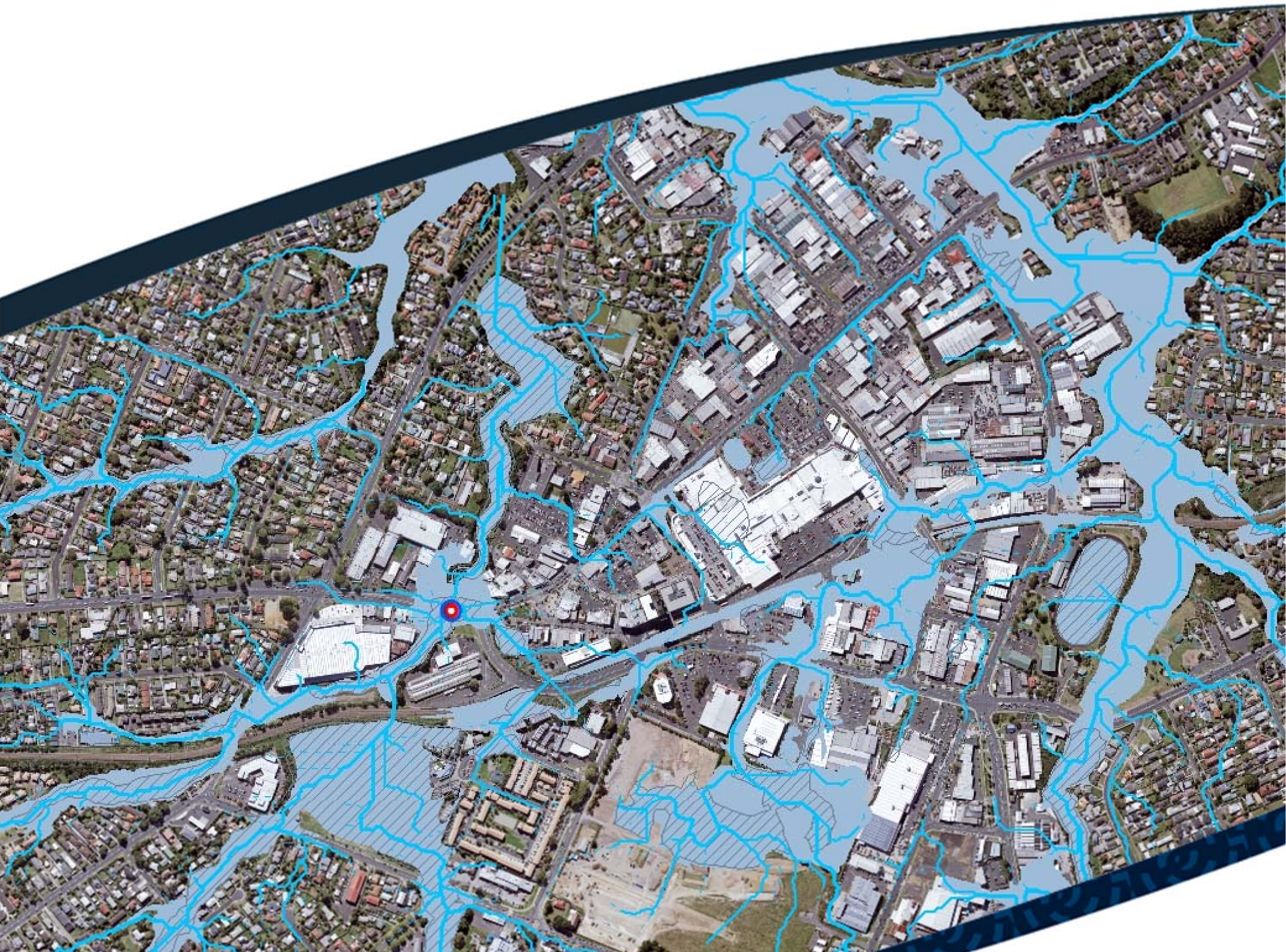
Evaluating Likelihood and Consequence: Understanding the New Lynn storms of 2017

Nancy E. Golubiewski

February 2019

Discussion Paper 2019/003



RIMU Research and Evaluation Unit

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Executive summary

In March and April 2017, a series of six storm events within six weeks battered Auckland. Heavy rainfall and ground saturation resulted in landslips and flooding throughout the region. The period has been categorised in public discourse as “unprecedented” in terms of both the severity of the storms themselves and their consequences. Indeed, the 2017 New Lynn storms have become a touchpoint for how major storms, and potentially climate change impacts, can affect Auckland. Yet, very little in the way of critical analysis has been conducted to understand the impacts of these storms.

In order to assess the storms’ consequences and the scale at which they occur, a risk-based planning tool was used to frame a *post hoc* thought experiment[1] analysis. The magnitude of the 12 March 2017 storm and its impacts in four overlapping study areas were quantified across four sectors: buildings, lifelines, economy, and health and safety. The severity of impact ratings across sectors ranged from Insignificant to Moderate. In particular, 4.5 per cent of buildings located in floodplains were considered functionally compromised in the New Lynn suburb (and 1.7 per cent of those in the Whau Local Board). The estimated value of damaged buildings was less than 0.5 per cent of the Whau Local Board GDP. All together, combining the likelihood and consequences in a risk framework resulted in a theoretical “acceptable” or “tolerable” risk rating, depending on the storm magnitude estimate used. In order for this postulated level of risk to be considered more definitive, it first needs to be vetted and affirmed via further stakeholder engagement.

For now, this assessment provides actual data and analysis of storm impacts, which relate to past and current development decisions, including the practice of building in flood hazard areas. The risk of building in flood plains is more evident when considering what happens to buildings in the most hazardous areas, as well as where incidents are likely to take place. Of the flooding incidents reported in March 2017, large proportions were on parcels intersecting with flood hazard zones: one-third of incidents in the Whau Local Board and Whau/Te Atatu South catchments and nearly 40 per cent of those in the New Lynn suburb occurred in flood plains.

That the storm events could be summarised as “tolerable” in no way diminishes the very real challenges suffered by those individually and collectively affected by the flooding, including damaged houses and businesses. Rather, the aim was to use a structured tool to undertake a dispassionate analysis at the appropriate scale, avoiding the trap of personal story (“anecdata”) and individual instances (a statistical sample of one). Acknowledging the importance of the major impact of the storm for those individuals, this case study contextualises the storm impacts for the neighbourhood and region. Thus, it also serves as

[1] A thought experiment is a device of imagination or thinking to investigate the nature of things, in this case to consider the consequences of an event.

a thought experiment to provide insight into what the actual effects of *a priori* land-use planning judgements could be, providing opportunity to consider their social acceptability and reinforcing the importance of considering hazard and risk in land-use planning.

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1.0 Introduction

In March and April 2017, six storms moved across Auckland over a six week period. Heavy rain and wind pummelled the region, resulting in significant flooding and landslips that strained Auckland Council's infrastructure and operations as well as the region's citizens and their property. The first three (7-8 March, 10-11 March, and 12 March) comprised a single weather event, the "Tasman Tempest" (NIWA 2017a; T Carey-Smith, personal communication, March 15, 2018). The last two brought the remnants of ex-Tropical Cyclone Debbie (4-6 April) and the power of ex-Tropical Cyclone Cook (12-13 April).

The series of March/April 2017 storm events affected the whole region, but not uniformly. Due to the shifting, localised intensity of the precipitation events, specific areas were affected differently in each of the events throughout the six week period. They were both short, high intensity rainfalls and long duration events, which "meant that areas with both a relatively steep contributing catchment, and a large upstream catchment, experienced flooding" (Nelson and others 2017).

The intensity of the weather events and their aftermath profoundly affected people and communities in specific locations. Understandably, these events loomed large in the public consciousness, underpinned by informative public service announcements and reporting as well as headline hyperbole:

- "Tasman tempest: Storm turns city into pool, clean up begins" (NewstalkZB Staff 2017).
- "Flood-hit families left homeless" (Brettkelly 2017).
- "Forecast rain unwelcome news for those still dealing with flood damage" (Stuff 2017b).
- "Chaos as rain hammers North" (Otago Daily Times 2017).
- "The day the Earth fell in – Four months on from dramatic flooding in the Auckland suburb of New Lynn" (Howie 2017).

Under this lens, the storms were labelled as unprecedented (Nelson and others 2017), with assurances that such flooding would not happen again (Howie 2017, Stuff 2017a).

Such descriptions inform all of society, including elected members, government officials, and private individuals, becoming conventional wisdom of the event. Yet, more is needed than anecdotes and eyewitness accounts to understand this series of storms and their ramifications from a systemic perspective. In order to move past the emotive reactions and to support improved (systemic) understanding of these events and preparation for future ones, it is necessary to examine their likelihood and consequences.

The traditional planning approach for addressing natural hazards has focused on selection of a numeric metric, such as a storm's annual recurrence interval (ARI), to assign the likelihood of an event occurring without consideration of the subsequent consequences should such an event occur (Kuhlicke and Steinführer 2013, Saunders et al. 2013). However, as a result of both experiencing and witnessing large storm events imposing catastrophic impacts on cities around the world, and recognising the false precision of data to plan for flood events (White 2013), flood risk management is receiving renewed attention (Scott 2013).

The objective of this study, then, is to bring a methodical approach to examining the events and their consequences in order to inform the public discourse about the scale of events. The analysis does that first by examining the magnitude of events against the historical record and then by adapting a risk-based assessment approach to understand impacts. This work is done through a case study of New Lynn, a suburb on Auckland's central isthmus, which was hit particularly hard by the third storm in the series on 12 March 2017. The resulting information can provide a broader perspective to inform both public understanding of the events and policy processes and decision-making that consider past events in order to undertake adaptive management (Lee 1994). For that reason, this report may be useful to those interested in the storms' occurrences, their consequences, and related policy and management, including emergency preparedness/ response, natural hazard management, and land-use planning.

2.0 Study area and methods

Investigating the impact of the storms necessarily becomes a matter of considering scale. Auckland Council is a unitary authority, a local government entity with both the roles of a city council and a regional authority, including responsibilities for city operations, urban planning, natural resource management, and emergency preparedness and response. While not the largest region in New Zealand, it is the country's main population and economic centre, housing one-third of the country's population and contributing 38 per cent of its gross domestic product. The Auckland region's land area covers approximately 4900 km^2, with an isthmus at the centre comprising the city of Auckland. This regional scale of the council's political boundary is too coarse for the localised nature of the weather events, diluting any impacts. Likewise, focusing on the neighbourhood or street scale emphasises individual experiences – a worthwhile exercise but lacking important information about societal impacts to inform policy, decision-making, and management.

2.1 Study area – scaling perspective

In order to understand the influence of scale on storm consequences, the case study was undertaken with four study area boundaries: two socially-defined and two biophysical. New Lynn was the focal point of the case study due to the effects of the 12 March storm on its town centre. New Lynn is a suburb on Auckland's isthmus, a locality based on socio-cultural understandings (and here, defined as the Fire and Emergency New Zealand's service area "suburbs"). It sits within the Whau Local Board, one of 21 community political entities across the region. The New Lynn suburb and Whau Local Board comprise the study areas at the local and sub-regional scales, respectively, as determined by social/political boundaries (Figure 1).

To understand the effects of weather events, it is necessary to consider the landscape from a biophysical perspective. New Lynn's town centre, "ground zero" of the biggest storm impact, sits at the bottom of the Manawa Stream catchment, which is used as the local biophysical study boundary (Figure 2). This catchment sits within the Whau catchment. It, along with the adjacent Te Atatu South catchment, was identified as the main biophysical study area (hereafter referred to as the Whau/TAS catchments), the original focus of the investigation (Figure 1).

