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REVIEW OF RAINFALL INTENSITY CURVES AND SEA LEVELS IN MANUKAU CITY MAKING PROVISIONS FOR CLIMATE CHANGE

Abstract

Manukau City Council, under the Resource Management Act 1991 and the Local Government Act 2002, has the responsibility to promote the sustainable management of natural and physical resources, to avoid or mitigate natural hazards and to have particular regard to the effects of climate change.

Under the Manukau Operative District Plan 2002, Council developed and maintains a set of Engineering Quality Standards (EQS) which outlines the functional requirements and design standards that land development within the city has to comply with. The EQS requires specifically the minimum building floor levels for properties along the coastline to avoid possible coastal inundation; it also sets forth design rainfall intensity curves on which the design of stormwater infrastructure and road drainage works relies.

The Intergovernmental Panel for Climate Change (IPCC) released its Fourth Assessment Report in April 2007, it confirmed that "Warming of the climate system is unequivocal", that extreme precipitation events are very likely to become more frequent and that sea level rise would continue throughout the 21st century. In light of the consequences of global climate change and associated impacts, Council decided to review the current standards to ensure that infrastructure and buildings built today can cope with the effects of climate change and still provide the desired level of service within their expected useful lives.

Regional frequency analysis was used to derive the design rainfall intensity duration curves from historic rainfall records. The rainfall patterns were then projected for the 2050s and 2080s for low, moderate and high temperature rise scenarios. Based on detailed assessment, projections on rainfall intensity curves for the 2080s for moderate temperature rise scenario are recommended for adoption in the EQS.

For sea level, the variability in astronomical tide levels and storm surge were assessed along both the Manukau Harbour and Waitemata Harbour coasts. Climate change impacts on Mean High Water Spring and 1% Annual Exceedance Probability water levels were determined for the 2050s and 2080s relative to the present day. For planning purposes a sea-level rise allowance towards the upper end of the IPCC Fourth Assessment Report projections has been adopted.

Key Words

Climate change, design rainfall intensity duration curves, sea level rise, 1% AEP water level, District Plan

Introduction

Manukau City is located within the Auckland region in the upper North Island of New Zealand. It covers an area of 552 square kilometres and two coastlines of 320 kilometres, being bounded by the Hauraki Gulf to the east, and Manukau Harbour to the west.

To provide for sustainable management of natural and physical resources within the city, Manukau City Council has set out, in Chapter 9 of the Manukau Operative District Plan 2002, the development rules and performance standards that land modification, development and subdivision activities within the city have to comply with. To ensure infrastructure works are designed and constructed for the intended use and the anticipated design life, Council sets forth in Chapter 9 of the District Plan general engineering performance standards which relate to the engineering aspects of land development. The standards are performance based, with the emphasis on outcomes, to allow flexible and innovative approaches to the engineering aspects of land development.

To ensure compliance with the District Plan, Council also developed and maintains a set of Engineering Quality Standards (EQS) to provide for minimum requirements and design standards of land development within the city. Works constructed in compliance with Council's "Engineering Quality Standards" are accepted as meeting the "Engineering Performance Standard" in the District Plan.

Under both the District Plan and EQS, minimum building floor level for properties along the coastlines is required to avoid coastal inundation that:

Sites where the finished building site level is not less than 0.5 meters above the following Reduced Levels (L & S Datum):

- *3.39m in catchments draining to the Manukau Harbour, or*
- *2.90m in catchments draining to the Waitemata Harbour or Hauraki Gulf.*

A stormwater drainage network is required under the District Plan for subdivisional development to safeguard people, property and the environment that:

- *The primary piped drainage system shall cater for a 20% Annual Exceedance Probability rainfall event;*
- *Culverts, bridge structures, Open channels and overland flowpath shall cater for a 1% Annual Exceedance Probability rainfall event.*

In addition, minimum freeboard to surface water is required for building ground levels to avoid surface water flooding that:

Finished ground level for potential building site areas shall meet the following standards relating to freeboard regarding 1% Annual Exceedance Probability levels:

- *Sites adjoning natural open stream channels -- 1000mm freeboard*
- *Sites adjoining formed open stream channels -- 800mm freeboard*
- *Sites adjoining formed (grassed) overland flowpaths -- 500mm freeboard*
- *Sites adjoining minor overland flowpaths fully formed in permanent materials (such as roadways and paths) -- 150mm freeboard*

To design stormwater infrastructure and determine the quantum of surface water in streams, channels & overland flowpaths, design rainfall intensity duration curves for 2 year, 5 year, 20 year & 100 year storm events are provided for in EQS.

