ASSESSING HAZARDS! FILLING THE HOLES IN OUR RISK ASSESSMENT METHODOLOGY

Tony Wang & Simran Bassan - Woods

ABSTRACT

The 2023 Auckland Anniversary flood events and ex-tropical Cyclone Gabrielle in mid-February brought with them record rainfalls, slips and subsidence, which caused extensive damage to the three waters, transport, and infrastructure. These events resulted in significant economic losses and even the loss of life, highlighting a need to better address flood-related risks and minimise the impacts of future flood events. It is now more than ever important for communities to assess the risks they face to inform future planning and build long term resilience.

In the Auckland Region, the flood hazard classification method provided in Auckland Council Stormwater Flood Modelling Specifications is commonly used to assess flood hazards and understand their significance. Flood vulnerability curves and flood hazard definitions provided in the Australian Rainfall Runoff Guidelines (ARR) further define these flood hazards in relation to their effects on people, vehicles, and structures.

Both the ARR and Auckland Council modelling specifications fall short in their methodology as they do not detail how to assess the impacts of the loss of infrastructure and its effects on the local economy. The available knowledge can be supplemented with the implementation of the RiskScape methodology detailed in NIWA's technical report 'RiskScape: Flood fragility methodology', August 2010 (NIWA, 2010). This methodology provides a way to assess household content damages, economic loss, infrastructural loss and identifies locations where to or where not to build any future infrastructure which may be affected by flooding. The RiskScape methodology sets thresholds and assigns classes with different levels of associated expected damage. With relation to future planning and building flood resilience communities, this information can be used to identify the most effective flood protection measures and to inform the development of any flood emergency response plans where necessary.

Flood fragility curves can be used to define a damage ratio. Damage ratios can predict expected damage for a building and its contents, the functional downtime for a business post flood event and the inundation depth for stormwater, water supply, and sewage pump stations to determine the loss/downtime of the critical infrastructures. Overall, this method provides insights into the vulnerability of

communities to flood events, depicting the potential harm or disturbance they may experience.

Currently, no single tool/guidance stands out as assessing the full extent of the consequences that a flood can have on the community. We believe it is in the best interest of the industry to standardise an approach that can be adopted at a national or regional level. The combination of AC modelling specifications, ARR and RiskScape methodologies are examples of methodologies that can be used to understand the damage caused by major flood events and ultimately inform planning for future development.

This paper explores the methodology to evaluate flood impacts and discusses ways in which flood-related risks can be better represented using various tools and methodologies and validated against the January flood event. Understanding the impacts of these hazards will form the basis of future planning to build long term resilience.

KEYWORDS

Hazards Evaluation, Resilience, Future Planning

PRESENTER PROFILE

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INTRODUCTION

Flooding is one of the most consequential natural hazards that communities worldwide face, posing significant threats to human life and infrastructure.

The exacerbation of flood hazards can be attributed, in part, to the ongoing expansion of urban areas and, notably, the impacts of climate change. As global temperatures rise (Ministry for the Environment, 2018), the repercussions of climate change have become increasingly apparent, manifesting in sea level rise, altered precipitation patterns, and a surge in the frequency and severity of extreme weather events. These climate change-induced phenomena are projected to intensify the flood risks faced by communities across the globe.

The 2023 Auckland Anniversary flood events and the ex-tropical Cyclone Gabrielle in mid-February were natural disasters of unprecedented magnitude, leaving a trail of destruction in their wake. The record-breaking rainfall, coupled with severe slips and subsidence, wreaked havoc on critical infrastructure, particularly stormwater, water, and wastewater assets. The consequences of these calamitous events were devastating, leading to substantial economic losses and, tragically, the loss of precious lives. The severity of these disasters has highlighted the urgent need for communities to proactively address flood-related risks and adopt comprehensive measures to mitigate the impacts of future flood events.

In developing our communities, it is important we learn to coexist with water and adapt to it, as is currently being done with the 'Making Room for Water' initiative. This is best done through successful design and careful future planning.

Flood events have disastrous effects on both people and property. Commonly used assessment methodologies have shortcomings in their approach, as they fail to provide a means for assessing the effects of infrastructure loss and its impact on the local economy. To bridge this gap, flood fragility curves can be utilised.

This research paper delves into the evaluation of flood impacts while exploring different tools and methodologies for better representing flood-related risks. Additionally, the findings will be compared against the January flood event to enhance their reliability and applicability.

RISK

With continued urban expansion, the effects of climate change have become even more evident. Climate change is projected to increase the frequency and severity of extreme weather events, which in turn means there will be an increase in flooding.

The current population of New Zealand in 2023 is 5,228,100, a 0.83% increase from 2022 (Macrotrends, n.d.). Over the past 10 years, the New Zealand population has increased by approximately 1 million people, bringing with it the need for more intensified cities and utilities to facilitate this growth.

The impacts of climate change, such as sea level rise, changes in precipitation patterns, and increased frequency and severity of extreme weather events, are expected to increase the flood hazards faced by communities. This, coupled with the ever-expanding cities, brings forward a need, now more than ever, to fully understand the impacts of our development and the effects this can have on generations to come.

FLOOD LOSSES AND DAMAGES

Flood losses refer to the material and non-material damages, both economic and social, that occur as a result of flood events. These losses encompass a wide range of negative impacts on individuals, communities, economies, and the environment.

Tangible flood damage refers to the physical and visible harm caused by flooding to structures, belongings, infrastructure, and the environment. This type of damage can be directly observed and assessed.

Intangible flood damage refers to the non-physical and less immediately visible effects that flooding can have on individuals, communities, and the environment. Unlike tangible flood damage, which includes physical destruction and visible losses, intangible flood damage is more abstract and often involves emotional, psychological, and social consequences.

To derive realistic estimates of flood impacts, this paper will focus solely on tangible flood loss. Within this loss classification, we can further define tangible losses as being either direct or indirect.

A direct tangible flood loss refers to the immediate and measurable economic or physical damage induced by physical contact with floodwaters. These losses are directly observable and often involve destruction or damage to property, infrastructure, and assets.

An indirect tangible flood loss refers to the secondary or consequential economic and physical damages that result from a flood event but are not immediately observable or directly caused by the floodwaters themselves. These losses are often a result of the disruption and cascading effects triggered by the initial flood impact.

A schematic of this classification process is shown below in Figure 1.

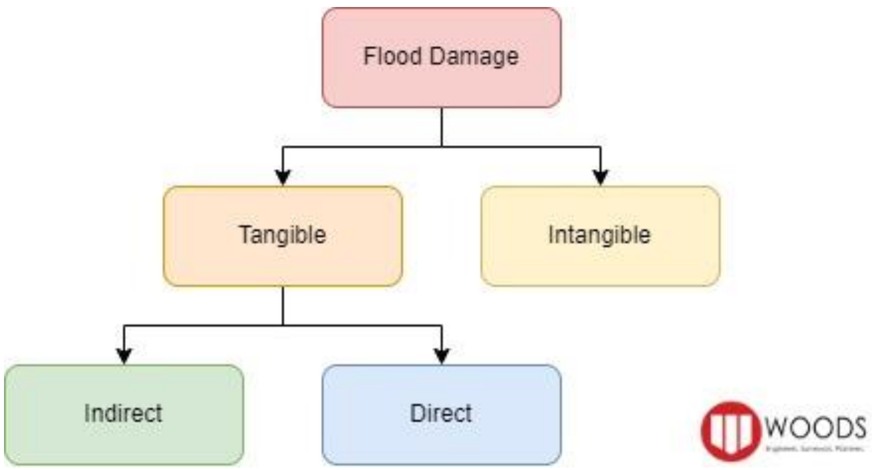


Figure 1: Flood Damage Classification Process

EXISTING TOOLS

In the realm of assessing hydrological phenomena and their implications, various established tools have been developed to aid professionals and researchers in comprehending and predicting water-related processes. Among these tools are the Australian Rainfall Runoff Guidelines (2019) and the Auckland Council Modelling Specifications Version 4 (2011), each designed to provide guidance and structure in understanding and assessing flood hazards.

