FLOOR LEVELS ABOVE THE 2% FLOOD EVENT – ARE THEY HIGH ENOUGH?

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ABSTRACT

The 2% Annual Exceedance Probability (AEP) flood level is our national benchmark, defined by Clause E1.3.2 of the Building Act. This level of service is used widely across the country with few territorial authorities requiring a more conservative approach. When applied to the letter, this level of service can have some unintended consequences and risks the creation of future flood disasters.

A 2% AEP flood event can be close to impossible to define, particularly when multiple flooding sources need to be accounted for, which can include rainfall, tidal, tsunami, rivers, stopbank/dam failures and infrastructure blockages. The uncertainty associated with the derivation of design events from short term records and 'best guess' allowances for climate change should also be accounted for. We look at the approaches and solutions that have been applied in the Canterbury environment and how these have fared in recent significant flood events. We also present recent case studies from residential developments and proposed plan changes where a higher level of service than required by the building act was provided and how this will help to reduce the probability of future flood disasters.

KEYWORDS

Flood Event, Exceedence Probability, Level of Service

PRESENTER PROFILE

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1 INTRODUCTION – THE FLOODING MENACE

Clause E1.3.2 of the Building Act states that "Surface water resulting from an event having a 2% probability of occurring annually shall not enter buildings". An event with a 2% probability of occurring annually is further defined as the 1 in 50-year flood. Thus to comply with this clause buildings must have finished floor levels (FFLs) greater than the water level resultant from a 2% probability event. There is a degree of interpretation in regards to defining the water level of a 2% event and in many cases this level is that which can be best practically derived.

A 2% AEP (Annual Exceedance Probability) event is difficult to define well and there are various approaches to its definition. One needs to determine what conditions does the event include or need to account for. It is also interesting to note that the 2% AEP event will change from year to year (or even day to day) as frequency analyses are updated and changed.

Given the difficulty in understanding and representing a 2% AEP event, perhaps a better approach is to also consider what the effects of a larger than design event are and ensure that these effects are acceptable. How would such an approach compare to the approach of the Building Act?

2 WHAT IS A 2% AEP EVENT?

There are a number of approaches to representing a 2% AEP event. A typical approach is to determine the time of concentration for a catchment, obtain the design rainfall depth from NIWA's High Intensity Rainfall System (HIRDS), apply a suitable rainfall profile and then route through a hydraulic model to obtain peak water levels. This approach has some drawbacks, the rainfall profile that is selected can hugely alter the results, for example, a hyetograph with a large peak at the end of the event will likely result in higher flood levels than a constant rainfall depth hyetograph or a hyetograph with a sharp peak at the start of the event. Antecedent conditions need to be estimated and accounted for and these vary from event to event.

The definition of the 2% AEP event can quickly become complicated if other factors are included such as tidal influences, tsunamis, river breakouts, groundwater levels, landslides creating temporary dams which are then breached and river infrastructure failures to name but a few. A true 2% AEP event definition that accounts for all factors which may affect the surface water level is probably impossible to define and therefore approximation is required. It is interesting to note that by definition, a 2% AEP rainfall depth that coincides with a high tide must, as an event have an exceedance probability of less than 2% due to the intersection of two events ($P(A \cap B) < P(A)$).

2.1 A NEW HOPE?

In an effort to better define a 2% AEP event, or at least, the water level resulting from the 2% AEP event, the following process, based on a Monte Carlo approach was applied. This approach was performed for a catchment in that was previously modelled using 1D/2D hydraulic modelling software. The model covered an area of approximately 500 ha and had a grid size of 100 m² with a 1D channel embedded. The model schematization is presented in Figure 1. Based on the assumption that a 2% AEP water level is the water level that results from a 2% AEP rainfall event, the following process was followed:

1. Define 10,000 AEP rainfall events using a pseudo random number generator to generate numbers between 0 and 1 (exclusive). For example, 0.20 was assumed

to represent a 20% AEP event, 0.01 was assumed to represent a 1% AEP event etc.;

2. For each event, using a pseudo random number generator, obtain an integer between 2 and 24 which will be used to represent the duration of the event in hours. Note this step assumes that the AEP of the event and the duration are statistically independent which has not been verified;

3. Use HIRDS V3.00 to obtain a rainfall depth for each event based on the AEP and duration of the event;

4. The rainfall depth and duration were fitted to a pseudo randomly selected hyetograph profile. The largest annual rainfall event (of each duration, from 2 to 24 hours) was extracted from each of the 20 years of rainfall data available at a nearby gauge. These events were all normalised by the event depth to create a database of normalised hyetographs. For each duration, there were 20 normalised hyetographs available for pseudo random selection;

5. An upper and lower bound for antecedent conditions (initial losses and constant and continuing losses) were obtained through the validation of the existing model to a significant historical event with very dry antecedent conditions and to a significant historical event with very wet antecedent conditions. For each rainfall event, an antecedent condition between the validated upper and lower bound was pseudo randomly selected. Note, this assumes that there is no relationship between the rainfall event and antecedent conditions;

6. Each rainfall hyetograph and corresponding antecedent condition was inputted to a pre made HEC-HMS model. This model was run to obtain hydrograph outputs that could be inputted to the 2D (TUFLOW) model; and,

7. The hydrographs were routed through the 2D model and maximum flood elevations extracted. A frequency analysis was conducted using all flood elevations to determine the 2% AEP water level.

