PUSHING OUT THE CLIMATE CHANGE HORIZON

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ABSTRACT

Consideration of climate change is increasingly embedded in design practice in New Zealand, and is an essential part of stormwater design and flood risk management. In 2008, the Ministry for the Environment (MfE) published national guidelines for expected changes to temperature, rainfall patterns and sea level rise, and there are also District and Regional Council guidelines. MfE uses a furthest horizon of 2090, which is 100 years on from the base data analysis at 1990, while other guidelines use a variety of horizons, often shorter. We are now a quarter of the way to this 100-year horizon.

Precedents set by some recent project resource consents have taken the same "100-year horizon" approach, but applied it from expected project delivery dates, setting thresholds beyond MfE's 2090 horizon, and not necessarily matching the horizons in other local guidance. As an example, the Mackays to Peka Peka Expressway project was set a 2115 horizon, with a need to generate five different climate change datasets:

- Mid-range storm rainfall;
- High-range storm rainfall;
- River flood flow (based on flood frequency data independent of any rainfall-runoff model);
- Mid-range sea level rise; and,
- High-range sea level rise.

It was concluded that a full suite of studies downscaling from global or national models was not practical or justifiable for the relatively modest extrapolation from published data. Instead, simplified pragmatic approaches were taken to generating each of the required datasets in a form suitable for compliance with resource consent requirements. The paper outlines the different techniques used for each of datasets, including peer review, and the application of these in the project design. The potential implications of the United Nations Framework Convention on Climate Change 'Paris Agreement' to increases in global average temperature of less than 2°C above pre-industrial levels is considered.

KEYWORDS

Climate change, flood risk, rainfall, Kapiti Coast, M2PP

1 BACKGROUND

Consideration of climate change is increasingly embedded in design practice in New Zealand, and is an essential part of stormwater design and flood risk management. The Ministry for the Environment (MfE) published national guidelines (MfE 2008) for expected changes to temperature, rainfall patterns and sea level rise. There are also specific local guidelines published by District and Regional Councils. MfE uses a furthest horizon of 2090, which is 100 years on from the base data analysis at 1990, while other guidelines use a variety of horizons, often shorter. We are now over a quarter of the way to this 100-year horizon.

Precedents set by some recent project resource consents have taken the same "100-year horizon" approach, but applied it from expected project delivery dates, setting thresholds beyond MfE's 2090 horizon, and not necessarily matching the horizons in other local guidance. As an example, consent conditions for the MacKays to Peka Peka (M2PP) Expressway project on the Kapiti Coast set a 2115 climate change horizon when considering:

- Rainfall;
- River flood flow; and,
- Sea level rise.

For M2PP, it was concluded that a full suite of studies downscaling from global or national models was not practical or justifiable for the relatively modest extrapolation from published data. Instead, simplified pragmatic approaches were taken to generating each of the required datasets in a form suitable for compliance with resource consent requirements.

This paper outlines the different techniques used to establish and document the 2115 climate change inputs for the stormwater design and modelling, including peer review, and the application of these in the project design. The potential implications of the United Nations Framework Convention on Climate Change 'Paris Agreement' to increases in global average temperature of less than 2°C above pre-industrial levels is considered.

2 MACKAYS TO PEKA PEKA EXPRESSWAY

2.1 LOCATION AND ALIGNMENT

The M2PP Expressway is an 18km upgrade of SH1 along the Kapiti Coast, north of Wellington. The expressway route bypasses the towns of Waikanae and Paraparaumu. The new alignment traverses a low-lying coastal plain of sand dunes and peat deposits between the urban area along the current SH1 and developed coastal strip. The coastal plain is drained by numerous small streams, some of which have their headwaters in the steeply rising hills behind the coast. The M2PP Expressway crosses these small streams and the Waikanae River, which has a catchment area of about 130 km^2. The expressway alignment is shown in Figure 1, with the crossing of the Waikanae River at the mid-point of the expressway.

Design of the expressway started in 2010, with consents granted by Greater Wellington Regional Council (GWRC) in 2012.

Figure 1 MacKays to Peka Peka Expressway (NZTA 2012b)

2.2 RESOURCE CONSENT COMPLIANCE

M2PP Technical Report 22, Assessment of Hydrology and Stormwater Effects (NZTA 2012a), prepared in February 2012 for the Expressway's Resource Consent application, was based on mid-range climate change predictions to 2090. This was in accordance with Ministry for the Environment (MfE), Kapiti Coast District Council (KCDC) and Greater Wellington Regional Council (GWRC) guidelines and practices which are in turn based on the International Panel on Climate Change's (IPCC) report (IPCC 2007).

The 2090 climate change parameters used for the modelling and design carried out prior to the granting of resource consents were:

- 16% increase in rainfall intensity in the 1% AEP storm (based on a 2.1°C temperature increase); and,
- 0.8m rise in sea level (applied to a 5% AEP storm tide).

Resource consent was granted, but contained conditions that required design with climate change to 2115. The relevant Project Resource Consent Conditions are:

> **SW.2 b)** - *Flood risk shall be assessed against the 1% AEP storm, with climate change to 2115 (mid-range) estimated* [sic] *and shall provide a sensitivity evaluation against high range climate change scenarios (to 2115);* and,
>
> **SW.2 d)** – *…. The report and modelling for each stage shall be independently peer reviewed by a suitably qualified and experienced engineer agreed with GWRC and KCDC (at the cost of the Consent Holder) to ensure that the hydraulic modelling is appropriate and that the stormwater design and flood risk management meets the performance criteria set out in SW.1, SW.2 and SW.3. The report and the results of the peer review shall be provided to the Manager …. Works in the relevant Stage that might affect hydrology and flood risk … shall not commence until the Manager has certified the report.*

However, the published MfE projections (MfE 2008) at the time of consent only extended out to 2090 so a practical method was needed to determine 2115 parameters. Initially advice was sought from NIWA to determine if they already had a method in that could be used. NIWA suggested an approach based on a fundamental analysis of the raw data, which they described as a considerable task. Given time constraints on the detailed design and delivery phase of the expressway, a simpler extrapolation approach was agreed with the peer reviewer.

The approaches developed, peer reviewed and adopted for the design of the M2PP Expressway to account for the effects of climate change to 2115 on rainfall, river flows and sea level rise are detailed in the next three sections of the paper.

3 RAINFALL

3.1 CLIMATE CHANGE SCENARIOS

MfE's guidance (MfE 2008) shows increases in temperature through to 2040 and 2090 for the Wellington Region of 0.9°C and 2.1°C, respectively, from the 1990 baseline. MfE's climate change projections for New Zealand are based on NIWA's downscaling of the IPCC A1B climate change scenario.

KCDC have their own estimates (KCDC 1999) for mid-range and high-emissions through to 2030 and 2090, which differ from MfE as outlined in Table 1.

Table 1: Increases in rainfall to 2115

Temperature increase to	MfE (2008) for Wellington Region	KCDC (1999)	
		mid-range	high-emissions
2030	-	0.7°C	1.7°C
2040	0.9°C	-	-
2090	2.1°C	2.0°C	5.0°C

It was agreed with the peer reviewer that MfE's A1B climate change scenarios are appropriate for use rather than KCDC's projections. The A1B-mid estimate for 2090 is slightly more conservative than KCDC's mid estimate but the A1B-high is significantly less than KCDC's high estimate. The differences are because KCDC proposes different climate change models from those used by MfE.

The KCDC high-emissions scenario represents unchecked use of carbon-emitting resources worldwide; referred to as a 'Resource Scramble'. This is an extreme situation which was considered to be well outside most other high range predictions and so was considered too conservative by both the Alliance and the peer reviewer. The Paris Agreement of December 2015 further reduces the likelihood of the 'Resource Scramble' eventuating.