AUCKLAND COUNCIL TECHNICAL SPECIFICATION FOR STORMWATER FLOOD MODELLING

The Auckland Council technical specification for stormwater flood modelling Version 4 (2011) outlines Auckland Council's requirements for the planning and management of stormwater drainage modelling. These modelling specifications provide a framework for developing models that simulate hydrological processes, contributing to effective decision-making regarding water management and flood risk assessment in the Auckland region of New Zealand.

In the Auckland Region, the flood hazard classification method provided in Auckland Council Stormwater Flood Modelling Specifications is commonly used to assess flood hazards and understand their significance.

The Auckland Council Stormwater Flood Modelling Specifications provides a set of standard flood hazard classification categories that can be used to assess flood hazard.

Hazards are classified in three different hazard classifications (1 – 3), with increasing levels of associated flood risk, as seen in Table 1 and Figure 2.

Table 1: AC Modelling Specifications Hazard Classification (Auckland Council, 2011)

Hazard Classification	Description	Depth-velocity Criteria
1	Potential Hazard	0.05m < Depth < 0.1m
2	Minor Hazard	0.1m < Depth < 0.3m and Velocity < 2.0m/s
3	Significant Hazard	Depth > 0.3m and Depth > 0.1m & Velocity > 2.0m/s

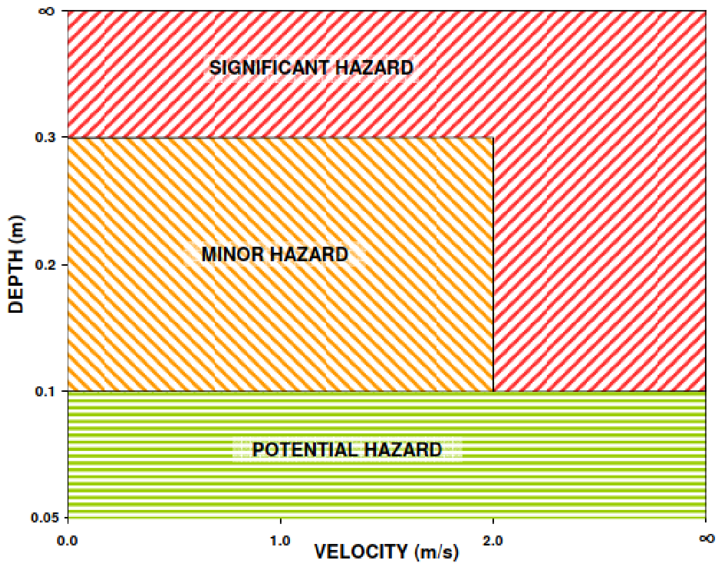


Figure 2: AC Modelling Specifications Hazard Classification (Auckland Council, 2011)

The Auckland Council Stormwater Flood Modelling Specifications also provide a methodology to assess flood damage. The assessment is mainly focused on building damages. The total residential damage is based on the structural damage and the contents damage. The commercial damage, however is calculated based on damage rate and the floor area.

$$\text{Total Damage}_{(\text{residential})} = (\text{Structural Damage } (\$/m^2) * \text{True Floor Area } (m^2)) + \text{Contents damages } (\$))$$

In the case of commercial buildings, the total damage is calculated by multiplying the floor area by the damage rate per m^2 for the respective flood height.

$$\text{Total Damage}_{(\text{commercial})} = \text{Damage Rate } (\$/m^2) * \text{Floor Area } (m^2)$$

AUSTRALIAN RAINFALL AND RUNOFF GUIDELINE

The Australian Rainfall and Runoff Guidelines (ARR) is a national guidelines document commonly adopted in New Zealand that can be used to estimate design flood characteristics. Flood hazard is quantified by considering velocity and depth in combination to define the different levels of flood hazard for people, vehicles, and structures.

Flood vulnerability curves and flood hazard definitions provided in the Australian Rainfall Runoff Guidelines (ARR) define these flood hazards in relation to their effects on people, vehicles, and structures.

The Australian Rainfall and Runoff Guidelines (ARR) is a national guidelines document commonly adopted in New Zealand that can be used to estimate design flood characteristics. Flood hazard is quantified by considering velocity and depth in combination to define the different levels of flood hazard for people, vehicles, and structures.

Hazards are classified into six different hazard vulnerability classifications (H1 – H6), with increasing levels of associated flood risk, as seen below in Table 2.

Table 2: Vulnerability thresholds classification limits (J. Ball, 2019)

Hazard Vulnerability Classification	Classification limit (Depth * Velocity)	Limiting Still Water Depth (m)	Limiting Velocity (m/s)
H6	D*V > 4.0	-	-
H5	D*V <= 4.0	4.0	4.0
H4	D*V <= 1.0	2.0	2.0
H3	D*V <= 0.6	1.2	2.0
H2	D*V <= 0.6	0.5	2.0
H1	D*V <= 0.3	0.3	2.0

Vulnerability curves are based on flood characteristics and set thresholds to identify which different parties will be at risk in different flood conditions. The flood characteristics and Hazard definitions for each vulnerability classification are defined in Figure 3.

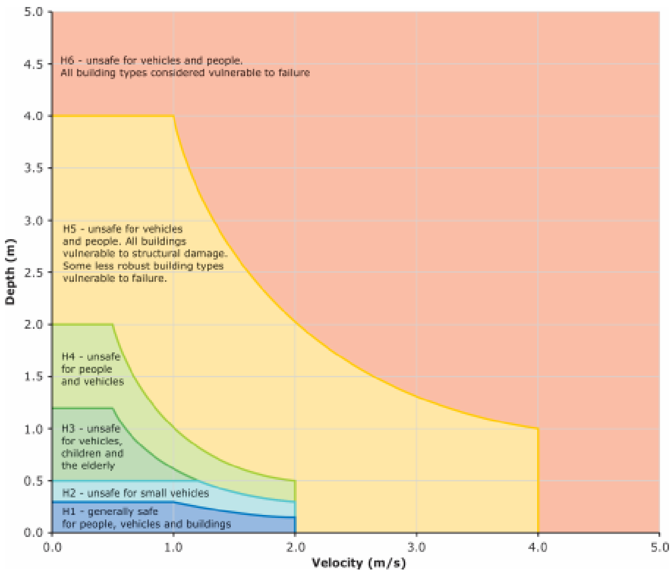


Figure 3: General Flood Hazard Vulnerability Curves (J. Ball, 2019)

DAMAGE AND ECONOMIC LOSS

A literature review brought to light a notable deficiency in both the Australian Rainfall Runoff Guidelines and the Auckland Council Modelling Specifications in their approach towards assessing the interplay between hydrological disruptions and the resultant economic implications. While these tools proficiently address hydrological aspects, they do not comprehensively detail the methodologies required to evaluate how the breakdown of critical infrastructure can reverberate through the local economy.

The absence of a robust methodology for assessing the cascading effects of infrastructure loss on economic activities can hinder the ability to formulate effective disaster response and recovery strategies. The aftermath of a disaster often involves more than just hydrological consequences; it encompasses a complex web of socioeconomic factors that influence livelihoods, businesses, and overall community well-being. Failing to account for the broader economic impacts of infrastructure disruption can lead to incomplete assessments, potentially hampering the ability to allocate resources efficiently, plan for resilience, and facilitate timely recovery.

