THE STORMWATER AND TIDE INTERFACE IN CHRISTCHURCH

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ABSTRACT

Christchurch city is mostly built on a floodplain of the Waimakariri River. This floodplain tapers gently toward the coast so the flooding risks at coastal interface is a particularly important area to understand in order to manage this risk into the future. Tidal flooding risk exists not only directly at the coast but also several kilometres inland where the tidal backwater effects extend.

This paper outlines the methods that have been used in Christchurch to estimate and plan for combined tidal and stormwater flooding risk using analyses of historical data and hydraulic modelling approaches. The results of these analyses have been used to develop planning rules and infrastructure programmes.

Recent tidal extreme events have focused attention on the trends in annual high tides. The Christchurch tidal statistics have now been updated following the previous review as recently as 2011. The trends in annual high tides since 1926 have been analysed and a comparison has been made with the higher trends in the last 20 years.

These new statistics are being used to set new finished floor levels for residential and commercial buildings and other infrastructure. They will also be used to re-map the flooding zones in the next revision of the Christchurch District Plan.

The data will also be used to inform Christchurch City Council's future approaches to floodplain management. Council has invested heavily in floodplain management infrastructure since the earthquakes. Major strategic tidal flood protection infrastructure was damaged during the earthquakes and have now been stabilized. This is to allow time for development of long term plans and financing of interventions which will be resilient or adaptable to ongoing sea level rise.

KEYWORDS

Flood risk, climate change, sea level rise, high tide statistics, multi-hazard

PRESENTER PROFILE

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Tom Parsons has been helping Christchurch City Council for the last 5 years on the Land Drainage Recovery Programme as technical manager. His focus has been on developing the programme from inception through to delivery. Tom relies on his experience in stormwater concept design and modelling from a range of different environments, here and overseas.

1 INTRODUCTION

Christchurch City is mostly built on the wide floodplain of the Waimakariri River. This floodplain rises very gradually from the shore to the Southern Alps. The interface with the tide is therefore of critical importance and has been a significant issue in relation to recovery from land settlement effects of the 2011 Christchurch Earthquakes and also the ongoing rise in sea level.

While the earthquakes have had a traumatic effect on Christchurch they have also provided an opportunity to take a very broad strategic view on how best to set up and rebuild the tidal interface infrastructure to be sustainable well into the future and to consider not only the tidal and stormwater flooding effects but also other natural hazards and the consequential and cascading effects that arise from these natural events.

Climate change, and in particular sea level rise, is one of those matters that must be considered in the long term planning for the tide interface. For the most part, the Council has adopted the Ministry for the Environment guidelines in relation to an allowance for sea level rise however the tidal statistics for say a 2% AEP event required for setting a minimum floor level must be derived from local tidal data. Similarly the establishment of various flood hazard zones in the Christchurch District Plan also relies on local tidal statistics. Fluvial and pluvial flood modelling requires a tidal interface to act as the model’s downstream boundary condition

2 CHRISTCHURCH TIDAL STATISTICS

2.1 DEVELOPMENT OF TIDAL STATISTICS

The Port of Lyttelton has been accumulating tide data for more than 100 years and there are also four sites close to Christchurch City that currently have a tide recordings for between 20 and 44 years. These four sites, known as Sumner Head (open sea), Ferrymead Bridge (Heathcote/Estuary), Bridge St (Avon/Estuary), and Styx Tidegates (Brooklands Lagoon) were initially used by Dr Derek Goring in 2011 to generate tidal statistics for use by the Council.

This enabled the Council to establish Building Act finished floor levels in directly tidally affected areas which were a 2% AEP high tide level plus 1 metre sea level rise plus a 400mm freeboard. For tidally affected rivers and floodplain areas back from the coast, the Council has adopted the approach of determining a 2% flood level by finding the highest level of two scenarios being: a 2% tide event with a 20% rainfall and a 20% tide event with a 2% rainfall. This recognizes that there is some correlation between tide and rainfall events but it is unlikely that a 2% tide would occur with a 2% rainfall. Certainly a 2% tide occurring with a 2% rainfall would have a combined probability much less than a 2% AEP. A similar approach has been taken to determining flood water levels for other flood return intervals.


Photograph 1: Mt Pleasant Yacht Club July 2017 high tide

In July 2017 there was a tide event which, according to the 2011 statistics, was 0.125% AEP (1 in 800 year ARI) as in Photograph 1. Then in February 2018 there was a tide event that was a 0.0067% AEP (1 in 15,000 year ARI). This prompted a review of the tidal statistics (Goring 2018) as it was clear that the 2011 statistics were now unrealistic.

The 2018 tide statistics now rank the July 2017 event as 2.4% AEP (1 in 41 years ARI) and the February 2018 tide event as 0.87% AEP (1 in 115 year ARI). This has raised the planning levels for various hazard determinations under the Building Act and the District plan by about 300mm (on average) as indicated in Table 1.

Table 1: Increases in planning levels as a result of the 2018 tide statistics from the Christchurch City Council website.

