5. EFFECTS OF EARTHQUAKE-INDUCED GEOTECHNICAL IMPACTS ON FLOODING

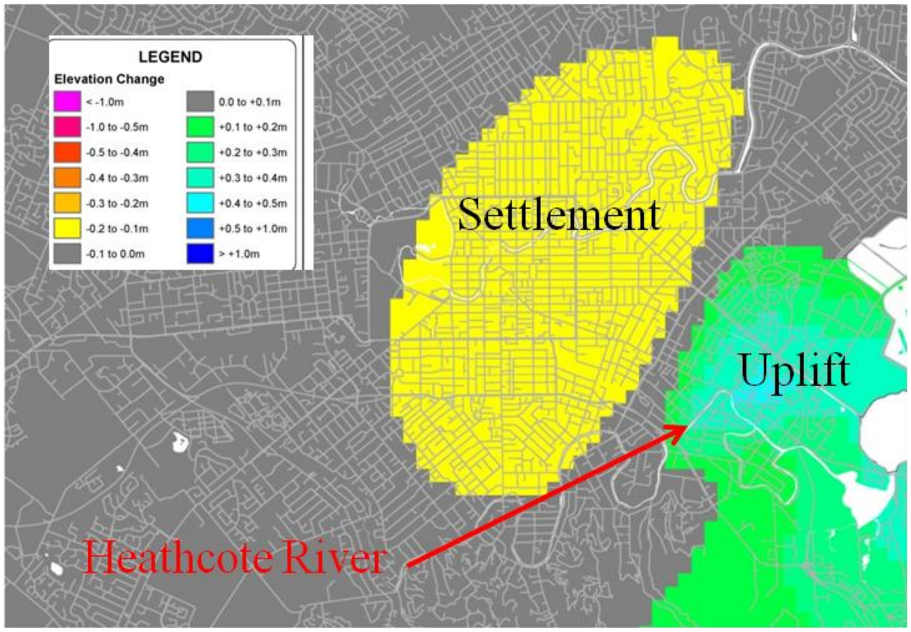
At the behest of CCC, T&T have performed both pre- and post-earthquake sequence overland flow and river flood modelling (Tonkin and Taylor, 2013). In this section, the river flood modelling outputs are compared with the seismic-induced geotechnical mechanisms that have played an important role in increasing the flood susceptibility in Christchurch, including vertical tectonic movements, liquefaction induced settlement, lateral spreading, and river channel capacity changes. Many factors other than these mechanisms, which influence overland and river channel flow, are recognized to have contributed to the observed flooding during the 5th March 2014 event. These include earthquake-induced damage to pre-existing flood protection and stormwater systems, and to other key water-conveying infrastructure, along with further impacts such as those from construction-induced obstructions and ecological system impacts. An overview on these aspects is provided in the following chapters.

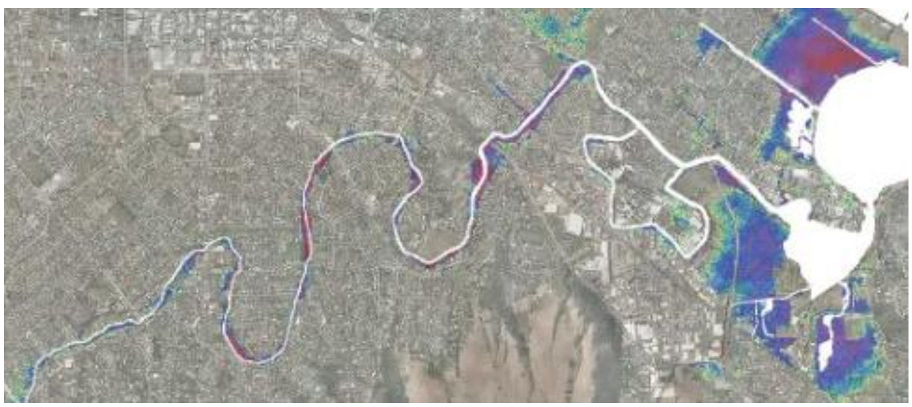
Tectonic Uplift and Settlement (Heathcote River)

LiDAR mapping from CERA Project Orbit indicates that there has been both land uplift and settlement over the lower Heathcote River catchment.