LOSS ASSESSMENT

Flood fragility curves play a pivotal role in assessing the vulnerability of infrastructure to flooding events. Flood fragility curves are graphical representations of the relationship between flood depth and the likelihood of damage to a building or infrastructure. Fragility functions are typically developed by experts by analysing historic flood events and damage datasets.

In essence, fragility curves offer a systematic means of establishing a direct correlation between the extent of floodwater penetration and the resultant structural damage. Fragility curves are used to define an associated damage ratio, which will help define a damage state as seen in Table 3. Each damage state acts as an indicator, serving to articulate the severity of the harm inflicted upon a structure and the repair actions required to restore the structure to its pre-flood condition.

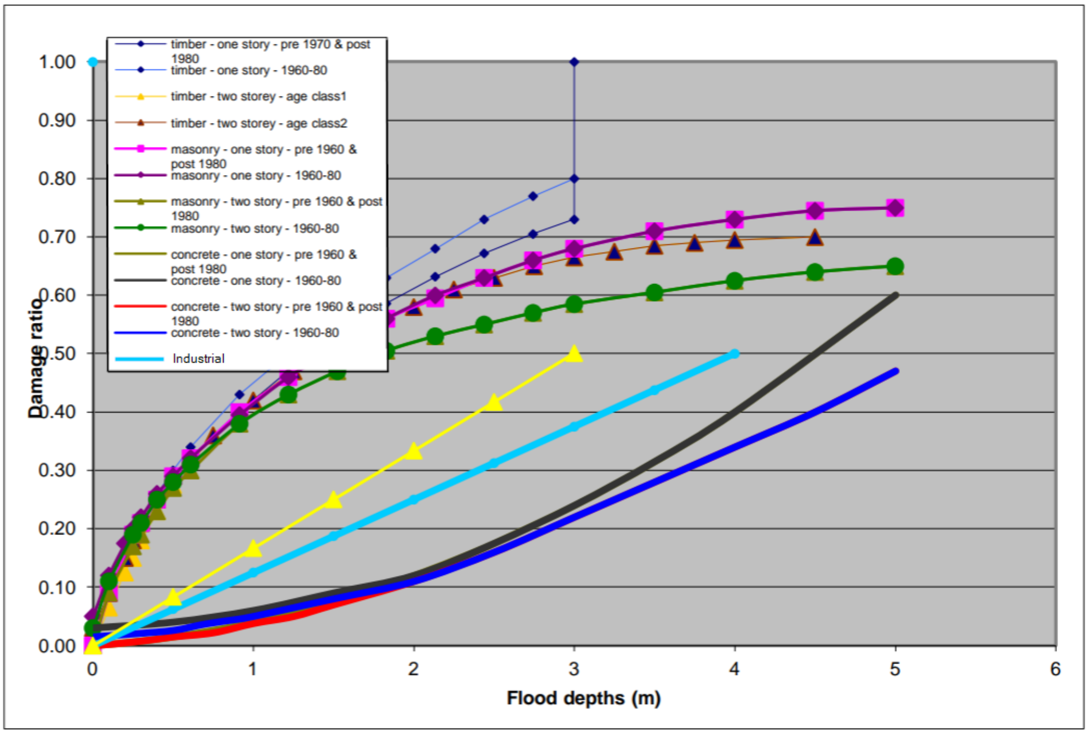
Table 3: Summary of damage states and damage descriptions (S. Resse, 2010)

Damage State	Description	Damage Ratio
DS0	Insignificant	0.00 – 0.02
DS1	Light – Non-structural damage, or minor non-structural damage	0.02 – 0.10
DS2	Moderate – Reparable structural damage	0.10 – 0.50

DS3	Severe – Irreplaceable structural damage	0.50 – 0.95
DS4	Collapse – Structural integrity fails	> 0.95

RESIDENTIAL BUILDING INTERRUPTION

Flooding can cause direct damage to a building and its contents. These damages stem from direct interaction with hazards, and the degree of harm incurred is determined by the intensity of the hazard and the susceptibility of the assets involved. Flood Damage to a building can be defined using the fragility curves defined in Figure 4.



[1]

Figure 4: Flood fragility curves for various building types, Flood depth above the floor level (S. Resse, 2010)

Displacement time is a crucial metric that encapsulates the span during which a building's inhabitants find themselves navigating the transition from their accustomed living or working spaces to alternative temporary arrangements. This shift becomes necessary when the integrity of the structure or critical infrastructure has been compromised by a large flood event, necessitating comprehensive repairs to reinstate its safety and functionality. It is important to note that displacement time is not always commensurate with the entirety of the repair process. Minor restorative actions, which might not demand a complete evacuation, can harmoniously coincide with the occupancy of the building.

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[1] Industrial line has been manually added into the legend.

The estimation is based on a logarithmic correlation between the building damage and displacement time, scaled between 30 and 365 days.

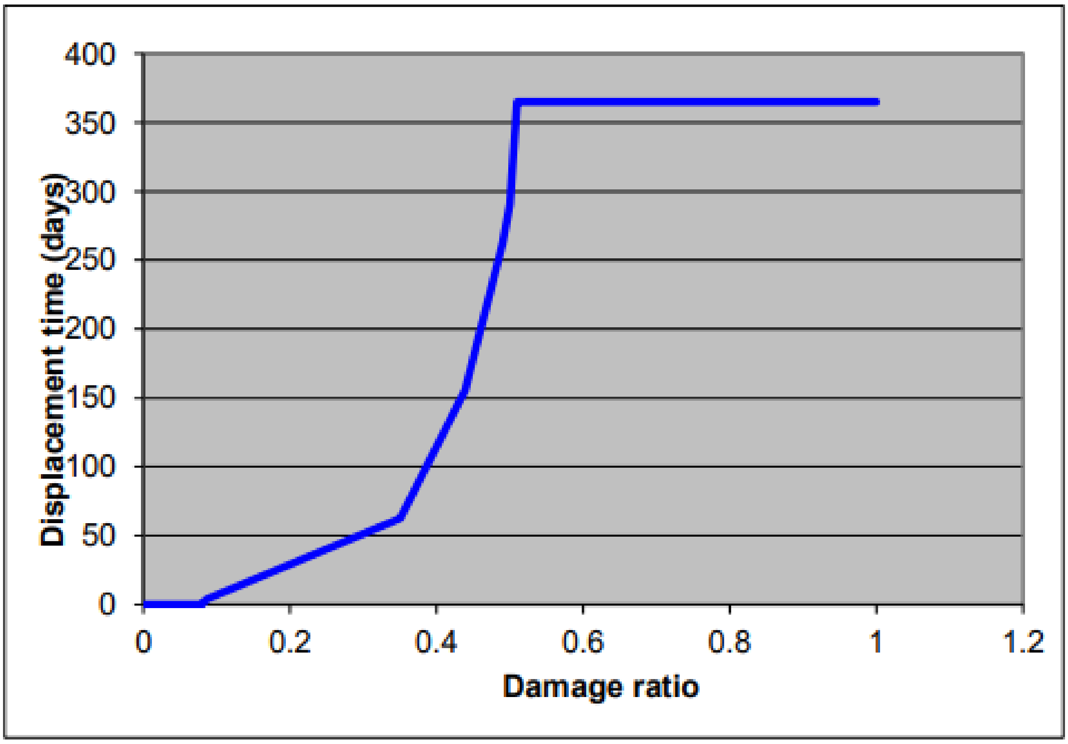

Figure 5: Residential Displacement Time (S. Resse, 2010)

BUSINESS INTERRUPTION

In the aftermath of a disaster, a business may encounter significant disruptions that impede its ability to function optimally. Interruption can occur due to direct tangible flood loss or indirect tangible flood loss.

