QUANTIFYING THE CONTRIBUTION OF RAINFALL AND TIDE LEVELS ON FLOODING IN LOW-LYING COASTAL AREAS

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ABSTRACT

Three rainfall events in three months flooded houses in the coastal area of Cockle Bay, Auckland between June and August 2018. Anecdotal evidence from residents, indicated that there had been no flooding in the previous 20 years. Auckland Council received several complaints from affected residents following each storm event. The experienced flooding issues led to significant political attention and pressure. Resolving the flooding issues became a priority for Auckland Council.

Short term remedial works have been implemented to reduce the likelihood of flooding from frequent storms, with the intention that larger scale mid and long-term options will be developed to further mitigate the risk of flooding in the area. For mitigation options to be most effective, an in-depth flooding study was initiated to better understand the issues, including determining the root causes and contributing factors that led to the recurrent flooding and to remove the opportunity for conjecture. In low-lying coastal areas of Auckland such as Cockle Bay, the respective contribution to pluvial flooding from tide levels is often poorly quantified and understood and is largely subjective.

The comprehensive study, to get to the root causes of the flooding and later to inform solutions development, included analysis of the catchment, long term rain gauge data, rain radar imagery, tide gauges, 1D/2D hydraulic modelling results and an in-depth analysis of the capacity of the main culvert under varying tide levels. The effect of climate change and impervious development in the catchment was also assessed.

Further work was carried out, for four low-lying coastal catchments in Auckland, to better understand the effect of extreme sea levels on pluvial flooding in coastal areas. This paper outlines how to spatially identify coastal areas that are sensitive to extreme tides and rainfall, how to understand what catchments might be susceptible to rising sea levels in the future and what ground elevations will sea levels now and in the future effect pluvial flooding. It can be used to understand the effect of rising sea levels will have on flooding in low-lying coastal areas, better assess development in coastal areas and to minimise numerous joint probability modelling runs.

KEYWORDS

Climate change, sea level rise, tide levels, flooding, joint probability, coastal areas, rain radar, rain gauges

PRESENTER PROFILE

Cheryl is a planning and modelling engineer with 14 years of experience in the water industry. Cheryl's experience lies mainly in hydraulic analysis, data manipulation and assessment, model development, issue identification and optioneering.

1 INTRODUCTION

Auckland is a coastal city, surrounded by the Waitemata and Manukau harbours. The Auckland region has 3,700km of coastline and over 5,000ha of flat low-lying areas that are susceptible to flooding exacerbated by coastal inundation. With climate change predicted to increase both likelihood and magnitude of rainfall and sea levels, flooding in coastal areas will become more frequent and severe.

Guidance from Ministry for the Environment states that for Auckland by the year 2100 the current 50yr ARI rainfall event will become a 10yr ARI event (MfE, 2008). A joint probability study by NIWA in 2018 indicated predicted sea level rise (SLR) would result in a 100yr ARI storm tide event becoming a 1yr ARI event in approximately 30 to 70 years' time (NIWA, 2018).

Auckland Council is interested in understanding what the current and future flooding risks are in low-lying coastal areas? What is the scale of the problem? What can we do to manage inundation risk in coastal communities? An in-depth understanding of how flooding occurs in the low-lying coastal areas, would provide some basis for answering the above questions.

This paper discusses the learnings from the Cockle Bay comprehensive flood investigation study, which leads to the question and discussion of how much influence sea level has on pluvial flooding in low-lying areas. To quantify the extent of tide influences, four low-lying coastal catchments were sampled for modelling using extreme sea level and rainfall data. This paper discusses the model results and outlines how to spatially identify coastal areas that are sensitive to extreme tides and rainfall, how to establish at what ground elevations sea levels will affect pluvial flooding now and in the future.

2 COCKLE BAY FLOOD ISSUE STUDY

2.1 BACKGROUND

2.1.1 FLOODING ISSUES

Local residents in Cockle Bay and Howick areas have experienced significant flood events on the 3rd of June, the 15th of July and the 29th of August 2018. The repeated flooding issues have caused significant emotional distress for the local community. Figure 1 shows some of the flooding photos during these events.

Interestingly, contradictory to the recent closely timed flooding events, anecdotal evidence indicates that no significant flooding has occurred in the past 10 to 20 years. Questions have been raised by the local community as to what has caused the recent flooding and what Council could do to mitigate the flooding risk.

A comprehensive flood investigation study was initiated, to understand the root causes of the flooding and to later inform flood mitigation options. The study included analysis of the catchment, long term rain gauge data, rain radar imagery, tide gauges, 1D/2D hydraulic modelling results and an in-depth analysis of the capacity of the main culvert under varying tide levels.