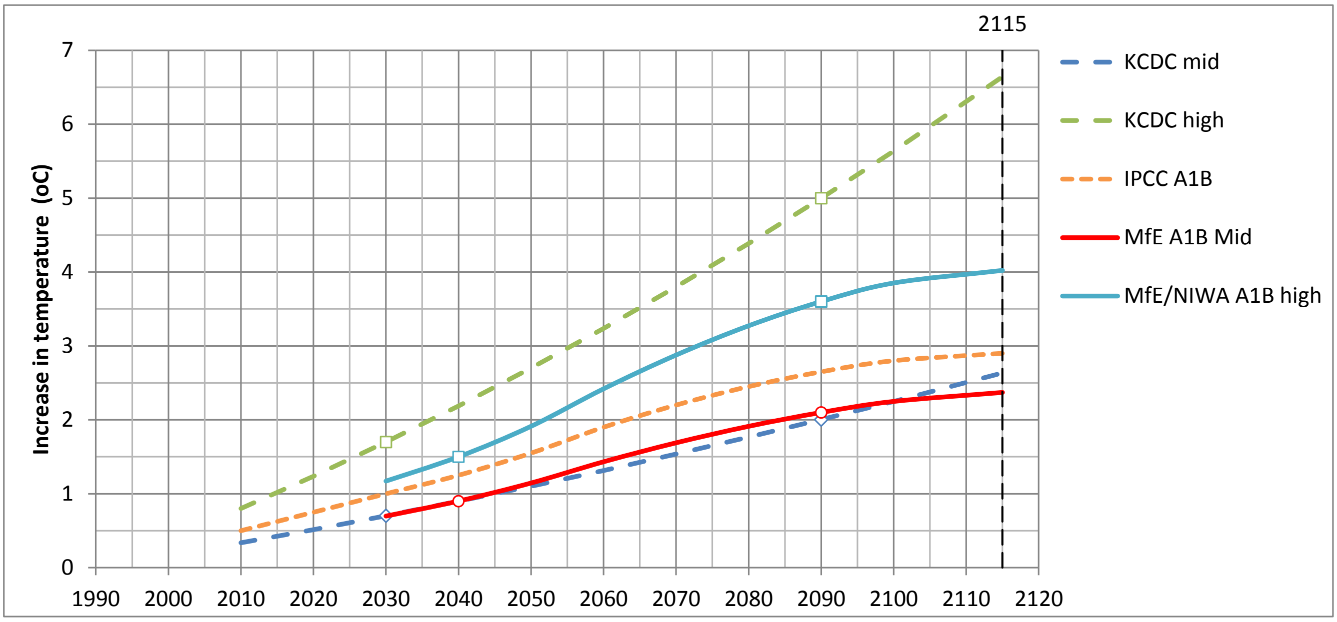
3.2 EXTRAPOLATION OF TEMPERATURE INCREASE

Early assessments of the temperature increase to 2115 were based on a simple extrapolation of temperature increases from 2040 and 2090 of the A1B mid and A1B high climate change scenarios over the 1990 baseline. These resulted in a projected increase of 2.8°C for the mid-range climate change scenario and 4.8°C for the high-range scenario. Increases in rainfall depths for these increases in temperature were then calculated within NIWA's HIRDS v3, which gave a 22% and 38% increase in the 24-hour duration 1% AEP (Annual Exceedance Probability) rainfall depths respectively for the A1B mid and A1B high climate change scenarios.

Continuing the theme of proactive involvement, these results were discussed with the peer reviewer, who indicated that these allowances were conservatively high and the extrapolation would be more appropriately reviewed with reference to Figure 2.1 of MfE (2008) that shows the IPCC's multi-model temperature projections for selected scenarios. IPCC's A1B mid scenario shows a slowing in temperature increase towards the end of the 21st century. The shape of this projection has been used to define the shape of the projected MfE A1B growth curves.

Figure 2 shows the updated temperature growth curves that were used for calculating increases in 24-hour rainfall depths along the M2PP Expressway.

Figure 2: Extrapolation of A1B scenarios using a based on the IPCC A1B plot.



The red line is the mid scenario climate change growth curve, which is based on the MfE's A1B mid-range temperature increases for 2040 and 2090 and the shape of the IPCC A1B mid curve (orange line). The MfE A1B mid curve intersects 2115 at 2.4°C.

The light blue line is the high scenario case that is to be used in the sensitivity testing required under the resource consent conditions. This curve, labelled MfE/NIWA A1B high, has been modelled on increases of 1.5°C for 2040 and 3.6°C for 2090; these being the upper bounds of the A1B scenario for Wellington. The shape of the curve, which intersects 2115 at 4.0°C, is similarly defined by the shape of the IPCC A1B mid plot.

The increase in rainfall per °C increase in temperature is reported in Table 5.2 of MfE (2008). The increase is greater for more extreme, smaller AEP, storms. Table 2 lists the increases in rainfall that have been applied for the above noted temperature increases. These increases were agreed with the peer reviewer.

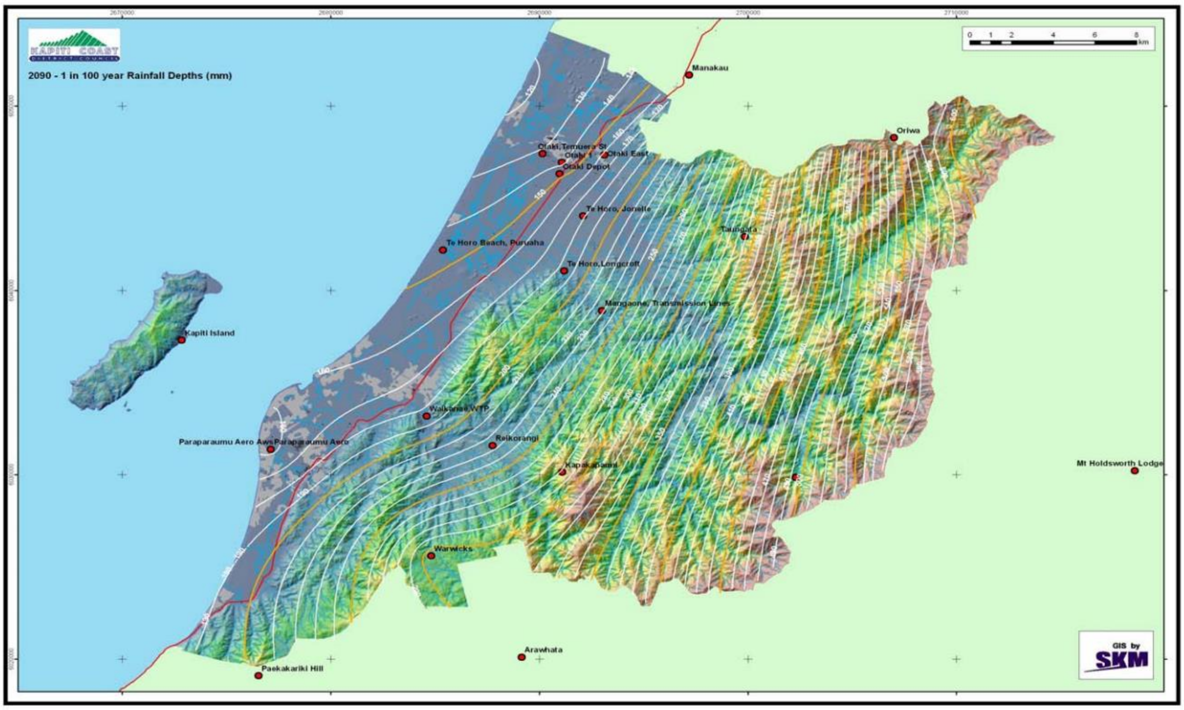
Table 2: Increases in rainfall to 2115

Climate Change Scenario	Temperature increase to 2115	Increases in 24-hour Rainfall Totals		
		50% AEP	10% AEP	1% AEP
Mid-range	2.4°C	10%	15%	19%
High range	4.0°C	-	-	32%
Rainfall increase per °C		4%	6%	8%

3.3 IMPLEMENTATION OF 2115 RAINFALL DEPTHS

The derived increases in rainfall to account for climate change to 2115 were applied to the rainfall depths and profiles being used for design and modelling of the M2PP Expressway. KCDC have developed and updated isohyet maps (KCDC 2011) of 24-hour rainfall depths for 1990 and 2090 for AEP's of 50%, 10% and 1% (i.e. 2, 10 and 100yr return periods). Figure 3 shows the 100-year isohyet map for 2090.

Figure 3: KCDC 1% AEP 24-hour rainfall depths to 2090 (KCDC 2011)



Given that these isohyet maps were derived from analysis of local gauges it was agreed with the peer reviewer that KCDC's 24-hour rainfall depths derived from the updated maps would be used for ongoing M2PP stormwater modelling.