Functional downtime refers to the specific duration, measured in days, during which a public, commercial, or industrial business is unable to operate due to direct damage resulting from a large rainfall event. This downtime is a critical metric that gauges the period in which normal business operations are disrupted, highlighting the extent of the impact caused by the adverse event.

This disruption can stem from a range of factors, including structural damage, infrastructure breakdown, or loss of essential resources. It is noteworthy that even if a business is compelled to temporarily relocate its operations to an alternate site. The emphasis remains squarely on the span of time during which the core operations of the business are halted or significantly hampered.

The fragility function below scales the functional downtime for a business between 10 and 45 days.

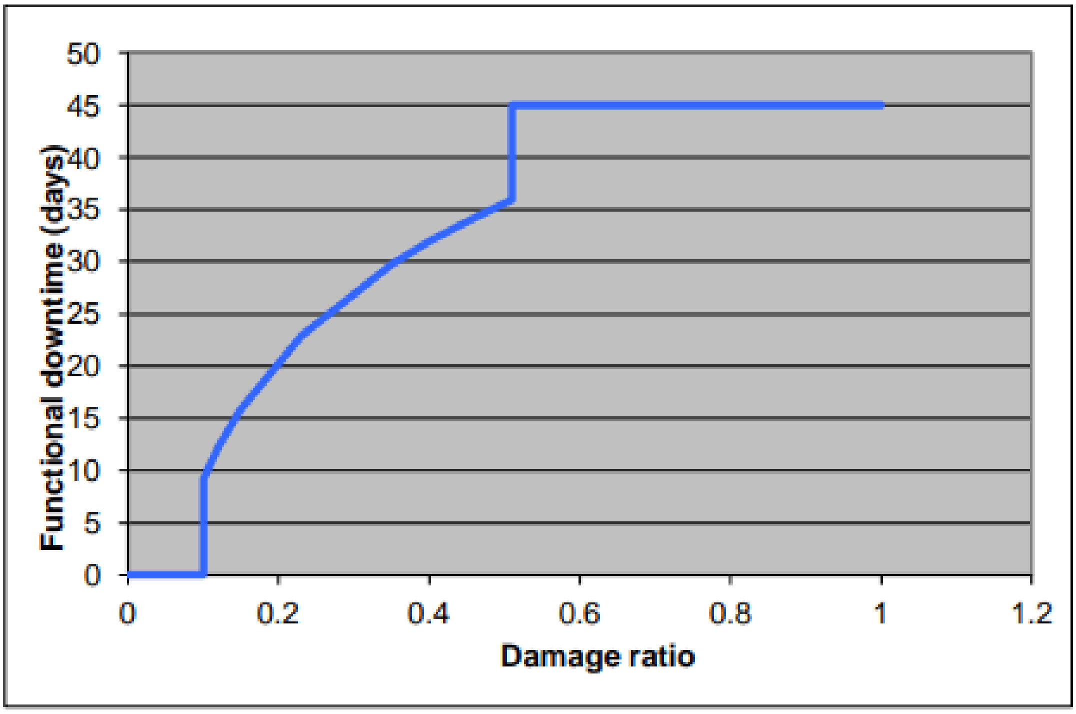

Figure 6: Functional Downtime Curve for Business (S. Resse, 2010)

DAMAGE TO UTILITIES

Disruption to water and wastewater systems during natural hazard events can have a major impact on community recovery in the aftermath of such events. These systems, constituting the backbone of urban water management, encompass a range of components within the water supply, wastewater, and stormwater networks. The networks generally consist of elements such as pipes, pump stations, manholes, valves, etc.

Most urban drainage systems are designed to cope with a flood event of a certain magnitude. Recent extreme weather events have shown that these systems are often failure points in the urban flood management system.

High-intensity rainfall events serve as a formidable challenge to the robustness of water-supply networks, primarily through inundation at pumping stations, valve chambers, treatment plants and similar structures.

These fragility curves estimate the potential damages that water infrastructure might suffer based on the depth of water within affected stations. Stormwater, water supply, and sewage pump stations have different damage characteristics and have separate fragility functions, as seen in Figure 7.

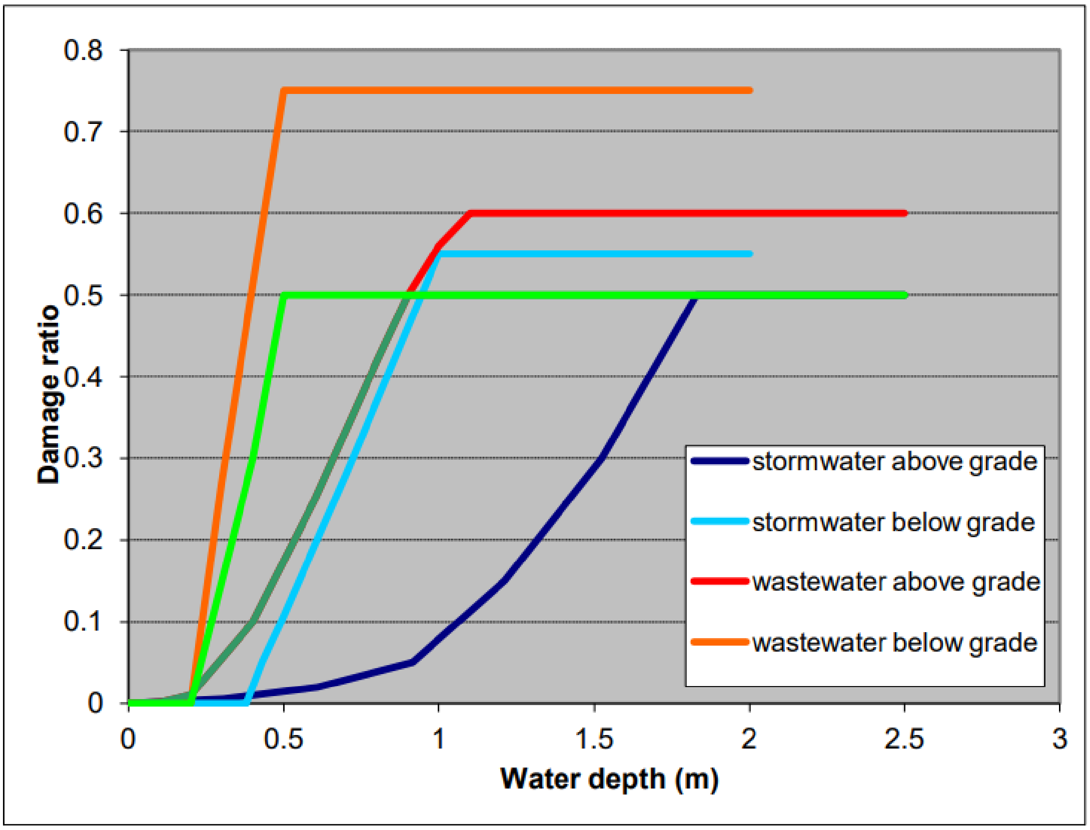

Figure 7: Water Transportation System Fragility Function

METHODOLOGY

With continued urban expansion, the effects of climate change have become even more evident. Climate change is projected to increase the frequency and severity of extreme weather events, which in turn means there will be an increase in flooding, as indicated in the Ministry of the Environment Guidelines (Ministry for the Environment, 2018).