Statutory Requirements

Under the Resource Management Act (RMA) 1991 and the Local Government Act (LGA) 2002, Manukau City Council as a territorial authority is required to promote the sustainable management of natural and physical resources to enable people and communities both for the present and in the future to provide for their social, economic and cultural wellbeing and for their health and safety.

Section 31(1) of the RMA 1991 requires Manukau City Council to have functions including:

- The establishment, implementation, and review of objectives, policies, and methods to achieve integrated management of the effects of the use, development, or protection of land and associated natural and physical resources of the district;

- The control of any actual or potential effects of the use, development, or protection of land, for the purpose of the avoidance or mitigation of natural hazards.

Section 7 (I) of the RMA 1991 requires that, all persons exercising functions and powers under the act, in relation to managing the use, development, and protection of natural and physical resources, shall have particular regard to the effects of climate change.

Climate Change

Anthropogenic greenhouse gases including carbon dioxide, methane, nitrous oxide and three groups of fluorinated gases (sulphur hexafluoride, HFCs and PFCs) (Lerner, 2006) are proved, based on scientific research, causing global warming via an enhanced greenhouse effect. The Intergovernmental Panel on Climate Change (IPCC) concluded in its fourth assessment report (2007a) that “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level”, and that “Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.”

The impacts of global warming and associated climate change are comprehensive and profound. It is projected by the IPCC (2007b) with high confidence that in the 21st century heavy precipitation events are very likely to become more common and will increase flood risk. The IPCC also projected with very high confidence that sea level rise would continue throughout the 21st century primarily because of thermal expansion within the oceans and loss of ice sheets and glaciers on land, and coasts will be exposed to increasing risks such as coastal erosion and flooding.

The current Manukau City Council standards on minimum building floor levels for properties along the coastlines and design rainfall intensity duration curves were developed in the early 1990s based on the IPCC First Assessment Report in 1990. In light of the observed and predicted global warming and associated climate change, it is considered that these standards may be out of date. The disastrous floods which occurred in 2007 affected communities in Hawkes Bay, Clutha and Northland, New Zealand and England and Wales in the UK, indicated how susceptible communities are to surface water flooding by extreme rainfall events. This further strengthened Council's intention to review and update, if necessary, the standards on minimum building floor level requirements and design rainfall intensity curves. National Institute of Water & Atmospheric Research Ltd. (NIWA) was engaged through a competitive tender process to undertake the review.

As predictions of climate change depend on projections of future concentrations of greenhouse gases and aerosols which, in turn, depend on changes in population, economic growth, technology, energy availability, and national and international policies (MfE, 2008), the IPCC developed a range of different future emissions pathways or scenarios as a basis for projecting future climate changes. Figure 1 below shows a range of possible future global temperature increases developed by IPCC in the Fourth Assessment report. The scenario labelled 'A1B', which gives an intermediate level of warming by the end of the century, is the scenario used by Ministry of the Environment to derive projections for New Zealand using downscaling methodologies. (MfE, 2008)

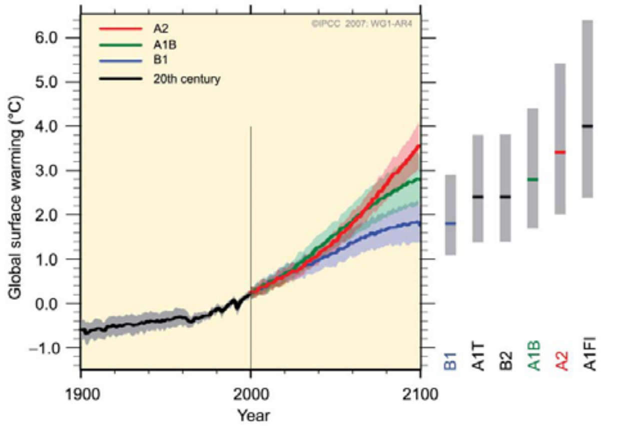

Figure 1: IPCC multi-model temperature projections for selected scenarios. The grey bars and solid horizontal line within each grey bar at right indicate the best estimate and the 'likely range' for all six illustrative scenarios. Source: IPCC 2007a (figure SPM.5).

