Impact of climate change on inflows to the Ruamahanga groundwater management zone

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Executive summary

The aim of this project is to estimate the potential climate change effects on river flows at nine locations within the Ruamahanga catchment, as part of Greater Wellington Regional Council (GWRC) Ruamahanga Whaitua modelling project. The changes in climate were generated using dynamical downscaling of one Global Circulation Model (GCM) used in the recent Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report within the Coupled Model Intercomparison Project Phase 5 (CMIP5).

Modelled climate during the present (1986-2005) and two future time slices (2031-2050 and 2081-2100, referred to as 2040 and 2090, respectively) will be used by GWRC as input to the Groundwater Management Zone (GWZ) hydrological model developed by GNS Science, Aqualinc Research and Jacobs as part of the modelling component of the Ruamahanga Whaitua project. The modelled discharges will be used to quantify the potential climate change effects on surface and groundwater availability for the study area, on water supply reliability to irrigated pastoral farms, and on nutrient leaching and sediment transport within the Ruamahanga catchment.

The climate change projections for 2040 and 2090 have been produced using dynamical downscaling of the Geophysical Fluid Dynamics Laboratory (GFDL) GCM model to the grid of New Zealand's Virtual Climate Network (VCN), thus providing daily climate data at a spatial scale of approximately 5 km in the study area. The emission scenario chosen is a 'business as usual' emission scenario characterised by Representative Concentration Pathway (RCP) 6.0. Under this scenario emissions are expected to peak around 2080 then decline (IPCC 2014). Climate change projections for 2040 and 2090 within the study area indicate:

- Average air temperatures are expected to increase across the catchment by 1 °C by 2040 and 2.5 °C by 2090;
- Annual precipitation in the area with river flows into the Ruamahanga Groundwater Management Zone (hereafter referred to GWZ) is expected to decrease by 2040 and 2090;
- Seasonal distribution of the precipitation is expected to change by 2090 but remain the same as the present period for 2040.

Simulated daily river flow time series are provided by using a Topnet model developed for the Upper Ruamahanga catchment (defined as the surface water Ruamahanga catchment except the Groundwater management zone- See Yang and Zammit, 2016), which is calibrated at nine flow recorder locations. The main changes in modelled flow between the present (i.e., 1985-2005), and future (2040 and 2090) climate are:

- mean flows are expected to decrease across the catchment, with the decrease in mean flows being larger by the end of the century than mid-century;
- changes in extreme hydrological characteristics are variable although high flows predominantly increase while low and mean flows predominantly decrease.
- changes in high flow frequency (characterised by changes in Fre3, the frequency of floods greater than three times the median flow) indicate that the occurrence of these high flows is expected to increase by mid-century with a larger increase by the end of the century;

- changes in low flows (characterised by changes in 7-day Mean Annual Low Flow or 7dMALF) indicate that a large change in low flows is expected by 2040 (average reduction up to 10%) with a larger change in low flow by 2090 (average reduction up to 21%). As a result further constraints on ecological flows are expected under climate change, resulting in potential additional constraints on water resources to maintain ecological and agricultural activities;
- notable changes in monthly mean flows include:
  - increased discharge in autumn by 2040, but decreased discharge in autumn by 2090;
  - decrease of mean monthly discharge for both 2040 and 2090, for winter, spring and summer, with the largest percentage decrease expected by 2090 in spring;
- changes in flow deciles indicate that flow thresholds are expected to decrease across all time slices and for all the catchments with larger decrease (up to 20%) by the end of the century.

A more robust assessment of the magnitude and uncertainty of expected changes could be gained by use of additional Regional Climate Models (RCMs) for a wider range of RCPs.

1 Background

Anthropogenic climate change has been identified as one of the defining societal challenges of the 21st century and the most significant environmental threat that global communities face (IPCC 2014). An important component of this threat is the impact a changing climate has already had, and will likely continue to have, on water resources and associated activities. For the Ruamahanga catchment, critical aspects include agricultural drought and the ability to meet changing water resource demands through supplemental irrigation. Crop productivity is liable to change and crop tolerances shift, as are crop management practices and irrigation demand.

Under climate change scenarios, temperatures have increased by about 1 °C over the past century (Mullan et al. 2010) and are projected to increase further (Ministry for the Environment (MfE) 2016). Precipitation spatial patterns, timings and magnitudes are projected to change too. According to earlier research, such climatic shifts would translate to shifts in agricultural drought (Clark et al. 2011) and river-based water supply (Collins et al. 2012). Droughts are expected to become more frequent or more severe along the eastern portions of New Zealand, implying an increase in water demand; changes in river flow are more complicated and depend on the season and the location of the river's headwaters.

Global Climate Models (GCMs) used to simulate future climate change projections are driven by natural climate forcing such as solar irradiance, and now increasingly by anthropogenic forcing which includes greenhouse gases and aerosols. As part of the assessment of IPCC AR5 report (IPCC 2014) for New Zealand, NIWA assessed 41 GCMs that form the NIWA AR5 model archive. Information regarding the validation and assessment of those GCMS for use in New Zealand can be found in MfE (2016).

Validation of those GCMs was carried out through comparison with large scale climatic and circulation characteristics across 52 metrics (MfE, 2016). This analysis provided a 23-member GCM ensemble that is used by NIWA to drive climate change impact assessments across New Zealand. Among this subset six GCMs were selected to provide the likely range of IPCC projections across all Representative Concentration Pathways (RCPs; alternative scenarios of radiative forcing). These six GCMs were selected for dynamical downscaling; that is, sea surface temperatures from the six models are used to drive an atmospheric global model, which in turn drives a higher resolution Regional Climate Model (RCM) over New Zealand. The output data fields are further downscaled to an approximate 5 km grid and bias-corrected relative to a 1980-1999 climatology (Sood, 2015).

The NIWA dynamical procedure involves a free running atmospheric global climate model (AGCM) (i.e., not constrained by observations), in this case HadAM3P (Anagnostopoulou et al. 2008), forced by Sea Surface Temperatures (SST) and sea ice fields from the CMIP5 models (Ackerley et al. 2012). Due to the nature of the historical climate runs for each GCM, year-to-year variability in a model does not correspond with observed variability. Further details on the validation of the six RCMs can be found in Sood (2015) and MfE (2016).

This technical report details the results associated with the projected impacts of climate change on river flows and related hydrological characteristics in the area from which rivers flow into the Ruamahanga Groundwater Management Zone. We refer to this area upstream of the GWZ as the Upper Ruamahanga catchment. Those hydrological time series, which have been supplied to Greater Wellington Regional Council (GWRC), will be used in combination with climate change fields as inflows to the hydrological model developed for the Ruamahanga Groundwater Management Zone.

This information will be used to quantify the potential climate change effects on surface and groundwater availability for the Upper Ruamahanga catchment, on water supply reliability to irrigated pastoral farms and on nutrient leaching and sediment transport.

2 Scope

As part of the Ruamahanga Whaitua Collaborative Modelling Process (Ruamahanga CMP), NIWA's national hydrologic model TopNet was set up in the Upper Ruamahanga catchment and was calibrated at nine flow stations (Table 2-1 and Figure 2-1). Details of the model set up, calibration and validation can be found in Zammit et al. (2016). The TopNet hydrological model was combined with a Modflow model (developed by GNS within the GWZ as part of the CMP) to form the hydrological model for the Ruamahanga catchment. This model is used as part of the Ruamahanga Cumulative Hydrological Estimator Simulation tool (CHES, Diettrich et al. 2016) developed to investigate the effect of water consenting activities on hydrological regimes within the catchment.

TopNet provides time series of daily discharge to the 310 river reaches discharging to the GWZ. Following discussion with the Ruamahanga CMP, NIWA was requested to estimate the potential impact of climate change on inflows to the GWZ. For the sake of clarity in this report, we will report on the potential impact of climate change on surface water discharge to the GWZ only at the locations where the TopNet model was calibrated in the Upper Ruamahanga catchment (Table 2-1). Due to the large number of reporting catchments where potential climate change impacts are to be reported, the nine catchments are spatially clustered in three geographic groups:

- west: catchments located on the Western side of the GWZ (Tauherenikau, Waiohine and Waingawa catchments);
- north: catchments located on the Northern side of the GWZ (Waipoua, Ruamahanga above Mt Bruce, Kopuaranga, and Whangaehu catchments);
- east- catchments located on the Eastern side of the GWZ (Taueru and Huangarua catchments).

Table 2-1: Physiographic information for the nine calibrated catchments within the Upper Ruamahanga catchment.