The methodology outlined in this study can be summarised as the following:

- Define the study area and review the surrounding topography.
- Develop a hydrodynamic model which is simulated for various storm events.
- Extract model results for the flood scenarios that have been simulated.
- Undertake a flood risk assessment to identify most at-risk properties.
- Compute estimates of economic loss and social impact using the fragility curves and global flood depth-damage functions

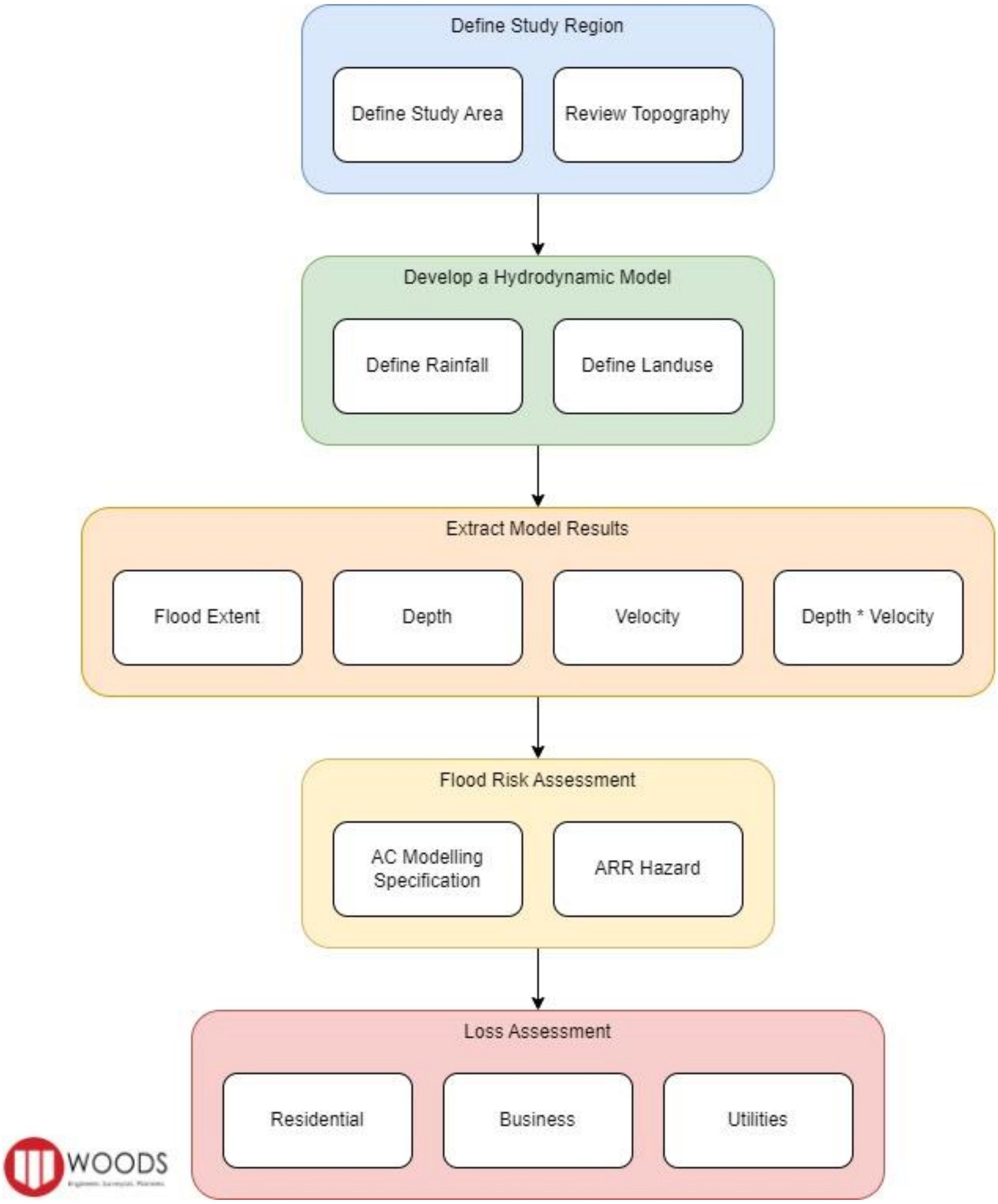

Figure 8: Flood Assessment Methodology

RESULTS AND DISCUSSION

Two comprehensive case studies were undertaken to evaluate the implications of flooding on commercial establishments and newly developed sites. The primary objective of these case studies was to analyse and comprehend the extent of functional disruption experienced by businesses following a flood event. Additionally, the investigations sought to ascertain the inundation depth levels experienced by crucial infrastructures such as stormwater systems, water-supply facilities, and sewage pump stations.

CASE STUDY 1 – COMMERCIAL DAMAGE

To assess commercial damage in an industrial and commercial environment, an analysis was undertaken over an area of interest. A hydrodynamic model was run for the 100-year rainfall event inclusive of climate change using HEC RAS version 6.4.1. Flood results from the model including depth and a hazard assessment, are shown below in Figure 9 and Figure 10, respectively.

