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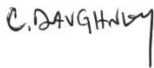
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This report is the third volume associated with the “Climate change impact across the Southland region- IPCC 6th Assessment Report update” report. Volume 3 presents the results of the modelling chain bias correction (Section 1), and the expected changes across the Cryosphere (Section 2), Hydrology (Section 3) and Stream temperature (Section 4) domains.

1 Modelling chain bias correction

1.1 Parametrisation

The spatial distribution of each bias corrected parameter, expressed as the ensemble average across all General Circulation Models (GCMs) used as part of , is presented in: Figure 1-1 for the correction of the precipitation volume, Figure 1-2 for the correction of the snow cover area (temperature of accumulation), Figure 1-3 for the correction of the catchment scale plant available water, and Figure 1-4 for the correction of the infiltration excess parameter at Freshwater Management Unit (FMU) scale.

Analysis of the bias correction values indicates that:

- Precipitation volume bias correction
 - CMIP6 average precipitation bias correction across the Southland region is 0.987 and ranges from 0.878 to 1.107 across GCMs. At FMU scale, the FMU average precipitation bias correction is larger than 1.000 only for the Waiau FMU. This indicates that the annual average volume of precipitation, generated by the Conformal Cubic Atmospheric Model (CCAM) model across the Southland region, is slightly smaller than what would be required to generate the observed long-term average discharge (assuming that a surface water conceptualisation is valid across Southland).
 - Spatial analysis of the precipitation bias correction indicates that precipitation needs to be generally reduced (correction factor lower than 0.800) in the upper Maitava-Oreti and Aparima FMUs as well as the west coast draining Fiordland FMU. Precipitation needs to be increased in areas downstream of regional aquifers (e.g., Oreti FMU Five Rivers aquifer, Maitava at Gore, lower Waiau River).
 - Precipitation bias correction is larger than 1.200 for the Manapouri draining surface water catchment. This analysis is valid across all the GCMs and would indicate a potential underestimation of the annual average volume of the precipitation by the CCAM model in this area.
 - Analysis of the precipitation volume bias correction across all GCMs and subbasins indicates that the full range of this parameter (i.e., 0.400–2.500) is only calculated for subbasins within the Maitava and Waiau FMUs, while the minimum value (i.e., 0.400) is calculated for subbasins within the Aparima and Oreti FMUs. The precipitation volume bias correction parameter is within the range of expected values following a complete calibration process for Fiordland (see Volume 1 Section 3.3.2 Table 3-6).
- Snow accumulation temperature threshold
 - CMIP6 average bias correction of the snow accumulation temperature threshold across the Southland region is 2.023°C, ranging from 1.443°C to 3.508°C across GCMs.
 - Spatial analysis of the snow accumulation temperature threshold indicates that this parameter needs to generally increase across all GCMs and FMUs. This

indicates that the air temperature, generated by the CCAM model at high elevation, is slightly warmer than what would be required to generate historical catchment scale snow cover area (assuming the annual volume of precipitation is correct). The exception is the Mataura FMU for which a slight decrease is required (less than 0.5°C).

- Analysis of the snow accumulation temperature threshold correction across all GCMs and subbasins indicates that the largest negative correction is required only for the NorESM2-MM GCM (by up to -4.0°C) for the Oreti FMU, while the largest positive correction is required for the Aparima FMU across all GCMs (by at least 3.945°C).
- Catchment scale plant available water
 - CMIP6 average bias correction of the catchment scale plant available water across the Southland region is 1.339, ranging from 1.267 to 1.435 across GCMs. This indicates underestimation of catchment scale plant available water by the a-priori parametrisation of the TopNet model.
 - Spatial analysis indicates that the catchment scale plant available water needs to be increased across all GCMs for all FMUs except for the Fiordland FMU, for which a slight decrease is required.
 - Analysis of the catchment scale plant available water bias correction parameter across all GCMs and subbasins indicates that the full range of this parameter (i.e., 0.500–5.000) is only reached for subbasins within the Waiau FMU, while the minimum value (i.e., 0.500) is calculated for subbasins within the Fiordland and Mataura FMUs (across all GCMs). Catchment scale plant available water is within the range of expected values following a complete calibration process for Fiordland (see Volume 1 Section 3.3.2, Table 3-6). While the behaviour of the catchment scale plant available water bias correction parameter across the Waiau-Fiordland and Mataura FMUs may be associated with hydrological process parameterisation across those FMUs (independent of the GCM realisations), GCM specific bias correction values set for the minimum or maximum values may point to some specific issues with specific GCMs at specific locations.
- FMU-scale infiltration excess runoff
 - Infiltration excess runoff correction was performed to better represent low flow simulations and associated hydrological metrics, but not to better represent flood magnitude.
 - CMIP6 average bias correction of the catchment scale infiltration excess runoff across the Southland region is 1.444, ranging from 0.520 to 2.060 across GCMs.
 - Spatial analysis indicates that the infiltration excess runoff correction was carried out for the Mataura and Oreti FMU only.
 - Analysis of the catchment scale infiltration excess runoff bias correction parameter across all GCMs and subbasins indicates that the full range of this parameter (i.e., 0.100–5.000) is only reached for the Mataura FMU, while the correction of the catchment scale infiltration excess runoff is uniform across all

GCMs for the Oreti FMU (i.e., 0.100). For the Maitaura FMU, the catchment scale infiltration excess runoff required to be reduced for ACCESS-CM2 and EC-Earth 3 GCMs and increased (i.e., 5.000) for the remaining GCMs.

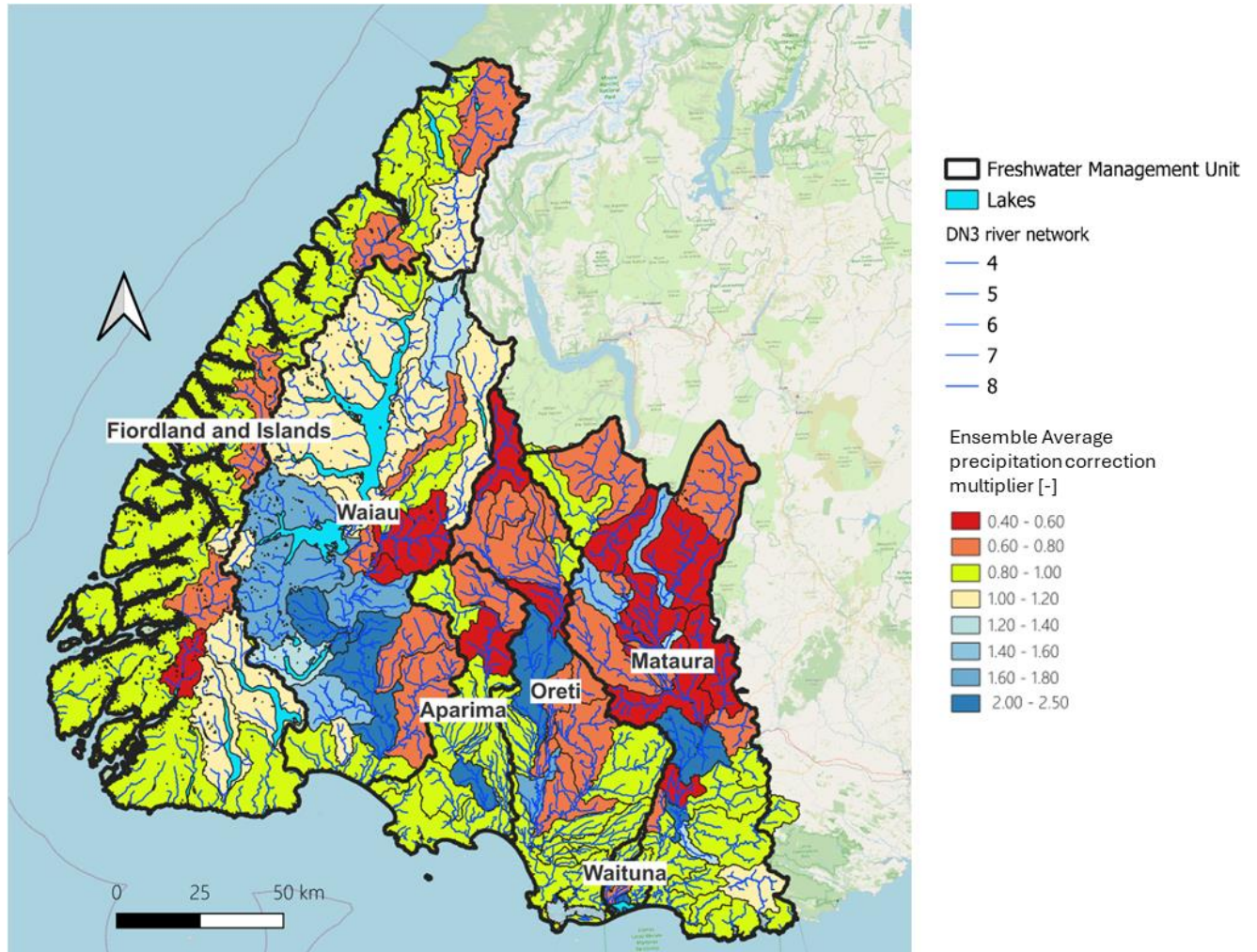


Figure 1-1: Multi-model average TopNet precipitation correction parameter. Precipitation correction parameter values less than 0.800 (red colour scale) indicate that CCAM precipitation is to be reduced. Precipitation correction parameter values larger than 1.2 indicate that CCAM precipitation is to be increased. Precipitation correction parameter values between 0.8 and 1.2 represent expected values of this parameter.

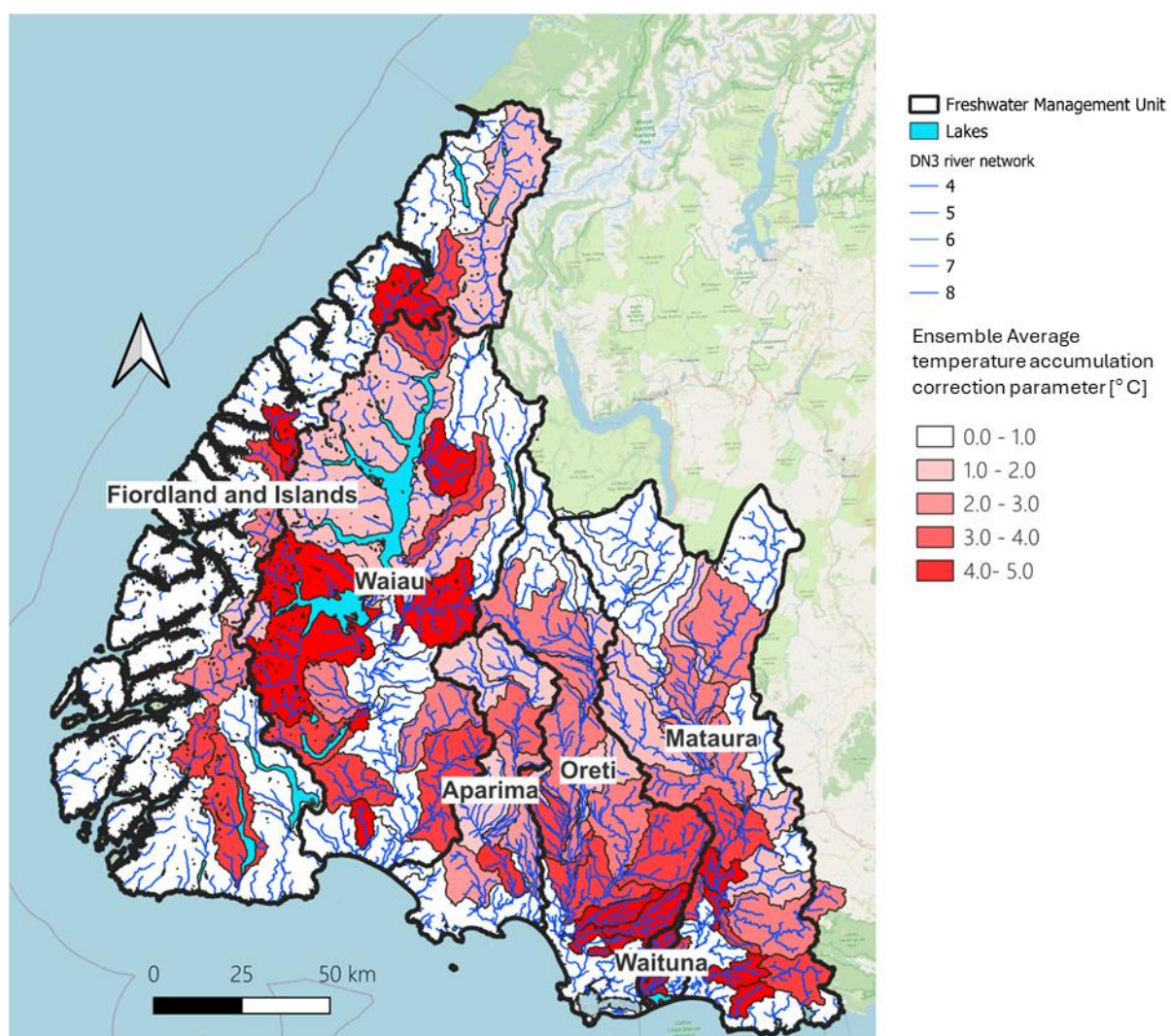


Figure 1-2: Multi-model average TopNet temperature accumulation correction parameter.

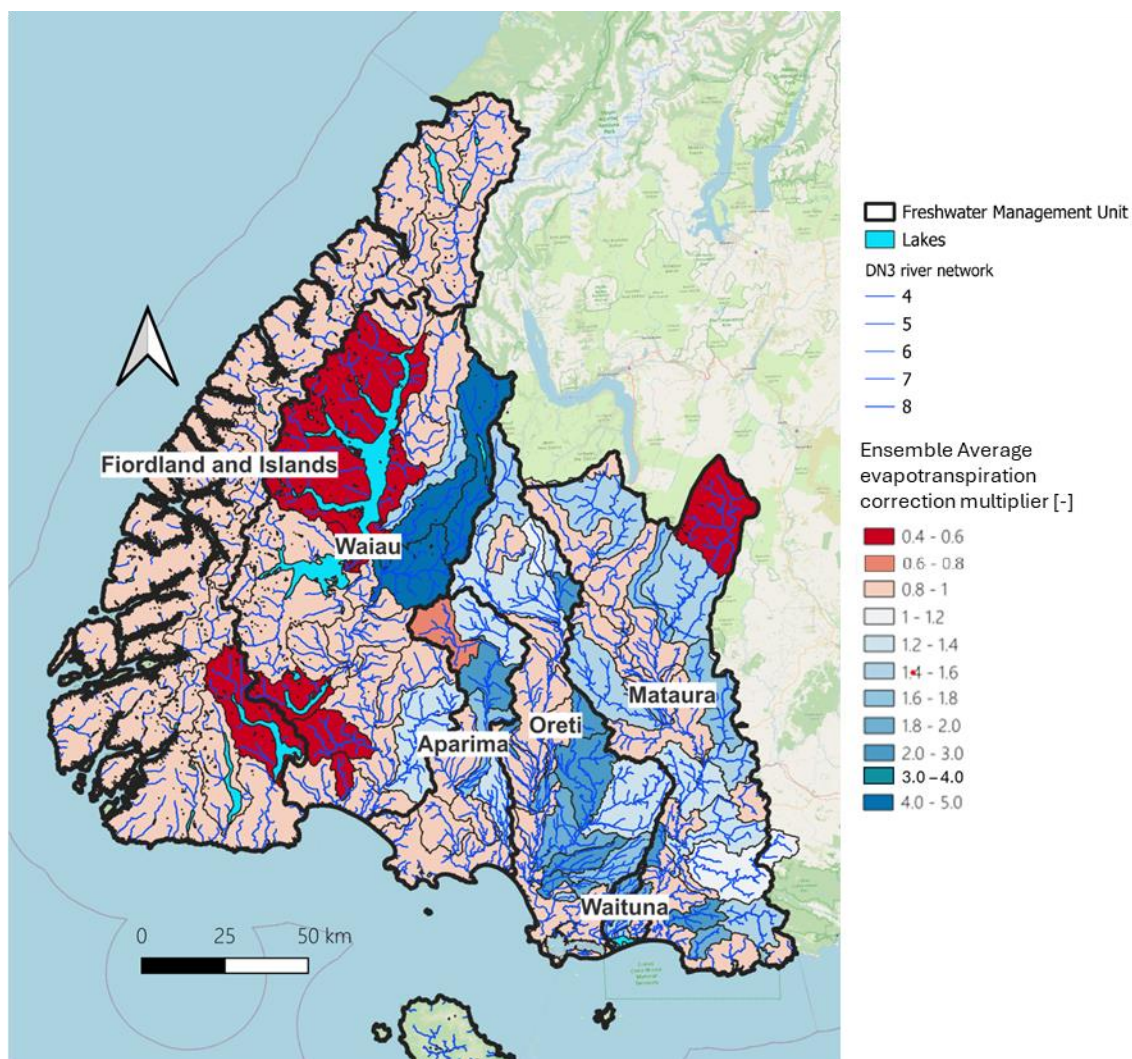


Figure 1-3: Multi-model average TopNet catchment scale plant available water correction parameter. Correction parameter values less than 0.8 (darker red colour scale) indicate that the a-priori catchment scale estimated plant available water is to be reduced. Correction parameter values larger than 1.2 indicate that the a-priori catchment scale estimated plant available water is to be increased. Correction parameter values between 0.8 and 1.2 represent expected values of this parameter.

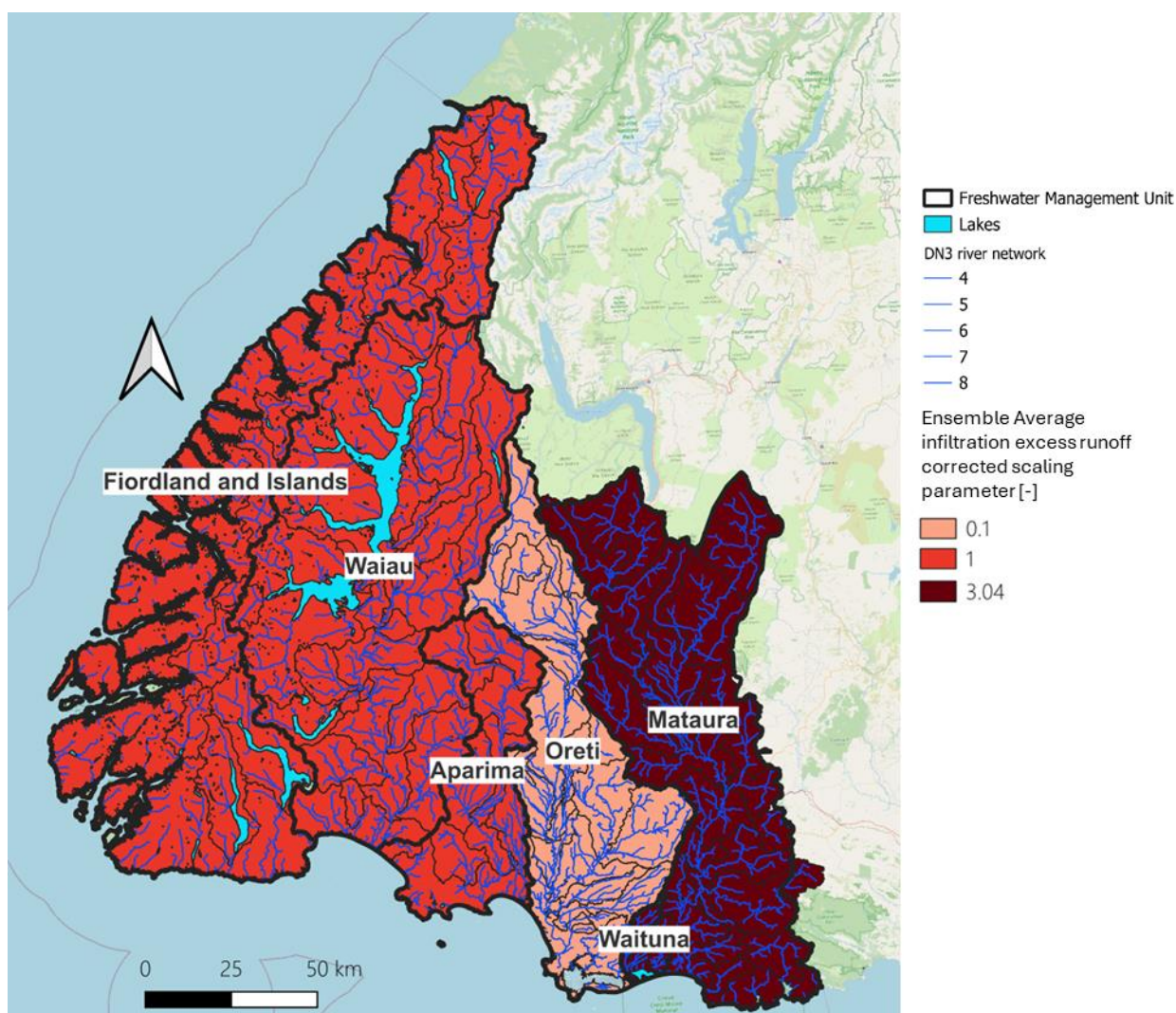


Figure 1-4: Multi-model average TopNet FMU scale infiltration excess runoff correction parameter. Correction parameter values less than 0.800 (light red colour) indicate that the a-priori infiltration excess runoff parameterisation is to be reduced across the FMU. Correction parameter values larger than 1.2 (dark red colour) indicate that the a-priori infiltration excess runoff parameterisation is to be increased across the FMU. Correction parameter values between 0.8 and 1.2 represent expected values of this parameter.

1.2 Validation

The validation of the bias correction is carried out as follows in the context of climate change impact assessment (Biondi et al. 2012).

- Visual inspection of the average daily traces. This inspection is a “fundamental step in model validation as it allows the study of temporal dynamics of model performance and facilitates the identification of patterns in error occurrence” (Biondi et al. 2012). It aims to assess: i) the ability of the simulated discharge to reproduce seasonality of the observed flows (average daily time series intercomparison), ii) any potential mass balance error or systemic bias introduced through the bias correction process (intercomparison of the observed and simulated average daily cumulative discharge), and iii) ability of the simulated discharge to reproduce the distribution of the observed flows (average daily flow duration curve intercomparison).

- Hydrological metrics intercomparison. This intercomparison assesses the ability of the simulated discharge to represent hydrological metrics (e.g., mean flow) that are expected to remain relatively constant over the period of interest.
- Hydrological goodness of fit statistics. This intercomparison aims to assess statistically the ability of the simulated discharge to represent observed hydrological flows. It is important to note that because GCMs are free running (i.e., climate observations are not ingested by CCAM during the historical period), the raw CCAM outputs struggle to capture seasonal cycles in Southland and several areas of the South Island (Cambell et al. 2024; Figure 3-4). As a result, the goodness of fit is expected to be poor for most conventional statistical metrics used to assess hydrological model accuracy (e.g., NSE, NSELog, etc.).

Figure 1-5 to Figure 1-8 present the outcomes of the bias correction process for two contrasting natural flow locations: the Aparima at Dunrobin, and Waikaia at Piano Flat. These two test locations were chosen as generally representative of the outcomes of the bias correction process. The outcomes of the bias correction for other natural flow sites are presented in Appendix A.

Figure 1-5 and Figure 1-6 present a comparison of the observed and simulated daily average hydrograph, cumulative hydrograph and flow duration curve for the Aparima at Dunrobin and Waikaia at Piano Flat, while Figure 1-7 and Figure 1-8 present the seasonal monthly average precipitation and the observed and simulated catchment-scale snow cover area at these same locations.

Figure 1-9 to Figure 1-11 present the outcomes of the bias correction process for three contrasting winter flow sites: the Aparima at Thornbury, Mokoreta at McKays, and Mararoa at Cliffs. These three test locations were chosen as generally representative of the outcomes of the bias correction process for the winter flow sites. The outcomes of the bias correction for other winter flow sites are presented in Appendix A.

The ability of the bias corrected streamflow to simulate hydrological metrics at all natural flow gauging stations used as part of the bias correction process is presented in Table 1-1. The tabulated hydrological metrics were chosen to represent flow regimes in Southland Rivers, including Q95 (high flow metric representing the river flow not exceeded ninety-five per cent of the time), Qmean (mid-range flow metric), and AnnQ25 (flow metric representing the annual average river flow that is exceeded twenty-five per cent of the time) and Q7DMALF (low range flow metric representing the mean of the lowest 7-day average flows in each year of a period of interest). Mean Annual Flood (MAF) is not included in the list of the metrics reported in Table 1-1 because Zammit et al. (2024) and Bakker (2025) demonstrated that its reproduction by the modelling chain requires additional bias correction of the annual average volume of precipitation. The accuracy of the bias corrected streamflow simulation is presented in Table 1-2 and Table 1-3. For clarity, these hydrological metrics are presented as averages across the six GCMs.

Graphical inspection of the average daily traces indicates that:

- The bias correction results in acceptably small mass balance errors (less than 5 percent) across all natural flow locations (small difference in the observed and simulated average daily cumulative discharge) except for Rowallanburn at Old Mill and for two GCMs (CNRM-CM6-1 and GFDL-ESM4) for Waikaia at Piano Flat. Minimisation of the mass balance error is the expected result because the bias correction aims to match the annual average hydrological metrics.

- The bias correction process failed to reproduce the seasonality of the river flows for the hydrological simulations for Waikaia at Piano Flat (i.e., large overestimation of the discharge in winter (up to 100% for CNRM-CM6-1 and GFDL-ESM4 GCMs), consequent underestimation of the river discharge during summer (up to 40% for CNRM-CM6-1 and GFDL-ESM4 GCMs) and poor representation of the timing of the river discharge peak (between 25 and 50 days earlier for most of the GCMs). This result is representative of the results obtained across the Mataura and Oreti FMUs. As the TopNet model was previously successfully applied to the Mataura, Oreti and Aparima FMUs (Zammit et al. 2019, 2020, 2021), this result could potentially be linked to the hindcast GCM climate inputs (e.g., timing of the precipitation) or the soil characteristics (derived from the Land Resource Inventory) used as part of the project.
- The ability of the bias correction to reproduce the daily average discharge time series and its distribution (flow duration curve) is location dependent. The former may be associated with the timing of the precipitation generated for each GCM (e.g., Figure 1-8), while the latter may be associated with the hydrological process parameterisation at those locations (e.g., Figure 1-6).
- The bias correction process failed for Rowallan Burn at Old Mill (see Appendix A). This is thought to be associated with the underestimation of the volume of precipitation over the catchment. This is due to the maximum permitted value of the precipitation bias correction factor not being large enough to produce the observed discharge volume. This result indicates that the CCAM model is potentially significantly underestimating the precipitation over that catchment.
- The use of winter flows (defined as river flow over the period May to September) to assess the validity of the bias correction illustrates one of the current limitations of the simple bias correction method implemented in regards of the climate datasets (i.e., correction in annual average magnitude of climate input datasets, not in seasonality of those datasets). Depending on location and GCM, winter flows are generally over-predicted (large difference in the observed and simulated average daily cumulative discharge), winter flow time series distribution is generally over-predicted (over-prediction of the winter flow duration curve), and seasonality of the winter flows is generally not reproduced. This result is currently under investigation but is thought to largely reflect the existing bias in the non-bias corrected precipitation seasonality at those locations as reported by Campbell et al. (2024). Despite those limitations, the winter based bias correction is thought to be acceptable and able to demonstrate the applicability of the modelling chain outside of natural flow sites.

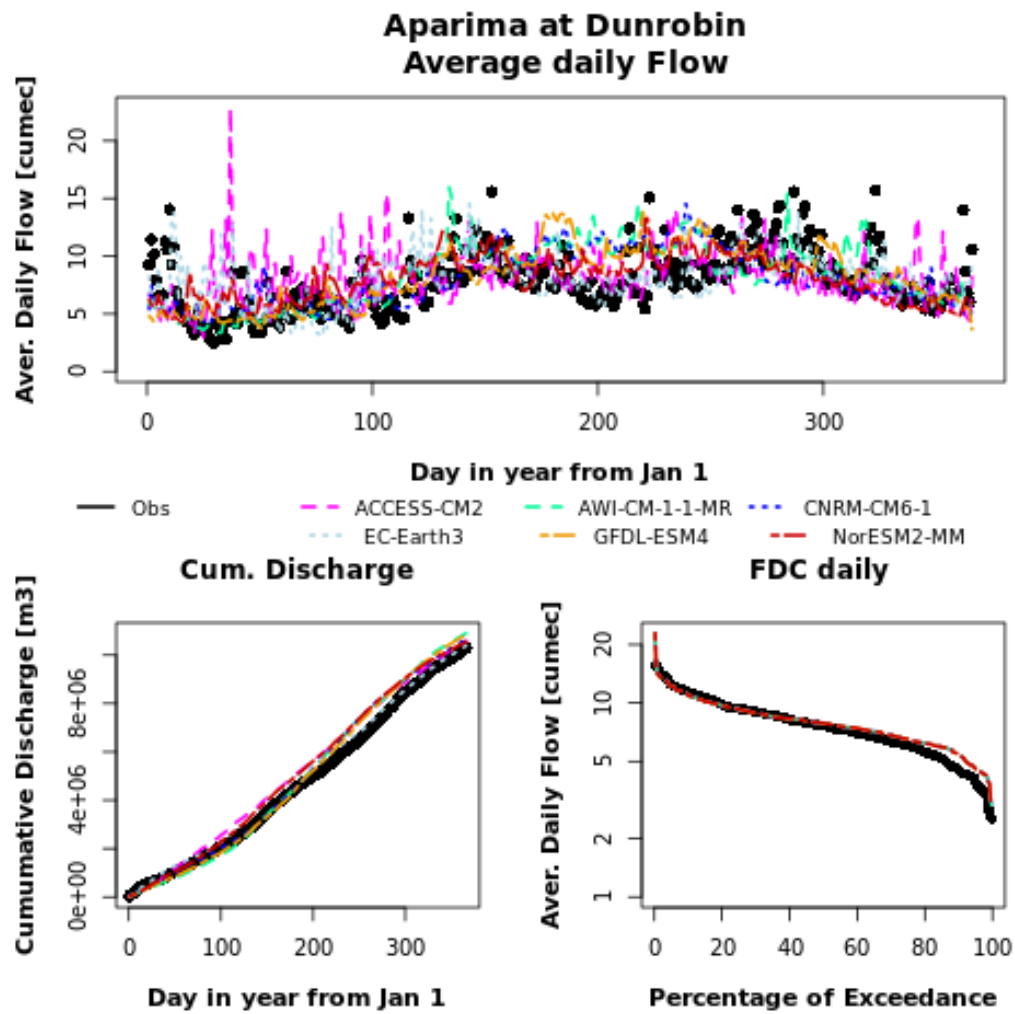


Figure 1-5: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Aparima at Dunrobin. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

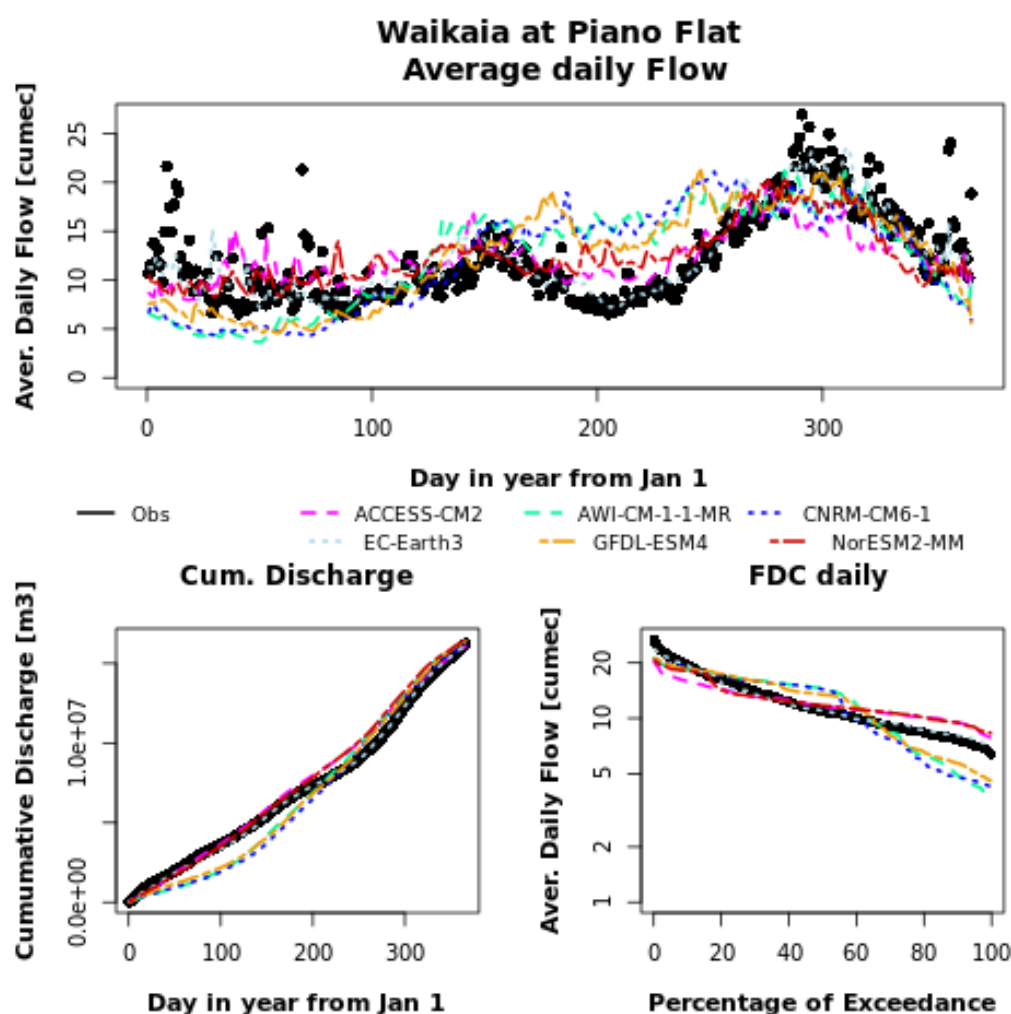


Figure 1-6: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Waikaia at Piano Flat. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

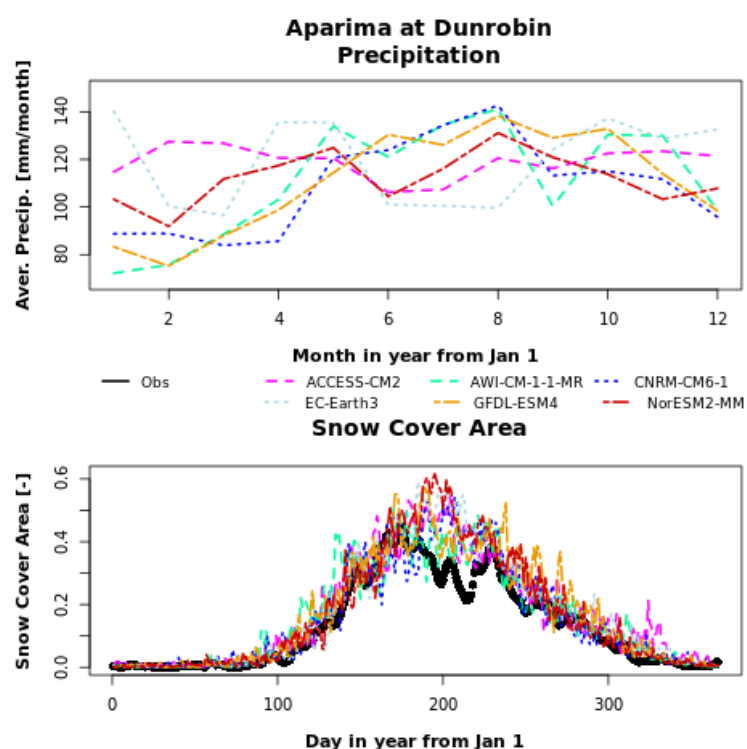


Figure 1-7: Catchment scale average monthly precipitation and daily average snow cover area for the Aparima at Dunrobin. Hindcast simulations presented for observed and the six GCMs over the period 1995–2004 calendar (precipitation) and snow year (snow cover area).

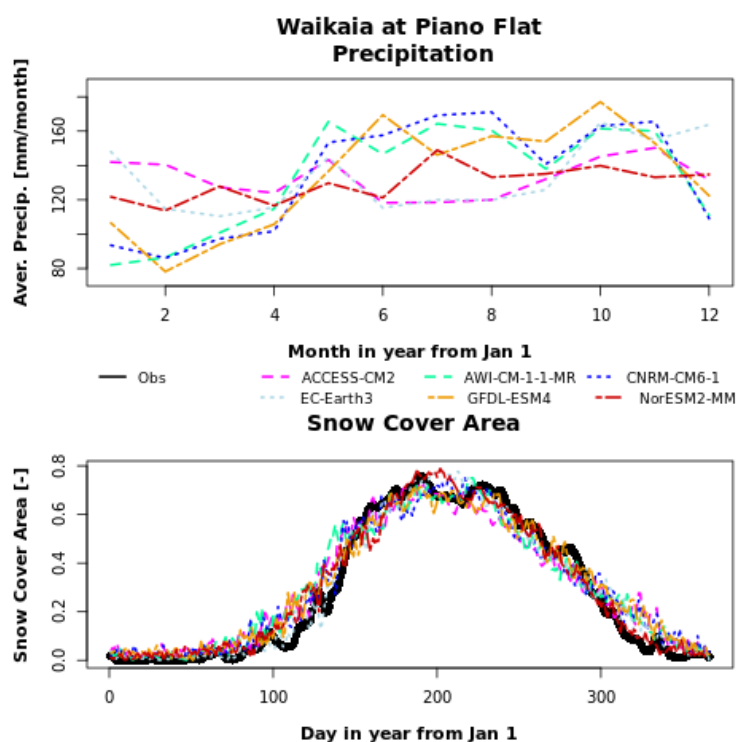


Figure 1-8: Catchment scale average monthly precipitation and daily average snow cover area for the Waikaia at Piano Flat. Hindcast simulations presented for observed and the six GCMs over the period 1995–2004 calendar (precipitation) and snow year (snow cover area).