Given the complications of various scenarios developed for future greenhouse gases emissions and global temperature warming, Manukau City Council decided that the scope of the standards review will involve the defining of current rainfall patterns and sea levels of the city using available historical gauging data; projections for future rainfall patterns and sea level rise for various projected climate change scenarios will then be made taking into account the natural climate variability. To make provisions for future climate change, revised standards on design rainfall intensity curves and minimum building floor level requirements will be recommended as a result of the study to ensure that infrastructure and buildings constructed today can provide the desired level of service throughout their design lives.

Review of Design Rainfall Intensity Curves

Annual maximum rainfalls for the durations from 10 minutes to 72 hours from six rainfall stations within or near Manukau city were collected to produce intensity duration curves of the current rainfall pattern. The rainfall stations studied are: Mangere, Pakuranga, Auckland Airport, Hunua - Cowan, Manukau & Otara as shown in Table 1.

Location	Latitude °S	Longitude °E	Record period	Comment
Mangere	36.970	174.776	1949 – 2005	
Otara	36.956	174.872	1956 – 1985	
Auckland Airport	37.008	174.789	1963 – 2005	
Hunua-Cowan	37.092	175.069	1990 – 2002	
Pakuranga	36.902	174.896	1972 – 2004	Composite
Manukau	36.916	174.929	1970 – 1986	Composite

Table 1: Details of rainfall stations for extreme analysis

Both Single-site analysis using a Generalised Extreme Value (GEV) distribution with the shape parameter set to zero and regional frequency analysis using NIWA software package HIRDS (High Intensity Rainfall Design System) were undertaken to produce the extreme rainfall intensity duration curves for each rainfall station. It was found that the rainfall intensity curves produced by single site analysis are generally lower compared with those by HIRDS software which employs a regional analysis approach.

It is known that using a GEV distribution for at-site estimation with small amounts of data (less than 30) often leads to unreliable results in the quantile estimates (Rosbjerg and Madsen, 1995). This is due to the difficulty in estimating reliably the shape parameter of the GEV distribution with small amounts of data (Lu and Stedinger, 1992). Reliable shape parameters, which are crucial to fitting the extremes in environmental data, can be obtained from regional averages from data for a number of sites within some defined region (Hosking and Wallis, 1997). Thus it was decided that rainfall intensity curves derived from HIRDS be adopted as the current rainfall profile and used as the bases for projections of future extreme rainfall.

Projections on design rainfall intensity duration curves were made for 2050s and 2080s for low, moderate and high temperature rise scenarios. As temperature projections show little spatial variation for a selected emission scenarios and climate models, the projections for the Auckland Region by the Ministry of the Environment (MfE, 2008) based on New Zealand downscaling study of climate projections from the IPCC fourth assessment global models are applied to Manukau City. The temperature scenarios used for the projection of future extreme rainfall depth-duration-frequency curves are listed in Table 2.

temperature change (°C)	**Low**	**Middle**	**High**
2050s	0.32	1.27	3.48
2080s	0.54	1.96	5.46

Table 2: Manukau City temperature change (°C) scenarios used to calculate changes in extreme rainfall. Changes are relative to 1980-1999. The low, middle and high scenarios relate to: smallest warming for lowest IPCC emissions scenario B1, average over 12 climate models for medium emission scenario A1B, and greatest warming for highest IPCC emissions scenario A1F1.

As buildings and infrastructure assets have design life span of between 50 and 100 years, it was decided that projections to 2080 be adopted for planning purposes. Because observed emissions are already increasing faster than the lowest B1 scenario, and the lowest temperature increase to 2100 projected from the B1 scenario is less than the linear extrapolation of the observed New Zealand temperature increase over the 20th century, it is considered that the actual temperature increase in New Zealand over the 21st century is very likely to be more than the ‘low’ scenario. The ‘high’ scenario is also considered unlikely to be exceeded as the high value arises from one of the climate models that exhibits a much greater temperature response than any other model to increasing greenhouse gas concentration. Design rainfall intensity curves projected based on the moderate temperature rise of 1.96 °C increase is considered the best to be adopted by Council as standards for the design of stormwater infrastructure.