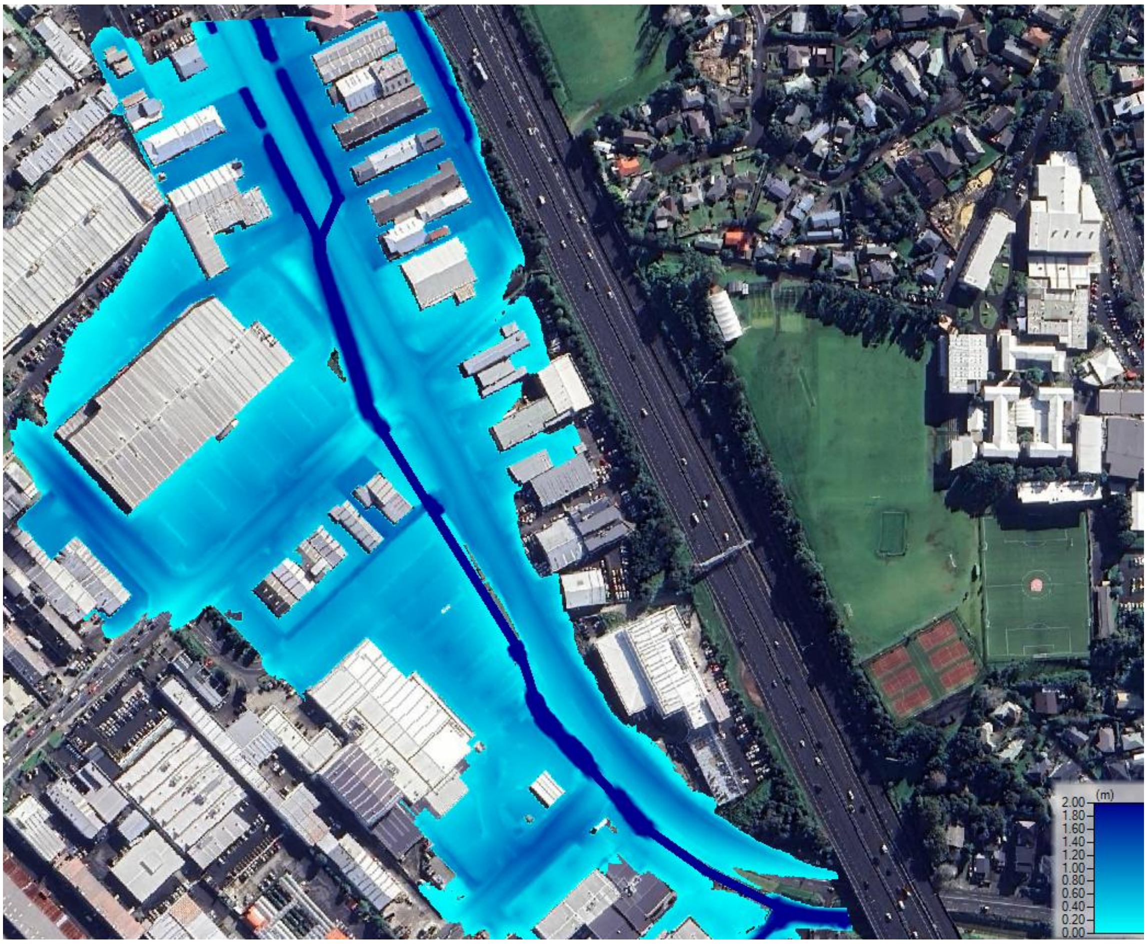

Figure 9: Modelled Flood Depth

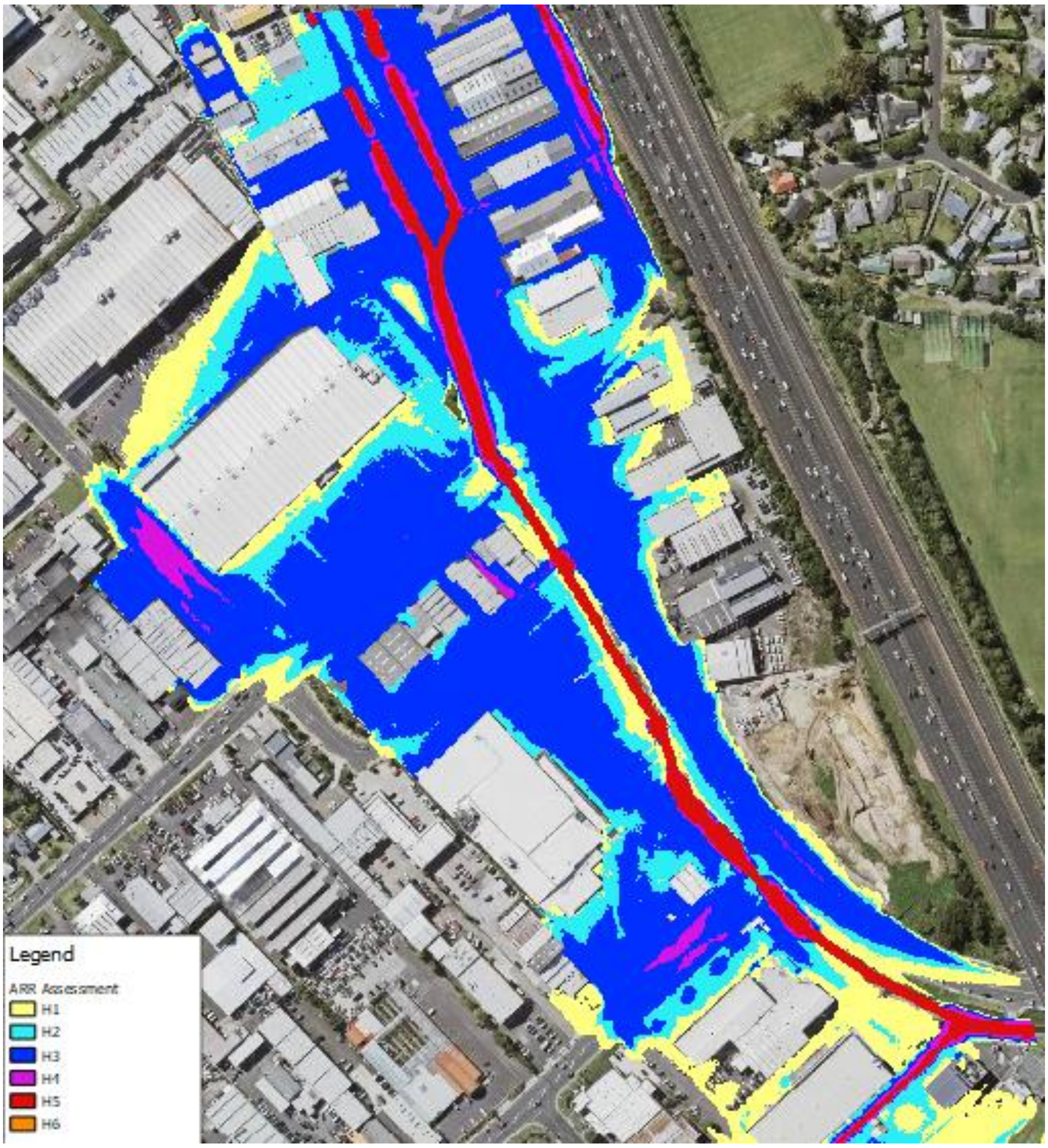

Figure 10: ARR Assessment

The assessment shows that the water level adjacent to buildings are generally no more than 1m. The ARR assessment indicates that during a theoretical 100-year ARI rainfall (RCP 8.5), the study area is generally unsafe for vehicles, children, and the elderly (ARR, Hazard Class H3). The buildings are expected to be inundated within the study area however, no structural damage is expected. Based on the harmonisation between damage function and maximum damages, the economic loss can be estimated. Based on the above assessment, the commercial damage and the risk can be estimated.

Furthermore, the flood fragility curves were also used to estimate the downtime. During the theoretical 100-year ARI rainfall (RCP 8.5), we can assume the building experienced a flood depth of between 0.2m to 1m. As per the industrial building fragility curve (Figure 4) this would equate to a damage ratio of approximately between 0 to 0.1. The downtime of the commercial building is expected to be between 0 to 9 days, as per Figure 11. It is to be noted that during the January event, the Pakn’Save Glenfield was affected by 8 days (Pak'n'Save, 2023) and the

Glenfield was affected at least by 5 days (Reidy, 2023), meaning the fragility curve has been generally consistent with predicting potential downtime for the businesses within the area.