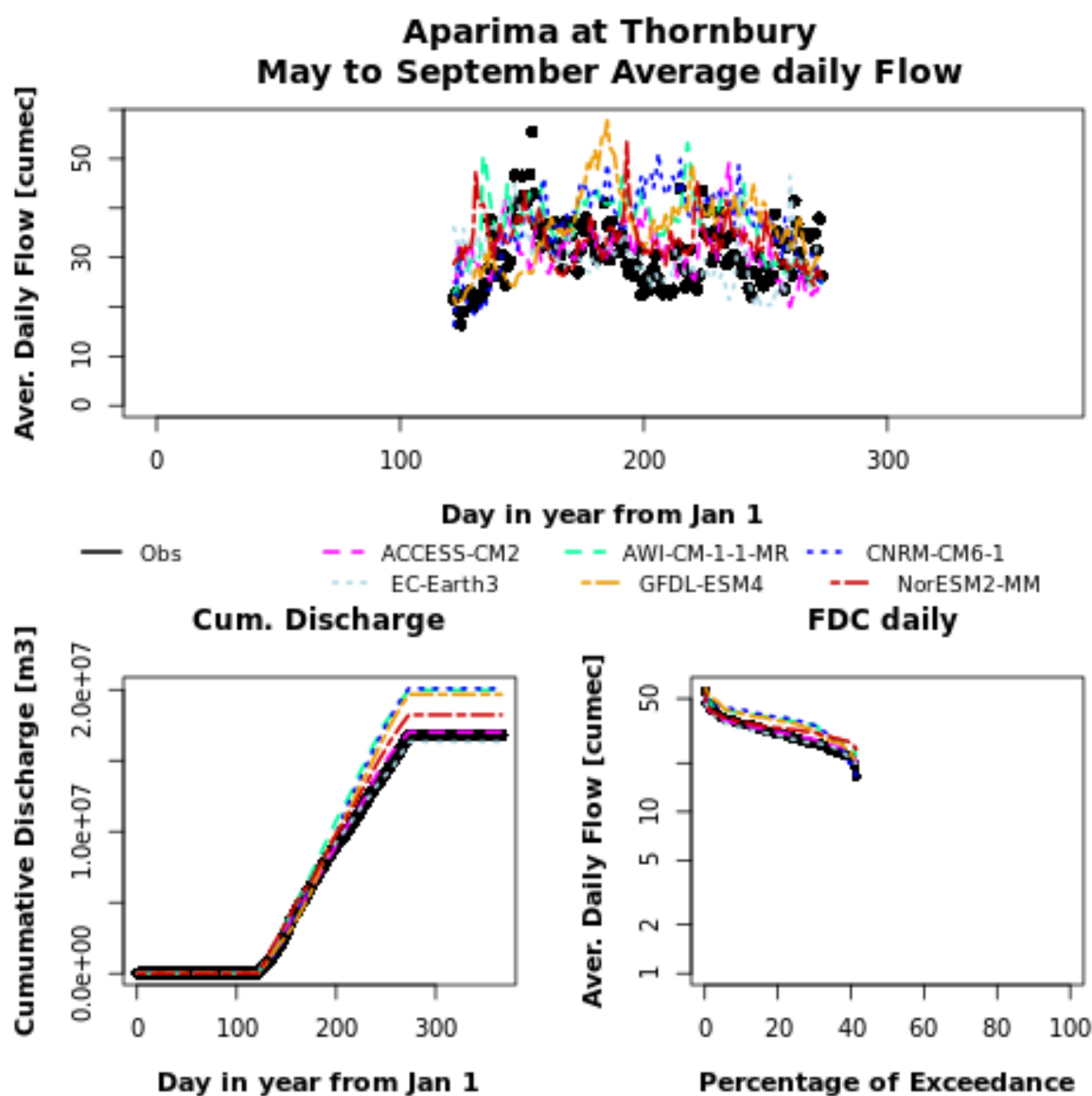


Figure 1-9: Hindcast bias corrected winter daily average hydrograph, cumulative hydrograph and flow duration curve for the Aparima at Thornbury. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years over May to September period.

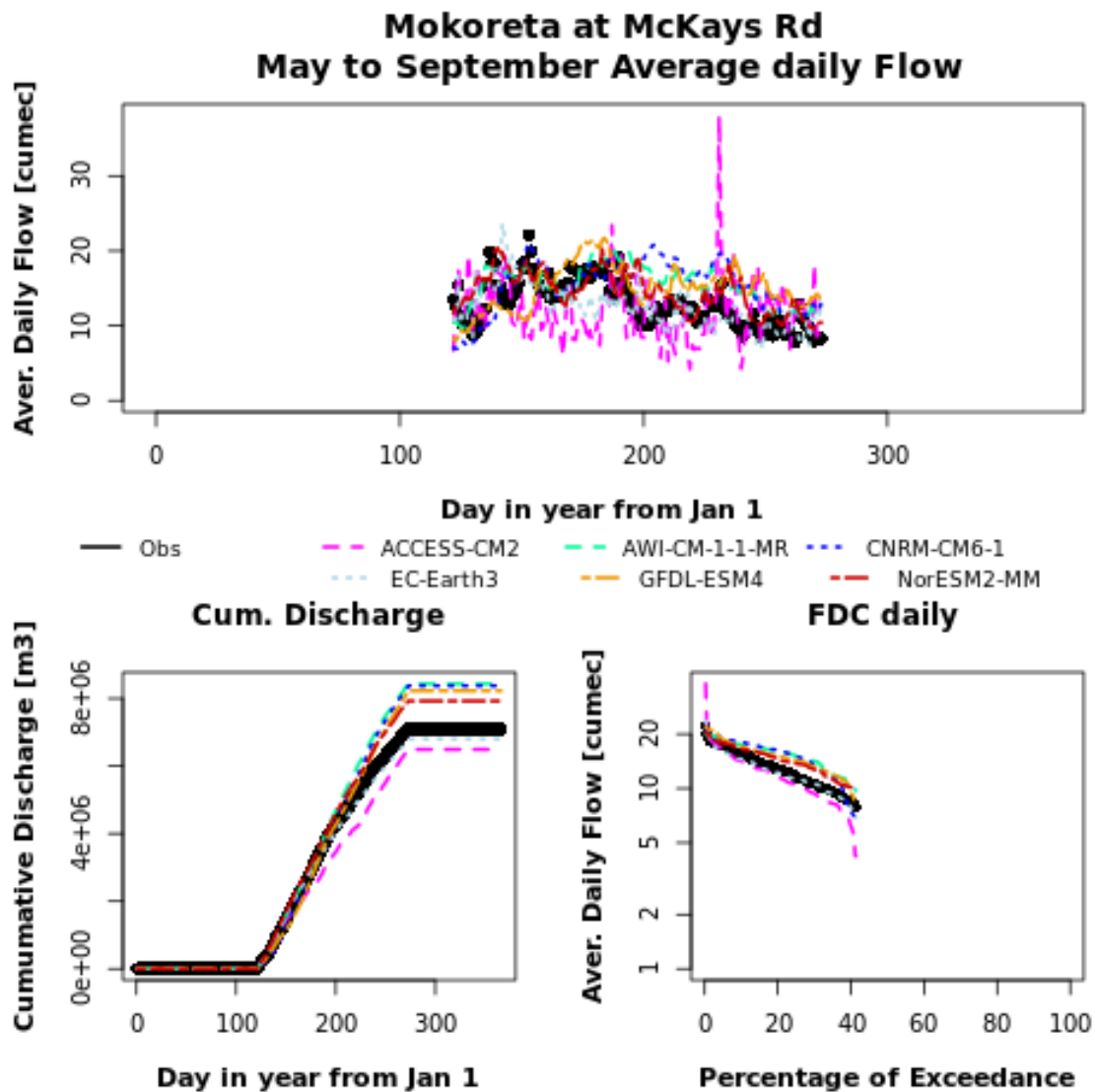


Figure 1-10: Hindcast bias corrected winter daily average hydrograph, cumulative hydrograph and flow duration curve for the Mokoreta at McKays Road. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years over May to September period.

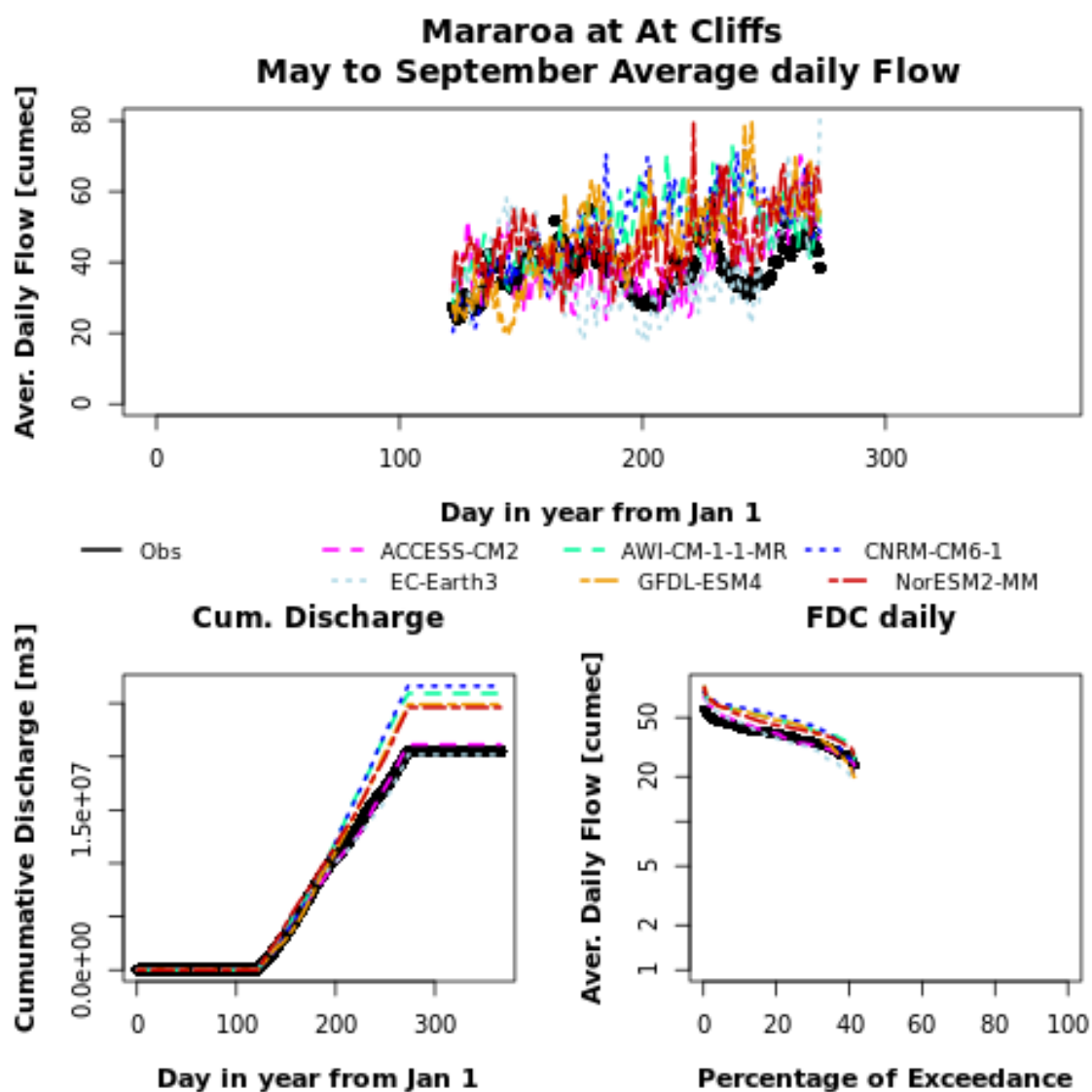


Figure 1-11: Hindcast bias corrected winter daily average hydrograph, cumulative hydrograph and flow duration curve for the Mararoa at Cliffs. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years over May to September period.

Table 1-1: Observed and bias corrected hydrological metrics for all natural flow sites.

FMU	Tideda ID	Site name	Q5 (m³/s)		QMean (m³/s)		AnnQ25 (m³/s)		Q7DMALF (m³/s)	
			Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Aparima	78906	Aparima at Dunrobin	22.04	18.36	7.82	8.10	6.84	7.46	1.41	2.13
Oreti	78606	Oreti at Three Kings	21.12	20.79	8.60	8.59	7.74	7.64	2.55	1.36
Mataura	77563	Waikaia at Piano Flat	31.20	27.05	12.30	12.36	11.70	10.37	3.11	3.08
Waiau	80201	Rowallan Burn at Old Mill	4.14	1.84	1.29	0.99	1.17	0.75	0.29	0.14
	79740	Spey at Spreydon	54.49	54.22	14.68	13.90	13.03	12.20	1.24	1.62
Fiordland	83201	Lyvia Ck at Deep Cove	36.17	23.31	10.76	10.54	10.17	9.77	1.25	1.20

Analysis of the outcomes of the bias correction on hydrological metrics indicates that:

- Bias correction of historical hydrological simulations generally improves the accuracy of mean flow metrics. Qmean error is usually less than 5%, even at sites affected by cryospheric processes. An exception is Rowallan Burn at Old Mill, where Qmean error is 23%. This is because the allowable range of volumetric precipitation bias correction (0.4 to 2.5) is not large enough to provide the required precipitation volume at that site.
- Bias correction of historical hydrological simulations also generally improves the accuracy of mid- to high-end low flow metrics. The error in AnnQ25 is usually less than 12%, even at sites affected by cryospheric processes. An exception is Rowallan Burn at Old Mill, where AnnQ25 error is 36%. This is linked to an underestimation of catchment-scale plant available water, caused by an underestimation of the volumetric precipitation bias correction at that location.
- Despite bias correction of cryospheric processes, the reproduction of low flow metrics is poor for nearly half of the natural flow sites, with Q7DMALF error reaching 50%. This is surprising because cryospheric processes were corrected for snow season duration and seasonal snow cover area. Previous studies show that TopNet reproduces Q7DMALF less accurately than statistical models (Booker and Woods 2014; McMillan et al. 2016). It is therefore likely that the simple bias correction method used in this project does not improve Q7DMALF if hydrological process conceptualisation and parameterisation in TopNet are incorrect. Another possible explanation is that over- or under-prediction of the low flow metrics is related to large variation and bias in GCM seasonal precipitation, as reported by Campbell et al. (2024). The causes of poor reproduction of the low flow metrics remains under investigation.

Table 1-2: Validation statistics (NSE, NSELog, KGE, KGEkm, KGEIf) for the natural streamflow stations.

	NSE	NSELog	KGE	KGEkm	KGEIf
Aparima Dunrobin	-0.146	0.017	0.369	0.384	0.403
Fiordland Lyvia Creek Deep Cove	-0.448	-0.525	0.201	0.215	0.214
Mataura Waikaia Piano flat	0.123	-0.207	0.509	0.575	0.356
Oreti Three Kings	-0.404	-1.266	0.363	0.598	-0.134
Waiau Rowallan Burn Old Mill	-0.320	-1.260	0.454	0.473	0.003

Table 1-3: Validation statistics (VE, D, Pbias and Pbiasfdc, VE and D) for the natural streamflow stations.

	VE	D	Pbias (%)	PBIASfdc (%)
Aparima Dunrobin	0.729	0.622	3.467	-17.505
Fiordland Lyvia Creek Deep Cove	0.723	0.527	-4.433	-10.069
Mataura Waikaia Piano flat	0.737	0.744	0.267	-23.498
Oreti Three Kings	0.721	0.738	-0.650	17.129
Waiau Rowallan Burn Old Mill	0.603	0.697	-21.733	55.689

Analysis of the hydrological statistics and calculated metrics over daily average time series indicates that:

- For all sites except Rowallan Burn at Old Mill, the long-term bias is small, with low Pbias values. The timing of hydrological simulations is generally correct, as shown by VE greater than 0.7, despite differences in precipitation seasonality across GCMs. The annual average hydrological regime can also be represented through the hydrological modelling (D).
- Nash–Sutcliffe metrics are not suitable for this study. Although these metrics are commonly used in hydrological modelling, the poor scores here likely reflect variation in precipitation timing across GCMs and the seasonal bias in historical precipitation before correction (Campbell et al. 2024).
- KGE metrics, like the Nash-Sutcliffe metrics, are deemed not suitable for this investigation. This is because KGE is influenced by bias and variability (Cinkus et al. 2022). Even so, we note that KGE scores larger than -0.41 could be considered as acceptable based on Knoben et al. (2019).

2 Cryospheric variables

This section covers the projected differences in cryospheric metrics between the baseline period (1995–2014) and two future periods. These are mid-century (2041–2060) and late-century (2081–2098).

2.1 Snowfall volume

Modelled historic and projected changes to future seasonal snowfall volume for the period April-May-June (“late autumn”) and July-August-September (“late winter”) are illustrated in Figure 2-1 to Figure 2-3 for Southland mountain domain, with the change for “late spring” (October-November-December time period) and “late summer” (January-February-March time period) presented in Appendix B. FMU-wide average projected changes (generated across each FMU) are summarised in Table 2-1 (for the period April-May-June) and Table 2-2 (for the period July-August-September).

Table 2-1: Projected changes in seasonal snowfall volume during April-May-June (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Aparima	-40.0	-63.5	-48.1	-72.4	-49.4	80.7
Mataura	-33.8	-58.6	-43.4	-72.2	-46.0	-79.3
Oreti	-38.6	-63.6	-47.6	-75.0	-52.8	-81.3
Waiau	-30.3	-49.5	-35.2	-64.0	-37.6	-70.6
Fiordland	-36.6	-56.2	-42.0	-49.9	-42.0	-76.7

Table 2-2: Projected changes in seasonal snowfall volume during July-August-September (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Aparima	-46.8	-71.1	-53.5	-85.0	-54.7	-90
Mataura	-38.4	-56.7	-42.8	-71.2	-40.4	-82.2
Oreti	-40.6	-61.8	-45.8	-76.6	-46.0	-86.8
Waiau	-39.1	-54.3	-39.3	-71.2	-40.2	-81.0
Fiordland	-43.8	-58.7	-42.7	-75.5	-42.4	-84.5

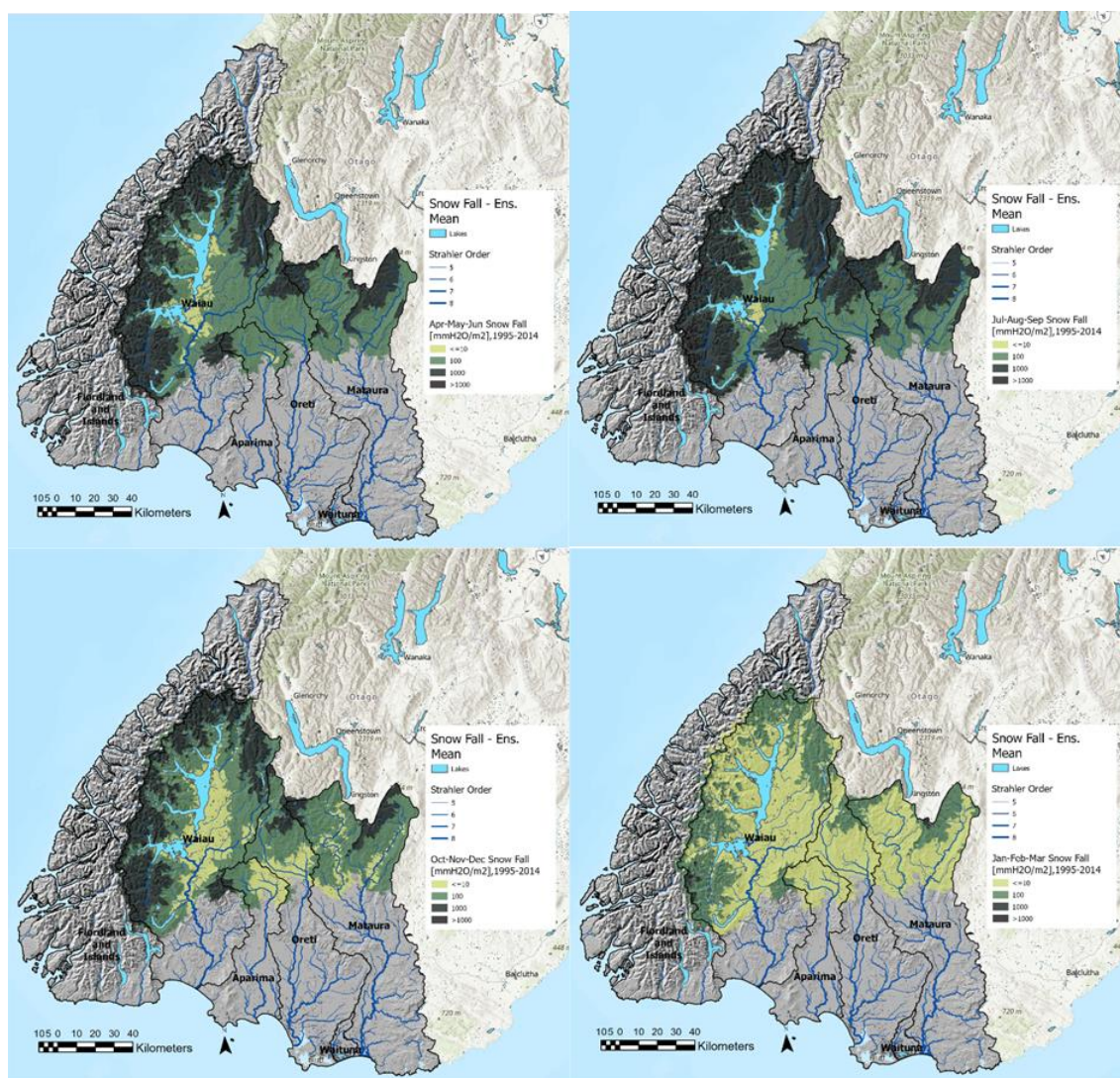


Figure 2-1: Historical multi-model average seasonal snowfall.

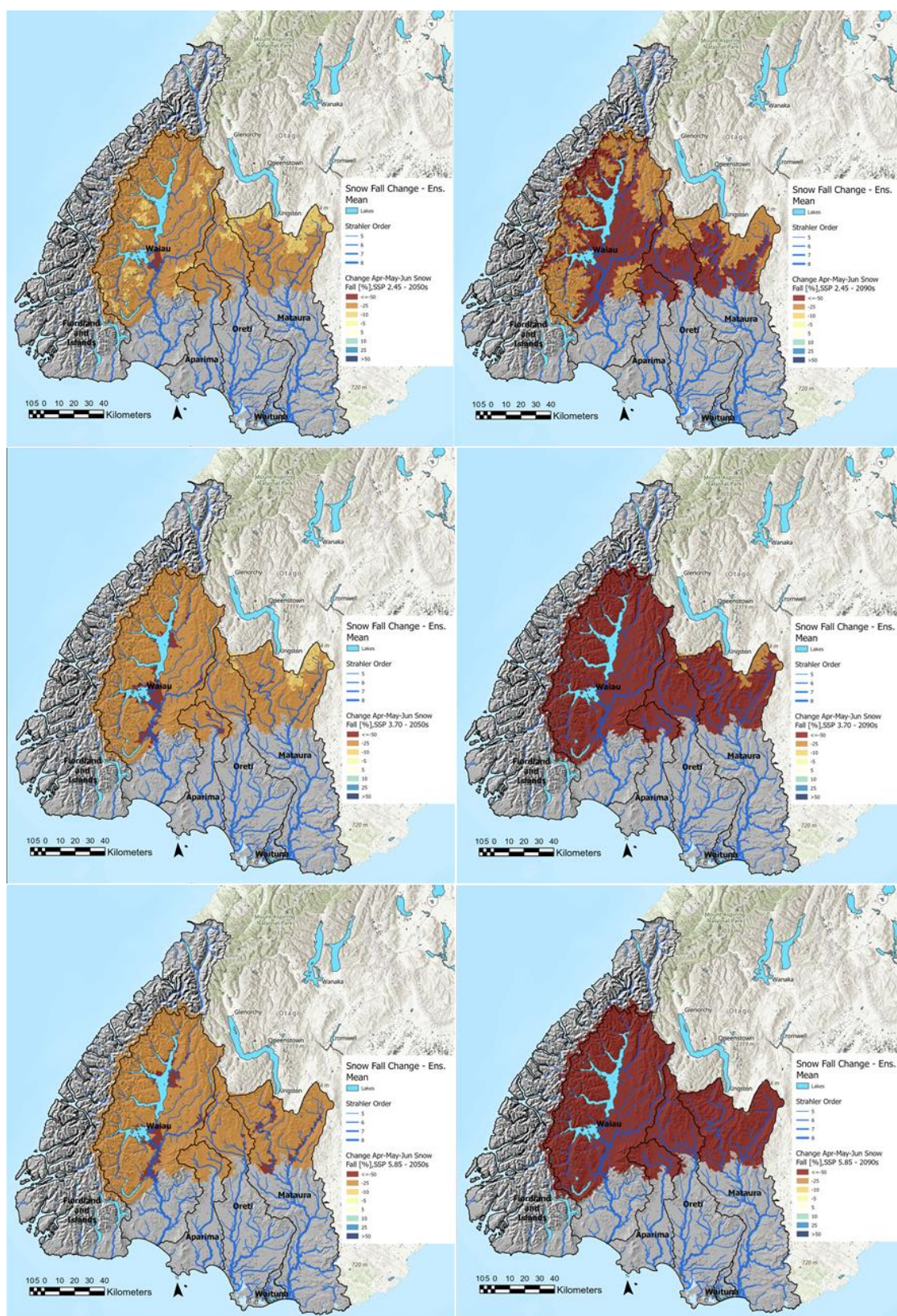


Figure 2-2: Change in multi-mode April-May-June (late autumn) snowfall (based on snow year). Change in multi-model average seasonal snow volume is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hands panels).

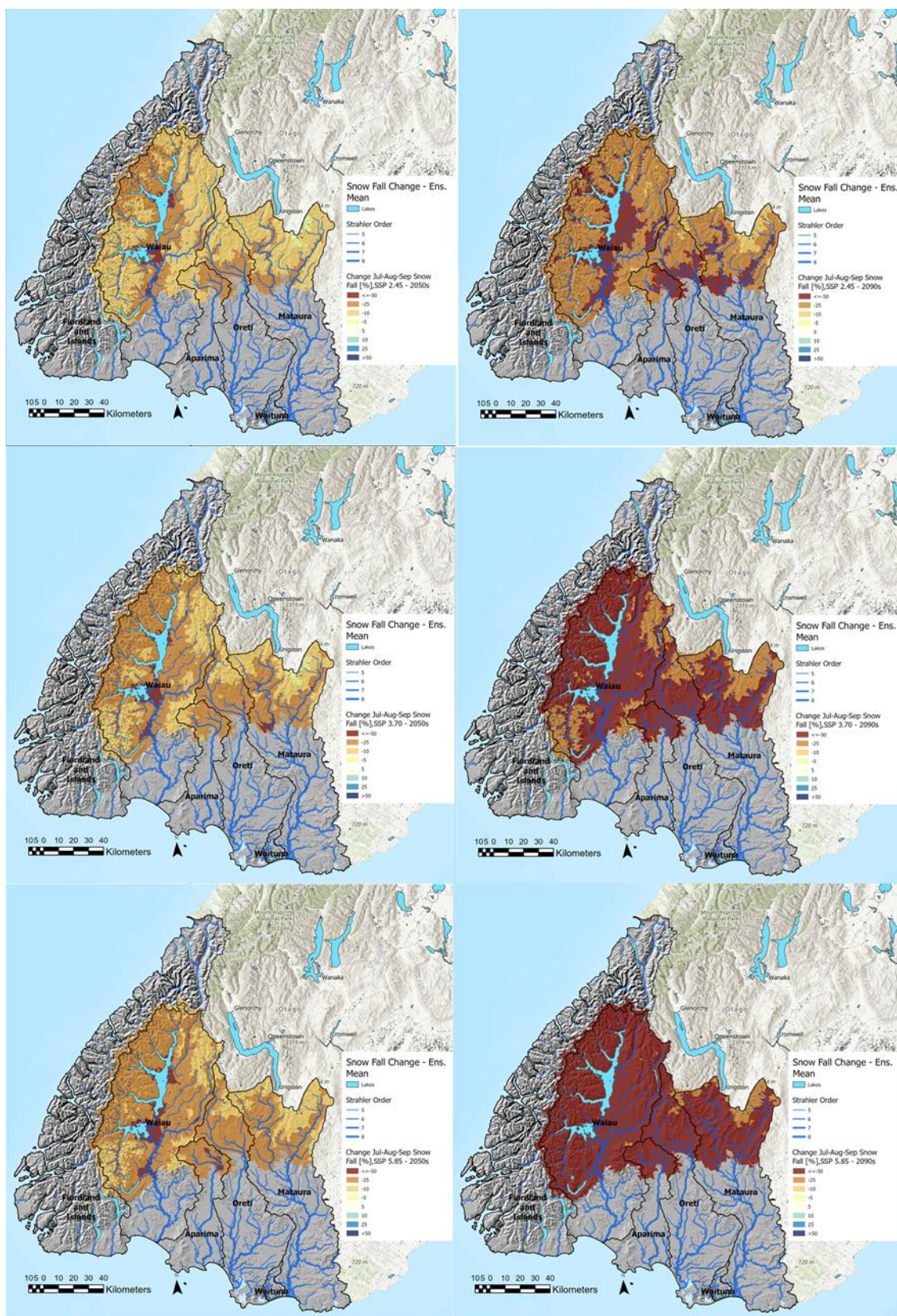


Figure 2-3: Change in multi-model average July-August-September (late winter) snowfall (based on snow year). Change in multi-model average seasonal snowfall is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hands panels).

2.2 Snow volume

Modelled historic and projected changes to annual and future seasonal snow volume for the period April-May-June (late autumn) and July-August-September (late winter) are illustrated for Southland mountain domain in Figure 2-4 to Figure 2-8, with the change for late spring (October-November-December time period) and late summer (January-February-March time period) presented in Appendix B. FMU wide average projected changes (generated across each FMU) are summarised in Table 2-3 (at annual time scale), Table 2-4 (during april-May-June and Table 2-5 (during July-August-September).

In this section, the snow volume is represented as the snow pack storage within the TopNet hydrological model and is represented as mm of snow water equivalent. To avoid confusion between snow volume and snow storage variable, the units associated with the snow storage are provided on Figure 2-4 and Figure 2-5 as mm H₂O/m².

Table 2-3: Projected changes in annual snow volume (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Aparima	-33.2	-68.8	-63.7	-83.2	-72.4	-95.8
Mataura	-37.2	-73.1	-63.2	-82.7	-67.2	-95.7
Oreti	-47.7	-77.2	-64.8	-81.2	-70.5	-96.2
Waiau	-48.4	-79.2	-63.7	-88.5	-66.8	-94.0
Fiordland	-53.8	-78.7	-65.6	-92.4	-65.4	-95.9

Table 2-4: Projected changes in seasonal snow volume during April-May-June (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Aparima	-45.4	-76.0	-61.7	-87.2	-64.9	-88.7
Mataura	-44.6	-78.3	-63.6	-85.6	-65.7	-87.5
Oreti	-39.9	-74.9	-62.4	-85.0	-68.7	-88.0
Waiau	-45.0	-75.3	-61.5	-84.8	-62.4	-88.8
Fiordland	-46.8	-77.4	-60.0	-85.8	-65.4	-75.1

Table 2-5: Projected changes in seasonal snow volume during July-August-September (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Aparima	-43.1	-68.7	-51.0	-81.7	-56.8	-83.9
Mataura	-39.0	-66.4	-46.9	-77.6	-51.3	-81.1
Oreti	-36.1	-67.1	-47.8	-80.8	-56.1	-83.0
Waiau	-34.7	-58.2	-42.5	-69.6	-44.6	-77.1
Fiordland	-36.4	-6.3	-42.2	-76.4	-49.3	-81.3

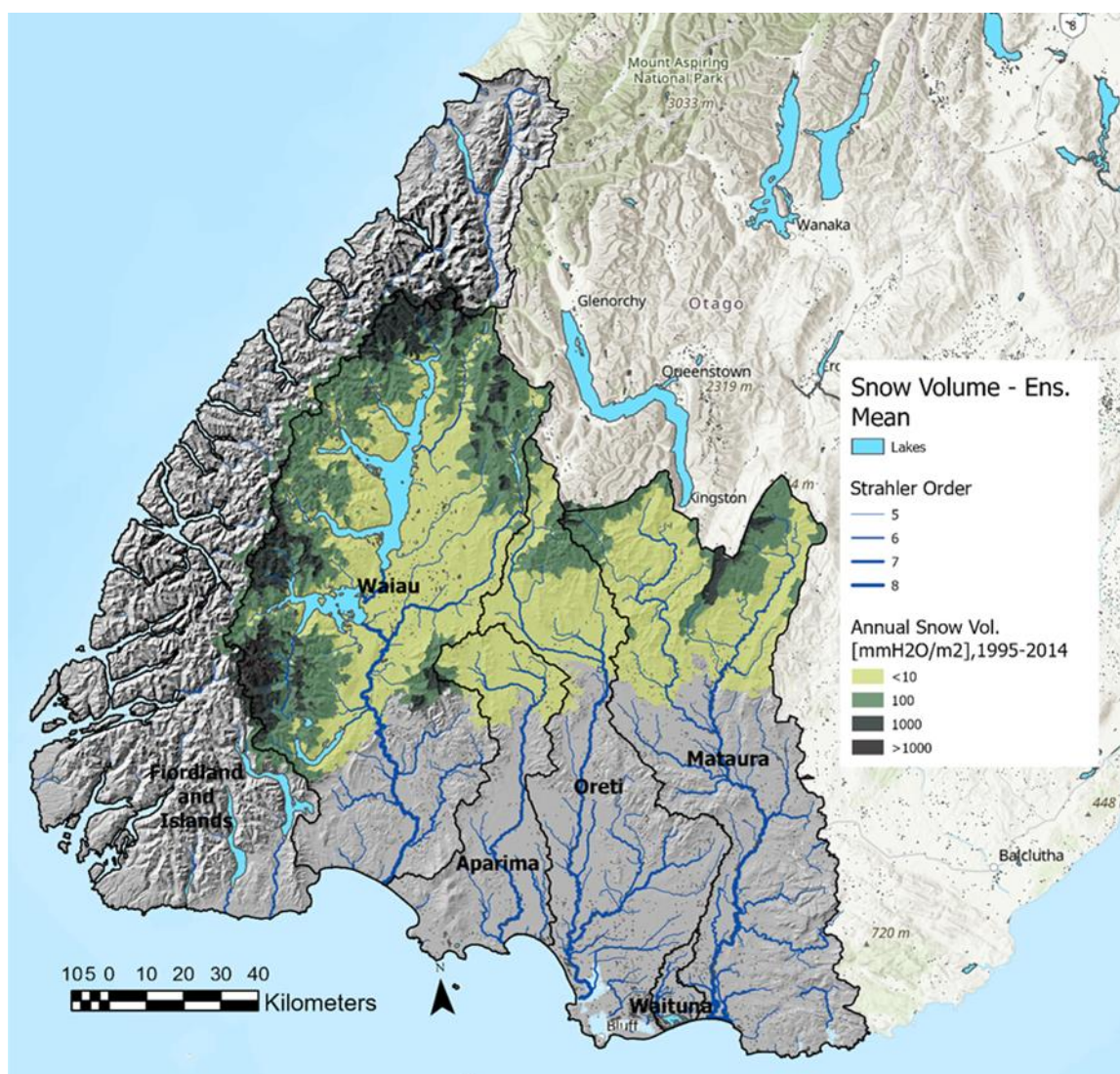


Figure 2-4: Historical multi-model average annual snow volume.

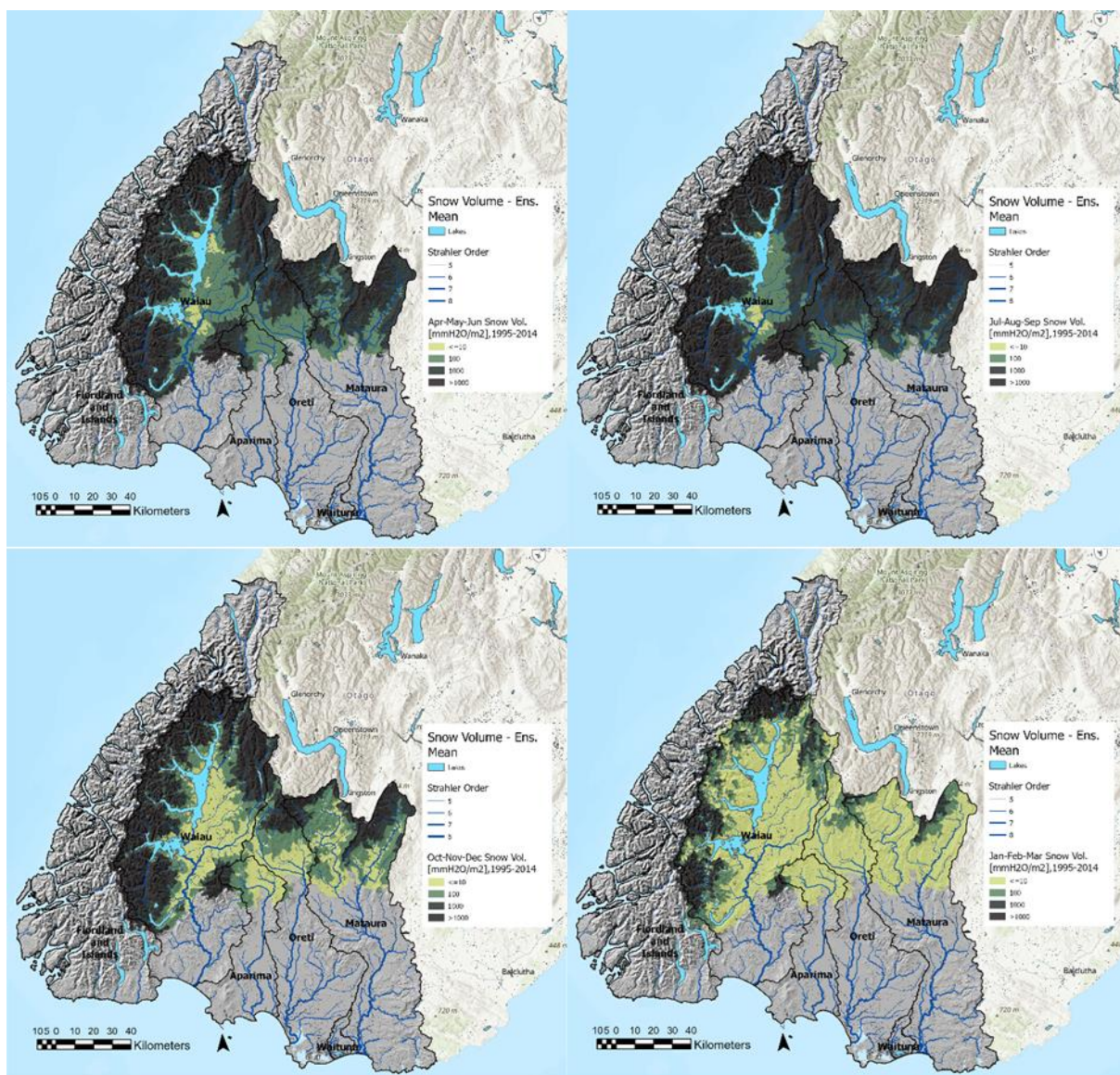


Figure 2-5: Historical multi-model average seasonal snow volume (based on snow year).

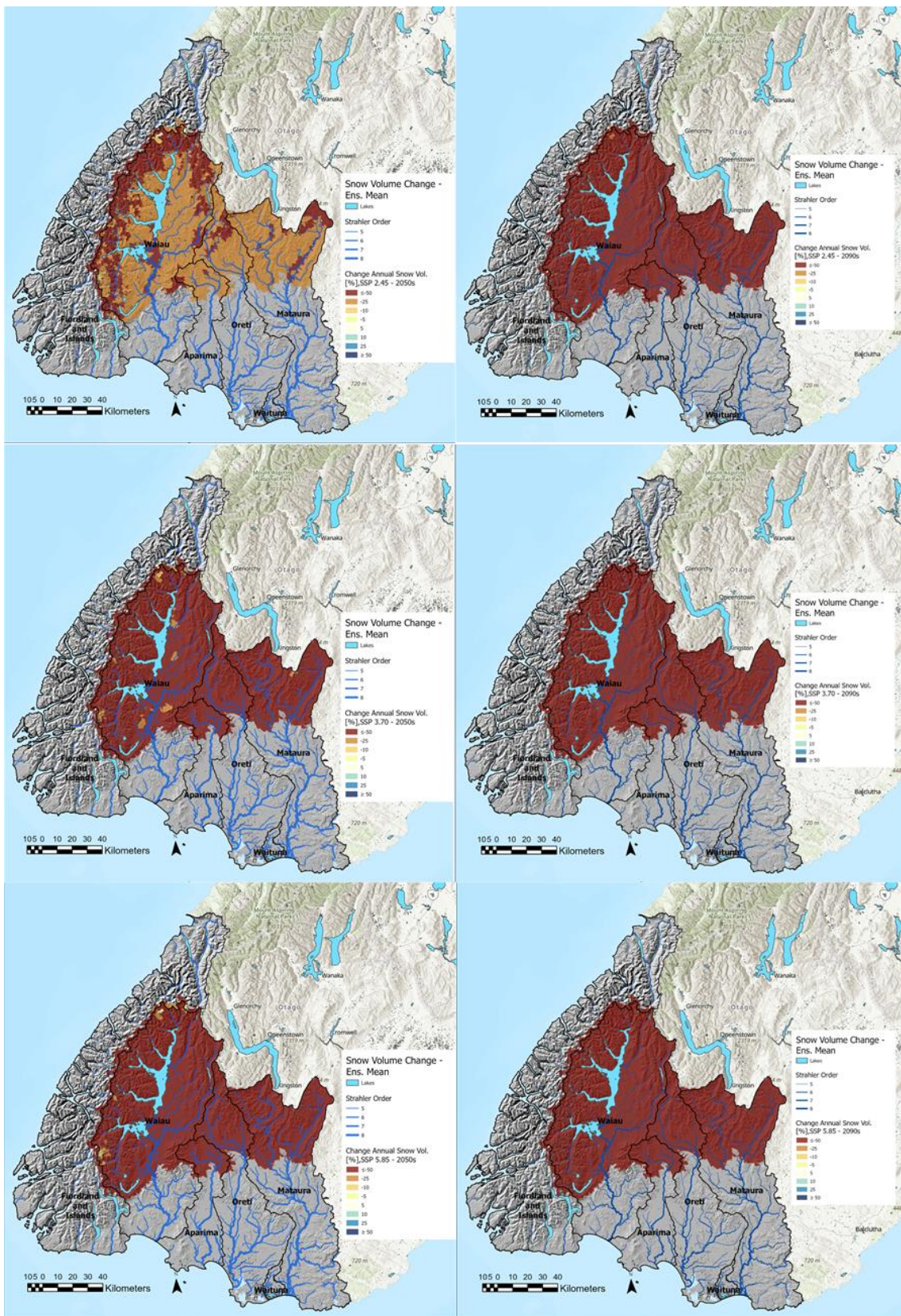


Figure 2-6: Change in multi-model annual average snow volume (based on snow year). Change in multi-model average annual snow volume is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hands panel).