Catchment	Site	Tideda ID	REC2 reach ID	Area [km^2]	Class	Elevation range [m]
Tauherenikau above Gorge	Tauherenikau at Gorge	29251	9259046	114.21	West	120-1472
Waiohine above Gorge	Waiohine at Gorge(new site)	29224	9257741	177.89	West	126-1437
Waingawa above Upper Kaituna	Waingawa at Upper Kaituna	29246	9254309	76.50	West	236-1456
Waipoua above Mikimiki	Waipoua at Mikimiki	29257	9253108	79.84	North	199-1013
Ruamahanga above Mt Bruce	Ruamahanga at Mt Bruce	29254	9250417	78.70	North	300-1426
Kopuaranga above Palmers Br	Kopuaranga at Palmers Br	29230	9252319	100.63	North	190-570
Whangaehu above Waihi	Whangaehu at Waihi	29244	9252727	36.80	North	180-440
Taueru above Te Weraiti	Taueru at Te Weraiti	29231	9257216	391.19	East	95-526
Huangarua above Hautotara	Huangarua at Hautotara	29222	9265072	139.23	East	72-950

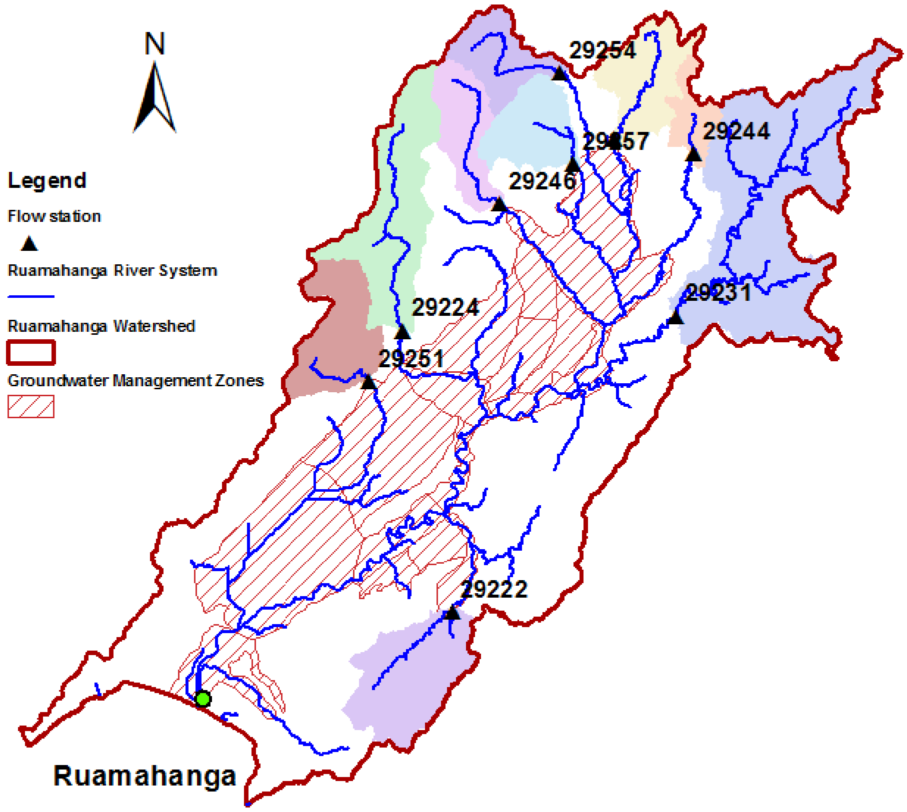

Figure 2-1: Location of the nine calibrated sub-catchments and associated flow station sites (represented by their Tideda ID) for model calibration in the Ruamahanga catchment.

The assessment of the potential impact of climate change is to be based on hydrological simulations driven by the GDFL-CM3 (https://www.gfdl.noaa.gov/coupled-physical-model-cm3/) General Circulation Model (GCM) under an assumption of Representative Concentration Pathway RCP6.0. The GDFL-CM3 model is one of the six models used by NIWA to drive national scale dynamically downscaled ensemble climate projections for New Zealand (MfE 2016). As per IPCC AR5 recommendations (IPCC 2014), potential impacts of climate change on water availability in-stream is reported as changes in hydrological characteristics for two time slices (referred to as 2040 (2031-2050) and 2090 (2081-2100)), compared to the present (1995) time slice (1986-2005). The reported hydrological characteristics are:

- changes in partitioning of the water balance between rain, evaporation and flow with time;
- changes in cumulative flows to indicate if changes are proportional with time;
- changes in mean annual flows to represent change in potential water availability;
- Fre3 flows and 7-day Mean Annual Low Flow for changes at the extremes;
- monthly average discharge to represent changes in the seasonal patterns of discharge;
- flow deciles to represent changes in the overall distribution of discharge.

The aim of this project is to generate projected discharge time series and report on the changes in the listed hydrological characteristics. It is not to explain those changes.

3 Results

The results are organised in two sections:

- Changes in precipitation over the period of interest, as a driver to the changes in the hydrological characteristics;
- Changes in hydrological characteristics.

3.1 Change in precipitation

The changes in precipitation for 2040 and 2090 are reported as follows:

- changes in cumulative precipitation (Figure 3-1). This represents the change in total volume of precipitation received upstream of each gauging station as well as changes to extreme precipitation events (represented by abrupt change - sharp increase for high precipitation event or flat line for extended period with low precipitation - in the cumulative volume);
- change in monthly average precipitation (Figure 3-2). This represents changes in the seasonal patterns of the precipitation which could be one of the contributing factors to potential changes in hydrological characteristics.

Further analysis of these changes at national and regional scales are provided in MfE (2016).

Analysis of the cumulative precipitation indicates that:

- an extended period of low precipitation is present during the present time slice in 1998 (represented by a period of relative low increase of the cumulative precipitation starting at day 4687. However events of a similar nature do not seem to be present in the future time slices;
- there are differences in behaviour of the precipitation within the 2040 and 2090 time slices. The 2090 time slice is consistently lower in volume of precipitation received by the Upper Ruamahanga catchment, as shown by a gradual divergence of the cumulative precipitation line. The 2040 time slice is characterised by much smaller divergence until around 2/3 of the time slice with a marked difference in the diverging rate in the later years of the time slice.