This method has a number of disadvantages:

1. It took roughly one week to complete the model runs running four models simultaneously, therefore more time input (and cost) is required compared to a conventional model;

2. An assumption has been made that rainfall events and antecedent conditions are statistically independent. It is likely that large rainfall events occur in winters which are preceded by wet antecedent conditions. This statistical relationship should be investigated to improve the approach;

3. A further assumption has been made that the rainfall event is not nested within a larger rainfall event. For example, a 2hr 2% AEP rainfall event may be nested inside a 6hr 20% AEP event. However, this assumption is also held for more traditional approaches (modelling of critical duration events); and,

4. Given that not all the factors which could influence a 2% AEP water level are accounted for, there is still no guarantee that the water level represented is the water level resulting from a 2% AEP event.

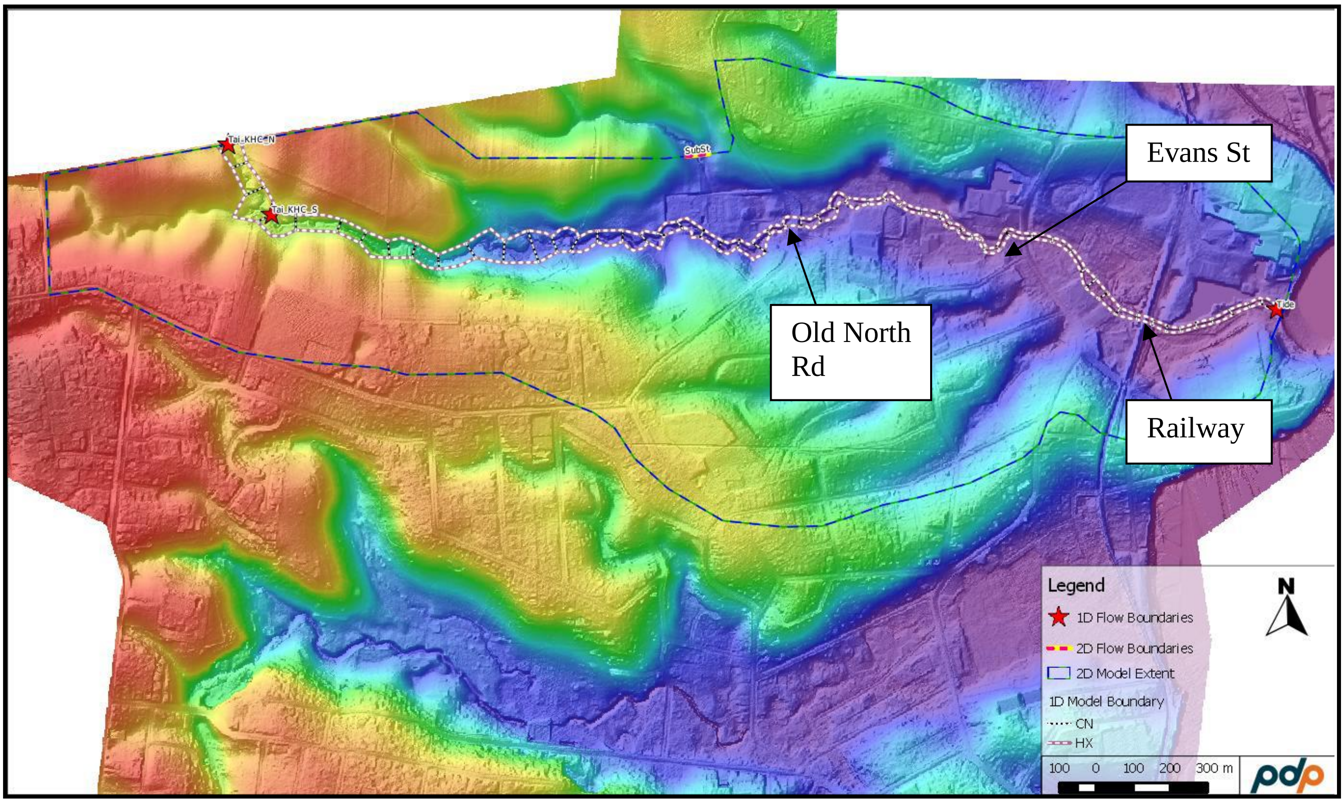

Figure 1 – 2D hydraulic model set up

2.2 COMPARISON TO CURRENTLY USED METHODS

A frequency analysis was conducted across all water level results to estimate the 2% AEP water level. This analysis considered the water level of each cell independently and therefore no one event will make up the 2% AEP water level. The resultant 2% AEP water level was compared with two typical methods of estimating the 2% AEP event:

1. Construct a hyetograph (to route through HEC-HMS) using Christchurch City Council guidelines, critical duration and a peak of double the average intensity occurring 0.7 of the way through the event; and,

2. Use a nested storm profile.

The hyetographs used for the two events are presented in Figure 2 below.