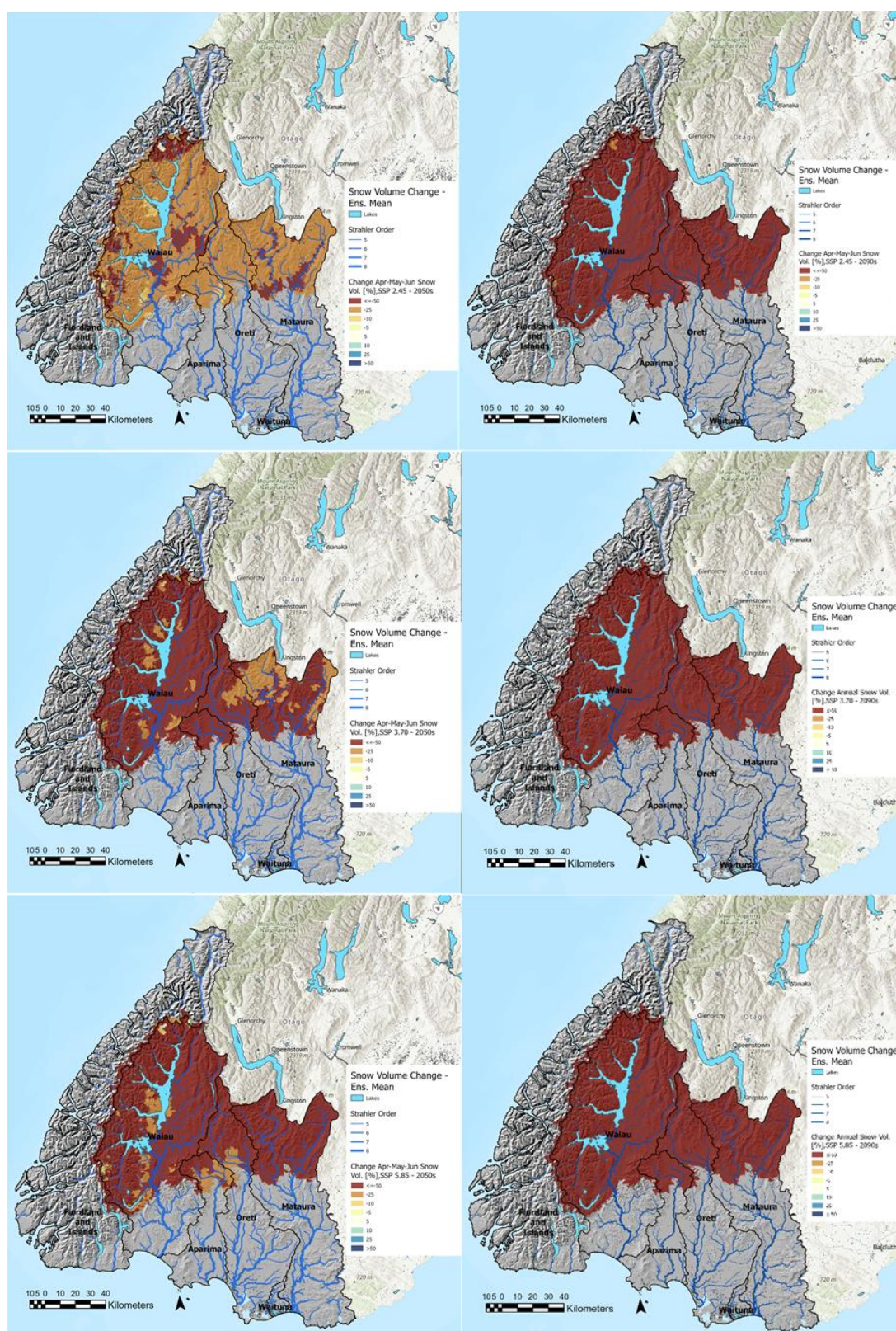


Figure 2-7: Change in multi-model average April-May-June (late autumn) snow volume (based on snow year). Change in multi-model average seasonal snow volume is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hands panels).

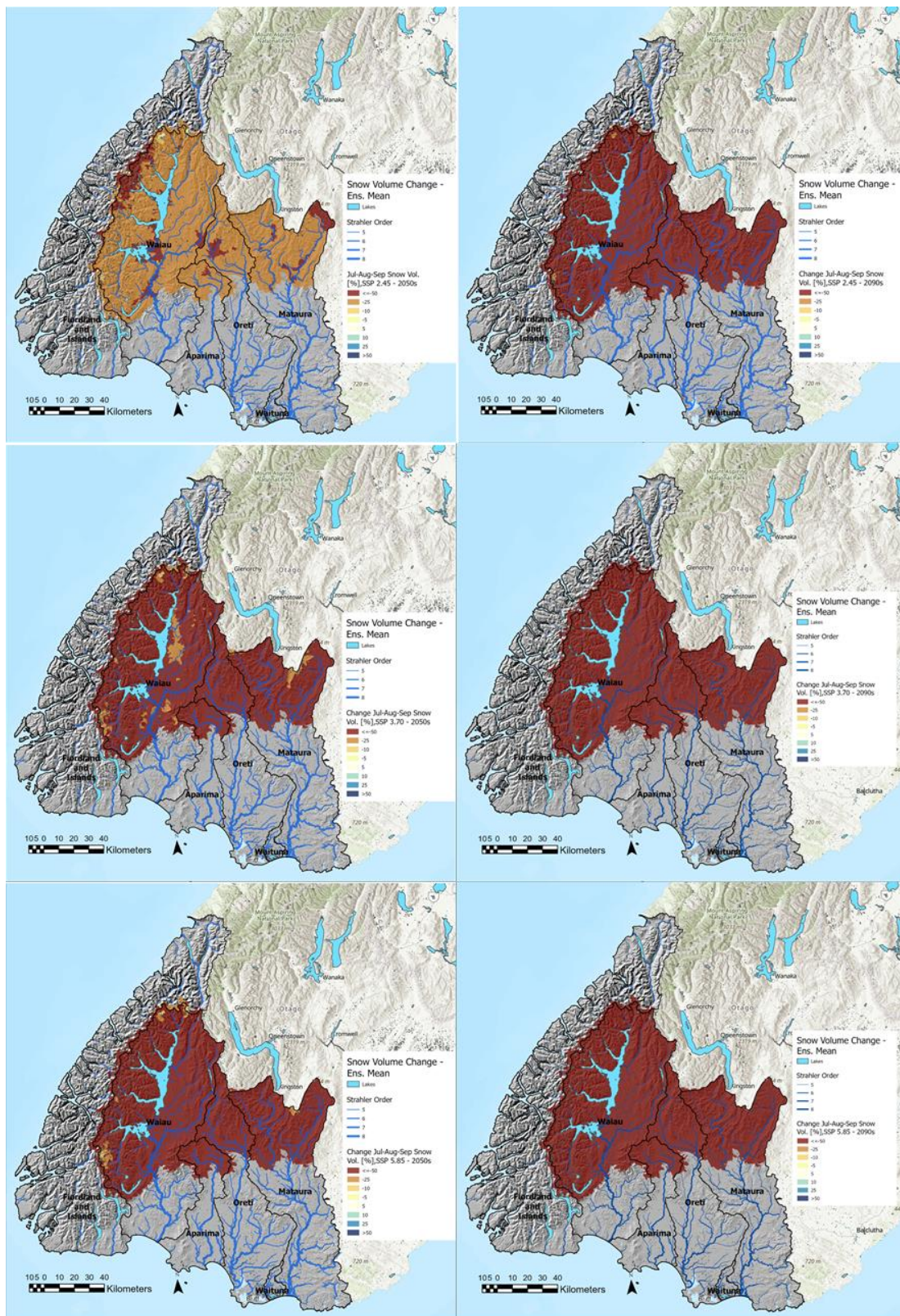


Figure 2-8: Change in multi-model average July-August-September (late winter) snow volume (based on snow year). Change in multi-model seasonal snow volume is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hands panel).

2.3 Snow melt

Projected changes to monthly snow melt across Southland's mountain domain are presented for the month of June (Figure 2-9), July (Figure 2-10), August (Figure 2-11) and September (Figure 2-12) with the change in snow melt across the remaining month presented in Appendix B.

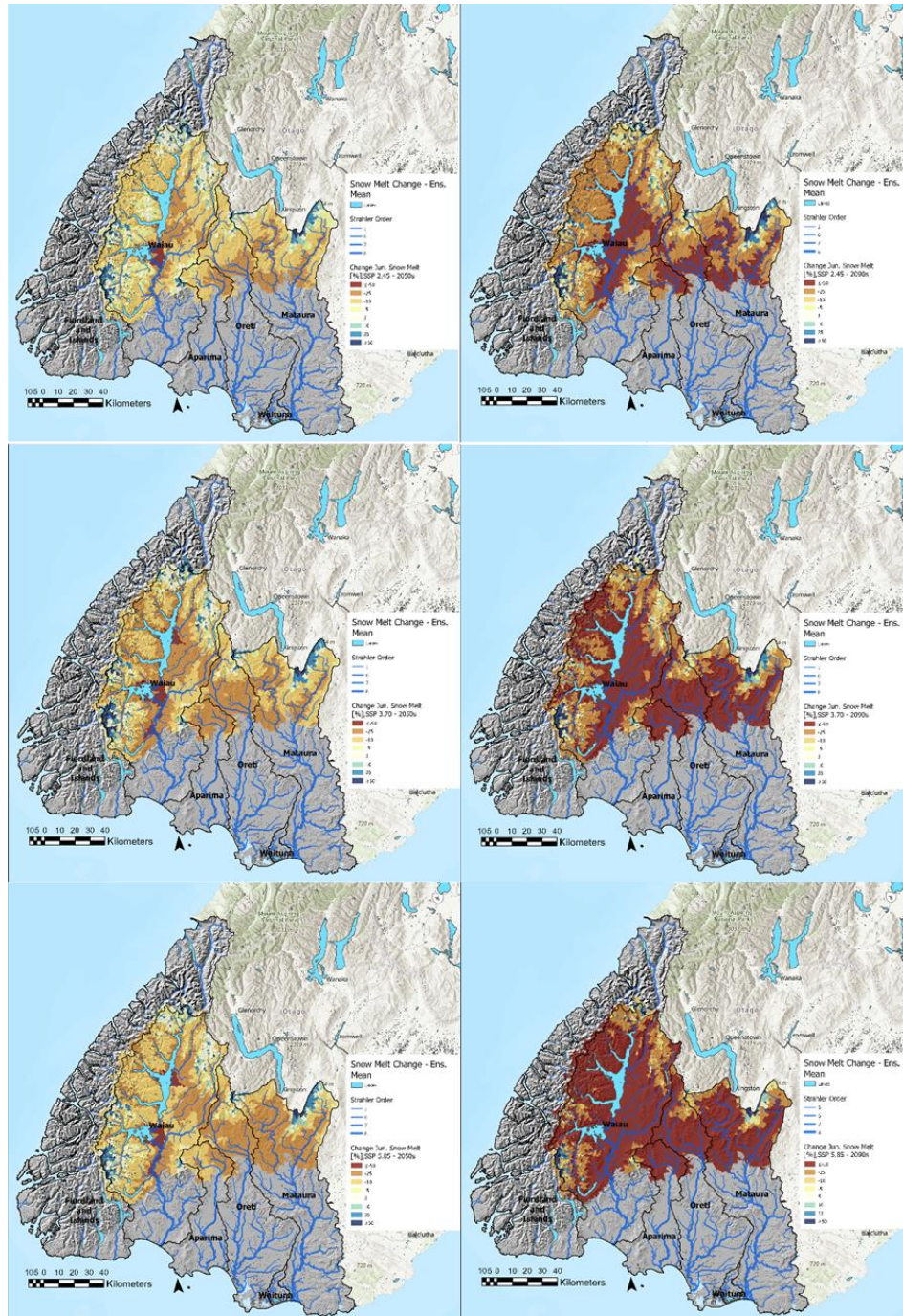


Figure 2-9: Change in multi-model average June snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hands panel).

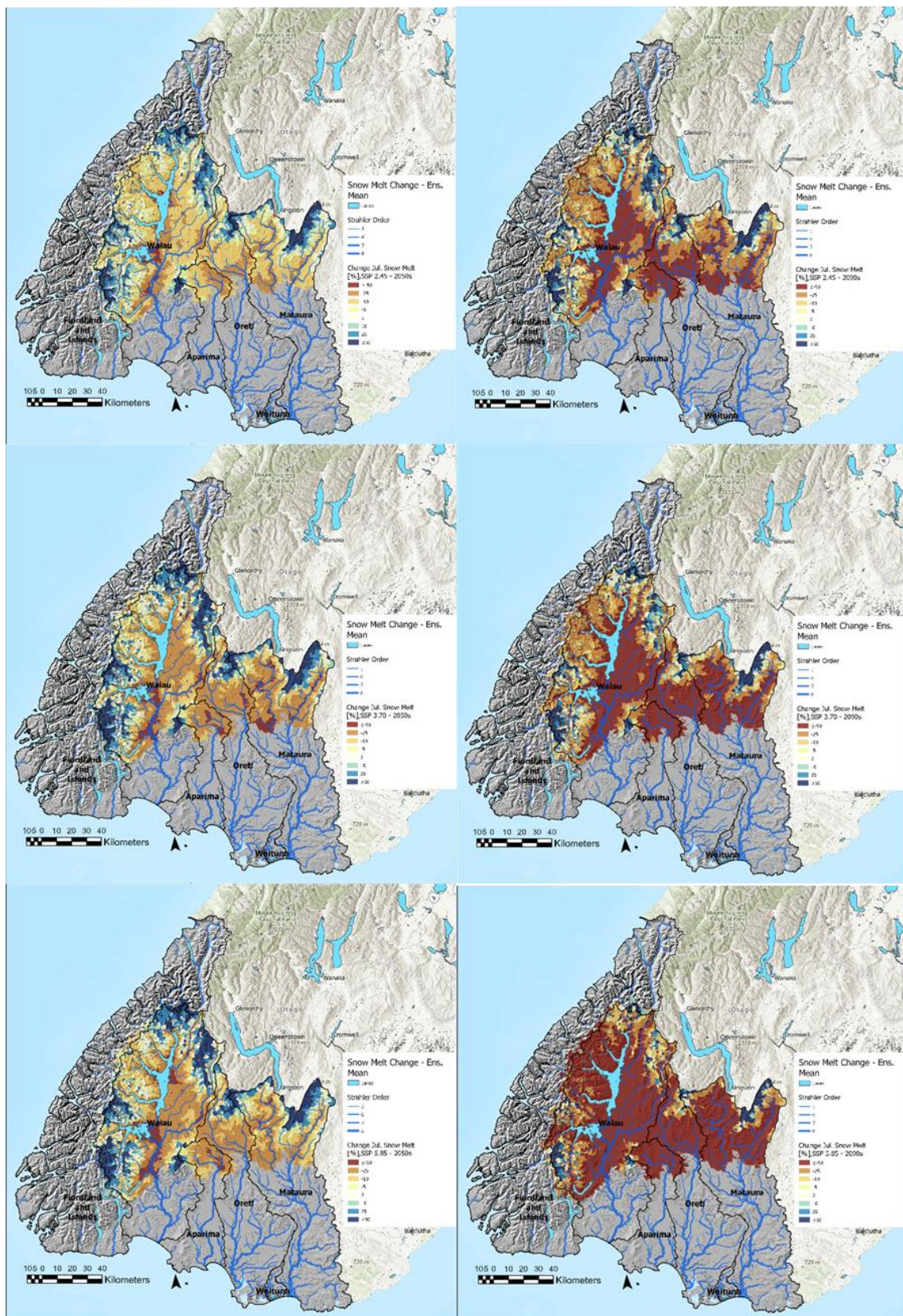


Figure 2-10: Change in multi-average July snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

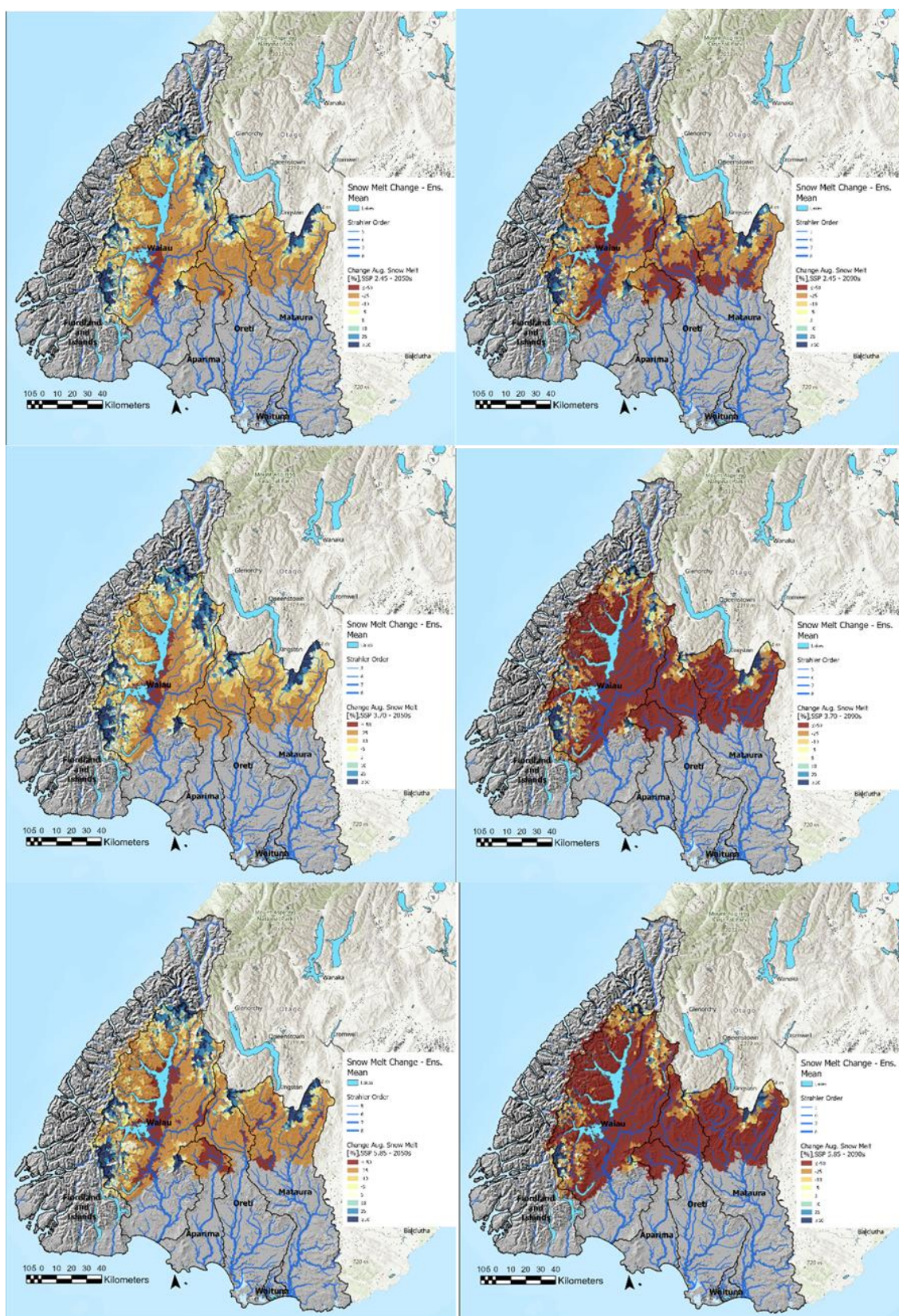


Figure 2-11: Change in multi-model August snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

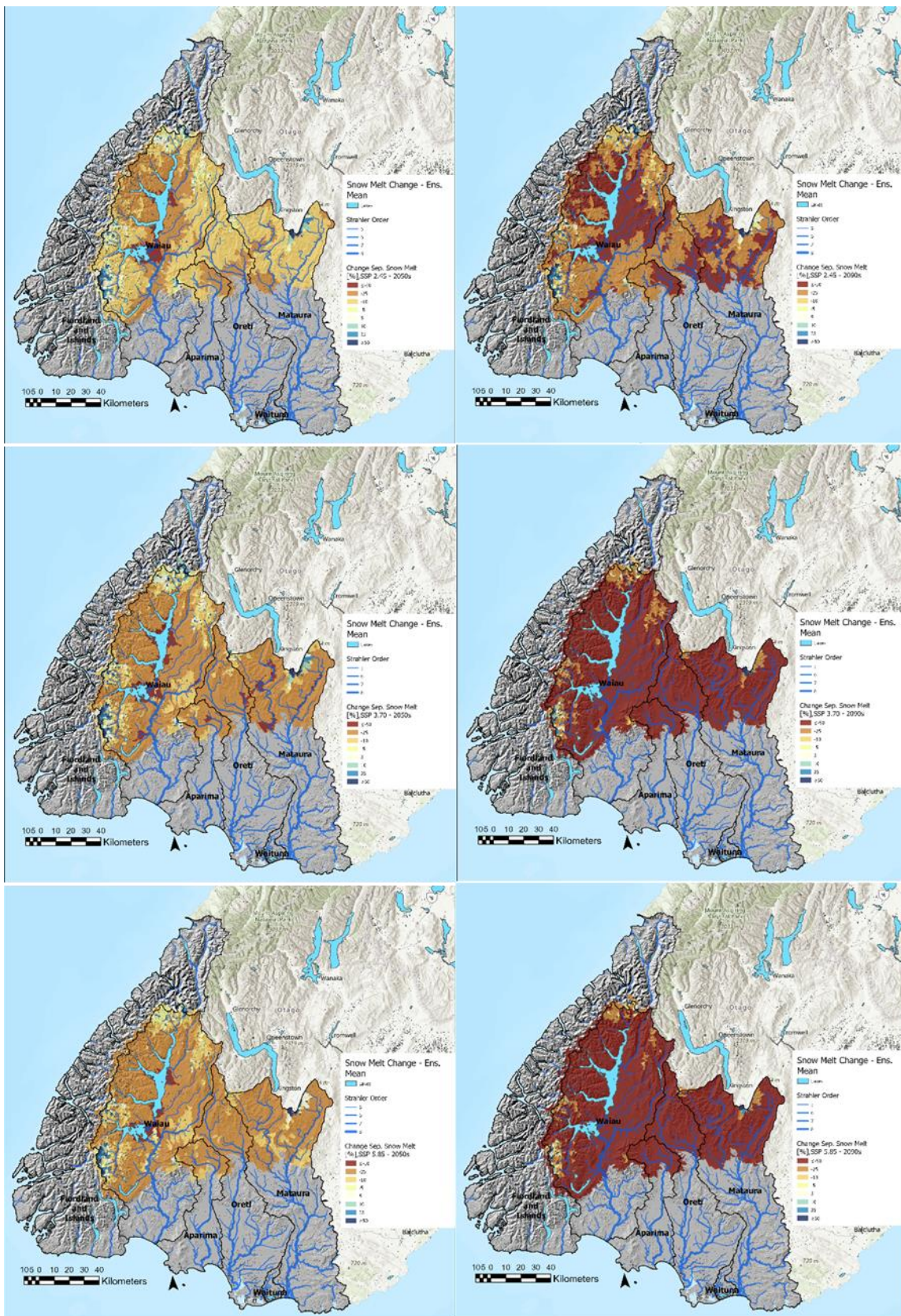


Figure 2-12: Change in multi-model September snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

2.4 Snow line

The seasonal snow line is defined as the elevation with an average annual snow cover duration of 90 days. The snow line is calculated here for the area upstream of terminal reach associated with each mountain range within each FMU (see Table 2-6). As the change in snow line elevation is to be used to assess the change in snow storage on hydro-electric lake storage within the Waiau FMU (Environment Southland, pers. comm.), snow line elevation for the Waiau mountain ranges is aggregated to the snow line elevation calculated at the outlet of each hydro-lakes.

Table 2-6: Mountain range information request.

Mountain range	Freshwater Management Unit	Terminal nzsegment
Eyre Mountains	Oreti	15335300
	Mataura	15405917
Thomson Mountains	Oreti	15317116
	Waiau (Mararoa)	15328572
Livingston Mountains	Waiau (Upukerora)	15217459
	Waiau (Whitestone)	15320684
Takitimu Mountains	Aparima (Hamilton Burn)	15404453
	Aparima	15325732
Garvie and Umbrella Mountains	Mataura (Waikaia)	15331068
Hunter Mountains, Kepler Mountains, Murchison Mountains, Stuart Mountains, Franklin Mountains, Earl Mountains (Waiau hydro-lakes)	Waiau – Te Anau	15325500
	Waiau – Manapouri	15333172
	Waiau - Monowai	15389669

Modelled historic and projected changes to snow elevation are illustrated in Table 2-8 and Table 2-9. Mountain averaged and hydro-lake projected changes in snow elevations are summarised in Table 2-7.

Table 2-7: Projected changes in annual snow volume (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Eyre Mountains	+220	+350	+260	+480	+280	+560
Thomson mountains	+220	+400	+250	+610	+280	+740
Livingston Mountains	+190	+360	+220	+540	+250	+660
Takitimu Mountains	+200	+350	+230	+460	+270	+510
Garvie and Umbrella Mountains	+260	+420	+300	+570	+330	+640
Te Anau	+210	+390	+250	+600	+280	+750
Manapouri	+220	+410	+260	+660	+290	+790
Monowai	+180	+350	+210	+500	+240	+580

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	+210	+380	+240	+560	+280	+670

Table 2-8: Historical multi-model ensemble snow line elevation for mountain ranges in Southland.

Mountain range	Freshwater Management Unit	Terminal nzsegment	Snow line elevation (masl)
Eyre Mountains	Oreti	15335300	1010
	Mataura	15405917	950
Thomson Mountains	Oreti	15317116	1060
	Waiau	15328572	980
Livingston Mountains	Waiau	15217459	870
		15320684	920
Takitimu Mountains	Aparima	15404453	1230
	Aparima	15325732	1000
Garvie and Umbrella Mountains	Mataura	15331068	1000
Te Anau	Waiau	15325500	940
Manapouri		15333172	870
Monowai		15389669	800

Table 2-9: Change in multi-model ensemble snow line elevation for mountain ranges in Southland (m).

Mountain range	Terminal nzsegment	SSP2-4.5		SSP3-7.0		SSP5-8.5	
		2050s	2090s	2050s	2090s	2050s	2090s
Eyre Mountains	15335300	+270	+460	+310	+670	+350	+780
	15405917	+310	+470	+350	+650	+380	+770
Thomson Mountains	15317116	+250	+430	+280	+630	+320	+740
	15328572	+180	+360	+210	+590	+240	+740
Livingston Mountains	15217459	+190	+360	+220	+580	+240	+750
	15320684	+180	+350	+210	+500	+250	+570
Takitimu Mountains ¹	15325732	+200	+350	+230	+460	+270	+510
Garvie and Umbrella Mountains	15331068	+260	+420	+300	+570	+330	+640

¹ Catchment draining to terminal nzsegment 15404453 is removed from the analysis as it does not extend high enough to be representative of changes on Takitimu Mountains.

Mountain range	Terminal nzsegment	SSP2-4.5		SSP3-7.0		SSP5-8.5	
		2050s	2090s	2050s	2090s	2050s	2090s
Te Anau	15325500	+210	+390	+250	+600	+280	+750
Manapouri	15333172	+220	+410	+260	+660	+290	+790
Monowai	15389669	+180	+350	+210	+500	+240	+580

2.5 Number of snow days

Modelled historic and projected changes to annual and future seasonal number of snow days across Southland's mountain range for the period April-May-June (late autumn) and July-August-September (late winter) are illustrated in Figure 2-13 to Figure 2-17, with the change for late spring (October-November-December) and late summer (January-February-March) presented in Appendix B. FMU wide average projected changes (generated across each FMU) are summarised in Table 2-10 (annual time scale) and Table 2-11 (during July-august-September).

Table 2-10: Projected changes in annual average snow days per year (days, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Aparima	-3.6	-6.4	-4.6	-8.0	-5.1	-8.8
Mataura	-6.2	-11.2	-8.1	-14.6	-8.7	-16.8
Oreti	-4.2	-7.5	-5.4	-9.5	-5.9	-10.8
Waiau	-15.2	-26.9	-18.6	-35.7	-20.4	-41.9
Fiordland	-10.3	-18.1	-12.6	-23.8	-13.8	-27.4

Table 2-11: Projected changes in seasonal snow days during July-August-September (days, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Aparima	-0.1	-0.1	-0.1	-0.2	-0.1	-0.2
Mataura	-2.7	-6.6	-5.2	-9.3	-6.0	-10.9
Oreti	-0.4	-0.4	-0.4	-0.6	-0.5	-0.6
Waiau	-5.2	-5.4	-5.1	-5.8	-5.4	-6.0
Fiordland	-34	-3.3	-3.4	-.8	-3.6	-3.8

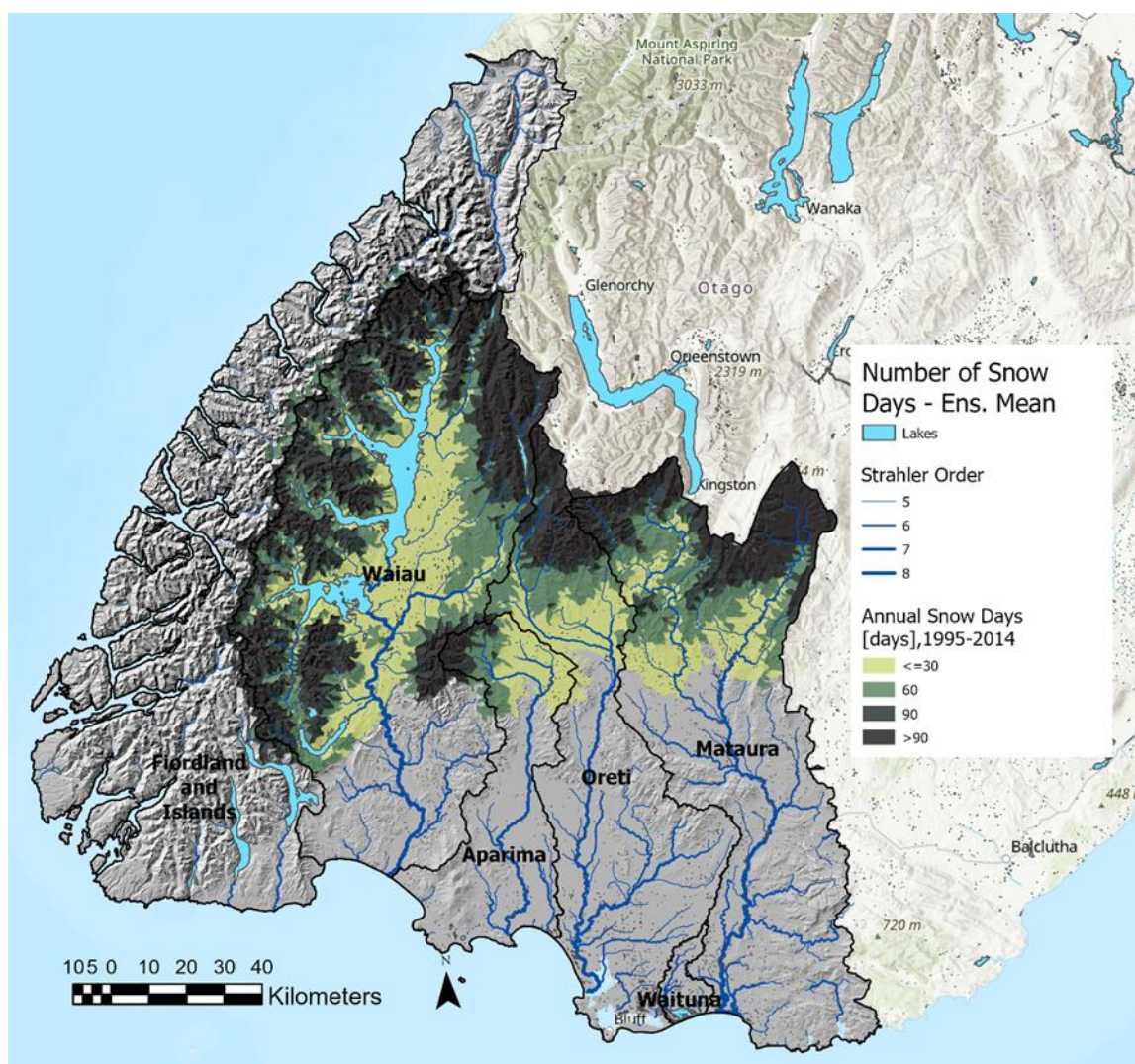


Figure 2-13: Historical multi-model average annual average snow days (based on snow year).

As part of the analysis, snow days are defined as days when snow fall occur and are identified as rainy days associated with air temperature lower than 1°C. As a result, it is likely that the historical winter snow days is underestimating the number of snow days during the winter period.

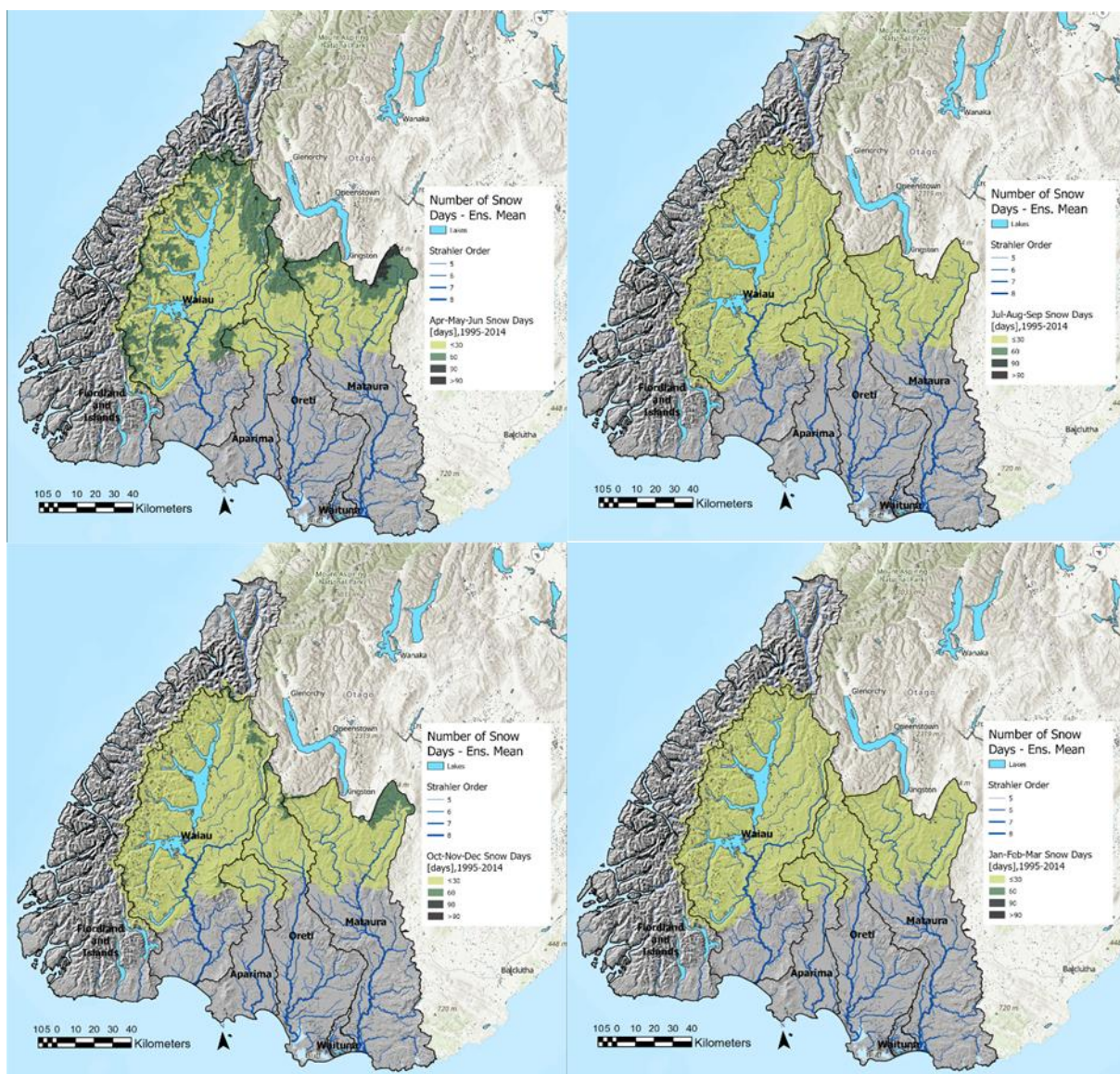


Figure 2-14: Historical multi-model average seasonal snow days (based on snow year). Snow days are defined as days when snow fall occur and are identified as rainy days associated with air temperature lower than 1°C.

