4 PRE & POST EARTHQUAKE FLOOD MODELLING

Extensive flood modelling has been completed for the City of Christchurch. This section outlines the modelling before and after the 2010-2011 Earthquake sequence. Land surface changes, discussed in Chapter 3, have contributed to changes in the areal extent of flooding. The modelling, groundwater and estuary are reviewed in this chapter with respect to changes that occurred as a result of the 2010-2011 Canterbury earthquake sequence.

4.1 Pre-earthquake Christchurch City Council Flood Management Area maps

The GEER team interviewed Mr. Graham Harrington, Senior Surface Water Planner for the Christchurch City Council (CCC), for information relating to the development of both the pre and post-earthquake Flood Management Area (FMA) maps. Prior to the Canterbury earthquake sequence, the CCC had identified areas that were prone to flooding from events such as major high tides or rainfall. These areas were also recognised as vulnerable to sea level rise (SLR) and the effects of climate change. The CCC modelled this risk and produced a FMA map (Figure 4-1) to inform the District Plan of minimum building floor levels.

Operative Variation 48 was established to assist the CCC to meet its statutory obligations with respect to floodplain management under the Resource Management Act 1991 (RMA) and is included in the District Plan (CCC, 2011). Operative Variation 48 was established because areas of Christchurch that were flood prone had floor levels set by the Building Act 2004, which only considered a 1 in 50 year precipitation event. Additionally, it was not thought at the time, in 2003, that the expected 0.5 m of SLR by the end of the century could be legally accounted for within the Building Act. This policy has changed and the allowance of 0.5 m SLR is routinely used in setting residential design floor levels under the Building Act.

Figure 4-1 shows the pre-earthquake FMA as modelled. This map was produced using a development scenario incorporating a 200-year return-period rainfall event, plus a 16% buffer allowing for a 2 degree temperature rise and 0.5 m of SLR by the end of the century. The flood level was created using DHI 1D models, with land elevations derived from the 2003 LiDAR data as a key input. The model is limited in extent to the areas around major rivers and some other flood plain areas around the city based on historical flooding experience. The model was not all inclusive, and did not include groundwater. Rather it was developed during the period 2003 to 2005 to allow the city to adapt to, and plan for, climate change and sea level rise. The FMA extends beyond the modelled flood level boundary to provide for a 400 mm freeboard on potentially affected homes. The 400 mm (FMA) of freeboard is made up of 250 mm added to the predicted surface flooding level, with an additional 150 mm which accounts for slab on grade foundations. This 400 mm level above the modelled extent was then projected sideways, encompassing more homes to create the final FMA.

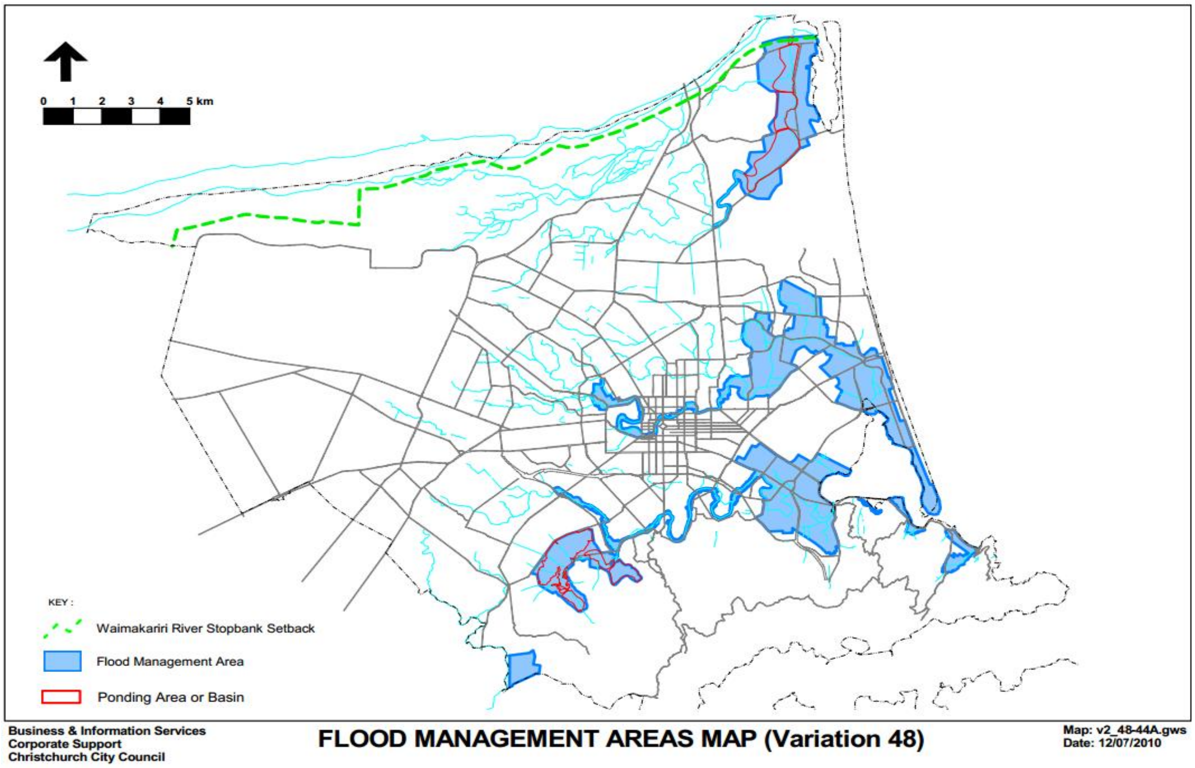

Figure 4-1 Pre-earthquake FMA developed by the CCC (Christchurch City Council, 2010).

4.2 Post-earthquake flood modelling: the Christchurch City Council FMA

The CCC has developed a post-earthquake updated, proposed FMA (Figure 4-2 and Figure 4.3), which has been released for comment under the District Plan review process. The updated FMA was required by the regional council, Environment Canterbury (ECAN), whose policy change recommends that the CCC provide 200-year return-period flood protection.