Stormwater modelling of the M2PP Expressway runoff (in InfoWorks CS software) was divided into three zones: north, central and south. The KCDC isohyets run approximately parallel to the Expressway alignment to the north of Te Moana Road (Waikanae), which includes the entire north zone InfoWorks model. Therefore, one rainfall depth was able to be used for each AEP for all of these Expressway catchments.

Further south, the Expressway alignment cuts across the mapped isohyets and so it is less appropriate to use the same storm depths for all of the Expressway catchments in the central and southern zone InfoWorks models. Therefore, the central model has two storm 'sub-zones' and the south model has three storm 'sub-zones'. A single rainfall depth will be applied for each AEP storm in each sub-zone. Figure 4 and Table 3 summarises the different rainfall zones.

Figure 4: M2PP Expressway rainfall zones

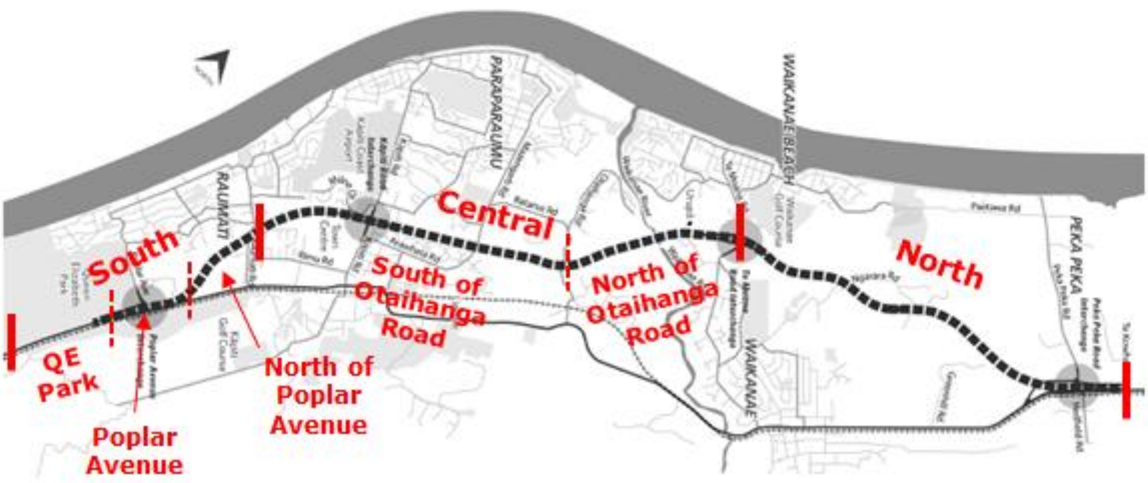


Table 3: M2PP Expressway rainfall zones

M2PP Model	Sub-zone	M2PP Chainage (m)	
		From	To
North	All	12750	1800
Central	North of Otaihanga Road	9200	12750
	South of Otaihanga Road	4800	9200
South	North of Poplar Avenue	3050	4800
	Poplar Avenue	1900	3050
	QE Park	0	1900

Tables 4 and 5 provide the 24-hour rainfall depths for climate change through to 2115 that were agreed and used for the M2PP stormwater modelling. The percentage increases listed in Table 2 have been applied to determine these figures.

Table 4: Summary of 2115 rainfall depths and % increases – South

M2PP Zone	**South**				**South**				**South**			
M2PP Sub-zone	QE Park				Poplar Avenue				North of Poplar Avenue			
AEP	50%	10%	1%	1%	50%	10%	1%	1%	50%	10%	1%	1%
1990 24hr rainfall (mm)	86	119	168		82	115	161		77	109	154	
Climate change scenario	A1B mid	A1B mid	A1B mid	A1B high	A1B mid	A1B mid	A1B mid	A1B high	A1B mid	A1B mid	A1B mid	A1B high
Temperature increase (°C) to 2115	2.4	2.4	2.4	4.0	2.4	2.4	2.4	4.0	2.4	2.4	2.4	4.0
2115 24hr rainfall (mm)	**95**	**137**	**200**	**222**	**90**	**132**	**192**	**213**	**85**	**125**	**184**	**203**
Increase in rainfall to 2115	10%	15%	19%	32%	10%	15%	19%	32%	10%	15%	19%	32%

Table 5: Summary of 2115 rainfall depths and % increases – Central and North

M2PP Zone	**Central**				**Central**				**North**			
M2PP Sub-zone	South of Otaihanga Road				North of Otaihanga Road				All			
AEP	50%	10%	1%	1%	50%	10%	1%	1%	50%	10%	1%	1%
1990 24hr rainfall (mm)	71	102	146		69	100	142		67	97	138	
Climate change scenario	A1B mid	A1B mid	A1B mid	A1B high	A1B mid	A1B mid	A1B mid	A1B high	A1B mid	A1B mid	A1B mid	A1B high
Temperature increase (°C) to 2115	2.4	2.4	2.4	4.0	2.4	2.4	2.4	4.0	2.4	2.4	2.4	4.0
2115 24hr rainfall (mm)	**78**	**117**	**174**	**193**	**76**	**115**	**169**	**187**	**74**	**112**	**164**	**182**
Increase in rainfall to 2115	10%	15%	19%	32%	10%	15%	19%	32%	10%	15%	19%	32%

For consistency with earlier modelling and design work, KCDC's nested storm profile that distributes the 24-hour rainfall depths was used though the M2PP design. The KCDC storm profile was updated in the revised guidance issued by KCDC in 2011 (KCDC 2011). The 2011 profile corrected an error in the percentage of 24-hour rainfall falling in the first two hours; increasing the percentage from 35% to 38%. The updated 2011 profile is detailed in Table 6.

Table 6: KCDC normalised depth-duration 24-hour storm profile

Duration (mins)	5	15	60	120	180	360	720	1440
Normalised rainfall depth (d/d24)	0.08	0.14	0.26	0.38	0.46	0.60	0.81	1.00

3.4 SUMMARY OF 2115 TEMPERATURE EXTRAPOLATIONS AND RAINFALLS

In summary, the following design criteria were adopted:

- The use of IPCC/MfE's A1B temperature scenarios;
- A 2.4°C increase for the 2115 mid estimate scenario using an extrapolation based on the IPCC A1B curve;
- A 4.0°C increase for the 2115 high estimate scenario using an extrapolation based on the IPCC A1B curve;
- The use of KCDC's rainfall data; and,
- The continued use of KCDC's nested storm profile.

4 WAIKANAE RIVER AND MUAUPOKO STREAM HYDROLOGY

4.1 BACKGROUND

The M2PP Expressway crosses multiple small streams and catchments draining to the west. Design flood flows for these catchments were calculated using the Clark Unit Hydrograph method prescribed by KCDC (KCDC 2011). 24-hour rainfall depths for the catchments draining to the M2PP crossing points were derived from the KCDC isohyetal maps, rather than from the rainfall zones (Table 3) used for the InfoWorks modelling of the Expressway catchments. The percentage increases in Table 2 were applied to 24-hour rainfall depths to determine 2115 climate change hydrology.

The only two cross-drainage catchments that were an exception to this approach were the Waikanae River and Muaupoko Stream catchments that are discussed below. The Muaupoko Stream joins the Waikanae River immediately upstream of the M2PP crossing of the Waikanae River.

For GWRC, NIWA developed a method (NIWA 2009) to derive design flood hydrographs for the Waikanae River and Muaupoko Stream. Peak flows for the Waikanae River are derived from a frequency analysis of data from GWRC's Waikanae River flow monitoring site at the Water Treatment Plant (upstream of SH1), while the shape of the hydrograph is an average shape from six of the most recent and largest flood events, as described in the NIWA report (refer Appendix D).

To derive Waikanae River design flood flows at the M2PP crossing, a 1% AEP flood event in the Waikanae River at the Water Treatment Plant is assumed to coincide with a 5% AEP event in Muaupoko Stream sub-catchment. This combination approach was adopted for earlier GWRC and pre-consent M2PP modelling, and was not changed for the post-consent modelling when the allowance for climate change to 2115 was required.