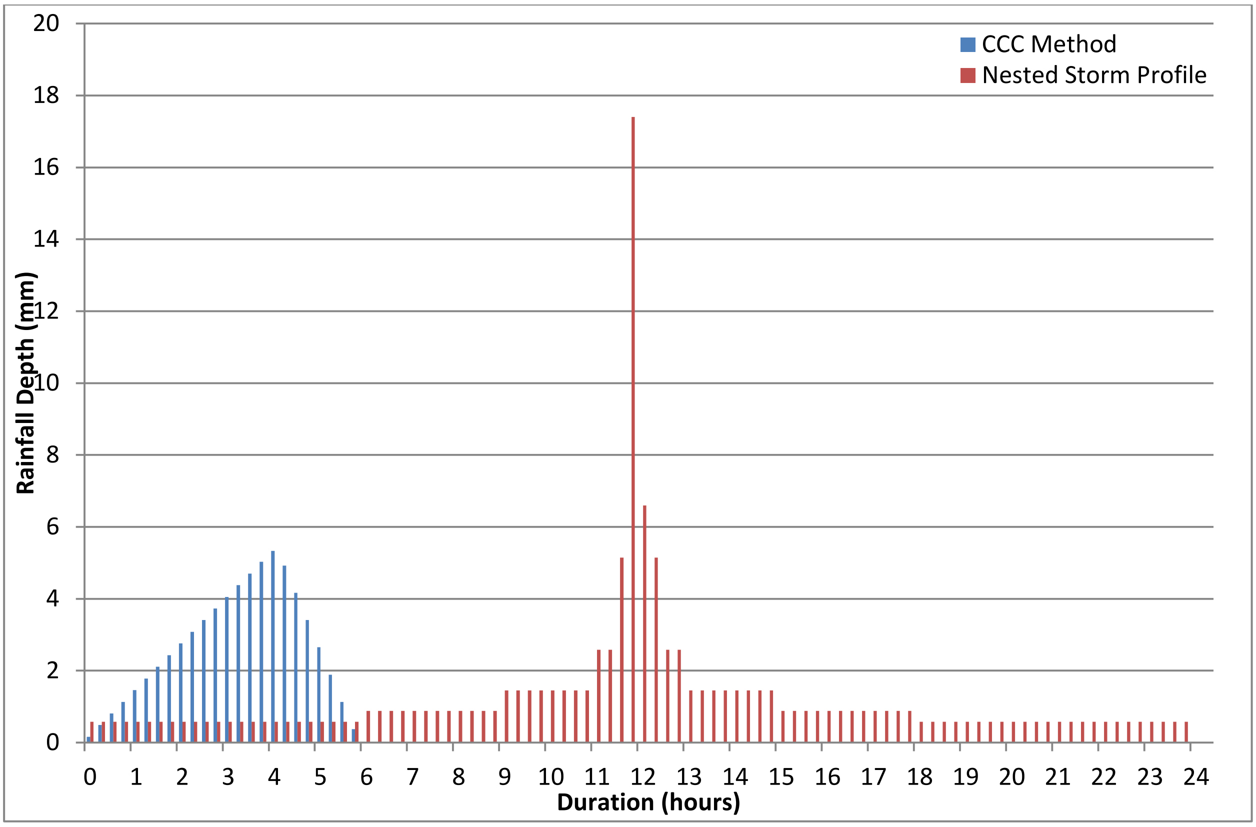

Figure 2 – Design rainfall hyetographs

A comparison of the flood levels at three points in the model is shown in Table 1. This shows that the nested storm profile generates the most conservative water level estimate with levels between 250 mm and 500 mm higher than the 2% AEP water level estimated from 10,000 events. The CCC triangular storm event resulted in water levels that were between 0 mm and 320 mm higher. This leads to the question, are the current approaches too conservative? Is there much benefit to more accurately defining the 2% AEP event?

Whilst outside the scope of this study, it would be interesting to investigate the disparity between other methods of generating a 2% AEP event. It would also be interesting to investigate other events and observe any disparity.

Table 1 –Comparison of water levels achieved by various design flood events

Location (Figure 1)	2% AEP Water Level (based on 10,000 events)	2% AEP CCC Triangular Storm	2% AEP Nested Storm Profile
Old North Rd	7.75	7.75	8.00
Evans St	4.37	4.54	4.70
Railway	4.20	4.52	4.70

2.3 CONSERVATISM STIRKES BACK, CAN WE BE TOO CONSERVATIVE?

Conservatism in flood modelling is necessary to provide a factor of safety when design decisions are based upon the modelled levels. There will be events such as blockages in waterways which will result in higher than expected flood levels and conservatism provides some buffer capacity for those situations. Too much conservatism however will result in floor levels that are too high and can cause building projects to become cost prohibitive.

A typical is to be conservative when estimating an unknown quantity. Possible sources of conservatism in a model include:

- Climate change;
- Tidal level ARI relative to rainfall ARI;
- Weed growth/Channel obstructions/Manning's n;
- Channel shape assumptions or simplifications;
- Antecedent weather conditions;
- Performance of the reticulation;
- Estimations of projected future development; and,
- Fixed value Factor of Safety e.g. Christchurch - 400 mm freeboard.

Whilst it is always preferable to err on the side of caution, the level of conservatism needs to be balanced. The easiest way to check assumptions is through the validation/calibration of the model. However, even perfect calibration will not ensure an accurate 2% AEP event if assumptions about the hydrology (design hyetograph etc.) are incorrect.