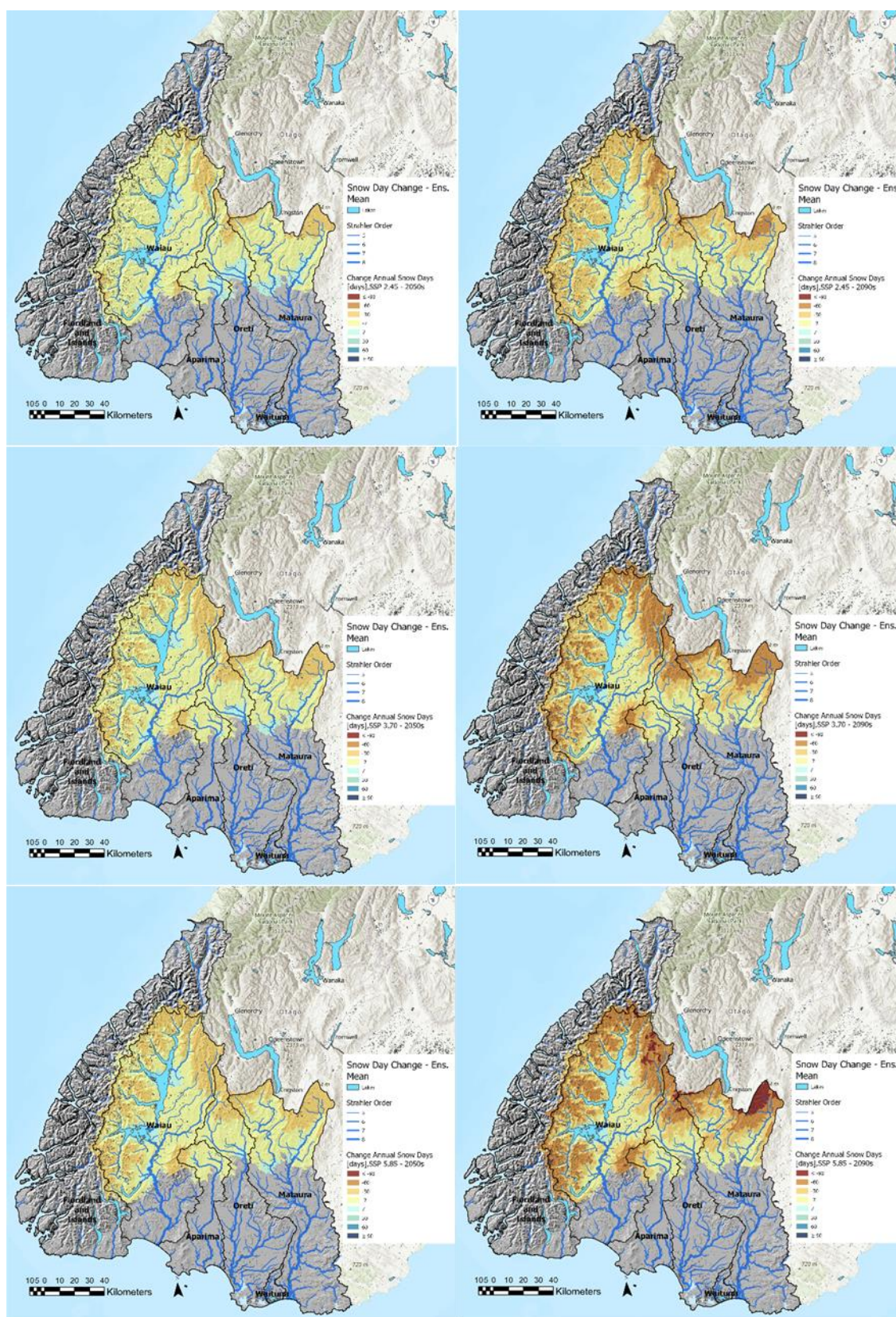


Figure 2-15: Change in multi-model average annual snow days (based on snow year). Change in multi-model average annual snow days is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

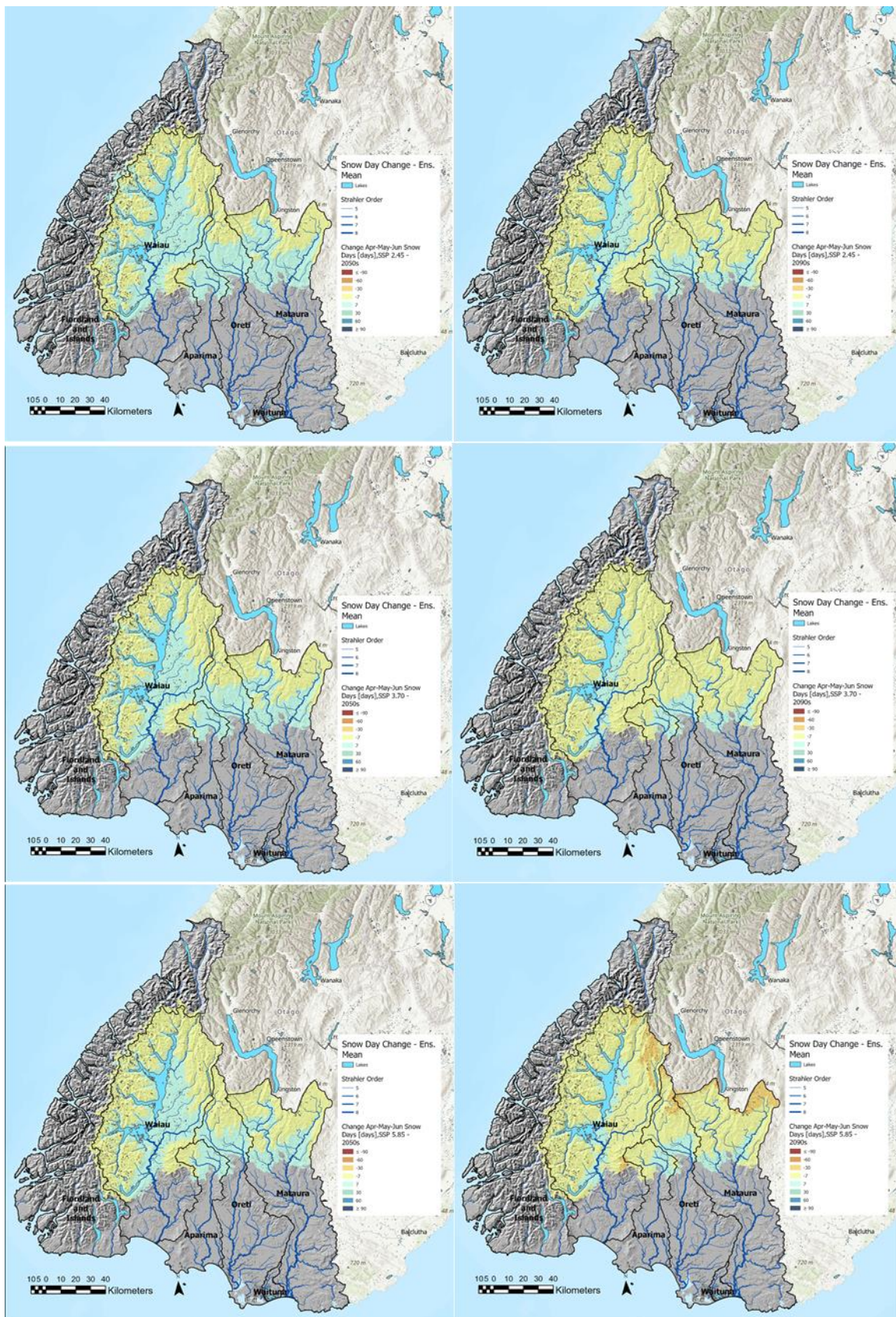


Figure 2-16: Change in multi-model average April-May-June (late autumn) snow days (based on snow year). Change in multi-model average seasonal snow days is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

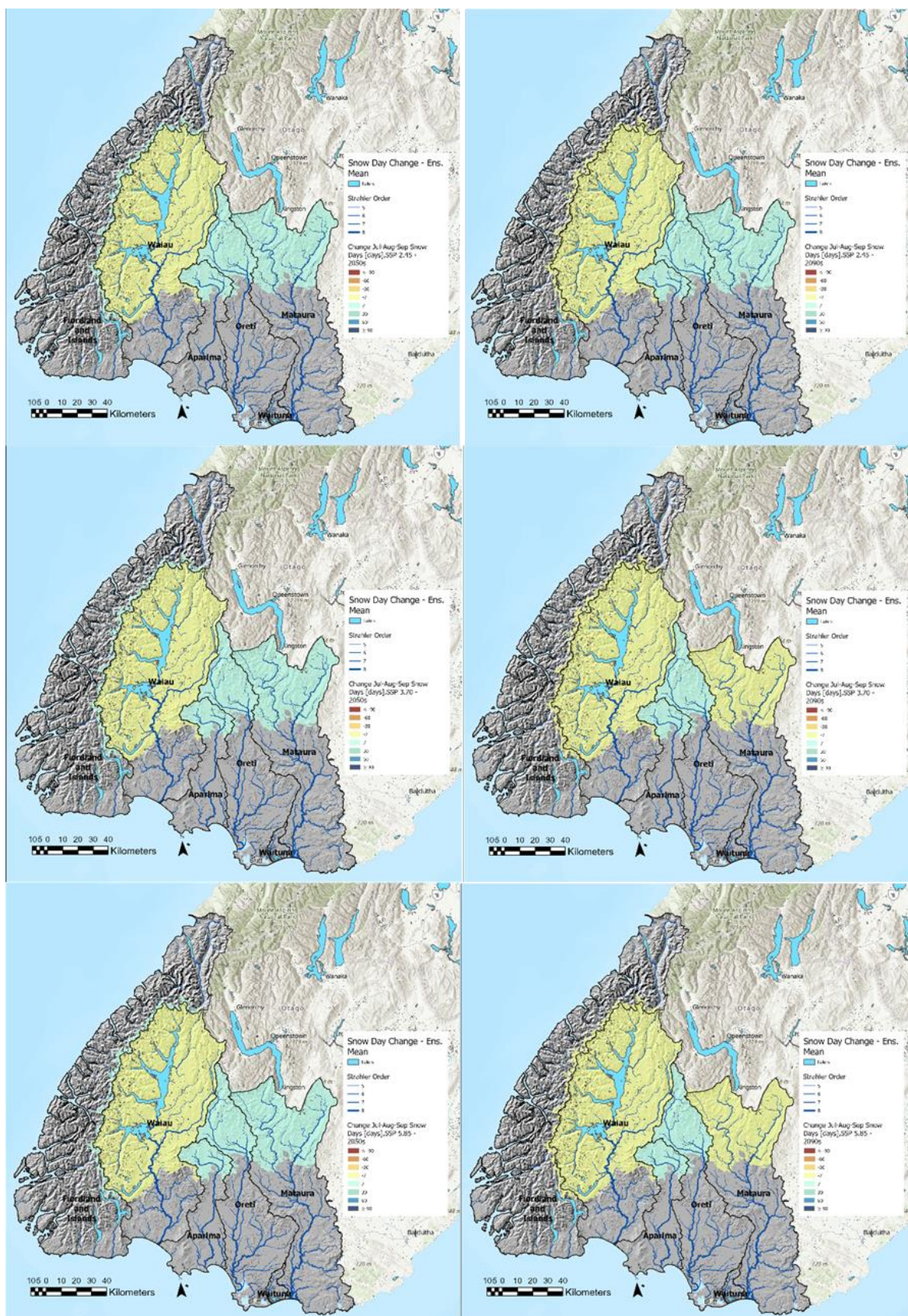


Figure 2-17: Change in multi-model average July-August-September (late winter) snow days (based on snow year). Change in multi-model average seasonal snow days is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3 Hydrological variables

This section covers the projected differences in several hydrological variables between the baseline period (1995–2014) and two future periods. These are mid-century (2041–2060) and late-century (2081–2098).

Figures in this section use the following colour scheme to represent the change in magnitude of the hydrological metrics (with the exception of the metric for flow and water supply reliability):

- Dark red-brown represents reduction by at least 50 percent.
- Light red-brown represents reduction between 25 percent and 50 percent.
- Orange represents reduction between 10 percent and 25 percent.
- Dark yellow represents reduction between 5 percent and 10 percent.
- Light yellow represents a change between -5 percent and 5 percent and is considered to represent little change in the hydrological metric.
- Light blue represents an increase between 5 percent and 10 percent.
- Blue represents an increase between 10 percent and 25 percent.
- Light dark blue represents an increase between 25 percent and 50 percent.
- Dark blue represents an increase by at least 50 percent.

3.1 Mean Annual Flood

Modelled historic daily and hourly mean annual flood (MAF) are illustrated Figure 3-1 and Figure 3-2 (*resp.*). Change in projected daily mean annual flood is presented in Figure 3-3, while change in projected hourly mean annual flood is presented in Appendix C. FMU-wide average projected changes in daily mean annual flood (generated across each FMU) are summarised in Table 3-1.

Table 3-1: FMU scale projected changes in daily MAF (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	20.0	28.2	25.6	29.3	25.2	41.5
Aparima	27.0	45.9	35.9	46.8	32.8	68.0
Fiordland and Islands	15.5	17.9	16.8	20.2	21.3	28.9
Mataura	23.5	34.3	34.1	30.7	26.1	40.4
Oreti	21.9	32.6	28.4	38.9	26.8	51.5
Waiau	18.7	27.9	23.9	27.6	25.4	45.0
Waituna	33.1	46.6	47.3	50.2	38.3	60.0

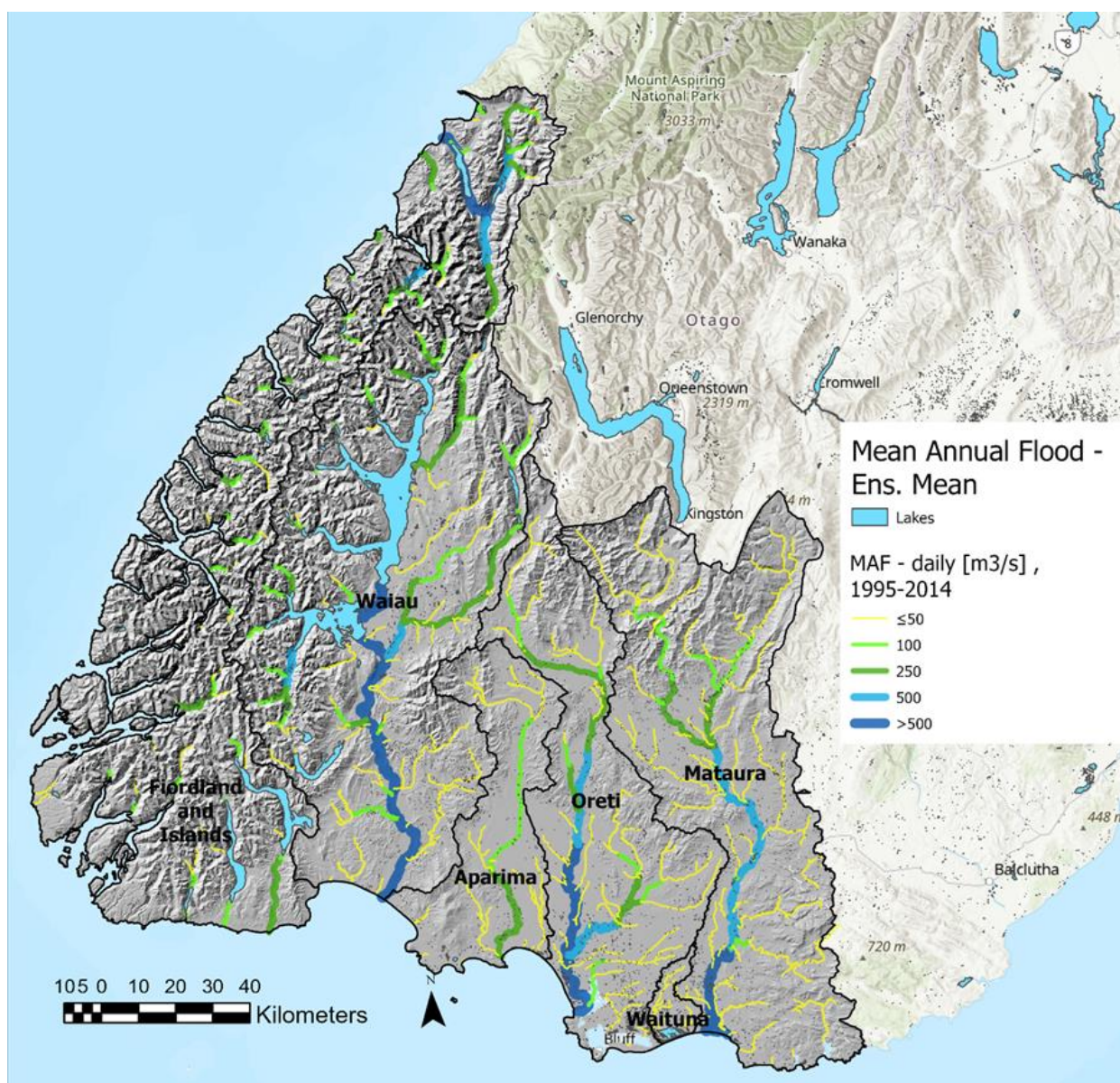


Figure 3-1: Historical multi-model average daily mean annual flood.

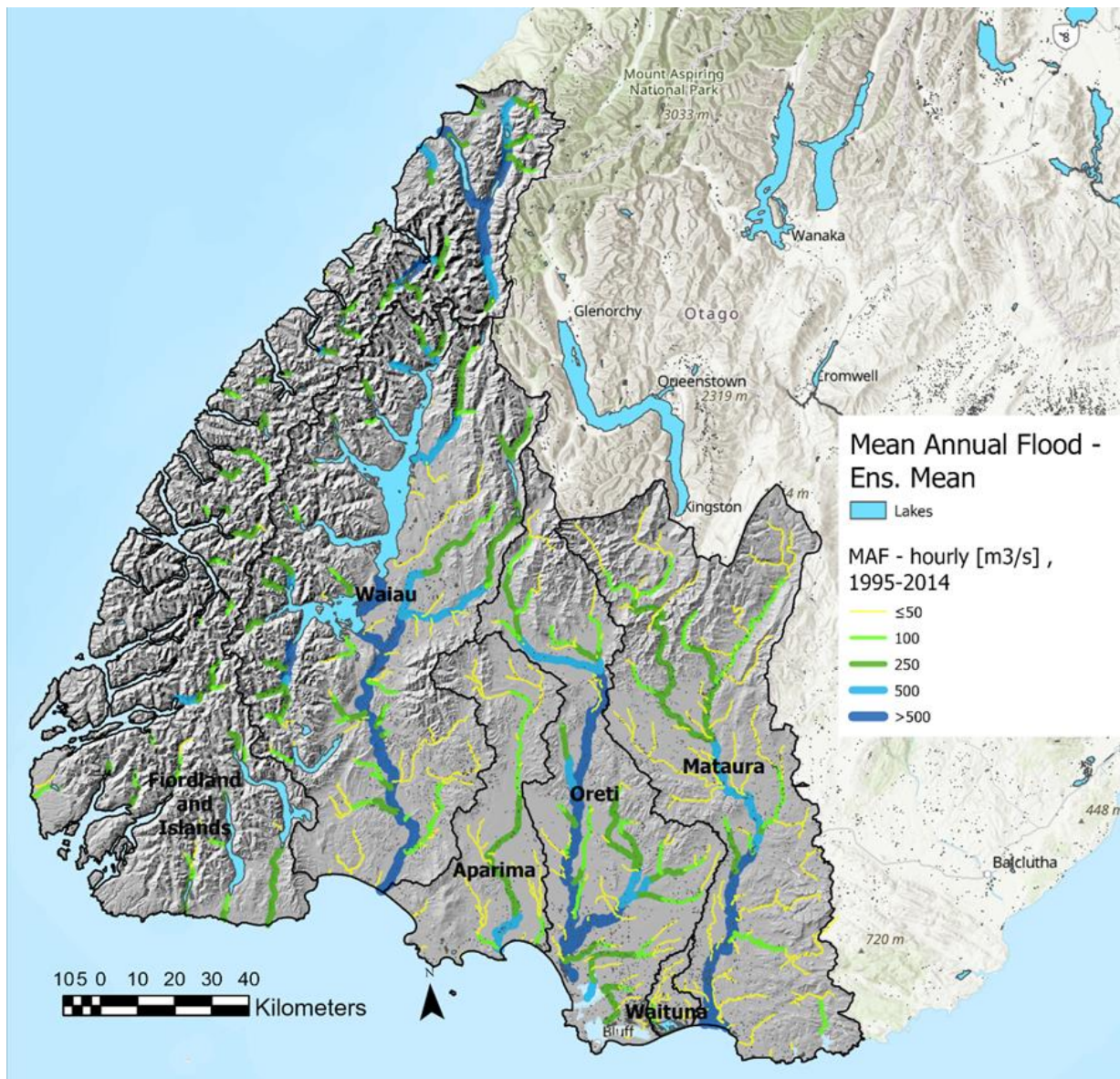


Figure 3-2: Historical multi-model average hourly mean annual flood.

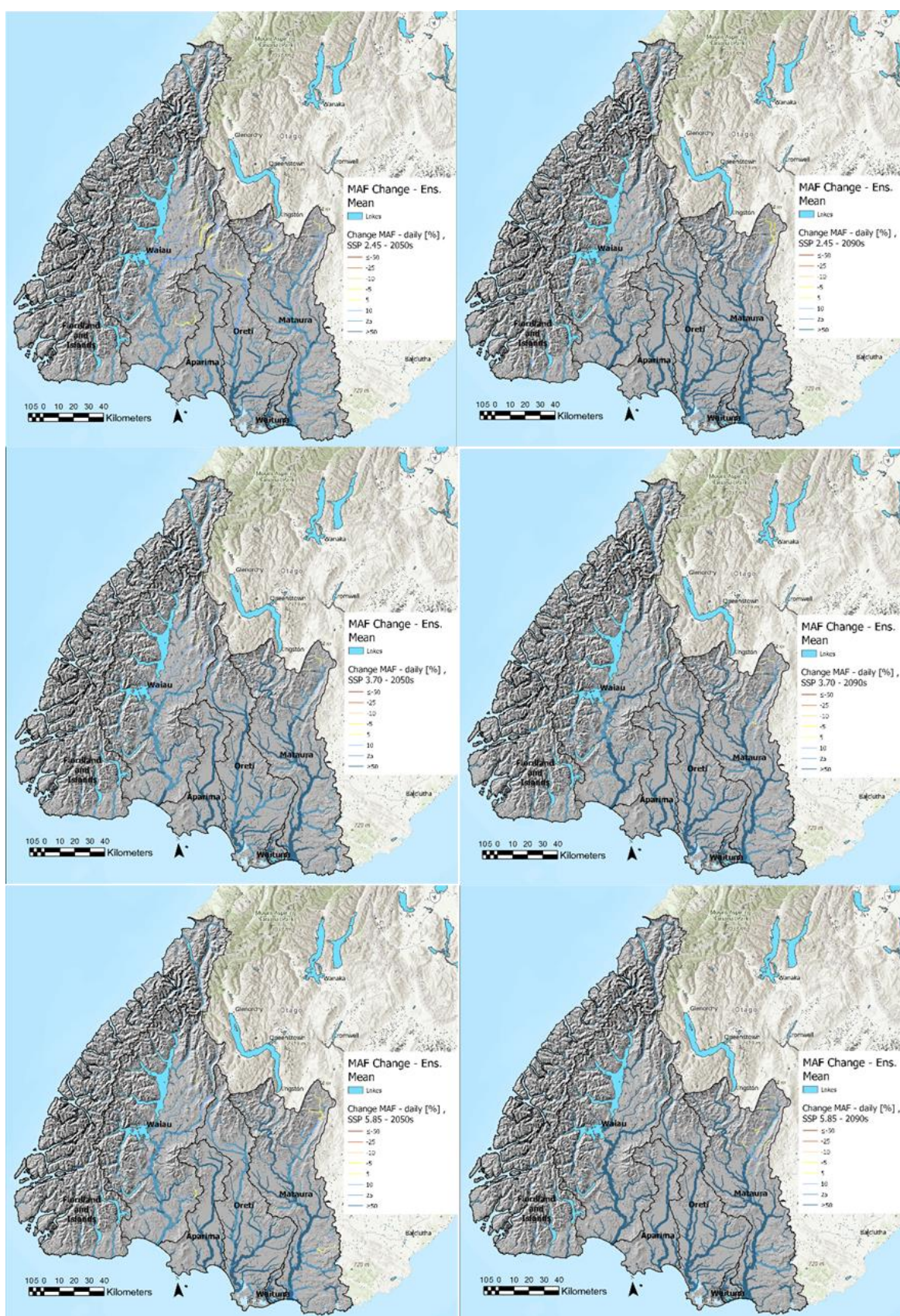


Figure 3-3: Change in multi-model average daily mean annual flood. Change in multi-model average daily mean annual flood for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.2 Q5

Modelled historic and projected changes to Q5 (river flow magnitude exceeded five percent of the time) are illustrated Figure 3-4 and Figure 3-5. FMU-wide average projected changes (generated across each FMU) are summarised in Table 3-2, while location-specific projected changes are shown in Table 3-3.

Table 3-2: FMU scale projected changes in Q5 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	7.3	12.7	7.5	13.6	7.7	20.0
Aparima	9.5	16.8	5.6	14.3	6.3	24.4
Fiordland and Islands	5.7	9.3	6.5	12.2	8.1	16.1
Mataura	6.8	11.6	7.6	9.4	5.9	16.1
Oreti	10.6	18.9	10.6	22.4	9.3	30.4
Waiau	7.3	12.9	7.1	12.7	7.9	19.4
Waituna	8.2	17.5	9.6	18.9	7.7	31.9

Table 3-3: Location specific projected changes in Q5 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	8.0	11.1	5.7	11.0	3.9	15.2
Mataura River at Gore Township	10.0	13.0	11.0	12.7	8.7	17.3
Mataura Catchment to Wyndham Catchment Township	9.7	13.3	9.7	11.9	9.0	17.0
Waikaia Catchment to Waikaia Township	1.7	5.4	0.6	6.3	0.0	5.5
Waikaka Stream to Gore Township	8.3	10.7	9.4	6.9	10.3	15.5
Waikawa Catchment	5.3	7.0	6.1	7.4	0.2	9.3
Waimea Catchment	11.4	18.2	12.2	11.1	12.3	23.5
Waituna Catchment	8.1	18.0	10.9	18.5	7.8	31.2
Mokoreta Catchment	5.9	7.3	7.7	4.7	3.7	10.9
Waikaia Catchment	5.5	8.6	5.9	9.8	5.9	12.1
Makarewa Catchment	15.1	19.6	16.2	26.9	17.0	38.9
Oreti Catchment to Lumsden Township	8.1	14.2	6.1	18.4	7.3	25.2
Oreti Catchment to Winton Township	11.5	15.4	11.2	19.5	11.3	23.7
Oreti Catchment to Wallacetown	9.4	13.9	11.4	20.3	11.2	24.4
Waihopai River to Invercargill City	10.1	15.7	10.7	16.6	8.9	27.6
Otepuni Stream to Invercargill City	8.5	18.9	11.0	17.2	7.8	30.6
Kingswell Creek at Invercargill City	8.0	16.0	10.8	18.2	7.1	23.1
Irthing Stream at Ellis Road	14.5	15.1	6.4	24.3	8.0	25.8
Winton Stream to Winton Township	9.7	21.6	8.9	24.8	8.8	30.7
Aparima River to Otautau Township	6.9	10.6	7.4	10.9	9.6	19.7

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Otautau Stream to Otautau Township	2.7	13.2	3.4	18.2	3.2	18.7
Aparima River at Thornbury Bridge	9.8	13.5	7.0	14.6	9.1	24.7
Whitestone Catchment	5.8	17.3	7.2	17.9	11.7	28.3
Upukerora Catchment	8.8	15.6	6.5	21.4	8.4	26.4
Mararoa Catchment	7.2	15.5	7.5	17.3	9.8	22.8
Orauea Catchment	6.1	10.1	6.8	9.7	1.1	14.2
Waiau River at Tutapere	10.4	15.7	8.9	22.0	10.8	26.7

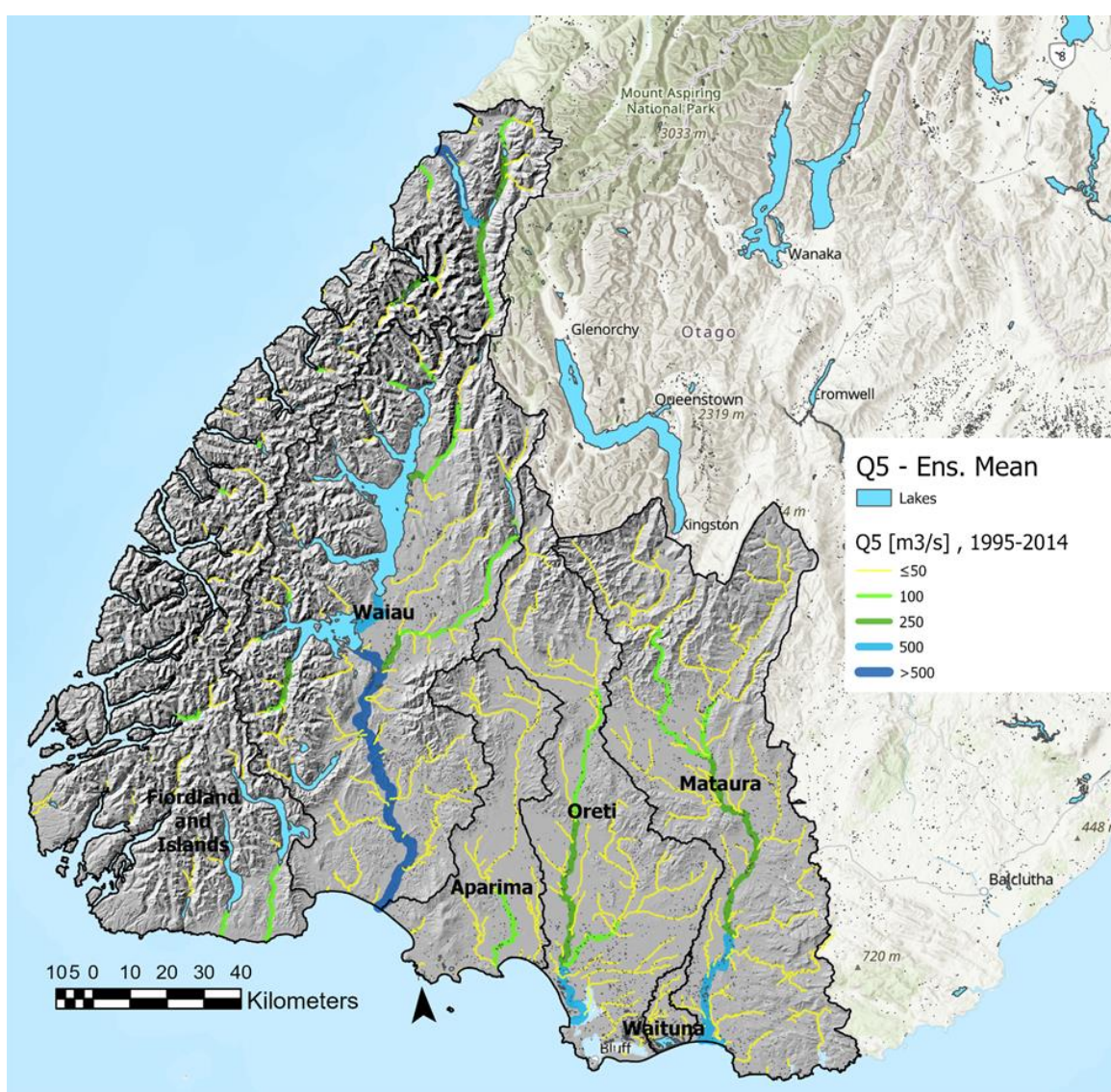


Figure 3-4: Historical multi-model mean Q5.

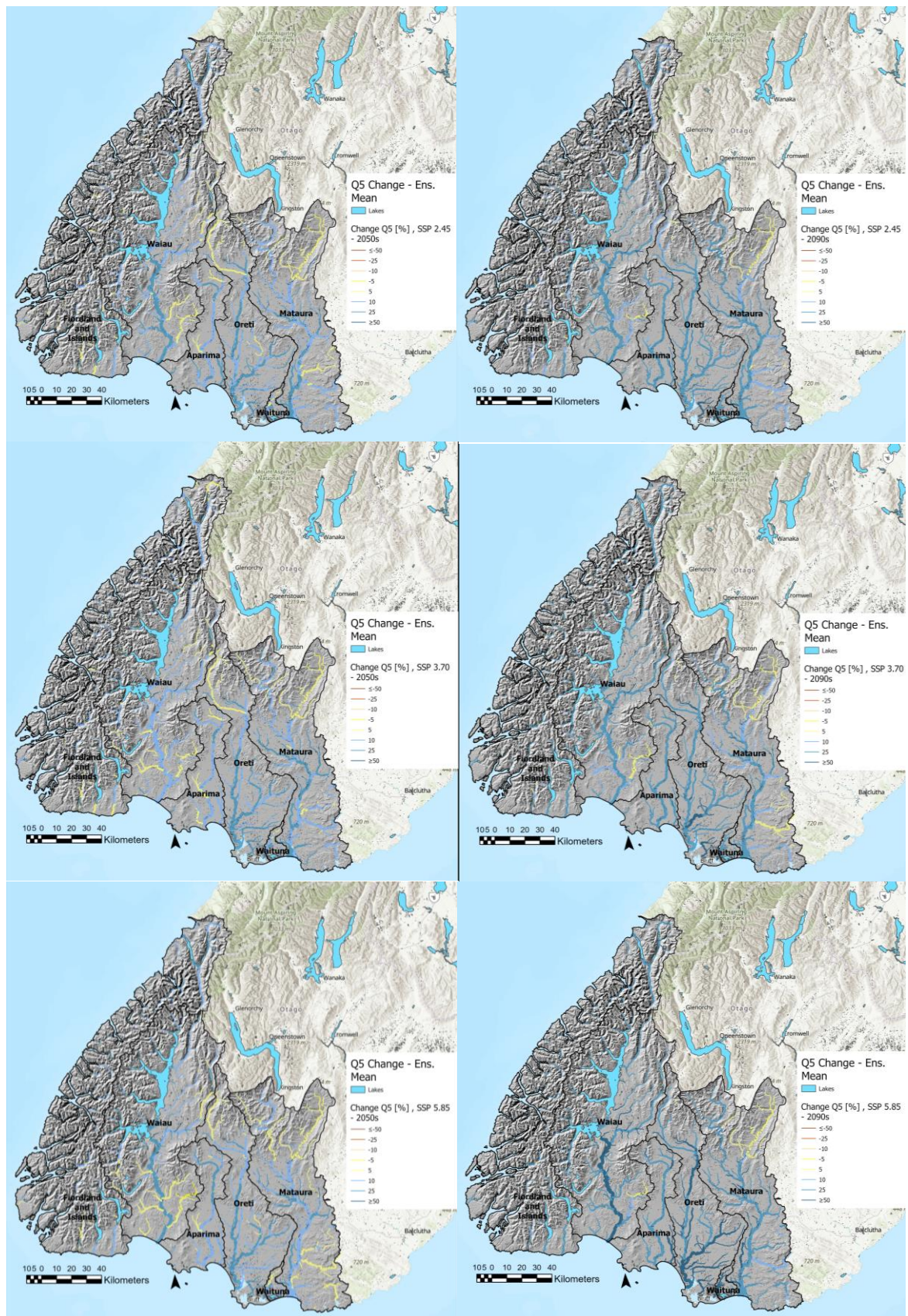


Figure 3-5: Change in multi-model average Q5. Change in multi-model average Q5 for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.3 Fre3 events

Modelled historical annual and seasonal average number of Fre3 events (flows exceeding three times the median flow), calculated as ≥ 3 day gaps between Fre3 events, are illustrated in Figure 3-6 and Figure 3-7, while Figure 3-8 and Figure 3-9 present historical annual and seasonal number of Fre3 events, calculated using 5 day gaps between Fre3 events. Projected changes in average annual number of Fre3 events calculated using 3 day gaps between Fre3 events are presented in Figure 3-10, while changes in June-July-August (winter) and December-January-February (summer) are presented in Figure 3-11 and Figure 3-12. Appendix C presents future changes in average number of Fre3 events calculated using 3 day gaps between Fre3 events for September-October-November (spring) and March-April-May (autumn), as well as annual and seasonal change in average number of Fre3 events calculated using 5-day gaps between Fre3 events. FMU wide average projected changes in average number of annual and winter and summer Fre3 events calculated using 3-day gaps between Fre3 events (generated across each FMU) are summarised in Table 3-4 (annual time scale), Table 3-5 (winter), and Table 3-6 (summer).

Table 3-4: FMU scale projected changes in annual average number of Fre3 events with 3-day gaps (average number of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.4	0.8	0.5	0.9	0.5	1.3
Aparima	0.5	0.9	0.6	1.2	0.5	1.6
Fiordland and Islands	0.4	0.9	0.7	1.1	0.8	1.4
Mataura	0.4	0.7	0.6	0.9	0.5	1.2
Oreti	0.3	0.9	0.3	0.9	0.3	1.3
Waiau	0.3	0.6	0.4	0.6	0.5	0.9
Waituna	0.4	0.4	0.4	1.0	0.6	1.4

Table 3-5: FMU scale projected changes in winter average number of Fre3 events with 3-day gaps (average number of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.2	0.4	0.4	0.5	0.3	0.5
Aparima	0.2	0.3	0.2	0.3	0.1	0.4
Fiordland and Islands	0.3	0.5	0.6	0.8	0.5	0.8
Mataura	0.1	0.3	0.2	0.3	0.2	0.3
Oreti	0.1	0.2	0.1	0.1	0.0	0.0
Waiau	0.3	0.5	0.5	0.6	0.4	0.7
Waituna	0.3	0.2	0.2	0.2	0.1	0.2

Table 3-6: FMU scale projected changes in summer average number of Fre3 events with 3-day gaps (average number of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	-0.1	0.0	0.0	0.0	0.0	0.2
Aparima	0.1	0.1	0.2	0.3	0.1	0.5
Fiordland and Islands	-0.2	-0.1	-0.1	-0.1	0.0	0.0
Mataura	0.0	0.1	0.1	0.2	0.1	0.3
Oreti	0.0	0.2	0.1	0.3	0.2	0.5
Waiau	-0.1	-0.1	0.0	-0.1	-0.1	0.1
Waituna	0.0	0.1	0.1	0.3	0.2	0.4

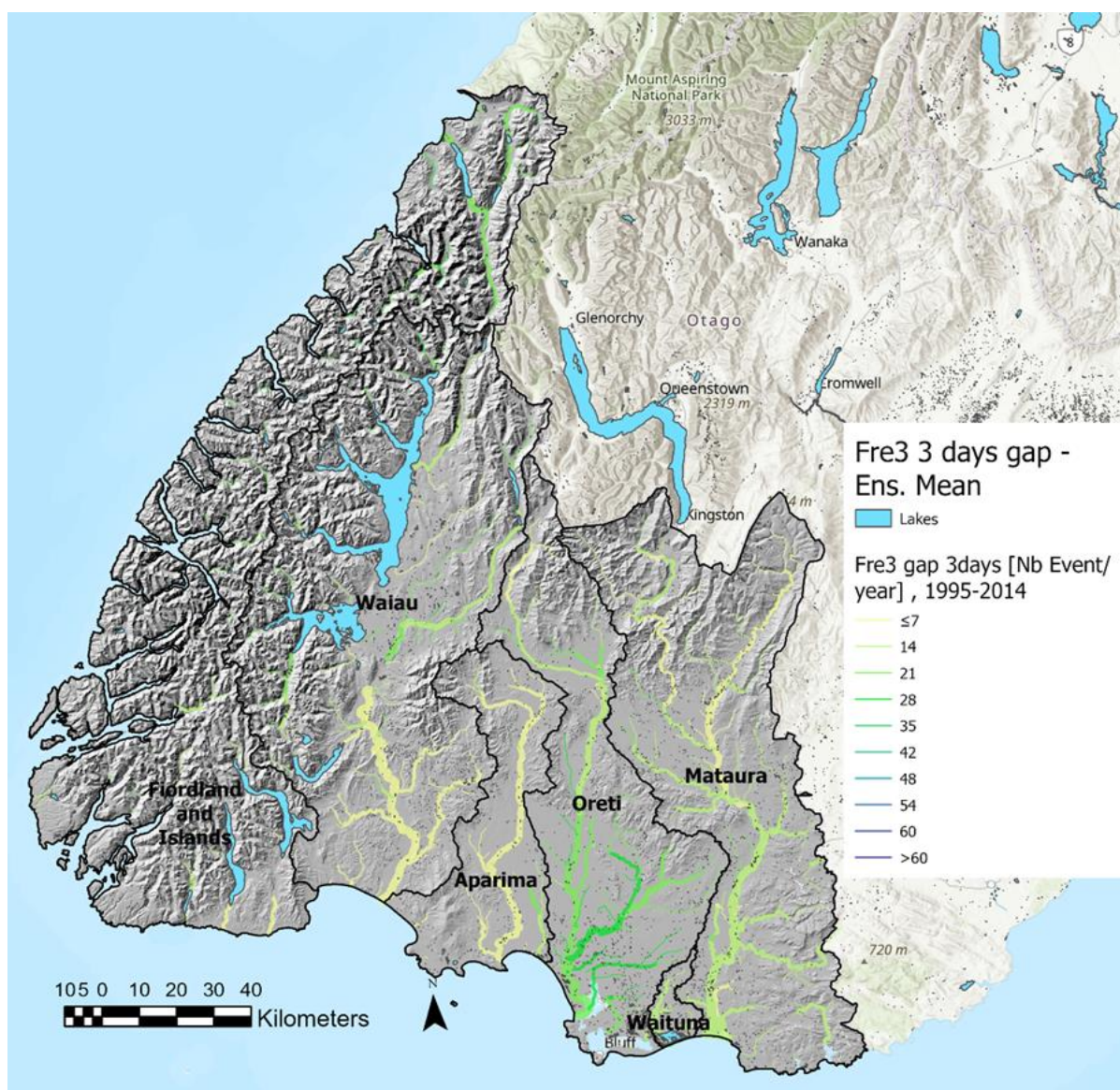


Figure 3-6: Historical multi-model average number of Fre3 events per year with 3-day gaps.

