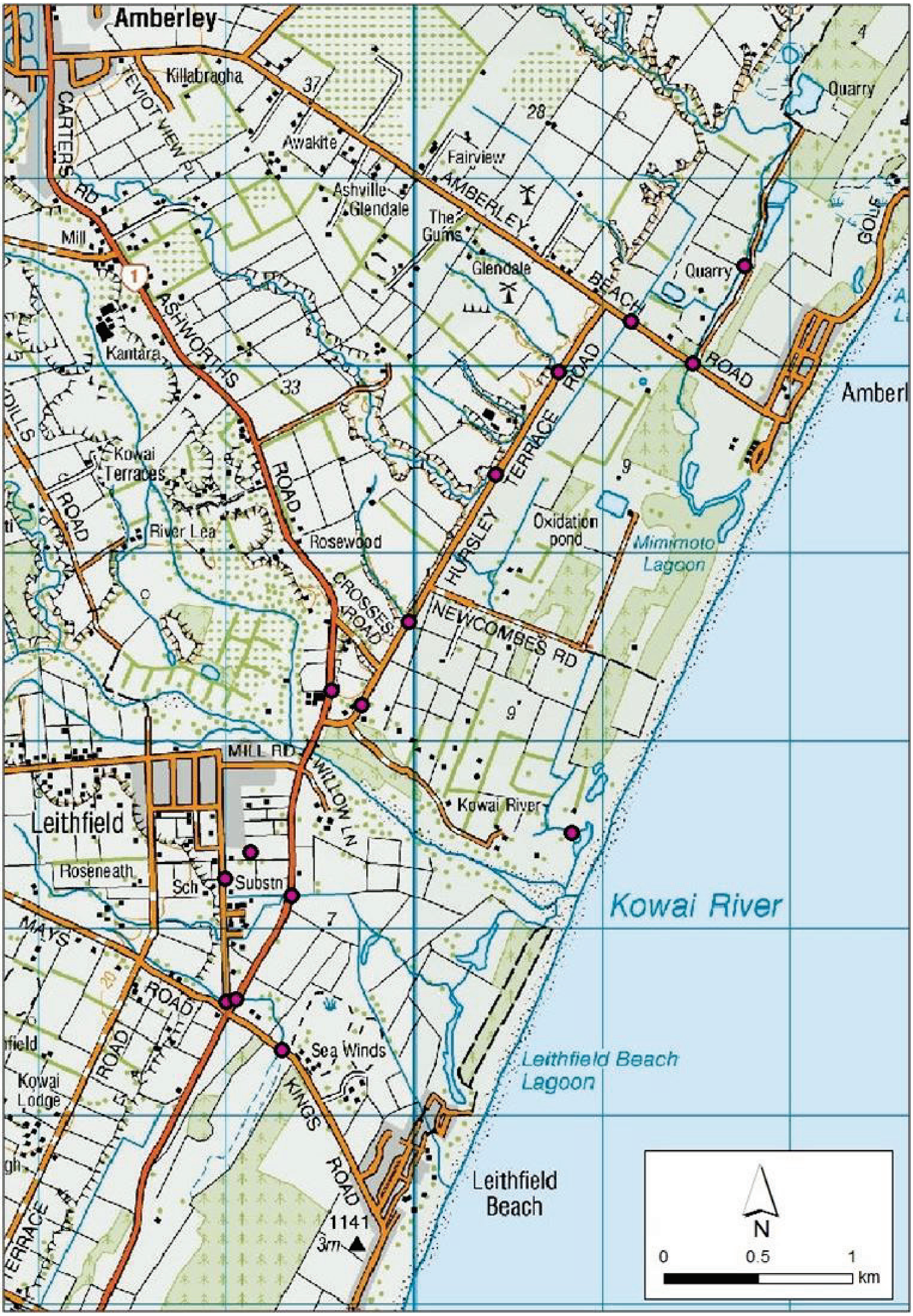



**Figure D-3:** **Amberley Beach, Leithfield and Leithfield Beach culvert location map (culverts are shown as crimson dots)**