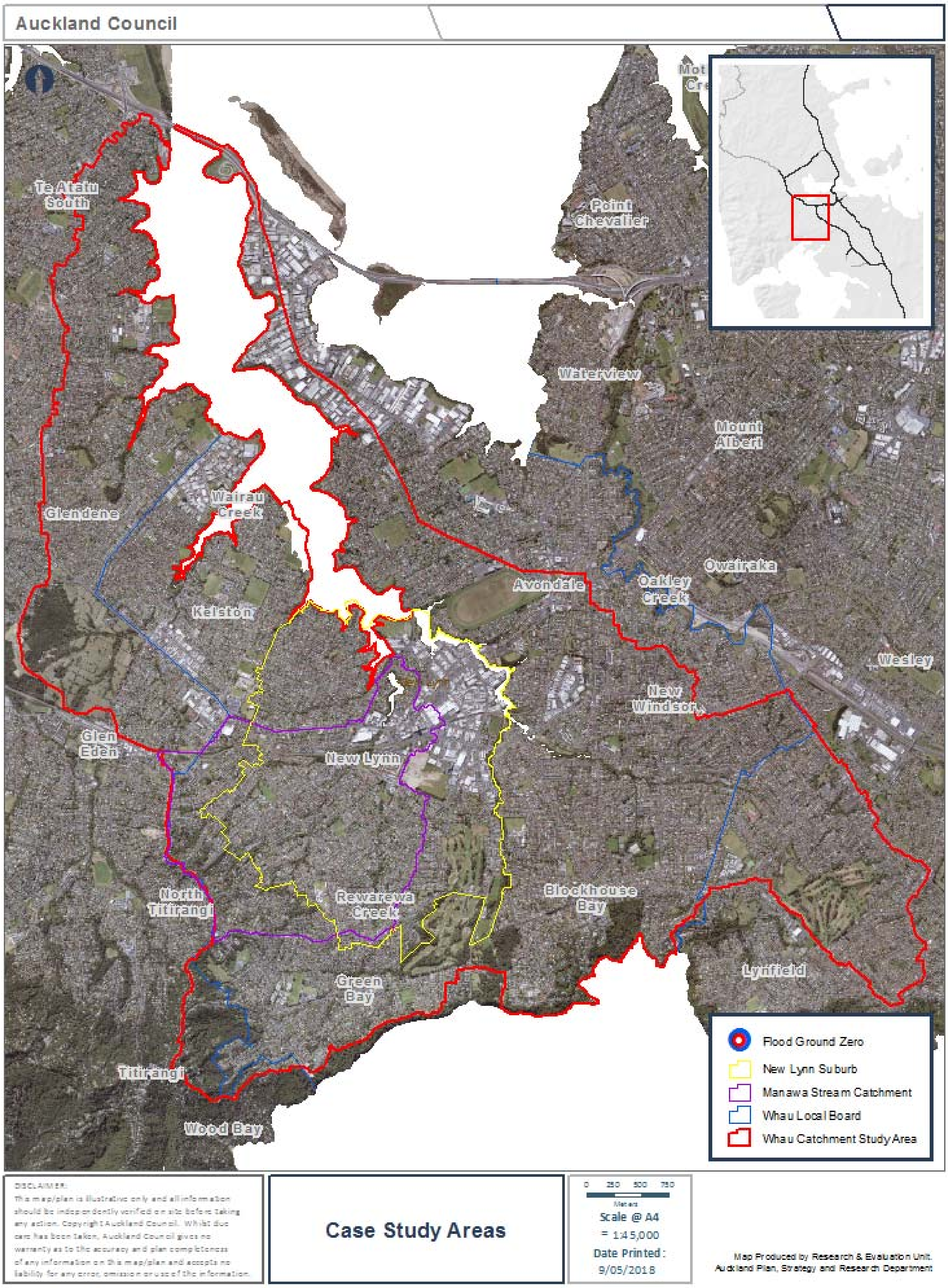


Figure 1 Study areas of interest: Manawa Stream catchment, New Lynn suburb; Whau/TAS catchments, and Whau Local Board.

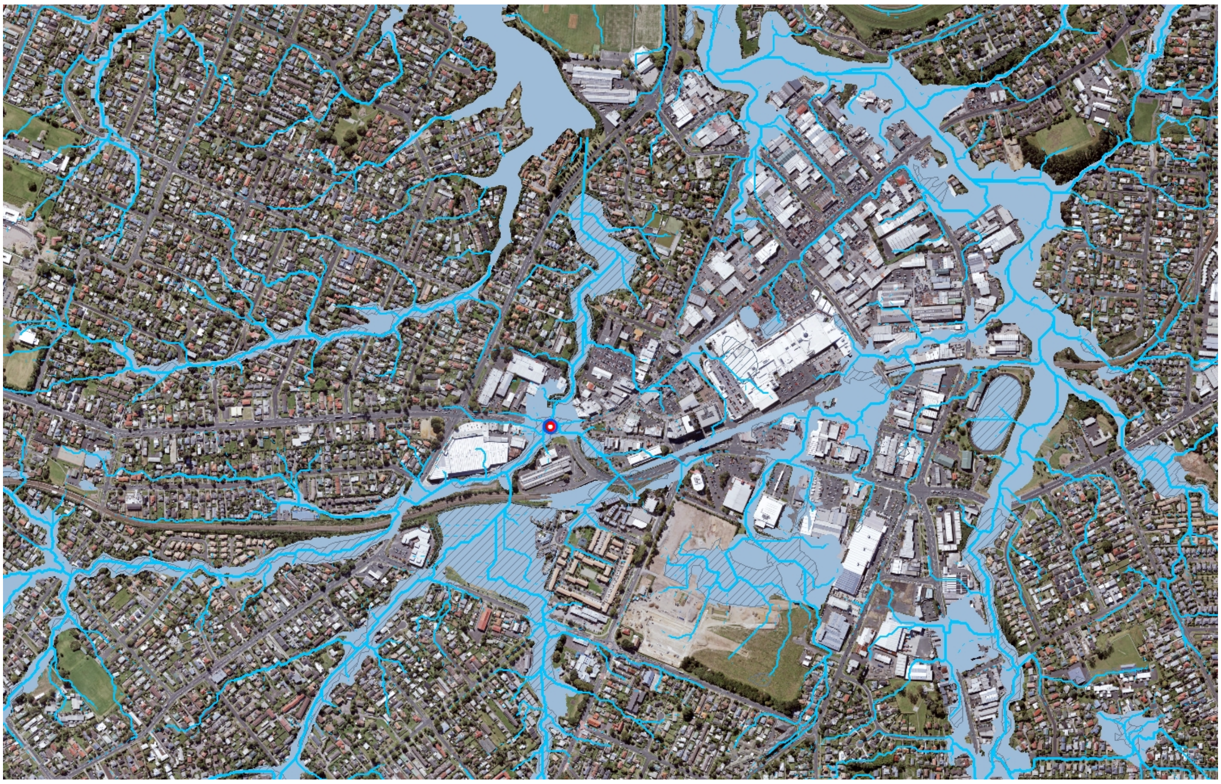


Figure 2 The bullseye target marks the site of the culvert collapse and street flooding on 12 March 2017
Flood hazards (modelled) are shown for context: 100 year floodplains (solid blue); flood prone areas (diagonal lines); and overland flow paths (bright blue lines); note this is not a post-storm map showing actual flooding.

The primary aim of the investigation is to assess how the storm's effects on New Lynn, situated within the Whau catchment, can be understood in terms of social and physical impacts. The four study areas provide different scale lenses through which to consider the weather events, sitting along a spectrum bounded on one side by the individual and on the other by the Auckland region.

2.2 Analytical approach and data

To evaluate the magnitude of the storms, rainfall and flood gauge data were downloaded from the Hydstra system run by Auckland Council's Research and Evaluation Unit (RIMU). In order to understand the magnitude of the storms, these data were assessed within Hydstra as well as by Healthy Water using the TP 108 tables (Beca Carter Hollings & Ferner Ltd 1999) and against the recently updated High Intensity Rainfall System, HIRDSv4 (Carey-Smith et al. 2018).

A risk-based assessment framework was used to assess the impact of the storms. In New Zealand, the Institute of Geological and Nuclear Sciences Limited (GNS Science) has developed a toolbox for risk-based planning for natural hazards in order to facilitate the consideration of both likelihoods and consequences in development decisions (GNS Science 2013). Auckland Council was a member of the project's steering group (Saunders et al. 2013). The risk-based approach to land-use planning for natural hazard risk reduction consists of five steps (Saunders 2017): 1) Know your hazard; 2) Determine the severity of the consequences; 3) Evaluate the likelihood of an event; 4) Take a risk-based approach; and 5) Monitor and evaluate. Stakeholder engagement has a role at each step (Saunders et al. 2013).

The general approach is to summarise and evaluate likelihood and consequences (Tables 1-3). For this case study, the tool provides a useful method to undertake a more holistic evaluation of the storms, with the caveat that it focuses on hazards and exposure without including vulnerability, the third main component of risk (Oppenheimer et al. 2014). As a thought experiment[2], the risk-based assessment approach is followed in a *post hoc* analysis of the storm for the various study areas using example levels of risk for demonstration purposes. A brief description of the tool's method is below, followed by its implementation in Section 5.

1) Know your hazard: To know the hazard means to be aware of the types and likelihoods of potential hazard events, in this case – floods.

2) Determine the severity of the consequences: In the GNS risk framework (Saunders 2017), consequences on community well-being are quantified via impacts on buildings, lifelines, economic impact, and health and safety (Table 1). For buildings, three metrics are used to capture the effect on the built environment (Saunders et al. 2013):

- The proportion of buildings with functionality compromised. Functionality connotes whether the building can continue to be used as intended immediately after the event. For example, a house that cannot be inhabited would be functionally compromised, whereas a flood-damaged house in which occupants can remain would not. Likewise for commercial premises.
- The proportion of *critical* buildings, those that have a post-disaster function, which have been functionally compromised. These include medical emergency or surgical facilities; emergency service facilities (e.g., fire and police stations);

[2] A thought experiment is a device of imagination or thinking to investigate the nature of things, in this case to consider the consequences of an event.

Table 1 Consequences

	Built					
Severity of impact	**Buildings**	**Critical**	**Social/ Cultural**	**Lifelines**	**Economic**	**Health and safety**
Catastrophic (V)	≥50% of buildings within hazard zone have functionality compromised	≥25% of critical facilities within hazard zone have functionality compromised	≥25% of buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for >1 month (affecting ≥20% of the town/city population) OR suburbs out of service for >6 months (affecting <20% of the town/city population)	≥10% of regional GDP	≥101 dead and/or ≥1001 injured
Major (IV)	>20-<50% of buildings within hazard zone have functionality compromised	>10-<25% of critical facilities within hazard zone have functionality compromised	>10-<25% of buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for 1 week to 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for 6 weeks to 6 months (affecting <20% of the town/city population)	1.0 to <10% of regional GDP	11-100 dead and/or 101-1000 injured
Moderate (III)	>10-20% of buildings within hazard zone have functionality compromised	>5-10% of critical facilities within hazard zone have functionality compromised	>5-10% of buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for 1 day to 1 week (affecting ≥20% of the town/city population) OR suburbs out of service for 1 week to 6 weeks (affecting <20% of the town/city population)	0.1 to <1.0% of regional GDP	2-10 dead and/or 11-100 injured
Minor (II)	1-10% of buildings within hazard zone have functionality compromised	<1-5% of critical facilities within hazard zone have functionality compromised	<1-5% of buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for 2 hours to 1 day (affecting ≥20% of the town/city population) OR suburbs out of service for 1 day 1 week (affecting <20% of the town/city population)	0.01 to <0.1% of regional GDP	1 dead and/or 1-10 injured
Insignificant (I)	<1% of buildings within hazard zone have functionality compromised	No critical facilities within hazard zone have functionality compromised	No buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for up to 2 hours (affecting ≥20% of the town/city population) OR suburbs out of service for up to 1 day (affecting <20% of the town/city population	<0.01% of regional GDP	No dead No injured

(Adapted from Saunders 2017)

emergency shelters and centres; and buildings designated as essential facilities or with special post-disaster functions.