The proposed FMA is also based on the methodology set out in section 4.1 with some changes. The flood modelling extent has been expanded over the city (as seen in Figure 4-3 and 4.3) with some modelling data yet to be confirmed. A post-earthquake LiDAR dataset was used to generate the new landform for the model to account for ground deformations such as subsidence and uplift within the city, and again groundwater was not used as an input. The extent of the proposed FMA is slightly larger than the modelled 200-year return period rainfall flooding extent, due to the additional 400 mm freeboard outlined in section 4.1 above. An important note is that the new proposed FMA has significantly larger coverage in eastern Christchurch due partly to landform model changes from the post-earthquake LiDAR data set and more so from the policy change to use the 200-year return period event across the city rather than the earlier policy of only including 50-year return period events and the areas near the sea and alongside the major rivers.

A recently released CCC commissioned report 'The Effects of Sea Level Rise on Christchurch City' recommended that CCC adopt a 1 m SLR strategy for the District Plan for timeframes up until the end of this century (Tonkin & Taylor, 2013). Graham Harrington, Senior Surface Water Planner from CCC has recommended that Christchurch adopt the 1 m SLR adaptation strategy in line with the report recommendations for the District Plan. The CCC District Plan is currently under review.

4.3 Tonkin & Taylor 'Increased Flooding Vulnerability' modelling

The team met with Tonkin & Taylor (T&T), a engineering and environmental consultant for the Earthquake Commission (EQC) currently working on the EQC category 9 land damage assessment program. T&T is leading the Increased Flooding Vulnerability (IFV) project. The IFV project was set up to inform EQC of the increased flood risk exposure in Christchurch and to define the extent for EQC land insurance settlement purposes. This process is driven by the Earthquake Commission Act 1993. The project is currently undergoing its final peer review process by international and national experts.

Modelling was carried out using both the DHI MIKE software suite (http://mikebydhi.com/) and TUFLOW packages (http://www.tuflow.com/flike.aspx). Groundwater changes, storm surges and climate-change induced sea level rises were not considered in this exercise. The model gave a 'snapshot in time' and differed from previous CCC modelling in that T&T developed an overland flow model to account for observed flooding outside of the major waterways. A major issue with the modelling was the accuracy of the pre-earthquake (2003) LiDAR data, which was never intended to form the basis of a flood modelling digital elevation model. The accuracy of the LiDAR data, specifically the sparse data points, has been a limiting factor of the project modelling to date.

The flooding observations carried out by both CCC and T&T are shown in Figure **4-4** The map is compiled from the March flood event observations that had been mapped at the time of this report. Note that no reconciliation of the frequency attributed to the flood event had been carried out to date. Hind-cast simulation modelling of the March 5th event was carried out using the TUFLOW software package and is shown in Figure **4-4** (Tonkin & Taylor, 2014).

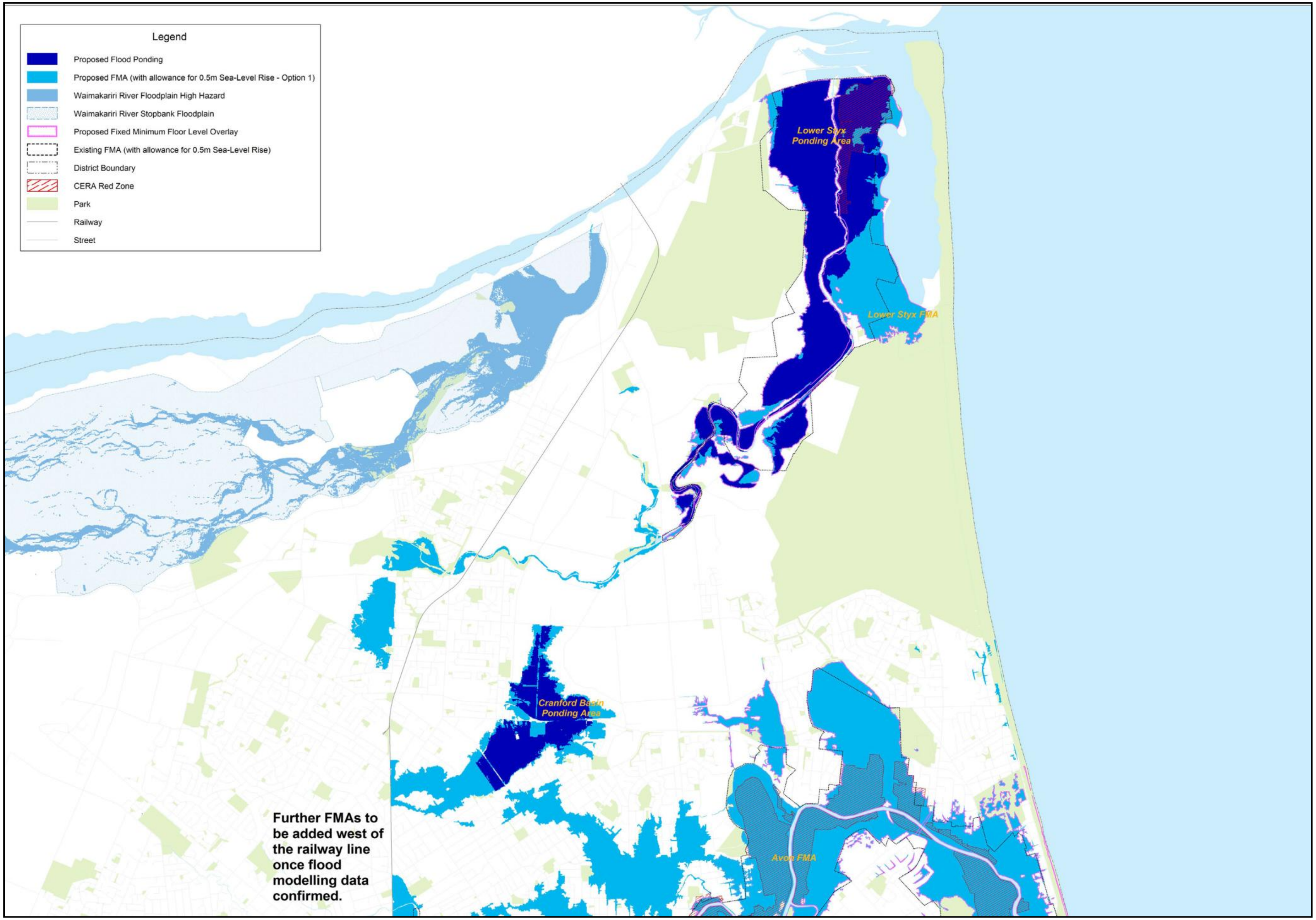

Figure 4-2 Existing and proposed Flood Management Area (FMA) with a 0.5m SLR (Christchurch City Council, 2014).