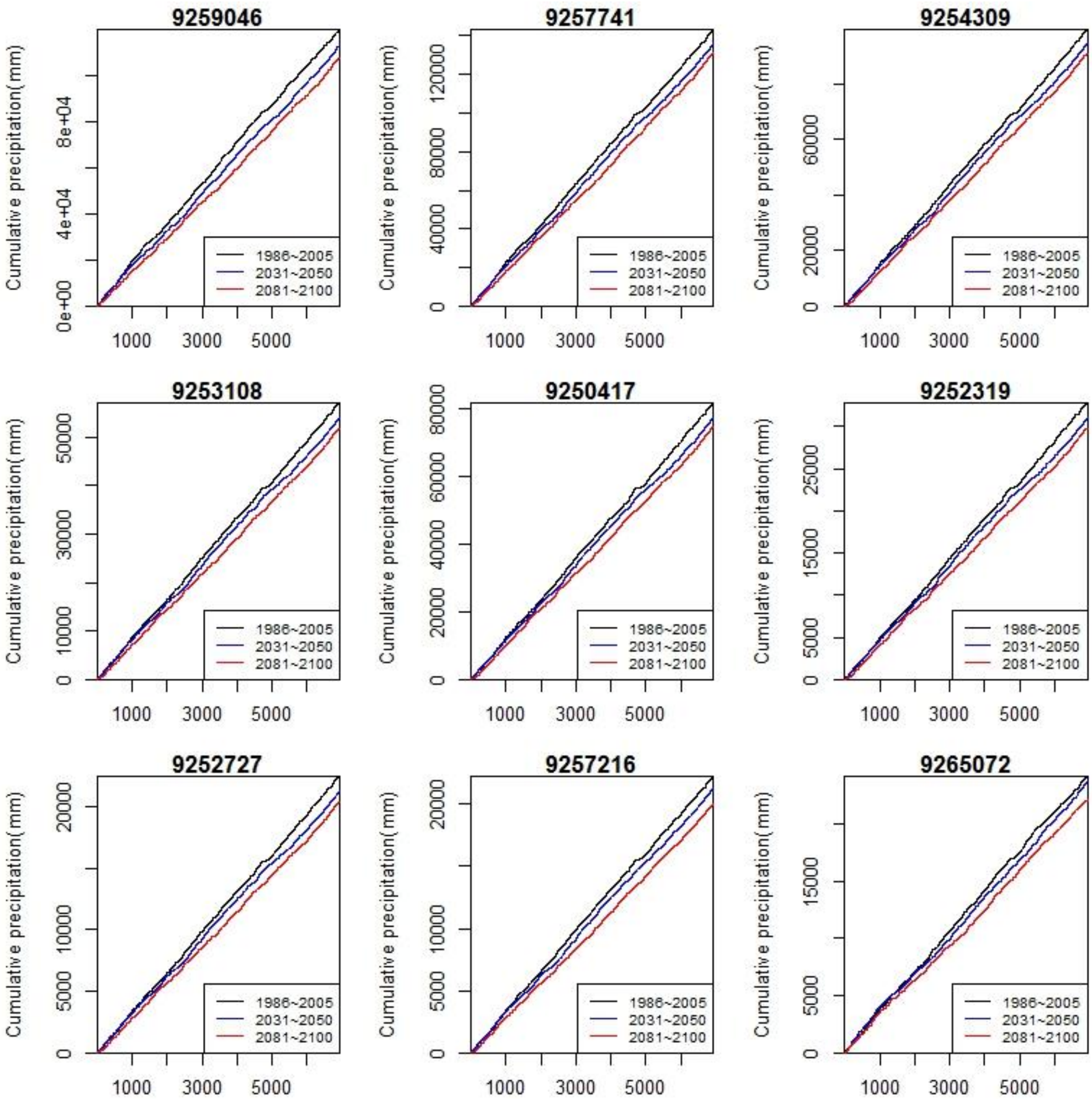

Figure 3-1: Change in total precipitation (mm) in the Upper Ruamahanga. Changes are presented for the catchment upstream of each gauging station (identified by the ID of the reach in the digital river network where the station is located). Black lines represent the cumulative precipitation over the present period, blue dotted lines represent the cumulative precipitation for 2040, and red dotted lines the cumulative precipitation for 2090. Time axis represents number of day since the start of the time slice.

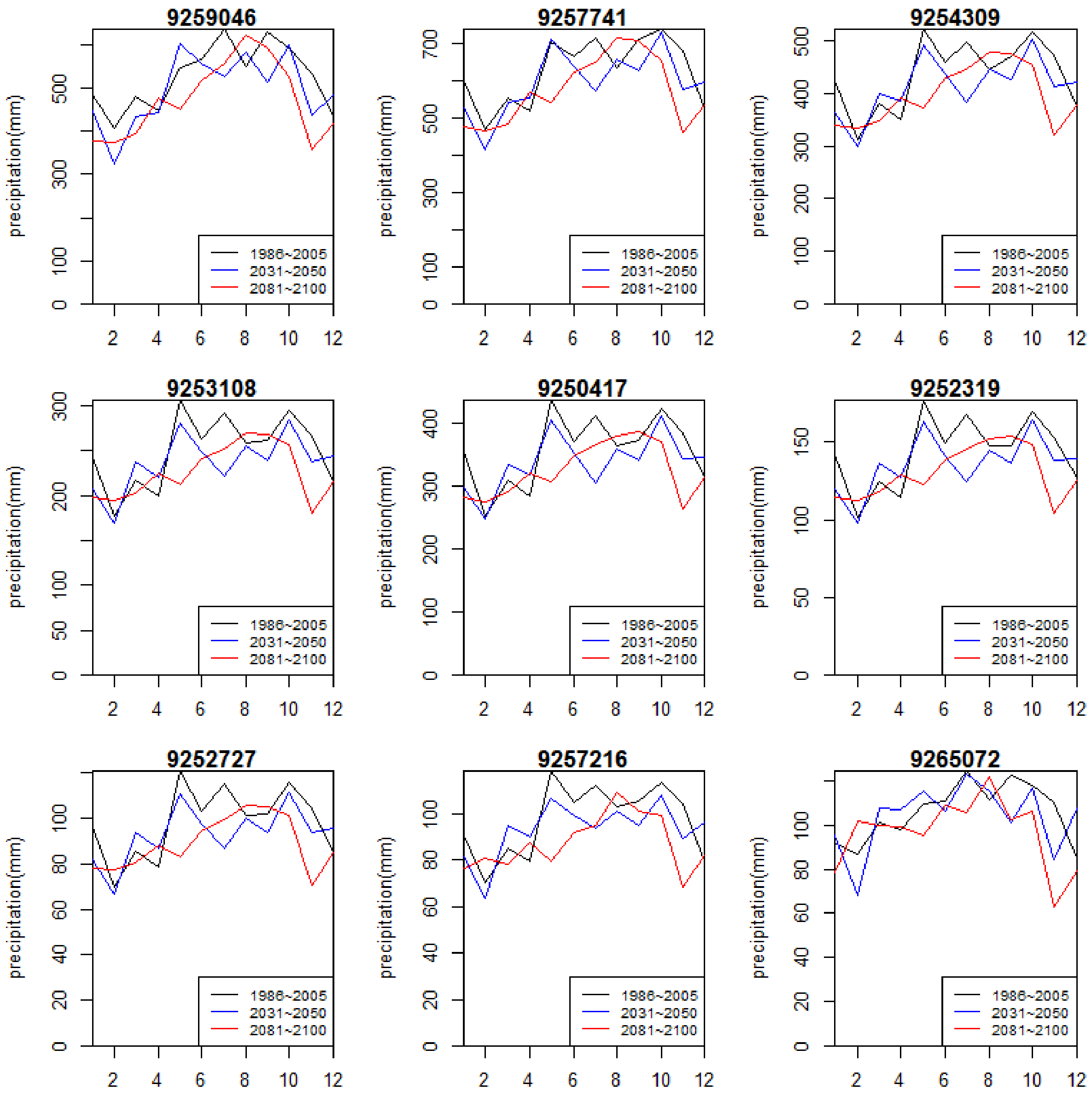

Figure 3-2: Change in monthly average precipitation for the Upper Ruamahanga catchment. Changes are presented for the catchment upstream of each gauging station (identified by the ID of the reach in the digital river network where the station is location). Black lines represent the monthly average precipitation over the present, blue dotted lines represent the monthly average precipitation for 2040, and red dotted lines the monthly average precipitation over 2090.