The Heathcote River lower section is tidally influenced and, as shown in Figure 5-1a, has risen by up to 400 mm, while the upstream portion of the river has settled by 100-300 mm. The mechanisms leading to this deformation pattern were described in Chapter 3. These elevation changes have resulted in a gentler hydraulic gradient, reducing the river’s hydraulic capacity and leading to increased bed levels (CCC Task Force, 2014). As example of the settlement along the Heathcote River, stop-banks constructed in 1986 in the vicinity of Radley to Garlands Roads have settled by up to 0.5 m (River Level 10.9 m to 10.4 m). Since the 2010-2011 earthquake sequence the ecology of the Heathcote River has begun to adjust to this change in the river-scape, with the re-establishment of invertebrates in the lower section.

Overland flow modelling was carried out by T & T, using both the DHI MIKE software suite and TUFLOW packages (Chapter 4), and making reference to pre- and post-earthquake LiDAR data. Figures 5-1b and 5-1c present maps showing the qualitative comparison for pre- and post-earthquake conditions, respectively, in the Heathcote River lower section, where the tectonic uplift was observed. These figures highlight the reduction of expected overland flow area and a decrease in the expected flood depth: that is, maximum expected flood depth in the area is in the range of 0.7-1 m (Figure 5-1b) for the pre-earthquake conditions and in the range of 0.5-0.7 m (Figure 5-1c) for post-earthquake conditions. However, as previously noted the model does not include groundwater changes, storm surges and climate induced accelerated sea level change. Also, the pre-earthquake LiDAR data (2003) is considered of limited accuracy. Thus the uncertainty in results is not well constrained, but the trend is consistent with observed ground movement and expected changes in flow patterns.

(a) 

(b) 

(c) 

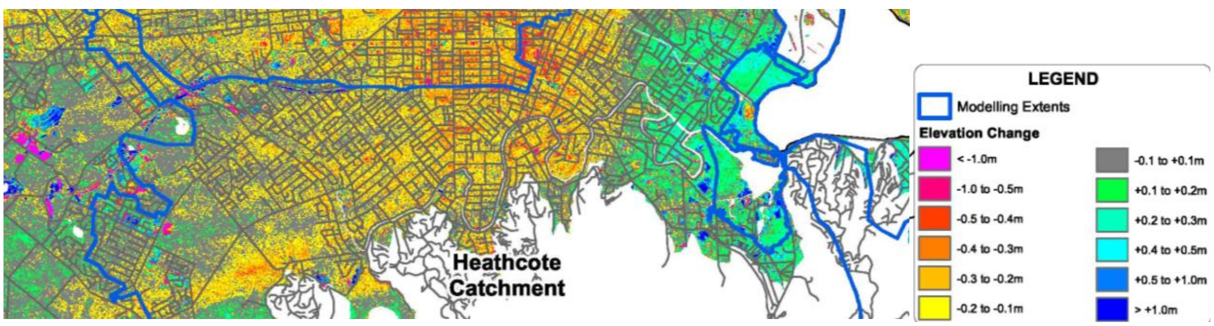
Figure 5-1 Heathcote River area: (a) impacts of tectonic uplift (Tonkin & Taylor, 2013); (b) pre-100 year annual return interval (ARI) event flood depth; and (c) post 2010-2011 earthquake sequence ARI event flood depth excluding stop-banks and climate change (Tonkin & Taylor 2013).

Liquefaction induced settlement and effects on flooding of the Heathcote River

Liquefaction induced settlement was documented in Christchurch and the surrounding communities after the four main events included in the 2010-2011 Canterbury earthquake sequence. Tonkin & Taylor (2013) documented elevation changes in the period from pre-2010 to December 2011.

In the Heathcote catchment area Figure 5-2a shows both settlements and uplift of ≤0.3 m were experienced. Canterbury Geotechnical Database (CGD) data show that vertical and horizontal ground movements occurred in the upper Heathcote River area (i.e. the area from Halswell Road to Cashmere View Street on both sides of the Heathcote River), with the land generally settling between -0.1m to -0.3 m after the earthquake events.

Figure 5-2b shows the resulting cumulative changes in overland flow flood depths estimated by T & T, taking into account both pre- and post-earthquake land elevations, which included both liquefaction-induced settlement and tectonic uplift. Figure 5-2b shows liquefaction induced settlement in the middle reaches of the Heathcote River increased the flood depth by up to 0.5 m.