	High flood hazard management areas (1/500yr)	**Flood management areas (1/200yr)**	**Building Act hazard notice (1/100yr)**	**Building Act floor level (1/50yr)**
Ferrymead	390mm	290mm	260mm	230mm
Bridge Street	360mm	260mm	200mm	150mm
Brooklands	460mm	330mm	280mm	240mm

It would be unreasonable to assume that Christchurch has had sea level rise of 300mm in the 7 years between the two determinations of tidal statistics. There has probably been some sea level rise but much of the change can also be attributed to the longer record of data which included some more extreme values. This underlines the point that these statistics will need to be reviewed from time to time with sea level rise in order to maintain their relevance to the regulatory regime that sets building standards. Alternatively the building standards will need to alter in some way to accommodate sea level rise. It also begs a question about what trends currently exist in the high tide data and how this compares with other published estimates of sea level rise?

2.2 TRENDS IN LYTTELTON AND CHRISTCHURCH HIGH TIDE LEVELS

From a pragmatic flooding point of view, the tidal parameter of interest is the high tide level rather than the Mean Sea Level (MSL) which is normally used in measurements of sea level rise. For the purposes of this analysis therefore, the high tide levels in each calendar year were extracted from the data and simple linear regression trend lines were fitted using standard Microsoft Excel spreadsheet procedures as in the Figures 1 to 5 below.

Figure 1 shows the long term trend in the annual highest tides since 1926 of 2.8mm/y and it also shows considerable scatter in the data and that the events in 2017 and 2018 were the highest tides recorded at Lyttelton. There are many constituents that contribute to extreme water levels at the recording points; including factors such as, astronomical tide, long waves, wind set up and barometric lift. This analysis is of the recorded data which include all these factors in varying degrees for each event. Therefore this simple analysis provides only a general understanding of change in extreme events and not solely sea level rise as the natural variability within the extremes may be more significant than the long term trends observable in the current length of record (without using analysis of other meteorological datasets).

Figure 1: Lyttelton high tides long term trend since 1926

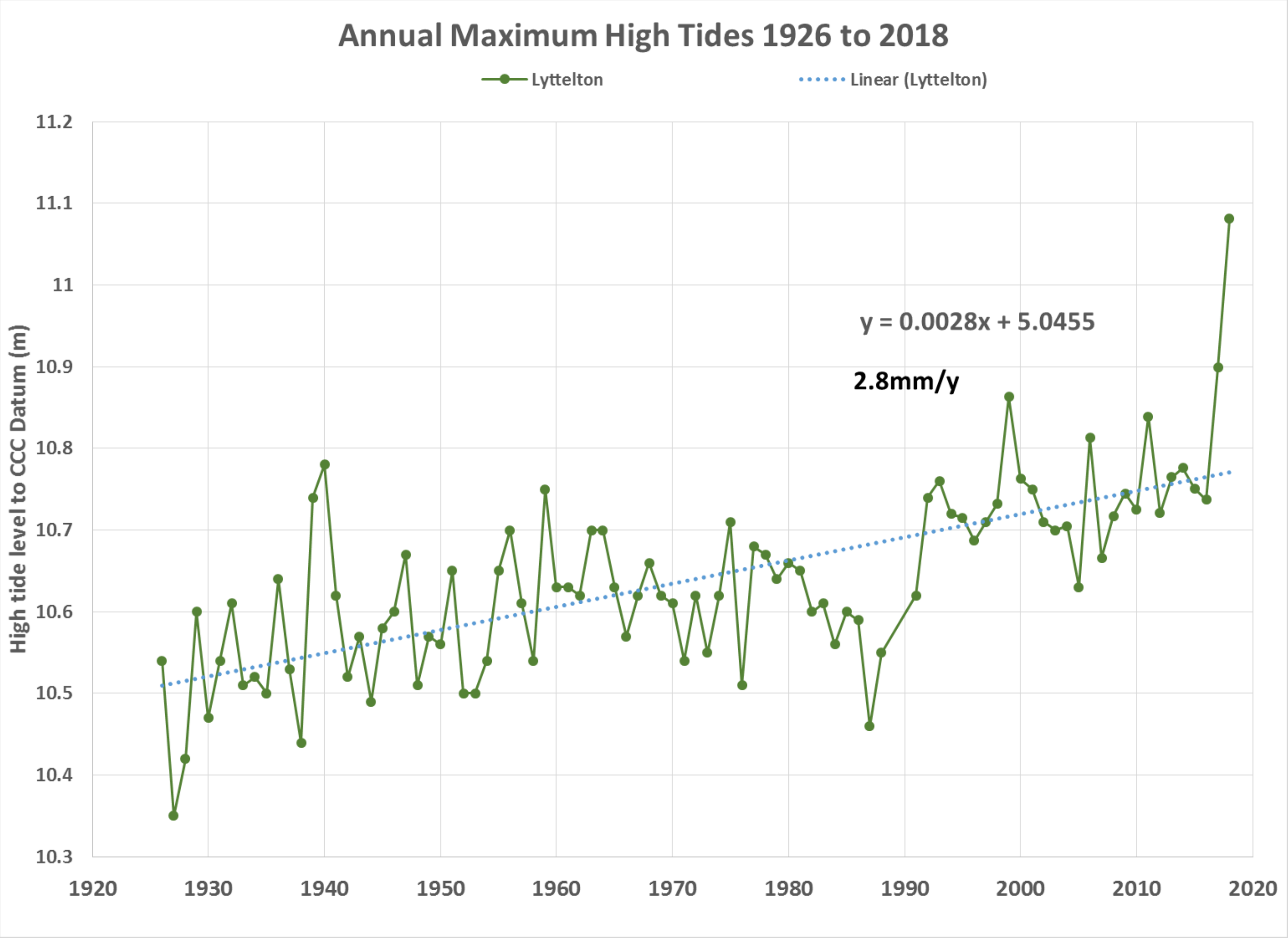


Figure 2 shows Lyttelton and all the other more recent Christchurch recording sites. All the tide recordings show a similar pattern but that there is also considerable scatter in the data. It is of interest to look at the trends in the more recent data to see if there has been a change in the long term trend.