A warmer atmosphere can hold more moisture at about 8% more for every 1°C increase in temperature (IPCC, 2001), thus heavy rainfall events are likely to become more common with temperature increases. The multiplicative factors for the mid-range temperature scenario for 2080s adopted in the study are listed in Table 3. As an example of interpreting this table, to estimate a 20-year 12-hour high intensity rainfall, the current rainfall is multiplied by a factor of 1.143.

ARI(yr)	**10m**	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	1.157	1.151	1.141	1.131	1.122	1.104	1.094	1.084	1.074	1.069
5	1.157	1.151	1.145	1.139	1.131	1.120	1.114	1.106	1.098	1.094
10	1.157	1.153	1.149	1.145	1.141	1.133	1.127	1.123	1.120	1.116
20	1.157	1.157	1.153	1.151	1.149	1.145	1.143	1.141	1.139	1.137
50	1.157	1.157	1.157	1.157	1.157	1.157	1.157	1.157	1.157	1.157
100	1.157	1.157	1.157	1.157	1.157	1.157	1.157	1.157	1.157	1.157

Table 3: Mid-Range Temperature Scenario for 2080s: Multiplicative factors to be applied to the current high intensity rainfall tables to estimate the future high intensity rainfalls.

Of the six rainfall stations studied, Otara has the highest intensities for design storms of durations less than one hour, and Manukau has the highest intensities for design storms of durations one hour or more. A conservative approach was adopted to take the rainfall data from Otara for storms of short durations and Manukau for storms of longer durations to produce a set of citywide rainfall intensity duration curves.

The natural climate variability due to El Nino-Southern Oscillation (ENSO), through El Nino and La Nina events, and the Interdecadal Pacific Oscillation (IPO) were also assessed for their impacts on the rainfall patterns of the city. To fully understand the relationship between the IPO and rainfall patterns, a composite rainfall record from four sites (Otara, Aucklland Airport, Whenuapai & Hunua – Cowan) was created to cover one complete cycle of the IPO from 1946 to 1999. It is concluded however that these natural climate fluctuations will have minimal impact on the rainfall patterns and no further adjustment is required.

Based on the above detailed study, the extreme rainfall intensity duration curves recommended to be adopted by Council as design standards are plotted in Figure 2. For comparison, the existing Council design intensity curves are shown in Figure 3.