It was agreed with the peer reviewer that the calculation of flow increases for 2115 for the Waikanae and Muaupoko catchments should be consistent with the temperature and rainfall increases with that described above. In the absence of a calibrated hydrological model for the Waikanae catchment, several approaches were considered to provide an indication of the likely effects of increase rainfall due to climate change, and hence calculate design flow hydrographs for the Waikanae River at the Water Treatment Plant. The approaches considered were:

- Extrapolation of the current NIWA predictions of runoff peak;

- Analysis of volumetric runoff change based on an SCS relationship, derived from historical rainfall and runoff data; and,
- Review of the historical relationship between peak flow and storm runoff, and extrapolating this.

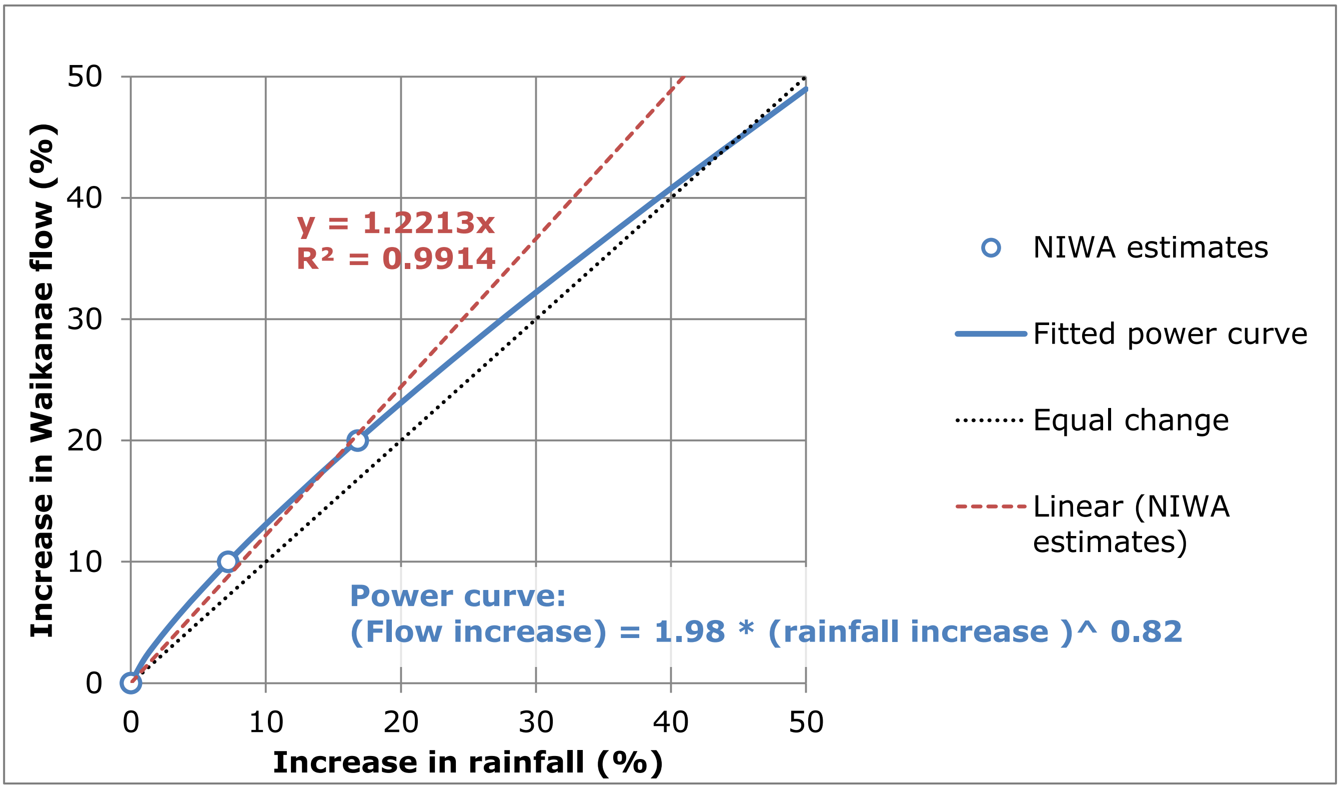
Consideration was also given to developing a catchment hydrological model. However, given the trends evident from the assessments described below, there was concern that without accurate representation of catchment characteristics at a high degree of resolution, and without accounting properly for hydraulic effects on attenuation, a model would be less reliable than an assessment based on the historical data.

4.2 EXTRAPOLATION OF NIWA'S PREDICTIONS

Initially, the guidance provided in NIWA's report for increases in runoff was *"of the order of 10% and 20% in 50 and 100 years respectively"* (NIWA 2009). Our understanding of the NIWA work is that these relate to rainfall intensity increases of 8% and 16%. This is a simplified assumption that the marginal increase in runoff is greater than the marginal increase in rainfall due to catchment saturation, and taken as a basis for extrapolating flows for M2PP. It is noted that these two values are rounded significantly, and the basis for them is not clear in the NIWA report.

There is therefore a risk in using them to project to higher rainfall increases. Instead, the appropriateness of the extrapolation approach was reviewed with reference to two other Wellington river models; those for the Waitohu Stream and the Waiohine River. Both reference models showed wide variations in the response of flow to increased rainfall. As such, there was no clear trend to support a refinement of NIWA's percentages for the Waikanae. NIWA's figures were extrapolated by plotting rainfall increase and flow increase, shown in Figure 5, to determine the 2115 peak flows from the increased rainfall described above.

Figure 5: Waikanae River peak flow increase vs. rainfall increase to 2115.



The blue power curve provides a precise fit to the NIWA estimates and the '0,0' origin. However, it is unlikely to be an appropriate extrapolation for the following reasons:

- The curve trends against the expectation that the increase in flow will be greater than the increase in rainfall; and,
- It is likely distorted by the approximate nature of the NIWA estimates.

While the linear approach does not provide as close a fit, it is considered to provide a more appropriate projection of effects, because the expectation would be that peak flows should increase approximately in proportion to rainfall, and that appears to have been the general finding of the NIWA study.

The results from the extrapolation of the NIWA guidance are outlined in Table 6. The linear extrapolation is preferred.

Table 7: Peak flow increase vs. rainfall increase – NIWA extrapolated

Scenario	2040	2090	2115 Mid	2115 High
Rainfall increase	7.2%	16.8%	19.2%	32%
Power extrapolation – percent increase	*10%*	*20%*	*22.3%*	*34.0%*
Power extrapolation – 1% AEP peak flow (m^3/s)	440	480	489	536
Linear extrapolation – percent increase	*8.8%*	*20.5%*	*23.4%*	*39.1%*
Linear extrapolation – 1% AEP peak flow (m^3/s)	435	482	494	556

4.3 VOLUMETRIC CHANGE – SCS METHOD

While peak flow is one measure of a flood that has to be taken into account with infrastructure design, flood volume is another. This is especially the case where flood storage and attenuation is a factor.

In consideration of this, the SCS curve number (CN) approach was used to characterise the Waikanae catchment, and hence derive a volumetric runoff increase due to climate change. This does not translate directly into peak flow, particularly as there appear to be flood plain areas in the mid-catchment that could come into action at high flows and might attenuate peaks relative to volume. Two volumetric approaches were tested:

- **Curve numbers and initial abstraction** values from KCDC hydrological method (KCDC 2011) were used to estimate the relative changes in volumetric runoff. While this method is not recommended for catchments as large as the Waikanae, the curve numbers have been calibrated by KCDC for use within the district. The following values were used:
  - CN=72, based on the land use in the Waikanae catchment being half hill pasture (CN=79) and half hill bush (CN=65); and,
  - An initial abstraction of 5mm in accordance with KCDC recommendations.
- **Large historical storms** were analysed to assess the relationship between storm rainfall and runoff volumes.

- Storm rainfall was derived from three gauges: Waikanae WTP, Waiotauru at Kapakapanui and Akatarawa at Warwicks, which were apportioned across the catchment using a Thiessen polygon approach at 33%, 31% and 36% respectively;
- Storm runoff was assessed by subtracting estimated base flow from the hydrographs; and,
- Values of CN and IA were trialled to achieve a good fit visually, and the selected values are 75 and 15mm respectively.