(a)


(b)


Figure 5-2 Heathcote River: (a) cumulative elevation change along the river pre-2010 to post June/December 2011 (Tonkin & Taylor Ltd, 2013, Figure A10); (b) overland flow increased flood depths post-December 2011 compared to pre-September 2010 (Tonkin & Taylor, 2013).

Liquefaction Induced Settlement and Effect on Flooding (Avon River)

Figure 5-3a shows the estimated Avon River catchment area cumulative changes in overland flow flood depth, as assessed by T & T, taking into account both pre- and post-earthquake land elevations. These results indicate an increased flood depth up to 1 m in this area, resulting from the cumulative settlement shown in Figure 5-3b from the 2010-2011 earthquake sequence exceeding 1 m within the same area.

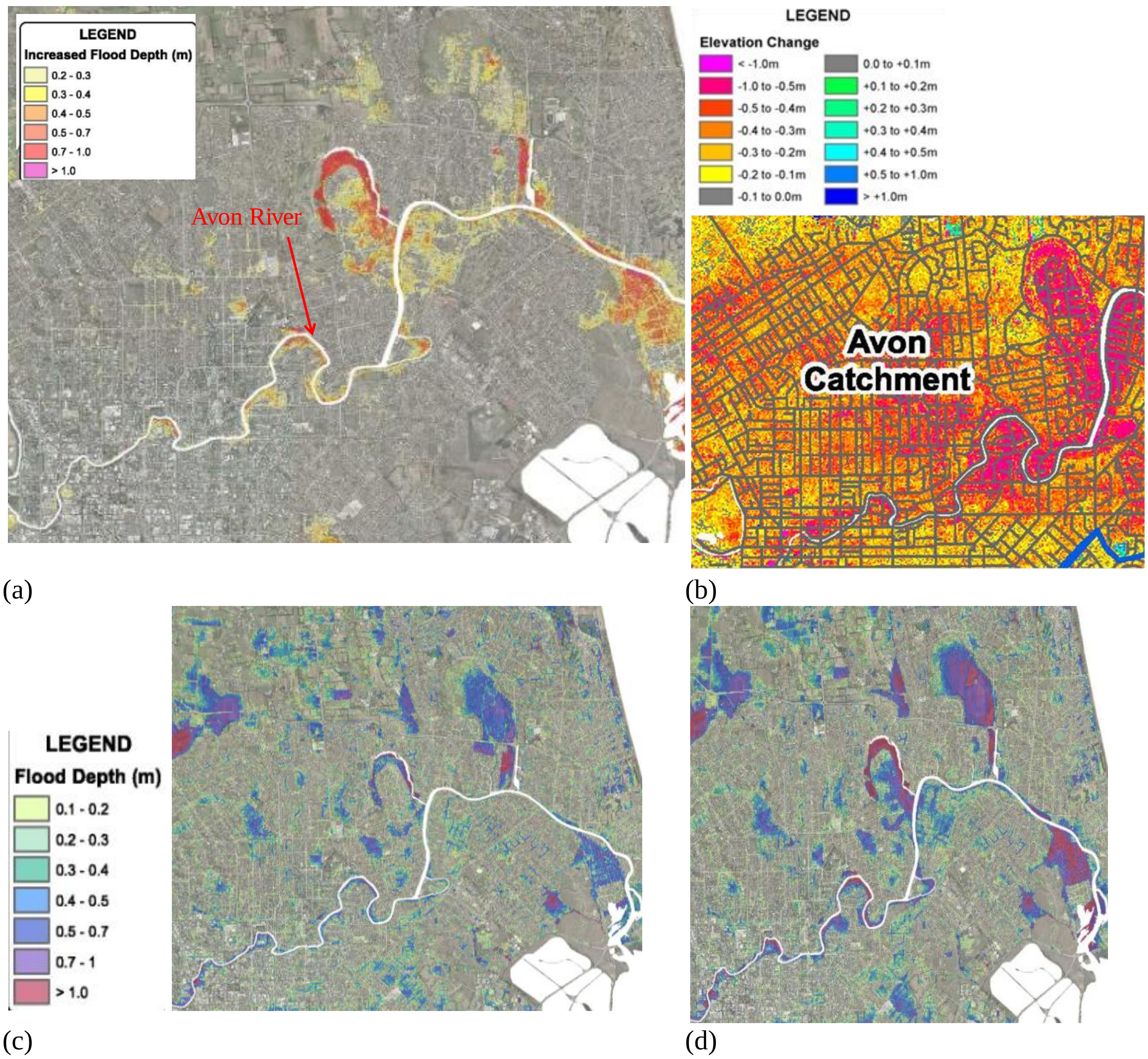


Figure 5-3 Avon River: (a) overland flow increased flood depth for the Avon River pre-September 2010 to post-December 2011; (b) cumulative elevation changes due to liquefaction; (c) increased overland flow flood depth from the overland flow model for the 100 year ARI excluding stop-banks and climate change for pre September 2010; and (d) post 2010-2011 earthquake sequence (Tonkin & Taylor, 2013).

Modelling of the overland flow was carried out by T & T, using both the DHI MIKE software suite and TUFLOW packages (Section 4), and making reference to pre- and post-earthquake LiDAR data. Figures 5-3c and 5.3d present maps showing the qualitative comparison of the pre- and post-earthquake conditions, respectively in the Avon River lower section. These results highlight an increase in the expected flood depth: that is, maximum expected flood depth in the area is in the range of 0.5-0.7 m (Figure 5-3c) for the pre-earthquake conditions, while expected to exceed 1 m in post-earthquake-conditions (Figure 5-3d).