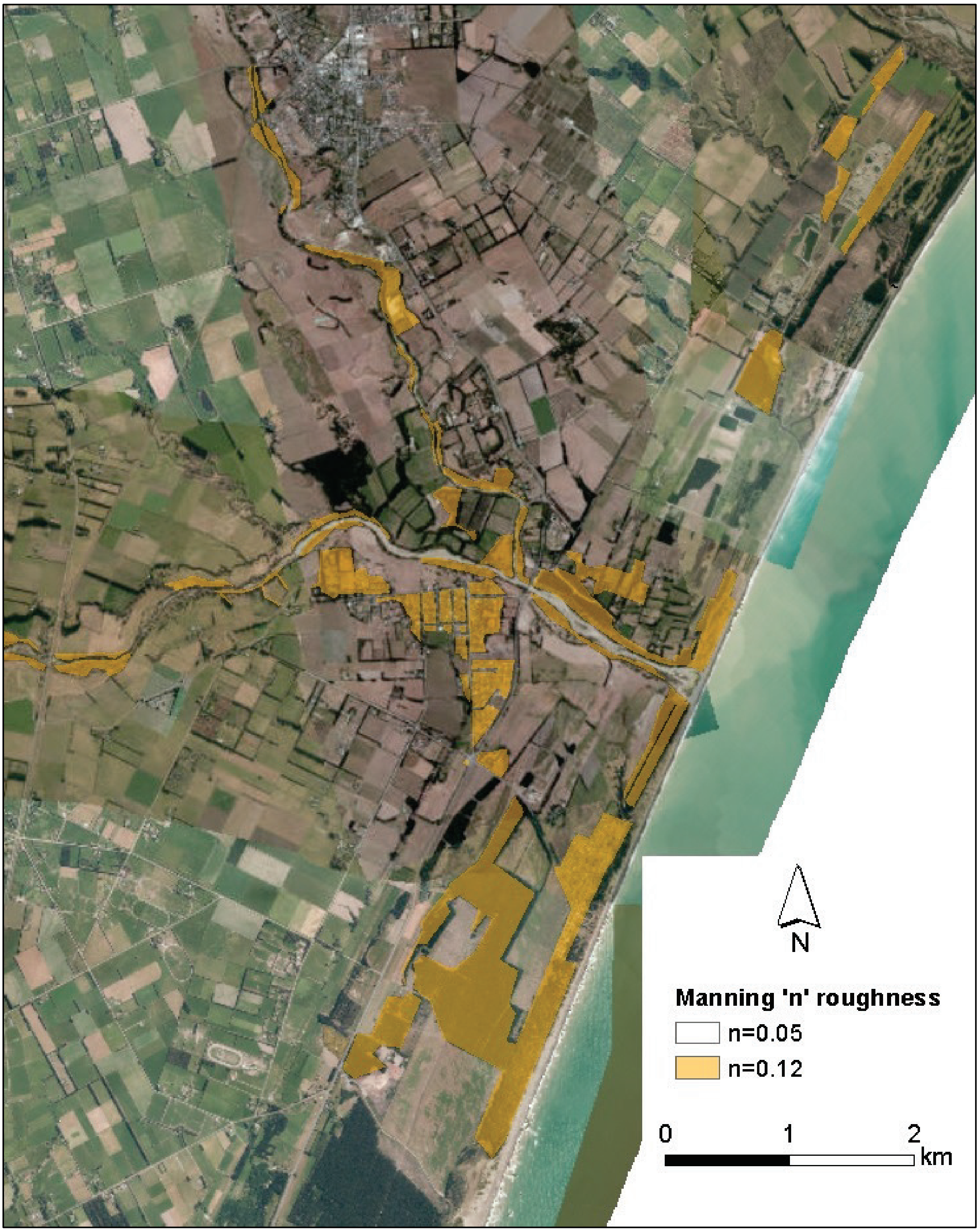



**Figure D-4:** **Kowai River, Amberley Beach and Leithfield Beach floodplain roughness map showing Manning 'n'**

# Appendix E: Newspaper article

Hurunui News October 4 2006

Natural Hazards
- Civil Defence
- Coastal
- Consents

## Leithfield Beach

## Digger a day late

Mr Dalziel said most attention was focused on Amberley Beach on Thursday, though council officers visited Leithfield Beach - as did police and Civil Defence personnel.

However, there was concern about two sewer pumps at Leithfield Beach, he said.

Engineering services manager Bruce Yates had recorded calls about the sewer pumps in his diary. Other calls enquired about Civil Defence.

"I was not aware of requests to open north lagoon but seas were extremely high and any artificial opening risks sea water inundation," he wrote. His diary also noted that incoming reports confirmed the outfall drain was flowing well.

Mr Yates was in Christchurch at the Environment Court all day on Friday but during calls to and from staff, no mention was made of Leithfield Beach.

But by Saturday morning the decision was made to open the lagoon, as water levels had dropped sufficiently for work to begin. A required large-scale digger was summoned from Oxford, but because it would take at least two hours to arrive, a start was made with a smaller machine.

The large digger arrived at 1pm and the outlet was finished within half an hour. The large digger was then moved to the outfall drain to repair scour damage, threatening ingress of sea water at high tide.

A council staff member advised Environment Canterbury of the actions that had been taken. The council had no resource consent to open the lagoon, but had decided to do it regardless.