Figure 3 below examines the trends in the sites since 1995. In this period all sites have at least 15 minute level recordings. All the more recent trend lines have a greater slope than the Lyttelton long term trend line. The average of these is recordings is 8.3mm/year. Linear trend lines have been used for illustrative purposed within this paper but may not be the best fit to the data and should not be used for extrapolations given that sea level rise is not forecast to be linear with time.

In addition, trend lines have been derived using all the high tides since 1995 (Figure 4) and also the full tide cycle in (Figure 5). These regression lines show slightly different slopes which are equivalent to 5.51mm/y and 7.08mm/y respectively – compared with the 5.3mm/y for the annual high tide analysis. The differences in these rates could be attributed to the significance of the natural variability of the extremes between the different approaches.

Figure 2: Lyttelton and other Christchurch tide recordings.

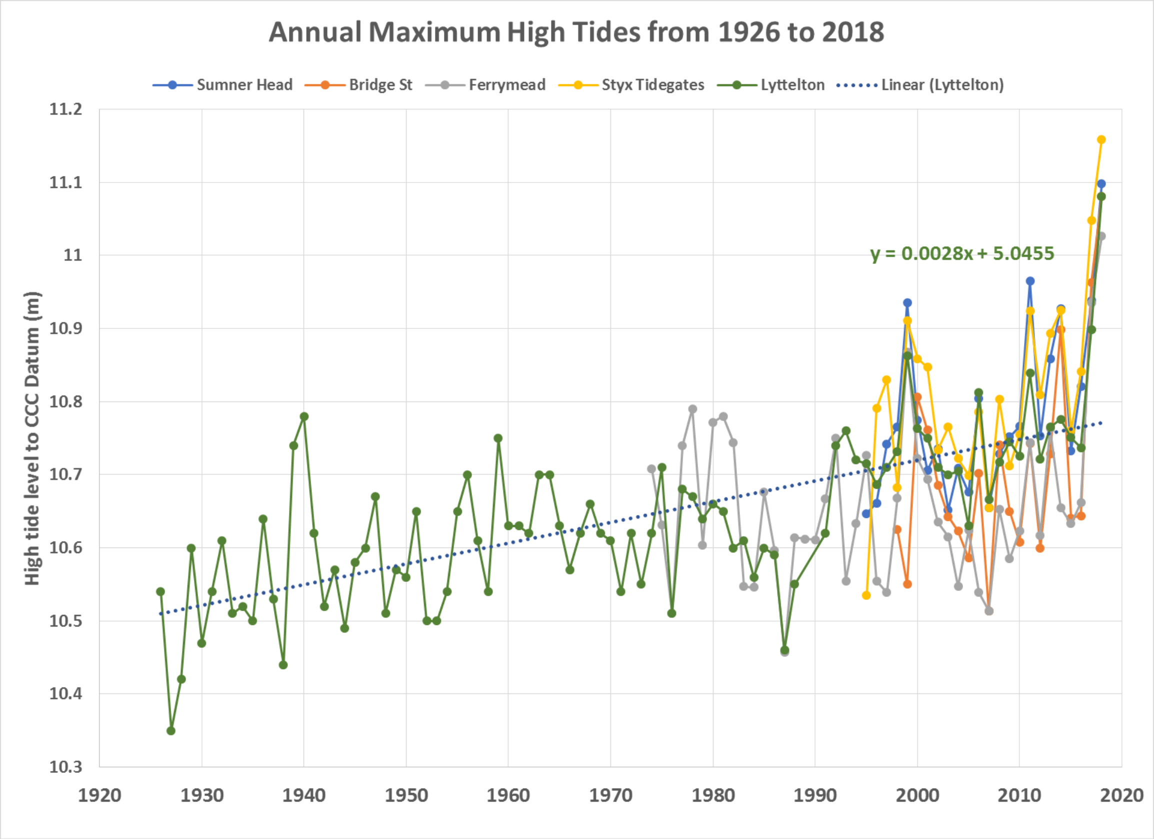
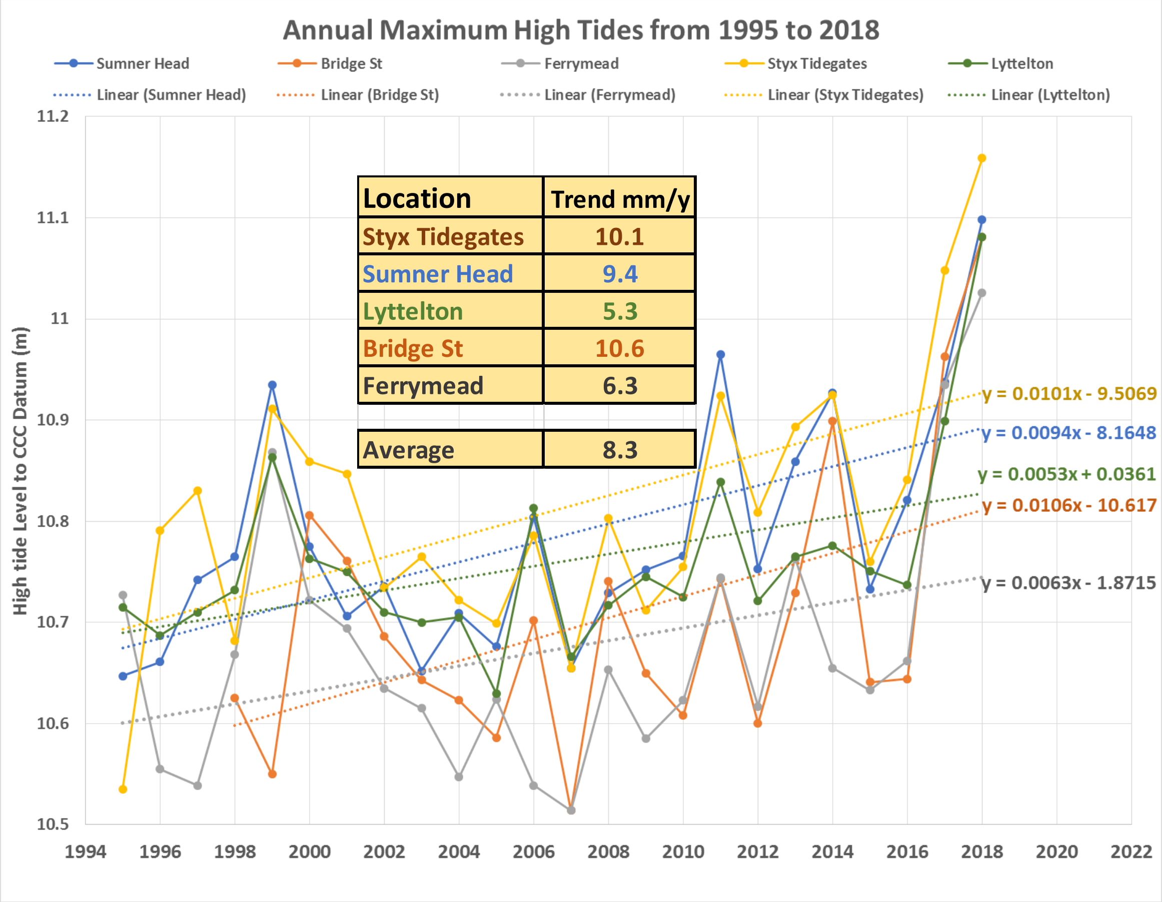