2.4 CONCLUSIONS

There are multiple methods for estimating a 2% AEP event which will all give different water levels. Given the difficulty in estimating a true 2% AEP event, perhaps a range of events should be considered. This would show how the asset performs throughout a range of event magnitudes which may be more useful than just considering a single event. These approaches will be explored in the following case studies

3 CASE STUDIES

Three case studies are presented;

1. Kaiapoi Township which was built prior to the Building Act and is an example of what could happen if only the 2% AEP event is considered; and,

2. Silverstream Estates, located adjacent to Kaiapoi Township but constructed post building act. This is an example of the benefits of considering the larger than design event.

3.1 RETURN OF THE STOPBANKS - KAIAPOI TOWNSHIP

Kaiapoi Township is located to the north of Christchurch (Figure 1, Appendix A). Kaiapoi Town has a long history of flooding. Oliver (2008) reports on multiple flooding events on a reasonably consistent basis of Kaiapoi Township throughout the 19th and 20th centuries. These flood events originated from the Ashley River and the Cust, Kaiapoi and Eyre Rivers. The Ashley River is a large braided river with headwaters that extend into the Southern Alps whilst the Cust and Eyre River catchments are confined to the Canterbury Plains. In this section we will consider whether the 2% protection is suitable.

3.1.1 FLOODING SOURCE – TIDAL

The Kaiapoi River bisects the township before joining the Waimakariri River. The section of the Kaiapoi River through the township is tidally influenced (and also affected by the flow in the Waimakariri River). Large areas of Kaiapoi Township are less than 2 m above mean sea level. Stopbanks along the Kaiapoi River provide protection from flooding during large events. Flap gates prevent water during high tides and floods being conveyed up the local stream channel.

3.1.2 FLOODING SOURCE – ASHLEY RIVER

The Ashley River, located to the north of Rangiora has in the past caused frequent flooding of Kaiapoi. A flood protection scheme undertaken in the 1930's saw stopbanks constructed along the Ashley River, however these were breached both during the building of the stopbanks and after they had been completed resulting in a further four significant flood events where evacuation of people was required. Figure 3 shows the 1945 flood event. Since 1953 there have been no breakouts onto the floodplain and work is currently underway to construct secondary stopbanks along the Ashley River to further reduce the risk of flooding from a breakout event.

Figure 3 – Flooding of Kaiapoi (Williams Street) during the February 1945 flood event. Obtained from Oliver (2008)

3.1.3 FLOODING SOURCE – CUST, EYRE AND KAIPOI RIVERS

The Cust, Eyre and Kaiapoi rivers are significantly smaller than the large braided Waimakariri and Ashley Rivers. The Cust River and Ohoka Stream are both tributaries of the Kaiapoi River. Figure 2, Appendix A shows the Digital Terrain Model (DTM) derived from LIDAR elevations flown in 2010. The elevations presented are relative to mean sea level. Kaiapoi is bounded by stopbanks and the northern Motorway (SH1) which whilst not designed to be a stopbank, provides the same function. A significant proportion of Kaiapoi is located on land with an elevation of less than 2.0 m AMSL. Without stopbank protection, this land would be inundated on a semi regular basis.

SH1 acts as a stopbank preventing flows from the rural catchments of Kaiapoi, Cust and Ohoka (which are located to the west of the Northern Christchurch Motorway) from inundating Kaiapoi Town. In large events, flow will traverse over a low point of the motorway and into east Kaiapoi.

3.1.4 FLOOD MODEL PREDICTIONS

Figure 3, Appendix A shows the flood elevation predicted by a flood model for the 50 year ARI event developed for the Silverstream Estates site. The predicted flood elevation adjacent to the motorway is 2.92 m AMSL which is approximately equal to the elevation of the SH1 crest. Therefore, SH1 acts as a stop bank in this event and will prevent the flooding of east Kaiapoi from the rural catchments. To comply with the Building Act, floor levels simply need to be above the 50 year level and this level is set by the internal flooding within the residential area which is not significant. It appears that much of Kaiapoi would comply with Clause E1.

Figure 4, Appendix A shows the flood elevation from a 100 year rainfall event. In this event, the northern motorway has been overtopped and floodwater can flow freely into Kaiapoi Township. Predicted peak water levels are around 3.25 m AMSL (a depth of 1.25 m). This is in contrast to the 50 year ARI event which shows no flooding in Kaiapoi Township. This is a very high level of residual risk, flooding of 1.25 m is generally considered to be high hazard and may cause loss of life.

It is worth noting that the ECan Regional Policy Statement (RPS) requires floor levels above the 0.5% AEP for new residential, however this does not cover existing residential (such as Kaiapoi township) and possibly not the rebuilding of existing residences (such as earthquake rebuilds). The ECan RPS also requires that development should be avoided in areas of high flood hazard. High hazard is defined as depths greater than 1 m or the product of velocity and depth greater than 1. Such policies will help to minimize the building of new residential in high hazard areas.

3.1.5 WHAT COULD BE DONE?

The possibilities for Kaiapoi are limited. Flood pumps are currently installed at the points where the local streams discharge to the Kaiapoi River. They are designed to pump localized runoff and would be unlikely to have the capacity to discharge flooding from external sources. Therefore, water cannot drain easily anywhere in a flood event. Increased capacity of pump stations is likely to be a very expensive solution given the flows and volumes of the events. The stretch of motorway that is low is around 400 m and therefore a cost effective solution may be another stopbank with a crest height of 4 m that runs adjacent to the motorway. It is also worth noting that, based on model results. SH1 may not meet the New Zealand Transport Authority criteria that it remains trafficable during a 1% AEP event.