Liquefaction induced settlement and effect on flooding of the Dudley Creek catchment, including the Flockton area

Dudley Creek and its tributaries are demonstrably under capacity in rainfall events. The Flockton area (around Flockton Street), having the topography of a basin, is one of the most flooding-prone areas within the Dudley Creek catchment (CCC Task Force, 2014). Even before the 2010-2011 earthquake sequence the Flockton area was prone to flooding, and often suffered from significant ponding. Since the earthquake sequence the area was flooded in August 2012, June 2013, and March 2014 showing how the frequency and magnitude of flooding seems to have increased (Chapter 2).

Jacobs Sinclair Knight Merz (JSKM), who conducted the Dudley Creek project under the Land Drainage Recovery Programme, have extensively studied the Dudley Creek catchment including the Flockton area. An increase up to 0.5 m in flood depth can currently be observed in the Flockton Basin when comparing the peak flooding depth expected for a 10-year return-period rainfall event pre-September 2010, resulting from the JSKM study and shown in Figure 5-4a, with the peak flooding depth expected for the same rainfall event in post-earthquake sequence condition shown in Figure 5-4b. This increased flooding depth is a result of subsidence across a large proportion of the Dudley Creek catchment. Subsidence of between 0.2 and 0.5 m is shown in Figure 5-4c, resulting from the 2010-2011 earthquake sequence. Bed heave has also occurred extensively along Dudley Creek and its tributaries, resulting in a subsequent loss in hydraulic capacity.