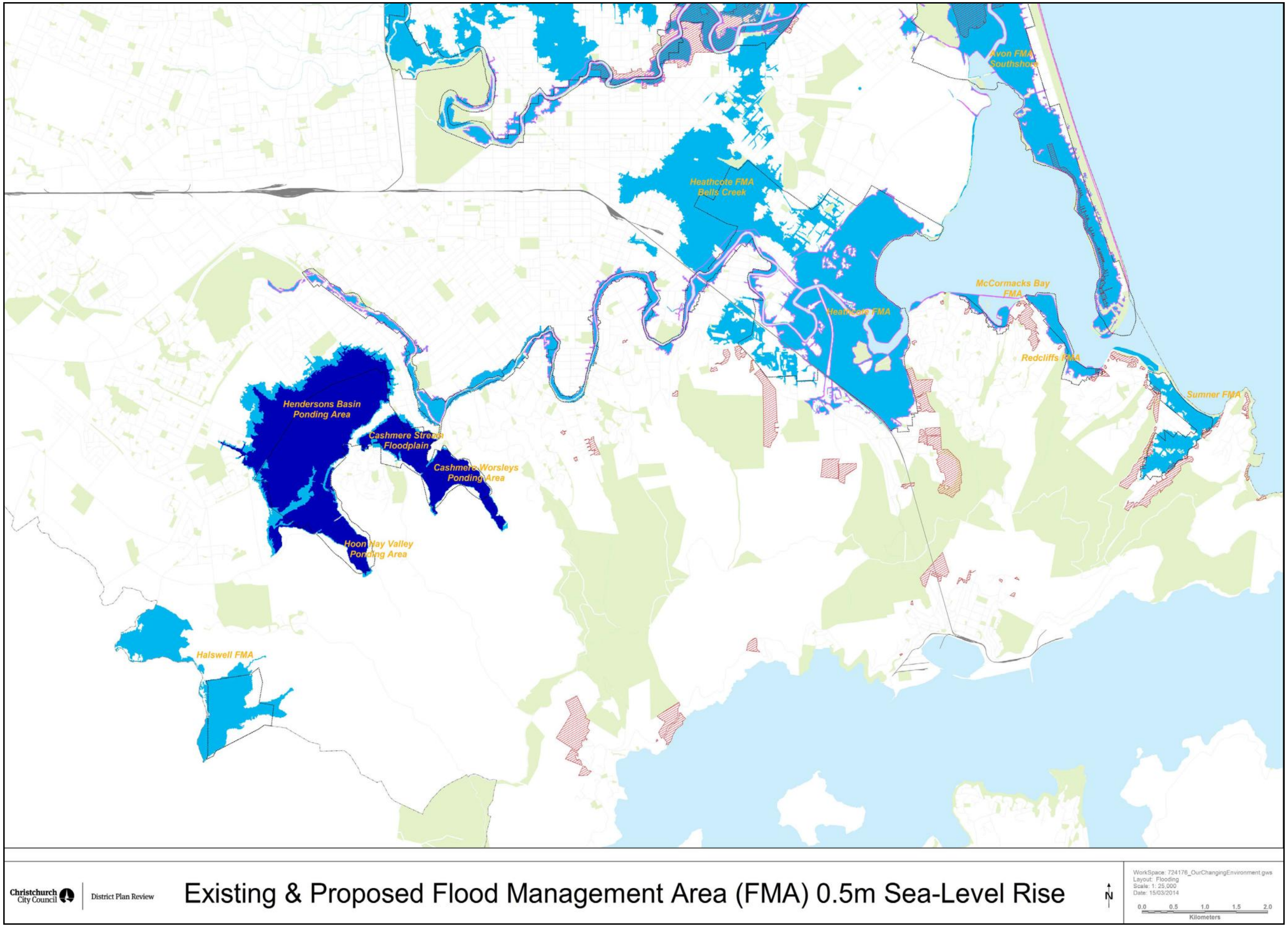

Figure 4-3 Existing and proposed Flood Management Area (FMA) with a 0.5m SLR (Christchurch City Council, 2010, 2014).