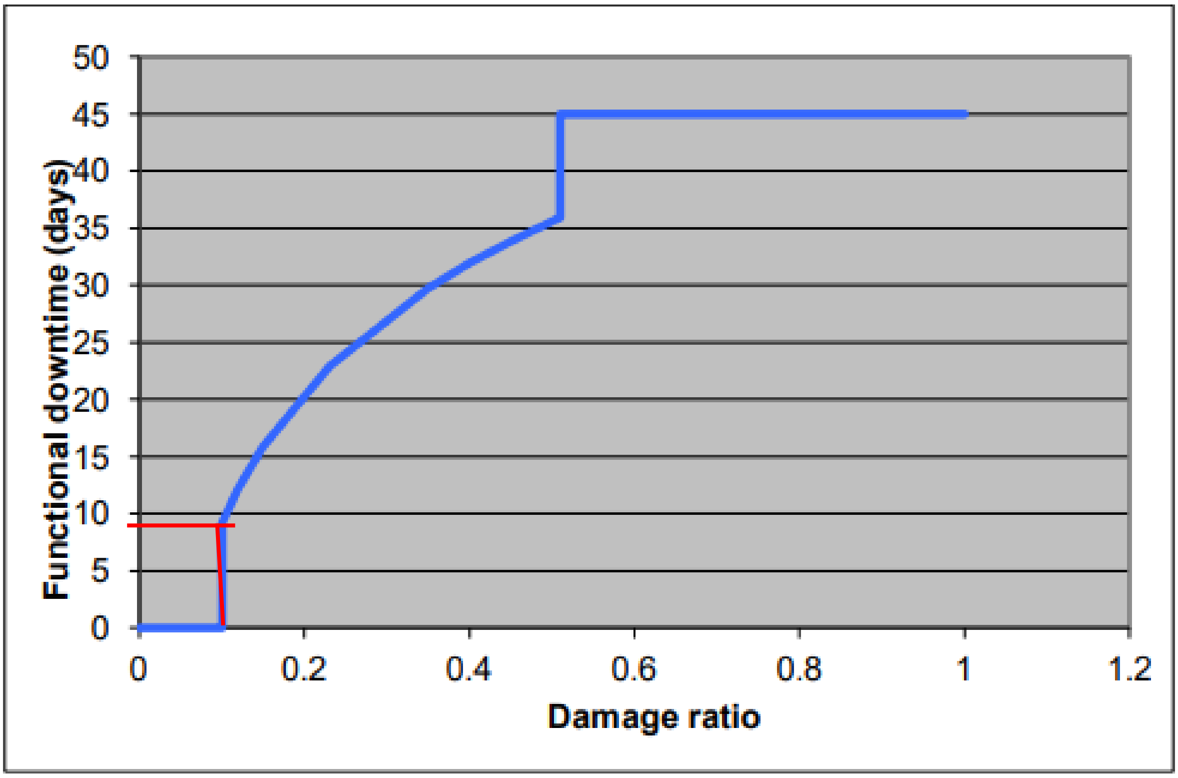

Figure 11: Commercial functional downtime

The assessment provides an overview of the expected business disturbance of a commercial site subjected to flooding. This can be used to support capital investment decisions and flood mitigation solutions.

Future planning becomes notably more manageable during the initial phases of any project. It holds paramount importance to factor in potential risks while formulating strategies for enhancing resilience throughout the site. Site-specific considerations will also wield significant influence on decision-making when planning for future resilience.

A pivotal aspect in the quest for resilience lies in tailoring strategies to the specifics of the site. Each location carries a unique set of characteristics, from geographical attributes to environmental conditions, which wield a considerable influence on the efficacy of any resilience-building endeavour. These considerations become evermore paramount when considering greenfield and brownfield developments. Typically, greenfield development presents more opportunities to build resilience when compared to brownfield developments. Greenfield projects, unencumbered by existing structures or limitations, often present more opportunities to integrate future planning measures. They allow for the implementation of innovative solutions, unrestrained by the constraints that brownfield developments, with their pre-existing infrastructure, might inherently carry.

CASE STUDY 2 – POTENTIAL DAMAGE

A site designated as a future urban zone under the Auckland Council Auckland Unitary Plan: Operative in Part (AUP) is used as a typical greenfield development case study. Currently, the site lacks water and wastewater infrastructure. The nearest wastewater system is available on the adjacent street. Results for the maximum modelled flood depth are shown in Figure 12, Figure 13, and Figure 14.