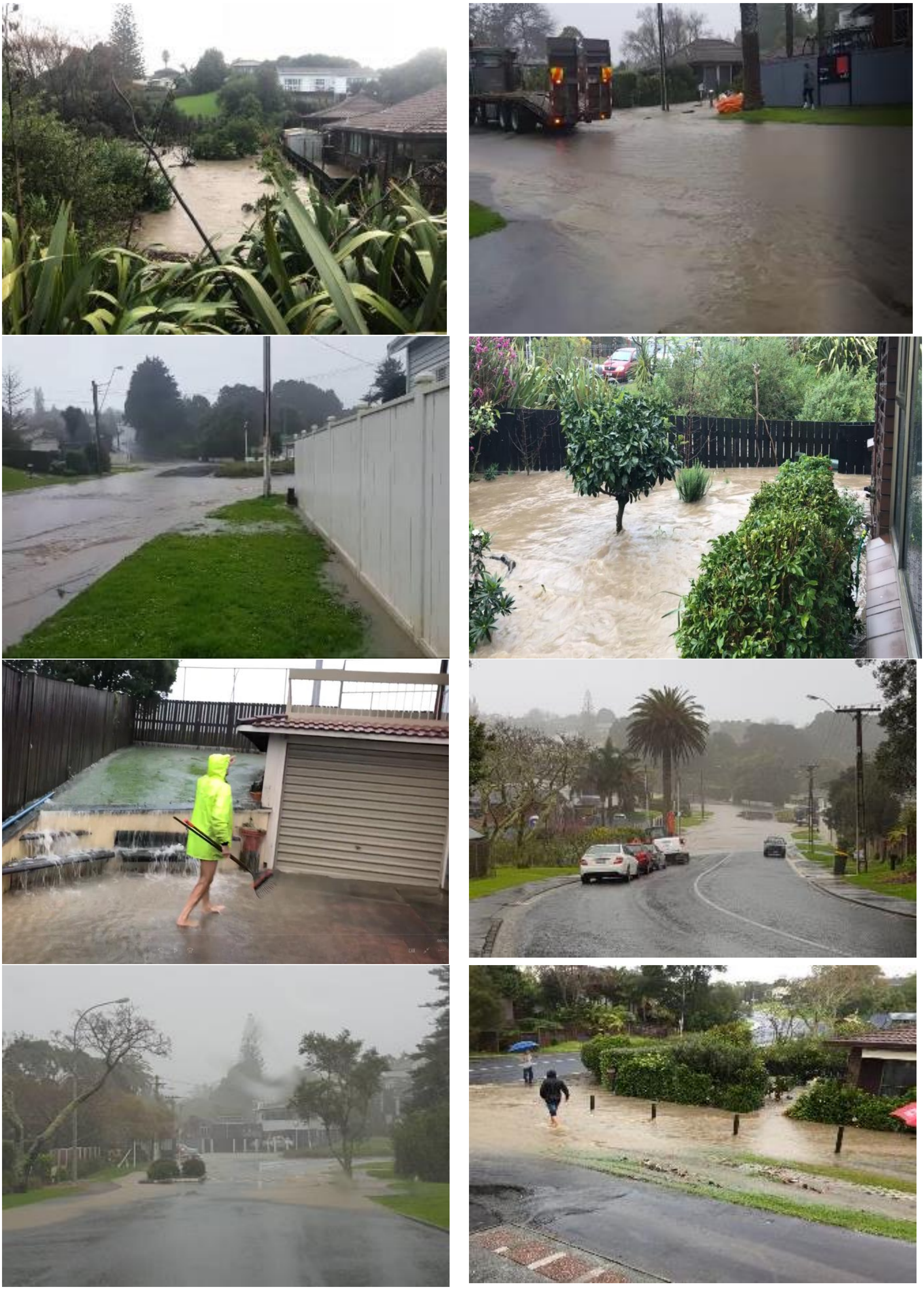

Figure 1: Photos of 2018 Flooding Events in Cockle Bay

2.1.2 THE CATCHMENT

The catchment is 114ha in size and relatively steep with an average slope of 3.2%. The catchment is predominantly residential and approaching being fully developed, as per the Unitary Plan. Critical duration of the catchment is calculated as approximately 30min. Short but intense rainfall events, which happen relatively frequently in the Auckland region, will have the potential to cause flooding in the catchment. The lower part of the catchment, where most of the flooding issues have been experienced, is a flat low-lying area predominately 3-4m RL, located in the coastal inundation zone.

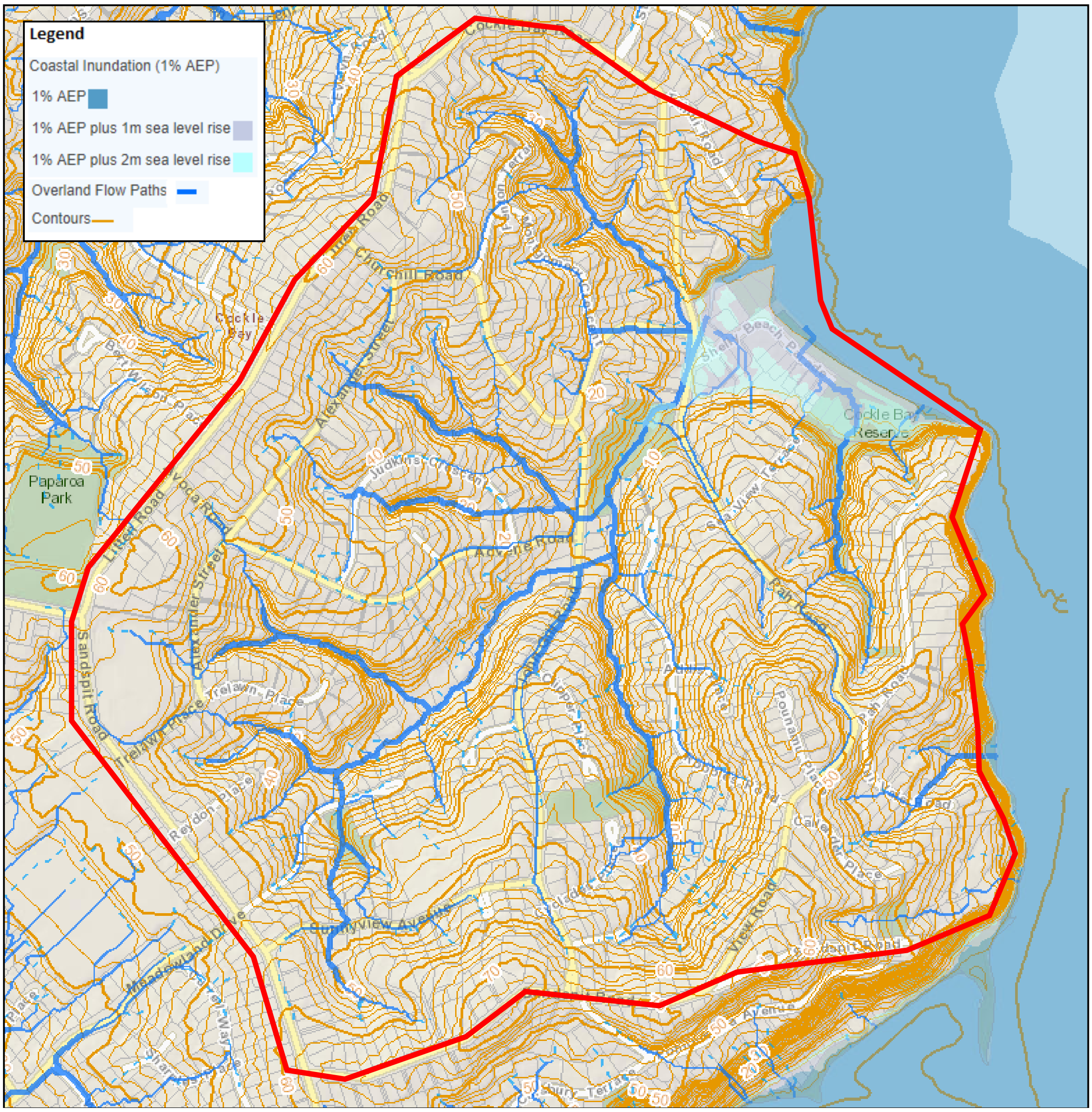

Figure 1: Cockle Bay Catchment and Coastal Inundation Area

2.2 THE ANALYSIS

2.2.1 RAINFALL

A rainfall data assessment was carried to confirm the magnitude of recent rain events as well as identify if events of similar magnitude happened in the record period.

The closest rainfall gauges to the Cockle Bay catchment are "the Pakuranga @ Park Village" and "the Mangamangaroa @ Craigs", with about 40 years and 17 years of rainfall records respectively. Both gauges are located outside of the catchment approximately

4km and 3km away. The rainfall data analysis showed that the rainfall events, except for the 3rd June event, were a relatively small magnitude of less than 2yr Annual Reoccurrence Interval (ARI), referring to Figure 2 and Table 1.

