Perspective

Where to next for our sinking city?

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If one were to concoct the perfect recipe for increasing flood hazard, it would go something like this: take a low elevation coastal environment with sandy and silty soils prone to liquefaction, add shallow water tables, add flood-prone rivers, add some hidden active faults, build a city on top, and stir. For maximum effect, stir repeatedly with strong earthquakes then finish with ample rainfall. The taste is that of negative economic impacts, insurance disputes and political controversy with an aftertaste of human anguish.

These are challenging times for our sinking city. As local residents and scientists we are both personally invested and intellectually interested in the question '*where to from here*'? To address this, we need to understand how we got here in the first place.

Earthquakes increase flood hazard

Christchurch was founded largely on an alluvial wetland system, and flooding has long been recognised as the city's primary natural hazard. To enable expansion of the city, formerly saturated areas were drained or elevated to provide drier ground for suburban development. The floodplains of the Avon and Heathcote Rivers have long been recognised as areas susceptible to flooding. The city has dealt with this vulnerability by engineering storm water and river stopbank systems. In 2003 the regional council commissioned airborne laser scanning of the city's topography for flood modelling purposes.

The Darfield earthquake on 4 September 2010 caused extensive liquefaction, land damage and subsidence in susceptible parts of our region, including eastern Christchurch. The 22 February, 13 June, and 23 December 2011 earthquakes caused severe liquefaction and land damage throughout much of eastern Christchurch. After each of these earthquakes, airborne laser scanning was repeated to help assess property damage. When combined with the pre-quake data we now have a very precise picture of how the earthquakes have reshaped the land beneath our city.

The map accompanying this article shows how faulting and earthquake shaking changed elevations of the land surface in Christchurch from 2003 to 2012. Movement on buried faults in the February 2011 earthquake caused uplift of up to 45 centimetres in the Port Hills, the Avon-Heathcote Estuary and Woolston, and subsidence up to 18 centimetres elsewhere. The solid grey lines show where the faults responsible for the Christchurch earthquakes would project to the surface. The lower stretch of the Heathcote River has been uplifted while the upper stretch has subsided, decreasing the river gradient and reducing the ability of water upstream to move to the estuary as efficiently as it did before the earthquakes. Both the uplift and subsidence caused by slip on these buried faults have increased flood hazard.

The greatest contributor to increased flood hazard is ground subsidence in suburbs on the floodplains and in northern coastal areas, most of which was caused by liquefaction. Across central and eastern Christchurch 86% of the area subsided; 10% of the area (including the residential red zone) subsided more than 50 centimetres and in localised areas (mainly the residential red zone) the ground subsided more than a metre. The riverside suburbs of Avonside, Dallington, Burwood/Horseshoe Lake, Avondale, Wainoni, and Bexley experienced significant drops. Many properties in these suburbs were Red Zoned because repairing the extensive land damage would take a long time, was not feasible on an individual basis, and would require potentially expensive engineering solutions that were not certain to satisfactorily reduce the risk of future liquefaction. Parts of Mairehau and Shirley (including the Dudley Creek area), inland North New Brighton and Parklands also dropped up to 50 cm; these areas are largely designated TC2 and TC3.

A cross section through the Avon River shows that flood plains have subsided, lateral spreading of river banks has narrowed the channels, and the deposition of liquefaction silts on the river bed has made the channels shallower. Stop banks have been constructed to account for the floodplain lowering and dredging will increase the depth of the rivers.

Can you spot your property's location on this image? How much you have sunk often (but not always) correlates with the amount of land damage incurred, and if you are in a flood plain next to one of the rivers how much your flood hazard has increased. Other factors, such as impacts on surface and subsurface drainage also contribute to future flood hazard.

Doing Mother Nature's work

The sinking from past (pre-European settlement) earthquakes in our region was counteracted by sediment deposition from the Waimakariri River and related tributaries. Ironically, by controlling the flooding potential of the Waimakariri using stop banks, we have shut off the long-term supply valve that formerly replenished our environment with topography-building sediment. We are now doing Mother Nature's work for her by trucking Waimakiriri River gravels back into our city for ground improvement engineering. In the short-term the city council is responding with infrastructure-based solutions, and insurance debates are before the courts. The longer-term future of our city is intimately tied to how we deal with the geologic, seismologic, and climatic factors imposed upon us.