Figure 3: Lyttelton and other Christchurch tide recordings since 1995.



Location	Trend mm/y
Styx Tidegates	10.1
Sumner Head	9.4
Lyttelton	5.3
Bridge St	10.6
Ferrymead	6.3
Average	8.3

Figure 4: Lyttelton all high tide recordings since 1995.

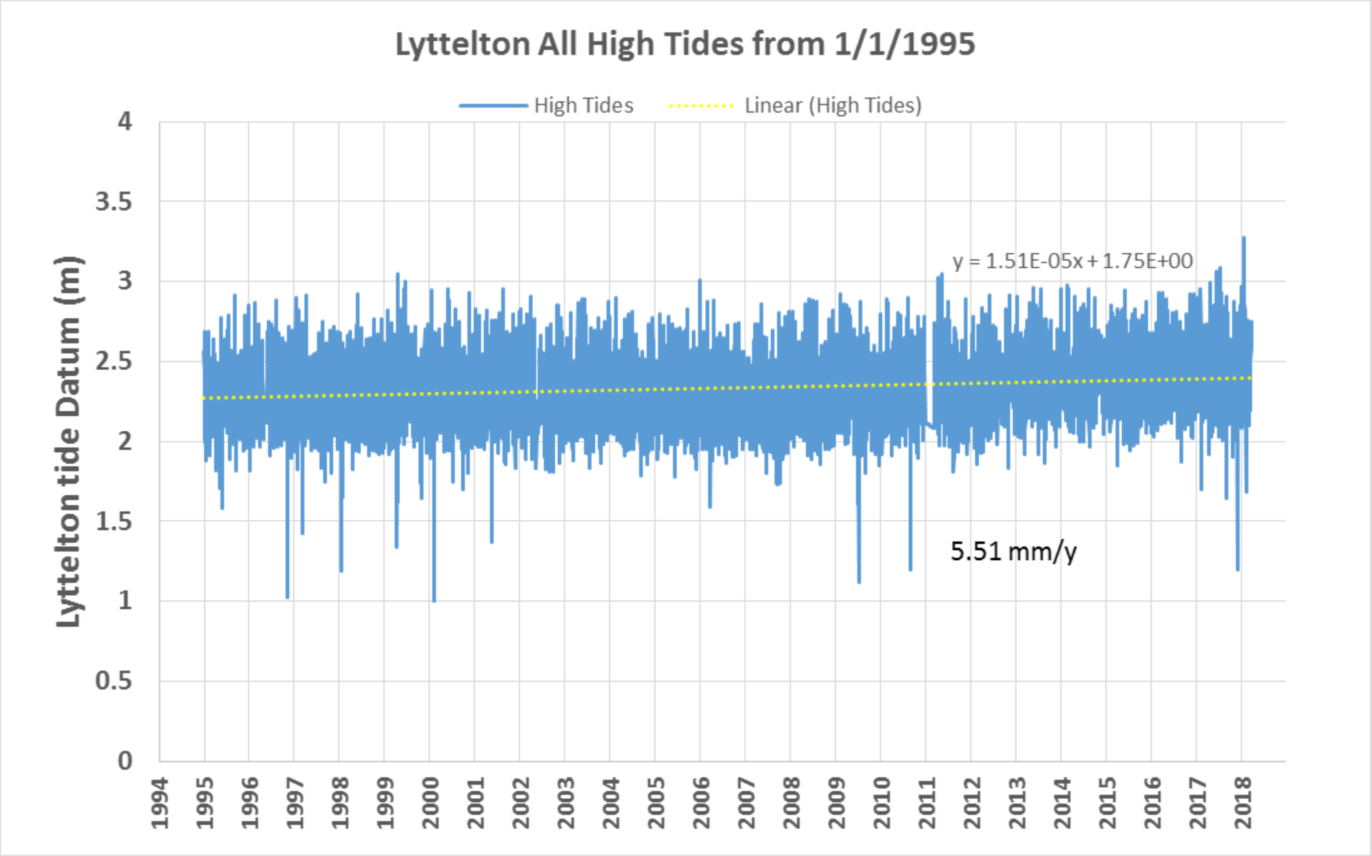
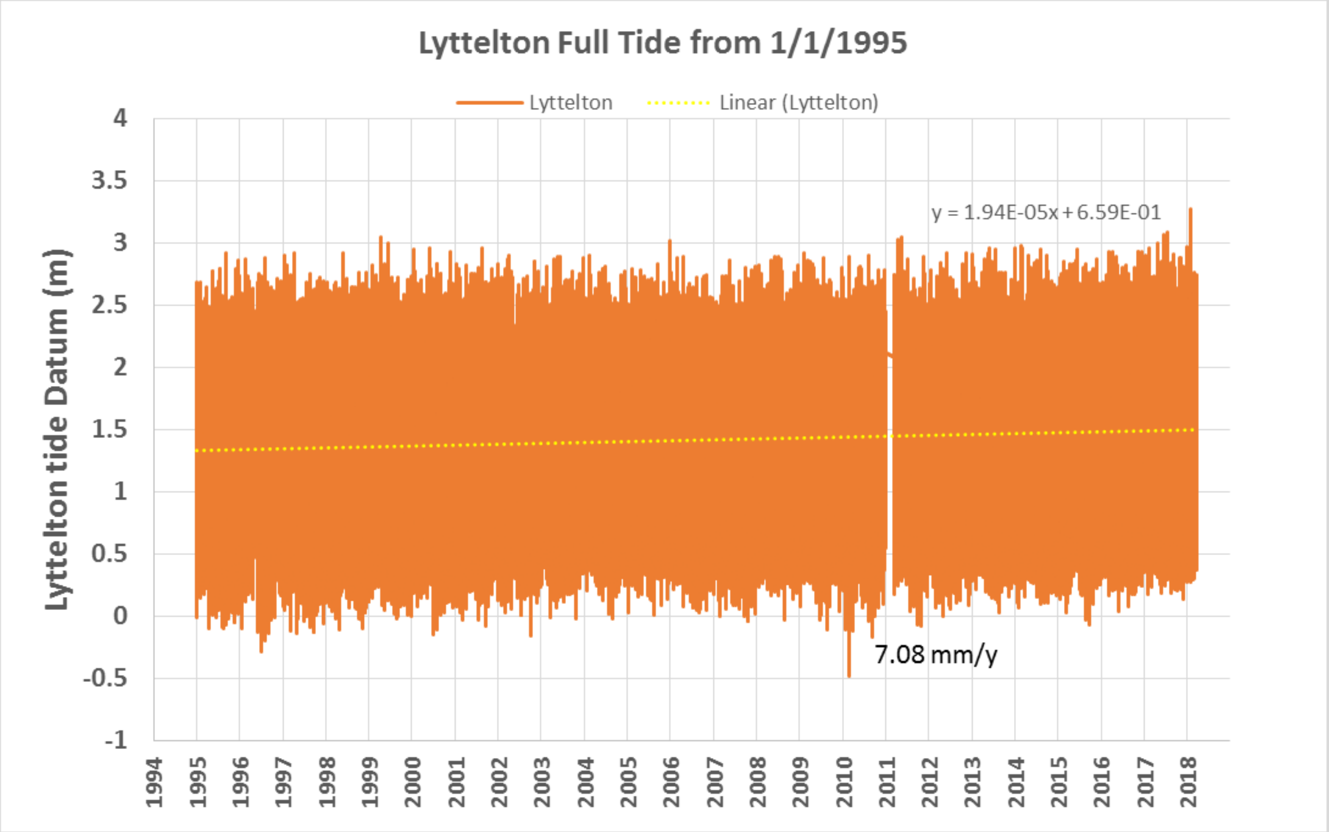


Figure 5: Lyttelton full tide recordings since 1995.