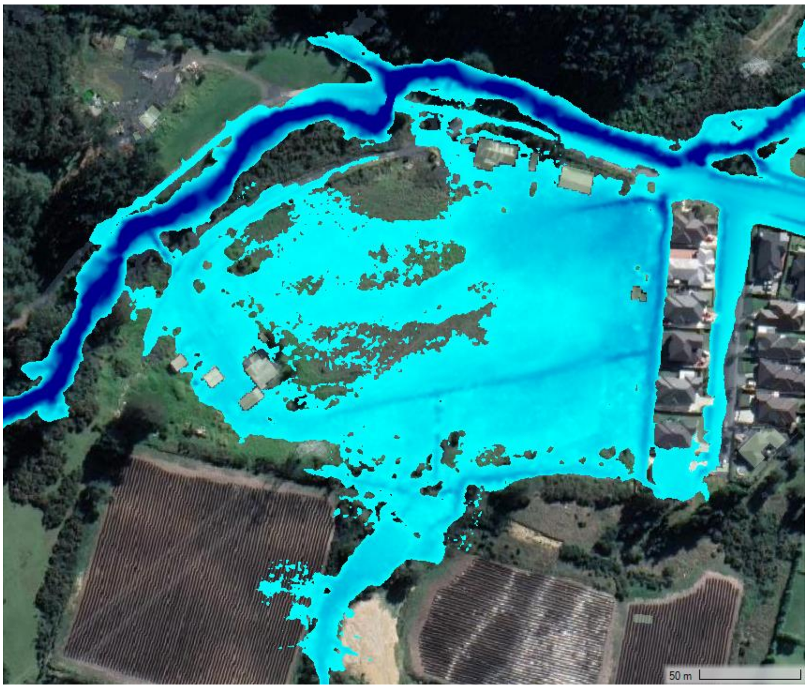

Figure 12: Modelled Flood Depth – 100-year ARI No CC

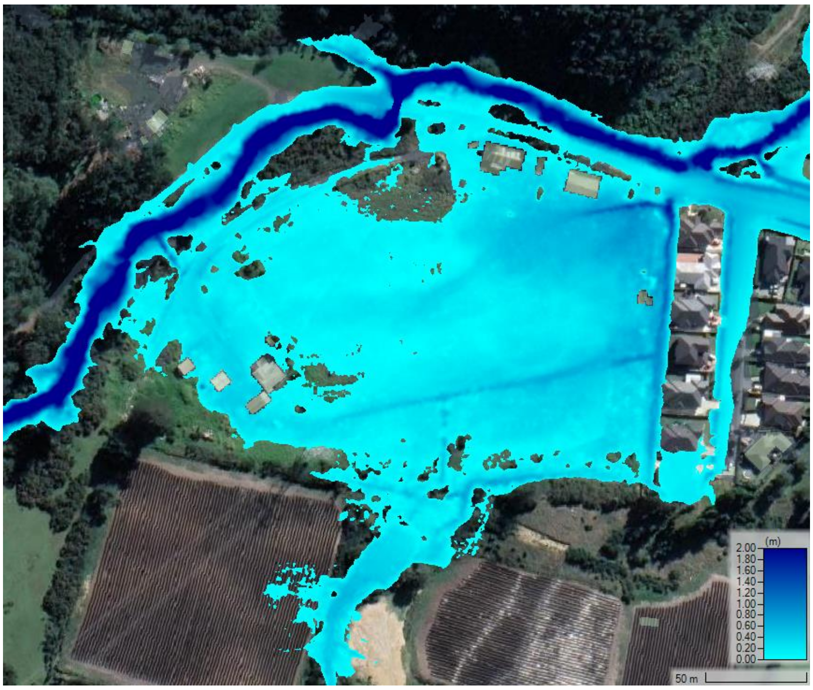

Figure 13: Modelled Flood Depth – 100-year ARI RCP 6.0

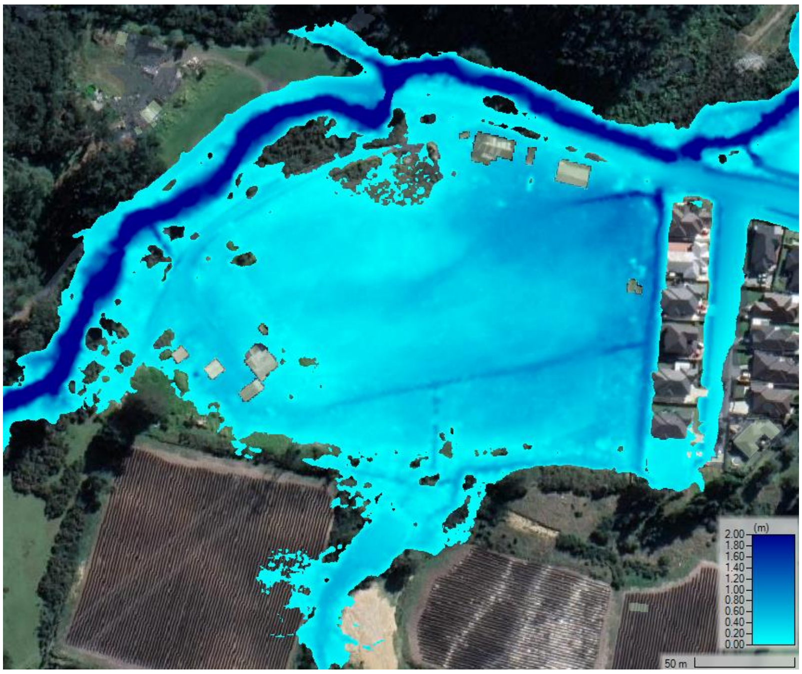

Figure 14: Modelled Flood Depth – 100-year ARI RCP 8.5

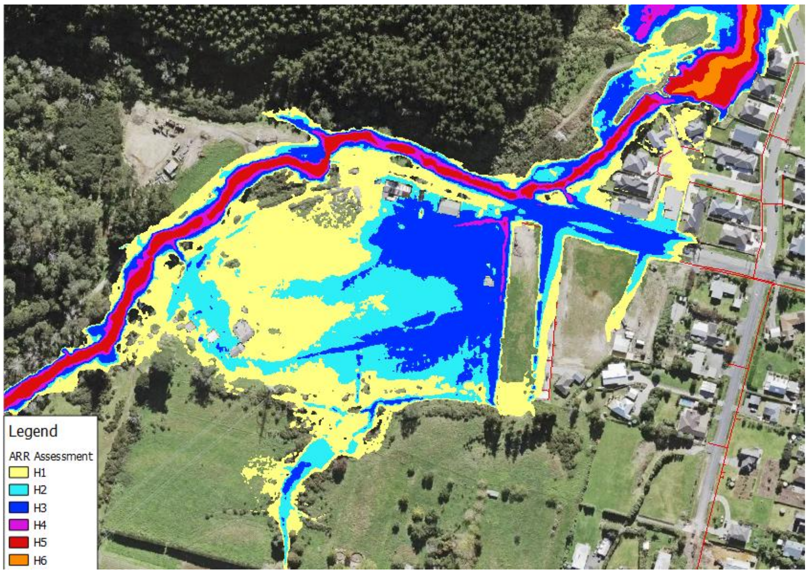

Figure 15: ARR Assessment – 100-year ARI RCP 8.5

The assessment has unveiled a wide floodplain situated next to a well-defined channel. During 100-year ARI no climate change scenario, the flood depth within this plain ranges from approximately 0 to 0.5m (average depth of 0.25m). For the RCP 6.0 scenario, the flood depth within this plain ranges from approximately 0.1 to 0.7m (average depth approximately 0.4m). For the RCP 8.5 scenario, The flood depth within this plain ranges from approximately 0.2 to 1 meter (average depth approximately 0.6m).

For the purpose of the assessment, it was assumed that the development planned to install at-source wastewater pump units. As per the curve in Figure 16, should the pump station be installed below ground (below grade), the station is likely to experience a damage ratio of 0.1 in a 100-year storm event without any consideration of climate change, 0.45 in a 100-year storm event (RCP 6.0) and

0.75 in a 100-year storm event (RCP 8.5). The assessment indicates that the flood risk for the below ground pump unit can increase with an increase in flood depths due to climate change. Due to potential flood depth, it is critical to consider flood depth and debris resistance and resilience when selecting pump stations. Other factors account for pump station emergency storage and overflow and location.

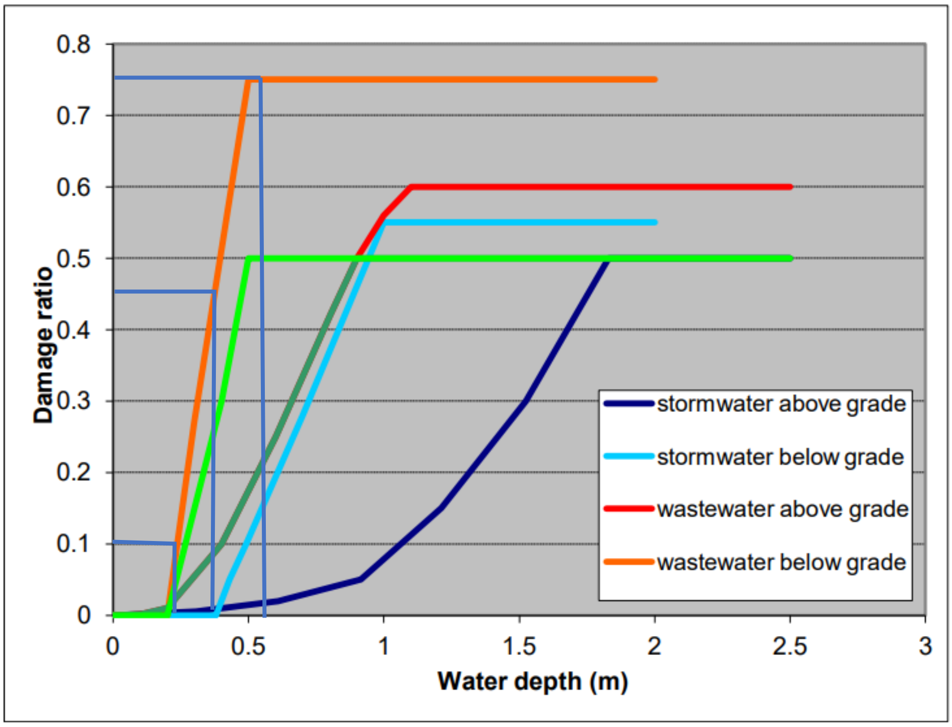

Figure 16: Case Study 3 – Water transportation pump station fragility curve

Moreover according to the ARR assessment, in the scenario of a theoretical 100-year ARI rainfall event (RCP 8.5), the study area falls into categories H2 and H3. This classification implies that the site is generally deemed unsuitable for vehicular traffic, children, and the elderly.

The assessment provides an overview of potential damages that may arise from flooding. This information can assist engineers in making informed engineering decisions and in comprehending the associated risks. For example, consider an RCP 8.5 scenario or higher, select a submersible pump approved for below-ground use or opt for a centralised above-ground pump station with sufficient freeboard and strategically position it on elevated terrain.

In terms of future planning and the establishment of long-term resilience, this information can be utilised to identify the most effective flood protection measures. It can also serve as valuable input for the formulation of any necessary flood emergency response plans.

CONCLUSIONS / RECOMMENDATIONS

Climate change affects every region on Earth in multiple ways. Globally, we are facing a series of climate crises, and flood risk is undoubtedly one of them. Due to population growth and centuries of urbanisation, in order to meet the increasing demand for housing, we are witnessing a large number of developments taking place on challenging land.

Climate change and its associated extreme events exacerbate this situation. It is important not only to focus on aspects such as flood depth and velocity but also to investigate other tangible and intangible risks during the decision-making phase of a flood risk assessment.

Future planning is easier to account for in the earlier stages of a project. It is important to consider these risks when designing for resilience across your site. Site-specific considerations will also wield significant influence on decision-making when planning for future resilience. Typically, greenfield development holds more opportunities to build resilience when compared to brownfield developments due to the presence of existing infrastructure and buildings.

The next step in the development of our communities is learning how to coexist with water and adapt to it, as is currently being done with the 'Making Room for Water' initiative. This is done best through design and careful future planning.

ACKNOWLEDGEMENTS

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