- The proportion of *social and cultural* buildings that have functionality compromised. These include places of worship; museums, art galleries, marae, sports facilities, and educational facilities.

The consequential effect on lifelines is assessed as the services affected for transportation, power distribution, and water and wastewater.

The economic impact is derived as a measure of regional (or territorial authority or local area) GDP in order to scale absolute values to the size of the affected area (Table 1). Only the immediate economic impact of the storm is calculated, using the equation (Saunders et al. 2013):

$$\frac{\text{Values of buildings damaged} + (\text{number of deaths} \times \$3.77 \text{ million}) + (\text{number of injuries} \times \$207{,}000)}{\text{Regional GDP}} \times 100$$

Health and safety consequences are determined by the counts of injuries and deaths.

3) Evaluate the likelihood of an event: The likelihood of storms is assigned a descriptor from Very Rare to Likely, depending on the frequency of events (Table 2).

Table 2 Likelihood scale

Level	Descriptor	Description	Indicative frequency
5	Likely	The event has occurred several times in your lifetime	Up to once every 50 years
4	Possible	The event might occur once in your lifetime	Once every 51 – 100 years
3	Unlikely	The event does occur somewhere from time to time	Once every 101 - 1000 years
2	Rare	Possible but not expected to occur except in exceptional circumstances	Once every 1001 – 2,500 years
1	Very rare	Possible but not expected to occur except in exceptional circumstances	2,501 years plus

(Source: Saunders 2017)

4) Take a risk-based approach: This risk-based approach derives from quantifying and combining the identified consequences and likelihoods (Saunders et al. 2013). A risk matrix uses a function of consequences multiplied by likelihood (Table 3), resulting in risk calculations ranging from 1 (extremely low) to 25 (extremely high).

Table 3 Quantifying consequences and likelihood

	Consequences				
Likelihood	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

(Source: Saunders 2017)

5) Monitor and evaluate: The framework is proposed as a planning tool, to be used to assess the possible impact of land-use decisions. In this proffered thought experiment, it can be used to consider how a *post hoc* assessment can inform those current practices and future land-use decisions.

The data required for the assessment were acquired from Council departments and external organisations. Storm incidents were obtained from the Request for Service (RFS) database operated by Auckland Council's Healthy Waters Department (Auckland Council 2017b). This information was supplemented with incidents logged by Fire Emergency New Zealand (FENZ) as a natural disaster event or a minor emergency during the weather events, supplied via an official information request (Deuchars 2018). Both incidents logged as "Flood" or "Domestic/commercial water problem" were considered as storm responses. While the latter is intended to denote unwanted water escaping from a water supply system, this category of incidents is included here, as it is likely to be used interchangeably with the Flood incident type by some personnel (Deuchars 2018).

The value of storm damage was derived from claims information lodged with major insurance companies for particular storms. Further information about consequences for lifelines and health and safety were determined through consulting with subject matter experts throughout Auckland Council and contemporaneous news reporting.

Spatial analyses were conducted in ArcGIS 10.1.2, using spatial data held by Council, including 2013 building footprints (Golubiewski et al. 2019), flood hazards of a 100-year ARI event (Auckland Council 2013), and coastal inundation for a 100-year ARI event (Hernandez et al. 2018). In order to analyse the occurrence of incidents within these hazard zones, the parcels upon which RFS and FENZ incidents occurred were intersected with the various hazard layers (so as to avoid the imprecision of the geolocation of an incident point).

In the next three sections, the results of each component of the assessment are presented and discussed: first, the magnitude of the storms, followed by the storm consequences, and finally the risk-based assessment.

3.0 Recurrence of low probability storms

Overall, autumn 2017 was an active season of weather events. March 2017 was the wettest March on record for three of NIWA's measurement stations in Whangaparoa, Mangere, and Pukekohe (NIWA 2017a). It was the second-wettest month (by 2mm) of any month on record for Whangaparoa in the region's north and the third-wettest month of any month for Mangere in south Auckland. Overall, Auckland received the third-highest monthly rainfall of any month on record (NIWA 2017a). In April, Whangaparoa received more than four times normal April rainfall (NIWA 2017c).

During a weather event that brought localised downpours across much of Auckland's central and western urbanised suburbs on 12 March 2017, New Lynn was the worst affected area (NIWA 2017a), receiving considerable rainfall over a one to two-hour period (Table 4) as measured by Auckland Council's three rain gauges in the area (Figure 3). Delivered by the third storm of the March/April series (the final act of the Tasman Tempest), these quantities approached monthly long-term averages for March and compounded already wet conditions caused by the over 100 mm of rain that had fallen in the preceding week (Nelson and others 2017). The total accumulated rainfall recorded for the six-hour period of the storm (11:00 to 17:00) was less than 100 mm at all rain gauges in the region (Nelson and others 2017).

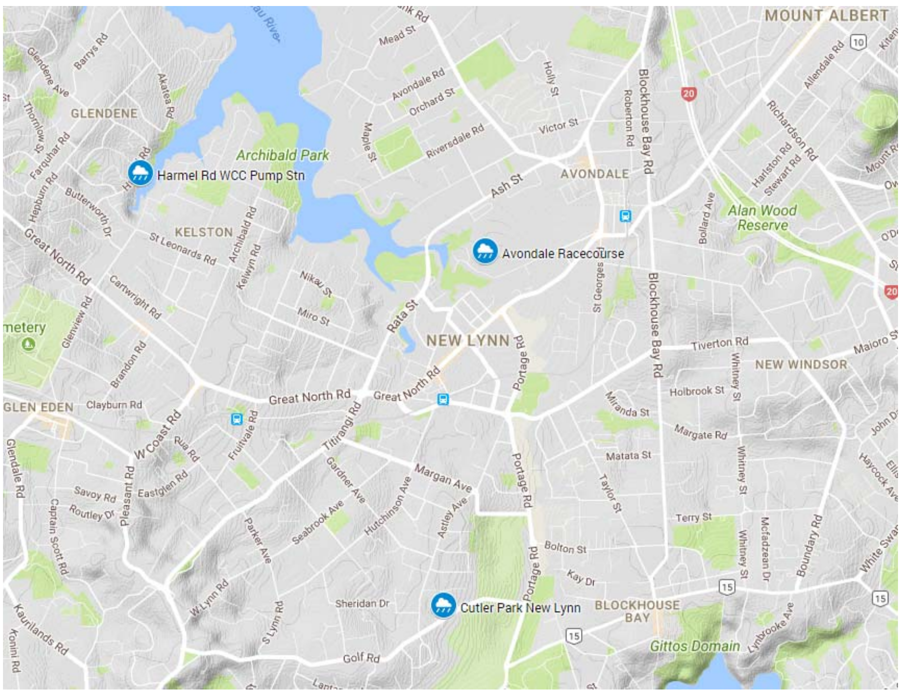


Figure 3 Auckland Council rain gauge locations in the New Lynn area

The understanding of the magnitude of the storms, and how “unprecedented” they were, has evolved through time. In a media release the day after the storm, NIWA (2017b) ascribed the two-hour, 60mm rainfall that caused flash flooding during the afternoon of 12 March as a 1 in 30 year annual recurrence interval (ARI), denoting an average or expected period of recurrence of 30 years, but more precisely meaning it had a 3.3 per cent annual exceedance probability (AEP), the probability of occurrence in any given year. Subsequent analyses, however, reassigned the storm to a considerably higher magnitude. In a post-storm event report, the one-hour and two-hour duration measurements from the three gauges indicated this storm had a one to two per cent AEP, a greater than a 1 in 50 year ARI (Nelson and others 2017). That estimate has increased with the ability to estimate storm magnitudes based on best-available data from three different methods: the Hydstra system, TP108 (Beca Carter Hollings & Ferner Ltd 1999), and the updated High Intensity Rainfall Design System (HIRDS) tables containing data through 2017 (Carey-Smith et al. 2018) (Table 4). The estimates range from less than 1% AEP (> 100 year ARI) to less than 2% AEP (~64-80 year ARI) for the 12 March 2017 storm in the New Lynn area.

Table 4 Rainfall measurements (two-hour duration) on 12 March 2017

Auckland Council rain gauge	**Rainfall (mm)**	**Annual recurrence interval (ARI)**	**Annual exceedance probability (AEP)**
Avondale Race Course	77.3	64[^]-69[#] to >100[*] years	<1-2%
Cutler Park	77.6	65[^] to >100[#,*] years	<1-2%
Harmel Road	83.0	79[^] to >100[#,*] years	<1-2%

(Sources: Rainfall data from Auckland Council rainfall gauges and ARI/AEP estimates from: [^]Hydstra system [supplied by Nicholas Holwarda in RIMU], [#]TP108 tables [supplied by Kris Fordham in Healthy Waters], and *NIWA’s HIRDS v 4.0).

Rainfall intensity is a key driver to ‘flashy’ floods. The event intensity on 12 March 2017 is the highest two-hour duration on record for the Avondale site and is significant in Auckland Council records. Short-term bursts included 102 mm/hr recorded for 10 minutes at Harmel Road and greater than 90 mm/hr at Cutler Park (Nelson and others 2017).

The flood events recorded in the Whau catchment during the March 2017 storms were the third and fourth highest in the 12-year record of flood events exceeding 1.7 m (Table 5) at the Blockhouse Bay river flow monitoring site 8006 (Figure 4). It is important to note that the flow recorder is on the edge of the 12 km^2 of the affected area, and the upper catchment received less rainfall than the affected zone. While the 12-year record is not very long for statistical analyses, there is no other site nearby with a long-term record in similar land use to quantify the significance of this event. Given these caveats, it is still evident that floods at this level have occurred four times in the past twelve years.