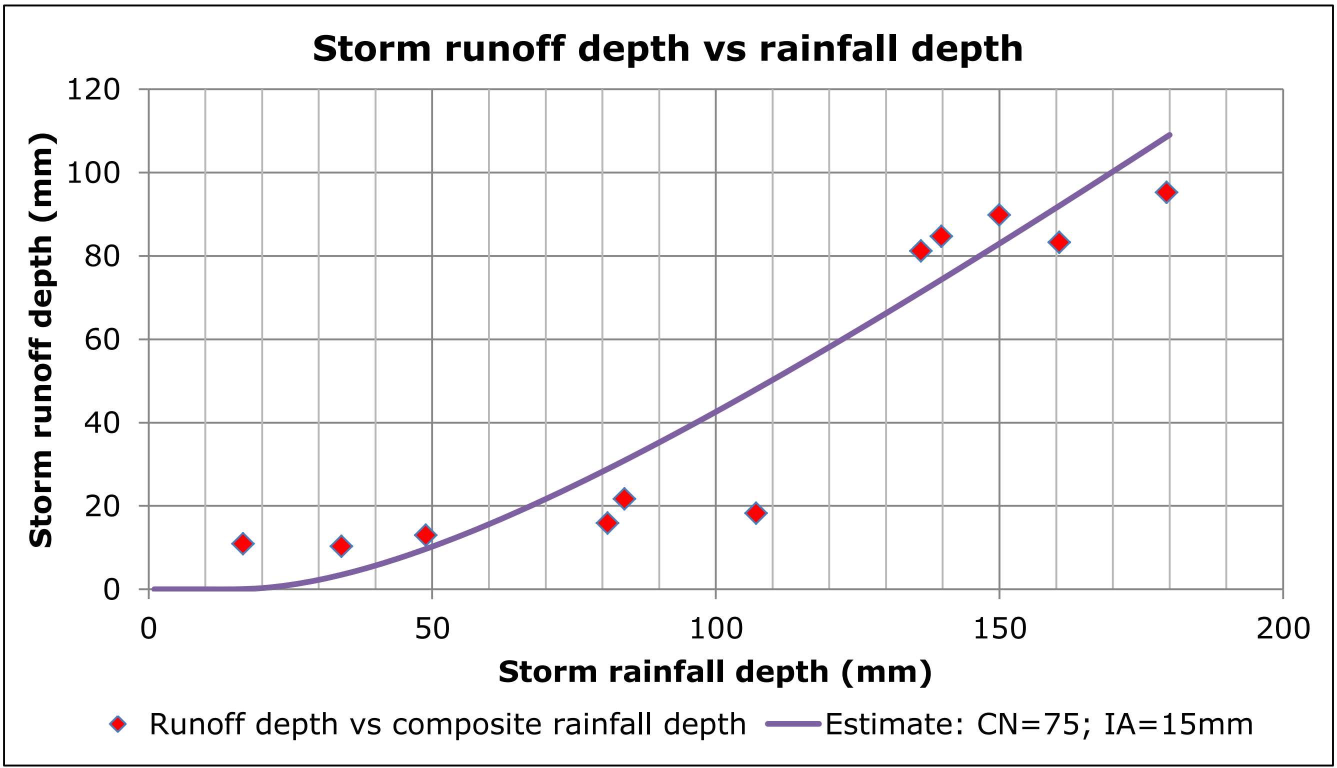
The results are shown in Figure 6 and tabulated in Table 7, which also includes the percentage increases derived from this method.

Table 7: Volumetric runoff change vs. increased rainfall

Scenario	CN	IA	2040	2090	2115 Mid	2115 High
Rainfall increase			7.2%	16.8%	19.2%	32%
Volume increase – KCDC CN and IA values	72	5	10.7%	25.1%	28.8%	48.6%
Volume increase – fitted to historical data	75	15	10.6%	24.9%	28.5%	48.0%
Mean of volume increase			**10.7%**	**25.0%**	**28.7%**	**48.3%**

These two sets of results are relatively similar, and since they correlate with historical data, they provide a reasonable basis for understanding how storm runoff volume might change with rainfall.

Figure 6: Waikanae River storm runoff volume vs. storm rainfall.



4.4 HISTORICAL PEAK FLOW AND FLOW DISTRIBUTION

This analysis has been undertaken from two perspectives:

- Comparison of flood peak distributions with rainfall distributions; and,
- Comparison of storm peak flow with corresponding storm rainfall depths.

The former involved using the flood frequency distribution derived by NIWA for the river, and plotting that against the HIRDSv3 design 24-hour rainfall depths of the same return period. This provides a basis for predicting how higher rainfall depths might affect peak flows. A similar comparison was undertaken against 6-hour rainfall distribution (six hours being the Waikanae River catchment time of concentration).

The latter involved plotting individual historical storm peaks against both the total storm volume, and against the 6-hour peak depth within each storm.

The peak flow is calculated from the design rainfall (including an allowance for climate change to 2115) using the 'straight line' and 'log curve' equations shown in Figures 7 and 8. 1% AEP results for the Waikanae River are set out in Table 8.

Figure 7: 1% AEP peak runoff vs. 24-hour storm rainfall.

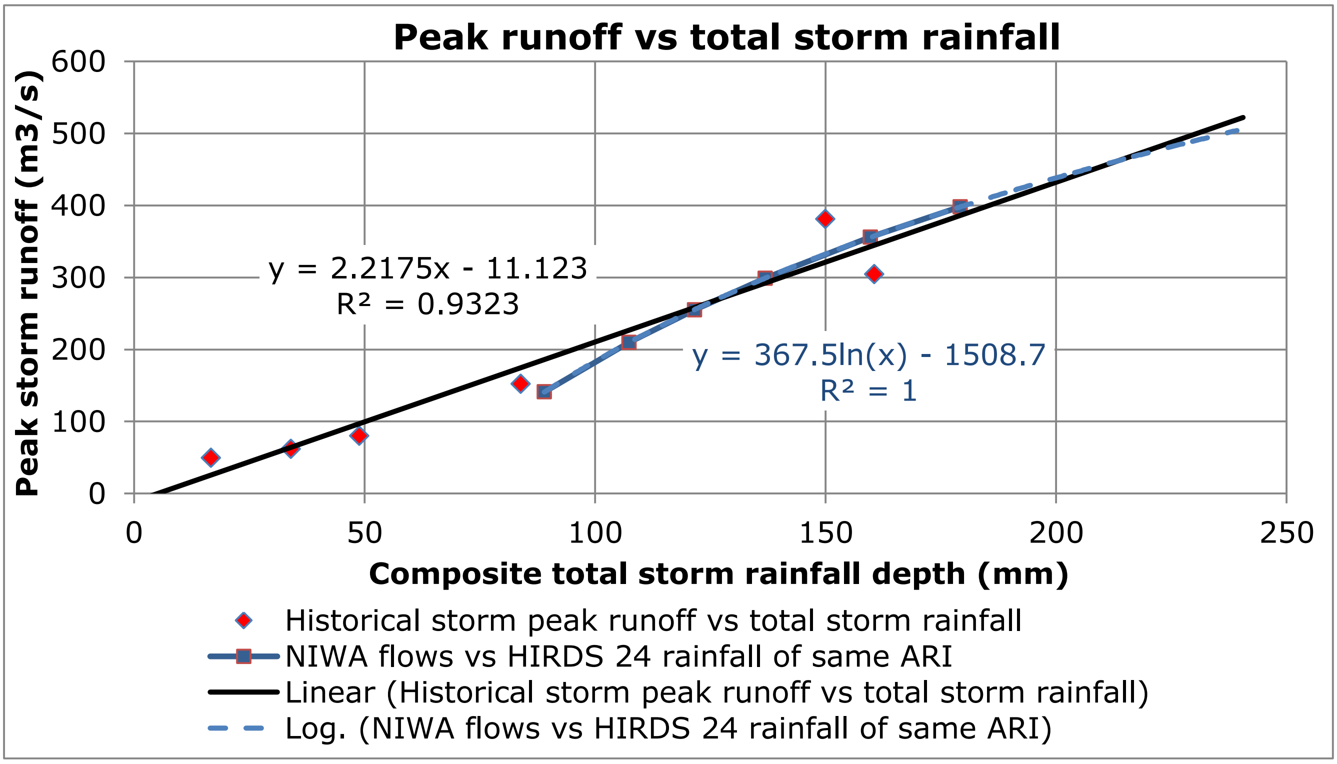


Figure 8: 1% AEP peak runoff vs. 6-hour storm rainfall.