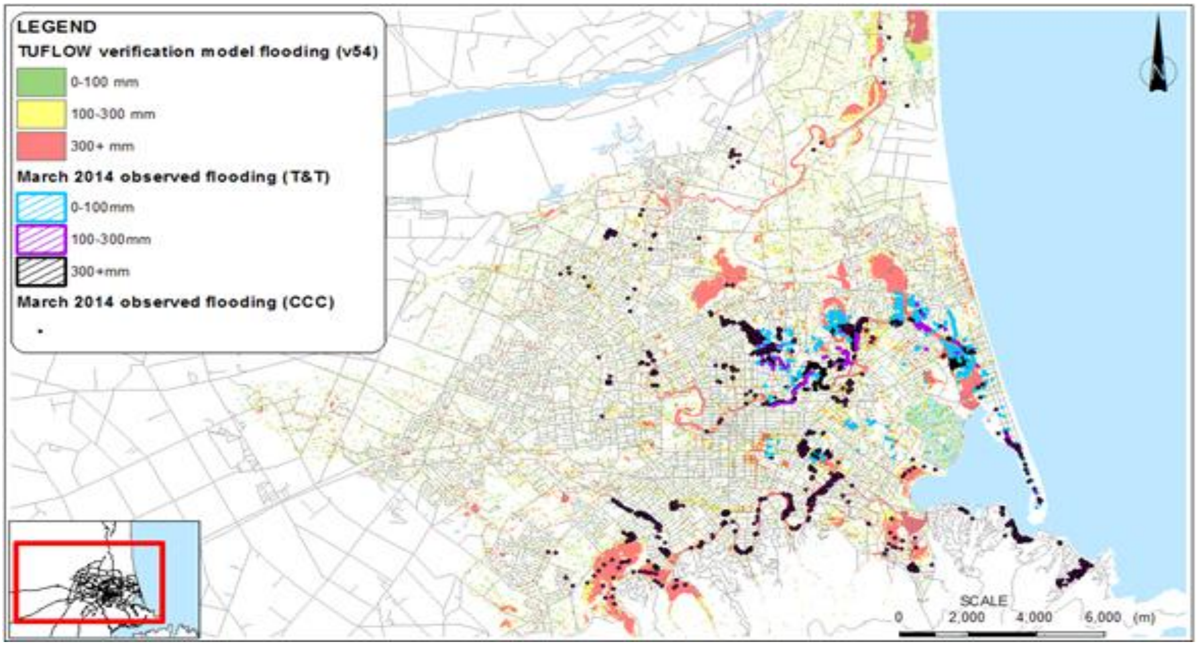

Figure 4-4 Observed flooding in Christchurch March 2014 versus hind-cast model predictions (Tonkin & Taylor, 2014).

4.4. Pre & Post- earthquake 100 year return period flood modelled maps

CCC has modelled the change in 100-year return period flood events for Christchurch in a post vs pre-earthquake scenario. Graham Harrington kindly provided the modelled pre- and post-earthquake 100-year return event maps for the Avon and Heathcote Rivers, noting that stopbanks were not included in the modelling. The Avon River and Southshore area changes in 100-year rainfall event flooding are shown in Figure 4-5 with the post-earthquake increase in flood extents indicated by the lighter blue color. Modelling indicates that under pre-earthquake conditions 1,820 properties could have be affected while in the post-earthquake scenario an estimated 3,720 properties could now be affected by flooding, showing the earthquake effects have more than doubled the number of properties at risk of flooding in this one area of the city.

The above flood predictions cover the lower Avon catchment. As explained in Chapter 2 of this report, this river represents one of the two main urban rivers flowing through Christchurch and draining into the Avon-Heathcote Estuary Ihutai. The other main urban river in Christchurch is the Heathcote, which lies to the south and west of the estuary. The Heathcote River changes in predicted 100-year flood extents are shown in Figure 4-6.

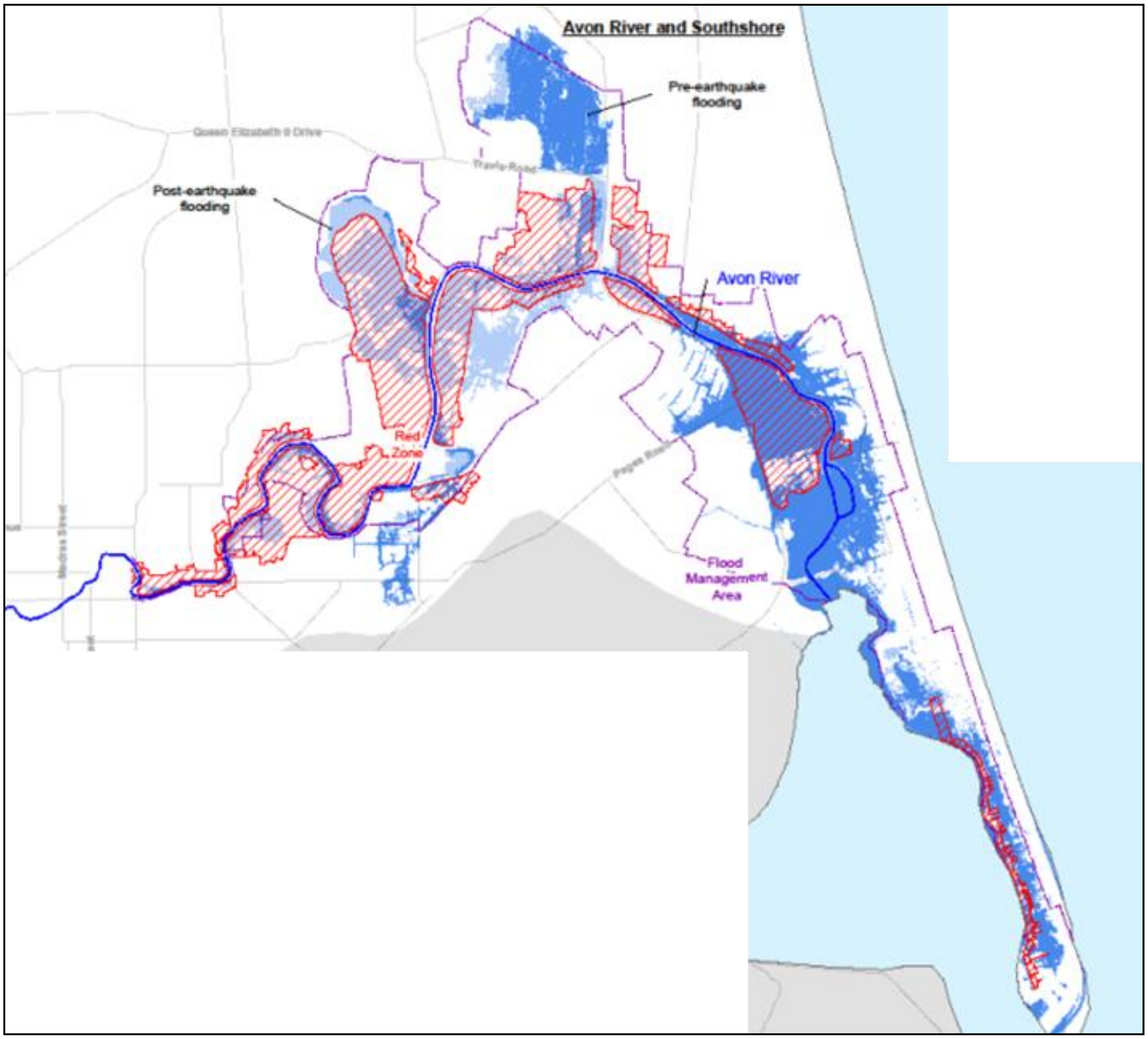

Figure 4-5 Avon River and Southshore change in 100-year predicted flood extents, with no stop banks. Dark blue indicates pre-earthquake flooding, light blue indicates the increase in flood extents post- earthquake (Harrington, 2014).