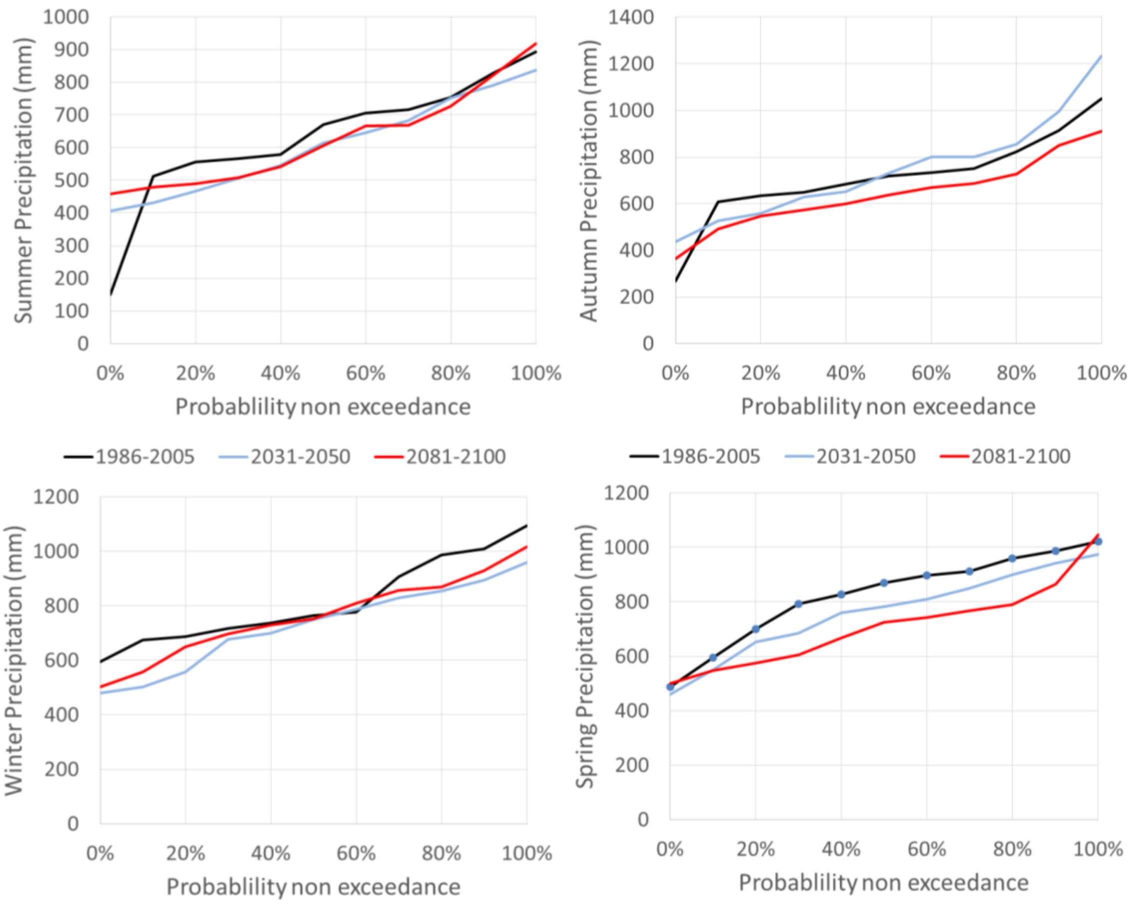

Figure 3-3: Seasonal precipitation distribution for the Waipoua catchment. Changes are presented for the catchment upstream of each gauging station (identified by the ID of the reach in the digital river network where the station is location). Black lines represent the seasonal total precipitation distribution over the present, blue dotted lines represent the seasonal total precipitation distribution for 2040, and red dotted lines the seasonal total precipitation distribution over 2090.

Analysis of the changes in the seasonality of the precipitation indicates that:

- seasonality of the 2040 precipitation is similar to the present;
- there is a consistent marked change in the seasonality of precipitation by 2090 as illustrated in Figure 3-3. In particular autumn and spring precipitation is are reduced by 2090.

3.2 Changes in long-term average hydrological characteristics

Potential climate change impacts on long-term average hydrological characteristics are represented using:

- runoff coefficient (runoff/rain) to represent the impact of changes in precipitation and temperature on the resulting flow;
- changes in cumulative discharge to represent changes in total volume of streamflow across the period of interest, as well as changes in seasonal weather patterns;

- changes in mean flows to represent changes in annual average discharge available for use.

3.2.1 Runoff coefficient

Table 3-1 presents the annual average precipitation (mm/year), runoff (discharge per unit of area) and runoff coefficient (annual average runoff/annual average precipitation) across three reporting periods. Changes in the water balance are expressed as changes in runoff coefficient to quantify the potential change in hydrological processes (i.e., precipitation, evaporation and discharge). Note that annual average evaporation is not provided, but is easily calculated as the difference between average annual precipitation and average annual runoff.

Analysis of the changes in water balance indicates that:

- the runoff coefficient simulated for 1986-2005 is higher than the one estimated during the calibration process (Zammit and Yang, 2016). This is due to the fact that the GDFL driven historical simulation is a “free run” simulation representing a potential version of the past, not the one observed (simulated using VCSN driven climate fields);
- changes in precipitation for the western and northern catchments are reflected in changes in runoff, as the runoff coefficients remain stable within each time slice;
- changes in precipitation in the eastern catchment results in a small change in the runoff coefficient.

Table 3-1: Annual average precipitation (mm/year), runoff (mm/year) for the present and runoff coefficient (C [%]) for the present, 2040 and 2090 time slices. The reporting locations are identified by the streamflow gauging station's stream reach ID.

Reach	Catchment	Class	Present (1986~2005) Rain [mm/year]	Present (1986~2005) Runoff [mm/year]	Present (1986~2005) C [%]	2040 (2031~2050) Rain [mm/year]	2040 (2031~2050) Runoff [mm/year]	2040 (2031~2050) C [%]	2090 (2081~2100) Rain [mm/year]	2090 (2081~2100) Runoff [mm/year]	2090 (2081~2100) C [%]
9259046	Tauherenikau above Gorge	West	6306	5671	90	5954	5336	90	5670	5061	89
9257741	Waiohine above Gorge	West	7523	7466	99	7154	7085	99	6891	6807	99
9254309	Waingawa above Upper Kaituna	West	5223	5089	97	4971	4851	98	4771	4665	98
9253108	Waipoua above Mikimiki	North	2997	1986	66	2848	1868	66	2719	1758	65
9250417	Ruamahanga above Mt Bruce	North	4282	4172	97	4068	3972	98	3910	3828	98
9252319	Kopuaranga above Palmers Br	North	1721	1251	73	1632	1170	72	1565	1102	70
9252727	Whangaehu above Waihi	North	1177	638	54	1118	590	53	1068	553	52
9257216	Taueru above Te Weraiti	East	1166	669	57	1120	632	56	1051	582	55
9265072	Huangarua above Hautotara	East	1268	815	64	1246	801	64	1161	727	63

3.2.2 Cumulative discharge

Changes in cumulative discharge (Figure 3-4) aim to represent the change in total discharge volume at each of the gauging stations, as well as changes to the hydrological regime due to changes in extreme precipitation events (a sharp increase in the cumulative volume for high discharge events or a flat line for an extended period with low discharge). Figure 3-5 presents the changes in cumulative discharge for the Waipoua catchment as a representative catchment.

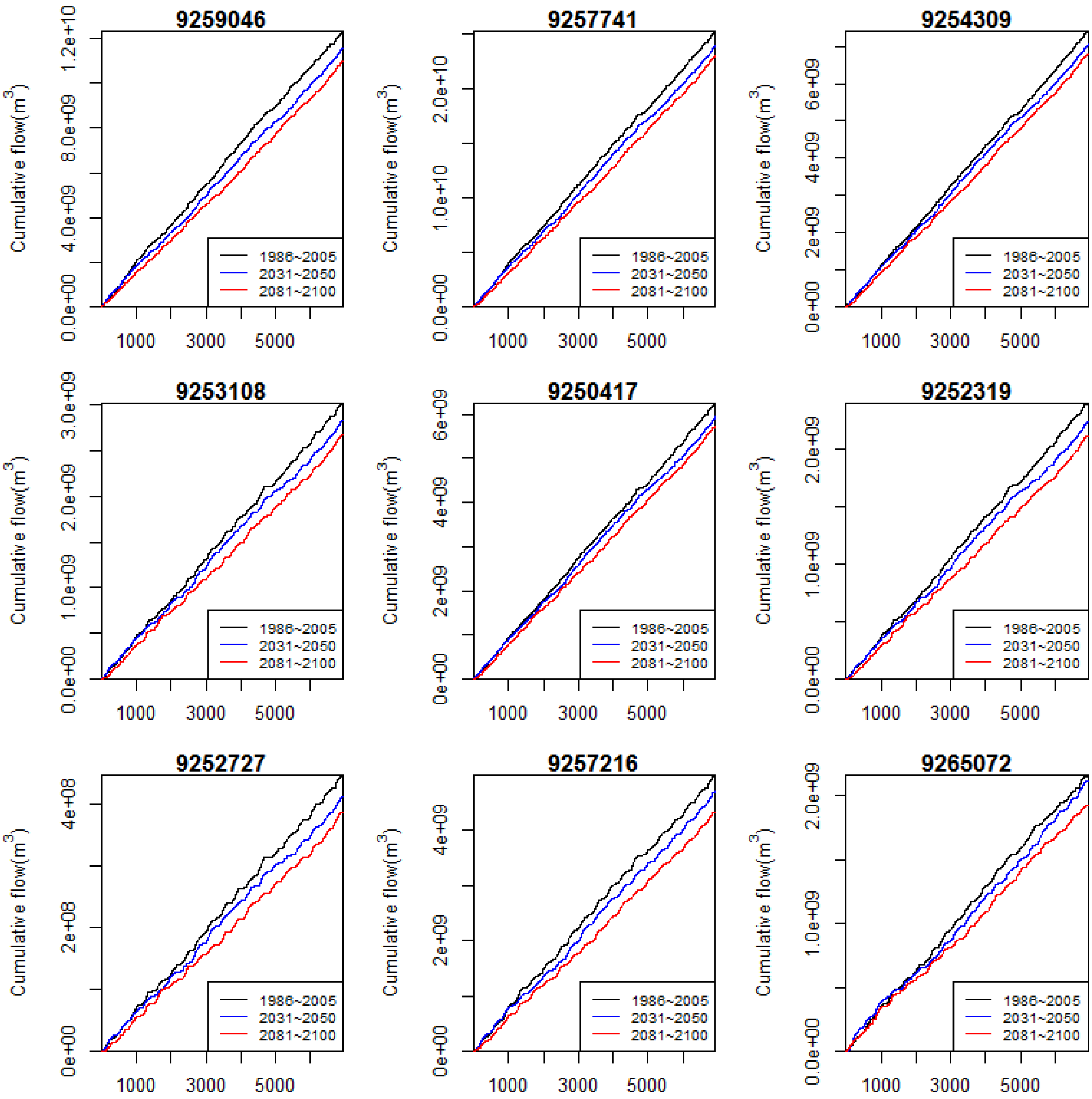

Figure 3-4: Predicted changes in cumulative discharge (m^3) in the Upper Ruamahanga catchment. Changes are presented for the catchment upstream of each gauging station (identified by the ID of the reach in the digital river network where the station is location). Black lines, cumulative precipitation over 1986-2005, blue dotted lines, cumulative precipitation over 2031-2050, red dotted lines, cumulative precipitation over 2081-2100. Time axis represents number of days since the start of the time slice.