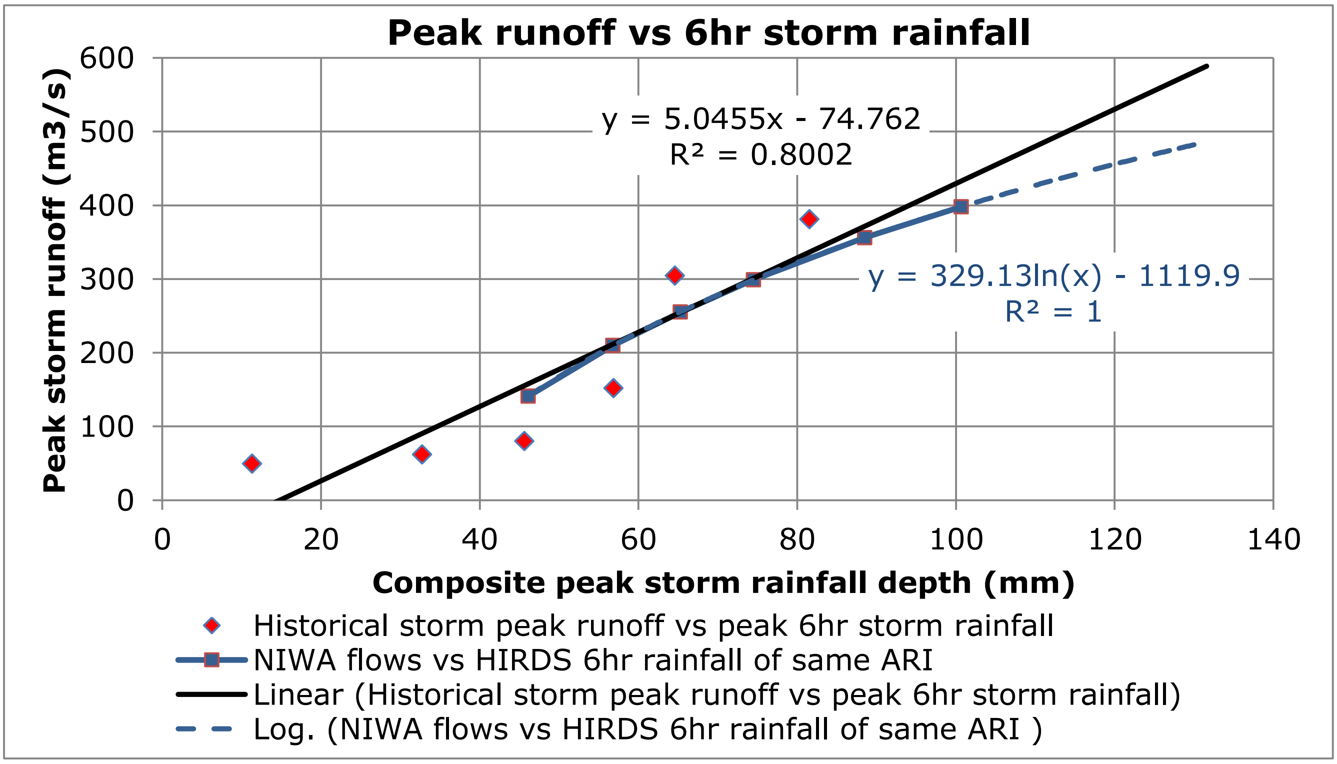


Table 8: Increase in 1% AEP peak flow rate

Scenario	2040	2090	2115 Mid	2115 High
Rainfall increase	7.2%	16.8%	19.2%	32%
Straight line - based on 6 hour (m^3/s)	470	519	531	596
Straight line - based on 24 hour (m^3/s)	415	453	463	513
Log curve – based on 6 hour (m^3/s)	421	449	456	490
Log curve – based on 24 hour (m^3/s)	424	455	463	500
Mean of scenarios (m^3/s)	**432**	**469**	**478**	**525**
Percentage increase	7.0%	16.1%	18.3%	29.9%

Of the four methods outlined above, the straight line 6-hour relationship gives much higher peak flows than the other three relationships, which are relatively consistent with each other. However, with regard to the results from the NIWA extrapolation (Section 4.2), and to offset reservations about the use of power curves that could significantly reduce the more extreme peaks, the average of the four sets of results was considered to provide the best estimate of peak flow using this method.

4.5 SUMMARY OF WAIKANAE RIVER FLOOD FLOW

Three different conceptual approaches have been considered to derive peak flows in the Waikanae River at the Water Treatment Plant. The first and third methods related to the calculation of peak flows, while the second method related to runoff volumes.

NIWA's approach to extrapolating peak flows from increases in rainfall resulted in higher estimates of peak flow than comparing distributions of peak flow and storm rainfall. The more conservative NIWA extrapolation approach was adopted for the M2PP design and modelling work. While conservative, this method is not markedly so, and produces increases in peak flow that are only slightly greater than the increase in rainfall. The reason for selecting these in preference to peak flows more closely tied to runoff volume increases, is that while the volume of storm runoff may increase more markedly, the increase in peak flow rate appears (from the historical records) to be attenuated to some extent.

Runoff volumes are expected to increase more markedly than peak flows, as indicated both by the historical data, and by the application of the SCS based KCDC hydrological method. It is therefore recommended that once the peak flow increases have been applied to the storm hydrographs being used for the Waikanae and Muaupoko, the peaks be extended slightly to accommodate the overall storm runoff volume increase set out below.

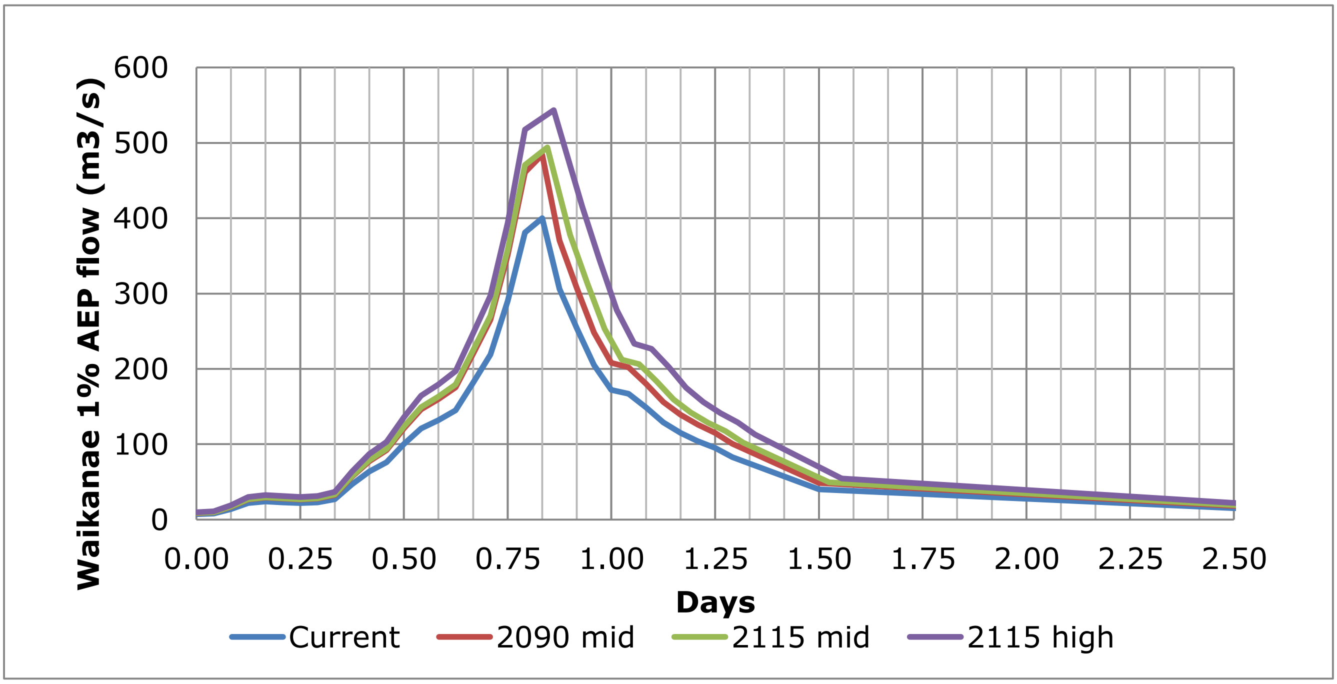
The best estimates for the effects of climate change and resultant increase in design rainfall, and the consequent increase in peak flow and runoff volume for the Waikanae River are summarised in Table 9. For the Muaupoko Stream, the percentage of peak flow and runoff volume percentage increase relative to 1990 base hydrograph set out in the table were used. These are the increases used in the design and modelling for the M2PP Expressway.