Mr Dalziel said that in hindsight, officers would have tried to get a digger in on Friday to open the north lagoon to the sea, rather than wait until Saturday.

"The judgement call at the time was that the seas were too high and that it might create more problems than it would solve by allowing sea water to enter the lagoon."

He added that difficulties were exacerbated by lack of availability of a suitably sized digger because of road closures throughout the district.

Mr Dalziel also commented on work which had been undertaken earlier in the year, in formulating an application to Environment Canterbury for permanent, twin concrete pipes with flap-gates to be installed at the outfall drain.

The application had been on hold after the Department of Conservation indicated it would oppose it, and the council sought to avoid a costly hearing.

However, the Amberley ward committee confirmed instructions to proceed with the application as it stood. The estimated construction cost is $250,000, and the project is unrelated to the lagoon or its catchment area.

# Appendix F: Flood probability

**Table F-1: Summary of flood probability**

| Event | Probability of occurring in period | | |
|---|---|---|---|
| **% AEP[1] (return period)** | **10 yr period** | **30 yr period** | **70 yr period** |
| 5% (20 yr ARI) | 40% | 80% | 97% |
| 2% (50 yr ARI) | 20% | 50% | 77% |
| 1% (100 yr ARI) | 10% | 25% | 50% |
| 0.5%(200 yr ARI) | 5% | 15% | 33% |
| 0.2% (500 yr ARI) | 2% | 6% | 12% |

[1]AEP = Annual Exceedance Probability i.e. the chance of a flood that size occurring in any one year

For example there is 25% chance that a 1% AEP (100 year return period) flood will occur within a 30 year period