Table 5 Flood events exceeding 1.7m in the Whau catchment

Start date and time	End date and time	Flood level (m)
22/9/2013 - 02:57	22/9/2013 - 03:49	1.975*
29/6/2016 - 13:32	29/6/2016 - 14:05	1.871
11/3/2017 - 06:47	11/3/2017 - 07:17	1.806
12/3/2017 - 10:59	12/3/2017 - 12:01	1.793

*Maximum recorded level at this site.
(Source: Auckland Council monitoring station 8006 at Blockhouse Bay and Hydstra data management system)

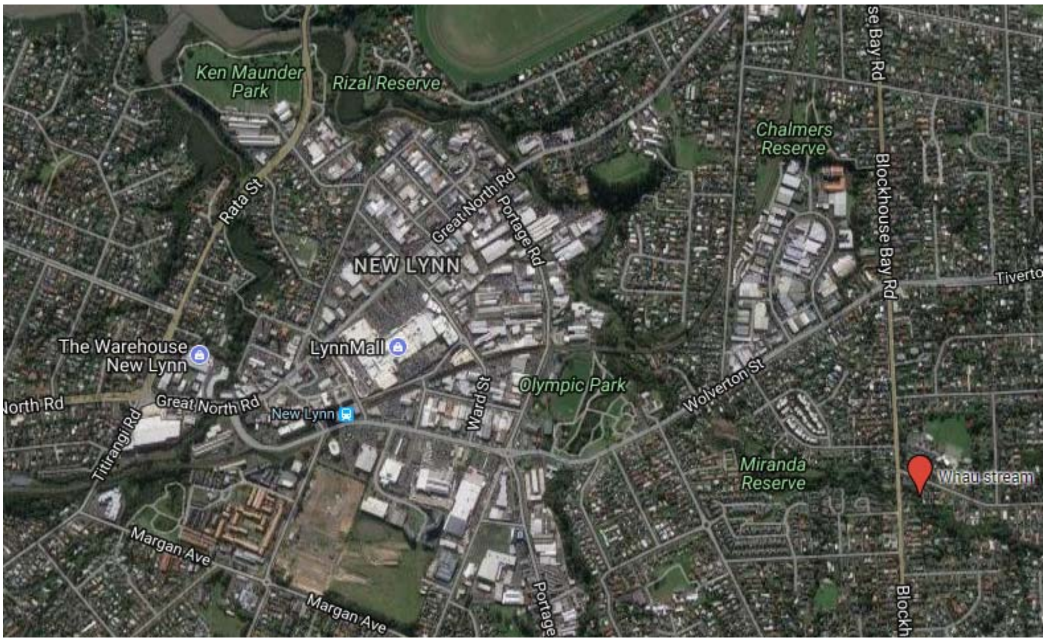


Figure 4 Blockhouse Bay site 8006 (established 2005), where Auckland Council monitor the flow and level of the Whau natural drainage catchment

Just over three weeks later (4-6 April 2017), the fifth storm in the March/April series brought the remnants of Cyclone Debbie to the region. In the New Lynn area, the rainfall event began on 4 April 2017 at 17:30 and finished on 5 April 2017 at 05:30 (Table 6). The Harmel rain gauge (Table 5) recorded 101 mm, ascribing this 12-hour event approximately a 10-20% AEP or a 1 in 8 (to more than 10) year ARI (Table 6) based on TP108 and NIWA HiRDS v4.0 tables (Beca Carter Hollings & Ferner Ltd 1999, Carey-Smith et al. 2018). Cutler Park recorded a similar rainfall event, whereas the Avondale Race Course gauge received relatively less rainfall, indicating a more common storm (Table 6).

Table 6 Rainfall measurements (12-hour duration) on 4-5 April 2017

Auckland Council rain gauge	Rainfall (mm)	Annual return interval (ARI)	Annual exceedance probability (AEP)
Avondale Race Course	76.6	3# - >5* years	<20 - 39%
Cutler Park	91.2	5# - >10* years	<10 - >20%
Harmel Road	100.9	8# - >10* years	<10 - >20%

(Source: Auckland Council rainfall gauges and NIWA's HIRDS v. 4.0)
(Sources: Rainfall data from Auckland Council rainfall gauges and ARI/AEP estimates from:
#TP108 tables [supplied by Kris Fordham in Healthy Waters], and *NIWA's HIRDS v 4.0).

Rather than unprecedented, the Tasman Tempest was a low probability event – one of rare, though still possible, occurrence. The probability that storms of similar magnitude (rainfall depth within a certain timeframe) would happen in any given year is approximately 1-2% for the 12 March storm based on current knowledge and tools. For its part, the remnants of Cyclone Debbie were of a relatively more common magnitude with approximately 10-20% AEP or greater for the 4-5 April storm, depending on location within the catchment. The scale of the weather event period – six storms over six weeks affecting the whole region – amplified the consequences of each, due to changed environmental conditions, and stretched resources. Auckland Council's long-term monitoring data reveal the (regular) recurrence of these low probability events, suggesting these types of storms are with precedent and can be expected to occur again.

NIWA's Historic Weather Events Catalog records 56 storms resulting in flooding over a 150 year prior to the 2017 events (NIWA 2016). An ever-changing metropolitan area, with both an increasing population and an expanding built environment (with its concomitant asset values), has developed in the paths of these recurring storms and floods.

4.0 Consequences of the weather events

The effects of large weather events, whether intensive, extensive, expansive or cyclonic, include surface flooding, coastal inundation, landslips, tomos[3], erosion, and wind damage. More than the specific magnitude of the storms, the context of the March/April 2017 storm series drove the consequences: repeated weather events in quick succession affected increasingly saturated ground.

Across the region, these storms resulted in 3631 requests for service (RFS) from Auckland Council (Figure 5) as well as an additional reported 726 stormwater-related call outs for the NZ Fire Service (Nelson and others 2017). This was six times the number of RFS logged during the same period in 2016 (Nelson and others 2017).

On 12 March 2017, there were 248 requests for service, 67 per cent (167) of which were emergencies (Priorities 1 and 2) across the Auckland region. More than 20 per cent (55) of these were located in the Whau/TAS catchments, 84 per cent of which were emergencies. The following day, 25 per cent (51) of the region's RFS were recorded in the Whau/TAS catchments, 24 per cent of which were emergencies.

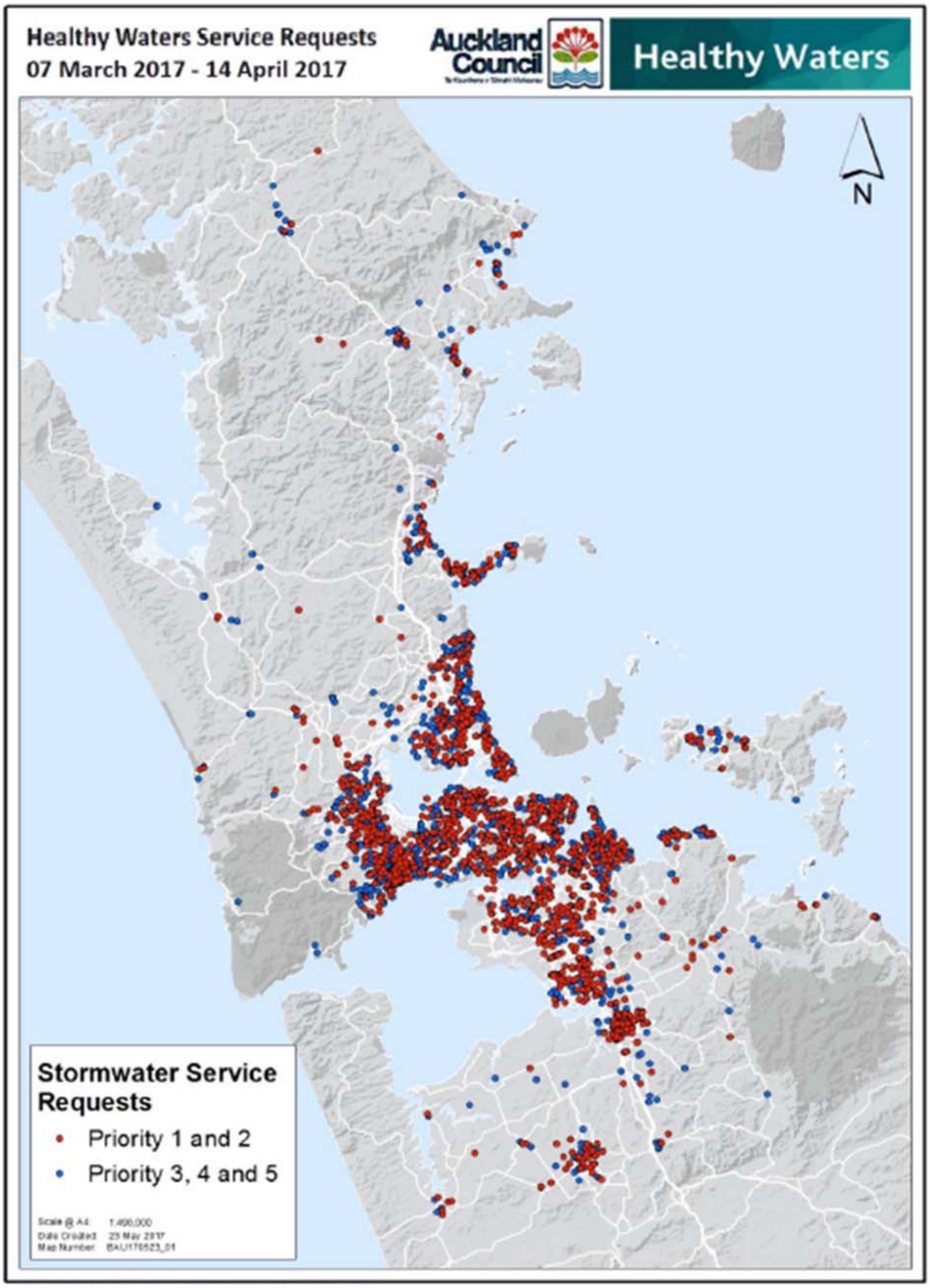
During the period encompassing the Tasman Tempest and its aftermath (7-18 March), 191 RFS were received in the Whau/TAS catchments, including eight erosion/tomo/slips (one an emergency); 47 flood investigations; and 22 flooding emergencies of structures (commercial properties, garages, and houses), as well as flood emergencies on nine sections (Fgure 6d). Fifteen road flooding incidents were reported, 13 of which were emergencies. The Fire Service also responded to 80 flood or domestic/commercial water problems in the Whau/TAS catchments on 12 March, 18 of which overlapped with Healthy Waters RFS. In total, then, 117 storm-related incidents, as reported to Healthy Waters and Fire Emergency NZ, occurred in the Whau/TAS catchments on 12 March 2017.

Within the political boundary of the Whau Local Board, the number of RFS calls was slightly lower, though the pattern and type of RFS were largely the same (Figure 6c). A total of 99 storm-related incidents, as reported to Healthy Waters and Fire Emergency NZ, were recorded across the Whau Local Board on 12 March 2017.