Table 9: 1% AEP storm runoff – Waikanae River at the Water Treatment Plant

Scenario	1990	2040	2090	2115 Mid	2115 High
Rainfall increase	-	7.2%	16.8%	19.2%	32%
Peak flow increase	-	8.8%	20.5%	23.4%	39.1%
Peak flow rate (m^3/s)	400	435	482	494	556
Volume increase	-	10.7%	25.0%	28.7%	48.3%

The resultant design hydrographs for the Waikanae River are shown in Figure 9.

Figure 9: Recommended hydrographs – Waikanae 1% AEP storms.



For design storms more frequent than the 1% AEP event, it was recommended that the increases shown below in Table 10 be used, based on recommended climate change design rainfalls, with proportionate scaling of runoff peak and volume relative to the 1% AEP 2115 mid-range scenario. As noted the Waikanae 1% AEP scenario is usually run with a 5% AEP Muaupoko inflow.

Table 10: Other return period increases

Scenario	50% AEP 2115 mid	10% AEP 2115 mid	5% AEP 2115 mid	5% AEP 2115 high
Rainfall increase	10.0%	15.0%	16.3%	28.8%
Peak flow increase	12.2%	18.3%	19.9%	35.2%
Volume increase	14.9%	22.4%	24.4%	43.3%

5 SEA LEVEL RISE

5.1 BACKGOUND

The alignment of the M2PP Expressway is set back from the coast; it is no closer to the shore than 1.2 km. However, flood levels where the Expressway crosses some of the watercourses are influenced by downstream sea levels due to the low-lying topography of the Kapiti Coast. Therefore, there was a requirement to consider potential increases in sea level to 2115 for the M2PP design and modelling work.

5.2 RECOMMENDED INCREASES

The sea level rise to 2115 is based on a report (Bell and Hannah 2012) prepared by NIWA for GWRC which focuses on sea level rise in the Wellington region. The range of recommendations given in that report is thorough and the M2PP design team decided that there was no benefit in carrying out further assessments for the M2PP Expressway. Increases based on the greenfield infrastructure assessment that is recommended in Bell and Hannah (2012) were used to derive the assumed sea level rise for the M2PP detailed design.

The NIWA recommendations are summarised in Table 11.

Table 11 - Sea level rise out to 2115 (NIWA)

Scenario	Medium Estimate	High Estimate
Present trends through (to 2115)	1.0 m	1.3 m
Planning guideline (no timeframe)	at least 1.5 m	Up to 2.0 m
Vulnerability assessment (no timeframe)	1.0 m	1.5 m

5.3 M2PP DESIGN EFFECTS

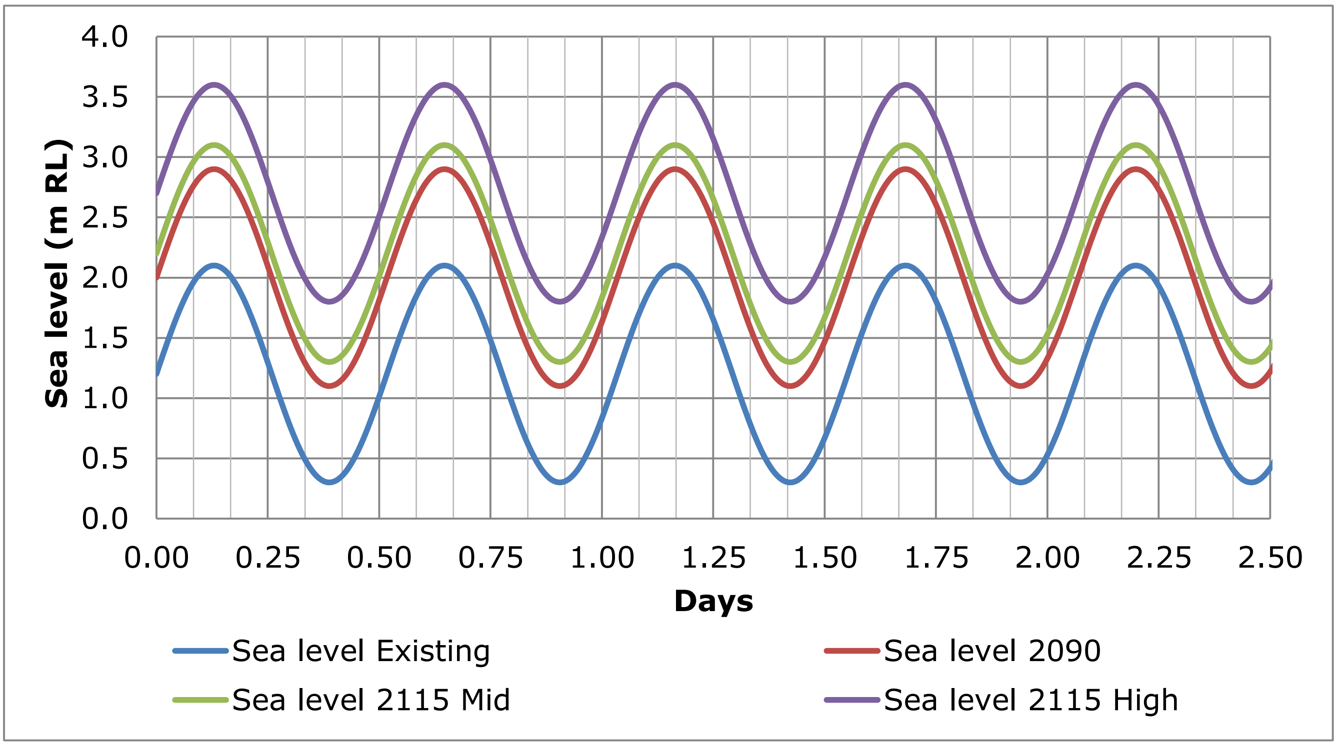
In the event that the high emissions estimate scenarios of 1.5 m (Vulnerability assessment) or 2.0 m (Planning guideline) were reached, there would be considerable effect on local urban areas irrespective of the presence of the Expressway. Any relative effects of the Expressway would likely be minor. Therefore, 1.0 m and 1.5 m sea level rise were used for the mid and high-estimate scenarios for M2PP detailed design. Both GWRC and KCDC’s methodology for modelling the 1% AEP storm applies a 5% AEP storm surge/sea level condition with climate change additional to this.

The tidal boundary conditions for used for modelling were updated for the increase to 2115 climate change. The peak sea levels are presented in Table 12. Tidal time series were calculated by adjusting the existing time-series by the change in peak tidal levels, and are shown in Figure 10.