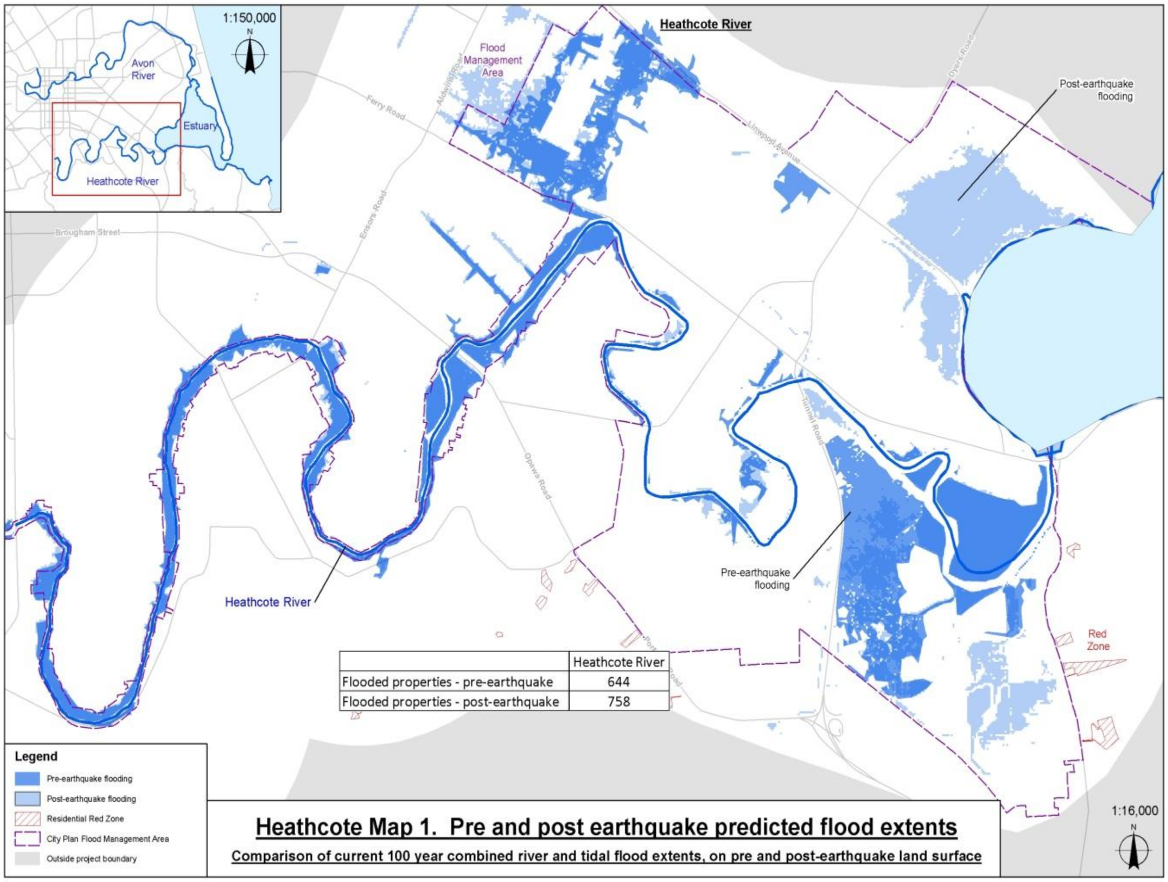

Figure 4-6 Heathcote River pre and post-earthquake 100 year predicted flood extents, (Harrington, 2014).

4.5 Groundwater

As explained in Chapter 2 of this report, the hydrogeology of the Canterbury plains are largely Quaternary deposits of gravel, sands and silts that formed as outwash fans from the braided channel rivers that formed as the Southern Alps were uplifted, with a layer of sandy coastal progradation deposits forming the Holocene subsurface of the city. In the Quaternary layers below Christchurch City, the alluvial deposits, mainly from the Waimakariri River, occur in alternating layers with a series of marine deposits. The marine deposits can be found at depths up to 15 km under Christchurch City from the current coastline. The alternating layers of gravel and marine deposits occurred because the gravel was deposited during periods of lower sea levels and the marine deposits occurred during periods of higher sea levels. As shown in Figure 4-7 the marine deposits have lower permeabilites and create a system of confined aquifers along the coast (Weeber, 2008). The system is recharged by infiltration from precipitation and irrigation and from the surface water flows from the Waimakariri River. Due to seasonal variation in the recharge sources, variability in the groundwater levels can also be observed in historical data.