# Appendix G: Model run files

## July 2008 calibration files

| | **July 2008** |
|---|---|
| | 31 July flood event |
| **MikeFlood** | ***…\Model\Kowai\MikeFlood\2014model*.**** |
| Couple file (*.mf) | Kowai_20140915_July08_outlets_in_ALL_closed |
| **Mike11** | ***…\Model\Kowai\1D\2014model*.**** |
| Simulation file (*.sim11) | Kowai_20140915_July08_outlets_ALL_closed |
| Network file (*.nwk11) | Kowai_20140818_w_outlets_in_ALL_closed_pipe_closed_NWK |
| Cross section file (*.xns11) | Kowai_20140815_weir_outlets_XS |
| Boundary file (*.bnd11) | July_2008_w_outlets_FINAL |
| HD parameter (*.hd11) | Kowai_20140818_July08_Tide_0.485_lag_high |
| Results file (*.res11) | Kow_201409015_outlets_all_closed_pipe_closed |
| **Mike21** | ***…\Model\Kowai\2D\2014model*.**** |
| Simulation file (*.21) | Kowai_20140915_July08_outlets_in_ALL_closed |
| Bathymetry file (*.dfs2) | Kowai_20140818_5m_Kow_stopbank_c_1_95_with_outlets |
| Initial surface elevation (*.dfs2) | Kowai_20140806_5m_Kow_stopbank_2_6_with_outlets_IC_WL_lag_high |
| Resistance (*.dfs2) | Kowai_rough_20140828_crop_NEW |
| Results (*.dfs2) | Kowai_20140915_July08_outlets_in_ALL_closed |
| Sources | 29 (sub-catchments + Stockdills Rd inflow) |
| Sinks | - |
| Drying depth (m) | 0.01 |
| Wetting depth (m) | 0.04 |
| Eddy viscosity | 2.5 |
| Number of structures | 16 |
| Simulation start time | 30/07/2008 12:00pm |
| Simulation end time | 2/08/2008 12:00am |
| Time step (s) | 2 |
| Length of run (# time steps) | 108000 |

## Design flood files

| | 50 year ARI | 200 year ARI |
|---|---|---|
| | 50 year average recurrence interval event (50 year Kowai River flows and local sub-catchment flows, 0.4m storm surge) | 200 year average recurrence interval event (200 year Kowai River flows and local sub-catchment flows, 0.4m storm surge) |

| MikeFlood | …\Model\Kowai\MikeFlood\2014model*.* | |
|---|---|---|
| Couple file (*.mf) | Kowai_20140908_50yr_outlets_closed | Kowai_20140901_200yr_outlets_closed |

| Mike11 | …\Model\Kowai\1D\2014model*.* | |
|---|---|---|
| Simulation file (*.sim11) | Kowai_20140908_50yr_openings_closed | Kowai_20140901_200yr_outlets_closed |
| Network file (*.nwk11) | Kowai_20140810_w_outlets_in_but_closed_Kow_weir_pipe_closed_NWK | |
| Cross section file (*.xns11) | Kowai_20140729_mod_nth_93957_XS. | |
| Boundary file (*.bnd11) | Q_50yr_w_outlets_tide_plus_0_4m | Q_200yr_w_outlets_tide_plus_0_4m |
| HD parameter (*.hd11) | Kowai_20140809_July08_n_040_from_grays_rd_w_outlets_lag_high | |
| Results file (*.res11) | Kow_20140908_outlets_closed | Kow_20140901_200yr_outlets_closed |

| Mike21 | …\Model\Kowai\2D\2014model*.* | |
|---|---|---|
| Simulation file (*.21) | Kowai_20140908_50yr_outlets_closed | Kowai_20140901_200yr_outlets_closed |
| Bathymetry file (*.dfs2) | Kowai_20140729_5m_Kow_stopbank_2_6_with_outlets | |
| Initial surface elevation (*.dfs2) | Kowai_20140806_5m_Kow_stopbank_2_6_with_outlets_IC_WL_lag_high | |
| Resistance (*.dfs2) | Kowai_rough_20140828_crop_NEW | |
| Results (*.dfs2) | Kowai_20140908_50yr_outlets_closed | Kowai_20140901_200yr_outlets_closed |
| Sources | 29 (sub-catchments + Stockdills Rd inflow) | |
| Sinks | - | |
| Drying depth (m) | 0.01 | |
| Wetting depth (m) | 0.04 | |
| Eddy viscosity | 2.5 | |
| Number of structures | 16 | |
| Simulation start time | 30/07/2008 12:00pm | |
| Simulation end time | 1/08/2008 12:00am | |
| Time step (s) | 2 | |
| Length of run (# time steps) | 64800 | |