New Lynn suffered the main effects of the 12 March 2017 storm, for the one-hour duration, coinciding with the time of concentration of the catchments (Nelson and others 2017). From the New Lynn suburb, 16 RFS were received on 12 March 2017, followed

[3] Tomos are sinkholes – voids or shafts created by the action of water on limestone or volcanic rock

Figure 5 Requests for service from Healthy Waters during March/April 2017 storms



Source: Nelson and others (2017)

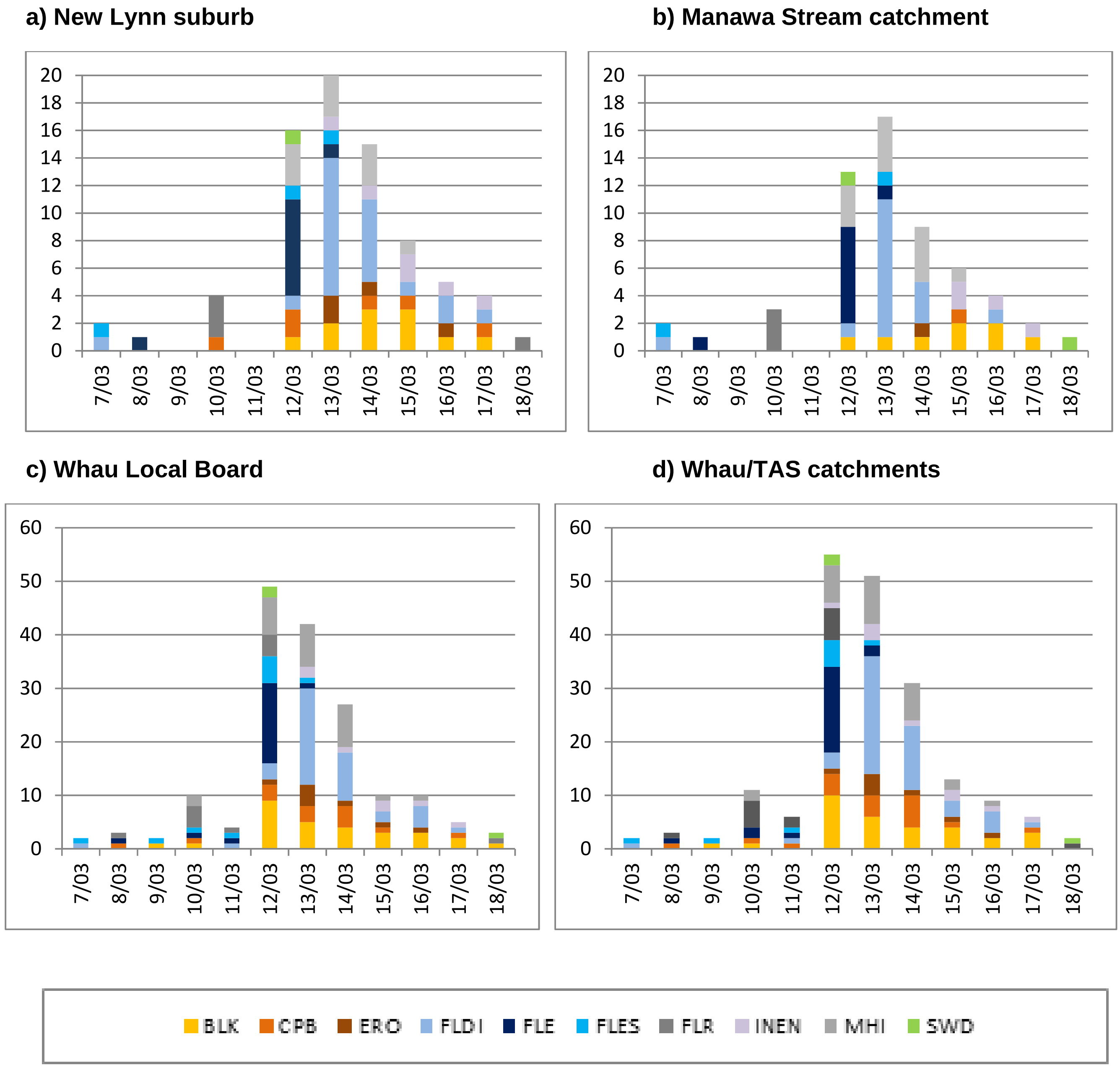


Figure 6 The number of requests for service received during, and in the aftermath of, the Tasman Tempest in March 2017 for the four different local areas under consideration: a) New Lynn suburb; b) Manawa Stream catchment; c) Whau Local Board; and d) Whau/TAS catchments.
The RFS codes shown are those recorded for each location over the period: BLK (Blockages*); CPB (Catchpit Blocked/Overflow*); ERO (Erosion/Tomo/Slip*); FLDI (Flooding Investigation); FLE (Flooding Emergency-Structures); FLES (Flooding Emergency-Section); FLR (Road Flood*); INEN (Investigation by Engineer); MHI (Manhole*); SWD (Stream watercourse/ Open Drain*). *These categories combine RFS recorded as emergency and routine/investigation. Note different vertical axes.

by 20 the next day and another 15 on the 14 March 2017 (Figure 6a).

In addition to 22 flooding investigations during the Tasman Tempest period, nine structures were reported as flood emergencies (including five houses and two commercial properties) as were three sections. There were also four road floods, three of which were emergencies. In addition, the Fire Service responded to 31 flood or domestic/commercial water problems in New Lynn on 12 March, eight of which overlapped with Healthy Waters RFS. In total, then, 39 incidents occurred in the New Lynn suburb on 12 March 2017.

According to Healthy Waters' assessment of the storm (Nelson and others 2017), the consequences for New Lynn were severe, including:

> Heavy rainfall exceeded the capacity of the network, exacerbated by the lack of upstream attenuation capacity due to two large rain events immediately prior to this event, which led to further flooding in several places and the partial culvert colapse (sic) under Great North Road. This resulted in road closures over a 4 week period, business closures and a building being inspected for structural integrity reasons, and subsequentially (sic) demolished.

Since then, Healthy Waters has said the culvert was blocked. This partial culvert collapse/blockage (Figure 2), and the subsequent flood at Great North Road and Clark Street, became one of three most significant sites of damage from these storms requiring Healthy Waters' involvement (Nelson and others 2017). Of the "more challenging flooding projects that require flood mitigation" assigned to the Recovery Works Team as a result of these events, almost one-third (11 of 35) were located in the Whau/TAS catchments. They comprised a combination of physical infrastructure failures or needs (4), flooding in overland flow paths (3), and other, unspecified flooding (4) (Nelson and others 2017).

The damage in New Lynn was further exacerbated by the remnants of ex-Tropical cyclone Debbie (the fifth storm in the series, occurring 4-6 April 2017), resulting in repeated flooding of the road and one commercial property in the business district (Figure 7). During this period, 49 RFS were received in the Whau/TAS catchments (Figure 7d). All but one were coded as emergencies on 4 April, as were almost half on 5 April 2017. Across the period, more than half (55%) of the RFS were flooding investigations and emergencies; there were also six manhole emergencies and one slip emergency (Figure 7d). In addition, nine Fire Service calls (four of which overlapped with RFS) were received 4-5 April, resulting in a total of 54 incidents across the Whau/TAS catchments related to ex-Tropical Cyclone Debbie.

Specific storm consequence categories are considered below in preparation for the risk-based assessment to follow.

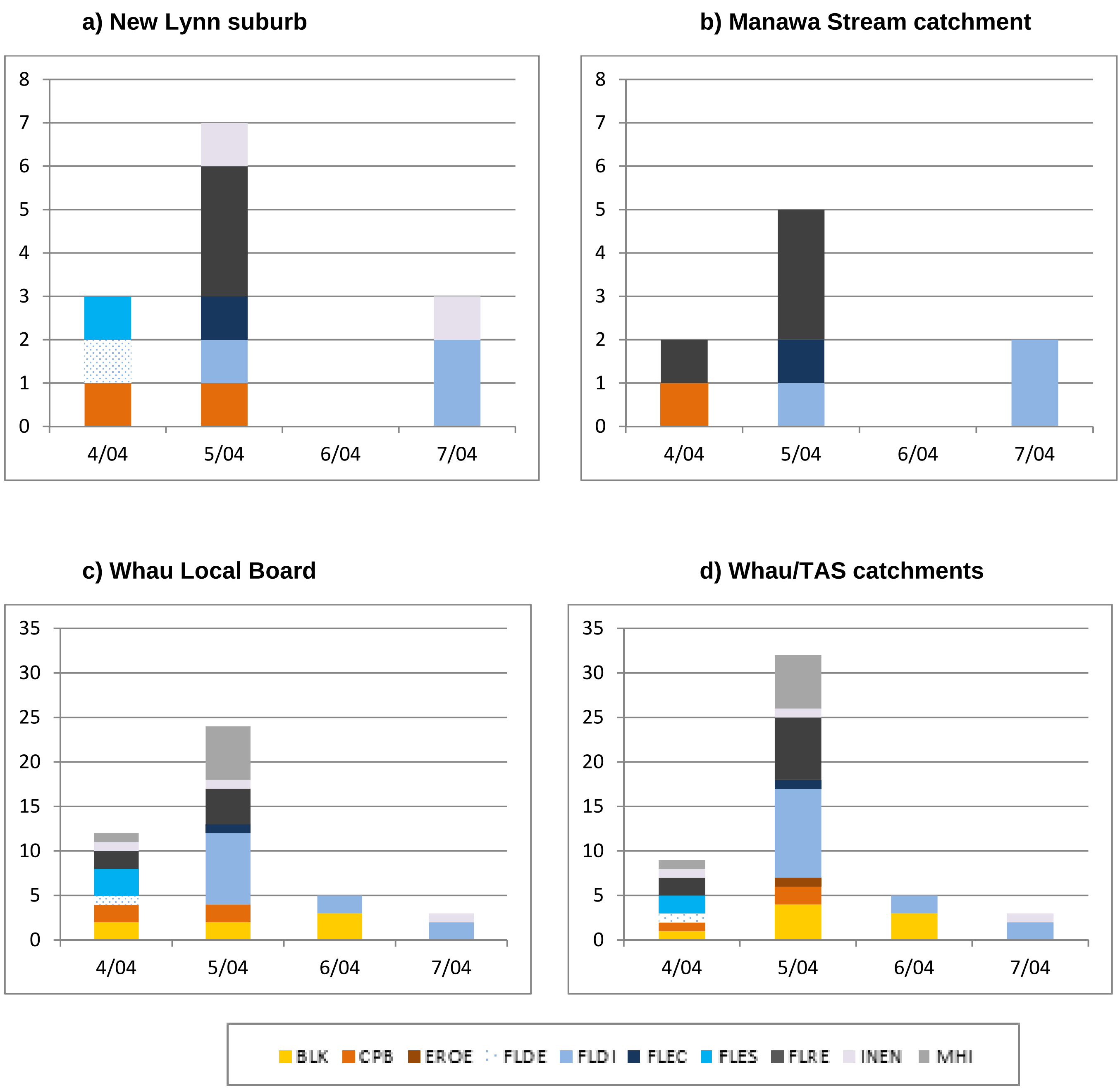


Figure 7 The number of requests for service received during, and in the aftermath of, the remnants of ex-Tropical Cyclone Debbie in April 2017 for the four different local areas under consideration: a) New Lynn suburb; b) Manawa Stream catchment; c) Whau Local Board; and d) Whau/ TAS catchments.

The RFS codes shown are those recorded for each location over the period: BLK (Blockages*); CPB (Catchpit Blocked/Overflow*); EROE (Erosion/Tomo/Slip Emergency); FLDE (Flooding Emergency-other); FLDI (Flooding Investigation); FLEC (Flooding Emergency-Commercial property); FLES (Flooding Emergency-Section); FLRE (Road Flood Emergency); INEN (Investigation by Engineer); MHI (Manhole*). *These categories combine RFS recorded as emergency and routine/investigation. Note different vertical axes.

4.1 Buildings

In the post-event reporting for the 12 March 2017 storm, Healthy Waters noted that 39 properties were reported as potentially experiencing habitable floor flooding and 10 as garage flooding, all needing to be verified (Nelson and others 2017). The finalised Healthy Waters' RFS records of the storm series (Auckland Council 2017b) recorded two RFS for commercial property flooding, which were among the seven structure flood emergencies (commercial, houses, and garages) at the local scale (whether considered as the New Lynn suburb or Manawa Stream catchment) on 12 March, and nine total across the Tasman Tempest period (Table 7a). Across the wider region, 15 flood emergencies associated with structures occurred on 12 March in the Whau Local Board area, for a total of 19 during the Tasman Tempest. In the Whau/TAS catchments, there were 16 structure flood emergencies on 12 March, with a total of 22 during the Tasman Tempest (Table 7a).