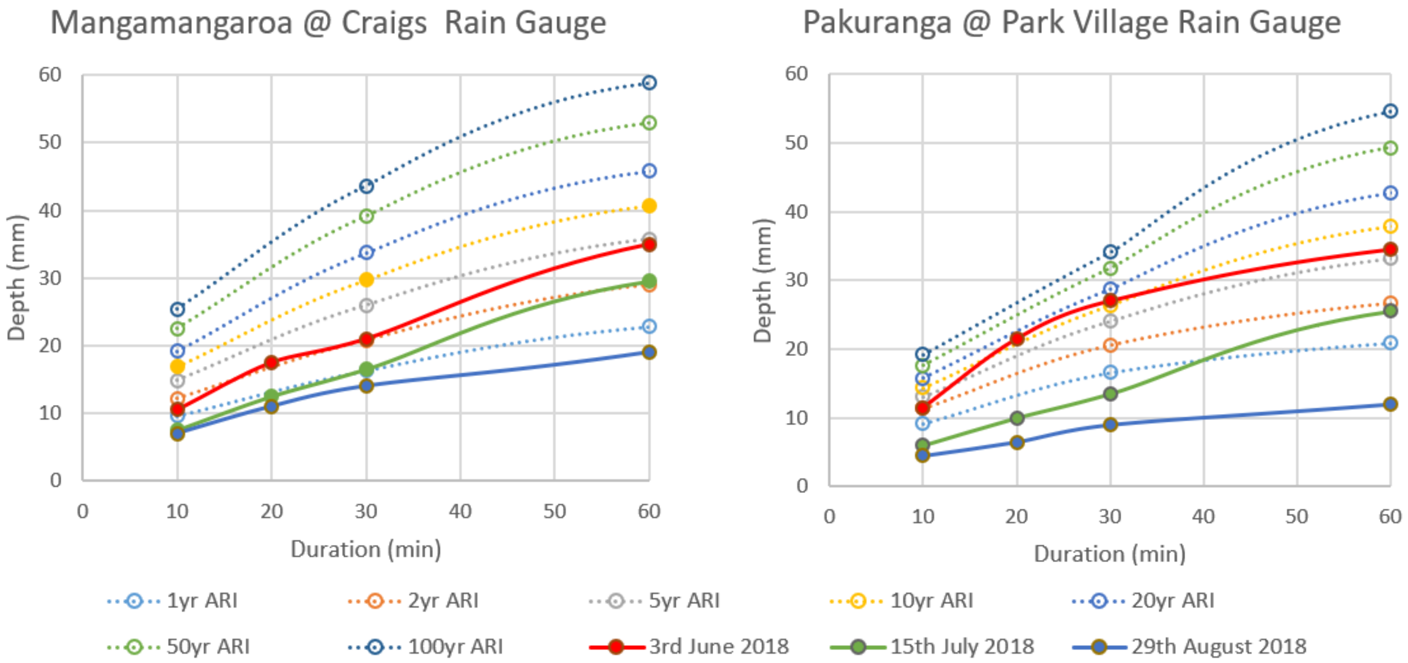

Figure 2: Rainfall ARI Analysis based on Long-Term Rain Gauge Data

Table 1: Maximum Rainfall Depth and ARI in 30min (=Catchment Tc) based on Long-Term Gauge Data

	3rd June 2018	15th July 2018	29th August 2018
Mangamangaroa @ Craigs	21mm (>2yrARI)	16.5mm (1-2yr ARI)	14mm (<1yr ARI)
Pakuranga @ Park Village	27mm (>10yrARI)	13.5mm (<1yrARI)	9mm (<1yrARI)

The relatively small rainfall magnitude contradicts the severity of flooding experienced in the catchment. Considering the locality of the rain gauges and the potential spatial and temporal variability of rainfall across the Auckland Region, it was suspected that the rain gauge data was not representative of the actual events that occurred in Cockle Bay. Rainfall RADAR imagery was analysed to better understand the rainfall that fell in these storm events. Figure 3 shows the RADAR image coloured by ARIs of the June 2018 event.

As suspected, the actual rainfall in Cockle Bay (the red circled area) varied significantly compared to the rainfall at the two rain gauges. Whilst Pakuranga may have experienced a 10-20yr ARI event, the storm in Cockle Bay is less than a 10yr ARI event.