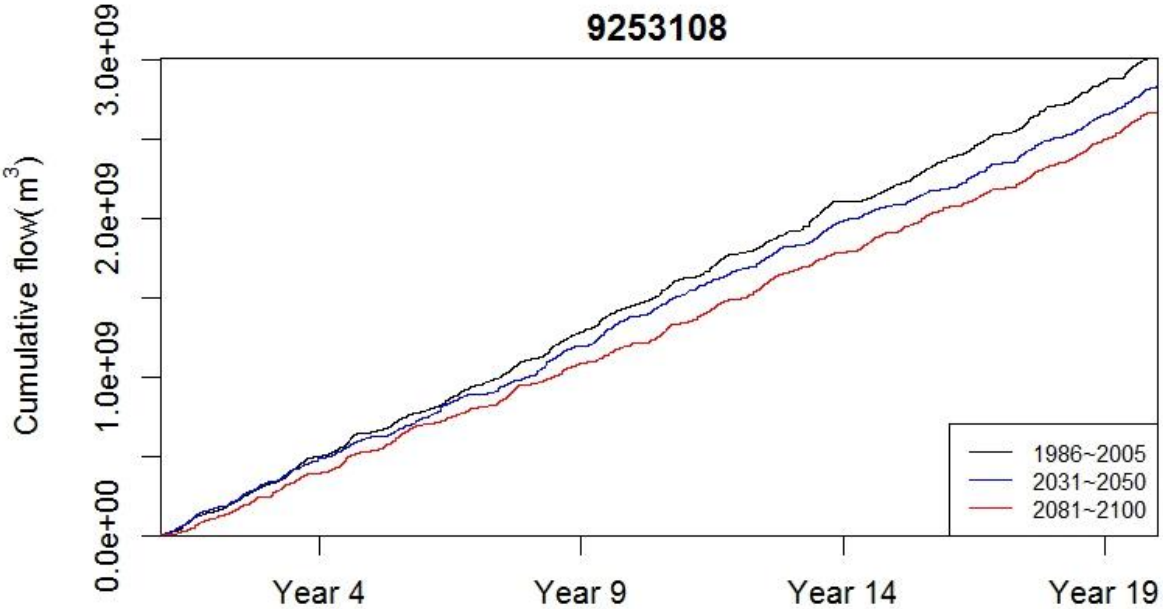

Figure 3-5: Predicted changes in cumulative discharge (m^3) in the Waipoua catchment. Changes are presented for the catchment upstream of the gauging station (identified by the ID of the reach in the digital river network where the station is located). Black lines, cumulative precipitation over 1986-2005, blue dotted lines, cumulative precipitation over 2031-2050, red dotted lines, cumulative precipitation over 2081-2100. Time axis represents number of days since the start of the time slice.

Analysis of the changes in cumulative discharge reflect changes in cumulative precipitation:

- an extended period of low discharge (corresponding to low precipitation) can be seen during the present time slice in 1998 (represented by a period of relative low increase of the cumulative discharge in year 14 on Figure 3-5). Low flow events are present in the 2040 and 2090 time slices (e.g., year 13 of the 2040 time slice and years 11-12 and 13 of the 2090 time slice). However, future low flow events are predicted to be briefer than the 1998 event;
- discharge behaviour differs within future time slices. Discharges in the Upper R seem consistently lower in the 2090 slice, whereas in the 2040 slice, they are mostly similar, except for marked differences in the latter years.

3.2.3 Mean flow

Changes in mean flows (Table 3-2) are a measure of changes to the average hydrological behaviour of the catchment. Table 3-2 presents the mean annual discharge (m^3/s), and the change as a percentage of the simulated mean flow for the present time.

Table 3-2: Simulated mean annual flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean annual flow are percentages of present (1986-2005) mean annual flows. There is an entry for each streamflow gauging station.

			Mean Annual flows [m^3/s]			Change relative to the present [%]	
Reach ID	**Catchment**	**Class**	**1986-2005**	**2031-2050**	**2081-2100**	**2031-2050**	**2081-2100**
9259046	Tauherenikau above Gorge	West	20.5	19.3	18.3	-5.9	-10.8
9257741	Waiohine above Gorge	West	42.1	39.9	38.4	-5.1	-8.8
9254309	Waingawa above Upper Kaituna	West	12.3	11.7	11.3	-4.7	-8.3
9253108	Waipoua above Mikimiki	North	5.0	4.7	4.4	-6.0	-11.5
9250417	Ruamahanga above Mt Bruce	North	10.4	9.9	9.5	-4.8	-8.3
9252319	Kopuaranga above Palmers Br	North	3.9	3.7	3.5	-6.5	-11.9
9252727	Whangaehu above Waihi	North	0.7	0.6	0.6	-7.6	-13.3
9257216	Taueru above Te Weraiti	East	8.3	7.8	7.2	-5.7	-13.1
9265072	Huangarua above Hautotara	East	3.6	3.5	3.2	-1.8	-10.8

Analysis of the changes in mean annual flows indicates:

- 2040 mean flows across the upstream Ruamahanga catchment are projected to be slightly smaller than at present (average decrease of 5.3%), with a decrease of 10.8% expected by 2090;
- percentage changes in mean flows are similar across sub-catchments for two future time slices, except in Huangarua above Hautotara at 2040, which is -1.8%.

3.3 Changes in hydrological extremes

Changes in hydrological regimes are usually characterised by changes in the extreme and changes in the average hydrological characteristics. This section presents the potential change on extreme hydrological characteristics of climate change for the Upper Ruamahanga catchment.

3.3.1 Fre3

Fre3 is defined here as number of days of a year with flows above three times the median flow. This is represents the occurrence of flushing events which control periphyton biomass. As a result, changes in Fre3 show potential changes in the high flow characteristics within each time period. Analysis of Fre3 (Table 3-3) indicates that:

- changes in Fre3 differ between sub-catchments and time slices;
- by 2040, changes in Fre3 are expected to be small [-4%, 4%], but greater than 10% at Waingawa, Taueru and Huangarua at Hautotara;
- by 2040 and for seven of the nine reporting locations, changes in Fre3 are expected to be positive;
- changes in Fre3 are expected to be large (between 10-20%) and positive by 2090 except at two locations (Waiohine and Taueru), indicating large increases in extreme precipitation by the end of century;

- by 2090, only one catchment (Taueru) is expected to experience a decrease in Fre3.

Table 3-3: Fre3 (number days per year) for the present, 2040 and 2090 time slices. Changes in Fre3 are expressed as changes compared to the present (1986-2005). The reporting location are identified by stream reach ID where the streamflow gauging station is located.

			Fre3 (days/year with flow >3 times median flow)			% change	
Reach ID	**Catchment**	**Class**	**1986-2005**	**2031-2050**	**2081-2100**	**2031-2050**	**2081-2100**
9259046	Tauherenikau above Gorge	West	38.7	40.9	42.7	5.9%	10.5%
9257741	Waiohine above Gorge	West	65.5	68.2	70.9	4.2%	8.3%
9254309	Waingawa above Upper Kaituna	West	32.9	36.6	38.9	11.0%	18.1%
9253108	Waipoua above Mikimiki	North	49.2	50.3	55.3	2.2%	12.4%
9250417	Ruamahanga above Mt Bruce	North	43.6	45.4	48.2	4.0%	10.4%
9252319	Kopuaranga above Palmers Br	North	24.9	26.1	29.9	4.4%	20.0%
9252727	Whangaehu above Waihi	North	53.1	50.9	63.1	-4.0%	18.9%
9257216	Taueru above Te Weraiti	East	18.0	12.9	16.5	-28.1%	-8.2%
9265072	Huangarua above Hautotara	East	46.2	52.6	53.6	14.0%	16.1%

3.3.2 7-day Mean Annual Low Flow

The 7-day Mean Annual Low Flow (7dMALF) is a low flow statistic calculated by taking the average of the lowest 7-day mean flow period in each year of record. Table 3-4 presents 7dMALF (m^3/s), and the associated change (%) compared to the simulated present (1995) 7dMALF. Analysis of the changes in 7dMALF indicates that:

- 7dMALF is projected to decrease by 2040 for all catchments except Huangarua (5.1%). By 2090, 7dMALF is expected to decrease significantly for all catchments by -10.0% to -38.4%];
- Changes in 7dMALF are larger by 2090 than 2040. This indicates a greater demand for water resources and increased stress on the river's ecological communities during summer months by the end of the century.