3.1.6 CONCLUSIONS

Consideration of just the design event is inadequate. Stopbanks may protect from flooding of frequent events but it is important to understand the residual risk of stopbank failure or overtopping from a larger than design event and ensure that the result is not catastrophic.

3.2 SILVERSTREAM ESTATES – WHEN GOOD DESIGN PAYS OFF

Silverstream Estates is a residential subdivision located adjacent to west Kaiapoi (Figure 1, Appendix A) which shares similar flood risks to Kaiapoi. The Kaiapoi River flows longitudinally through Silverstream Estates. The confluence of the Kaiapoi River, Ohoka Stream and Cust Main Drain is located on the north-west corner of the site. Of these, the Cust Main Drain is the largest draining a catchment area of around 200 km². Ten kilometres to the north, flows the Ashley River whilst the Waimakariri River flows 5 km to the south. Both these are large braided rivers with headwaters located in the Southern Alps.

Flood studies of both the Waimakariri River and the Ashley River have been completed. At the time of the subdivision design, the Waimakariri River was not considered a hazard due stopbanks located along both the Waimakariri River and the Eyre River. The Eyre River stopbanks also act as secondary stopbanks for the Waimakariri River. In a 0.5% AEP breakout event, the Ashley River was predicted to cause flooding on the proposed Silverstream estates site with flooding up to a depth of 0.5 m (flood level of 3.6 m AMSL (Above Mean Sea Level). Given the average land elevation was 3.1 m AMSL and the proposed development area was 100 ha, a significant volume of fill was required for the proposed subdivision.

Flooding from the Canterbury plains, in particular, the Cust Main Drain and Kaiapoi River was outside the scope of both flood studies. PDP was engaged to perform this study. Figure 5, Appendix A shows the 2004 Digital Terrain Model (DTM). Three watercourses converge on the north western boundary of Silverstream Estates; the largest of these is Cust Main Drain with a catchment area of around 200 km^2. The remaining two water courses have a combined catchment area of around 100 km^2. Figure 5, Appendix A shows that the Cust Main Drain is well stopbanked with crest heights of 4.0 to 4.3 m AMSL. Setting floor levels about 3.6 m AMSL (above the Ashley River 0.5% AEP breakout event) would put floor levels at least 400 mm below the crest of the stopbank.

3.2.1 FLOOD MODEL PREDICTIONS

Flood modelling predicted that the 2% AEP event would result in a peak water level of 3.8 to 3.9 m AMSL whilst the 0.5% AEP event would result in a peak water level of 4.2 to 4.3 m AMSL. Larger events did not significantly increase the water level as the stopbanks were breached. The flow record from which hydrological parameters were derived from spanned a relatively short period (30 years) and therefore was subject to some uncertainty. Rather than setting floor levels above the 2% AEP event, it was recommend that they be set above the 0.5% AEP event, between 4.2 m to 4.4 m AMSL, this also meant that floor levels were above the stopbank crest height which negated any residual risk from stopbank failure.

3.2.2 FURTHER FLOOD EVENTS

In June 2014, a large flood event (between a 30 and 50 year based on rainfall) resulted in flooding close to the predicted 2% AEP event (3.8 to 3.9 m AMSL). Due to a thorough investigation and the setting of floor levels above the 0.5% AEP event, no households of the new subdivision were flooded. There were also significant (approximately 20% AEP) flood events in 2012 and 2013. A revised frequency analysis using the TIDEDA software which included the three most recent flood events showed that the predicted 2% AEP river flow event had increased by about 16% since the original 2011 assessment.

3.2.3 CONCLUSIONS

Although Silverstream Estates is located adjacent to Kaiapoi, the flood risk to residential households is significantly lower due to a thorough flood risk assessment which incorporated the uncertainties of the hydrological record, climate change and the risk of stopbank failure.

4 CONCLUSIONS

Whilst Clause E1.3.2 of the Building Act aims to protect floor levels from the 2% AEP event, the definition of a 2% AEP event can only be approximated. Comparing methods for defining a 2% AEP event shows that multiple water levels can be obtained through various approaches.

Rather than trying to accurately define a 2% AEP event, it may be more useful to consider what the other flood risks might be. This could include residual risk from stopbank failures, infrastructure blockages/failures and what happens in the larger than design event. There seems to be little point in protecting for the 2% AEP event if the 1% AEP event causes significant damage and potentially loss of life.

The case studies demonstrate the importance of considering not just the design event which can theoretically result in unintended significant flood risks.