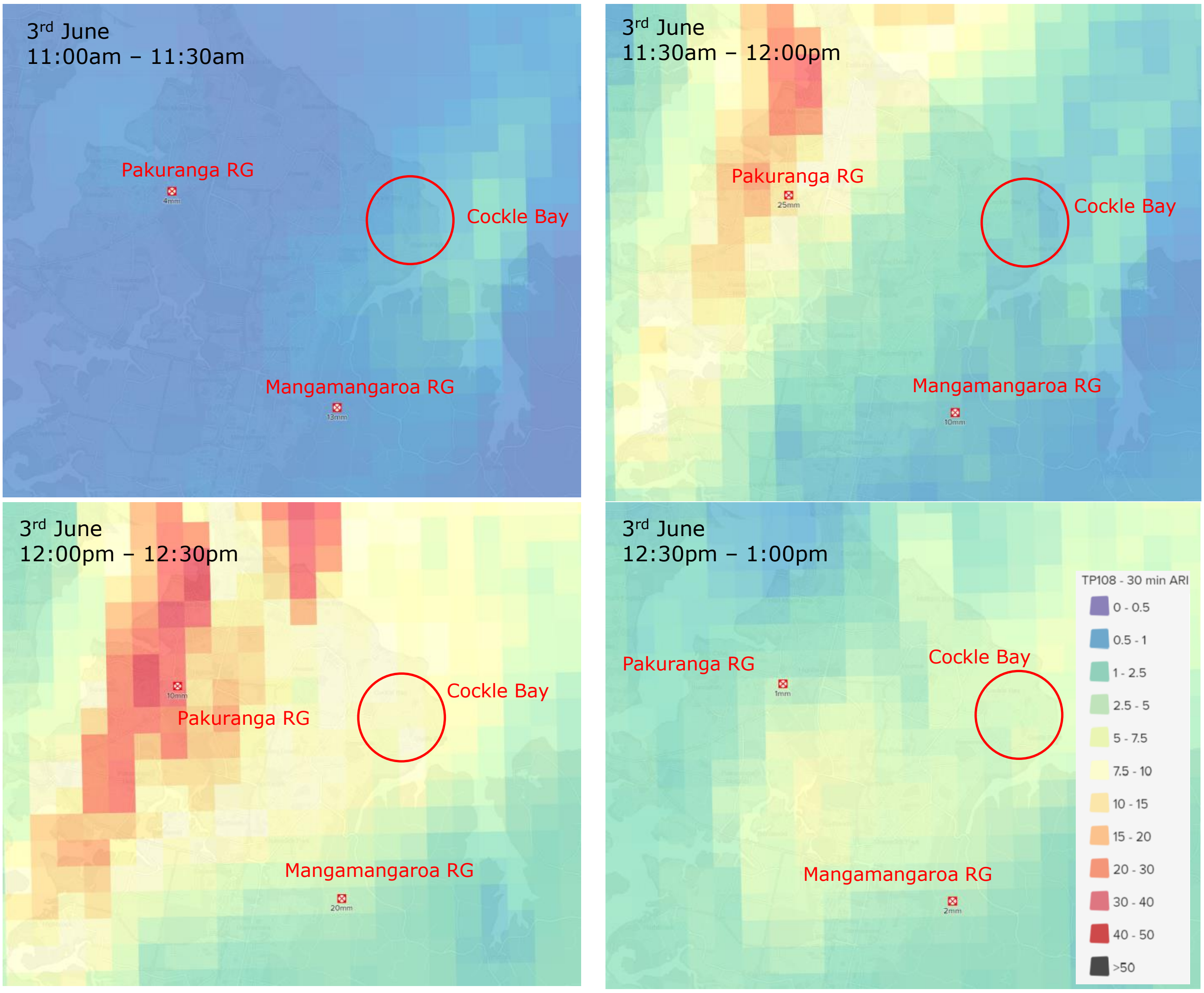

Figure 3: Rainfall ARI based on Rain RADAR Image in 30min

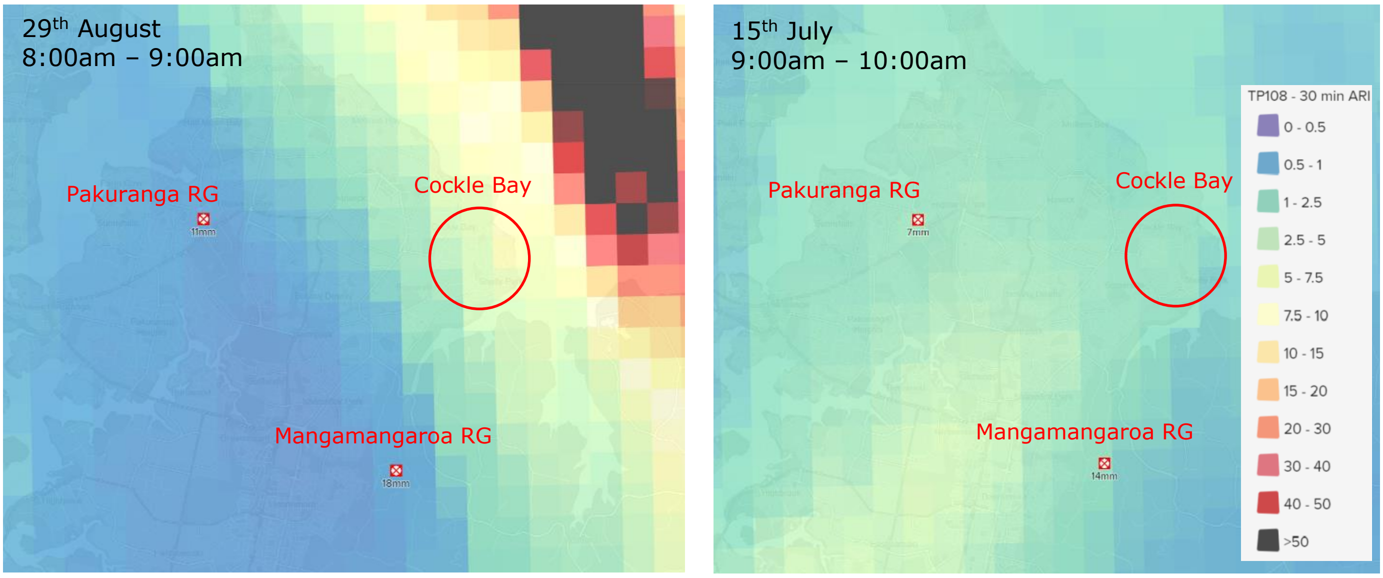

Figure 4: July and August Event in ARI based on RADAR Image

Similar spatial variation has also been observed for the other two storm events, as shown below in Figure 4. Combining both rain gauge data and rainfall RADAR imagery, we have concluded the magnitude of the events as 10%AEP, 20-50%AEP, and 10-20%AEP for the 3 June, 15 July and 29 August events, respectively.

17 years of long-term rainfall records at Mangamangaroa rain gauge was also analysed to identify any rainfall events greater than 2yr ARI at 30min-1hr duration. As shown in Figure 5 below, the Mangamangaroa rain gauge recorded eight rainfall events with an ARI of 2yr or higher since January 2002 and no significant event has been recorded between 2008 and 2017. This aligns with the anecdotal evidence of no significant flooding events for years before 2018. The July and August 2018 events were marked as dotted lines as they have been recorded as less than 2yr ARI as this rain gauge site.

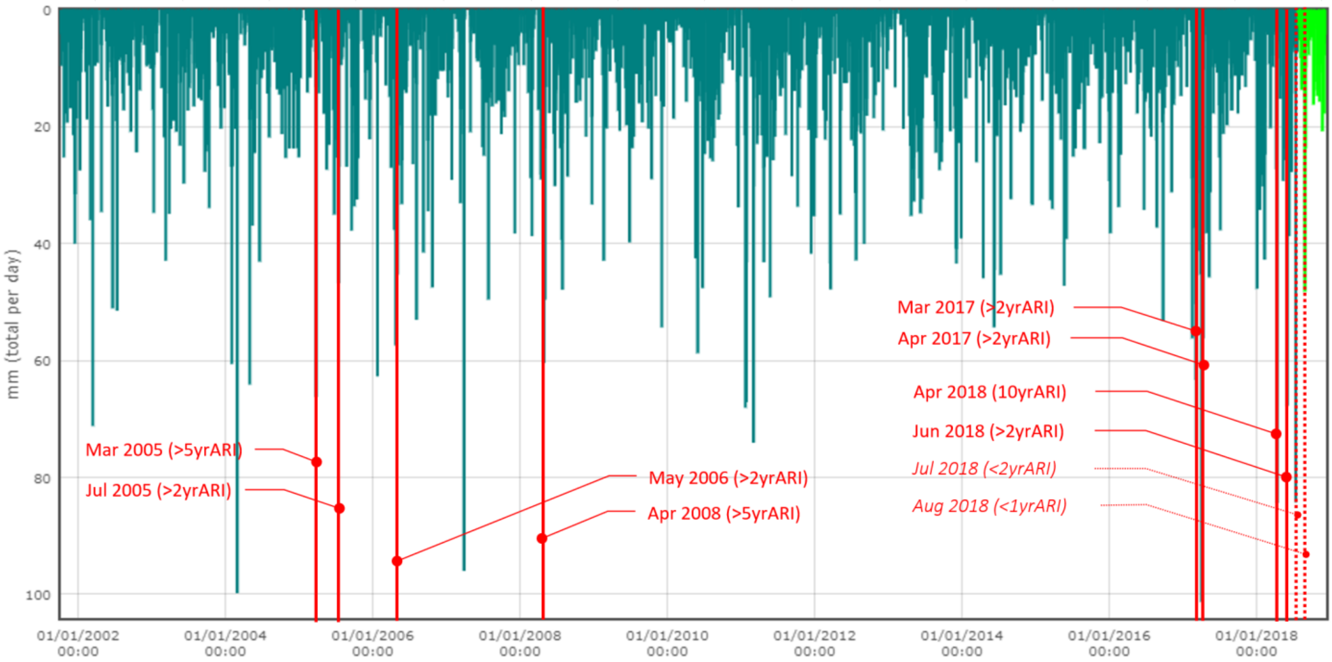

Figure 5: Events greater than 2yr ARI at 30min-1hr Duration

It should be noted however that the above recorded events could vary significantly to the rainfall that fell in Cockle Bay, due to the spatial variability of rainfall and the distance of the Mangamangaroa rain gauge from Cockle Bay.

2.2.2 TIDE LEVELS

Cockle Bay has a flat lower-lying area at the bottom of the catchment with many houses built in the 3-4mRL elevation range. This area is identified as under the risk of coastal inundation, as shown in Figure 2.