Future seismicity

The rate of earthquakes over the last three months in the Canterbury region, from the eastern Alps to offshore, is about 1/60th to 1/100th of that between September 2010 and September 2012. We have not had a strongly felt earthquake since a magnitude 4.6 in November 2013. However, the rate of earthquakes over the last three months is still about 5 to 10 times higher than the average rate of earthquakes prior to the 2010 Darfield earthquake. So the chance of a larger earthquake in this broad region is still higher than it was before September 2010. Seismic modellers at Geonet still estimate a 69% chance of a magnitude 5 or greater earthquake and 9% chance of a magnitude 6 or greater in our region over the next year. These probabilities decrease with time and decrease if we focus on a smaller part of that region, for instance within 10 km of Christchurch.

Whether an earthquake causes liquefaction and related sinking depends on the intensity and duration of the earthquake shaking. Our preliminary data suggests that there are at least 10 to 15 faults (that we know about) that could cause liquefaction in Christchurch if they were to rupture in large earthquakes. There may be other ones. Shaking of sufficient intensity to cause moderate liquefaction in the most susceptible Red Zoned areas probably recurs (on average) every 150 to 300 years, and requires peak ground accelerations of about 15% of gravity and earthquakes of magnitude 6 or greater. TC3 land typically requires higher peak ground accelerations (about 30% of gravity) and magnitude 6 or greater earthquakes to cause moderate liquefaction, and is thus expected to occur less frequently. In contrast, we estimate that the strong shaking that caused the major rockfall events in the Port Hills probably recurs every 6000 to 8000 years or so. In summary, we know that earthquakes sourced from some faults could be strong enough to cause further sinking in our city, particularly in the most susceptible areas, although the amount of sinking is unlikely to be as severe as the total sinking experienced in the earthquakes of 2010 to 2011.

Where to from here?

Coastal living is a delicate balance. Both surface subsidence and climate warming may cause relative sea level rise, and uncertainties in future seismicity and sea-level rise projections provide variables to consider in future planning. The 1 metre and 2 metre contours of Christchurch are shown on the map. This gives us an idea of which areas are most susceptible to the effects of future sea level rise.

We are deeply invested in our natural and built environment, but this environment has changed beneath our feet. The westward migration of our city is more geologically and economically sensible, but comes at the expense of the social and economic recovery of much of the eastern and central parts of the city.

With these paradoxes in mind, we make the following suggestions for discussion and debate. We need to continue to add economically viable assets to eastern Christchurch that are resilient to liquefaction and subsidence to increase scenic beauty and quality of life there. Parks, food forests, earthquake memorials, cycling and hiking trails and nature and agricultural reserves are all good and resilient initiatives. Large and expensive developments in the areas most susceptible to liquefaction will be challenging to justify to the people of New Zealand, who share in these investments via earthquake insurance premiums and council and central government bail outs. Red-zoned land should not be re-developed in the future without extensive remediation against future liquefaction, lateral spreading, and flooding. Although this is possible, it is unlikely to be economically viable for most of the Red Zone in our currently low population density framework. Any future developments of the Red Zone that require major engineering could also influence flood hazard elsewhere, including Green Zone areas. Strategic land remediation and re-population of small pockets of the Red Zone with tighter population densities could provide a compromise between recouping financial losses and adding value to the area without increasing liquefaction and flood vulnerability.

The large earthquake rubble mounds in eastern Christchurch could be used for recreation areas and possibly for well-marked tsunami evacuation zones. Engineering solutions to combat further subsidence and relative sea-level rise will need to be continuously implemented and modified given the inevitability of future seismicity and climate change. Further land rezoning and retirement could be considered in this context. Given the inevitability of future westward expansion, are smaller property sizes and affordable housing options being made available there? A combined population of worst hit TC3 land and Red Zoners could be housed in an area equivalent to the size of Riccarton Race Course at the modest population densities equivalent to those currently in Riccarton.

Most importantly, it is absolutely essential that all criteria used for past and future land use decisions are made publically available and explained carefully to those most affected. This includes both the scientific data underpinning these decisions, and any other social or economic criteria that were used to draw the thin boundaries that currently define our colour coded city. The decisions made by previous generations to build on a challenging landscape, and continued through to modern times by building areas of high liquefaction and flooding risk (e.g. Bexley) have left us in a challenging place. Striking the balance between social well-being, economic prudence and environmental realities is challenging. Do we possess the courage to tackle the inevitable challenges of our future now?

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