Table 3-4: 7-day mean annual low flow (7dMALF) (m^3/s) for the present (1995), 2040 and 2090 time slices. Changes in 7dMALF are percentages of simulated 1995 7dMALF. The reporting locations are identified by stream reach ID where the streamflow gauging station is located.

			7dMALF [m^3/s]			% change [%]	
Reach ID	Catchment	Class	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
9259046	Tauherenikau above Gorge	West	3.56	3.00	2.81	-15.8	-21.2
9257741	Waiohine above Gorge	West	8.34	7.47	7.24	-10.5	-13.2
9254309	Waingawa above Upper Kaituna	West	2.71	2.37	2.24	-12.6	-17.3
9253108	Ruamahanga above Mt Bruce	North	0.45	0.40	0.35	-10.9	-23.2
9250417	Waipoua above Mikimiki	North	1.89	1.63	1.55	-13.4	-17.8
9252319	Kopuaranga above Palmers Br	North	0.48	0.37	0.30	-22.1	-38.4
9252727	Whangaehu above Waihi	North	0.05	0.05	0.04	-1.9	-29.2
9257216	Taueru above Te Weraiti	East	2.10	1.93	1.76	-8.0	-16.4
9265072	Huangarua above Hautotara	East	0.36	0.38	0.33	5.1	-10.0
Average						-10.0	-20.7

3.4 Seasonal flows - mean monthly flows

The mean monthly flows illustrate seasonal variation. Changes in mean monthly flows usually indicate a shift in hydrological regime, which could affect water availability. The changes in seasonal flow characteristics are reported using the spatial clustering described in Section 1.1.

3.4.1 Western catchments

Tables 3-5 to Table 3-7 present the expected changes in mean monthly flows for Tauherenikau, Waiohine and Waingawa catchments. Analysis of the changes in seasonal flows for the western catchment cluster indicate that:

- changes in seasonal flows vary widely between months reflecting the change in the seasonal precipitation. The variability is due to the relatively short length of record (20 years), within which large flow events markedly change the mean monthly discharge;
- by 2040, large reductions of mean flows for spring and summer can be expected (except in December when a slight increase is expected for three reporting catchments);
- by 2040, changes in autumn and winter flows are more variable between catchments. Changes are expected to differ month to month, with a tendency to increase in autumn and slightly decrease in winter;
- by 2090, large reductions of mean flows are expected throughout the year, with the largest reductions experienced during spring and summer;
- by 2090, changes in autumn and winter flows are expected to be more variable between the catchments. Changes are expected to be variable month to month with a tendency to decrease in autumn and slightly increase in winter.

Table 3-5: Tauherenikau mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flows are expressed as change compared to the 1995 simulated flows. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	**1986-2005**	**2031-2050**	**2081-2100**	**2031-2050**	**2081-2100**
January	16.95	15.20	12.48	-10.3%	-26.4%
February	15.64	12.15	14.19	-22.3%	-9.3%
March	17.26	16.16	14.70	-6.4%	-14.8%
April	17.87	17.94	18.98	0.4%	6.2%
May	21.65	23.24	17.55	7.3%	-18.9%
June	21.35	22.39	21.17	4.9%	-0.9%
July	23.21	20.28	21.40	-12.6%	-7.8%
August	21.79	23.89	25.31	9.6%	16.2%
September	27.38	23.17	25.86	-15.4%	-5.6%
October	26.00	22.88	20.64	-12.0%	-20.6%
November	20.98	17.33	13.40	-17.4%	-36.1%
December	16.10	16.74	14.06	4.0%	-12.7%

Table 3-6: Waiohine mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flows are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	**1986-2005**	**2031-2050**	**2081-2100**	**2031-2050**	**2081-2100**
January	39.10	34.49	30.07	-11.8%	-23.1%
February	33.52	28.61	32.23	-14.7%	-3.9%
March	35.35	35.05	31.32	-0.8%	-11.4%
April	34.41	38.13	37.49	10.8%	9.0%
May	44.73	44.56	35.11	-0.4%	-21.5%
June	40.09	40.66	40.28	1.4%	0.5%
July	39.99	34.62	41.50	-13.4%	3.8%
August	40.01	43.37	46.73	8.4%	16.8%
September	54.96	48.33	52.00	-12.1%	-5.4%
October	55.77	49.76	45.11	-10.8%	-19.1%
November	49.58	42.10	33.56	-15.1%	-32.3%
December	37.49	39.20	35.15	4.6%	-6.2%

Table 3-7: Waingawa mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flows are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
January	11.78	10.35	9.40	-12.2%	-20.2%
February	9.73	9.06	10.20	-6.9%	4.8%
March	10.44	11.23	10.03	7.5%	-4.0%
April	9.86	11.34	10.99	15.0%	11.4%
May	13.63	13.16	10.12	-3.5%	-25.7%
June	11.29	11.28	11.38	-0.1%	0.8%
July	11.25	9.68	11.94	-13.9%	6.1%
August	11.42	11.92	12.95	4.4%	13.4%
September	15.49	13.56	14.71	-12.4%	-5.0%
October	16.85	14.45	13.10	-14.2%	-22.3%
November	14.73	13.14	10.04	-10.8%	-31.8%
December	11.49	11.87	10.90	3.2%	-5.2%

3.4.2 Northern catchments

Tables 3-8 to 3-11 present the expected changes in mean monthly flows for Waipoua, Ruamahanga, Kopuaranga, and Whangaehu catchments. Analysis of these changes for the northern catchment cluster indicates that:

- changes in seasonal flows change appreciably from month to month reflecting the changes in the seasonal precipitation. The variability is due to the relatively short length of record (20 years), within which large flow events markedly change the mean monthly discharge;
- by 2040, a large reduction of mean flows for spring can be expected. Changes in summer flows are variable but tend to decrease throughout the season (mainly due to larger change in January);
- by 2040, changes in autumn and winter flows are expected to be more variable across the catchments. Changes are expected to be variable month to month with a tendency to increase in autumn and decrease in winter;
- by 2090, a large reduction of mean flows is expected throughout the year, with the largest reductions experienced during spring and summer;
- by 2090, changes in autumn and winter flows are expected to be more variable across the catchments. Changes are expected to be variable month to month with a tendency to decrease in autumn and winter;
- by 2090 changes on seasonal discharge in October do not align with changes in monthly precipitation. This is thought to be associated with changes in snow melt in the upper reaches of the catchments by the end of the century.

Table 3-8: Waipoua mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flows are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	**1986-2005**	**2031-2050**	**2081-2100**	**2031-2050**	**2081-2100**
January	2.65	2.40	1.98	-9.6%	-25.4%
February	2.23	2.00	2.82	-10.3%	26.5%
March	3.31	4.01	3.31	21.1%	0.0%
April	4.20	4.97	4.66	18.3%	10.9%
May	7.70	7.14	5.04	-7.2%	-34.5%
June	7.12	6.73	6.61	-5.5%	-7.1%
July	7.88	5.98	6.76	-24.1%	-14.2%
August	6.44	6.14	6.73	-4.6%	4.5%
September	6.10	5.36	6.20	-12.2%	1.7%
October	5.77	4.77	4.20	-17.3%	-27.2%
November	3.91	4.15	2.60	6.2%	-33.5%
December	2.83	2.93	2.40	3.5%	-15.3%

Table 3-9: Ruamahanga mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flow are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
January	9.96	8.73	7.98	-12.4%	-19.9%
February	8.06	7.69	8.62	-4.5%	7.1%
March	8.80	9.68	8.62	10.1%	-2.0%
April	8.33	9.70	9.30	16.5%	11.7%
May	12.00	11.29	8.66	-5.9%	-27.8%
June	9.77	9.65	9.80	-1.2%	0.4%
July	10.35	8.33	10.48	-19.5%	1.2%
August	10.09	10.23	10.93	1.4%	8.4%
September	12.63	10.97	12.14	-13.1%	-3.9%
October	13.44	11.80	10.68	-12.2%	-20.6%
November	11.78	10.93	8.21	-7.2%	-30.3%
December	9.57	9.81	9.16	2.5%	-4.2%