In addition to the rain events, it was suspected that tide levels may have also influenced the flooding in 2018, as the rain events coincided with high tide. The closest tide gauges are the Ports of Auckland and Devonport Naval Base gauges, which are located 20km and 17km respectively.

Using these two tide gauges, it was found that the maximum tide level for the three events generally coincided with the peak rainfall intensities. All three storm events had sea levels higher than the mean high-water neap (MHWN) and the 3rd June and 15th July events had tide levels higher than the mean high-water spring (MHWS), as listed in Table 2.

Table 2: Sea levels during the heaviest rainfall of the three assessed storm events

Tide	Ports of Auckland Tide Level (m RL)		Devonport Naval Base Tide Level (m RL)		Magnitude of the Tide Events
	Min	Max	Min	Max	
3rd June 2018 (11:00am-1:00pm)	0.64	1.37	0.82	1.39	Greater than MHWS
15th July 2018 (8:00am – 9:00am)	1.91	1.97	1.86	2.07	1yr ARI Tide
29th August 2018 (9:00-10:00am)	1.32	1.47	1.38	1.46	Greater than MHWS

It should be noted however, the actual sea levels experienced at Cockle Bay may differ than those recorded at the same time at the Ports of Auckland and Devonport Naval Base gauges, due to storm surge, wind and wave setup, and localised ocean bathymetry.

2.2.3 JOINT PROBABILITY

In coastal areas both rainfall and tidal levels can influence the severity of flooding. The joint probability of both the rainfall and tide needs to be considered. The joint probability of the three storm events were estimated based on the NIWA report of "Joint-probability Analysis of Rainfall and Sea Level Records in Auckland" (NIWA, 2018). The NIWA study calculates the probability of various combinations of extreme rainfall depths and extreme sea-level coinciding, using the Ports of Auckland sea level gauge, and the Albert Park and Whenuapai rainfall gauge information.

Table 3: Joint probability of the three storm events

Flood events	Rainfall AEP	Tide Level AEP	Joint Probability AEP (using NIWA 2018 Study)
3rd June 2018	10%	63-100%	2-5%
15th July 2018	20-50%	63%	5-10%
29th August 2018	10-20%	63-100%	2-5%

As can be shown in above Table 3, both estimation methods resulted in very rare joint probability of the rainfall and tide events happening at the same time. However, this is only relevant for the areas of the catchment that are affected by the tide level, i.e. in the lower lying area at the bottom of the catchment. Furthermore, whilst a 2% AEP rainfall event may be treated as roughly equivalent to a 2% AEP flooding event, a 2% AEP joint probability event may not produce nearly as much flooding, even in areas where the sea level affects flooding. This is due to the rainfall being the primary driver and contributes more to the flooding at Cockle Bay, as confirmed by the stormwater system and flood mechanism analysis described in the following Section 2.2.4. Further analysis has been undertaken to quantify spatially how tide or sea level impacts on pluvial flooding in Section 3.

2.2.4 STORMWATER SYSTEM

Cockle Bay is reticulated with streams largely remained as natural open channels. This provides a positive contributor to limiting the number of flooding issues, especially in the middle parts of the catchment. Inevitably some culverts have been constructed to convey flows under roads. The most significant and critical culvert is a 1,500mm diameter culvert that conveys the majority of the catchment runoff from the Cockle Bay Domain to the coast, as highlighted in green in Figure 5 below. The capacity of the culvert has been known to have been exceeded in two of the three recent flooding events, with flow spilling over Pah Road causing flooding issues.

Figure 5: Flooded properties in the three storm events at Cockle Bay

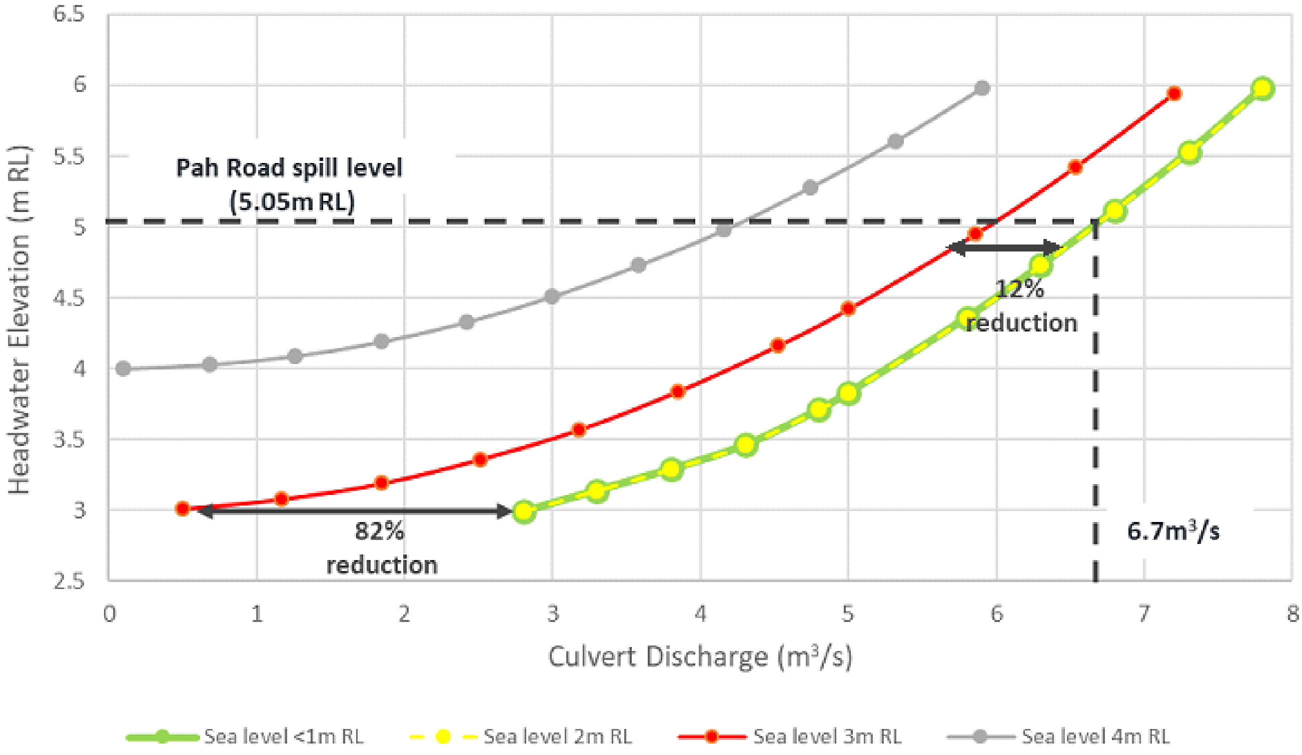

Figure 6: Capacity of the 1,500mm diameter culvert for varying tide levels

The culvert's capacity was analysed in detail, considering different tide levels, as shown in Figure 6. From the analysis, it was found the culvert's capacity is unaffected when the tide level is less than 2.5mRL. As the boundary tide level increases to 3mRL, culvert capacity is reduced by approximately 82% and 12% at a headwater of 3mRL and 5mRL, respectively.