Considerably more buildings were affected than these RFS codes for structures indicate. In addition to these, the outcome for a variety of RFS codes were recorded as "Flooded Habitable Floor", indicating the incident concerned a flooded building despite the original RFS designation. Including all non-structure RFS codes with Flooded Habitable Floor outcomes more than doubles the number of RFS related to flooded buildings (Table 7a). In addition to the calls received by Healthy Waters, Fire Emergency New Zealand also responded to calls for weather-related incidents and minor emergencies. Two incident categories, "Domestic/commercial water problem" and "Flood", are generously interpreted as pertaining to flooded buildings (Table 4a).

The number of building-related incidents during the Tasman Tempest, then, ranged from 42 in the New Lynn suburb (and 40 in the Manawa catchment) to 92 for the Whau Local Board and 111 in the Whau/TAS catchments (Table 4a). This comprised less than one per cent of all buildings affected in each area, with a larger proportion affected at the neighbourhood scale – 0.4 per cent in the New Lynn suburb (and 0.6 per cent in the Manawa stream catchment) than at the sub-regional scale – 0.2 per cent in the Whau Local Board and 0.3 per cent in the Whau/TAS catchments.

The number and proportion of buildings affected by the remnants of ex-Tropical Cyclone Debbie were an order of magnitude smaller (Table 4b). One structure-related RFS was received across all four scales, with a handful of both flooded habitable floor incidents at the sub-regional scale and flood-related calls to FENZ at each scale (Table 4b).

Table 7 Number of buildings affected (a) during the Tasman Tempest (7-18 March 2018), and (b) from the remnants of ex-Tropical Cyclone Debbie (4-5 April 2018)

Columns show: [1] Request for Service (RFS) calls received by Auckland Council's Healthy Waters Department. [2] RFS-Structures specify flood emergencies for commercial properties (FLEC), houses (FLEH), and garages (FLEG). [3] Additional RFS-Flooded Habitable Floor denotes where a flooded habitable floor was recorded as the outcome against non-building RFS codes (i.e. codes other than FLEC, FLEH, FLEG). [4] Total RFS pertaining to flooded buildings ([2]+[3]). [5] FENZ-Domestic/commercial water problem are unique incidents (not overlapping parcels with RFS calls) responded to by Fire Emergency New Zealand. [6] FENZ-Flood are unique incidents (not overlapping parcels with an RFS) responded to by Fire Emergency New Zealand. [7] Total Building Incidents as recorded by Auckland Council's RFS system and Fire Emergency New Zealand ([4] + [5] +[6]). [8] Total Buildings shows the total number of buildings in the area (as of 2013).

(a)

Area	**[1] Total RFS**	**[2] RFS-Structures (FLEC, FLEH, FLEG)**	**[3] Additional RFS-Flooded Habitable Floor**	**[4] Total RFS-Flooded Buildings**	**[5] FENZ-Domestic/ commercial water problem**	**[6] FENZ-Flood**	**[7] Total Building Incidents**	**[8] Total Buildings**
New Lynn suburb	76	9	10	19	9	14	42	9,449
Manawa Stream catchment	58	9	11	20	6	14	40	7,228
Whau Local Board	167	19	22	41	14	37	92	37,133
Whau/TAS catchments	191	22	24	46	15	50	111	43,035

(b)

Area	**[1] Total RFS**	**[2] RFS-Structures (FLEC, FLEH, FLEG)**	**[3] Additional RFS-Flooded Habitable Floor**	**[4] Total RFS-Flooded Buildings**	**[5] FENZ-Domestic/ commercial water problem**	**[6] FENZ-Flood**	**[7] Total Building Incidents**	**[8] Total Buildings**
New Lynn suburb	13	1	0	1	0	1	2	9,449
Manawa Stream catchment	9	1	0	1	0	2	3	7,228
Whau Local Board	44	1	4	5	0	3	8	37,133
Whau/TAS catchments	49	1	7	8	1	4	13	43,035

4.2 Lifelines

For the purposes of this assessment, lifelines are defined as transportation; water and wastewater; and power distribution.

4.2.1 Transportation network and nodes

New Lynn's town centre was flooded by the intense deluges on 12 March 2017. Due to the culvert collapse/blockage of the Rewarewa Stream under Great North Road (Figure 1b), the road closed for just over four weeks. It was re-opened on the morning of 14 April 2017. Surface flooding occurred throughout the region.

4.2.2 Water supplies and wastewater

The water supply system was stretched to its limits but held (NIWA 2017a). Due to land slips and erosion in the Hunua Ranges during the Tasman Tempest, water contained high levels of silt requiring Watercare to slow down water treatment at the Ardmore Water Treatment Plant. To prevent the need to release partially treated water, Aucklanders were asked to reduce their water consumption to 20 litres per day. These were the first water restrictions in Auckland since 1994 (RadioNZ 2017). In the end, the system coped, and the treated water supply was not interrupted.

4.2.3 Power distribution

Power outages occurred in suburbs largely adjacent to, and partially overlapping, the focus areas for this study. The rain flooded the electricity utility, Vector's, substation on Waikaukau Road, causing an outage to 2800 households in Glen Eden and surrounding suburbs. Earlier in the day, downed lines caused a short-term power outage to 1300 households in Sunnyvale.

4.3 Economy

Commercial premises were flooded, and there were a few short-term business closures. The Probett Building at 3107 Great North Road, New Lynn required emergency partial demolition due to structural impairment from flooding (Auckland Council 2017a). A carpark and footpath were swallowed by a sink hole on the northern side of Great North Road near the culvert collapse (Figure 1b).

4.4 Health and safety

MetService warned of hazardous driving conditions due to surface flooding and poor visibility during heavy rain. After flooding inundated the New Lynn shopping area, 23 people were rescued by the NZ Fire Service (Nelson and others 2017, Deuchars 2018). In Kelston, 12 residents were evacuated from a multi-dwelling residential block (Auckland Council 2017c). There were no reports of injuries or deaths connected to this storm series in the areas under consideration.

5.0 Risk: a thought experiment

The risk-based assessment approach developed by GNS (Section 2.2) was used as a methodical analytical tool to contextualise the storm data (Sections 3 and 4) for the purposes of understanding impact on Aucklanders and policy or management responses. The process outlined in Section 2.2 is followed in this section.

Step 1: Know your hazard

In this post-storm analysis, the storm magnitude and consequences have already been experienced. Also, prior to the event, the flooding hazard was a recognised issue insofar as one per cent AEP flood hazard mapping has been completed by Auckland Council across the region, including for the study areas (Figure 1b, Figure 8). The flood hazard experienced in the 2017 storms corresponded to those with approximately 1-2 per cent and 10-20 per cent AEPs (Section 3.0).

Step 2: Determine the severity of the consequences

In the GNS risk framework (Saunders 2017), consequences on community well-being are quantified via impacts on buildings, lifelines, economic impact, and health and safety (Table 1). Below, each category is considered in turn.

Buildings

In the case of the New Lynn suburb, the Manawa Stream catchment, the Whau/TAS catchments, and the Whau Local Board, less than one per cent of total buildings were functionally compromised (Table 7), including none with social, cultural or critical significance (Section 4.1), which would result in rating the severity of impact as Insignificant for each building category (Table 9). Although this may be an underestimate insofar as some flooding events may have not been called in to Auckland Council or Fire Emergency New Zealand, it also may be an overestimate insofar as not every building affected by flooding was *functionally* compromised.

These data correspond well, though, with the 10 known instances of functionally compromised buildings that were no longer habitable: the Probett building mentioned above and nine households requiring new accommodation, aided by Auckland Emergency Management (L. Benge, personal communication, April 19, 2018). Yet, this is also likely to be an underestimation, as not all people requiring help would have made themselves known to local government or emergency services.

More to the point, the risk-based assessment tool focuses on the effect upon buildings in a hazard area. In terms of understanding the March/April storms, this can be interpreted as buildings within the 1% AEP flood hazard zones (Figure 8).

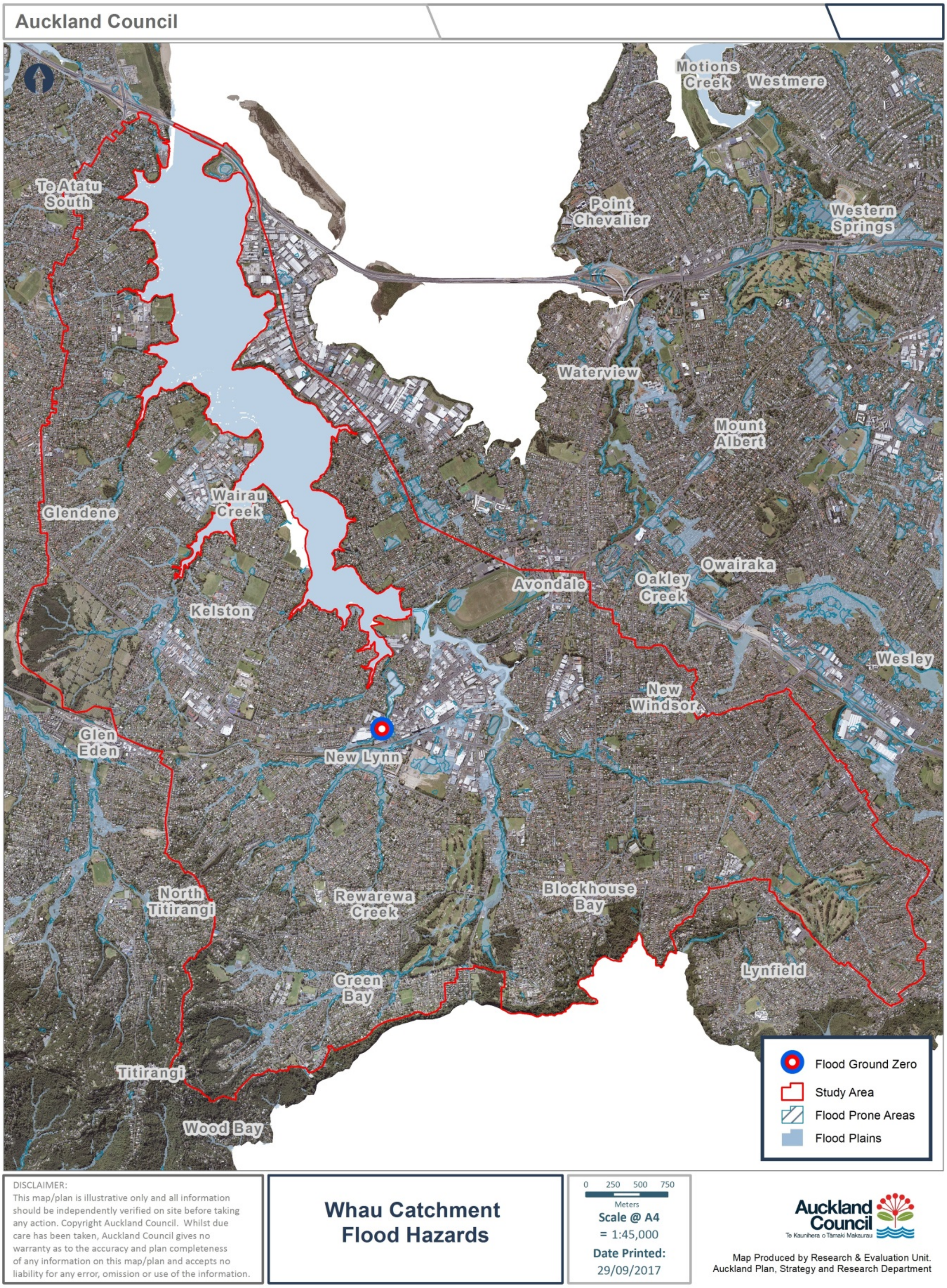


Figure 8 Flood hazards in the Whau and Te Atatu South catchments

Table 8 Occurrence of flooded buildings within flood hazard zones during the Tasman Tempest (7-18 March 2017).