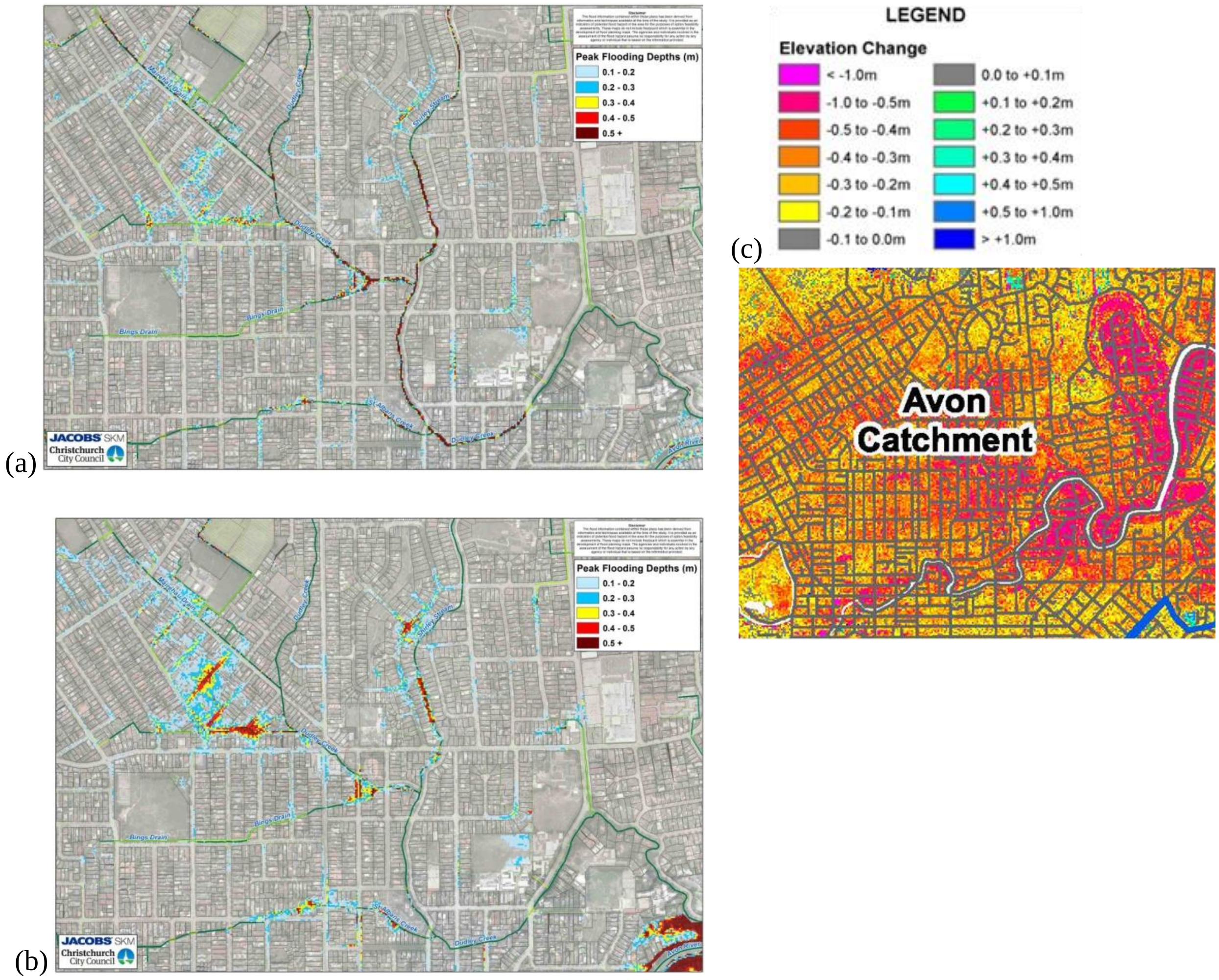


Figure 5-4 Dudley Creek catchment, including the Flockton area: (a) height of flood water for a 10-year return-period rainfall event pre-September 2010 (CCC, 2014); (b) increased height of flooding for same rainfall event post-earthquake sequence (CCC, 2014); (c) cumulative liquefaction induced settlement in the area as a result of the 2010-2011 earthquake sequence (Tonkin & Taylor, 2013).