The analysis demonstrates the capacity of the culvert does not reduce significantly with elevated sea levels and is largely inlet controlled with reasonable headwater depths, until the tailwater level is larger than 2.5m RL, which equates to approximately the soffit of its outlet. Based on the Port of Auckland tide data, the current mean high water spring (MHWS) level of 1.37mRL is well below the 2.5mRL. The current 100year ARI storm tide of 2.18mRL is also lower than the above critical tide level, based on the 2013 NIWA report of "Coastal Inundation by Storm-tides and Waves in the Auckland Region" (NIWA, 2013).

In conclusion, the road overtopping and house flooding in the lower part of Cockle Bay catchment is entirely due to the intense rainfall event, regardless of the intersection of peak rainfall event occurring with high tide. The multiple 2018 flooding events in Cockle Bay were all independent of the tide events.

2.3 OTHER CONSIDERATIONS

Other factors that may have contributed to the flooding experienced in Cockle Bay have been considered, such as development changes in the catchment and climate change effects.

Based on the Unitary Plan, the Cockle Bay catchment is almost exclusively zoned Residential Single House, with no significant growth and redevelopment potential. Figure 7 shows aerial photography of the Cockle Bay catchment taken at 1996 and 2017, which showed very similar urbanisation coverage. However, further impervious development and infilling is possible, and the catchment could eventually have an imperviousness of approximately 65-70% under the Unitary Plan rules. This means roughly an increase 20% of impervious areas comparing to the current situation, which is expected to further exacerbate flooding issues if not appropriately managed.

Figure 7: Aerial photography of the Cockle Bay Catchment at 1996 and 2017

Climate change is predicted to increase both the likelihood and magnitude of rainfall as well as rising sea levels. For Auckland by the year 2100 the current 50yr ARI rainfall event is expected to be a 10yr ARI rainfall event (MfE, 2008). The latest guidance from the Ministry for the Environmental in 2018 indicates that very extreme rainfall is likely to increase for all durations and with more pronounced increases for shorter duration events, of which Cockle Bay is susceptible to (MfE, 2018). Sea level is predicted to increase between 0.4-1.2m in the next 100 years (NIWA, 2018). Rising sea levels will worsen flooding issues, reducing the ability of the stream and the culvert to convey flows to the coast, which leads to reduced level of service and increased costs of flood mitigation solutions as well as operation and maintenance costs.

3 RAINFALL AND TIDE IMPACT IN COASTAL AREAS

A combined rainfall and tide event of a rare joint probability may not be equivalent to a similar rare flooding event, as the sea level may have less influence on flooding than expected. The frequency and magnitude of flooding is dependent on the physical characteristic of the catchment and its stormwater system, in addition to rainfall and tide levels.

Between the two factors of rainfall and tide, it is commonly understood that rainfall would be the sole contributor for flooding, for areas outside the influence of coastal inundation. However, for the areas currently located within the coastal inundation areas, further study would be required to quantify how much influence tide has on flooding and how to understand the potential effect of extreme sea levels on flooding in and outside of the coastal inundation area.

The following section of the paper demonstrates how rainfall and tide influence on flooding is quantified and displayed spatially, using four sample coastal catchments.

3.1 SELECTED CATCHMENTS

In addition to the Cockle Bay Catchment, three additional low-lying coastal catchments were selected for assessing the influence on flooding in coastal areas from rainfall and tide. The catchments assessed were Stanley (CBD), Mission Bay and Sulphur Beach. All three catchments have available detailed 1D/2D hydraulic models for the assessment and are known to be prone to coastal inundation. Figure 8 below shows the catchment boundaries and coastal inundation areas within the catchments.

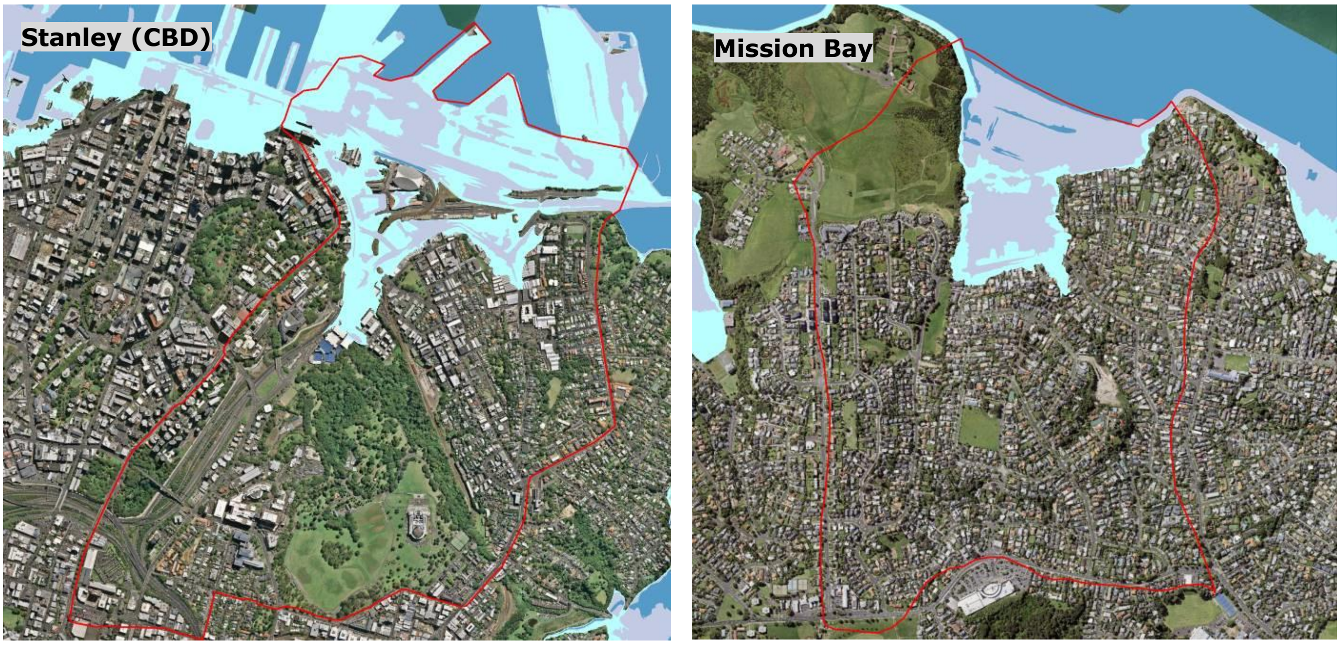

Figure 8: Coastal Inundation Areas within the Selected Catchments

Table 4 summarises some basic characteristics of the four catchments.

Table 4: Catchment Characteristics

Catchment	Catchment Area (ha)	Coastal Inundation Area (ha)	Notes
Stanley (CBD)	360	90	Lower lying area significantly formed by land reclamation
Mission Bay	170	25	Lower lying area partly formed by land reclamation
Sulphur Beach	50	12	Lower lying area partly formed by land reclamation
Cockle Bay	150	5	Natural Catchment

3.2 METHODOLOGY

For the purpose of this study, the 100yr ARI storm tide event was selected as the boundary sea level to assess the flooding under the 100yr ARI rainfall event. A simple simulation matrix has been developed to understand how much impact sea level has on flooding, as shown in Table 5 below. A fourth scenario was also assessed for each of the catchments to quantify the effect of storm tide with 1m sea level rise.