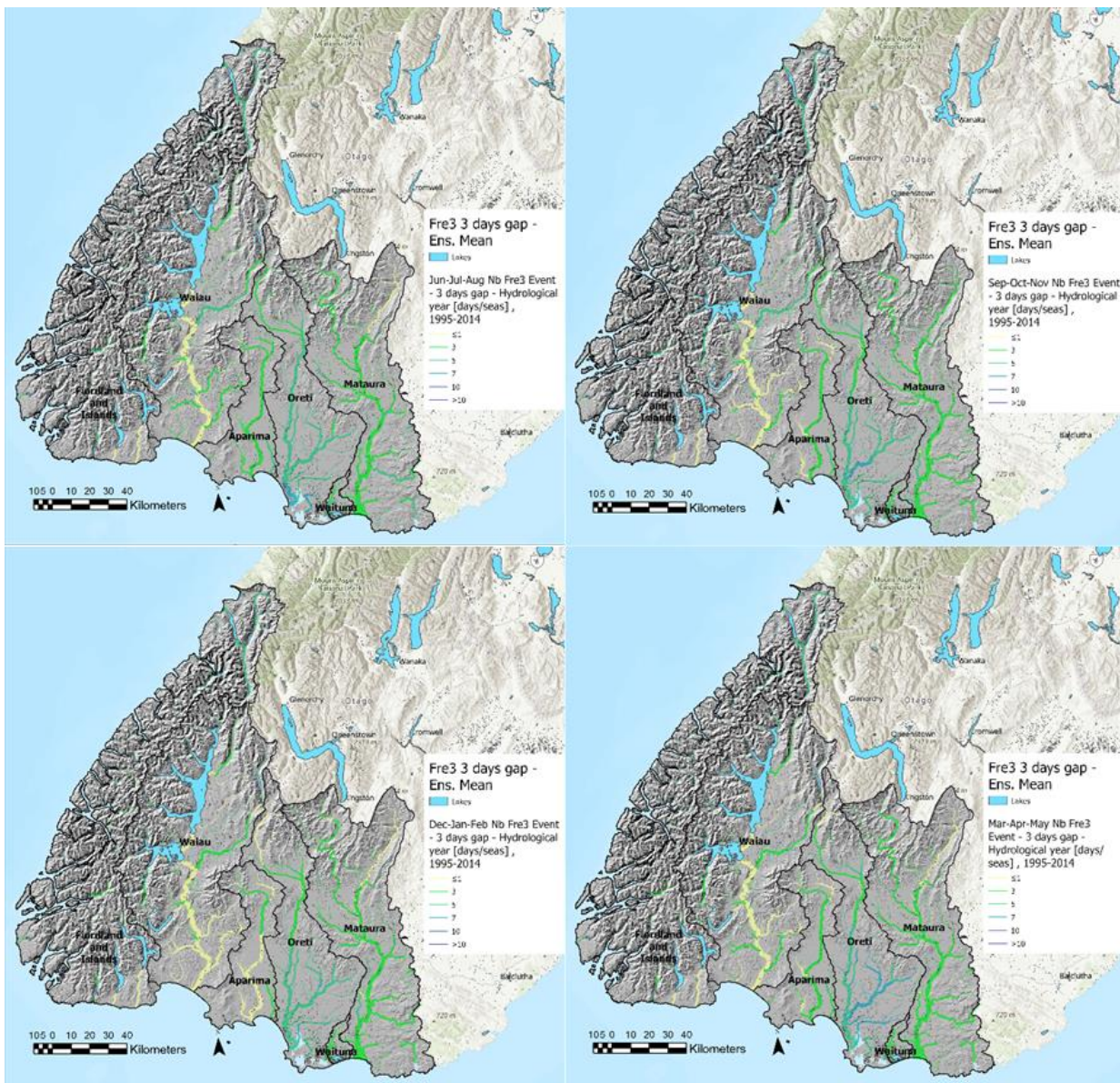


Figure 3-7: Historical multi-model seasonal average number of Fre3 events, using 3-day gaps between Fre3 events.

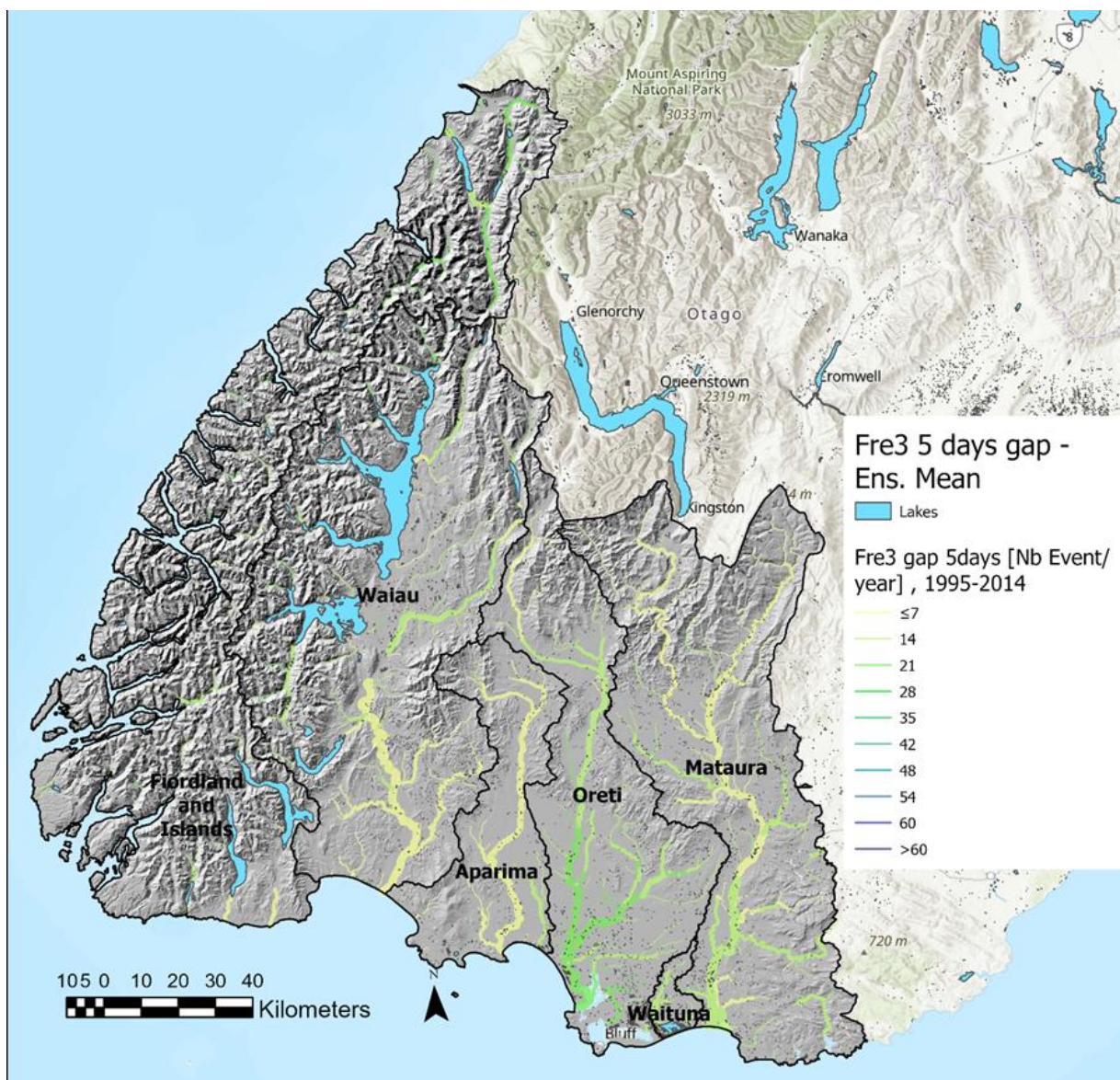


Figure 3-8: Historical multi-model average number of Fre3 events per year using 5-day gaps between Fre3 events.

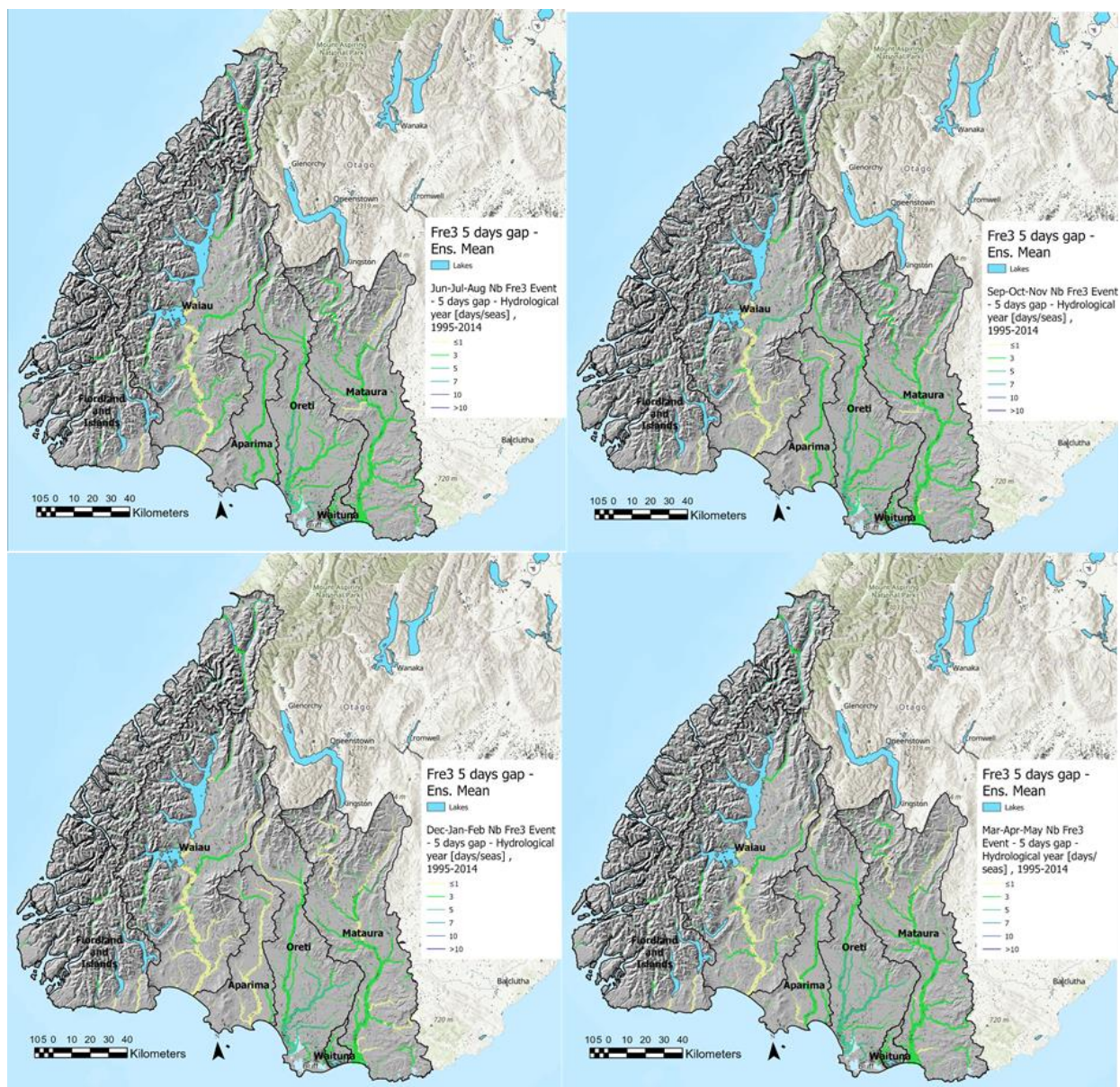


Figure 3-9: Historical multi-model ensemble seasonal average number of Fre3 events, using 5-day gaps between Fre3 events.

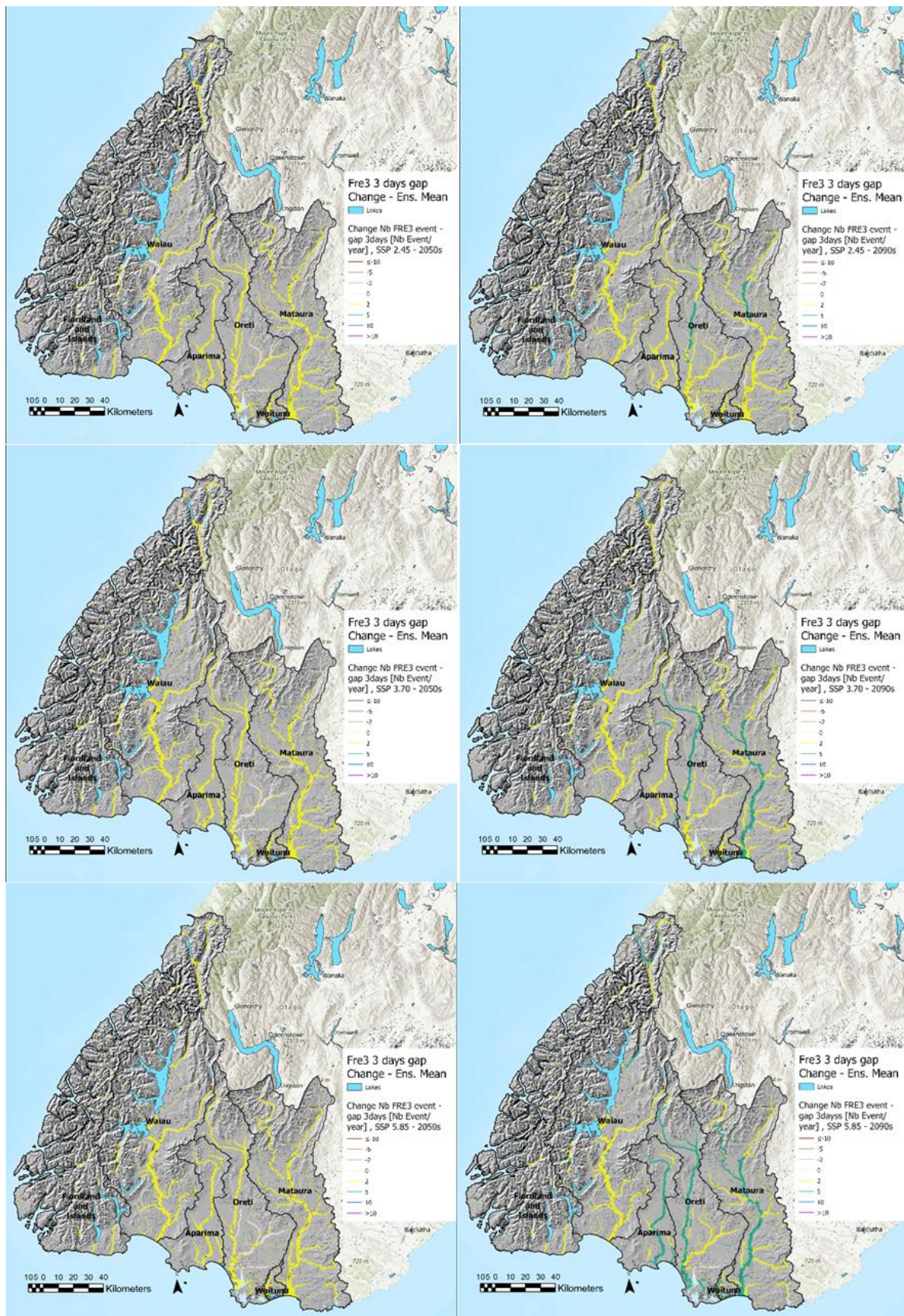


Figure 3-10: Change in multi-model average number of Fre3 events per year, calculated using 3-day gaps between Fre3 events. Change in multi-model average number of Fre3 events with 3-day gaps for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

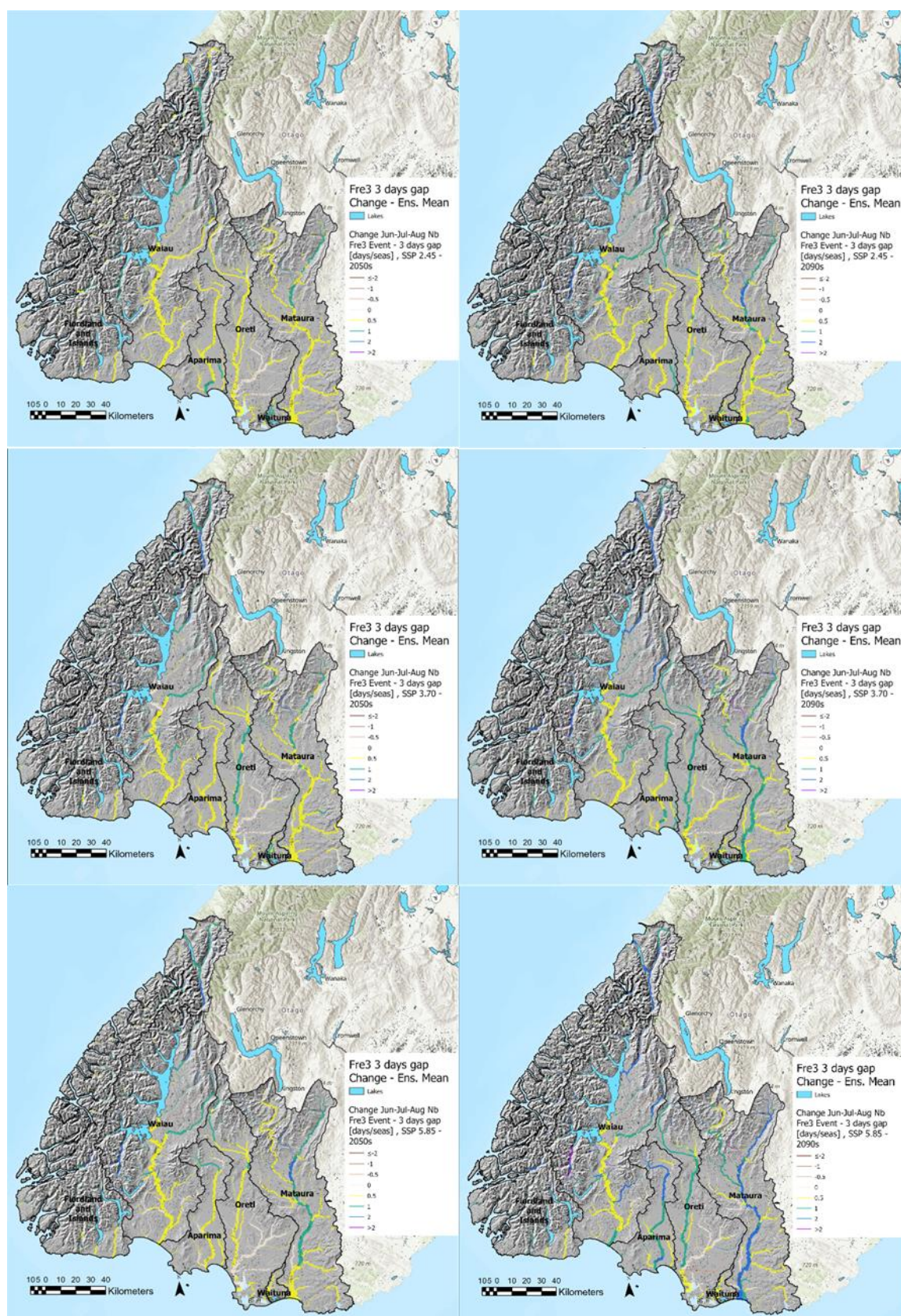


Figure 3-11: Change in multi-model average number of Fre3 events, calculated using 3 day gaps between Fre3 events, for June-July-August (winter, based on hydrological year). Change in multi-model average seasonal number of Fre3 events with 3-day gaps presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

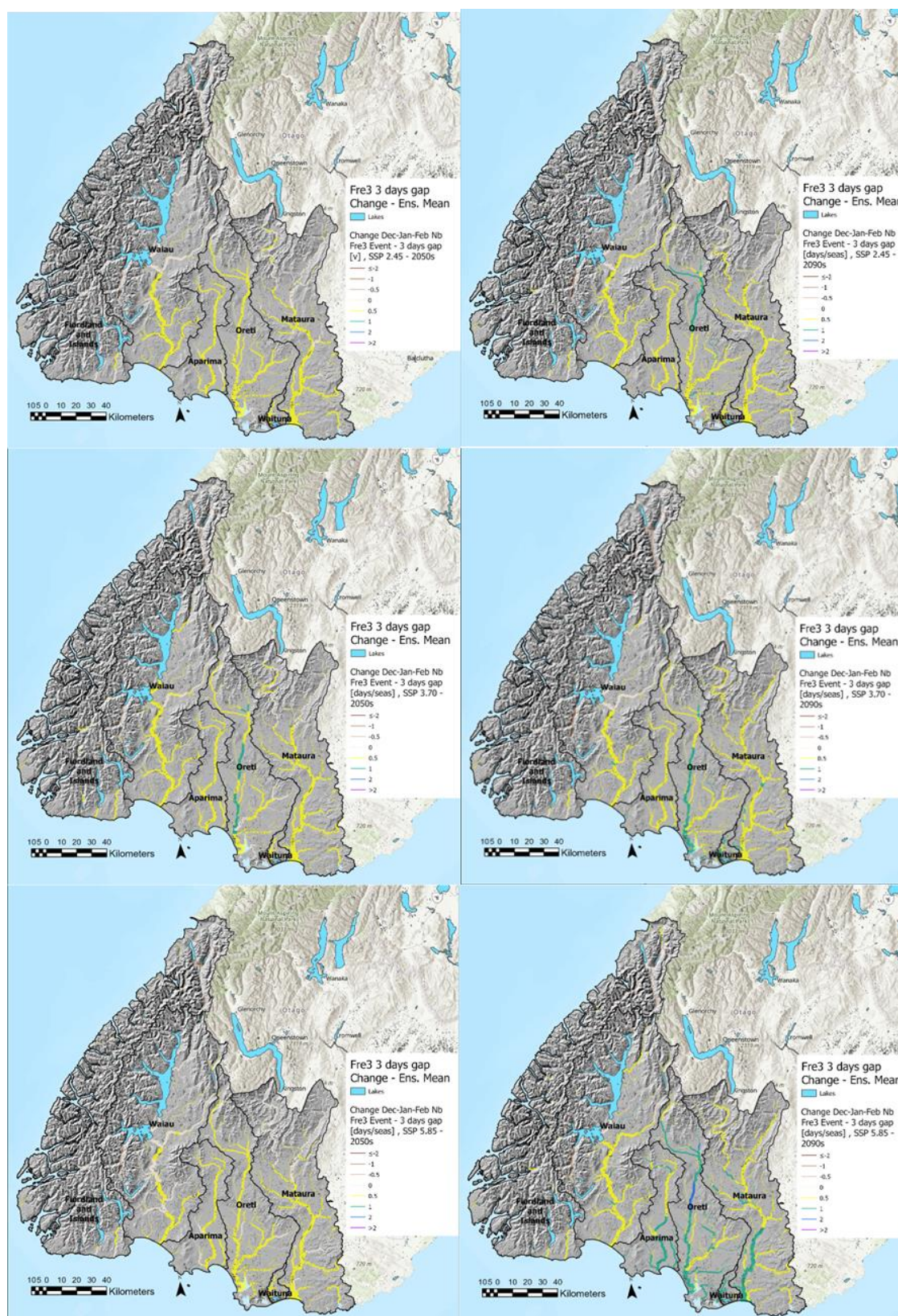


Figure 3-12: Change in multi-model average number of Fre3 events, calculated using 3 day gaps between Fre3 events, for December-January-February (summer, based on hydrological year). Change in multi-model average seasonal number of Fre3 events with 3-day gaps presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.4 Q25

Modelled historic and projected changes to Q25 (river flow magnitude exceeded twenty-five percent of the time; the upper quartile of flow) are illustrated Figure 3-13 and Figure 3-14. FMU-wide average projected changes (generated across each FMU) are summarised in Table 3-7, while location-specific projected changes are shown in Table 3-8.

Table 3-7: FMU scale projected changes in Q25 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	4.6	9.4	3.4	5.5	2.7	9.2
Aparima	6.4	13.6	6.2	6.5	1.1	12.1
Fiordland and Islands	4.1	7.3	2.8	6.2	5.2	11.1
Mataura	3.5	10.0	3.3	3.8	0.2	4.7
Oreti	6.4	10.8	2.4	4.1	0.6	6.8
Waiau	3.6	8.7	3.4	5.3	2.6	9.7
Waituna	10.8	19.9	9.1	17.0	8.1	21.9

Table 3-8: Location specific projected changes in Q25 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	-1.4	2.4	-1.8	-1.3	-1.3	-1.3
Mataura River at Gore Township	1.0	5.4	-1.0	1.3	0.4	0.5
Mataura Catchment to Wyndham Catchment Township	1.4	6.1	0.0	3.4	0.6	4.1
Waikaia Catchment to Waikaia Township	-1.7	-0.7	-5.5	-10.0	-6.2	-11.1
Waikaka Stream to Gore Township	2.9	10.4	3.5	4.9	0.5	7.1
Waikawa Catchment	1.9	7.2	0.3	1.6	-1.7	1.1
Waimea Catchment	5.1	16.4	7.0	11.8	0.0	9.9
Waituna Catchment	13.9	18.1	6.9	14.0	7.8	17.6
Mokoreta Catchment	3.4	9.2	1.6	5.1	-0.8	4.8
Waikaia Catchment	-0.7	2.1	-3.7	-7.0	-3.7	-8.6
Makarewa Catchment	8.2	10.9	-0.2	6.7	5.2	9.7
Oreti Catchment to Lumsden Township	0.1	1.8	-0.3	-1.4	-1.0	-2.6
Oreti Catchment to Winton Township	1.9	2.7	-0.8	-1.4	-1.6	-0.1
Oreti Catchment to Wallacetown	2.6	3.6	-0.8	0.7	-2.1	1.5
Waihopai River to Invercargill City	8.5	14.0	-0.2	8.2	-1.1	11.4
Otepun Stream to Invercargill City	7.5	9.5	1.8	9.2	0.1	10.9
Kingswell Creek at Invercargill City	12.3	19.3	9.4	19.4	6.4	22.7
Irthing Stream at Ellis Road	1.4	1.2	-3.2	-5.1	-4.3	-5.2
Winton Stream to Winton Township	6.3	9.6	2.0	2.8	-1.3	-0.7
Aparima River to Otatau Township	6.4	7.8	2.2	6.3	2.6	9.8

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Otautau Stream to Otautau Township	5.5	9.5	3.1	12.9	-3.3	9.4
Aparima River at Thornbury Bridge	6.6	9.8	4.1	8.8	2.9	8.8
Whitestone Catchment	1.9	8.6	3.8	1.0	-0.4	0.1
Upukerora Catchment	0.7	7.5	3.5	6.5	4.6	6.1
Mararoa Catchment	3.9	6.2	0.9	3.9	2.2	5.1
Orauea Catchment	2.6	10.1	2.7	7.0	-3.2	-0.7
Waiau River at Tutapere	4.5	9.0	4.4	12.0	7.6	17.0

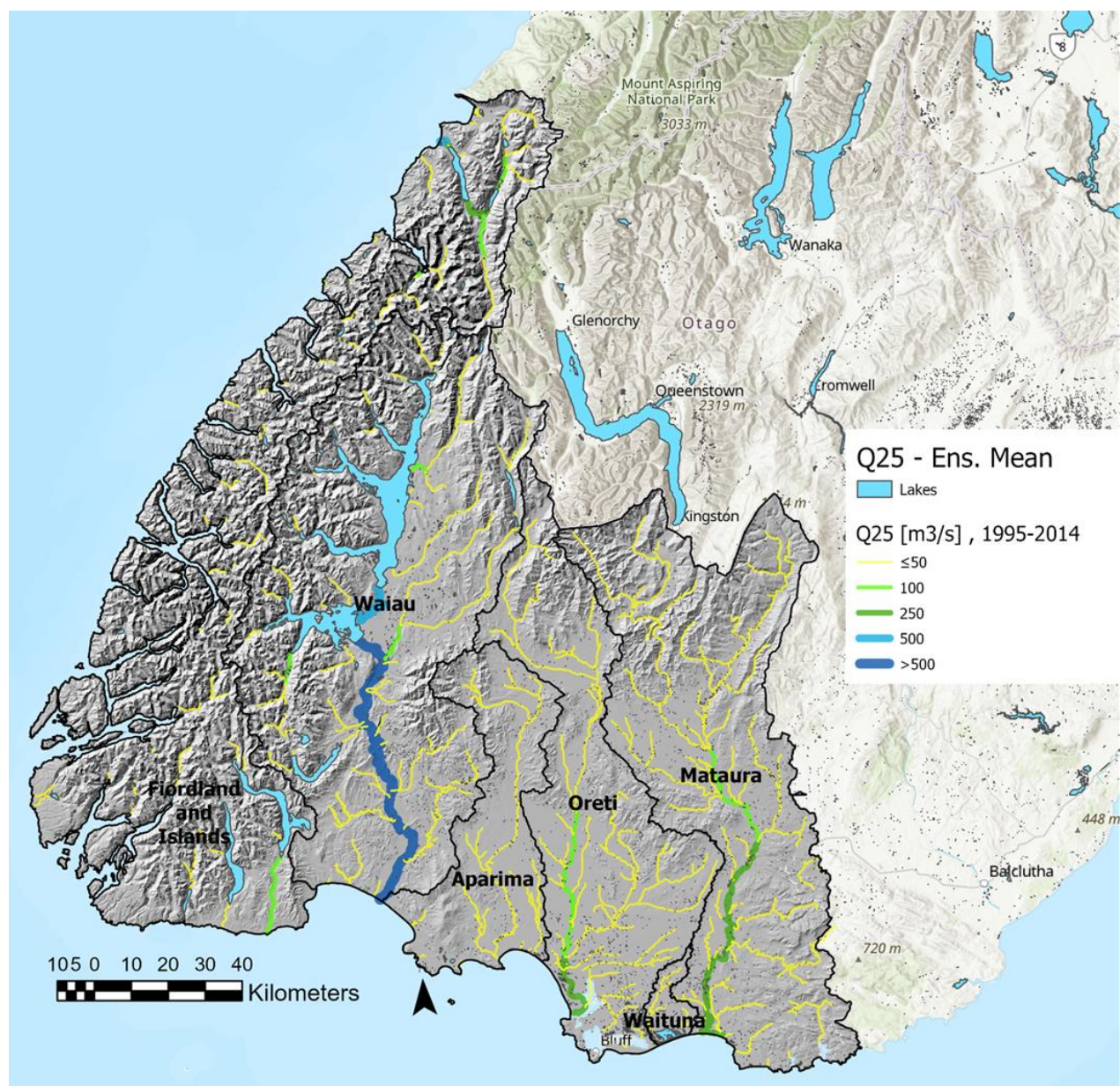


Figure 3-13: Historical multi-model mean Q25.

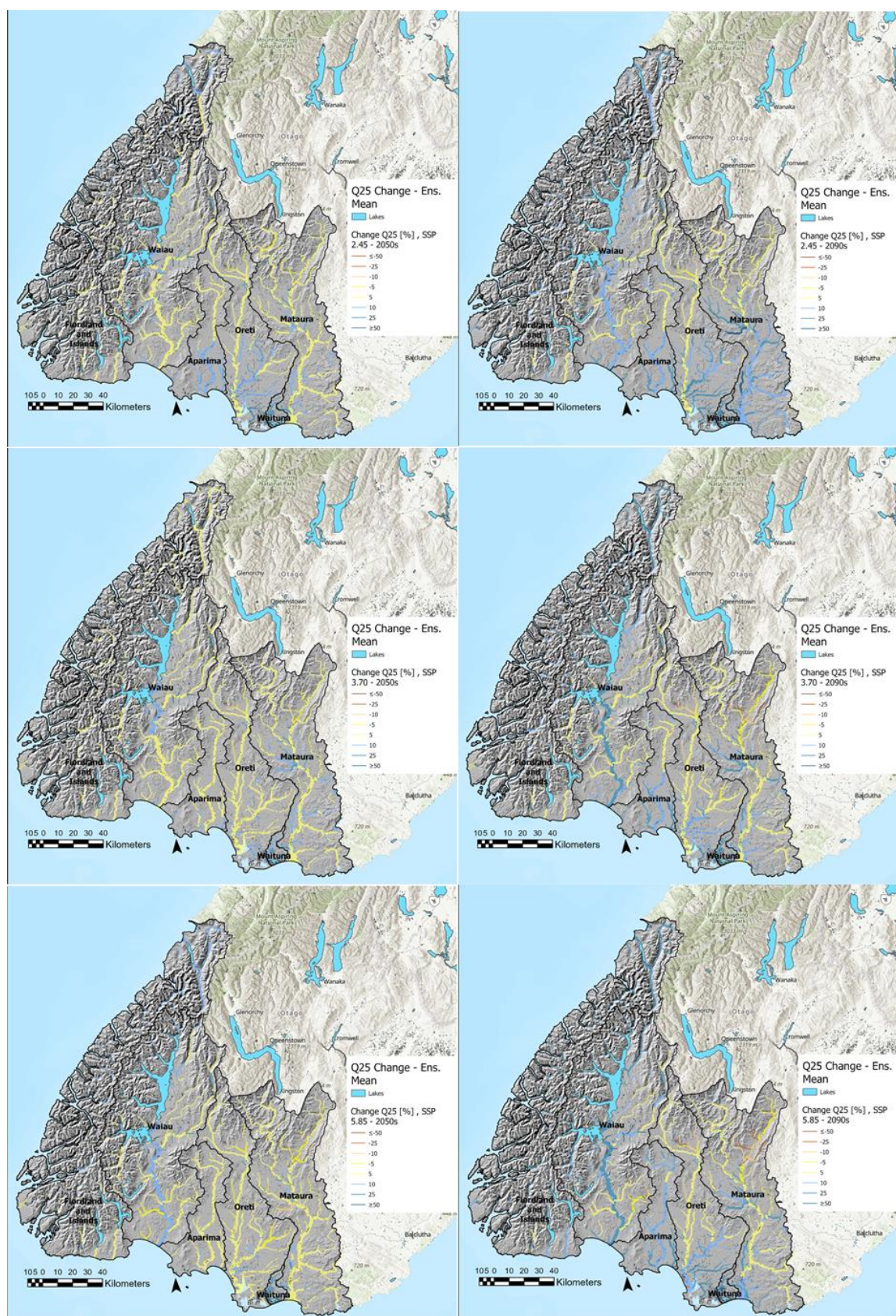


Figure 3-14: Change in multi-model Q25. Change in multi-model Q25 is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.5 Mean discharge

Modelled historic daily mean discharge, calculated on the Gregorian calendar, is illustrated in

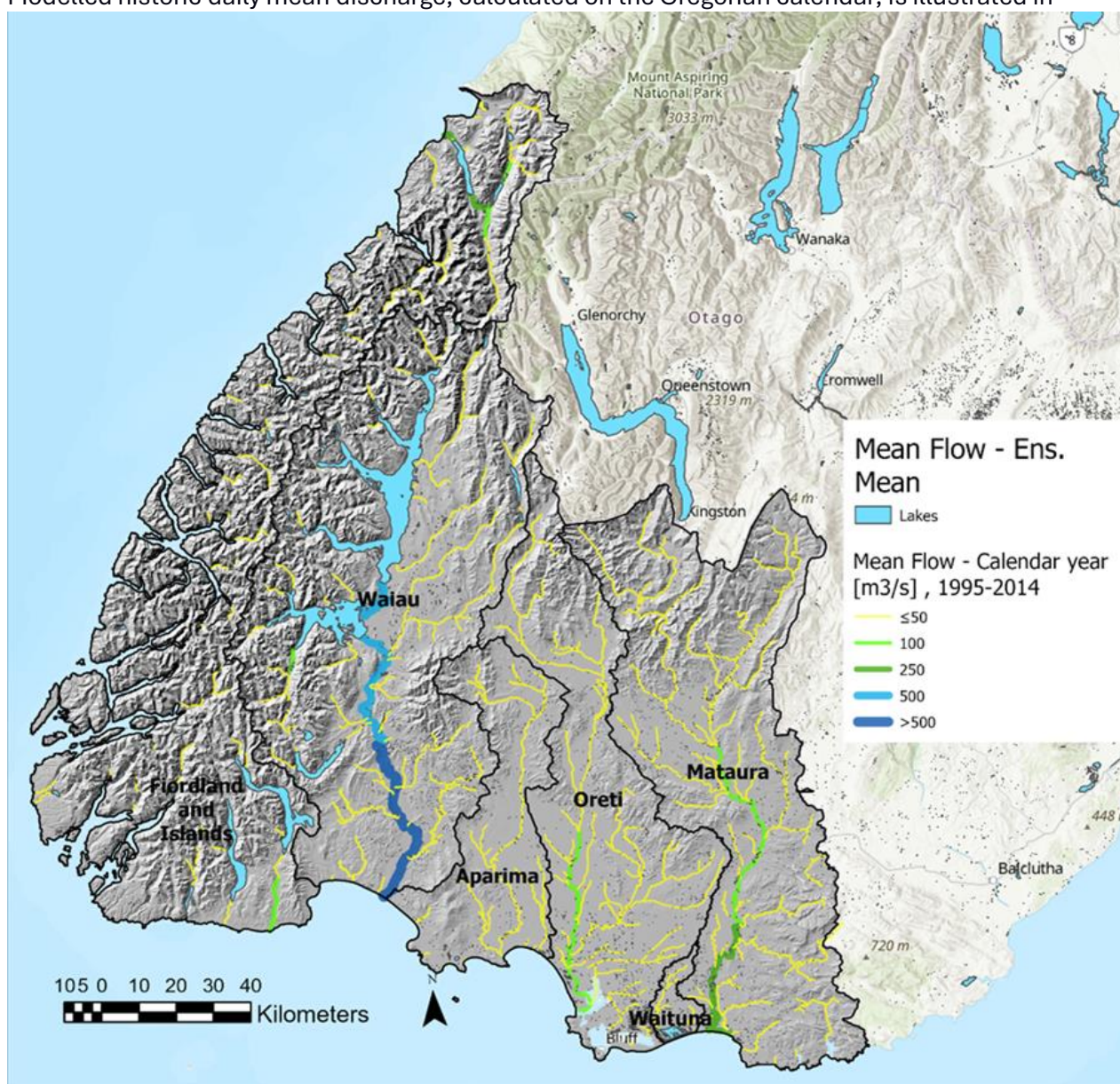


Figure 3-15, while Figure 3-16 presents the modelled historic daily mean discharge calculated using the complete hydrological year. Projected change in daily mean discharge, calculated on the Gregorian calendar, is presented in Figure 3-17. FMU-wide average projected changes in daily mean discharge (generated across each FMU and calculated on the Gregorian calendar), are presented in Table 3-9, while location-specific projected changes are shown in Table 3-10.