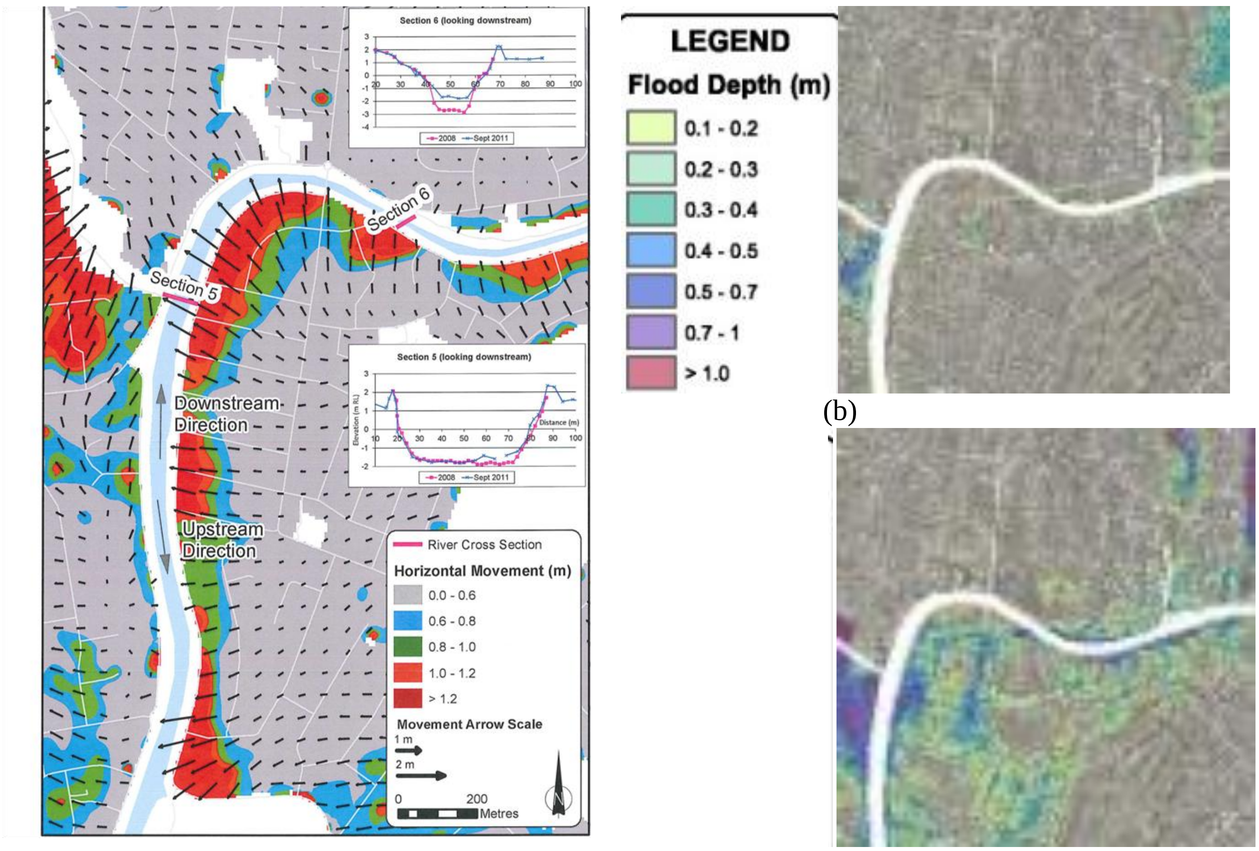
Lateral spreading and river channel capacity reduction effects on flooding of the Avon River

Figures 5-5a and 5-6a illustrate the moderate to severe lateral spreading that has occurred along the length of the Avon River, where major horizontal movements in excess of 1.2 m were observed as a result of th4e 2010-2011 earthquake sequence.

As previously described in Chapter 3 and shown in cross-section 6 in Figure 5-5a, the channel area between Avondale Bridge and Anzac Bridge was subject to significant infilling following the 2010-2011 earthquake events, resulting in a shallower water depth of ~1.8 m in 2011. The Avon River banks suffered significant slumping from liquefaction and lateral spreading. Figure

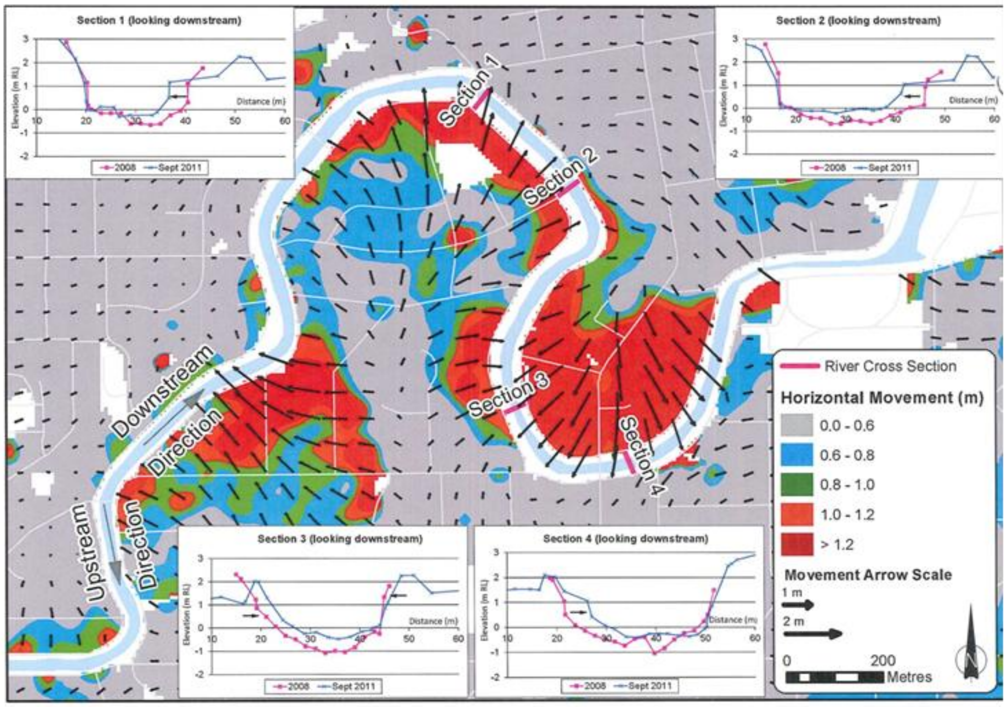
5-5a cross-section 6 clearly shows a shallower slope on submerged banks, especially on the northern bank.