## Sensitivity run files (using 200 year ARI) – Runs 1 to 3

| | Outlets open | Increased sub-catchment flow | Increased Kowai River flow |
|---|---|---|---|
| | All outlets opened (& remain open) prior to flood event | Local sub-catchment inflows increased by 25% | Kowai River flows increased by 25% |
| **MikeFlood** | ***…\Model\Kowai\MikeFlood\2014model*.**** | | |
| Couple file (*.mf) | Kowai_20140909_200yr_outlets_open | Kowai_20140830_200yr_outlets_closed_Qlocal_incr_25perc | Kowai_20140831_200yr_outlets_closed_Qkow_incr_25perc |
| **Mike11** | ***…\Model\Kowai\1D\2014model*.**** | | |
| Simulation file (*.sim11) | Kowai_20140909_200yr_outlets_open | Kowai_20140830_200yr_openings_closed_qlocal_incr_25perc | Kowai_20140831_200yr_openings_closed_Qkow_incr_25perc |
| Network file (*.nwk11) | Kowai_20140822_w_outlets_in_ALL_open_weirs_pipe_open_v2_NWK | Kowai_20140810_w_outlets_in_but_closed_Kow_weir_pipe_closed_NWK | Kowai_20140810_w_outlets_in_but_closed_Kow_weir_pipe_closed_NWK |
| Cross section file (*.xns11) | Kowai_20140822_weir_outlets_XS | Kowai_20140729_mod_nth_93957_XS | Kowai_20140729_mod_nth_93957_XS |
| Boundary file (*.bnd11) | Q_200yr_w_outlets_tide_plus_0_4m | Q_200yr_w_outlets_tide_plus_0_4m | Q_200yr_incr_25perc_w_outlets_tide_plus_0_4m |
| HD parameter (*.hd11) | Kowai_20140809_July08_n_040_from_grays_rd_w_outlets_lag_high | | |
| Results file (*.res11) | Kow_20140909_outlets_open | Kow_20140830_outlets_closed_qlocal_incr_25perc | Kow_20140831_outlets_closed_Qkow_incr_25perc |
| **Mike21** | ***…\Model\Kowai\2D\2014model*.**** | | |
| Simulation file (*.21) | Kowai_20140909_200yr_outlets_open | Kowai_20140830_200yr_outlets_closed_qlocal_incr_25_perc | Kowai_20140831_200yr_outlets_closed_Qkow_incr_25perc |
| Bathymetry file (*.dfs2) | Kowai_20140729_5m_Kow_stopbank_2_6_with_outlets | | |
| Initial surface elevation (*.dfs2) | Kowai_20140806_5m_Kow_stopbank_2_6_with_outlets_IC_WL_lag_high | | |
| Resistance (*.dfs2) | Kowai_rough_20140828_crop_NEW | | |
| Results (*.dfs2) | Kowai_20140909_200yr_outlets_ope | Kowai_20140830_200yr_outlets_closed_qlocal_incr_25perc | Kowai_20140831_200yr_outlets_closed_Qkow_incr_25perc |

| Mike21 *(cont'd)* | …\Model\Kowai\2D\2014model*.* |
|---|---|
| Sources | 29 (sub-catchments + Stockdills Rd inflow) |
| Sinks | - |
| Drying depth (m) | 0.01 |
| Wetting depth (m) | 0.04 |
| Eddy viscosity | 2.5 |
| Number of structures | 16 |
| Simulation start time | 30/07/2008 12:00pm |
| Simulation end time | 1/08/2008 12:00am |
| Time step (s) | 2 |
| Length of run (# time steps) | 64800 |