Along the coast, the system discharges to the ocean. This discharge could reverse and become saltwater intrusion if the groundwater levels lower compared to the sea level or the sea level rises compared to the groundwater levels. To the west of Christchurch city and along the Port Hills, in an area of alluvial aquifers west of the marine deposits, allow groundwater to be discharged through a series of springs. These springs feed the local rivers including the Styx, the Avon, and the Heathcote (Weeber, 2008). Following the Darfield 10 September 2010 Earthquake, a series of new springs emerged to the south and east of the city where few had emerged prior to the earthquakes (White, et al. , 2007; van Ballooey et al., 2013)

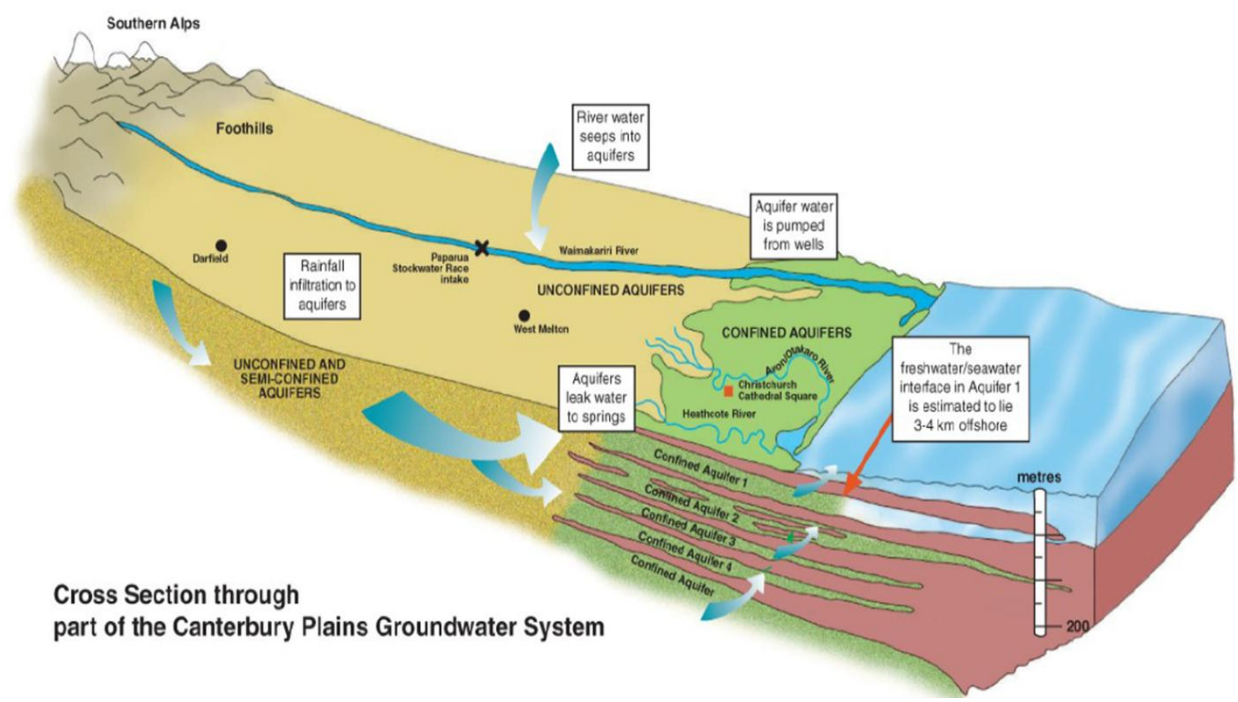

Figure 4-7 Environment Canterbury "Christchurch Groundwater Protection" (Weeber, 2008).

In addition to natural discharge, the groundwater system in the Canterbury plain is pumped for numerous uses. Up to 80% of municipal and 50% of agricultural demands in the region are satisfied through groundwater (Brown & Weeber, 1992). The groundwater is of very high quality and does not require treatment for domestic consumption. Because of its high quality, the government has set up an extensive and thorough monitoring program. Following the Canterbury Earthquake Sequence this monitoring programme was significantly expanded.

The groundwater table below Christchurch City is typically less than 10 m deep throughout the area (van Balleooy et al., 2013). Due to the shallow water table, groundwater plays an important role in the liquefaction potential in the city, as well as the potential to increase local flooding. The CCC, ECAN and EQC have data for 806 shallow monitoring wells throughout the city. These shallow wells are less than 10 m deep (van Balleooy et al, 2013). The groundwater table ranges in depth from less than 1 m to 5 m under the city, and follows the general topography of the land surface.

The local flooding from the rainfall event of on the 5th March 2014 had little contribution from groundwater. Given the time of year and indications from the groundwater records, it is estimated that groundwater levels were near the 85th percentile level under the city (Tonkin & Taylor, 2014)

4.6 Changes in estuary inlet and bed morphology, plus possible ecosystem impacts

Estuaries and their inlets represent some of the most morphologically and ecologically sensitive systems of the coastal zone (Healy et al., 1996). Figure 4-8 illustrates the ocean-side of the Avon-Heathcote Estuary Ihutai inlet. Hydrodynamics, geomorphology and sedimentology interact in these environments in a highly complex manner, potentially leading to rapid and significant system-wide changes when one element of an estuary is altered (Pritchard, 1967).

The Avon Heathcote Estuary Ihutai, Christchurch’s main coastal waterbody, underwent significant changes in ground surface elevation during the 2010-2011 earthquake sequence (Figure 4-9). These ground changes, including mainly uplift, suggest possible impacts for the entire system including physical and ecological characteristics.

(a)

(b)

Figure 4-8 The inlet from the south-side beach perspective (a), and from one of the upper roads on the Sumner side (b) taken on 19 March 2014.