2.3 DISCUSSION OF TRENDS IN HIGH TIDE LEVELS

MfE (2017) guidance for local government (Table 7) gives a long term average rate of rise in Mean Sea Level (MSL) to year 2015 of 2.12mm/year at Lyttelton. Analysis of the type shown in Figure 1 produces a trend in Lyttelton annual maxima tide level of 2.8mm/y. MfE (2017) also quotes a rate of 2.54mm/yr at Lyttelton from 1961 to 2015. The annual maxima tide analysis as in Figure 1 results in 3.1mm/y at Lyttelton for 1961 to 2015. If the period is extended from 1961 to 2018 to include the two recent high tide events then this results in a rate of 3.8mm/y for the trend in high tide levels at Lyttelton. The natural variability in the annual maxima time series could be attributable for some of the difference.

If the 26 year period 1961 to 1987 (see Figure 1) is selected then the rate of increase in high tide level is minus 2.5mm/y at Lyttelton. So there may be quite long term influences on trends in annual maxima tide levels that underlie the natural variability in the system.

MfE (2017) guidance states that satellite altimeter measurements in the wider New Zealand exclusive economic zone ocean water in the period 1993 to 2015 indicate a rise of 4.4mm/y. It is suggested that this higher rate may be influenced by climate variability over the 'short' 23 year satellite record. This paper does not attempt to explain the variability in the tide record by correlating it with longer term climatic events such as El Nino or La Nina or Interdecadal Pacific Oscillation or address tectonic rises and falls in land level or tidal epoch data. There may also be changes in storm surge as a result of climate change.

The paper seeks to show the practical observations and trends that are occurring in the Christchurch tide data which engineers and planners can use in their planning and also give some local information on what could otherwise be thought of as esoteric global science. This paper does not seek to define the underlying causes for the variability in the data.

Analyses presented here of the Christchurch sites (Figure 3) gives an average increase in annual maxima of 8.3mm/y in the period 1995 to 2018.

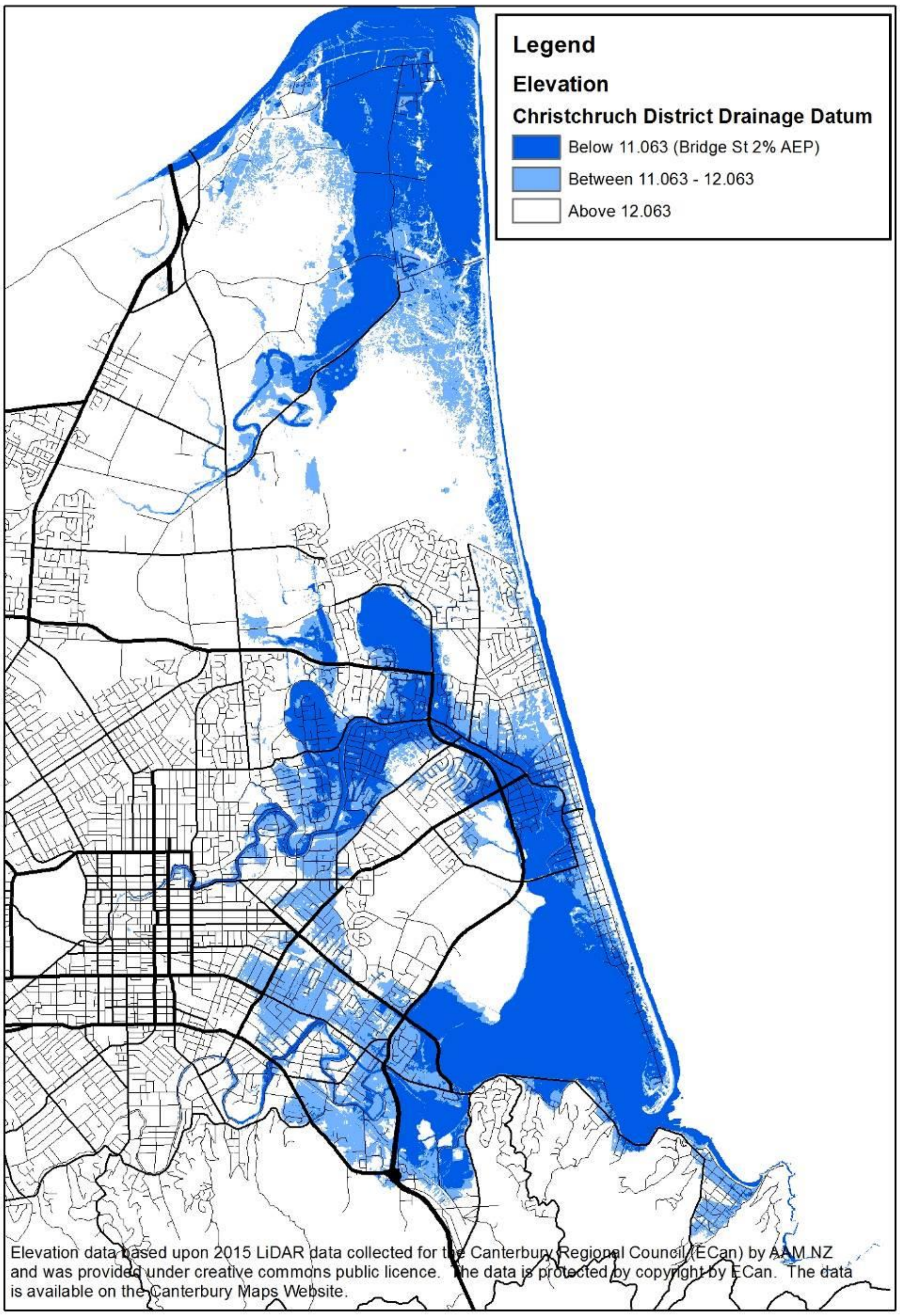
The negative trend in high tide increases in the period 1961 to 1987 however, provides a good reason for caution in interpreting the trends in high tide levels for periods as 'short' as 26 years. The 2017 and 2018 extreme tides may simply be rare events even if they do conform to an anticipated pattern of increasing high tides. Long term strategies, policies and infrastructure will none-the-less need to be developed and implemented well in advance of significant sea level rise as part of the earthquake recovery and the ongoing development of Christchurch.