Table 3-10: Kopuaranga mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flows are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
January	2.28	1.98	1.64	-12.8%	-27.9%
February	2.11	1.78	2.16	-15.7%	2.3%
March	2.68	3.12	2.72	16.7%	1.6%
April	3.24	3.80	3.49	17.5%	7.7%
May	5.75	5.49	3.94	-4.5%	-31.5%
June	5.35	5.07	4.87	-5.1%	-8.8%
July	6.11	4.48	5.17	-26.7%	-15.5%
August	4.73	4.48	5.01	-5.2%	5.9%
September	4.72	4.26	4.94	-9.7%	4.7%
October	4.72	4.04	3.58	-14.4%	-24.1%
November	3.42	3.60	2.41	5.4%	-29.5%
December	2.68	2.56	2.20	-4.5%	-17.8%

Table 3-11: Whangaehu mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flows are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
January	0.22	0.22	0.15	-0.8%	-32.6%
February	0.21	0.16	0.27	-20.4%	30.2%
March	0.33	0.46	0.37	39.6%	11.3%
April	0.58	0.67	0.59	16.3%	1.6%
May	1.30	1.20	0.81	-8.1%	-37.7%
June	1.24	1.17	1.13	-5.8%	-9.1%
July	1.40	1.02	1.16	-27.0%	-16.8%
August	1.02	0.97	1.12	-4.7%	9.0%
September	0.92	0.83	0.97	-9.5%	5.7%
October	0.85	0.64	0.56	-24.4%	-33.8%
November	0.48	0.55	0.36	14.8%	-23.7%
December	0.35	0.33	0.24	-6.7%	-32.0%

3.4.3 Eastern catchments

Table 3-12 and Table 3-13 presents the expected changes in mean monthly flow for Taueru and Huangarua catchments. Analysis of the changes in seasonal flows for the eastern catchment cluster indicates that:

- Changes in seasonal flows exhibit large month to month variability reflecting changes in the seasonal precipitation (Figure 3-2) . The variability is due to comparison of the mean monthly discharge that is affected by large flow events and the relative short length of record (20 years);
- By 2040, a large reduction of mean flows for spring and increase for summer can be expected;
- By 2040, changes in autumn and winter flows are expected to be more variable across the catchments. Changes are expected to be variable month to month with a tendency to increase in autumn and slightly decrease in winter;
- By 2090, a large reduction of mean flows are expected throughout the year, with the largest reductions experienced during winter and summer;
- By 2090, changes in autumn and winter flows are expected to be more variable across the catchments. Changes are expected to be variable month to month with a tendency to decrease in autumn and winter;

Table 3-12: Taueru mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flows are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
January	3.83	4.09	3.40	6.8%	-11.0%
February	3.84	3.48	4.49	-9.4%	16.9%
March	4.55	5.36	4.82	17.9%	6.0%
April	5.62	7.35	6.09	30.8%	8.4%
May	11.35	11.04	7.65	-2.8%	-32.6%
June	14.01	12.37	10.45	-11.7%	-25.4%
July	14.46	12.60	12.01	-12.9%	-16.9%
August	11.83	10.81	12.15	-8.7%	2.7%
September	10.67	9.17	10.45	-14.0%	-2.0%
October	9.07	7.27	6.77	-19.8%	-25.3%
November	5.77	5.53	4.27	-4.2%	-26.0%
December	4.40	4.69	3.86	6.6%	-12.2%

Table 3-13: Huangarua mean monthly flows (m^3/s) for the present, 2040 and 2090 time slices. Changes in mean monthly flows are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Mean Monthly Flow [m^3/s]			% change [%]	
Month	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
January	1.62	2.16	1.24	32.9%	-23.4%
February	1.84	1.34	2.53	-27.3%	37.5%
March	2.57	2.99	2.81	16.3%	9.4%
April	3.54	3.88	3.55	9.7%	0.3%
May	4.80	4.96	3.89	3.4%	-19.0%
June	5.25	5.28	5.14	0.6%	-2.2%
July	6.03	5.93	4.92	-1.7%	-18.5%
August	4.80	4.98	5.40	3.8%	12.5%
September	4.73	3.65	3.85	-22.9%	-18.6%
October	3.75	2.90	2.74	-22.6%	-26.7%
November	2.41	1.96	1.16	-18.7%	-52.0%
December	1.73	2.20	1.25	27.4%	-27.6%

3.5 Flow deciles

Average water availability of a stream is characterised by the flow duration curve (FDC), which relates the percentage of time that flow in a stream is likely to equal or exceed a specific discharge of interest. In this report changes in FDC (between future and present conditions) will be summarised by changes in flow deciles. These will be reported based on the spatial clustering defined in Section 1.1. Changes in flow deciles are reported from 10 to 90% as changes for the lower and higher flow ranges are reported in section 3.4.

3.5.1 Western catchments

Tables 3-14 to Table 3-16 present the expected changes in flow deciles for Tauherenikau, Waiohine and Waingawa catchments. Analysis of the changes in decile flows for the western catchment cluster indicates that:

- Changes in flow deciles indicate consistent change throughout the time slices. On average discharges in the western catchments of the Upper Ruamahanga are expected to decrease;
- Changes in flow deciles are consistent across the two future time slices with 2090 to experience larger flow reductions than 2040;
- Changes in flow deciles are not consistent across the different deciles. Changes in the extreme decile (ie 10% and 90%) are generally different from changes in other deciles.

Table 3-14: Tauherenikau flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles flows are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

		Flow deciles [m^3/s]		% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	41.64	39.56	36.74	-5.0%	-11.8%
20%	26.51	24.72	23.74	-6.8%	-10.4%
30%	20.09	18.77	17.73	-6.6%	-11.8%
40%	16.02	14.88	13.95	-7.1%	-12.9%
50%	13.31	12.17	11.23	-8.6%	-15.6%
60%	10.97	10.15	9.14	-7.5%	-16.7%
70%	9.01	8.36	7.37	-7.2%	-18.2%
80%	7.30	6.60	5.82	-9.6%	-20.3%
90%	5.37	4.78	4.35	-11.0%	-19.1%

Table 3-15: Waiohine flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

		Flow deciles [m^3/s]		% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	99.81	93.64	91.85	-6.2%	-8.0%
20%	59.02	54.22	52.65	-8.1%	-10.8%
30%	39.44	36.70	33.98	-6.9%	-13.8%
40%	28.46	26.09	24.34	-8.3%	-14.5%

	Flow deciles [m³/s]			% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
50%	21.66	19.51	18.08	-9.9%	-16.5%
60%	17.08	15.52	14.41	-9.1%	-15.6%
70%	14.25	12.98	12.07	-8.9%	-15.3%
80%	11.83	10.99	10.40	-7.1%	-12.1%
90%	9.63	9.24	8.74	-4.1%	-9.3%

Table 3-16: Waingawa flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Flow deciles [m³/s]			% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	24.22	23.66	23.24	-2.3%	-4.0%
20%	16.72	15.64	15.17	-6.4%	-9.2%
30%	12.70	11.92	11.49	-6.1%	-9.5%
40%	10.22	9.49	9.20	-7.1%	-10.0%
50%	8.54	7.87	7.47	-7.8%	-12.6%
60%	7.26	6.56	6.24	-9.6%	-14.1%
70%	6.08	5.49	5.16	-9.6%	-15.1%
80%	4.95	4.52	4.21	-8.6%	-14.9%
90%	3.75	3.55	3.27	-5.6%	-12.8%

3.5.2 Northern catchment

Table 3-17 to Table 3-20 presents the expected changes in mean monthly flow for Waipoua, Ruamahanga, Kopuaranga, and Whangaehu catchments. Analysis of the changes in seasonal flows for the northern catchment cluster indicates that:

- changes in flow deciles are consistently negative between the time slices (except for the Waipoua where discharge for 90% exceedance is 3.1% at 2040).
- changes in flow deciles are consistent across the two future time slices with 2040 to experience larger flow reductions than during mid-century (except for the Waipoua for the 90% exceedance during 2040);
- changes in flow deciles are not consistent across the different deciles. Changes in the extreme decile (i.e. 10% and 90%) are generally different from changes in other deciles.