Table 12 – M2PP design peak sea levels

Scenario	Sea level
Existing	2.1 mRL
2090 mid-estimate	2.9 mRL
2115 mid-estimate	3.1 mRL
2115 high estimate	3.6 mRL

Figure 10: New Zealand annual mean temperatures 1865-1990 (NIWA 2015b)



6 THE PARIS AGREEMENT ON CLIMATE CHANGE

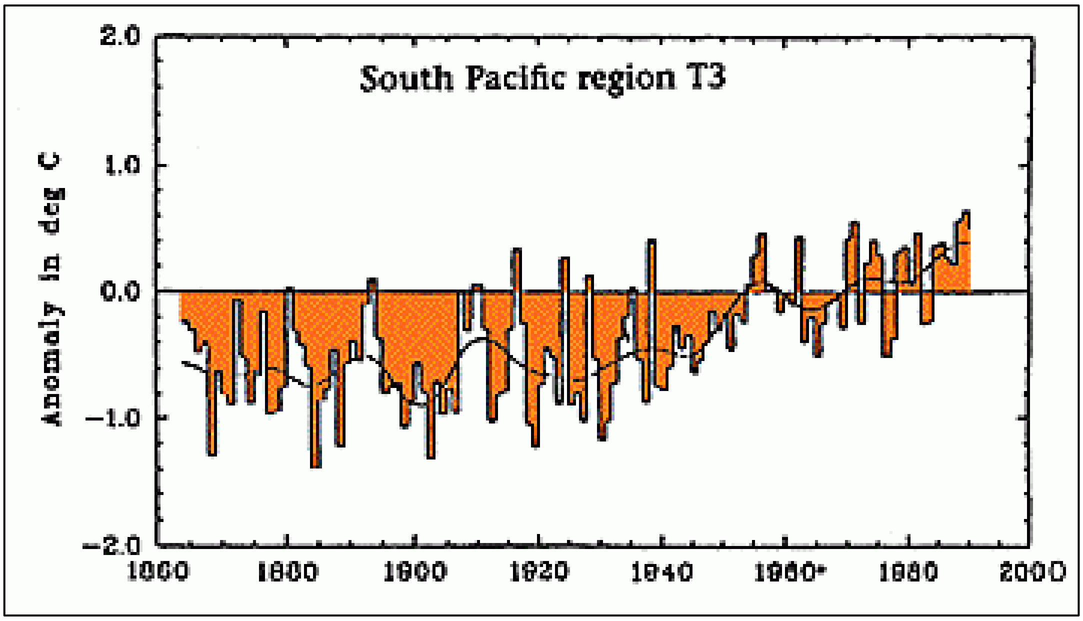
On 12 December 2015 (and after the M2PP Expressway design and modelling had been completed), 195 member states of the United Nations Framework Convention on Climate Change (UNFCCC) adopted L'accord de Paris (The Paris Agreement) governing greenhouse gases emissions measures from 2020. The member states promised to reduce their carbon output "as soon as possible" and to do their best to keep global warming "to well below 2 degrees C" [3.6 degrees F]. This was generally in line with one aim of the convention that was described as:

> "(a) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

While the agreement was adopted by consensus, it has not yet entered into force. However, it was hailed by Laurent Fabius, France's foreign minister, as an "ambitious and balanced" plan that was a "historic turning point" in the goal of reducing global warming.

It is noted that aim of the convention refers to rises in temperature relative to “above pre-industrial levels”, whereas the baseline date for New Zealand’s MfE guidance on temperature increases is 1990. Figure 11 indicates that annual mean temperatures in New Zealand rose by about 1°C between 1920 and 1990. On this basis, MfE are predicting about 3°C rise above pre-industrial levels for New Zealand by 2090. For the M2PP design and modelling work, the increases above pre-industrial levels are 3.4°C (mid-estimate) and 5.0°C (high-estimate) for 2115.

Figure 11: New Zealand annual mean temperatures 1865-1990 (NIWA 2015b) expressed as differences from the1951 – 1980 average



While not guaranteeing that global temperature increases will be limited to less than 2°C, the Paris Agreement increases the likelihood of temperature increases being capped to below the levels predicted by MfE or used in the design of the M2PP Expressway. With this in mind, it is worth considering the implications on infrastructure development of making allowances for climate change.

If accommodating larger allowances for climate change does not significantly add to cost, then a conservative approach is more acceptable, given the uncertainties surrounding the science and the implementation of policies such as the Paris Agreement. However, adopting a conservative approach could set a precedent, whereby there is an expectation that a price sensitive project is expected to accommodate higher allowances for climate change when it is not necessary from a technical perspective.

On this basis, a project by project risk- and cost-based approach is advocated. Infrastructure promoters, developers and regulators must address the sensitivity of each scheme, and be supported by rigorous science. The goal posts of adapting to climate change will move; particularly if there is the political will and technical expertise to tackle climate change.

7 CONCLUSIONS

Potential climate change increases are generally reported in New Zealand by MfE and NIWA for 2040 and 2090 against a baseline of 1990. However, consent condition SW.2b for the M2PP Expressway on the Kapiti Coast required that the effects of climate change through to 2115 must be accounted for with relation to:

- **Rainfall depths:** These are closely related to increases in mean temperatures, so mid- and high-range temperature increases for 2115 were estimated using MfE predictions for 2090 and the shape of the IPCC A1B temperature growth curve. Baseline design rainfall depths were then adjusted to account for the increase in temperature;
- **River flows:** Peak flows and runoff volumes for local catchments draining across the Expressway, and for stormwater catchments within the Expressway designation, were calculated using the SCS method and the Clark Unit hydrograph and incorporating the 2115 rainfall. For the flows at the Waikanae River crossing, flood frequency and volume analysis was used to derive the 2115 peak flows and hydrograph shape; and,
- **Sea level:** Previous work by NIWA for GWRC was adopted for the M2PP design.

As required by consent condition SW.2d, there was frequent involvement of the peer reviewer in the derivation of the 2115 climate change parameters. The work benefitted from this involvement, especially as climate change extrapolation is an area of uncertainty. Early involvement of the peer reviewer allowed their comments and recommendations to be considered and, where appropriate, adopted. All of the issues raised by the peer reviewer were resolved so that there were no outstanding issues.

The 2115 climate change parameters set out in Table 13 are those agreed with the peer reviewer and used for the detailed design and modelling of the M2PP Expressway to address consent condition SW.2b).

Table 13 – Summary of 2115 climate change information

Item		Mid Estimate	High Estimate
IPCC Climate Change Scenario		A1B Mid	A1B High
Temperature Increase		+2.4°C	+4.0°C
Rainfall	1% AEP	+19%	+32%
	10% AEP	+15%	-
	50% AEP	+10%	-
Peak Flows	Waikanae River 1% AEP	494 m^3/s	556 m^3/s
	Muaupoko Stream 1% AEP	30 m^3/s	33 m^3/s
	Muaupoko Stream 5% AEP	22 m^3/s	24 m^3/s
Peak Tide	Rise in sea level, base is a 5% AEP storm surge/sea condition	3.1m RL	3.6m RL

The Paris Agreement demonstrated a political will to respond to the challenges presented by climate change, and resulted in temperature increase targets lower than those accommodated in the M2PP design. Climate change predictions will continue to be refined to account for political and technical changes. As such, the effect on infrastructure projects of addressing climate change should be addressed on a project by project risk- and cost-based approach, with consideration of the sensitivity of each scheme.

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REFERENCES

Bell, R.G. and Hannah, J. (2012) 'Sea Level Variability and Trends: Wellington Region', NIWA, June 2012.

IPCC (2007) 'Fourth Assessment Report: Climate Change', 2007

KCDC (1999) Page 8, Kapiti Coast District Council Plan Review, Global Change: Issues and Pressures, KCDC, 1999.

KCDC (2011) Updated Isohyet Based Calculation of Design Peakflows KCDC Subdivision Principles and Requirements, Schedule 4, KCDC Altered Requirements To Part 4 NZS 4404:2004, Stormwater Drainage, Appendix 1.

MfE (2008) 'Climate Change Effects and Impacts Assessment – A Guidance Manual for Local Government in New Zealand'. 2nd Edition, Ministry for the Environment, 2008

NIWA (2015a) 'Climate change scenarios for New Zealand' [Online]. Prepared by David Wratt & Brett Mullan. Available at: https://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios [Accessed 2 March 2016].

NIWA (2015b) 'Past climate variations over New Zealand' [Online]. Prepared by David Wratt, Jim Salinger, Rob Bell, Drew Lorrey and Brett Mullan. Available at: https://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/pastclimate [Accessed 2 March 2016].

NIWA (2009) 'Review of Flood Hydrology for the Waikanae and Otaki Rivers', NIWA, 2009.

NZTA (2012a) M2PP Technical Report 22, Assessment of Hydrology and Stormwater Effects (February 2012)

NZTA (2012b) New Zealand Transport Agency MacKays to Peka Peka Assessment of Environmental Effects: Non-Technical Summary, March 2012. Available at http://www.nzta.govt.nz/assets/projects/mackays-to-peka-peka-application/docs/non-technical-summary.pdf [Accessed 4 March 2016]