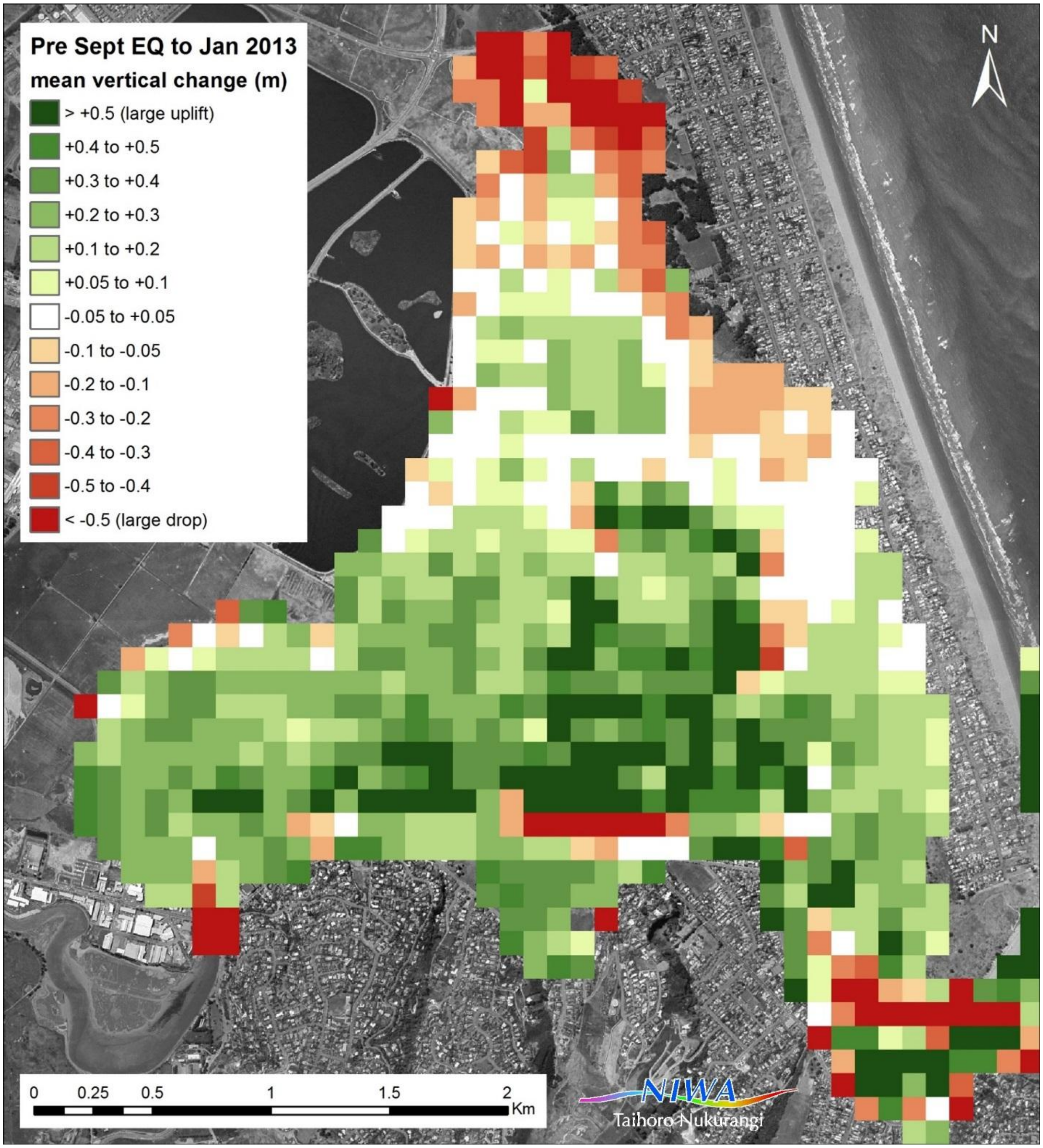

Figure 4-9 Bathymetric changes in the Avon Heathcote Estuary calculated from digital elevation models derived from a composite of LiDAR and echosounder survey data. The change analysis shows that the main body of the estuary has experienced uplift with some subsidence in the northern end around the mouth of the Avon River. Uplift patchiness in the southern part of the estuary represents morphological change between surveys rather than earthquake effects. A full description of the digital elevation models used for this analysis is contained in Measures (2013).

Figure 4-10 Time series of Google Earth images of the inlet (43° 33' 41.45"S, 172° 45' 14.44"E) and the estuary from 29 January 2003 to 25 April 2013. For direct comparison of the inlet and estuary morphology, it has to be considered that the images have not been referenced to the respective tidal phases yet.

To demonstrate the rapid changes from the earthquake sequence, a time series of Google Earth images from 2003 to 2013 is shown in Figure 4-10. The images indicate no significant changes of the inlet from 2003 to 2009. However, in the 2010, a distinct channel can be seen interrupting the line of breaking waves, likely corresponding to a sandbar-like feature as can often be observed at deltas and inlets. This behaviour can continuously be found in the following images. A generally limited wave action must also be considered an influencing factor. A major change in inlet morphology can then be seen in the image from 2013. The channel at the ocean side bends northward leading to a pointed flat at the southern side of the inlet. Entering the estuary, the channel bends southward, intensifying the meandering loop that seemed to have had less significance in the past, and creating a larger flat at the inner side of the end of the spit (Figure 4-10). It should be noted that the Google Earth images are not referenced to a particular tidal phase and state of wave action, introducing a degree of variation when comparing the images.

To examine changes in hydraulic behaviour, NIWA has carried out a detailed study of the morphological changes of the estuary and inlet including a numerical hydraulic modelling over pre- and post-earthquake topography. The observed and ongoing changes in geomorphology, regarding the inlet and channel dynamics as well as the uplift and subsidence in the estuary, are expected to interact with tidal and possibly sediment characteristics. The average tidal prism of the estuary has reduced from 9.5 million m^3 prior to the earthquakes to 8.1 million m^3 after the earthquakes. This leads to changes in the state of inundation across the estuary over a tidal cycle, as indicated in Figure 4-11, as well as changes to saltwater wedge penetration up the Avon and Heathcote River channels. Such changes can represent a major change for the eco-system, especially related to overall changes in the salinity level (Crain et al. 2004). In conjunction with flood events introducing high amounts of freshwater into the system, areas might undergo more rapid as well as long-term changes in inundation and salinity (Pennings et al. 2004). The reduced tidal prism volume (14.6% reduction) has also resulted in a substantial narrowing of the inlet as shown in Figure 4-12. It is expected that the reduced tidal prism will lead to smaller ebb and flood-tidal deltas, with the surplus sand distributed onto the adjacent beaches.