Taken in the context of all the data and scientific opinion currently available, the precautionary approach in relation to assessing urban developments would be to err on the high side and conclude that the current rates of rise in high tide level could be in the range of 5 to 10mm/yr and that there will be an ongoing increase in the upward trend of high tide levels. This being the case it is reasonable to allow for at least a 1m rise in high tide levels by 2100 as recommended by national guidance (MfE 2017).

3 PLANNING AND INFRASTRUCTURE RESPONSES

Figure 6 shows the extent of the city that is below the current 2% AEP tide level and the same event increased by 1 m to simulate a future sea level rise scenario. This 'bathtub' model clearly illustrates the importance of tide levels when considering future approaches to floodplain management in Christchurch. Given the magnitude of this area, the challenges that the city will face in the future with climate change would be hard to overstate. The Canterbury Region has one of the highest values of infrastructure at risk in the country (Simonson & Hall 2019) with over $2.5 billion at risk within 3m of current mean high water spring tide level. As such, steps have already been taken through the district plan, detailed planning is underway (Parsons, Todd, Cobby, Hart, Kingsbury 2018) and physical works have already been undertaken in some areas to reduce current and future risks to the community (McKay, Christensen and Parsons 2016). These actions are supported by a range of strategies and plans, including: the Resilient Greater Christchurch Plan (Christchurch Partnership 2016), Councils strategic priority of *informed and proactive approaches to natural hazard risks* (Christchurch City Council 2018a), Christchurch City Council 30 year Infrastructure Strategy 2018 – 2048 (Christchurch City Council 2018b) and the Surface Water Strategy (Christchurch City Council 2009).

Figure 6: Areas of Christchurch below Current and Future Tide Levels.



Elevation data based upon 2015 LiDAR data collected for the Canterbury Regional Council (ECan) by AAM NZ and was provided under creative commons public licence. The data is protected by copyright by ECan. The data is available on the Canterbury Maps Website.

Large scale infrastructure responses have been considered in the past. Most recently an Estuary Tidal Barrier was considered within the Ihutai / Avon-Heathcote Estuary (Maclaren and Parsons 2016) (GHD 2015). These types of engineering interventions are costly, difficult to consent and have very long lead in times. Relocation and raising of the existing stopbanks within the Otakaro / Avon River corridor was discussed in the recent draft regeneration plan for the area that was open for public consultation (Regenerate Christchurch 2018). Similar options may exist along the lower Ōpāwaho / Heathcote River, Pūharakekenui / Styx River and other areas as a possible response to changing sea levels. Engineering interventions are best considered alongside and in concert with planning and policy responses to manage residual risks. Both engineering and non-engineering interventions can be used to form dynamic adaptive pathways for long term floodplain management.