Table 3-9: FMU scale projected changes in daily mean discharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	6.3	12.2	6.2	9.8	6.0	14.8
Aparima	10.0	19.3	6.6	12.0	5.3	20.7
Fiordland and Islands	4.5	7.9	4.4	8.2	6.5	12.3
Maitaura	6.2	12.9	6.5	7.6	4.5	11.2

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Oreti	8.7	15.8	7.9	14.8	7.0	20.7
Waiau	5.7	12.1	6.5	9.0	5.9	15.0
Waituna	11.6	22.8	11.6	19.5	8.1	24.2

Table 3-10: Location specific projected changes in daily mean discharge (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	3.7	2.9	4.0	-1.1	-0.7	2.3
Mataura River at Gore Township	2.3	2.7	2.1	-0.9	-0.4	-0.2
Mataura Catchment to Wyndham Catchment Township	3.8	4.8	3.5	2.6	1.9	4.5
Waikaia Catchment to Waikaia Township	-1.1	-0.5	-6.8	-5.0	-6.5	-8.2
Waikaka Stream to Gore Township	6.4	9.6	8.6	6.0	9.7	11.7
Waikawa Catchment	5.4	10.4	7.0	9.5	2.8	10.2
Waimea Catchment	10.1	26.4	15.7	10.7	11.6	19.0
Waituna Catchment	10.2	23.2	12.5	18.7	7.9	22.9
Mokoreta Catchment	5.1	10.6	7.1	8.4	4.9	10.6
Waikaia Catchment	-1.2	0.6	-5.6	-6.9	-4.9	-8.6
Makarewa Catchment	10.6	12.5	10.3	15.9	12.3	24.5
Oreti Catchment to Lumsden Township	2.6	8.6	3.3	5.4	2.0	11.5
Oreti Catchment to Winton Township	3.5	11.9	4.7	6.7	1.6	11.9
Oreti Catchment to Wallacetown	4.1	12.6	5.4	7.6	2.3	13.4
Waihopai River to Invercargill City	6.7	17.4	7.2	15.8	8.5	23.4
Otepuni Stream to Invercargill City	11.3	19.0	9.2	15.5	7.9	28.8
Kingswell Creek at Invercargill City	9.3	17.1	10.8	19.4	8.3	26.1
Irthing Stream at Ellis Road	5.1	9.2	5.5	7.2	1.8	15.0
Winton Stream to Winton Township	7.6	16.9	9.7	13.5	4.7	20.6
Aparima River to Otautau Township	6.7	13.6	6.7	7.1	4.8	16.3
Otautau Stream to Otautau Township	5.6	17.7	6.4	11.2	0.7	15.0
Aparima River at Thornbury Bridge	6.2	15.0	7.6	9.4	4.3	17.1
Whitestone Catchment	2.1	14.9	4.3	7.7	5.0	17.7
Upukerora Catchment	0.5	7.1	1.7	4.9	1.4	7.9
Mararoa Catchment	1.5	7.8	3.1	4.3	3.2	10.5
Orauea Catchment	6.3	14.2	4.0	5.6	-1.2	10.7
Waiau River at Tutapere	5.7	8.2	5.9	7.0	5.8	12.5

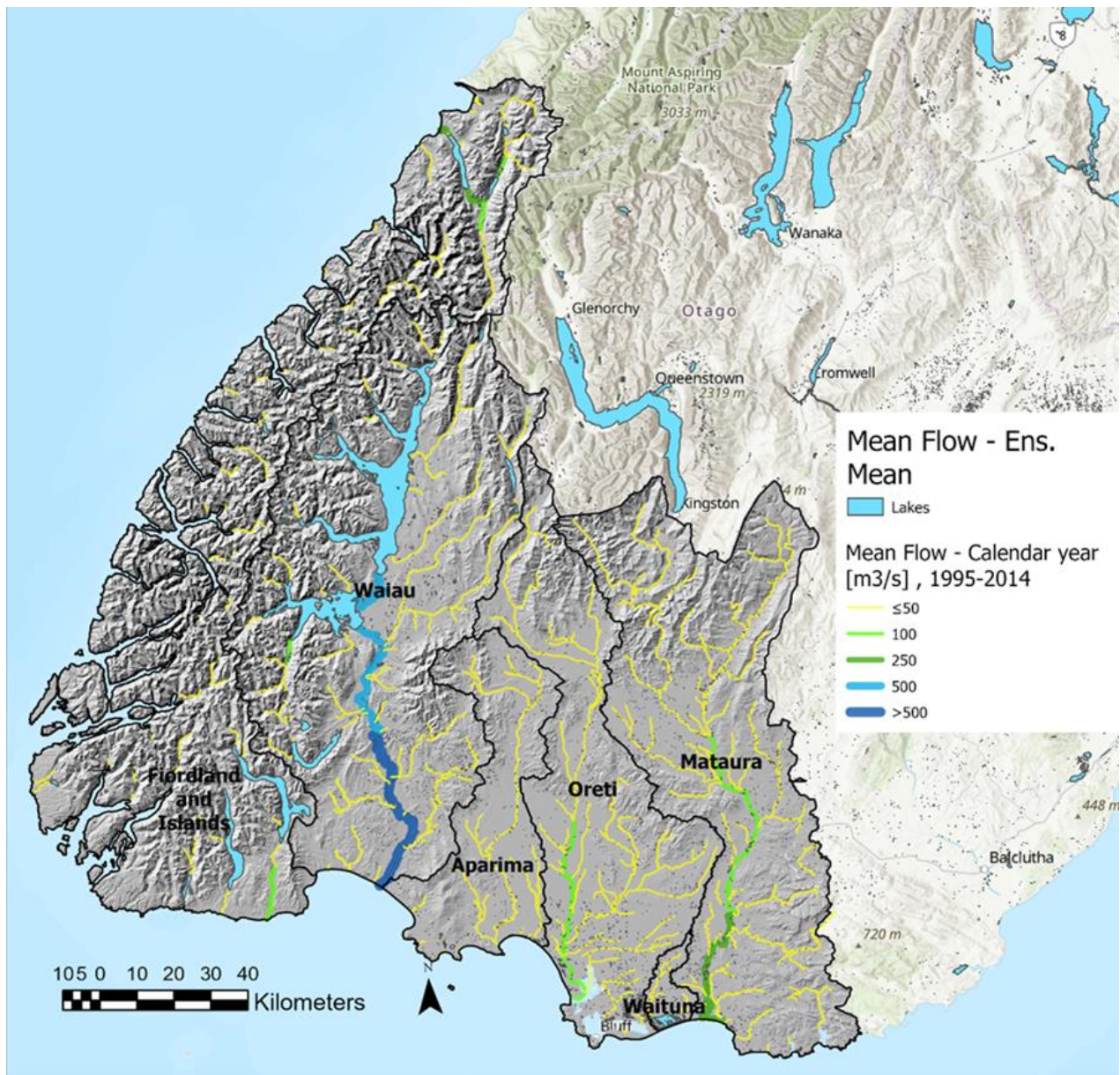


Figure 3-15: Historical multi-model mean discharge calculated on Gregorian calendar.

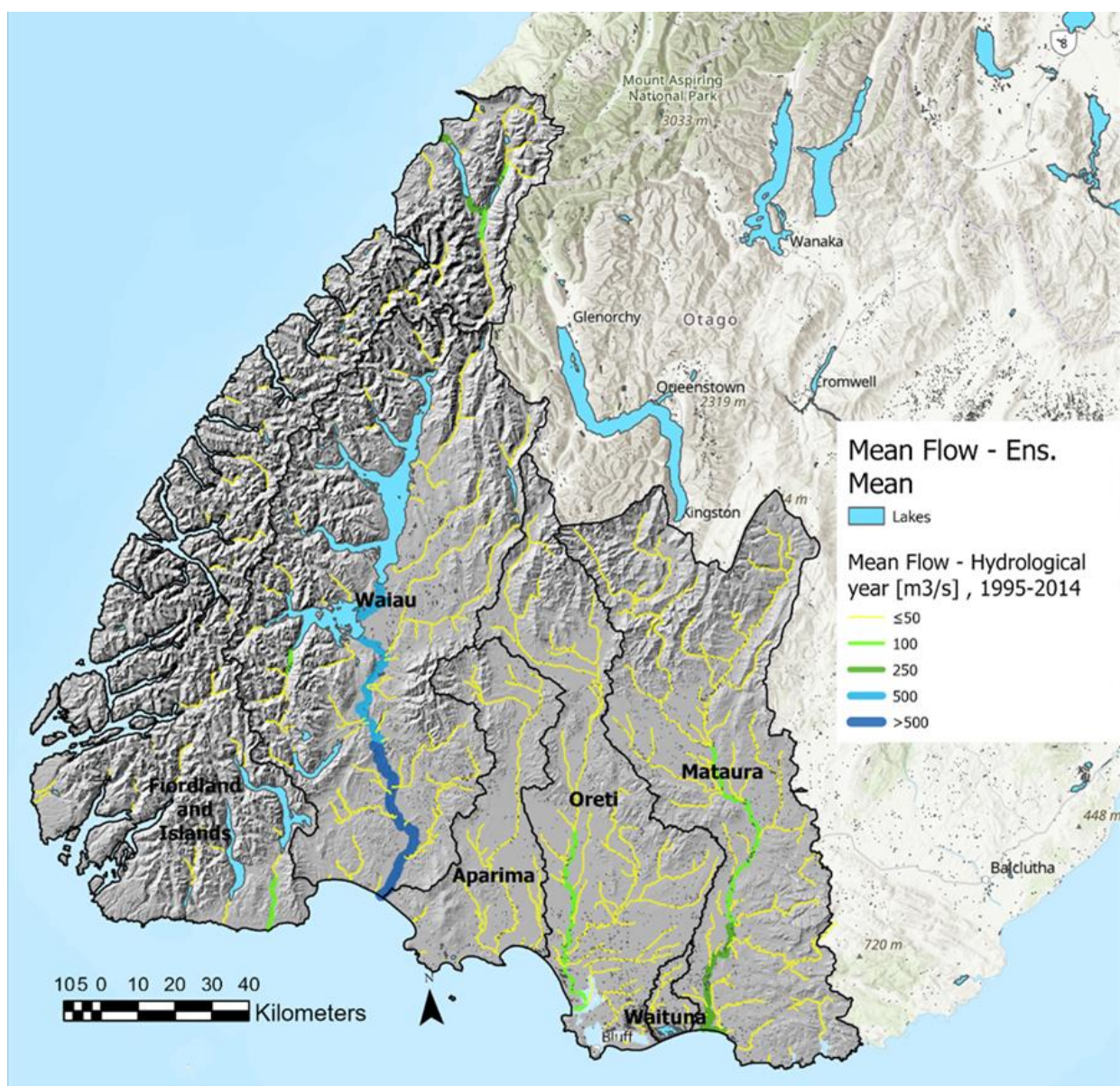


Figure 3-16: Historical multi-model mean discharge calculated on hydrological year.

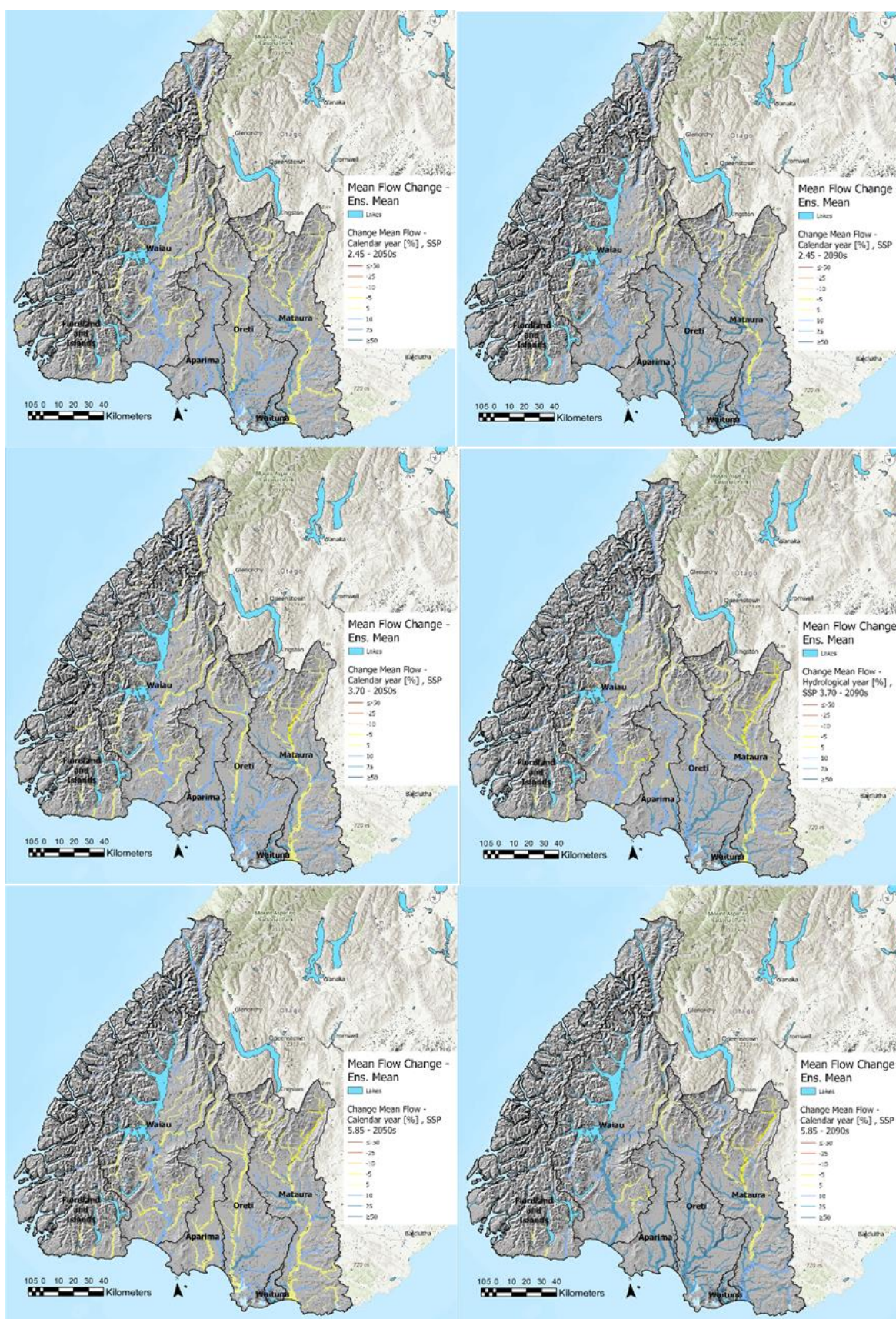


Figure 3-17: Change in multi-model average mean discharge calculated on Gregorian calendar. Change in multi-model average mean discharge for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.6 Mean and median annual flows

Modelled historic mean and median annual flows (calculated on hydrological year) are presented in Figure 3-18 and Figure 3-19. Projected changes to mean annual flows are illustrated in Figure 3-20, while projected changes in median annual flows are presented in Appendix D. FMU-wide average projected changes in mean annual flow (generated across each FMU) are presented in Table 3-11, while location-specific projected changes in mean annual flows are shown in Table 3-12 and median annual flows are shown in Table 3-13.

Table 3-11: FMU scale projected changes in mean annual flow (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	6.3	12.8	6.1	10.4	6.0	15.2
Aparima	10.0	20.0	6.6	12.6	5.3	21.2
Fiordland and Islands	4.5	8.2	4.4	8.6	6.5	12.4
Mataura	6.2	13.7	6.5	8.4	4.6	11.8
Oreti	8.7	16.5	7.9	15.3	7.0	21.1
Waiau	5.7	12.8	6.5	9.5	5.9	15.4
Waituna	11.6	23.9	11.6	20.2	8.1	24.9

Table 3-12: Location specific projected changes in mean annual flow (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	3.7	3.8	4.0	-0.2	-0.7	2.6
Mataura River at Gore Township	2.3	3.7	2.1	-0.1	-0.3	0.3
Mataura Catchment to Wyndham Catchment Township	3.8	5.9	3.6	3.2	2.0	5.0
Waikaia Catchment to Waikaia Township	-1.1	0.1	-6.8	-4.5	-6.5	-7.4
Waikaka Stream to Gore Township	6.5	10.5	8.7	6.8	9.8	12.3
Waikawa Catchment	5.4	11.1	7.0	9.6	2.8	10.4
Waimea Catchment	10.2	27.9	15.7	11.5	11.7	19.9
Waituna Catchment	10.2	24.5	12.5	18.9	8.0	23.5
Mokoreta Catchment	5.1	11.4	7.1	8.7	5.0	10.9
Waikaia Catchment	-1.2	1.6	-5.6	-6.1	-4.9	-7.7
Makarewa Catchment	10.6	13.4	10.3	16.5	12.3	24.6
Oreti Catchment to Lumsden Township	2.6	9.3	3.3	6.2	2.0	11.9
Oreti Catchment to Winton Township	3.5	12.1	4.7	7.2	1.6	12.5
Oreti Catchment to Wallacetown	4.1	13.5	5.4	8.0	2.3	13.9
Waihopai River to Invercargill City	6.7	18.3	7.2	16.2	8.5	24.0
Otepun Stream to Invercargill City	11.3	20.1	9.2	15.5	7.9	29.3
Kingswell Creek at Invercargill City	9.4	17.9	10.8	19.3	8.3	26.6
Irthing Stream at Ellis Road	5.1	9.9	5.5	7.9	1.8	15.9

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Winton Stream to Winton Township	7.6	17.9	9.7	14.3	4.7	21.7
Aparima River to Otautau Township	6.7	14.9	6.7	7.5	4.8	16.5
Otautau Stream to Otautau Township	5.6	17.8	6.4	11.7	0.7	15.7
Aparima River at Thornbury Bridge	6.2	16.2	7.6	9.9	4.3	17.7
Whitestone Catchment	2.1	15.4	4.3	8.1	5.0	18.3
Upukerora Catchment	0.5	7.3	1.7	6.2	1.4	8.3
Mararoa Catchment	1.5	8.2	3.1	5.0	3.2	11.4
Orauea Catchment	6.3	15.5	4.0	6.6	-1.2	11.8
Waiau River at Tutapere	5.7	8.9	5.9	7.2	5.8	12.8

Table 3-13: Location specific projected changes in median annual flow (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	0.9	1.4	1.5	1.2	-3.2	-0.6
Mataura River at Gore Township	3.6	3.9	4.3	1.1	0.6	3.4
Mataura Catchment to Wyndham Catchment Township	4.3	6.9	5.1	3.3	2.0	7.1
Waikaia Catchment to Waikaia Township	-1.0	0.2	-6.4	-3.7	-8.1	-7.9
Waikaka Stream to Gore Township	7.9	11.9	11.8	7.1	10.9	18.9
Waikawa Catchment	6.4	10.1	9.8	9.5	3.6	10.1
Waimea Catchment	11.8	22.9	16.8	10.3	13.4	17.4
Waituna Catchment	8.4	23.2	13.2	20.4	9.1	25.9
Mokoreta Catchment	8.7	13.0	10.8	9.2	7.3	14.2
Waikaia Catchment	-1.9	-0.4	-4.8	-5.9	-6.5	-6.1
Makarewa Catchment	11.4	14.0	13.1	14.0	9.6	24.9
Oreti Catchment to Lumsden Township	2.2	3.3	3.2	3.6	-1.7	11.1
Oreti Catchment to Winton Township	3.3	11.5	6.4	9.0	2.6	16.8
Oreti Catchment to Wallacetown	5.7	13.1	7.6	11.3	3.3	17.0
Waihopai River to Invercargill City	8.3	17.7	8.0	17.0	6.5	23.3
Otepuni Stream to Invercargill City	8.5	17.4	7.1	14.4	3.4	20.8
Kingswell Creek at Invercargill City	7.1	15.5	9.1	15.7	7.3	28.0
Irthing Stream at Ellis Road	3.0	4.0	2.5	3.6	-5.2	14.2
Winton Stream to Winton Township	11.0	22.3	12.0	15.4	6.8	20.1
Aparima River to Otautau Township	6.0	14.8	9.2	9.9	3.9	20.4
Otautau Stream to Otautau Township	7.0	19.0	9.9	15.3	2.5	15.7
Aparima River at Thornbury Bridge	7.7	15.8	8.9	12.2	2.8	16.7
Whitestone Catchment	8.0	16.5	3.9	11.2	7.4	17.6
Upukerora Catchment	2.3	10.3	3.5	9.4	2.8	6.7

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mararoa Catchment	4.2	9.1	1.5	6.7	3.8	6.5
Orauea Catchment	10.9	9.1	8.4	10.8	-0.1	10.1
Waiau River at Tutapere	6.5	9.0	4.4	10.1	7.6	12.6

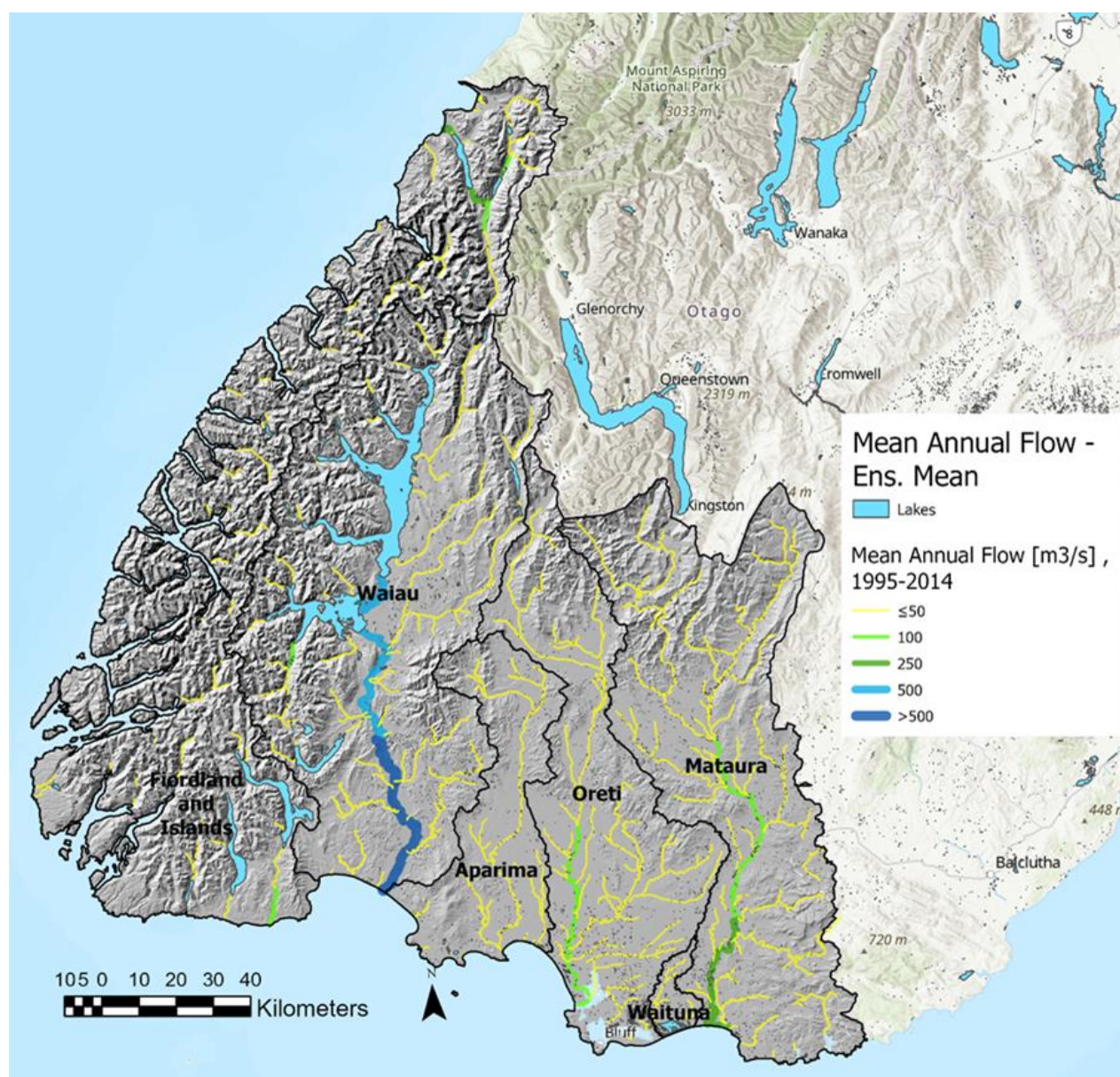


Figure 3-18: Historical multi-model mean annual discharge.

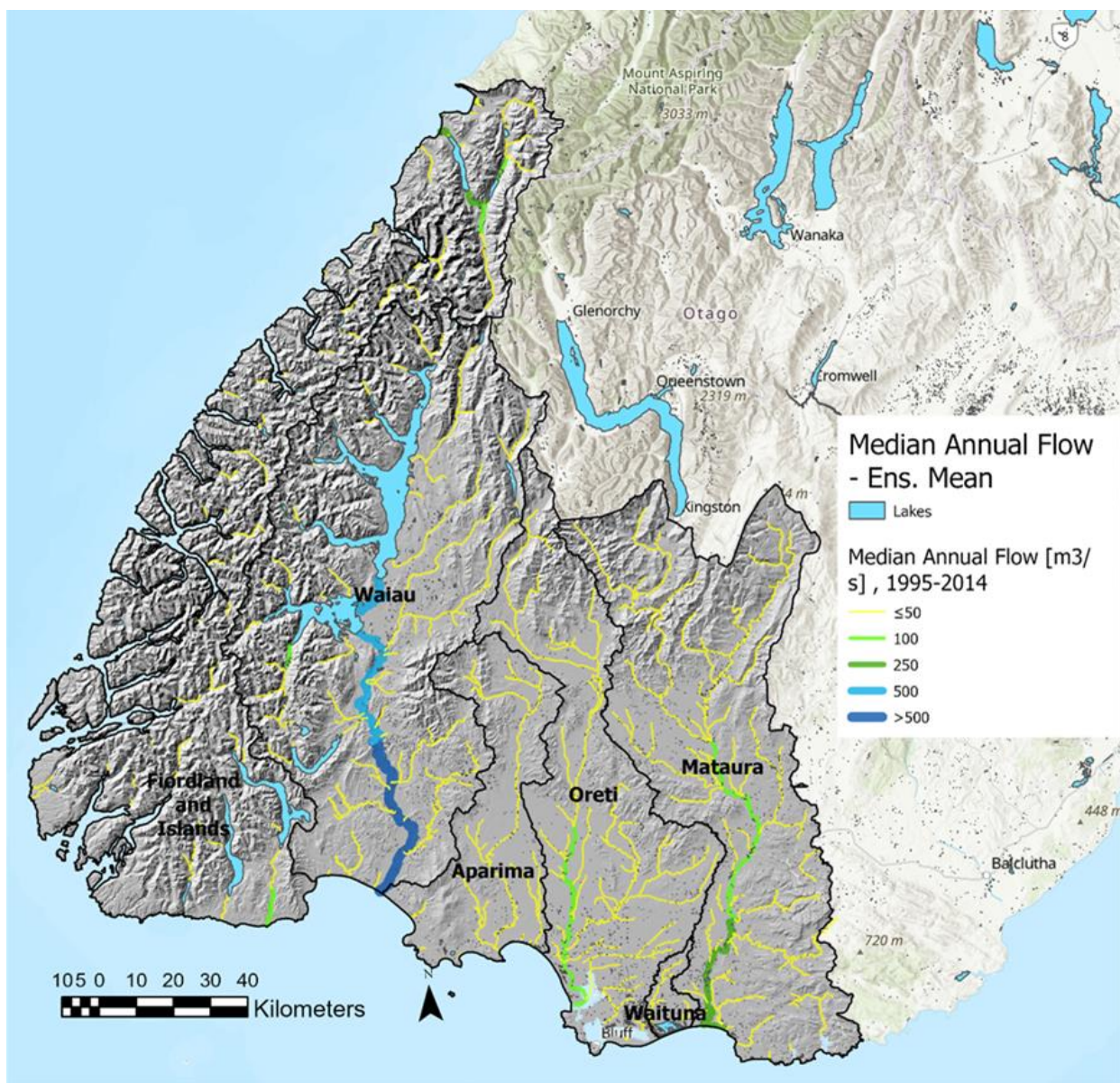


Figure 3-19: Historical multi-model median annual discharge.

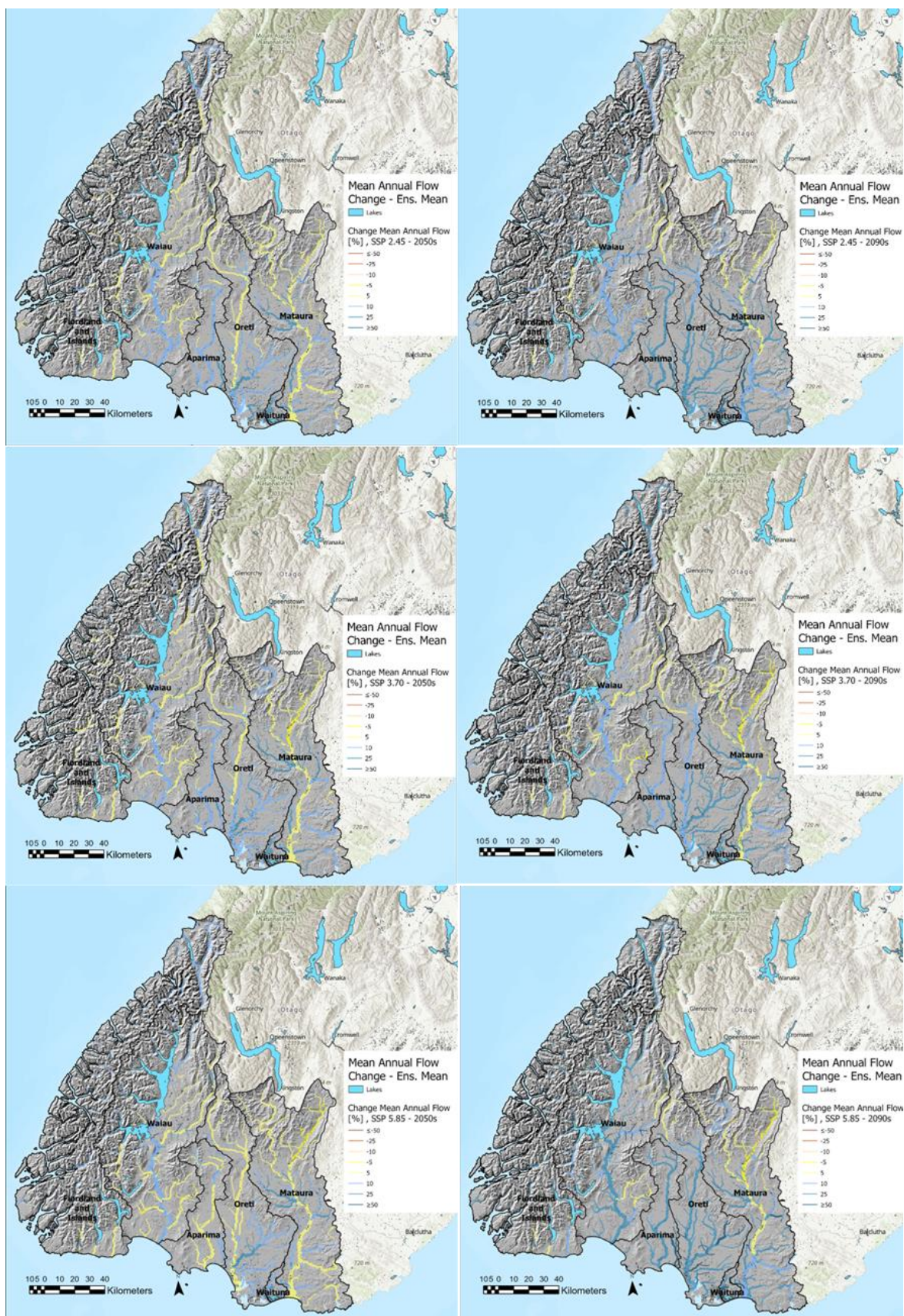


Figure 3-20: Change in multi-model average mean annual flow. Change in multi-model average annual flow for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.7 Seasonal average flows

Modelled historic seasonal average flows, calculated based on hydrological year, are illustrated in Figure 3-21. June-July-August (winter) and December-January-February (summer) projected changes in seasonal flows are illustrated by Figure 3-22 and Figure 3-23, while Appendix D presents the change in autumn and spring seasonal flows. Hydrological year season FMU-wide average projected changes in seasonal average flows (generated across each FMU) are summarised at seasonal time scale in Table 3-14 to Table 3-17, while location-specific projected changes during summer are shown in Table 3-18. Location-specific projected changes for winter, spring and autumn are presented in Appendix D.

Table 3-14: Projected changes in winter average daily discharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	9.8	20.0	15.6	21.9	14.4	30.8
Aparima	7.3	17.1	12.2	13.8	6.5	23.0
Fiordland and Islands	12.5	20.2	18.4	26.6	19.1	35.1
Mataura	4.0	15.0	10.0	13.0	8.1	21.4
Oreti	4.5	17.0	11.9	16.1	7.4	24.6
Waiau	16.0	27.5	20.5	30.0	21.1	39.6
Waituna	8.3	18.7	11.3	17.4	8.9	30.0

Table 3-15: Projected changes in spring average daily discharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	10.5	15.7	9.9	11.7	11.2	16.2
Aparima	14.9	21.6	10.1	15.3	12.7	24.6
Fiordland and Islands	10.1	13.9	9.2	13.2	11.2	16.4
Mataura	9.2	17.1	10.9	6.6	11.3	10.6
Oreti	15.6	21.0	14.0	18.4	15.2	25.2
Waiau	6.5	10.2	5.5	6.3	6.9	9.4
Waituna	18.2	28.5	22.3	25.6	19.2	35.9

Table 3-16: Projected changes in summer average daily discharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	2.3	2.8	4.7	-6.1	-3.0	5.3
Aparima	11.0	9.4	16.0	3.1	2.6	29.3
Fiordland and Islands	-2.3	-0.6	-1.7	-7.9	-1.8	-2.6
Mataura	5.5	2.6	6.0	-12.2	-7.8	-1.5
Oreti	7.6	11.0	13.3	7.8	1.1	22.4
Waiau	-0.8	-0.9	3.2	-10.9	-5.1	3.7

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Waituna	9.4	10.8	9.2	-2.7	-3.7	12.0

Table 3-17: Projected changes in autumn average daily discharge (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	3.5	13.4	-0.6	3.7	3.2	3.9
Aparima	6.2	18.6	-2.1	6.1	6.8	13.3
Fiordland and Islands	2.0	7.5	-1.4	-1.8	1.7	0.7
Mataura	4.9	17.3	2.4	4.0	3.4	0.4
Oreti	5.4	18.1	0.9	12.7	4.6	9.0
Waiau	1.8	12.8	-3.2	2.6	3.5	5.6
Waituna	9.1	23.2	3.3	21.1	3.0	4.8

Table 3-18: Location specific projected changes in summer seasonal flow (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	3.3	11.6	7.1	12.8	8.9	14.8
Mataura River at Gore Township	7.3	17.6	12.8	18.9	13.4	22.8
Mataura Catchment to Wyndham Catchment Township	7.5	17.9	14.3	21.9	13.6	27.0
Waikaia Catchment to Waikaia Township	7.4	15.5	12.8	11.7	13.7	14.7
Waikaka Stream to Gore Township	9.2	16.3	15.4	26.3	15.6	35.8
Waikawa Catchment	2.0	8.8	5.1	14.5	5.3	17.5
Waimea Catchment	7.7	17.0	15.6	24.0	13.5	34.5
Waituna Catchment	4.0	20.3	10.5	23.8	7.4	29.6
Mokoreta Catchment	3.8	10.5	10.4	18.5	8.5	23.8
Waikaia Catchment	9.8	20.4	15.8	17.9	16.4	21.5
Makarewa Catchment	3.5	13.9	11.1	22.0	6.5	31.4
Oreti Catchment to Lumsden Township	-0.4	7.8	4.3	10.2	5.7	13.7
Oreti Catchment to Winton Township	-0.2	9.7	5.3	13.6	5.7	17.0
Oreti Catchment to Wallacetown	0.6	10.5	6.3	15.3	5.9	19.6
Waihopai River to Invercargill City	5.5	20.2	13.9	24.2	10.6	33.2
Otepuni Stream to Invercargill City	9.5	22.1	14.9	25.7	12.2	34.4
Kingswell Creek at Invercargill City	10.4	23.0	20.0	33.8	10.4	40.4
Irthing Stream at Ellis Road	1.0	6.3	5.4	8.6	2.9	10.8
Winton Stream to Winton Township	2.7	12.4	11.7	19.3	5.5	26.1
Aparima River to Otautau Township	1.0	10.1	5.8	16.5	5.2	19.5

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Otautau Stream to Otautau Township	5.5	12.5	9.8	19.9	7.3	24.2
Aparima River at Thornbury Bridge	3.2	11.6	6.7	18.4	5.6	20.6
Whitestone Catchment	4.5	16.2	6.9	17.4	10.5	25.5
Upukerora Catchment	6.3	19.0	11.5	20.3	15.2	29.0
Mararoa Catchment	9.2	18.8	12.7	22.8	15.8	30.1
Orauea Catchment	2.0	7.4	7.9	9.6	-1.8	10.7
Waiau River at Tutapere	11.7	20.1	15.8	29.6	20.1	35.8

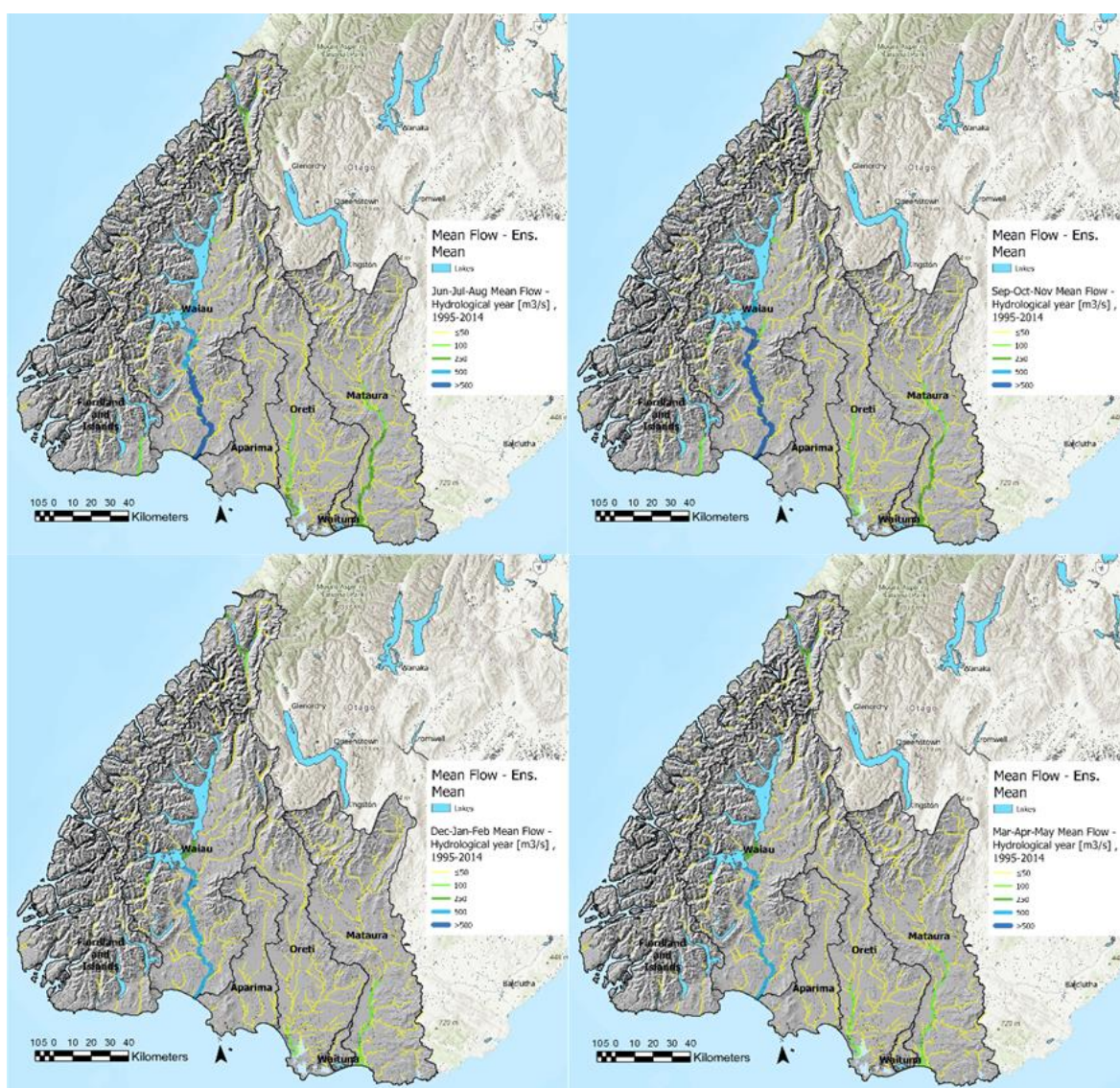
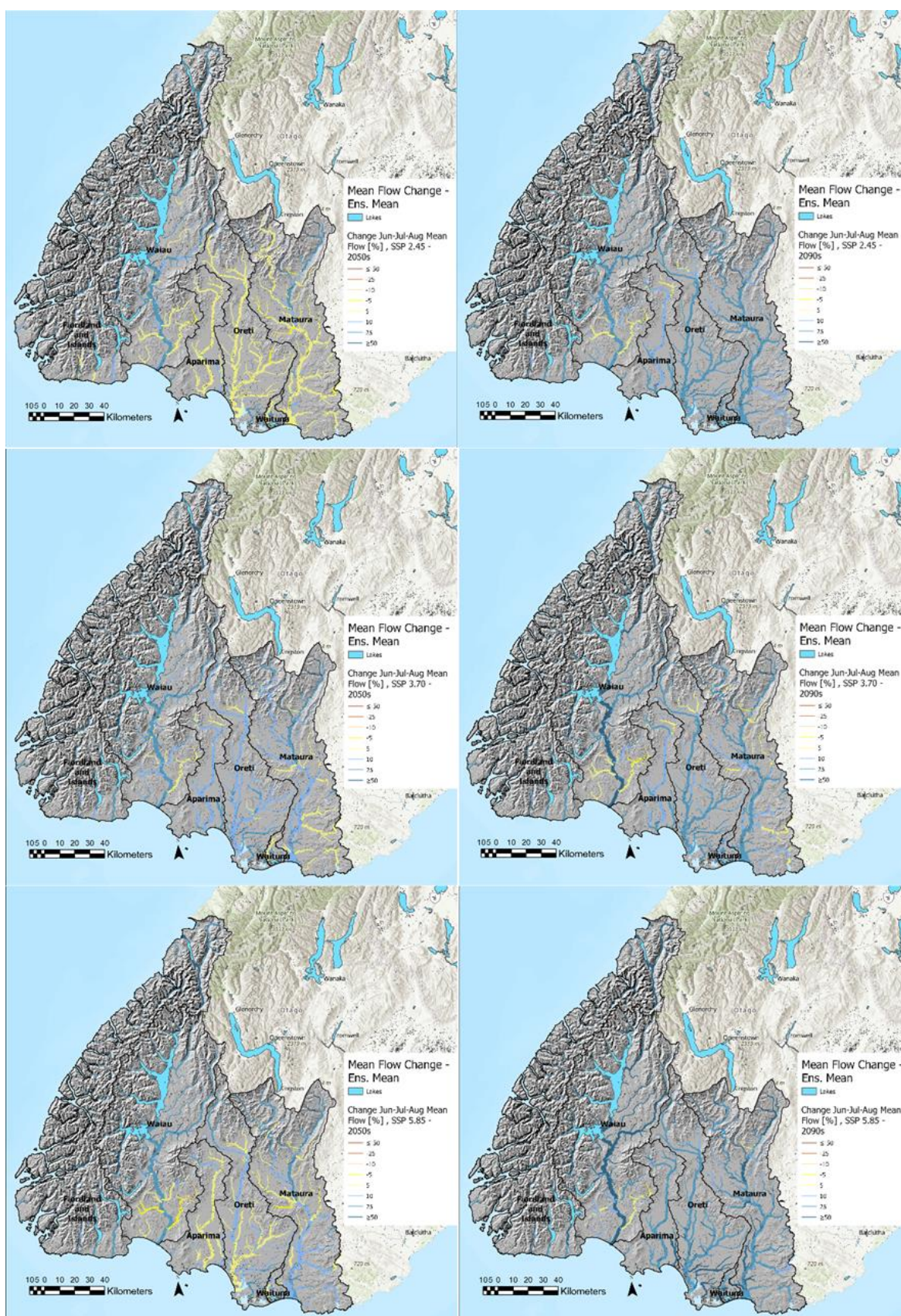


Figure 3-21: Historical multi-model average seasonal discharge. The multi-model average seasonal discharge is calculated based on hydrological year.