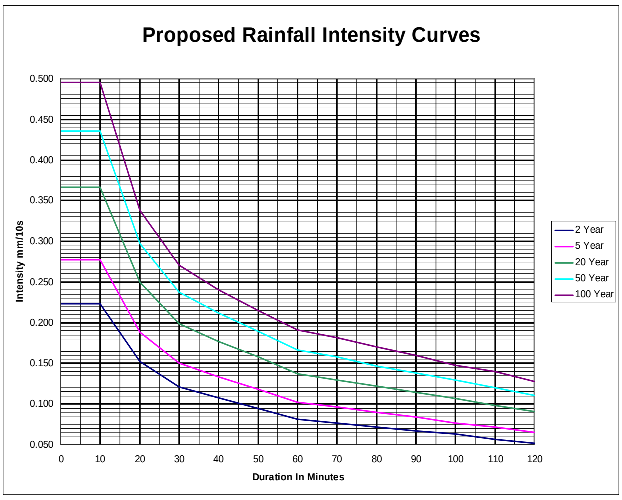

Figure 2: Proposed design rainfall intensity curves

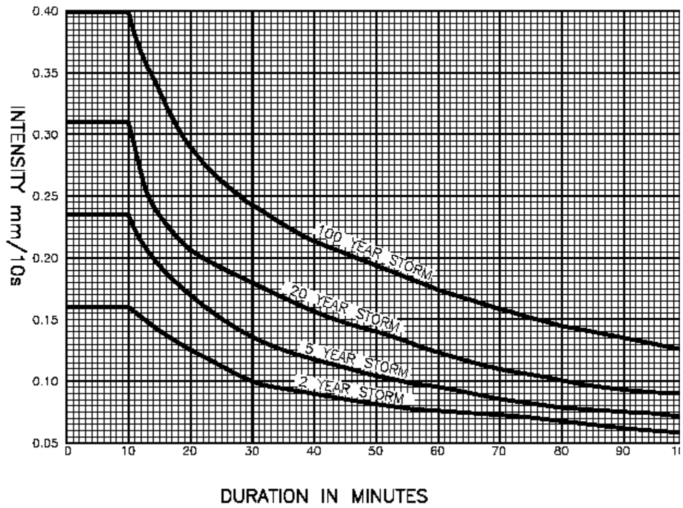

Figure 3: Existing MCC design rainfall intensity curves

Review of Sea Levels

It has been a well established consequence that global climate change causes global sea levels to rise. The mean annual sea levels recorded at the Port of Auckland tide gauge since 1900 has showed a linear trend of around 1.4 mm/yr up to 2006. For New Zealand coastal environment, the MfE (2008) advocates a precautionary approach for incorporating the uncertainties surrounding sea-level rise considerations within development and infrastructure planning. The MfE recommended (2007) that for planning and decision timeframes out to the 2090s (2090-2099) a minimum sea-level rise of 0.5 m relative to the 1980-1999 average is used along with an assessment of the sensitivity to a possible higher sea-level of up to 0.8 m relative to the 1980-1999 average (to account for a possible high emission scenario and uncertainties associated with increased contribution from Greenland and Antarctica Ice sheets, and possible differences from the global average sea-level rise in the New Zealand region). Thus the values of sea level rise for the two timeframes adopted in this study are:

- 2050s (2040-2060): 0.33 m rise in sea level relative to 1990s
- 2080s(2070-2090): 0.66 m rise in sea level relative to 1990s

Sea-level rise will result in a landward retreat of the position of Mean High Water Spring (MHWS), which forms the landward jurisdictional boundary of the coastal marine area under the Resource Management Act 1991 and the Foreshore and Seabed Act 2004.

Sea level, with astronomical tide as its main component, can be elevated or lowered due to variability in climate, such as seasonal, El Niño-Southern Oscillation, and Interdecadal Pacific Oscillation cycles which in total can cause fluctuations of up to about ±0.25 m in background sea levels in some years or seasons. Sea levels can also be temporary increased over 1-3 days due to reduction in atmospheric pressure and influence of wind on the sea surface. To identify coastal margins at potential risk from coastal inundation in extreme weather events, current static extreme sea levels (i.e. not including waves) in 1% Annual Exceedance Probability (AEP) event were assessed along the Hauraki Gulf (Waitemata Harbour) and Manukau Harbour coastlines.

Historic sea levels recorded at the Port of Auckland and the Port of Onehunga were used to develop the present Mean High Water Perigean Spring (MHWPS) and 1% AEP event storm levels at the two gauging sites. For the Hauraki Gulf coast, the Port of Auckland has 33-year high-quality digital dataset record, from 1974 to present, which is sufficiently long to reliably estimate expected 1% AEP level at the site. Classical generalised extreme-value (GEV) method was applied to the annual maxima sea levels from the gauged modern record to estimate the 1% AEP sea level. A historical GEV model fit to the modern data supplemented by the historical storm tides was also developed as shown in Figure 4 to both raise the storm-tide level estimates for a given AEP and to decrease the uncertainty around the extreme sea level estimates.

For the Manukau Harbour coast, only 4 years of suitable data (2001-2005) is available for the Port of Onehunga which is of insufficient length to reliably extrapolate estimates out to 1% AEP. Monte Carlo modelling was used to simulate annual maxima data at the Port of Onehunga, by recombining components of the sea level measured during the 4-years of recording. The Monte Carlo estimates were compared against historically large sea level events to check that the method was reliable.

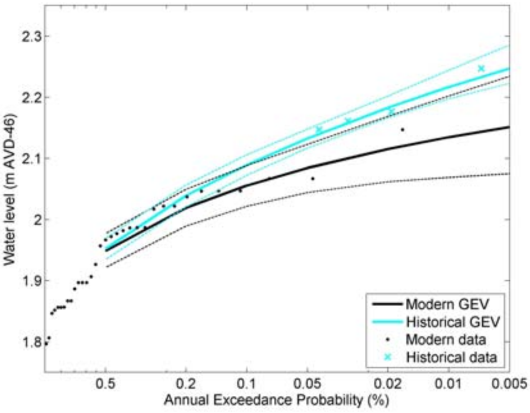

Figure 4 - Generalised extreme-value (GEV) model fits to modern data and to modern data supplemented by the historical data for the Port of Auckland.