Table 5: Base Scenarios

	Rainfall	Sea Level	Note
Scenario 1	100yr ARI rainfall	100yr ARI storm tide	Model Simulated
Scenario 2	100yr ARI rainfall	no tide	Model Simulated
Scenario 3	no rainfall	100yr ARI storm tide	Analysed in GIS
Scenario 4	100yr ARI rainfall	100yr ARI storm tide +1m sea level rise	Model Simulated

TP108 hydrology was used to generate the standard 24-hour 100yr ARI design rainfall (ARC, 1999). The 100yr ARI storm tide levels were obtained from the 2013 NIWA Coastal Inundation Study (NIWA, 2013), as shown in Table 6, and applied as static boundary water levels in the models. Detailed 1D/2D hydraulic models were used to simulate the above scenarios. The difference in maximum water levels/depths from Scenario 2 and

Scenario 1 were calculated and analysed. In a similar way the differences in flood level and extent were calculated between Scenario 4 and Scenario 2.

3.2.1 FLOOD LEVEL DIFFERENCE

No significant differences in flood extent were observed with or without a 100yr storm tide (between scenario 1 and 2). However, the difference in flood depths showed measurable differences for all catchments, as displayed in Figure 9. Generally, the results show that the closer it is to the coastline, the bigger impact sea level has on flood depth. An exception is Stanley and Sulphur Beach catchments where the ground is more elevated at foreshore areas due to land reclamation activities.

Figure 9: Increase in 100yr Flood Depth with 100yr Storm Tide compared to No Tide Scenario (Scenario 1 minus Scenario 2)

The small Cockle Bay tide influence area in Figure 9 also indicates that the flooding events in Cockle Bay in 2018 were likely not influenced by tide levels, as no storm events in 2018 corresponded with a tide level exceeding the 100yr ARI storm tide (Table 2). This result is consistent with the culvert capacity analysis under different tide levels, as discussed in Section 2.2.4.

As the low-lying areas in the selected catchments mostly have an elevation between 2 - 4m RL range, additional scenarios were also assessed to test how sensitive these areas are to increased sea levels due to climate change. As shown in Figure 10, flood depths were predicted to increase significantly in all catchments under the 1m sea level rise scenario.

Figure 10: Increase in 100yr Flood Depth with 100yr Storm Tide+1m SLR compared to No Tide Scenario (Scenario 4 minus Scenario 2)

Based on the above sample catchments, it is observed that elevated sea levels have a much larger effect in Stanley, Mission Bay and Sulphur Beach catchments, compared to Cockle Bay catchment. One of the potential reasons could be that areas created by land reclamation are not as resilient to sea level rise than a natural catchment such as Cockle Bay. As reclaimed land generally extends low-lying areas further off the natural coast, land reclamation could create further low-lying ponding areas, constrained over land flow paths, longer and a flatter hydraulic grade line and drainage route, that are more susceptible to elevated sea levels and have reduced flood resilience towards extreme storm events and climate change.

3.2.2 EXTENT OF TIDE INFLUENCE

The difference in flood depth was also plotted against flood levels, to identify how high up the catchment could sea level potentially affect flooding. Figure 11 illustrates the Mission Bay example, whilst the 100yr ARI storm tide level of 2.3mRL is lower than the ground elevation of most Mission Bay area, this elevated sea level would exacerbate flooding for elevations as high as 3.6mRL. However, only areas lower than 2.8mRL are predicted to have flooding significantly (>100mm) influenced by the 100yr ARI storm tide level.

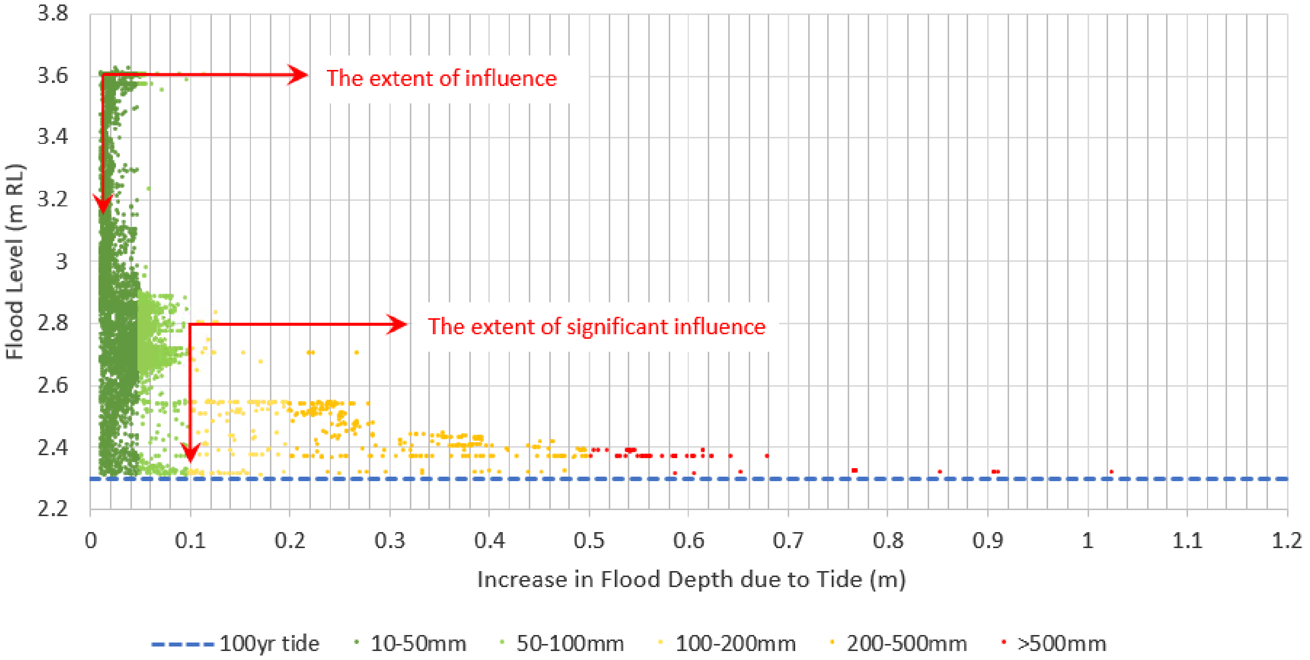

Figure 11: Extent of Influence for Sea Level at 2.3mRL in Mission Bay

Table 6 summarises the sea levels applied to each catchment and the maximum ground elevations where the corresponding sea level is predicted to influence or significantly influence flooding. Although the numbers for each catchment are slightly different, it can be found that for most of the sample catchments, the 100yr ARI storm tide would only significantly affect areas that are within approximately 300 to 500mm of the tide level. With 1m sea level rise, the maximum extent of tide influence would extend to roughly between 3.5-4mRL, but minor influence could be felt as high as 5 or 6m above mean sea level.