Qualitative comparison of the T&T overland flow maps for pre (Figure 5-5b) and post (Figure 5-5c) earthquake conditions along the Avon River in the area from Avondale Bridge to Anzac Bridge highlights an extended overland flow and an increase in the expected flood depth of up to 0.7 m (Figure 5-5c).

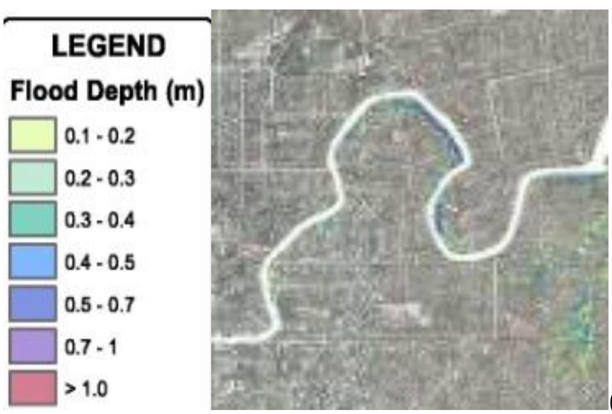


(a) (b) (c)

Figure 5-5 Avon River from Avondale Bridge to Anzac Bridge: (a) post-earthquake sequence cross sections; (b) pre-earthquake sequence river flood depth modelling for the 100 year ARI, excluding stop-banks and climate change; and (c) post-earthquake sequence river flood depth modelling for the 100 year ARI, excluding stop-banks and climate change (Tonkin & Taylor, 2013).



(a)



(b)

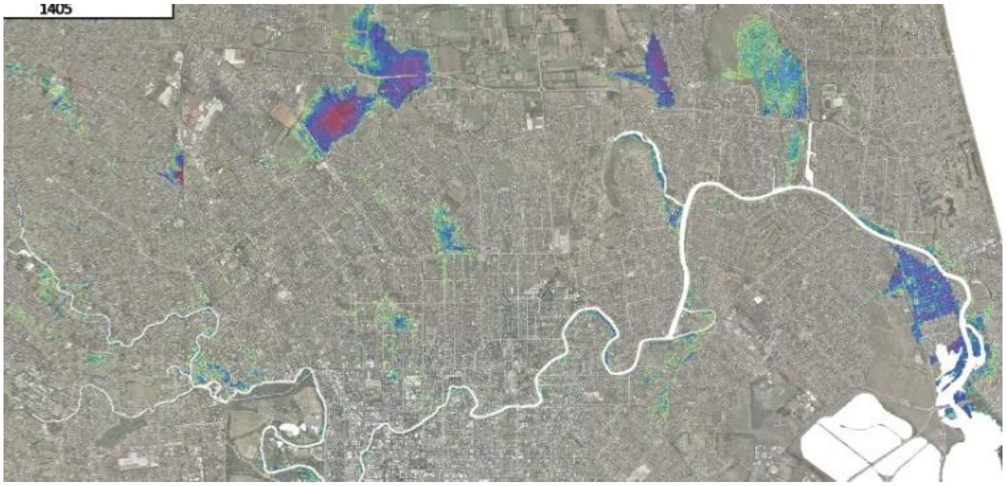
(c)

Figure 5.6 Avon River from Avonside Drive to Stanmore Road Bridge: (a) post earthquake sequence cross sections; (b) pre-earthquake sequence river flood depth modelling for the 100 year ARI, excluding stop-banks and climate change; and (c) post-earthquake sequence river flood depth modelling for the 100 year ARI, excluding stop-banks and climate change (Tonkin & Taylor, 2013).