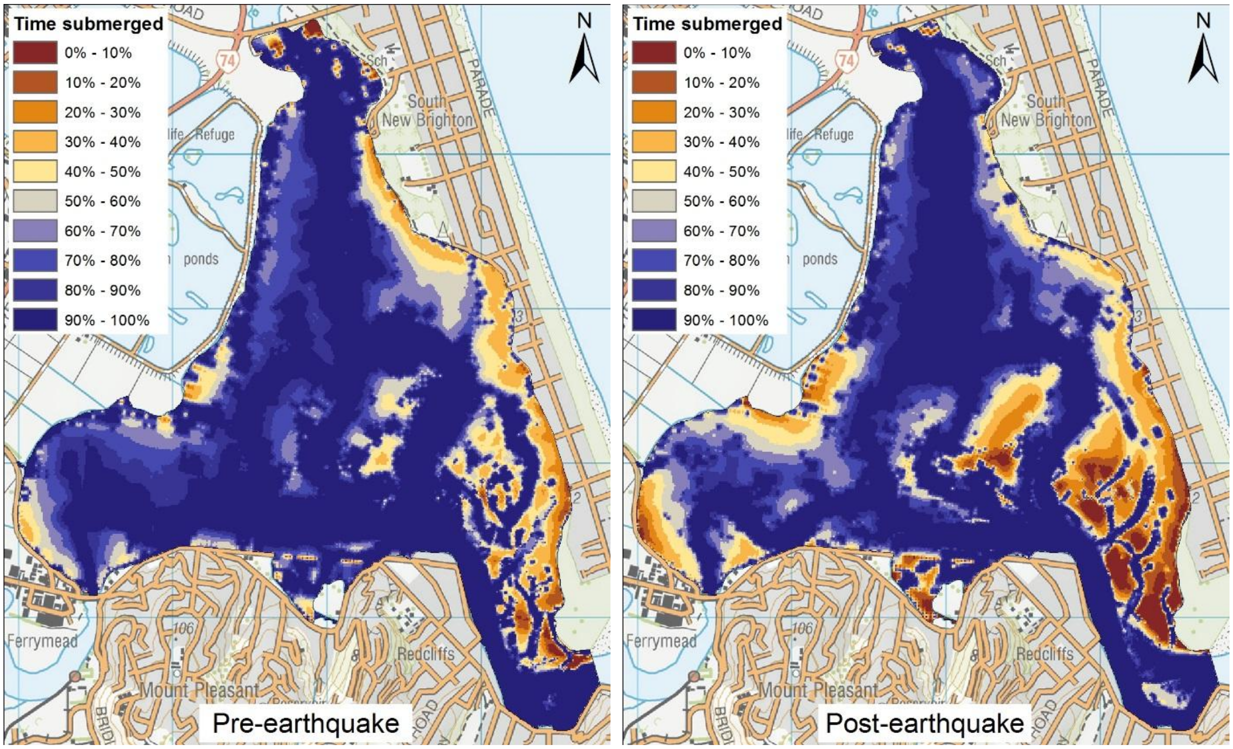

Figure 4-11: Proportion of time estuary bed is submerged pre and post-earthquake. Clear changes are visible in the southern and eastern parts of the estuary which are having significant effects on habitat and morphology. Figure reproduced from Measures (2013).

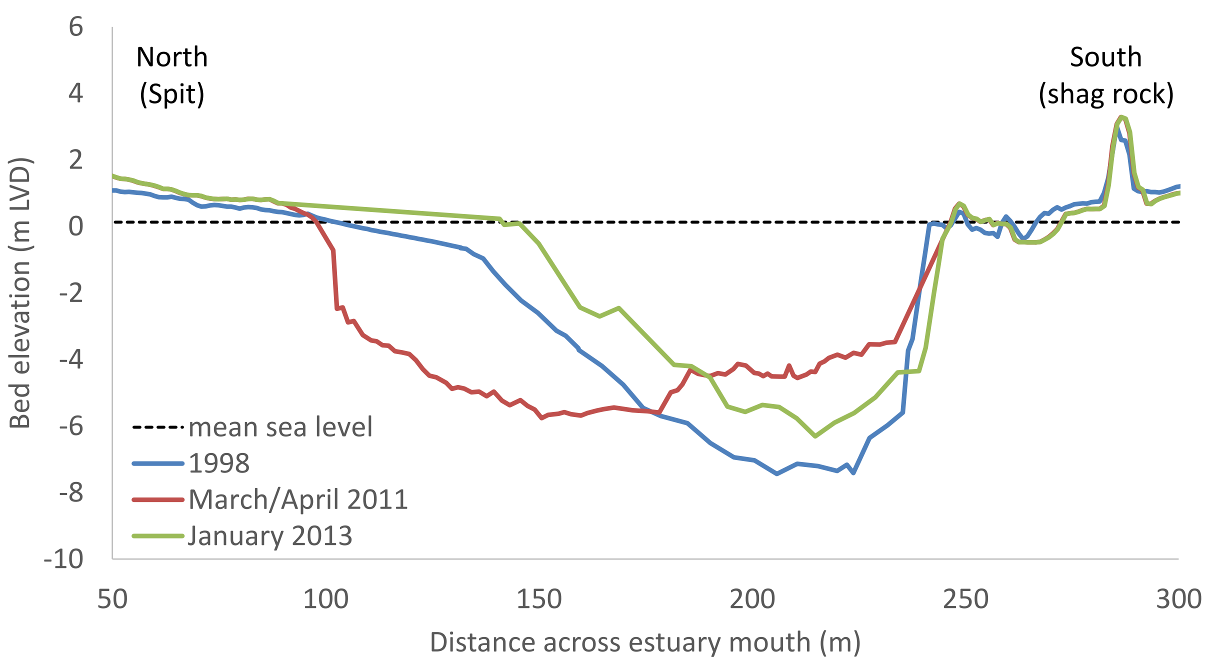

Figure 4-12 Changes in mouth cross-section pre-earthquake (1998), immediately post-earthquake (March/April 2011) and following morphological adjustment (January 2013). Cross-section extracted from echo-sounder surveys of the neck of the estuary. Figure reproduced from Measures (2014).

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