5 REFERENCES

Oliver, T. 2008: Waimakariri District Flood Planning Hazard Management Strategy Ashley River Floodplain Investigation. Environment Canterbury, Report R08/23

APPENDIX A – FIGURES

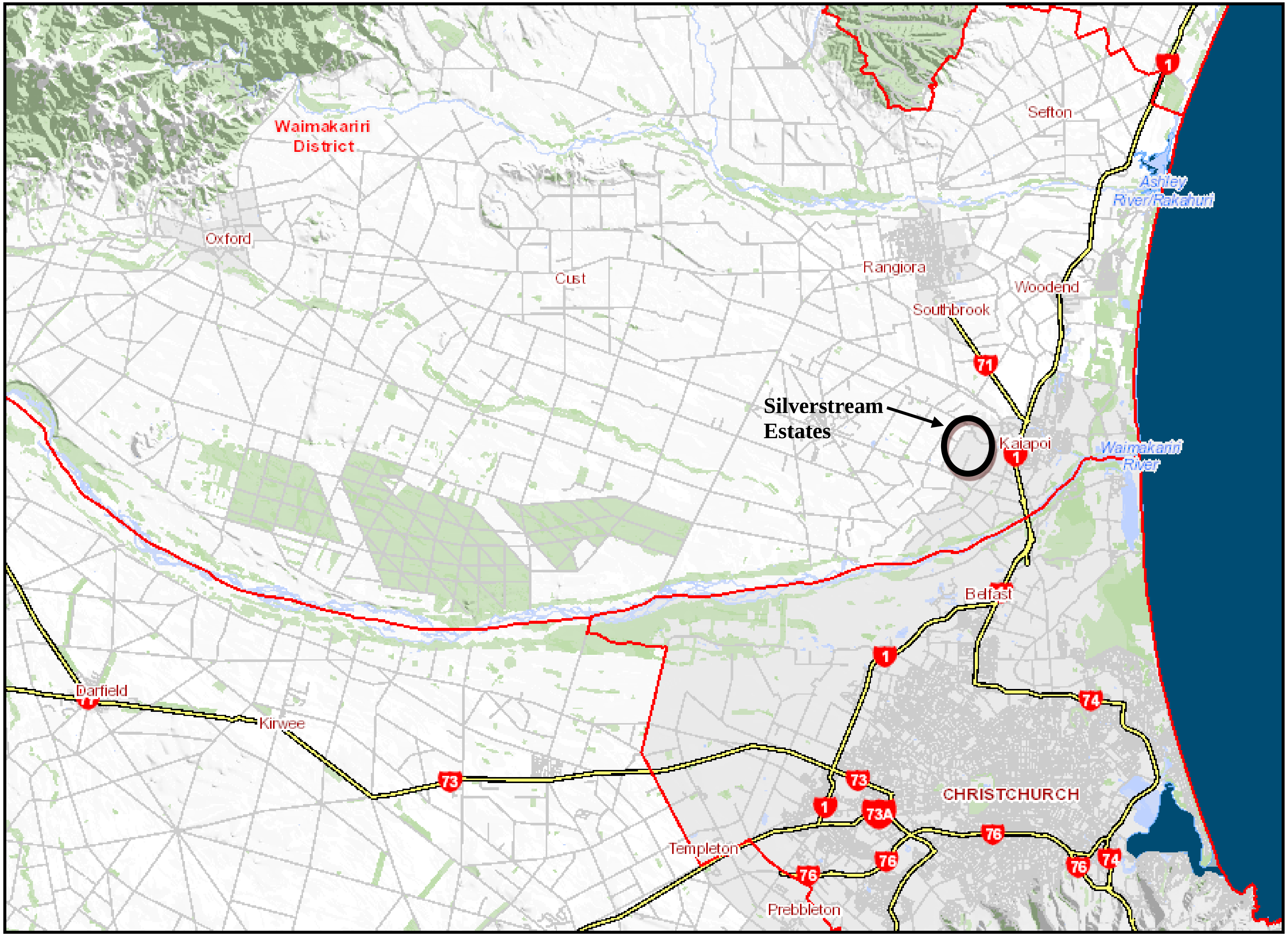

Figure 1: Site locations