	New Lynn suburb	Manawa Stream catchment	Whau Local Board	Whau/TAS catchments
Total Buildings	9,449	7,228	37,133	43,035
Total RFS incidents (Table 4a)	42	40	92	111
Total FENZ incidents (Table 4a)	23	20	51	65
Flood Plains (FP)				
Buildings in FP	791	529	2760	2875
% of total buildings	8%	7%	7%	7%
RFS occurring in FP	13	12	24	27
% FP buildings	1.6%	2.3%	0.9%	0.9%
FENZ in FP	12	12	23	30
% FP buildings	1.5%	2.3%	0.8%	1.0%
Total incidents (RFS+FENZ) in FP	25	24	47	57
% FP buildings	3.2%	4.5%	1.7%	2.0%
Flood prone Areas (FPA)				
Buildings in FPA	306	256	1165	858
% of total buildings	3%	4%	3%	2%
RFS occurring in FPA	6	5	11	12
% FPA buildings	2.0%	2.0%	0.9%	1.4%
FENZ in FPA	7	6	13	16
% FPA buildings	2.3%	2.3%	1.1%	1.9%
Total incidents (RFS+FENZ) in FPA	13	11	24	28
% FPA buildings	4.2%	4.3%	2.1%	3.3%
Overland Flow Paths (OFP)				
Buildings in OFP	1,013	689	4,333	4,777
% of total buildings	11%	10%	12%	11%
RFS occurring in OFP	16	16	32	36
% OFP buildings	1.6%	2.3%	0.7%	0.8%
FENZ in OFP	20	17	42	56
% OFP buildings	2.0%	2.5%	1.0%	1.2%
Total incidents (RFS+FENZ) in OFP	36	33	74	92
% OFP buildings	3.6%	4.8%	1.7%	1.9%
Any flood hazard area				
Buildings in FP or FPA or OFP	1,634	1,120	6,565	6,930
% of total buildings	17%	15%	18%	16%
RFS occurring in FP or FPA or OFP	16	16	33	37
% FP or FPA or OFP buildings	1.0%	1.4%	0.5%	0.5%
FENZ in FP or FPA or OFP	21	18	44	56
% FP or FPA or OFP buildings	1.3%	1.6%	0.7%	0.8%
Total incidents in FP or FPA or OFP	37	34	77	93
% buildings in FP or FPA or OFP	2.3%	3.0%	1.2%	1.3%

From this perspective, a different picture emerges of storm consequences. Across all four study areas, RFS and FENZ incidents occurred on more than one per cent of buildings situated in floodplains (Table 8), with a relatively higher proportion of floodplain buildings affected in the smaller study areas (3 per cent in New Lynn and 4 per cent in Manawa) than in the larger study areas (2 per cent in the Whau Local Board and Whau/TAS catchments). The same trend exists when considering the buildings affected in *any* flood hazard area (flood plains or flood prone areas or overland flow path): for all areas, more than one per cent of the buildings were affected, with a higher proportion affected in the smaller study areas versus the larger ones (Table 8). A relatively smaller proportion of buildings were affected across all flood hazard areas than just those in flood plains given the relatively high proportion of buildings that sit within one of these hazard zones (15%-18%) in contrast to flood plains alone (7%-8%) (Table 8).

In any case, crossing the one per cent threshold of buildings affected with the hazard zone results in a severity of impact as Minor for the Buildings category (Table 9). The severity of impact for critical and social/cultural buildings remains Insignificant due to no records of flooding incidents for these types of buildings (Table 9).

These represent the best available data for estimating the impact of the storms, but again, could be under- or overestimating the impacts. Since not all flood events were called in to a government organisation (thus becoming an RFS or FENZ callout), the figures will underestimate the total number of buildings flooded. On the other hand, they are an overestimate insofar as these incidents are generously used as a proxy for functionally compromised buildings when, indeed, most buildings were not functionally compromised, even if flooded to some degree. Indeed, one insurance provider communicated that they considered none of their claims were for functionally compromised buildings.

Lifelines

For New Lynn and the Whau, water supply, waste water, and power distribution were maintained for the most part (Section 4.2), and so would result in an Insignificant severity of impact rating (Table 9).

Larger impacts, however, affected the transportation network due to the culvert collapse/blockage and the repeated road closures on Great North Road. Were these insignificant, minor, or moderate? The answer depends on the scale considered and on the loss of functionality ascribed. The severity of impact depends on the proportion of population affected by the transportation network and nodes that are "out of service" (Table 1). Roads were closed for more than one week (up to four), with the collapsed culvert requiring a large repair effort.

Table 9 **Consequences of the March/April storms on New Lynn and the Whau.** Red outline denotes data-driven assessment; pink outline offers alternative interpretation for transport lifeline (see text).

	Built					
Severity of Impact	**Buildings**	**Critical**	**Social/ Cultural**	**Lifelines**	**Economic**	**Health and Safety**
Catastrophic (V)	≥50% of buildings within hazard zone have functionality compromised	≥25% of critical facilities within hazard zone have functionality compromised	≥25% of buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for > 1 month (affecting ≥ 20% of the town/city population) OR suburbs out of service for > 6 months (affecting < 20% of the town/city population)	≥ 10% of regional GDP	> 101 dead and/or >1001 injured
Major (IV)	>20-<50% of buildings within hazard zone have functionality compromised	>10- <25% of critical facilities within hazard zone have functionality compromised	>10- <25% of buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for 1 week to 1 month (affecting ≥ 20% of the town/city population) OR suburbs out of service for 6 weeks to 6 months (affecting < 20% of the town/city population)	1.0 to < 10% of regional GDP	11-100 dead and/or 101-1000 injured
Moderate (III)	>10-20% of buildings within hazard zone have functionality compromised	>5-10% of critical facilities within hazard zone have functionality compromised	>5-10% of buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for 1 day to 1 week (affecting ≥ 20% of the town/city population) OR suburbs out of service for 1 week to 6 weeks (affecting < 20% of the town/city population)	0.1 to < 1.0% of regional GDP	2-10 dead and/or 11-100 injured
Minor (II)	1-10% of buildings within hazard zone have functionality compromised	<1-5% of critical facilities within hazard zone have functionality compromised	<1-5% of buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for 2 hours to 1 day (affecting ≥ 20% of the town/city population) OR suburbs out of service for 1 day 1 week (affecting < 20% of the town/city population)	0.01 to <0.1% of regional GDP	≤ 1 dead and/or 1-10 injured
Insignificant (I)	< 1% of buildings within hazard zone have functionality compromised	No critical facilities within hazard zone have functionality compromised	No buildings of social/cultural significance within hazard zone have functionality compromised	Out of service for up to 2 hours (affecting ≥ 20% of the town/city population) OR suburbs out of service for up to 1 day (affecting < 20% of the town/city population	< 0.01% of regional GDP	No dead No injured

Yet the transportation network itself still functioned with alternative routes in place. Although travel routes were altered, resulting in increased travel distances and times, neither the study areas (New Lynn specifically and the Whau/TAS catchments/Local Board more broadly) nor their resident populations were cut off or isolated. The New Lynn commercial centre was still accessible, even if inconvenient, while repairs were underway. The management of this crisis point translates to an Insignificant severity of impact rating, as alternative routes were in place and no one was isolated or trapped (Table 9). This does not discount the disruption caused by road flooding (including the culvert collapse/blockage and sinkhole), but that rather scales it in the context of the continued operation of the transportation network and the ability to traverse the area. Alternatively, it could be argued that the severity of impact was Moderate insofar as road closures lasted four weeks (Table 9).

Economy

For the New Lynn suburb and Whau/TAS catchments, only the value of buildings damaged is relevant in the GNS tool's economic impact calculation due to no reported casualties (Section 2.2).

As an approximation, the 2016 Gross Domestic Product for the Whau Local Board was $2.65 billion in 2010 prices (Infometrics 2016), translated to $2.96 billion in 2017 prices. Using this figure, the relevant thresholds for economic consequences (Table 1) can be calculated in order to determine a severity of impact (Table 10).

Table 10 Regional economic consequence thresholds for the Whau Local Board area

Economic Consequence Threshold*	**Threshold (2017 $)**	**Limit for Severity of Impact (< Threshold)**
10.00% GDP	$295,511,738	Major**
1.00% GDP	$29,551,174	Moderate
0.10% GDP	$2,955,117	Minor
0.01% GDP	$295,512	Insignificant

*Thresholds based on 2016 local GDP (in 2017 $) for severity of impact categories in Saunders (2017). **A Catastrophic severity of impact rating would be applied when economic costs are 10 per cent or greater of regional GDP.

The value of buildings damaged was estimated by the claims information provided by the four major insurance companies. Claims for domestic or commercial properties were considered as the values of the buildings damaged. These claims totals exceeded the 0.10 per cent GDP threshold (Table 10) at ~0.2 per cent for the wider Whau Local Board and ~0.4 per cent for the smaller area New Lynn suburb, again demonstrating the more intense consequences of the localised storm intensity for New Lynn. In either case, the Economic severity of impact is rated Moderate (Table 9).

Health and safety

With no deaths or injuries associated with the storms, the severity of impact for health and safety consequence is “Insignificant” (Table 9). It is important to recognise that this tool narrowly defines “Health” in contrast to broader definitions (e.g., World Health Organisation 2005), which would incorporate other aspects of well-being such as mental health.

Summarising consequences

In this risk-based assessment tool, the consequence with the highest severity of impact determines the overall level of impact. Thus, in this case, the severity of the consequences of the Tasman Tempest on New Lynn and the Whau are considered Moderate, due to the Moderate rating for the severity of the economic consequences. Repeating this exercise for the impacts of the remnants of Cyclone Debbie (4-6 April 2017) assessed that storm’s severity of impact as Insignificant.

Step 3: Evaluate the likelihood of an event

The likelihood of storms is assigned a descriptor from Very Rare to Likely, depending on the frequency of events (Table 2). For the study areas, the likelihood frequency of the 12 March storm, estimated as between 64 to more than 100 years (Table 4), would fall into the “Possible” (denoting such an “event might occur once in your lifetime”) or “Unlikely” (denoting “the event does occur somewhere from time to time”). The 4-5 April storm, on the other hand, would be classified as “Likely”, given the calculated ARIs of approximately 3-10 years (<10-39% AEP) (Table 6).

Step 4: Take a risk-based approach

The risk matrix uses a function of consequences multiplied by likelihood (Table 3), providing a risk assessment for this thought experiment.

For the 12 March storm, the Moderate consequences have an assigned value of 3 (Table 9) and a Possible event has an assigned value of 4, or an Unlikely event a value of 3 (Table 2). The risk, then, is either quantified as 12 for storm considered possible (Table 3), translating to the lower end of the range for a “Tolerable” level of risk in an example[4] schema (Table 11), or as 9 (the upper bound of "Acceptable") if the storm is considered Unlikely.

For the 4-5 April storm, the Insignificant consequences have an assigned value of 1 (Table 9) and a Likely event has an assigned value of 5 (Table 2), creating a risk of 5

[4] The example schema used here is for demonstration purposes only; how the actual levels would map for Auckland should be determined via stakeholder engagement.