## Sensitivity run files (using 200 year ARI) – Runs 4 to 5

| | 0.5m sea level rise – outlets all closed | 0.5m sea level rise – outlets all open |
|---|---|---|
| | Pegasus Bay sea level raised by 0.5m – Kowai River outlet to sea adjusted | Pegasus Bay sea level raised by 0.5m – Kowai River, Leithfield & Mimimoto Lagoon outlets adjusted. |

| **MikeFlood** | ***…\Model\Kowai\MikeFlood\2014model*.*** | |
|---|---|---|
| Couple file (*.mf) | Kowai_20140910_200yr_outlets_closed_SLR | Kowai_20140828_200yr_outlets_in_ALL_open_weirs_v3_1m_inv_SLR_0_5m |

| **Mike11** | ***…\Model\Kowai\1D\2014model*.*** | |
|---|---|---|
| Simulation file (*.sim11) | Kowai_20140910_200yr_outlets_closed_SLR | Kowai_20140828_200yr_outlets_ALL_open_weirs_v3_1m_inv_SLR_0_5m |
| Network file (*.nwk11) | Kowai_20140910_outlets_closed_SLR_NWK. | Kowai_20140828_w_outlets_in_ALL_open_weirs_pipe_open_v3_1m_inv_NWK |
| Cross section file (*.xns11) | Kowai_20140729_mod_nth_93957_XS | Kowai_20140822_weir_outlets_XS |
| Boundary file (*.bnd11) | Q_200yr_w_outlets_tide_plus_0_4m_plus_0_5m_SLR | Q_200yr_w_outlets_tide_plus_0_4m_plus_0_5m_SLR |
| HD parameter (*.hd11) | Kowai_20140809_July08_n_040_from_grays_rd_w_outlets_lag_high | Kowai_20140827_July08_n_040_from_grays_rd_w_outlets_lag_high_SLR_0_5m |
| Results file (*.res11) | Kow_20140910_200yr_outlets_closed_SLR | Kow_20140828_outlets_all_OPEN_weirs_pipe_open_v3_1m_inv_SLR_0_5m |

| **Mike21** | ***…\Model\Kowai\2D\2014model*.*** | |
|---|---|---|
| Simulation file (*.21) | Kowai_20140910_200yr_outlets_closed_SLR | Kowai_20140828_200yr_outlets_in_ALL_open_weirs_v3_1m_inv_SLR_0_5m |
| Bathymetry file (*.dfs2) | Kowai_20140729_5m_Kow_stopbank_2_6_with_outlets | |
| Initial surface elevation (*.dfs2) | Kowai_20140806_5m_Kow_stopbank_2_6_with_outlets_IC_WL_lag_high | |
| Resistance (*.dfs2) | Kowai_rough_20140828_crop_NEW | |
| Results (*.dfs2) | Kowai_20140910_200yr_outlets_closed_SLR | Kowai_20140828_200yr_outlets_in_ALL_open_weirs_v3_1m_inv_SLR_0_5m |
| Sources | 29 (sub-catchments + Stockdills Rd inflow) | |
| Sinks | - | |
| Drying depth (m) | 0.01 | |

| Mike21 *(cont'd)* | …\Model\Kowai\2D\2014model*.* |
|---|---|
| Wetting depth (m) | 0.04 |
| Eddy viscosity | 2.5 |
| Number of structures | 16 |
| Simulation start time | 30/07/2008 12:00pm |
| Simulation end time | 1/08/2008 12:00am |
| Time step (s) | 2 |
| Length of run (# time steps) | 64800 |

**Environment Canterbury Regional Council**
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www.ecan.govt.nz

**Environment Canterbury offices**

**Christchurch**
58 Kilmore Street
PO Box 345
Christchurch 8013
P: 03 365 3828
F: 03 365 3194

**Timaru**
75 Church Street
PO Box 550
Timaru 7940
P: 03 687 7800
F: 03 687 7808