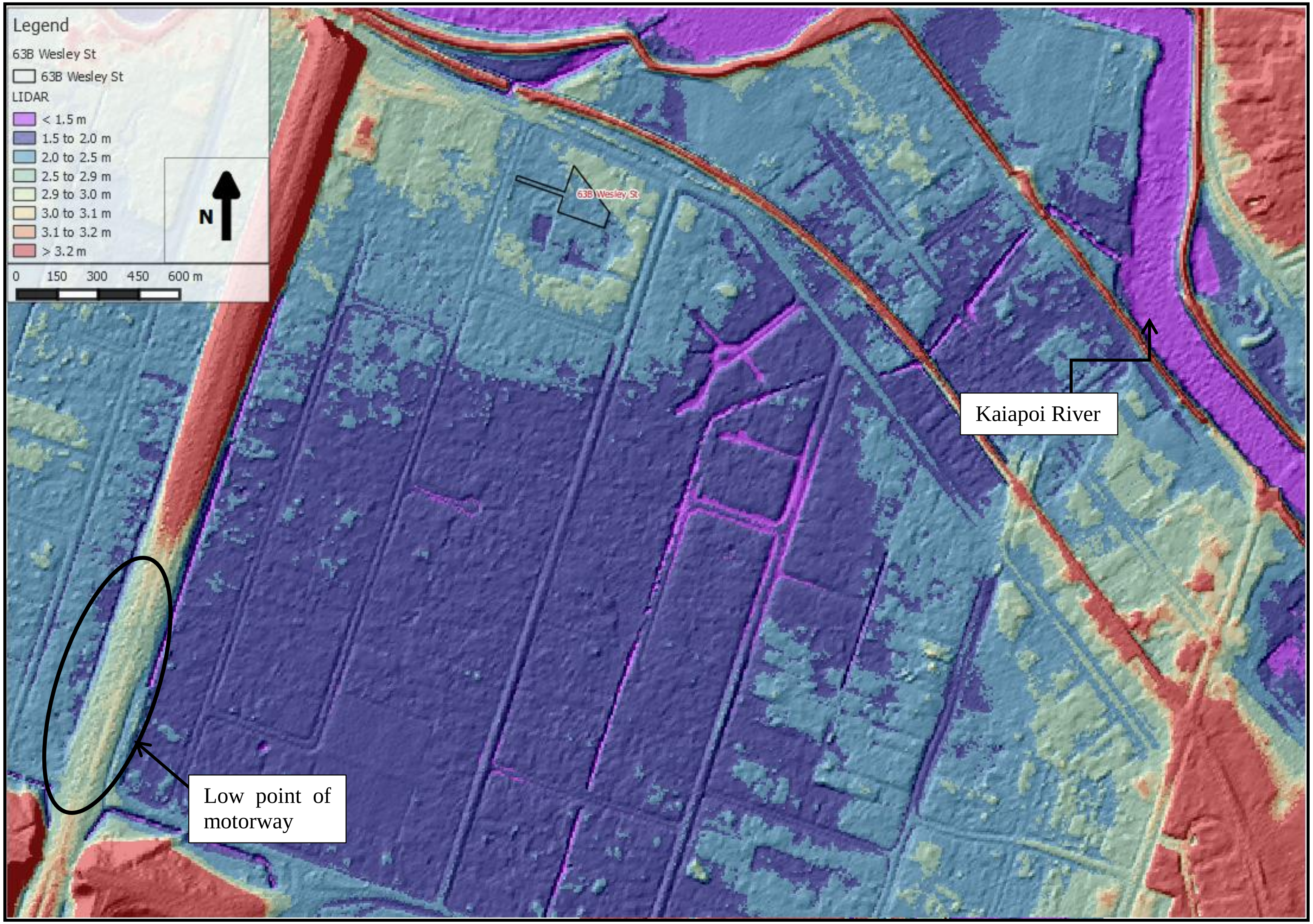

Figure 2: Post earthquake ground elevations derived from LIDAR data flow on 6 September 2010

Figure 3: Flood elevation predicted by the PDP Model for the 50 year ARI event, note no overtopping of the motorway