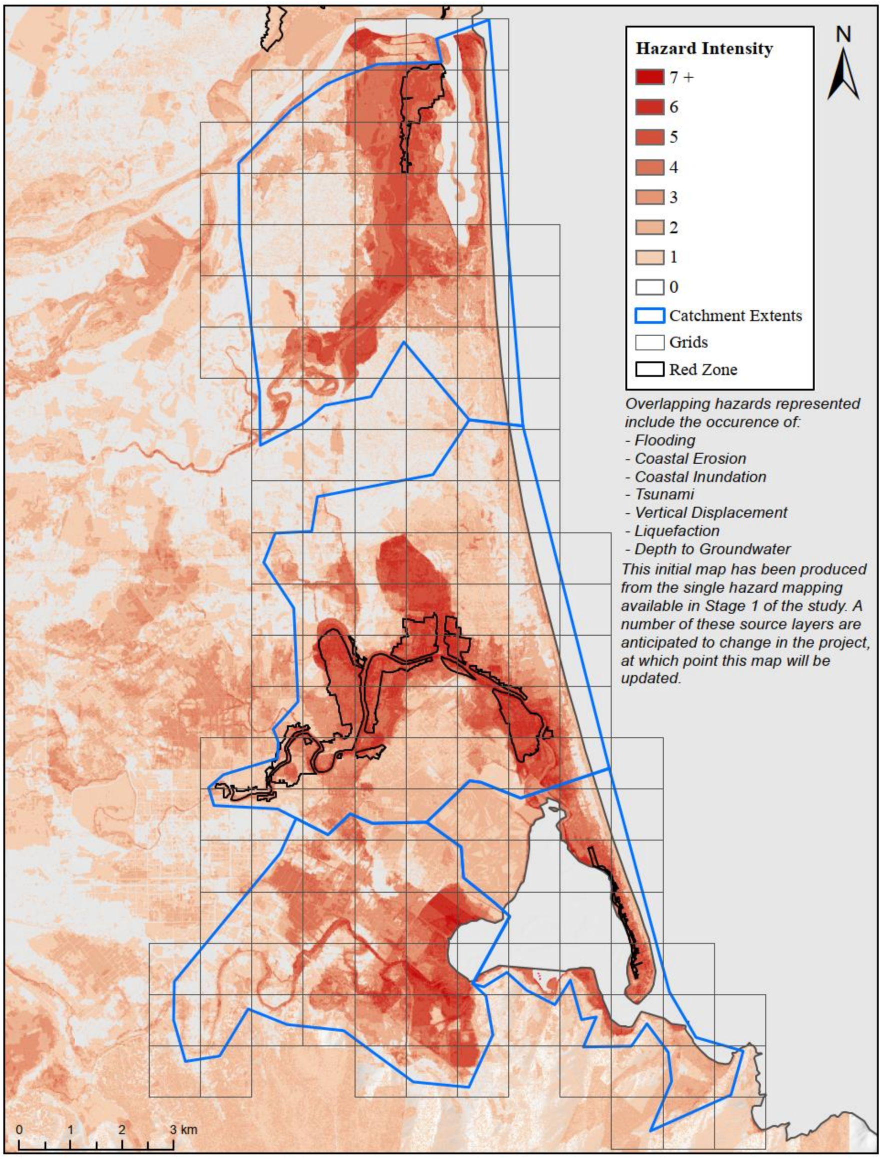
Dynamic adaptive pathway options to respond to rising sea levels are being developed by the Council within a multi-hazard context (Parsons et al 2018). Given the multitude of hazards that the tidally affected areas are subject to decisions on tidal flood risk management cannot be considered in isolation. A map of the preliminary assessment of located hazard co-location has been developed during the early stages of the multi-hazard assessment (Figure 7 replicated below from Jacobs New Zealand Limited (2017) Map B2). It is recognised within guidance documents that decisions will need to be made based upon uncertain predictions for future tide levels (MfE 2017) and that Council will continue to closely monitor tide levels over time as part signals or triggers with dynamic pathways which will result in climate change adaptation actions being taken.

In the absence of achievable and implementable long term strategies and plans there will be a prevalence for reactive interventions to be enacted during or following an extreme event. An example of this was the work enacted by Council during the extreme tide events in July 2017 (Christchurch City Council 2017a, 2017b, 2018c) where emergency works were enacted to prevent tidal inundation of Southshore. In the absence of a long term strategy an operational response was delivered to reduce the impact on the local community. The Southshore / South New Brighton Regeneration Strategy is currently in development and that seeks to find short, medium and long-term options to adapt to the effects of climate change (Regenerate Christchurch 2019).

However, some actions have already been taken by Council in other areas. Most notably Council has invested in repair of and extending the durability of the Ōtākaro / Avon River stop banks. The stop banks were severely damaged in the Canterbury Earthquake Sequence and emergency works were enacted. The emergency repairs were showing signs of deterioration and works were enacted to extend the life of these assets by up to 20 years (Christchurch City Council 2016). This has been to allow sufficient time for adaptation planning and spatial planning (Regenerate Christchurch 2018) to develop and funding to be sought.

Other infrastructure projects (new infrastructure, repairs and renewals) have also been enacted behind the stop banks in order to provide essential services to the community across a range of infrastructure asset types. The performance of these networks will be directly and indirectly affected by sea levels and extreme tide events. Blue sky flooding and groundwater seepage has been observed in low lying parts of the city. These events will impact on the effectiveness and durability of other assets, such as, road pavements, sewer networks and stormwater network either through increased deterioration of the assets or through occupation of network capacity. Understanding current and future tide levels is instrumental in understanding the future of this critical infrastructure.

Figure 7: First Pass Spatial Co-location of Hazards across Christchurch (replicated from Jacobs New Zealand Limited (2017))



Overlapping hazards represented include the occurence of:
- *Flooding*
- *Coastal Erosion*
- *Coastal Inundation*
- *Tsunami*
- *Vertical Displacement*
- *Liquefaction*
- *Depth to Groundwater*

This initial map has been produced from the single hazard mapping available in Stage 1 of the study. A number of these source layers are anticipated to change in the project, at which point this map will be updated.

4 CONCLUSIONS

- The measured trend in rate of increase in Christchurch high tide levels since 1995 is well in excess of the published long term rate of sea level rise however this could be as a result of long term climate fluctuations.

- The local Christchurch tide data generally supports the need to plan for at least 1m rise in high tide levels by 2100.

- Infrastructure planning needs to progress utilising the best data available. Local recorded data can be used to inform analyses in addition to regional or national guidance. However, the authors recognise that decisions will need to be made based upon uncertain data and decisions cannot wait until the recorded data proves the predictions to be right or wrong as this would be too late to influence outcomes for the community.

- Applying a dynamic adaptive pathways planning approach is appropriate in the Christchurch context for aiding in floodplain management in an uncertain future.

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