(Table 3), which translates to a mid-range Acceptable level of risk in the example schema (Table 11).

Table 11 Levels of risk. An example of how risk ratings can be assigned a normative value from Saunders (2017) and used in this report for demonstration purposes.

Risk	Level of risk
1-9	Acceptable
10-19	Tolerable
20-25	Intolerable

Step 5: Monitor and evaluate

In other words, given the magnitude of the storms and their consequences in the study area, this is what “acceptable” or “tolerable” feel like. So – Acceptable. Tolerable. Was it? Should it be? Was it something less, or more? And how is this assessment affected by the “acceptable” event that closely followed?

For the purposes of this evaluative thought exercise, the existing risk-assessment scale suffices as a means to capture a holistic view of storm consequences. Although the public and media attention were captured by the touching and sympathetic stories of those flooded out of their homes and businesses— all legitimate and important occurrences, flooded buildings were a minor impact when put in context of the entire built environment across the areas, although the more intense impact upon a specific area was evident in the higher proportion of buildings affected in the New Lynn suburb and Manawa stream catchment. The consequence with the most leverage in this assessment was the economic one, due to having the highest impact rating in the Moderate category. It is interesting to note that the economic consequences reached this level even with the Minor impact on buildings and Insignificant impacts across other categories. Across all scales in the Whau, the main impacts were the cost of building damage and one crisis point: the broken/blocked culvert and its subsequent flooding affecting some businesses and part of the transportation network.

Notwithstanding these caveats and the longer list of impacts across the Auckland region (and the risk-based assessment tool could be used in a separate analysis at this scale), the New Lynn story is a somewhat contained one in contrast to other catastrophic events. All together, perhaps this event is best understood as tolerable: that is, the consequences of a large, but expected (possible) event were surmountable, as it has been possible to attend to and recover from them.

It is worth noting that in practice, Saunders et al. (2013) encourage participatory debate within council and across the community to determine the thresholds for levels of risk (Table 11). Through such a process, various stakeholder groups (e.g., communities, Māori, council staff, and lifelines utilities) can identify their levels of risk, which can be reconciled with expert opinion and may differ from that presented here. Thus, this post-event analysis offers an opportune moment to reflect on how such weather events affect the city and region. Given the consequences wrought by this magnitude of storm, what is the assessment of the city's vulnerability and preparation for floods, and its management of the storm and its aftermath? How would the findings compare to expectations and values of all stakeholder groups?

Remembering that this tool is proposed as a planning tool, to be used to assess the possible impact of land-use decisions, it is important to consider how this *post hoc* assessment can inform those current practice and future land-use decisions. In particular, this assessment provides actual data on past and current development decisions, including the practice of building in flood hazard areas. The risk and vulnerability of building in flood plains is more evident when considering what happens to buildings in the most hazardous areas, as well as where incidents are likely to take place. For those buildings located in all three flood hazard areas (that is, their parcels overlap with a floodplain and a flood prone area and an overland flow path), 19-24 per cent of them were affected in the small study areas and 9-14 per cent in the larger ones (Table 12) substantially higher than the one to three per cent of buildings affected in any of the flood hazard zones or the two to five per cent of those in flood plains (Table 8).

Table 12 Occurrence of flooding for buildings situated in all flood hazard zones

All flood hazard areas	New Lynn suburb	Manawa stream catchment	Whau Local Board	Whau catchment study area
Buildings in FP and FPA and OFP	69	45	247	194
% of total buildings	1%	1%	1%	0%
RFS occurring in FP and FPA and OFP	6	5	11	12
% FP and FPA and OFP buildings	8.7%	11.1%	4.5%	6.2%
FENZ in FP and FPA and OFP	7	6	12	15
% FP and FPA and OFP buildings	10.1%	13.3%	4.9%	7.7%
Total incidents (RFS+FENZ)-all hazard	13	11	23	27
% buildings – all flood hazard areas	18.8%	24.4%	9.3%	13.9%

Of the flooding incidents that occurred in March 2017, large proportions were on parcels intersecting with flood hazard zones: one-third of incidents in the Whau Local Board and Whau/TAS catchments and nearly 40 per cent of those in the New Lynn suburb occurred in flood plains (Table 13). Due to the prevalence of overland flow paths throughout the area, more than half of incidents occurred on parcels with overland flow paths at all scales. This is also true overall: more than half of building flood incidents occurred on a parcel located in any combination of flood hazard areas (Table 13).

Table 13 Proportion of building flood incidents that occur in flood hazard zones

(Incident data from Table 5)

	New Lynn suburb	**Manawa Stream catchment**	**Whau Local Board**	**Whau/TAS catchments**
Total incidents (RFS + FENZ)	65	60	143	176
Incidents in FP	25	24	47	57
% of all incidents	38%	40%	33%	32%
Incidents in FPA	13	11	24	28
% of all incidents	20%	18%	17%	16%
Incidents-OFP	36	33	74	92
% of all incidents	55%	55%	52%	52%
Incidents in FP or FPA or OFP	37	34	77	93
% of all incidents	57%	57%	54%	53%
Incidents in FP + FPA + OFP	13	11	23	27
% of all incidents	20%	18%	16%	15%

6.0 Discussion

That the storm events were summarised as “Acceptable” or “Tolerable” via this thought experiment exercise in no way diminishes the very real challenges suffered by those individually and collectively affected by the flooding, including damaged houses and businesses. Rather, the aim was to use a structured tool to undertake a dispassionate analysis at the appropriate scale, avoiding the trap of personal story (“anecdata”) and individual instances (a statistical sample of one). Acknowledging the importance of the major impact of the storm for those individuals, this thought experiment seeks to contextualise a storm event for management and planning responsibilities, duty of care, and stewardship for risk-based planning across scales: catchment, local board, city, and region. It is difficult for most people to understand or visualise the actual risk of a disaster unless it happens (Sobel 2014); this thought experiment is one, though not the only, way to make those connections.

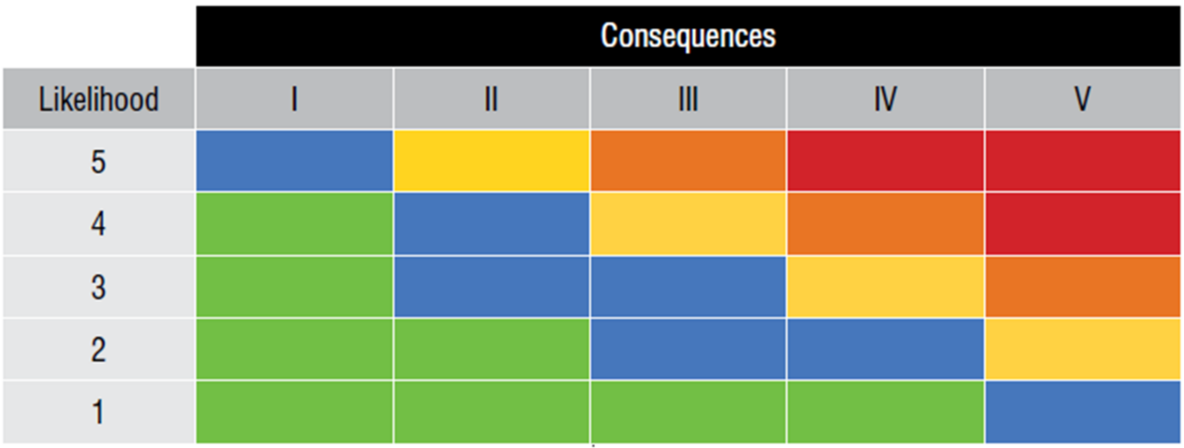
It is important to note the tool’s focus on assessing the event itself does not provide the long-term understanding of the event. Indeed, the immediate consequences of events such as these storms can extend well past the aftermath into a recovery phase. For this case study, this is most evident in consideration of economic impacts, based only on the value of buildings damaged in the risk assessment tool (Step 2). Yet, one year later New Lynn locals suffered traffic congestion due to ongoing road repairs, which retailers also blamed for business decline in addition to flood damage (Ali 2018). For another example, Christchurch is still in the midst of a multi-year recovery after the 2010 and 2011 earthquakes (with long-term consequences across all four sectors). Beyond the direct assessment of the storm (or any event) as undertaken here, direct consequences morph into flow-on and cumulative effects in a recovery phase, to some extent implicit in the consequence rating. Indeed, the recovery phase will have its own trajectories of timing and outcomes (e.g., differences between post-event New Lynn and Christchurch). This indicates the need for additional assessment of the long-term impacts, a combination of the event itself (as reviewed here), informed by monitoring and evaluation of recovery, resilience, and even land-use planning. Through both kinds of evaluation, spatial and temporal impacts of storms can be understood.

The utility of such risk-based assessments for land-use planning lies in the decision-making that will ensue. Indeed, the ramifications of other powerful storms have been found to be rooted not in crisis preparedness or response, but in the decades of decision-making about development along coastlines or in flood hazard areas, such as when Superstorm Sandy swept over the greater New York City area in 2012 (Sobel 2014). In New Zealand, the Bay of Plenty Regional Council is using the approach for its Regional Policy Statement. It can also be used as the framework against which to assess development decisions. The levels or risk can be translated into consent decision-making points (Figure 9), which can also be remapped onto the consequence and likelihood cross-matrix to create a risk-based planning framework (Figure 10). Both consideration of and learnings from events can not only inform Auckland's (2016) readiness, response, and recovery phases of emergency management but also the reduction and resilience ones.

Figure 9 **An example of consent status associated with level of risk.**
(Source: Saunders 2017)

Level of risk	Consent
Acceptable	Permitted
Acceptable	Controlled
Tolerable	Restricted Discretionary
Tolerable	Discretionary
Intolerable	Non complying, prohibited

Figure 10 **Risk-Based Planning Framework.**
(Source: Saunders 2017)



Is it enough to experience an “Acceptable” or “Tolerable” event – to understand what it feels like – in order to make proactive decisions about land use for both established suburbs and greenfield developments? The alternative is waiting to experience a higher level of risk – a larger magnitude storm inflicting more severe consequences – before implementing changes in a reactive atmosphere.

More severe consequences are indeed possible, and imagination is not even required. It is worth noting that Cyclone Cook, the last storm in the March/April 2017 series, did not travel directly over Auckland as originally forecast but veered farther east, wreaking havoc in other locales. Had it stayed its course, it is quite likely that the impact severity rating would be one or two levels higher across one or more consequences (Table 9). Following these storms and others from the South Pacific cyclone season (November 2016 - April 2017), the 2017 Atlantic Hurricane season (June-November 2017) delivered multiple demonstrations: among the record-breaking eight hurricanes formed, three Category 4 hurricanes made landfall and wreaked devastation across three major population centres and metropolitan areas in the United States. During the 2017-2018 South Pacific cyclone season, three ex-tropical cyclones traversed New Zealand, above the average of one per year. And the 2018 Atlantic Hurricane delivered another two catastrophic storms to the United States late in the season.

Storms of the magnitude experienced in March/April 2017 are expected to become more common. Under a business as usual climate change scenario (Carey-Smith et al. 2018), storms similar to the 12 March 2017 in New Lynn are projected to move from approximately a 1-1.2 per cent AEP (80-100 year ARI) in 2040 to a 3.3-5 per cent AEP (20-30 year ARI) in 2090. Such low probability storms, then, are likely to evolve into those having considerable precedent.

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