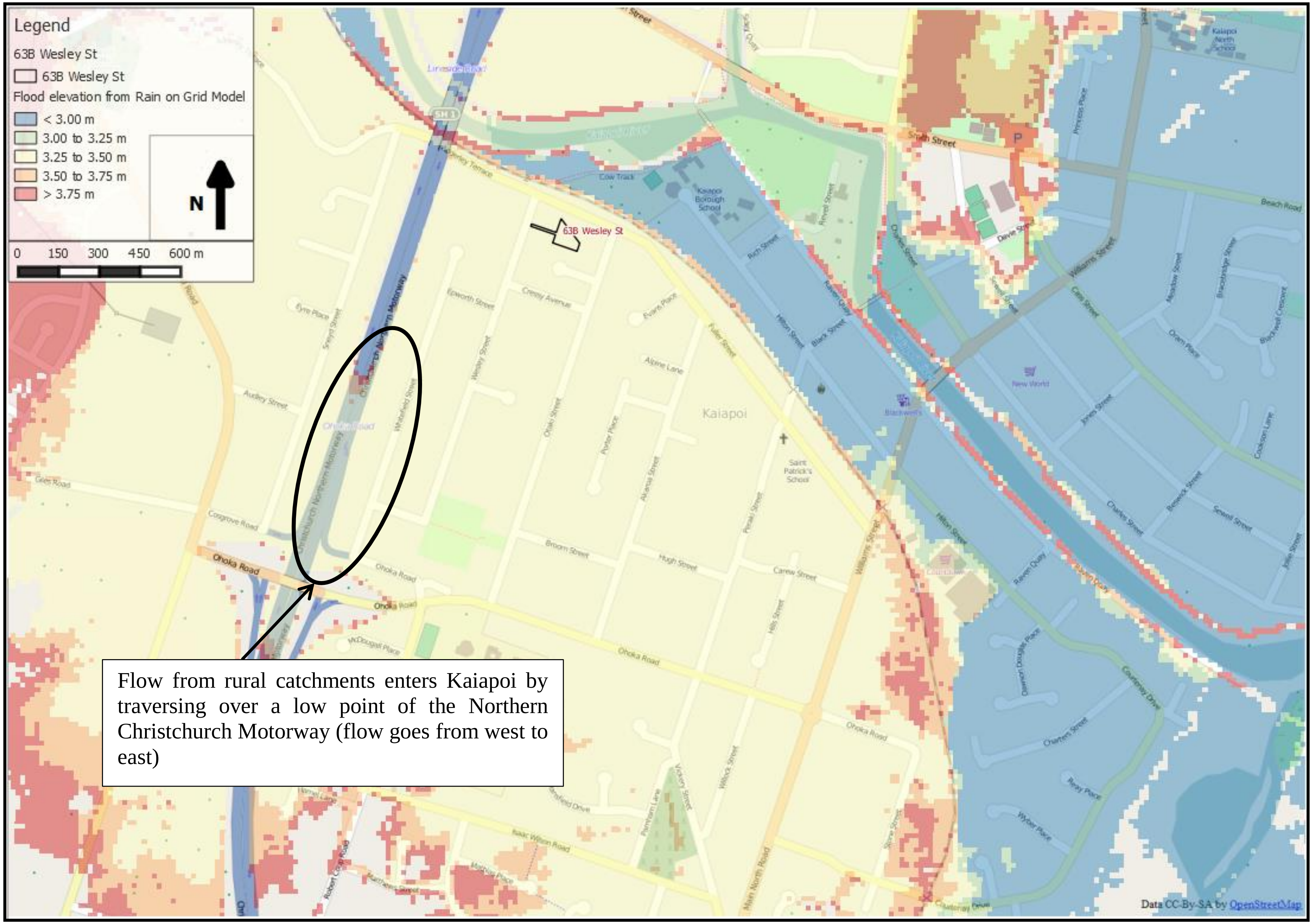

Figure 4: Flood elevation predicted by the WDC Rain on Grid Model for the 100 year ARI event

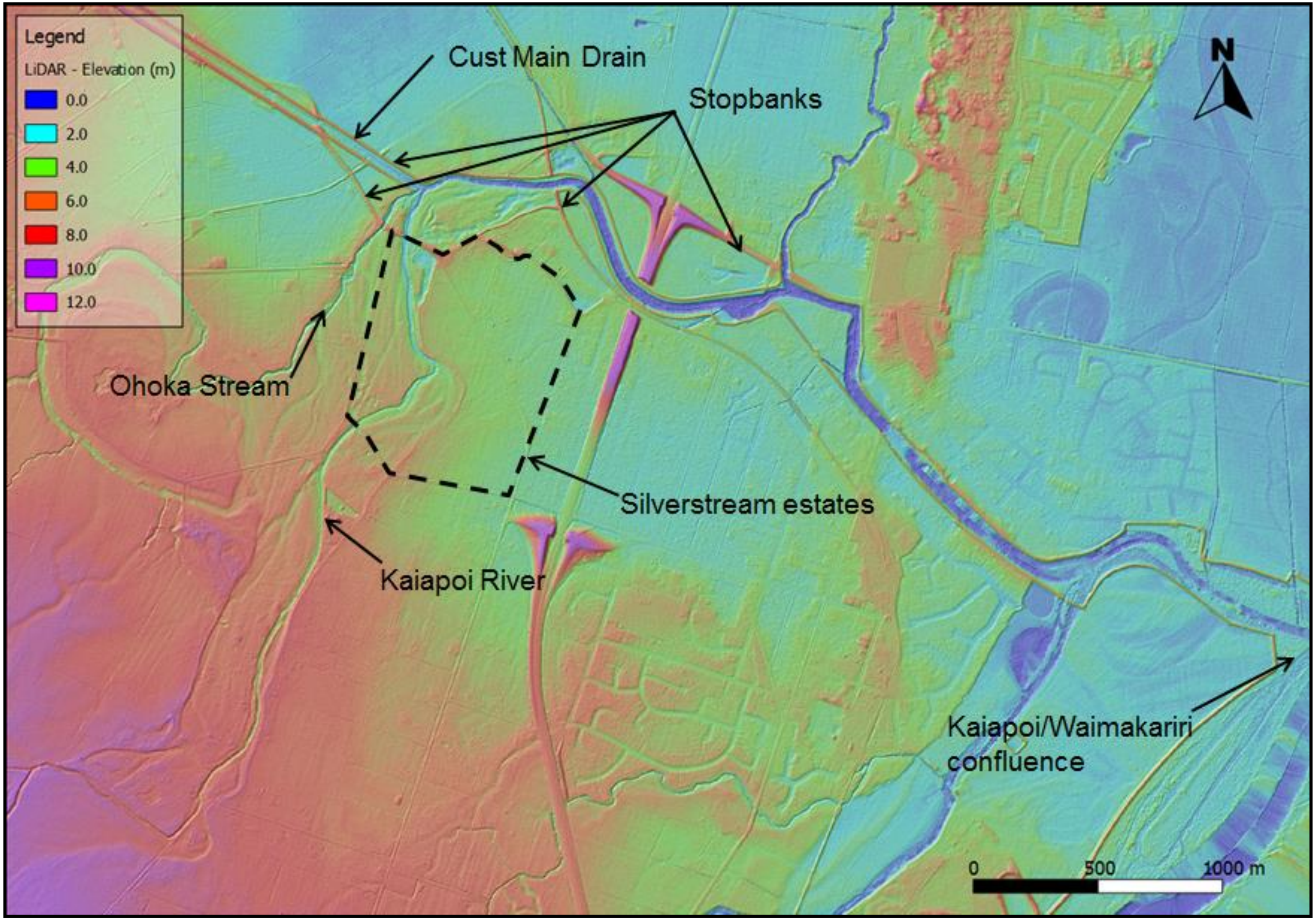

Figure 5: 2004 digital terrain model of Silverstream Estates and surrounding area