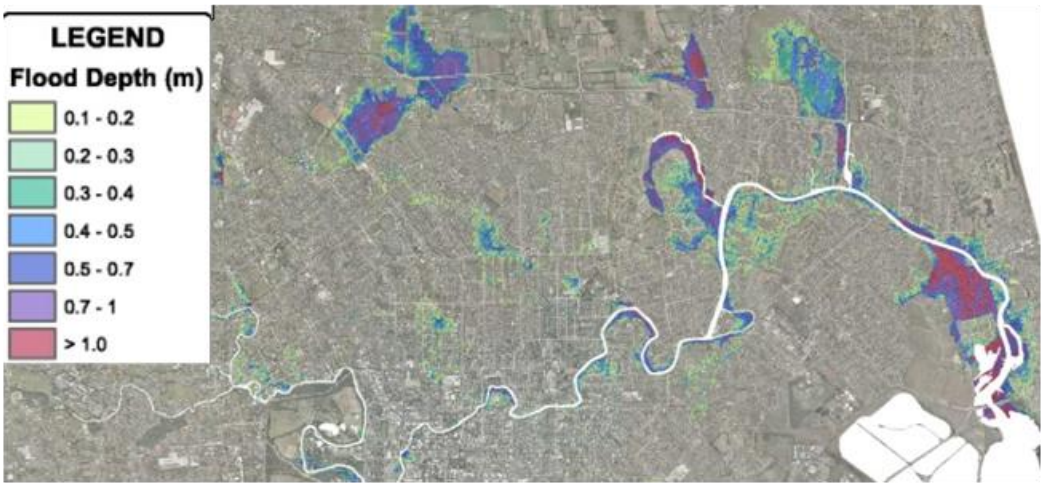
Figure 5.6a presents the horizontal movements (up to 1.2m) observed along the Avon River section in the area from Avonside Drive and to Stanmore Road Bridge. In Section 4 of Figure 5.6a a shift of the northern bank narrowing the river to a width of around 20 m can be observed, along with a decrease of the river depth of around ~0.4 m. At cross-section 3 the river width was narrowed to around 16 m and the water depth was decreased from approximately 1 m to 0.4 m. For both cross-sections 2 and 1 the northern/north-eastern bank remained steady, while the southern/south-western bank shifted laterally by around 5 m into the river and the water depth at the deeper part of the channel decreased by around 0.5m to between 0 and 0.3 m. Further details and comments on the earthquake-induced impacts and changes to river morphology can be found in Chapter 3 of this report.

The qualitative comparison of the T&T overland flow maps for pre (Figure 5-6b) and post (Figure 5-6c) earthquake conditions for the Avon River highlights, in the area from Avonside Dive to Stanmore Road Bridge, an extended overland flow and an increase in the expected flood depth that is expected to exceed 1 m (Figure 5-6c). It is worth noting that the overland flow model, while accounting for the earthquake-induced changes in the river morphology does not account for stop-banks and climate change. The performance of the Avon River stop-banks after the 2010-2011earthquake sequence is described in Chapter 6 of this report.

Figure 5-7 shows the pre- post-earthquake estimated Avon River flood depths (Tonkin and Taylor, 2014). A comparison of these figures identifies increased river flooding depths of over 1 m along portions of the Avon River and in the Avon-Heathcote Estuary Ihutai.



(a)



(b)

Figure 5-7 Increased river flood depths for the Avon River, excluding stop-banks and climate change for the 100 year ARI for (a) pre September 2010 and (b) post 2010-2011 earthquake sequence (Tonkin & Taylor, 2013)

References

Tonkin & Taylor Ltd (2013). Liquefaction vulnerability study. Earthquake Commission. T&T Ref: 52020.0200/v1.0.

Tonkin & Taylor Ltd (2013). Surface and Stormwater Modeling. T&T Ref: 52010-1500.

Christchurch City Council (2014) Land Drainage Recovery Programme: Dudley Creek – Options Feasibility Report March 2014.
http://resources.ccc.govt.nz/files/CityLeisure/projectstoimprovechristchurch/landdrainage/DudleyCreekFloodManagementRestorationFeasibilityReport.pdf