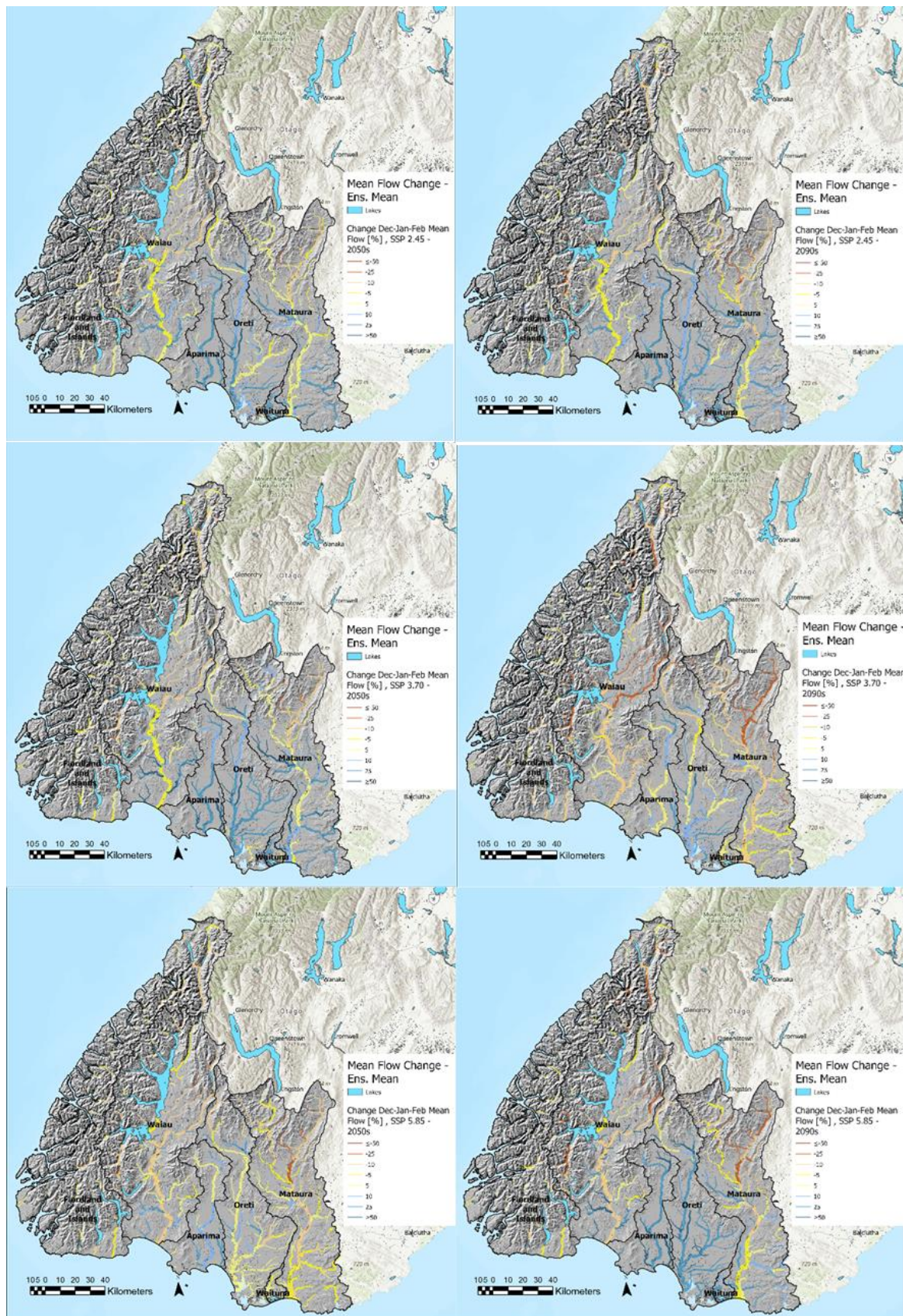


Figure 3-23: Change in multi-model average summer flow (December-January-February). Change in multi-model average summer flow is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.8 Q75

Historic and projected changes in Q75 (river flow magnitude exceeded seventy-five percent of the time; the lower quartile of flow) are illustrated in Figure 3-24 and Figure 3-25. FMU-wide average projected changes in Q75 (generated across each FMU) are presented in Table 3-19, while location-specific projected changes are shown in Table 3-20.

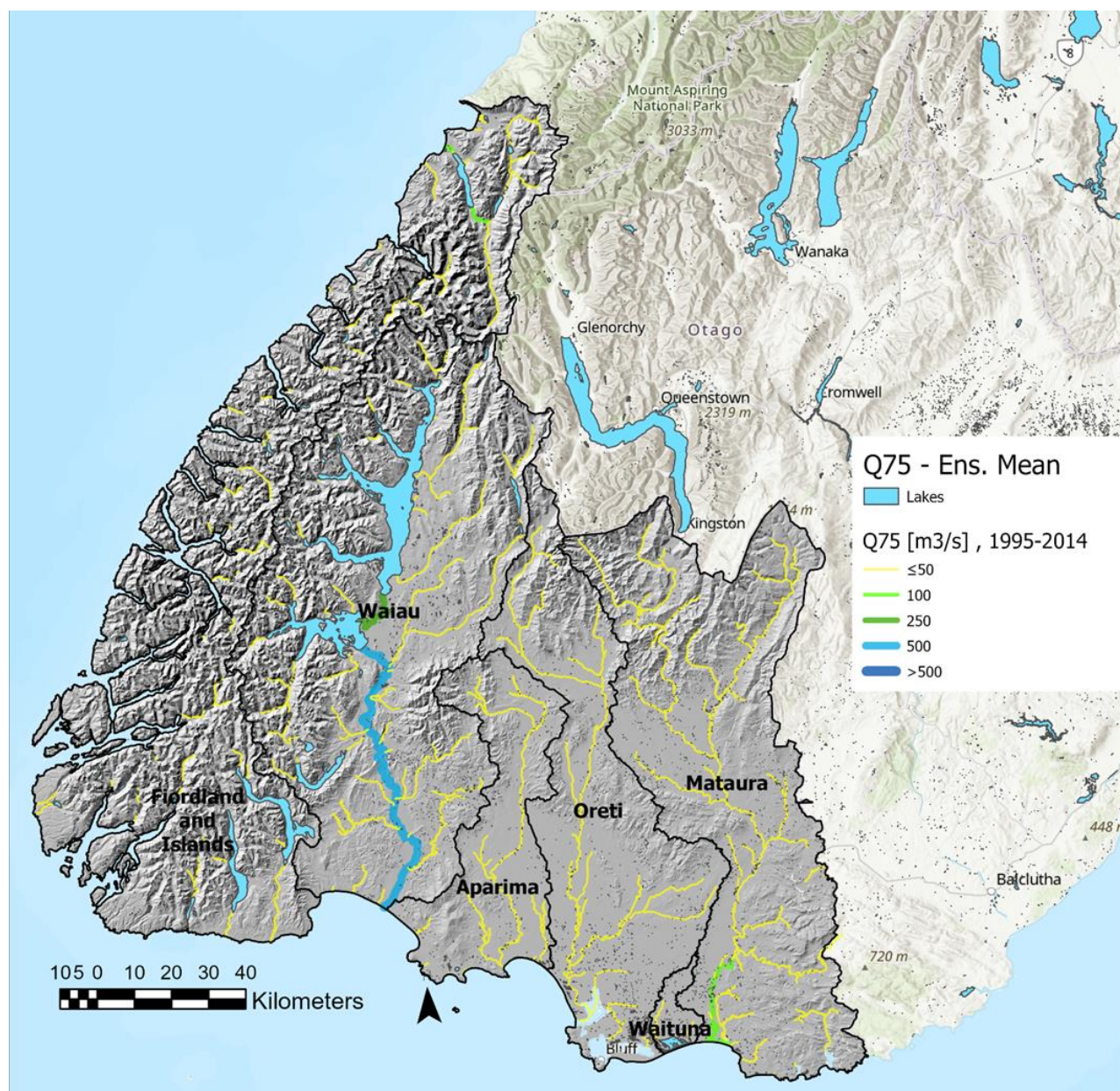


Figure 3-24: Historical multi-model mean Q75.

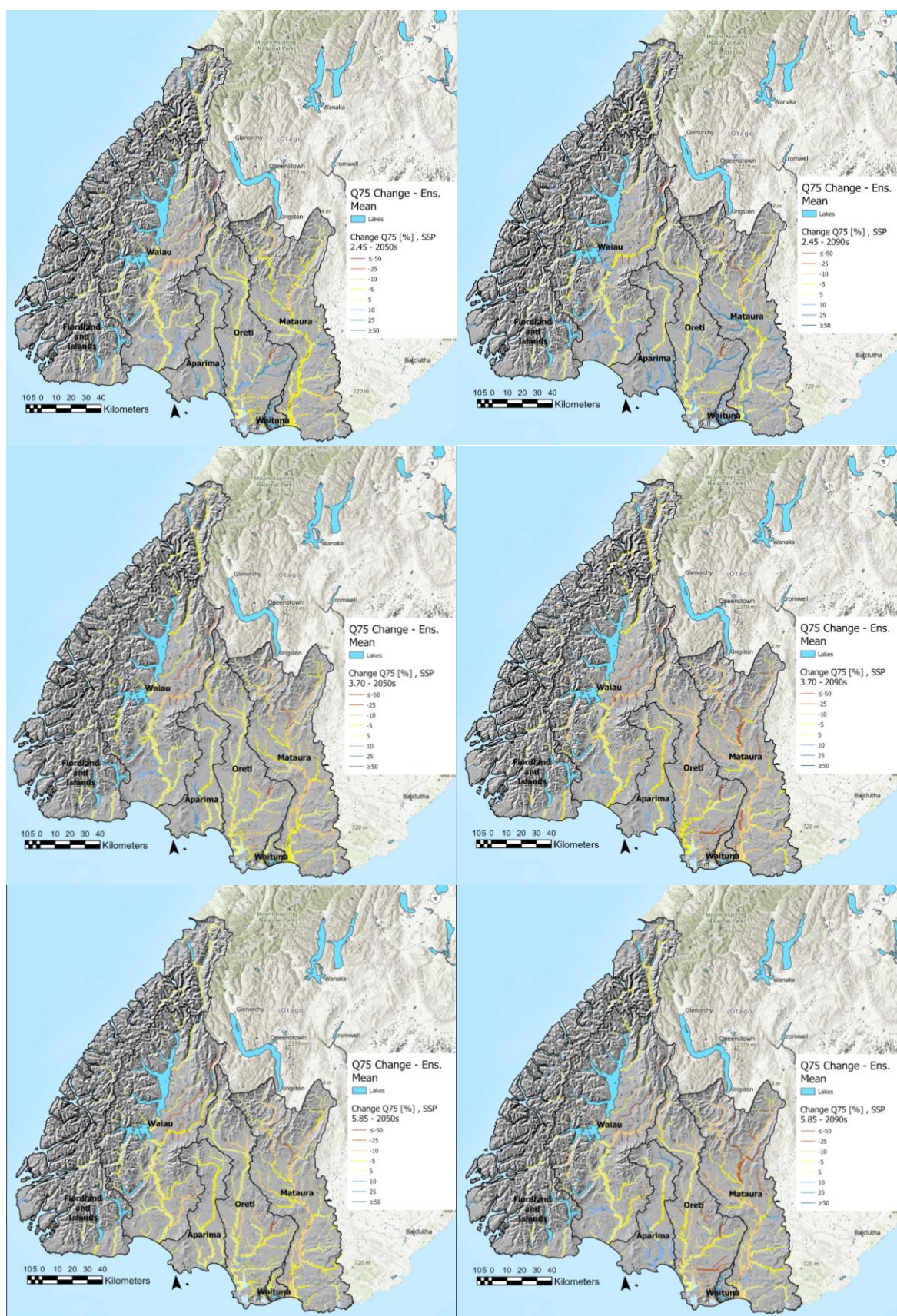


Figure 3-25: Change in multi-model Q75. Change in multi-model Q75 is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Table 3-19: Projected changes in Q75 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.9	6.7	-2.0	-5.7	-1.9	-2.5
Aparima	5.8	14.6	4.1	-2.7	-2.5	4.7
Fiordland and Islands	5.2	10.3	3.1	3.3	6.8	8.1
Mataura	-3.1	4.3	-6.6	-12.0	-6.9	-9.9
Oreti	-3.9	1.0	-9.9	-18.9	-11.3	-20.1
Waiau	-0.8	4.0	-1.9	-5.5	-4.1	-2.9
Waituna	3.8	12.7	-1.5	-8.4	-4.0	4.6

Table 3-20: Location specific projected changes in Q75 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	-8.4	-4.4	-11.0	-16.7	-11.1	-12.9
Mataura River at Gore Township	-8.1	-6.6	-12.5	-19.7	-12.9	-18.7
Mataura Catchment to Wyndham Catchment Township	-7.1	-1.0	-10.3	-16.0	-12.1	-15.2
Waikaia Catchment to Waikaia Township	-6.5	-7.2	-13.9	-18.2	-12.8	-17.0
Waikaka Stream to Gore Township	1.0	-3.2	-13.2	-14.9	-8.0	-5.7
Waikawa Catchment	-1.5	2.5	-4.2	-5.7	2.7	-2.1
Waimea Catchment	8.8	17.1	5.5	-6.9	-1.4	-9.3
Waituna Catchment	-1.1	8.4	-3.9	-1.0	0.6	-4.7
Mokoreta Catchment	-0.7	4.5	-4.6	-3.3	4.0	0.4
Waikaia Catchment	-12.2	-12.5	-19.3	-28.6	-18.4	-28.6
Makarewa Catchment	8.2	4.2	1.7	-8.0	4.8	-1.4
Oreti Catchment to Lumsden Township	0.3	-0.5	-2.8	-11.4	-4.5	-4.4
Oreti Catchment to Winton Township	2.1	-0.6	-1.0	-11.3	-2.0	-5.8
Oreti Catchment to Wallacetown	3.2	1.1	0.5	-9.2	-1.2	-3.8
Waihopai River to Invercargill City	-9.8	-4.5	-16.4	-24.9	-1.3	-26.0
Otepuni Stream to Invercargill City	-6.6	-19.4	-19.7	-37.8	-15.4	-39.4
Kingswell Creek at Invercargill City	4.6	4.7	-11.7	-26.5	-24.8	-26.3
Irthing Stream at Ellis Road	-7.8	-6.2	-1.9	-15.9	-14.9	-17.7
Winton Stream to Winton Township	3.7	16.5	3.2	0.7	-13.0	-12.7
Aparima River to Otautau Township	0.6	4.5	-3.5	-5.6	-6.0	-0.8
Otautau Stream to Otautau Township	12.7	12.7	14.3	7.9	-0.2	10.5
Aparima River at Thornbury Bridge	2.2	5.4	2.4	-1.6	-0.9	5.6
Whitestone Catchment	-22.8	-14.4	-22.5	-39.1	-35.4	-48.2
Upukerora Catchment	-2.2	3.4	-7.2	-14.2	-9.4	-8.6
Mararoa Catchment	-15.0	-6.9	-20.6	-24.7	-9.5	-17.2

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Orauea Catchment	5.8	11.0	3.2	-5.7	-10.5	-4.9
Waiau River at Tutapere	-1.0	3.6	-1.2	-5.4	-1.0	-0.4

3.9 Annual Q25

The Annual Q25 is the annual average river flow that is exceeded twenty-five per cent of the time (upper quartile of the annual mean flow series). This is typically a flow metric providing insights into the average flow during the second quartile of the year. Historic and projected changes in annual Q25 are illustrated Figure 3-26 and Figure 3-27. FMU-wide average projected changes in annual Q25 (generated across each FMU) are presented in Table 3-21, while location-specific projected changes are shown in Table 3-22.

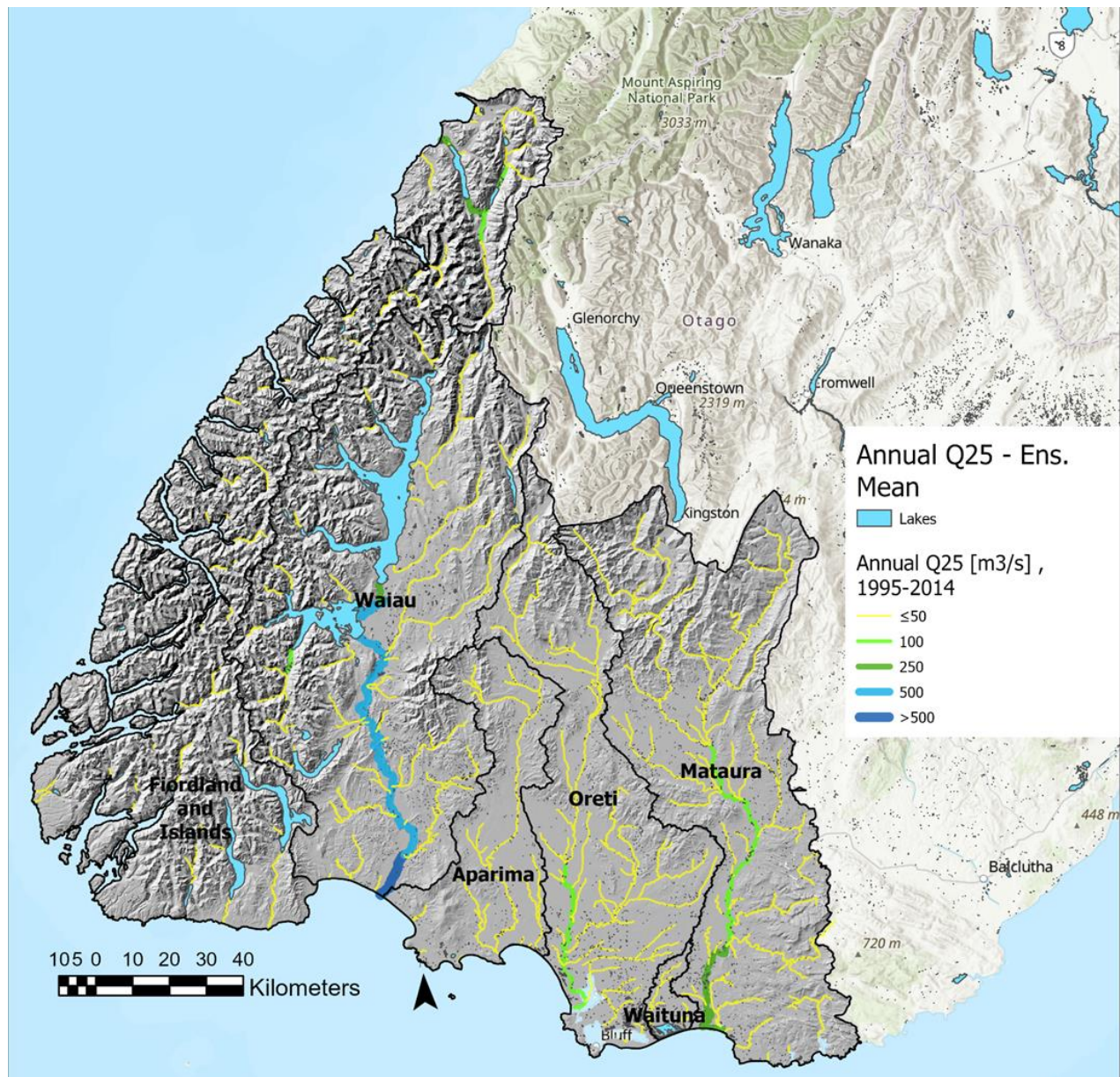


Figure 3-26: Historical multi-model average annual Q25.

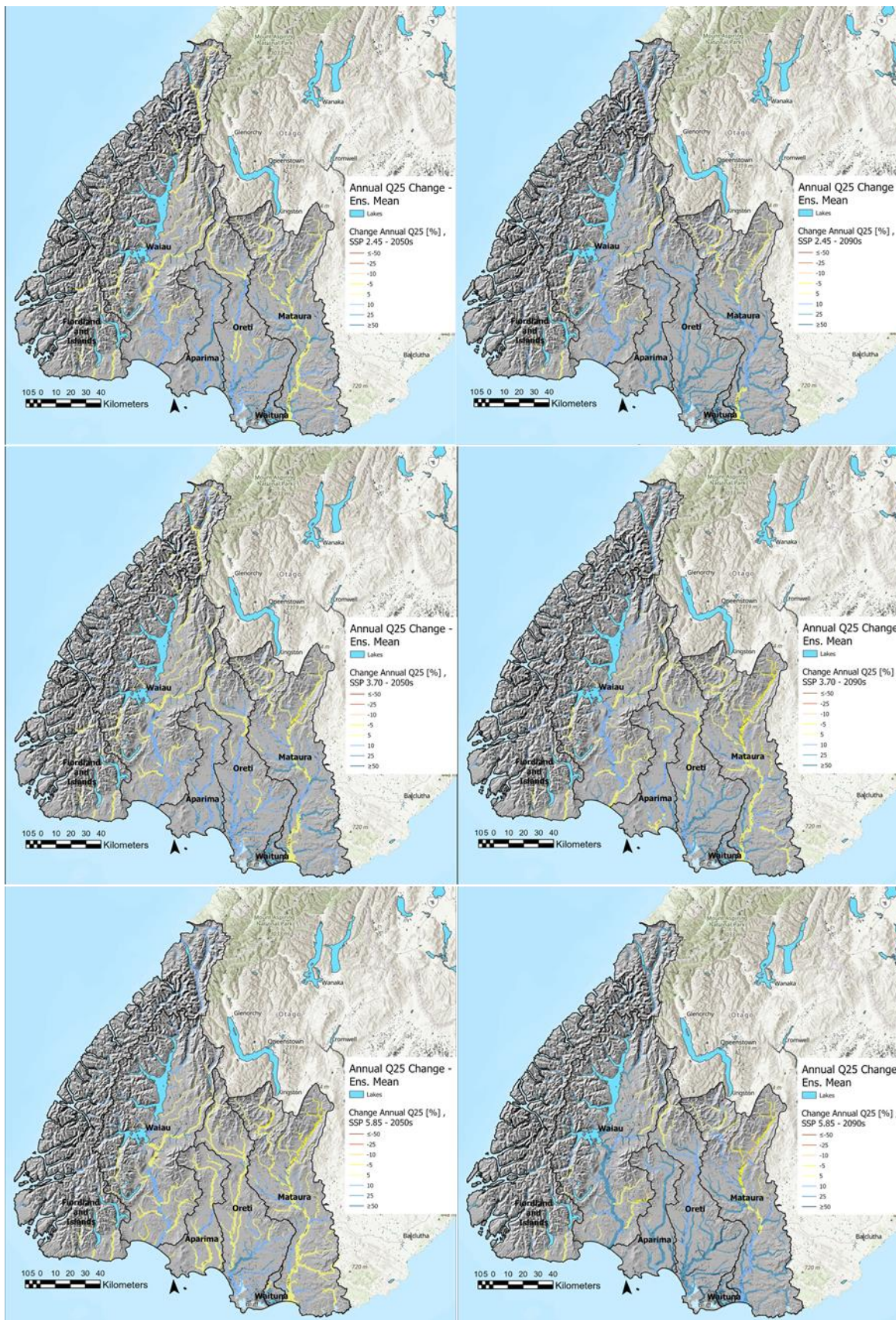


Figure 3-27: Change in multi-model average annual Q25. Change in multi-model average annual Q25 is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Table 3-21: Projected changes in annual Q25 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	7.8	13.4	7.6	10.1	6.1	15.4
Aparima	12.4	17.8	11.2	10.0	4.6	17.9
Fiordland and Islands	5.7	10.6	5.9	10.6	8.3	14.8
Mataura	8.5	13.7	7.6	6.2	3.1	11.4
Oreti	9.4	17.7	9.6	14.7	6.3	21.2
Waiau	7.4	11.6	6.7	8.8	5.4	13.8
Waituna	12.4	24.6	14.9	16.7	7.9	24.1

Table 3-22: Location specific projected changes in annual Q25 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	3.6	2.4	3.1	-2.3	-1.3	5.0
Mataura River at Gore Township	3.4	8.1	4.8	-2.4	2.0	2.5
Mataura Catchment to Wyndham Catchment Township	4.6	5.7	5.0	0.7	3.1	6.6
Waikaia Catchment to Waikaia Township	2.9	-0.6	-6.5	-7.9	-6.3	-10.5
Waikaka Stream to Gore Township	13.2	13.6	10.3	6.9	7.2	11.8
Waikawa Catchment	5.9	10.3	6.8	4.7	2.3	11.9
Waimea Catchment	9.2	23.0	7.3	7.7	5.7	16.1
Waituna Catchment	7.7	19.5	13.4	10.3	6.3	18.4
Mokoreta Catchment	3.1	11.4	7.2	5.5	4.4	12.0
Waikaia Catchment	2.1	2.3	-4.1	-4.8	-3.6	-7.9
Makarewa Catchment	10.3	18.3	9.2	12.9	11.1	22.7
Oreti Catchment to Lumsden Township	5.0	10.2	4.5	4.3	1.7	7.5
Oreti Catchment to Winton Township	4.3	9.7	7.2	4.7	3.5	9.0
Oreti Catchment to Wallacetown	6.6	12.6	8.0	6.6	4.8	12.1
Waihopai River to Invercargill City	9.4	21.4	7.7	14.7	8.1	24.1
Otepuni Stream to Invercargill City	12.5	20.3	12.1	14.7	8.1	29.4
Kingswell Creek at Invercargill City	9.1	16.8	11.8	14.9	11.8	25.6
Irthing Stream at Ellis Road	2.7	8.4	5.3	2.8	-1.3	8.3
Winton Stream to Winton Township	4.6	19.4	9.8	14.4	0.6	22.1
Aparima River to Otautau Township	12.7	12.9	7.8	9.2	8.2	13.5
Otautau Stream to Otautau Township	7.3	16.8	7.6	9.4	-4.0	11.7
Aparima River at Thornbury Bridge	7.5	11.6	7.4	5.0	3.8	10.9
Whitestone Catchment	6.7	19.7	2.9	2.5	1.6	16.0
Upukerora Catchment	3.3	9.0	3.4	0.5	2.5	8.7
Mararoa Catchment	0.9	8.1	1.3	-0.1	3.6	8.4

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Orauea Catchment	7.7	15.9	7.9	3.6	-4.0	5.2
Waiau River at Tutapere	6.4	8.4	5.2	4.8	5.1	11.4

3.10 Mean annual 7-day low flows

Modelled historic and projected changes to daily mean annual 7-day low flows (Q7day MALF) are illustrated in Figure 3-28 to Figure 3-29. FMU-wide average projected changes in Q7day MALF (generated across each FMU) are presented in Table 3-23, while location-specific projected changes are shown in Table 3-24.

Table 3-23: Projected changes in in mean annual 7-day low flows (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	9.6	26.4	-1.7	3.7	-8.1	0.0
Aparima	24.8	51.9	10.5	-7.8	-5.4	11.3
Fiordland and Islands	16.7	13.4	-2.1	14.1	-5.6	-2.2
Mataura	4.6	39.2	-0.8	-2.2	-10.6	9.6
Oreti	17.7	37.4	-1.5	6.0	-10.4	-4.0
Waiau	-8.4	12.7	-11.1	-10.0	-10.4	-11.0
Waituna	16.4	73.6	39.6	37.3	1.4	37.4

Table 3-24: Location specific projected changes in in mean annual 7-day low flows (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	3.7	3.8	4.0	-0.2	-0.7	2.6
Mataura River at Gore Township	2.3	3.7	2.1	-0.1	-0.3	0.3
Mataura Catchment to Wyndham Catchment Township	3.8	5.9	3.6	3.2	2.0	5.0
Waikaia Catchment to Waikaia Township	-1.1	0.1	-6.8	-4.5	-6.5	-7.4
Waikaka Stream to Gore Township	6.5	10.5	8.7	6.8	9.8	12.3
Waikawa Catchment	5.4	11.1	7.0	9.6	2.8	10.4
Waimea Catchment	10.2	27.9	15.7	11.5	11.7	19.9
Waituna Catchment	10.2	24.5	12.5	18.9	8.0	23.5
Mokoreta Catchment	5.1	11.4	7.1	8.7	5.0	10.9
Waikaia Catchment	-1.2	1.6	-5.6	-6.1	-4.9	-7.7
Makarewa Catchment	10.6	13.4	10.3	16.5	12.3	24.6
Oreti Catchment to Lumsden Township	2.6	9.3	3.3	6.2	2.0	11.9
Oreti Catchment to Winton Township	3.5	12.1	4.7	7.2	1.6	12.5
Oreti Catchment to Wallacetown	4.1	13.5	5.4	8.0	2.3	13.9

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Waihopai River to Invercargill City	6.7	18.3	7.2	16.2	8.5	24.0
Otepuni Stream to Invercargill City	11.3	20.1	9.2	15.5	7.9	29.3
Kingswell Creek at Invercargill City	9.4	17.9	10.8	19.3	8.3	26.6
Irthing Stream at Ellis Road	5.1	9.9	5.5	7.9	1.8	15.9
Winton Stream to Winton Township	7.6	17.9	9.7	14.3	4.7	21.7
Aparima River to Otautau Township	6.7	14.9	6.7	7.5	4.8	16.5
Otautau Stream to Otautau Township	5.6	17.8	6.4	11.7	0.7	15.7
Aparima River at Thornbury Bridge	6.2	16.2	7.6	9.9	4.3	17.7
Whitestone Catchment	2.1	15.4	4.3	8.1	5.0	18.3
Upukerora Catchment	0.5	7.3	1.7	6.2	1.4	8.3
Mararoa Catchment	1.5	8.2	3.1	5.0	3.2	11.4
Orauea Catchment	6.3	15.5	4.0	6.6	-1.2	11.8
Waiau River at Tutapere	5.7	8.9	5.9	7.2	5.8	12.8

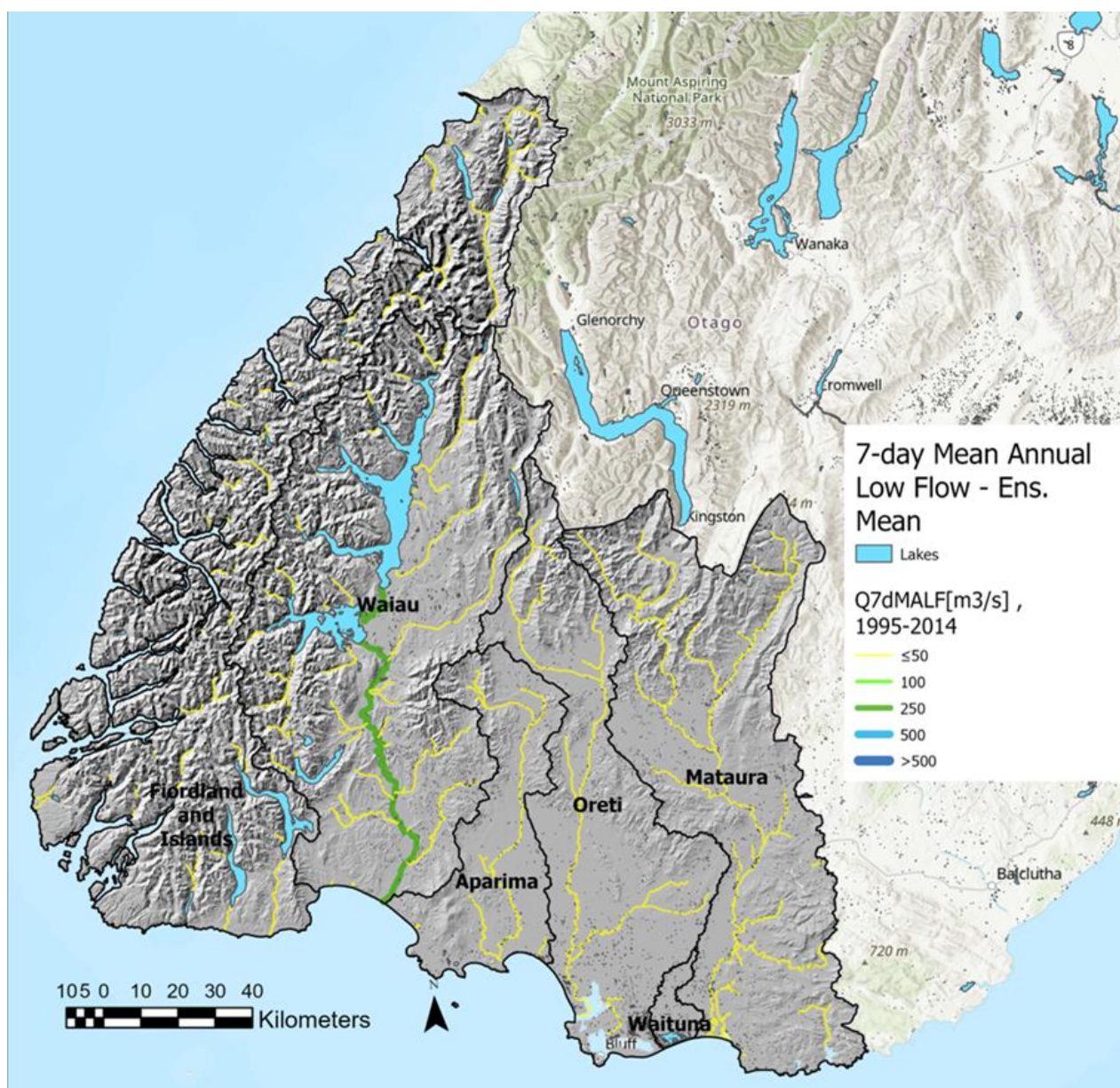


Figure 3-28: Multi-model ensemble historical Q7day MALF.

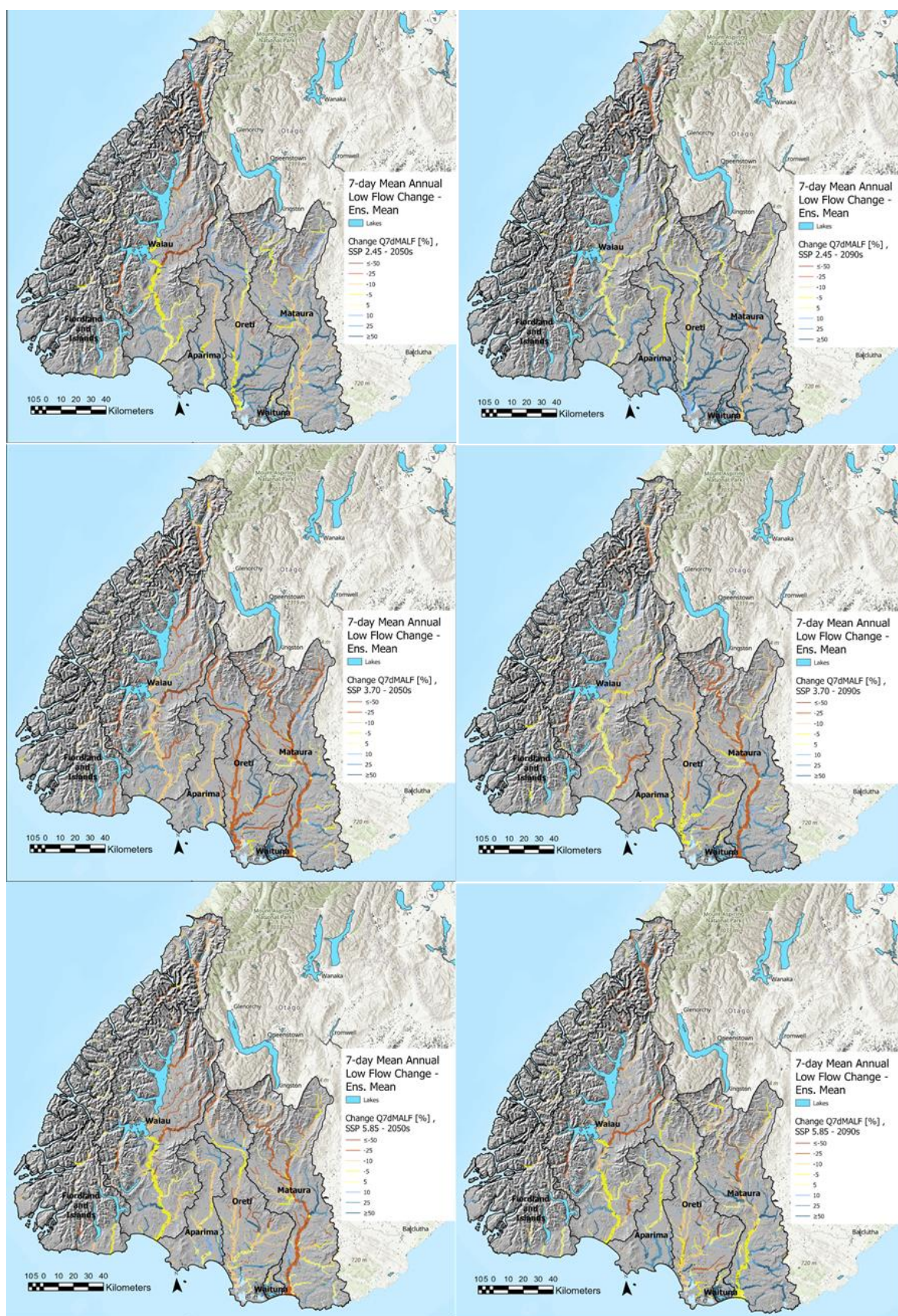


Figure 3-29: Change in multi-model average Q7day MALF. Change in multi-model average Q7day MALF is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.11 Q95

Historic and projected changes in Q95 (river flow magnitude exceeded ninety-five percent of the time) are illustrated in Figure 3-30 and Figure 3-31. FMU-wide average projected changes in annual Q95 (generated across each FMU) are presented in Table 3-25, while location-specific projected changes are shown in Table 3-26.