Table 3-17: Waipoua flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

		Flow deciles [m^3/s]		% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	10.91	10.17	9.76	-6.7%	-10.5%
20%	7.04	6.53	6.15	-7.2%	-12.6%
30%	5.10	4.70	4.44	-7.7%	-12.8%
40%	3.90	3.61	3.30	-7.4%	-15.4%
50%	3.02	2.80	2.52	-7.3%	-16.5%
60%	2.31	2.16	1.90	-6.4%	-17.4%
70%	1.73	1.61	1.39	-6.9%	-19.9%
80%	1.18	1.09	0.94	-8.0%	-20.5%
90%	0.65	0.67	0.56	3.1%	-13.2%

Table 3-18: Ruamahanga flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

		Flow deciles [m^3/s]		% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	21.81	21.03	20.74	-3.6%	-4.9%
20%	14.05	13.34	12.78	-5.0%	-9.0%
30%	10.26	9.65	9.23	-5.9%	-10.0%
40%	8.09	7.43	7.15	-8.1%	-11.7%
50%	6.53	6.02	5.78	-7.9%	-11.5%
60%	5.49	4.91	4.70	-10.5%	-14.5%
70%	4.53	4.04	3.83	-10.8%	-15.6%
80%	3.66	3.28	3.08	-10.4%	-15.8%
90%	2.68	2.53	2.35	-5.5%	-12.2%

Table 3-19: Kopuaranga flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

		Flow deciles [m^3/s]		% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	7.86	7.38	7.24	-6.1%	-7.8%
20%	5.68	5.32	5.12	-6.3%	-10.0%
30%	4.52	4.20	3.99	-7.1%	-11.6%
40%	3.72	3.40	3.22	-8.5%	-13.3%

	Flow deciles [m^3/s]			% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
50%	3.06	2.81	2.62	-8.3%	-14.5%
60%	2.49	2.31	2.06	-7.4%	-17.4%
70%	1.94	1.82	1.59	-6.0%	-18.1%
80%	1.41	1.29	1.10	-8.4%	-22.2%
90%	0.77	0.76	0.63	-0.6%	-18.5%

Table 3-20: Whangaehu flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Flow deciles [m^3/s]			% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	1.64	1.52	1.52	-7.0%	-7.4%
20%	1.05	1.00	0.95	-5.5%	-9.8%
30%	0.77	0.72	0.68	-6.1%	-11.7%
40%	0.58	0.55	0.50	-5.3%	-14.0%
50%	0.44	0.41	0.35	-5.1%	-18.7%
60%	0.32	0.29	0.25	-7.0%	-22.6%
70%	0.21	0.19	0.16	-13.1%	-27.2%
80%	0.12	0.12	0.09	-7.1%	-25.3%
90%	0.07	0.07	0.05	-2.6%	-27.5%

3.5.3 Eastern catchments

Table 3-21 and Table 3-22 presents the expected changes in mean monthly flow for Taueru and Huangarua catchments. Analysis of the changes in seasonal flows for the eastern catchment cluster indicates that:

- changes in flow deciles indicates consistent negative change throughout the time slices (except for the Huangarua where discharge for 90% exceedance and above is increasing by 2040).
- changes in flow deciles are consistent across the two future time slices with 2040 to experience larger flow reductions than 2040 (except for the Huangarua for the 90% exceedance during 2040);
- changes in flow deciles are not consistent across the different deciles. Changes in the extreme decile (i.e. 10% and 90%) are generally different from changes in other deciles.

Table 3-21: Taueru flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Flow deciles [m^3/s]			% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	15.71	14.45	13.69	-8.0%	-12.9%
20%	12.21	11.68	10.59	-4.3%	-13.3%
30%	9.86	9.59	8.67	-2.8%	-12.0%
40%	8.05	7.89	7.12	-2.0%	-11.6%
50%	6.65	6.47	5.83	-2.6%	-12.4%
60%	5.48	5.23	4.67	-4.6%	-14.7%
70%	4.37	4.18	3.77	-4.3%	-13.7%
80%	3.44	3.29	3.05	-4.3%	-11.2%
90%	2.59	2.46	2.41	-4.8%	-6.9%

Table 3-22: Huangarua flow deciles (m^3/s) for the present, 2040 and 2090 time slices. Changes in flow deciles are expressed as change compared to the present. The reporting location are identified by stream reach ID where the streamflow gauging station is located.

	Flow deciles [m^3/s]			% change [%]	
Percentage	1986-2005	2031-2050	2081-2100	2031-2050	2081-2100
10%	7.77	7.46	6.75	-4.0%	-13.1%
20%	4.96	4.79	4.22	-3.5%	-15.0%
30%	3.63	3.45	3.04	-5.0%	-16.2%
40%	2.82	2.61	2.30	-7.4%	-18.2%
50%	2.20	2.01	1.75	-8.5%	-20.5%
60%	1.69	1.55	1.33	-8.4%	-21.2%
70%	1.24	1.16	0.99	-6.5%	-19.7%
80%	0.87	0.84	0.73	-3.6%	-15.9%
90%	0.56	0.58	0.50	3.9%	-10.4%

4 Conclusion

Potential climate change effects on river flows discharging to the Ruamahanga GWZ for two identified time slices (i.e., 2031-2050 (the 2040 climate scenario) and 2081–2100 (the 2090 climate scenario)) have been generated using a single dynamical downscaled GCM, as used in the recent IPPC AR5 report. This is a ‘business as usual’ emission scenario, characterised by the Representative Concentration Pathway (RCP 6.0), under which emissions are expected to peak around 2080, then decline (IPCC, 2014). The projected discharges provide an initial/robust/tentative/etc. estimate/projection of potential climate change effects on surface and groundwater availability for the study area, on water supply reliability for irrigating pastoral farms, and on nutrient leaching and sediment transport within the Ruamahanga catchment.

Climate change projections for 2040 and 2090 within the study area indicate:

- average air temperature are expected to increase across the catchment by 1 °C by 2040 and 2.5 °C by 2090;
- total volume of precipitation received by the upper Ruamahanga catchment is decreasing by 2040 and 2090;
- seasonality of the precipitation changes by 2090, but remains the same as in 1995 for 2040.

Simulated daily river flow time series were generated using a TopNet model for the Upper Ruamahanga catchment discharging to the GWZ (310 reaches). The hydrological model has been calibrated at nine locations (Tauherenikau at Gorge, Waiohine at Gorge(new site), Waingawa at Upper Kaituna, Waipoua at Mikimiki, Ruamahanga at Mt Bruce, Kopuaranga at Palmers Br, Whangaehu at Waihi, Taueru at Te Weraiti, Huangarua at Hautotara) and detailed information on the calibration can be found under Zammit and Yang (2016). Potential climate change impacts on discharge were generated for the following hydrological characteristics:

- water balance, cumulative flows, mean annual flows for changes in annual pattern of hydrological characteristics;
- Fre3 flows and 7-day Mean Annual Low Flows for changes at the extreme;
- monthly average discharge to represent changes in seasonal patterns of discharge;
- flow deciles to represent changes in the distribution of discharge time series over future time slices.

The main changes in modelled flow for the present (i.e., 1985-2005), 2040, and 2090 climate are:

- mean flows are expected to decrease for all catchments, with decreases in mean flows being larger by the end of the century than mid-century; and
- changes in both high flows and low flows are towards more extreme values;
- the duration and frequency of high flows (characterised by changes in Fre3) are expected to increase by mid-century with larger increase by the end of century;

- low flows (characterised by changes in 7-day MALF) are expected to reduce by 20% by mid-century, with greater (up to 40%) reductions by end of century. This is expected to result in greater challenges for water resource management at times of low flow;
- changes in monthly mean flows are usually characterised by:
  - autumn discharges increase by 2040, and decrease by 2090;
  - winter, spring and summer mean monthly discharges decrease by 2040 and 2090, with the largest decrease by 2090;
- changes in flow decile statistics indicate that lower flows are expected for 2040 and 2090, for all catchments, across the whole mid-range of the hydrograph (10% to 90% of the time), with the larger decrease (up to 20%) by the end of the century.

A more robust assessment of the magnitude and uncertainty of expected changes could be gained by additional RCM modelling for a wider range of RCPs.

5 Glossary of abbreviations and terms

AR5	IPCC Assessment Report 5
CMIP5	Coupled Model Intercomparison Project Phase 5
CMP	Ruamahanga Collaborative Modelling Project
FDC	Flow Duration Curve
GCM	General Circulation Model
GWRC	Greater Wellington Regional Council
GWZ	Groundwater Management Zone
IPCC	Intergovernmental Panel on Climate Change
7 day MALF	7 day Mean Annual Low Flow
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SST	Sea Surface Temperature
VCN	Virtual Climate Network

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