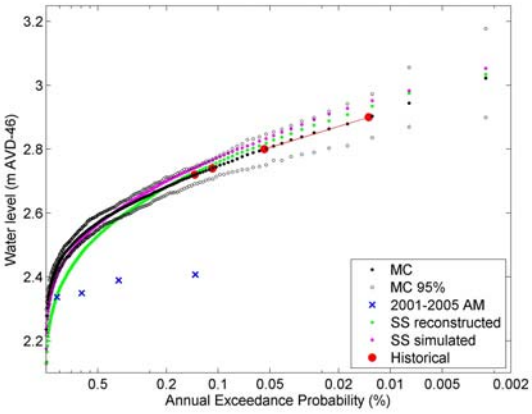

Figure 5 Monte Carlo extreme-value predictions at the Port of Onehunga.

According to the MHWPS and 1% AEP water levels predicted for the Port of Auckland and Port of Onehunga, the MHWPS and 1% AEP water levels at key locations along the two coastlines were developed using the Regional Harbour Model for Hauraki Gulf coast and a MIKE-21 hydrodynamic model for the Manukau Harbour coast. The impacts of sea level rise of 0.33 m and 0.66 m on MHWPS and 1% AEP water levels along the two coastlines were then determined using the computer models for the 2050s and 2080s relative to the present day. A summary of the 1% AEP storm-tide levels for the Manukau Harbour and Hauraki Gulf Coasts is given in Table 4.

Period	Manukau Harbour coast		Hauraki Gulf coast	
	Alongshore range (m AVD-46)	Representative value (m AVD-46)	Alongshore range (m AVD-46)	Representative value (m AVD-46)
Present day	2.82 – 3.03	3.05	2.18 – 2.40	2.40
2050s	3.15 – 3.36	3.40	2.53 – 2.82	2.85
2080s	3.48 – 3.69	3.70	2.85 – 3.13	3.15

Table 4 Representative 1% AEP storm-tide values derived for the Manukau Harbour and Hauraki Gulf coasts of Manukau City.

The estimates of the MHWPS and 1% AEP water level vary along the two coastlines, values tend to be higher inside embayed areas due to tidal and storm surge amplification. There is also a general trend of higher water levels towards the east. For planning purposes, it is considered a uniform minimum building floor level requirement is desirable for each of the coastlines using sea level projections out to 2080s. However, as detailed study shows the sea levels at Bucklands Beach and Eastern Beach are about 200mm lower than other areas of the Hauraki Gulf Coast, considering high market value of the land within the area, a variation is recommended to be considered by Council for the Bucklands Beach and Eastern Beach area. Thus the following revision to the minimum building floor level requirements is proposed:

Sites where the finished building floor level is not less than 0.5 meters above the following Reduced Levels (L & S Datum):

- *3.70m in catchments draining to the Manukau Harbour, or*
- 3.15*m in catchments draining to the Waitemata Harbour or Hauraki Gulf with the exception of the Bucklands Beach and Eastern beach areas where the building floor level may be reduced to no less than 0.5 m above 2.95m.*

Coastal inundation is typically caused by a combination of tide, storm surge and wave conditions, although only the static 1% AEP water levels were assessed in the study, the approach is considered robust to protect local communities from coastal inundation. Previous studies on the Hauraki Gulf (Gorman & Heydenrych, 2004) and Manukau Harbour (Gorman and Nielson, 1999) identified that wave conditions along the two coastlines of the Manukau region are dominated by locally generated, fetch limited and relatively short-period wind waves. Based on empirical wave set-up and run-up formulae (e.g., Stockdon et. al., 2006) the highest levels of wave set-up and run-up are unlikely to reach more than 1 m above static water levels and that the maximum wave set-up and run-up levels are highly unlikely to occur at the same time as a 1% AEP storm-tide level, thus a combination of storm tide and ran-up levels would be much lower than the static 1% AEP water levels.

Conclusion

Scientific research worldwide has shown global warming is inevitable to occur due to the increase of anthropogenic green house gases. It is considered important to update Council standards on design rainfall intensity curves and minimum building floor level requirements to make provisions for predicted climate change. It is a precautionary approach necessary to avoid surface water flooding and coastal inundation which might be exacerbated by the effects of climate change.

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