Table 6: Extent of Sea Level Influence

Catchments	**Sea Levels (m RL)**		**Elevation that sea level significantly influences flooding in m RL (more than 100mm influence)**		**Elevation that sea level influences flooding in m RL (more than 10mm influence)**	
	100yr Storm	**100yr + 1m SLR**	**100yr Storm**	**100yr + 1m SLR**	**100yr Storm**	**100yr + 1m SLR**
Cockle Bay (natural)	2.18	3.18	<2.5	<3.5	<4.1	<6.5
Mission Bay (reclaimed)	2.3	3.3	<2.8	<3.9	<3.6	<4.0
Sulphur Beach (reclaimed)	2.38	3.38	<2.7	<3.7	<4.3	<5.0
Stanley (reclaimed)	2.3	3.3	<3.9	<5.4	<4.3	<5.4

An exception is the Stanley catchment, where much wider or higher extent of significant sea level influence (>100mm increase in flood depth) is observed. This could be due to that the catchment is largely built on reclaimed land, where flat coastline has been extended further and the foreshore areas has been built slightly higher than the inner areas. This results in flatter gradient stormwater system, constrained overland flow paths, longer drainage route which all contributes to more severe flooding with elevated sea levels.

3.2.3 SEA LEVEL INFLUENCE ON SMALLER RAIN EVENTS

Additional scenarios have also been analysed, to confirm whether sea level influence on flooding would be more profound for smaller rain events. The 10yr ARI design rainfall event was selected for the assessment for the Mission Bay Catchment, referring to Table 7 below.

Table 7: Additional Scenarios and Extent of Influence for Mission Bay

	Rainfall	Sea Level	Note
Scenario 5	10yr ARI rainfall	100yr ARI storm tide	Model Simulated
Scenario 6	10yr ARI rainfall	no tide	Model Simulated
Scenario 7	10yr ARI rainfall	100yr ARI storm tide +1m sea level rise	Model Simulated

Flood level differences were calculated and illustrated in Figure 12. It can be found that whilst greater increase in flood depth is predicted at certain localized areas in Scenario 5, the extent of significant sea level influence in elevation does not exceed the previous values of <2.8mRL and <3.9mRL (Table 6), for both Scenario 5: 100yr storm tide level and Scenario 7: the 100yr storm tide plus 1m SLR scenario, respectively.

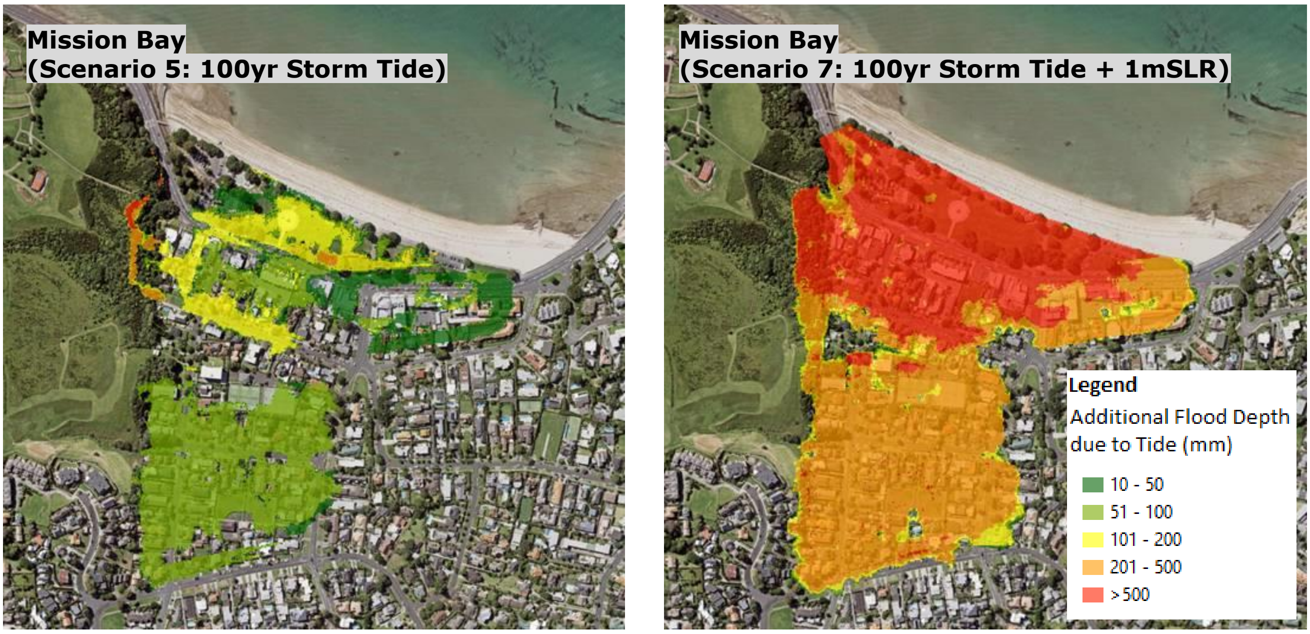

Figure 12: Increase in 10yr Flood Depth with Different Sea Levels compared to No Tide Scenario (Scenario 5 minus 6, Scenario 7 minus 6)

4 CONCLUSIONS

Based on the observations made in Section 3, elevated sea levels can potentially have significant impacts on pluvial flooding in lower-lying coastal areas. Generally, significant increases in flood levels (>100mm) were not predicted for areas higher than 3.5 - 4mRL, as shown in Table 6, but minor influences could extend further up the catchment. This means if there are no significant assets or properties within the areas lower than 4mRL, no effort is necessary to test the impact of varying sea levels on flooding.

When there are properties within the 4mRL and below areas, more detailed analysis needs to be carried out to understand exactly what impact tide may have on the level of service that the stormwater system could achieve and how resilient a specific coastal area is to extreme storm events and climate change.

When developing flood mitigation options within the above-mentioned below-4mRL tide influence zone, a full flood risk mitigation solution may not always be possible. Instead, a reduced level of service may need to be considered, such as design for smaller events and focus on reducing flood frequency, or design without considering sea level influences, acknowledging that not all flood risks can be resolved.

The study also indicated that coastal areas created by land reclamation are likely to be less resilient to climate change compared to natural catchments. When considering land reclamation and development activities in coastal areas below 4mRL, detailed assessment is recommended to understand the effect that extreme sea levels would have on flooding.

To enable more resilient communities, catchments and coastlines, future focused policy and planning framework need to be put in place with the requirements and rules that ensure Auckland's growth and development does not exacerbate natural hazards risk in the future. Community engagement and education is also imperative for raising awareness and acknowledging the implications of climate change and natural hazard risk.

In addition to coastal resilience, the following conclusions are also made from the Cockle Bay flood investigation and the analysis of sea level influence on pluvial flooding:

- A rare joint probability event is not necessarily equivalent to a rare flooding event, even if occurred within the coastal inundation area. Properties further up the catchment are only affected by rainfall. It was found that the tide did not affect the flooding of the properties in the 2018 flooding events that occurred in Cockle Bay.

- Low lying stormwater assets in coastal areas (e.g. Cockle Bay culvert) can still convey flows at rising sea levels without significantly reduced capacity as long as there is sufficient head to 'push' the water through.

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