Table 3-25: Projected changes in Q95 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	1.9	6.4	-1.8	-6.1	0.9	-5.7
Aparima	5.7	12.6	5.2	-6.1	-2.2	-2.5
Fiordland and Islands	8.2	12.8	3.8	5.1	11.0	6.2
Mataura	-5.7	1.0	-10.3	-17.0	-7.2	-16.5
Oreti	-3.3	-3.1	-9.6	-19.3	-7.9	-20.8
Waiau	1.1	5.6	1.6	-3.3	-0.4	-5.2
Waituna	4.8	10.1	-8.7	-13.3	-1.2	-4.9

Table 3-26: Location specific projected changes in Q95 (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	-11.9	-7.6	-9.3	-21.2	-14.0	-15.1
Mataura River at Gore Township	-11.9	-10.6	-10.8	-23.4	-12.0	-20.3
Mataura Catchment to Wyndham Catchment Township	-11.6	-5.4	-9.4	-21.3	-9.0	-20.1
Waikaia Catchment to Waikaia Township	-7.4	-9.0	-10.5	-23.9	-10.8	-22.7
Waikaka Stream to Gore Township	-1.1	-1.8	-10.3	-15.6	-7.4	-10.2
Waikawa Catchment	-6.1	5.1	-4.9	-6.6	1.1	-9.0
Waimea Catchment	-7.4	-1.6	-7.5	-18.9	-14.7	-24.4
Waituna Catchment	6.1	19.3	7.7	7.5	15.4	8.5
Mokoreta Catchment	-5.9	-3.0	-11.8	-7.4	-1.8	-7.6
Waikaia Catchment	-14.0	-16.7	-16.4	-31.6	-17.8	-29.3
Makarewa Catchment	1.0	-5.0	-2.2	-9.5	3.1	-8.2
Oreti Catchment to Lumsden Township	-0.1	-0.7	4.5	-6.8	0.4	-4.8
Oreti Catchment to Winton Township	-3.8	-6.8	0.3	-11.0	0.3	-8.8
Oreti Catchment to Wallacetown	-4.5	-7.6	0.1	-11.0	-0.1	-8.7
Waihopai River to Invercargill City	-4.0	-3.3	-10.4	-26.2	-5.9	-25.7
Otepun Stream to Invercargill City	-15.3	-26.7	-23.1	-44.6	-21.0	-47.4
Kingswell Creek at Invercargill City	-6.0	-9.5	-20.3	-26.6	-9.7	-29.0
Irthing Stream at Ellis Road	-5.7	-4.3	0.2	-15.0	-9.1	-16.3
Winton Stream to Winton Township	2.3	15.3	1.7	-19.8	-13.5	-18.2

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Aparima River to Otautau Township	-0.1	1.4	-2.9	-1.4	-0.9	-2.2
Otautau Stream to Otautau Township	5.7	8.4	13.3	-4.1	-2.2	0.5
Aparima River at Thornbury Bridge	2.1	5.0	5.4	3.4	7.3	3.2
Whitestone Catchment	-6.4	-5.3	-10.3	-24.8	-17.3	-35.0
Upukerora Catchment	-9.5	3.3	-1.5	-13.3	-5.0	-13.0
Mararoa Catchment	-13.2	-11.9	-25.0	-30.1	-10.8	-36.4
Orauea Catchment	5.3	17.6	10.2	-9.9	-7.3	-9.9
Waiau River at Tutapere	-2.3	2.4	-2.3	-7.3	-1.4	-12.7

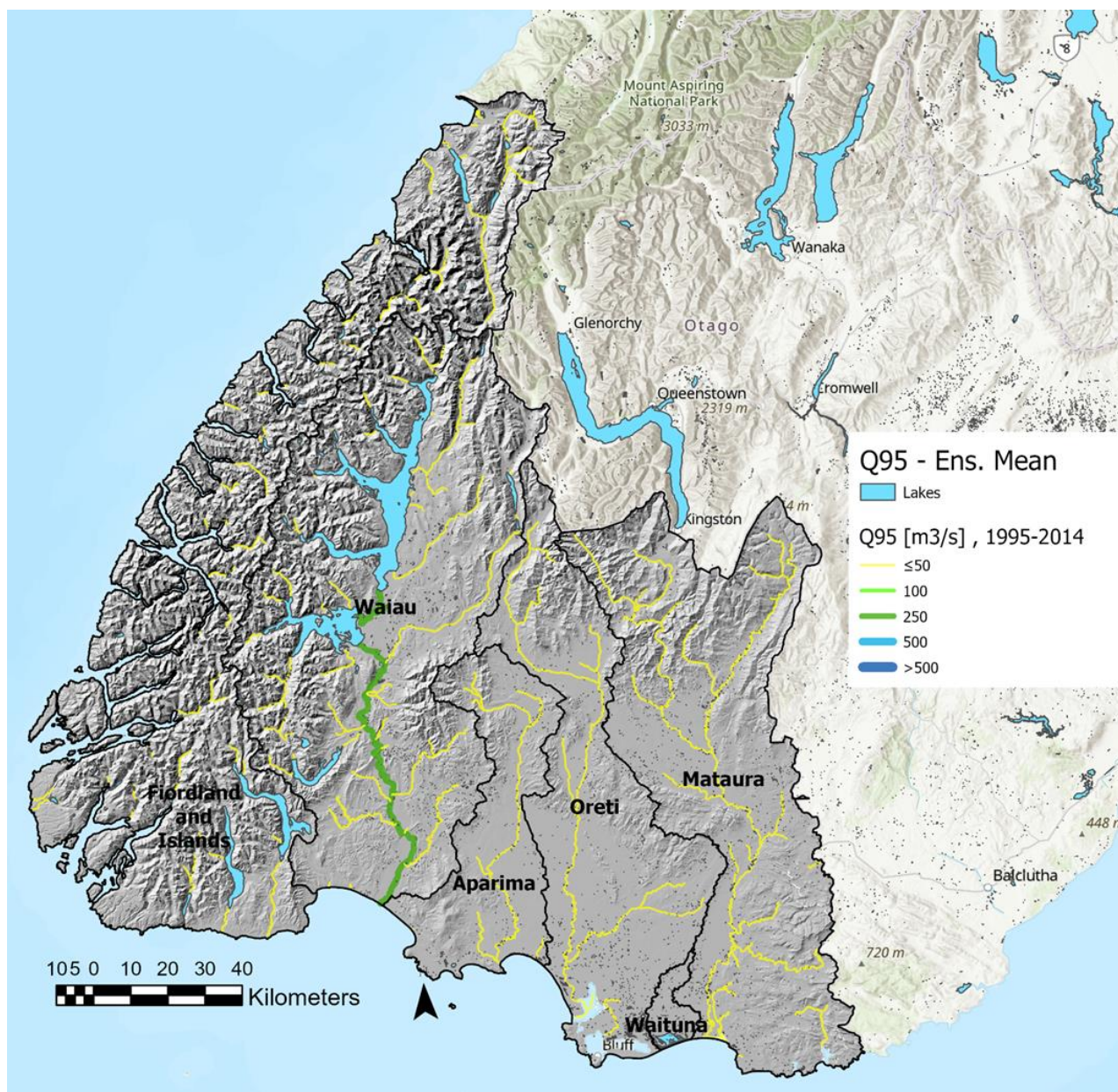


Figure 3-30: Historical multi-model mean Q95.

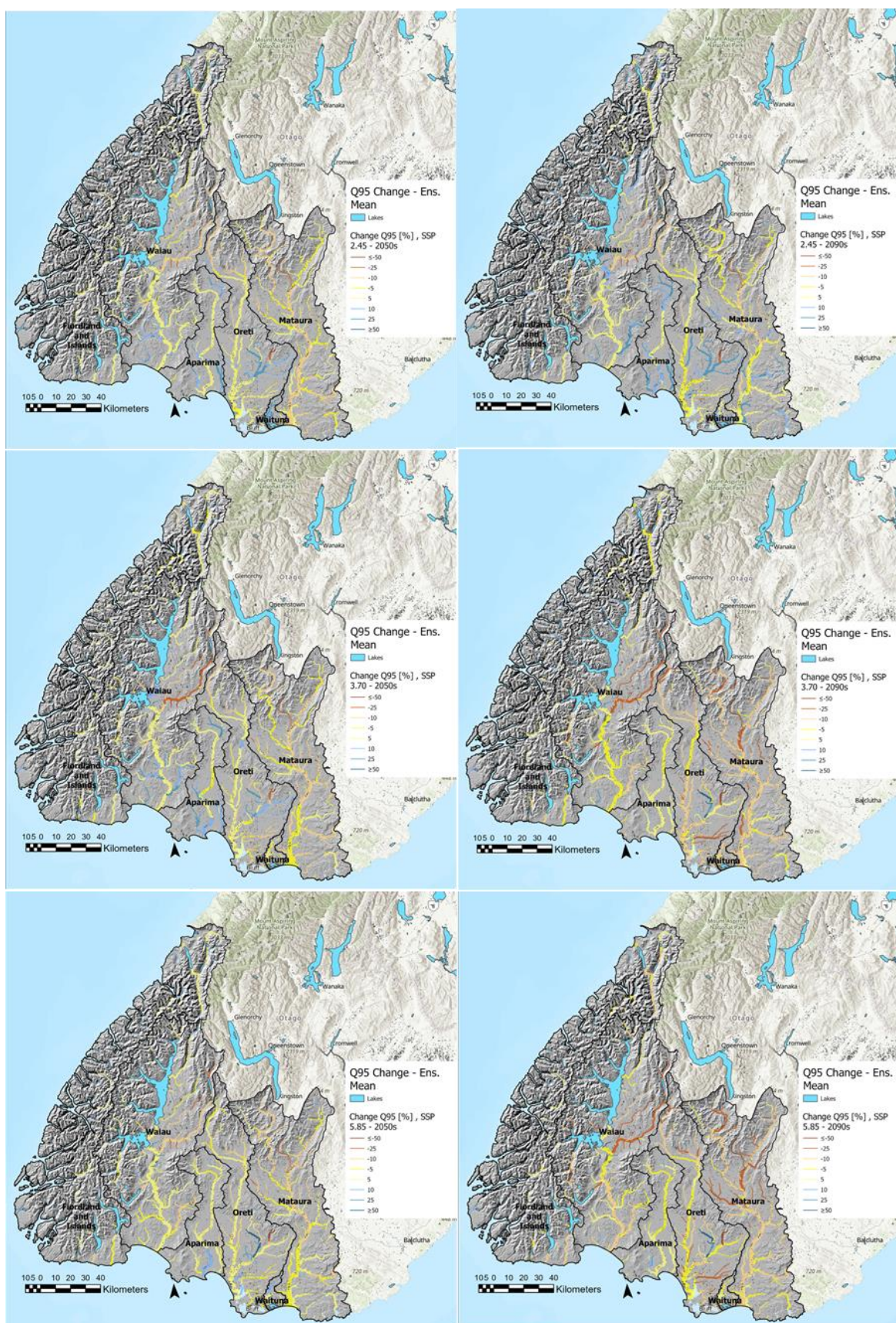


Figure 3-31: Change in multi-model Q95. Change in multi-model Q95 is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.12 Flow reliability

Modelled historic and projected changes to flow reliability² are illustrated in Figure 3-32 and Figure 3-33. FMU-wide average projected changes in average flow reliability (generated as a difference relative to 1995-2014 across each FMU) are summarised in Table 3-27, while location-specific projected changes are shown in Table 3-28.

Table 3-27: Projected changes in flow reliability (-, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.00	-0.02	-0.01	-0.01	0.01	0.00
Aparima	-0.03	-0.05	-0.03	-0.01	0.00	-0.02
Fiordland and Islands	0.00	-0.01	0.00	-0.02	0.01	0.01
Mataura	-0.01	-0.04	-0.03	-0.01	0.01	-0.02
Oreti	-0.01	-0.03	-0.02	-0.02	0.01	-0.01
Waiau	0.02	0.00	0.00	0.01	0.02	0.02
Waituna	-0.01	-0.08	-0.05	-0.04	0.00	-0.02

Table 3-28: Location specific projected changes in flow reliability Q25 (-, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	0.01	0.00	-0.02	0.03	0.02	0.00
Mataura River at Gore Township	0.03	0.01	0.00	0.03	0.03	-0.01
Mataura Catchment to Wyndham Catchment Township	0.02	0.00	-0.02	0.02	0.02	-0.02
Waikaia Catchment to Waikaia Township	0.02	-0.01	-0.01	0.02	0.02	-0.01
Waikaka Stream to Gore Township	-0.02	-0.04	-0.02	0.00	0.00	-0.03
Waikawa Catchment	0.02	-0.03	-0.04	-0.02	0.02	-0.01
Waimea Catchment	-0.01	-0.03	0.00	0.00	0.02	-0.03
Waituna Catchment	-0.02	-0.05	-0.04	-0.03	0.00	-0.03
Mokoreta Catchment	-0.02	-0.05	-0.06	-0.03	-0.02	-0.03
Waikaia Catchment	0.04	0.01	0.01	0.04	0.05	0.01
Makarewa Catchment	-0.01	-0.04	-0.03	-0.03	0.00	-0.01
Oreti Catchment to Lumsden Township	0.01	-0.01	-0.01	0.00	0.02	-0.01
Oreti Catchment to Winton Township	0.01	0.00	0.00	-0.01	0.02	-0.01
Oreti Catchment to Wallacetown	0.01	0.00	-0.01	-0.01	0.01	-0.02
Waihopai River to Invercargill City	-0.01	-0.03	-0.03	-0.03	0.00	-0.02
Otepuni Stream to Invercargill City	0.02	0.02	0.00	-0.01	0.06	0.01
Kingswell Creek at Invercargill City	-0.03	-0.01	-0.04	-0.06	0.00	-0.02
Irthing Stream at Ellis Road	0.01	0.00	0.00	0.02	0.02	0.00

² The fraction of time that the flow is equal to or below the National Environmental Standard (NES) for Environmental Flows and Water Levels (Ministry for the Environment 2008).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Winton Stream to Winton Township	-0.01	-0.03	-0.03	-0.02	0.00	-0.01
Aparima River to Otautau Township	0.01	0.00	0.00	0.01	0.01	-0.01
Otautau Stream to Otautau Township	-0.04	-0.04	-0.03	0.01	0.00	-0.02
Aparima River at Thornbury Bridge	0.00	-0.01	0.00	0.01	0.01	-0.02
Whitestone Catchment	0.05	0.05	-0.03	-0.01	0.02	0.04
Upukerora Catchment	-0.01	-0.02	-0.01	0.01	0.04	0.00
Mararoa Catchment	0.04	0.00	-0.02	0.00	0.04	0.01
Orauea Catchment	-0.01	-0.04	-0.02	0.01	0.00	0.01
Waiau River at Tutapere	0.01	-0.01	-0.02	0.01	0.02	-0.01

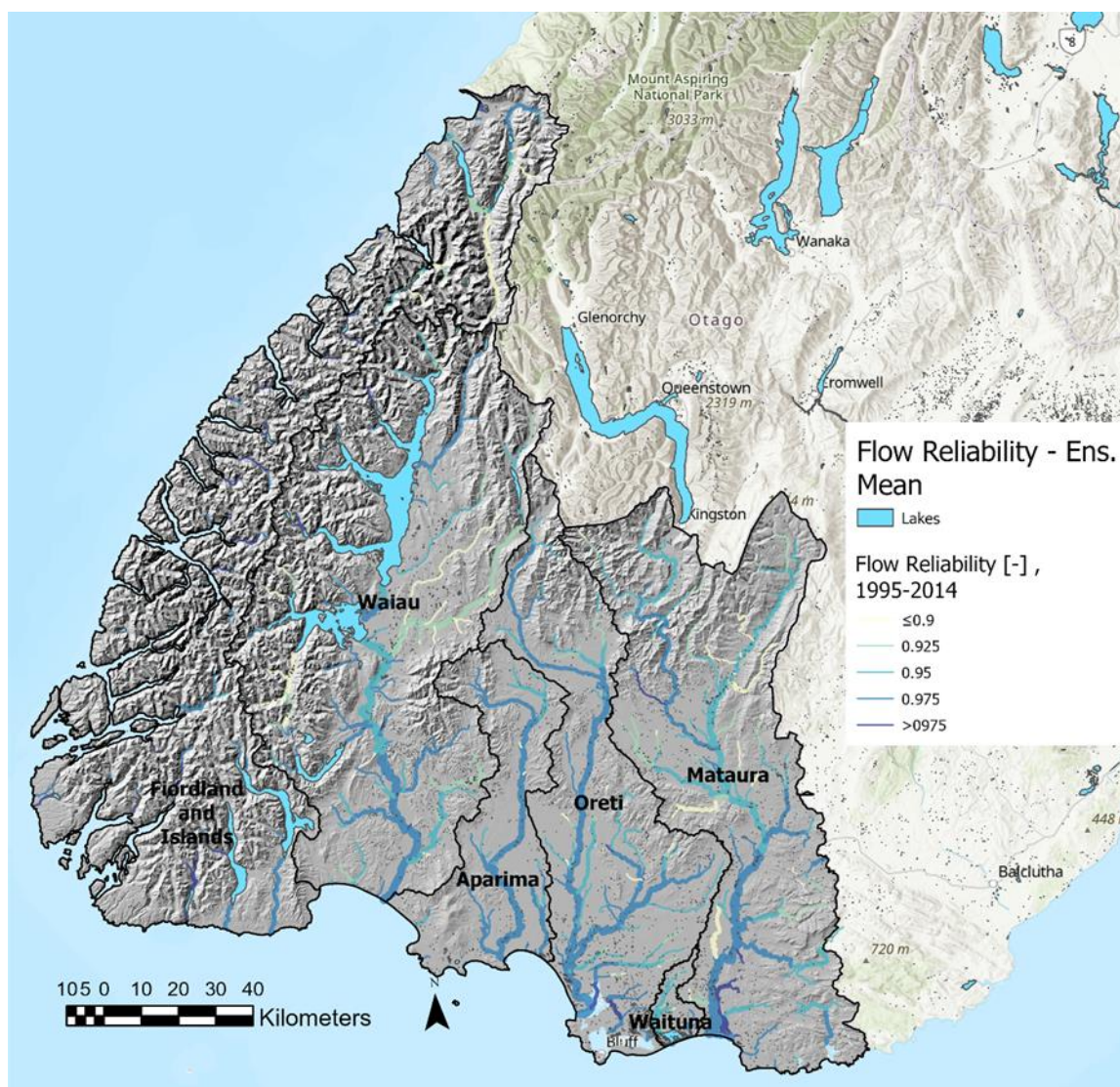


Figure 3-32: Historical multi-model average flow reliability.

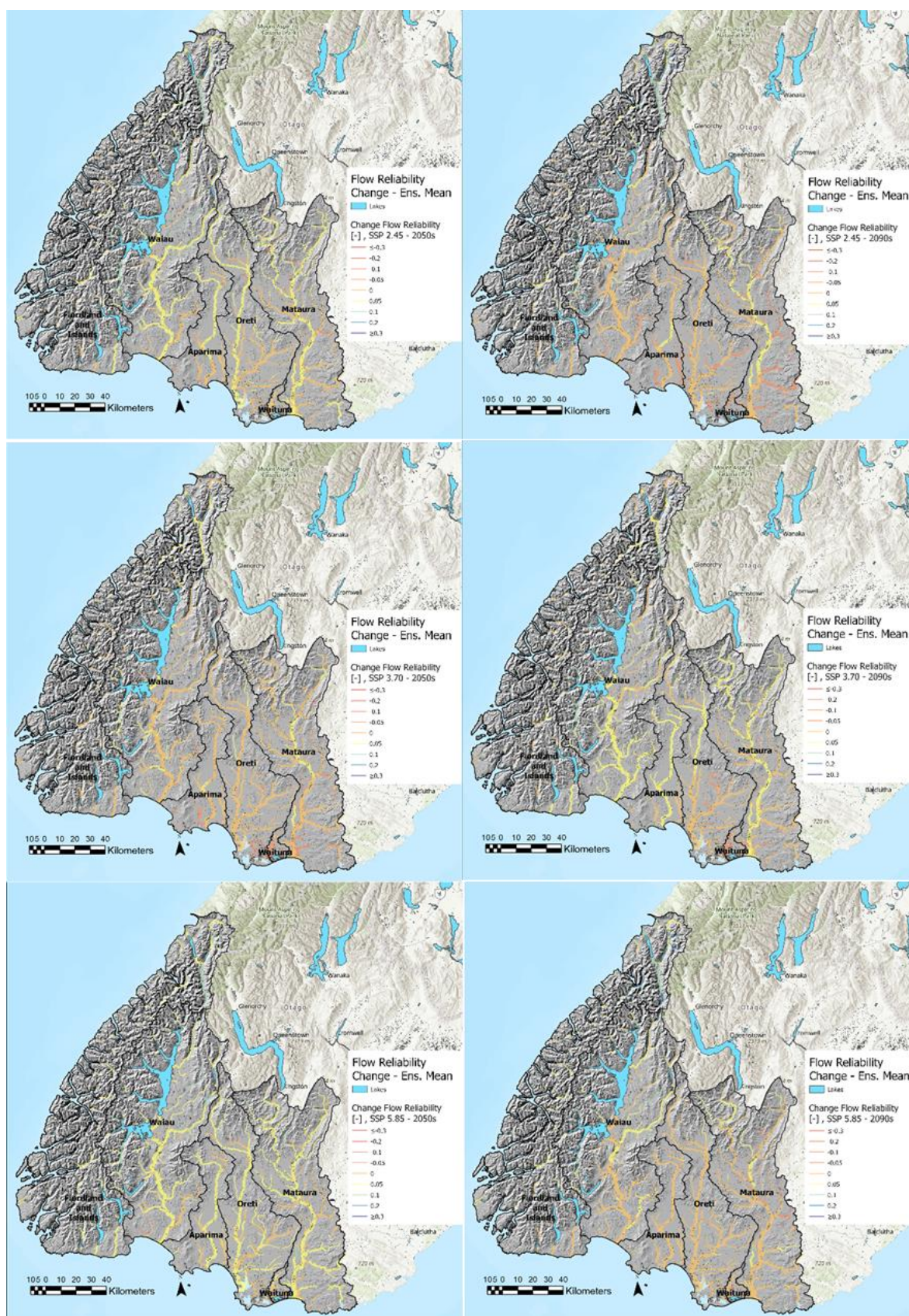


Figure 3-33: Change in multi-model average flow reliability. Change in multi-model average flow reliability is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.13 Water supply reliability

Modelled historic and projected changes to water supply reliability³ are illustrated in Figure 3-34 and Figure 3-35. Regional average projected changes are summarised in the box below. FMU-wide average projected changes in water supply reliability (generated as a difference across each FMU) are presented in Table 3-29, while location-specific projected changes are shown in Table 3-30.

Table 3-29: Projected changes in water supply reliability (-, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	-0.01	-0.03	-0.02	-0.01	0.01	-0.01
Aparima	-0.03	-0.05	-0.03	-0.01	0.00	-0.02
Fiordland and Islands	-0.01	-0.01	-0.01	-0.02	0.01	0.00
Mataura	-0.01	-0.04	-0.03	-0.01	0.00	-0.02
Oreti	-0.01	-0.03	-0.02	-0.02	0.01	-0.01
Waiau	0.01	-0.02	-0.01	0.00	0.01	0.00
Waituna	-0.01	-0.07	-0.04	-0.04	0.00	-0.02

Table 3-30: Location specific projected changes in water supply reliability (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	0.01	0.00	-0.01	0.03	0.02	0.00
Mataura River at Gore Township	0.03	0.01	0.00	0.03	0.03	-0.01
Mataura Catchment to Wyndham Catchment Township	0.02	0.00	-0.01	0.02	0.02	-0.01
Waikaia Catchment to Waikaia Township	0.02	-0.01	0.00	0.02	0.02	-0.01
Waikaka Stream to Gore Township	-0.02	-0.04	-0.02	0.00	0.00	-0.03
Waikawa Catchment	0.01	-0.03	-0.04	-0.02	0.01	-0.02
Waimea Catchment	-0.01	-0.03	0.00	0.00	0.02	-0.03
Waituna Catchment	-0.02	-0.05	-0.04	-0.03	0.00	-0.02
Mokoreta Catchment	-0.02	-0.05	-0.05	-0.03	-0.02	-0.03
Waikaia Catchment	0.04	0.01	0.01	0.04	0.04	0.01
Makarewa Catchment	-0.02	-0.04	-0.03	-0.03	0.00	-0.01
Oreti Catchment to Lumsden Township	0.01	-0.01	-0.01	0.00	0.02	-0.01
Oreti Catchment to Winton Township	0.01	0.00	0.00	-0.01	0.02	-0.01
Oreti Catchment to Wallacetown	0.01	-0.01	-0.01	-0.02	0.01	-0.01
Waihopai River to Invercargill City	-0.01	-0.03	-0.03	-0.03	0.00	-0.02
Otepun Stream to Invercargill City	0.02	0.01	0.00	-0.01	0.05	0.00
Kingswell Creek at Invercargill City	-0.03	-0.01	-0.03	-0.05	0.00	-0.01
Irthing Stream at Ellis Road	0.01	0.00	-0.01	0.02	0.02	0.00

³ The average fraction of time during each irrigation season (spanning September 1 to April 30 of each hydrological year) that the river flow is too low and thus irrigation is restricted.

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Winton Stream to Winton Township	-0.02	-0.03	-0.03	-0.02	0.00	-0.01
Aparima River to Otautau Township	0.01	0.00	0.00	0.01	0.01	-0.01
Otautau Stream to Otautau Township	-0.04	-0.05	-0.03	0.01	-0.01	-0.02
Aparima River at Thornbury Bridge	0.00	-0.01	0.00	0.01	0.01	-0.02
Whitestone Catchment	0.04	0.03	-0.03	-0.01	0.02	0.04
Upukerora Catchment	-0.01	-0.03	-0.01	0.01	0.04	0.00
Mararoa Catchment	0.03	-0.01	-0.01	-0.01	0.04	0.00
Orauea Catchment	-0.01	-0.04	-0.02	0.01	0.00	0.01

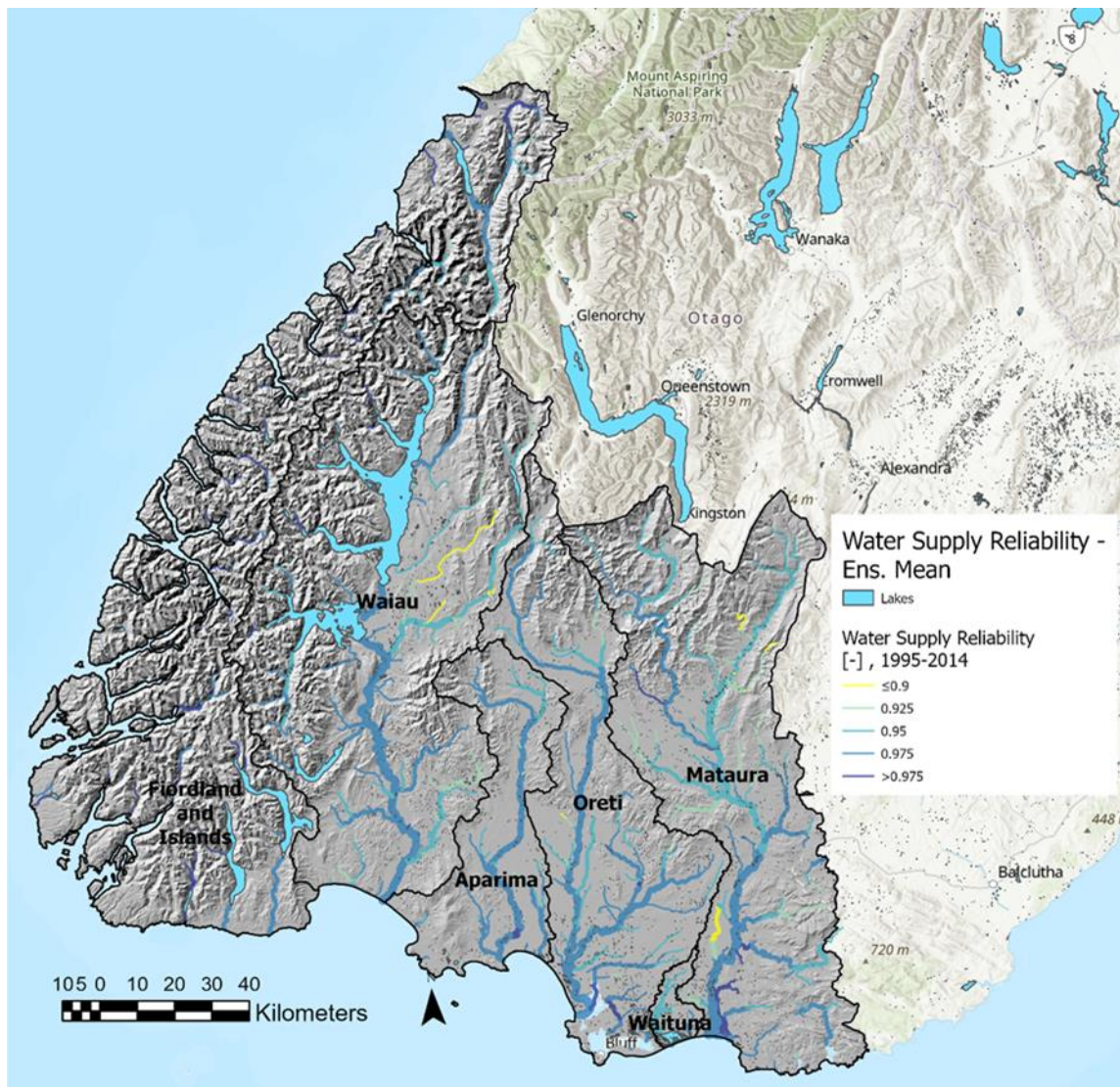


Figure 3-34: Historical multi-model average water supply reliability.

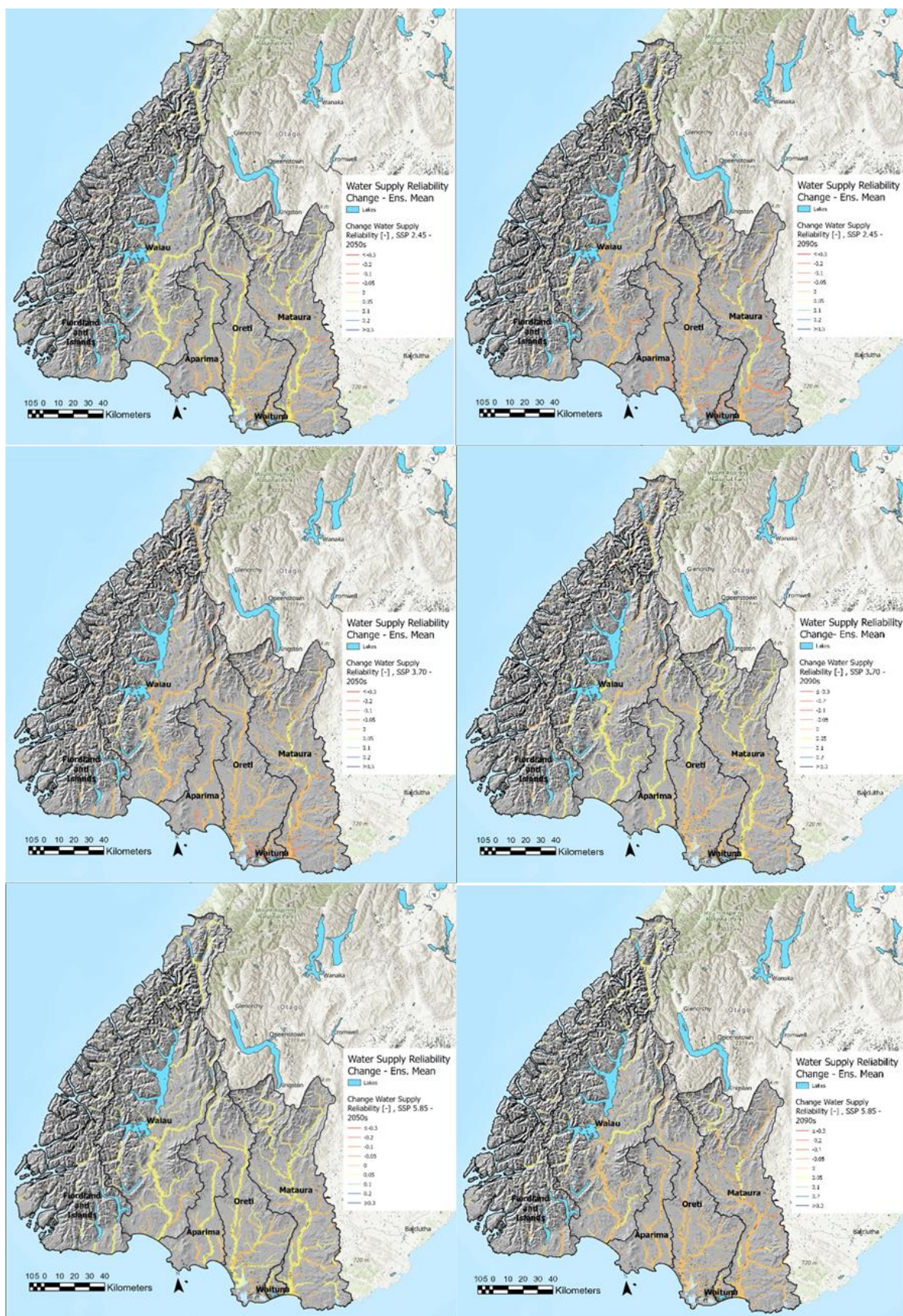


Figure 3-35: Change in multi-model average water supply reliability. Change in multi-model average water supply reliability is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.14 Groundwater

Modelled historic annual and seasonal land surface recharge across Southland's shallow aquifers are illustrated in Figure 3-36 and Figure 3-37. Projected changes in annual land surface recharge are illustrated in Figure 3-38, while projected changes in the June-July-August (winter) and January-February-March (late summer) land surface recharge are illustrated in Figure 3-39 and Figure 3-40, with Appendix D presenting projected changes in autumn and spring land surface recharge. FMU-wide average projected annual average changes and winter and summer changes in land surface recharge (generated across each FMU, not only Southland's aquifers) are presented in Table 3-31 (annual time scale), Table 3-32 (winter), Table 3-33 (summer), while aquifer-specific projected changes at annual and seasonal scales are presented in shown in Appendix D.

Table 3-31: Projected changes in annual land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	3.4	6.9	2.6	3.0	3.1	6.5
Aparima	5.6	10.9	3.2	4.6	3.0	12.7
Fiordland and Islands	5.3	8.4	4.4	7.5	6.8	11.3
Mataura	2.8	8.5	3.8	1.9	2.2	4.4
Oreti	0.3	1.0	-1.7	-6.2	-2.4	-5.6
Waiau	1.9	4.6	0.7	1.7	1.4	6.1
Waituna	8.1	17.1	8.3	10.6	5.7	17.0

Table 3-32: Projected changes in June-July-August (winter) land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	6.6	21.4	11.0	20.3	11.5	28.3
Aparima	3.6	18.9	10.4	13.5	6.2	25.5
Fiordland and Islands	10.7	24.8	15.7	29.4	17.0	37.9
Mataura	0.8	18.8	8.4	16.2	8.1	23.9
Oreti	1.5	12.1	2.6	3.7	1.7	7.2
Waiau	10.0	25.1	12.4	23.4	14.6	32.0
Waituna	3.3	25.0	6.5	18.0	7.3	31.7

Table 3-33: Projected changes in December-January-February (summer) land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	-3.4	-0.2	6.1	-12.9	-3.7	-1.5
Aparima	12.1	7.4	21.0	2.2	3.2	25.0
Fiordland and Islands	-0.9	3.2	0.8	-4.9	-0.1	-1.4
Mataura	-4.8	1.6	12.3	-20.4	-3.4	2.7

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Oreti	-7.3	-11.4	3.9	-26.6	-10.4	-26.4
Waiau	-5.9	-3.1	3.9	-12.9	-8.7	1.5
Waituna	-19.4	11.1	21.0	-17.9	8.3	12.5

Table 3-34: Shallow aquifers projected changes in annual land surface recharge (% relative to 1995-2014).

Shallow aquifer	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Awarua	6.9	12.8	6.1	6.7	4.3	10.3
Blackmount	4.4	9.0	4.2	6.6	-0.1	8.6
Castlerock	5.3	13.9	6.9	9.2	4.7	12.0
Cattle Flat	1.9	8.1	3.6	1.4	2.0	2.1
Central Plains	2.0	3.0	0.0	-3.5	-1.5	-4.5
Centre Hill	1.0	1.2	-0.6	-5.5	0.4	-2.6
Croydon	7.2	14.9	7.5	12.6	8.0	17.9
Dipton	-3.2	-4.0	-4.0	-11.5	-6.3	-14.1
Edendale	5.9	12.3	5.8	6.7	4.4	9.4
Five Rivers	0.8	3.9	1.3	-2.4	-0.4	-0.8
Knapdale	6.8	15.2	7.4	11.2	7.9	16.6
Longridge	5.4	15.3	7.6	7.5	6.2	11.8
Lower Aparima	6.7	11.3	6.1	9.2	4.1	13.2
Lower Maitara	5.0	10.9	4.8	5.4	3.9	9.6
Lower Oreti	1.5	1.9	0.1	-4.5	-0.8	-3.7
Makarewa	-0.1	0.5	-2.2	-8.0	-2.9	-6.6
Orepuki	6.9	12.9	6.8	11.2	5.6	14.4
Oreti	4.7	12.8	6.7	8.3	4.9	11.0
Riversdale	6.9	14.8	7.5	11.8	7.5	16.2
Te Anau	0.0	0.7	-3.5	4.2	-2.7	16.4
Te Waewae	4.0	9.1	4.8	6.0	2.2	7.5
Tiwai	8.9	15.4	8.6	17.4	7.5	22.5
Upper Aparima	4.7	12.6	1.7	2.9	2.9	16.0
Upper Maitara	-2.5	1.1	0.4	-5.3	-3.4	-7.2
Waihopai	3.9	3.8	0.2	-3.9	-0.5	-4.3
Waimatuku	7.6	12.0	6.0	9.1	4.5	12.7
Waimea Plains	4.1	14.3	6.8	4.8	4.5	8.3

Shallow aquifer	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Waipounamu	6.7	14.4	7.6	12.6	7.8	17.0
Wendon	0.8	6.5	3.3	-1.9	1.5	-1.2
Wendonside	4.5	11.4	5.5	7.1	5.0	9.4

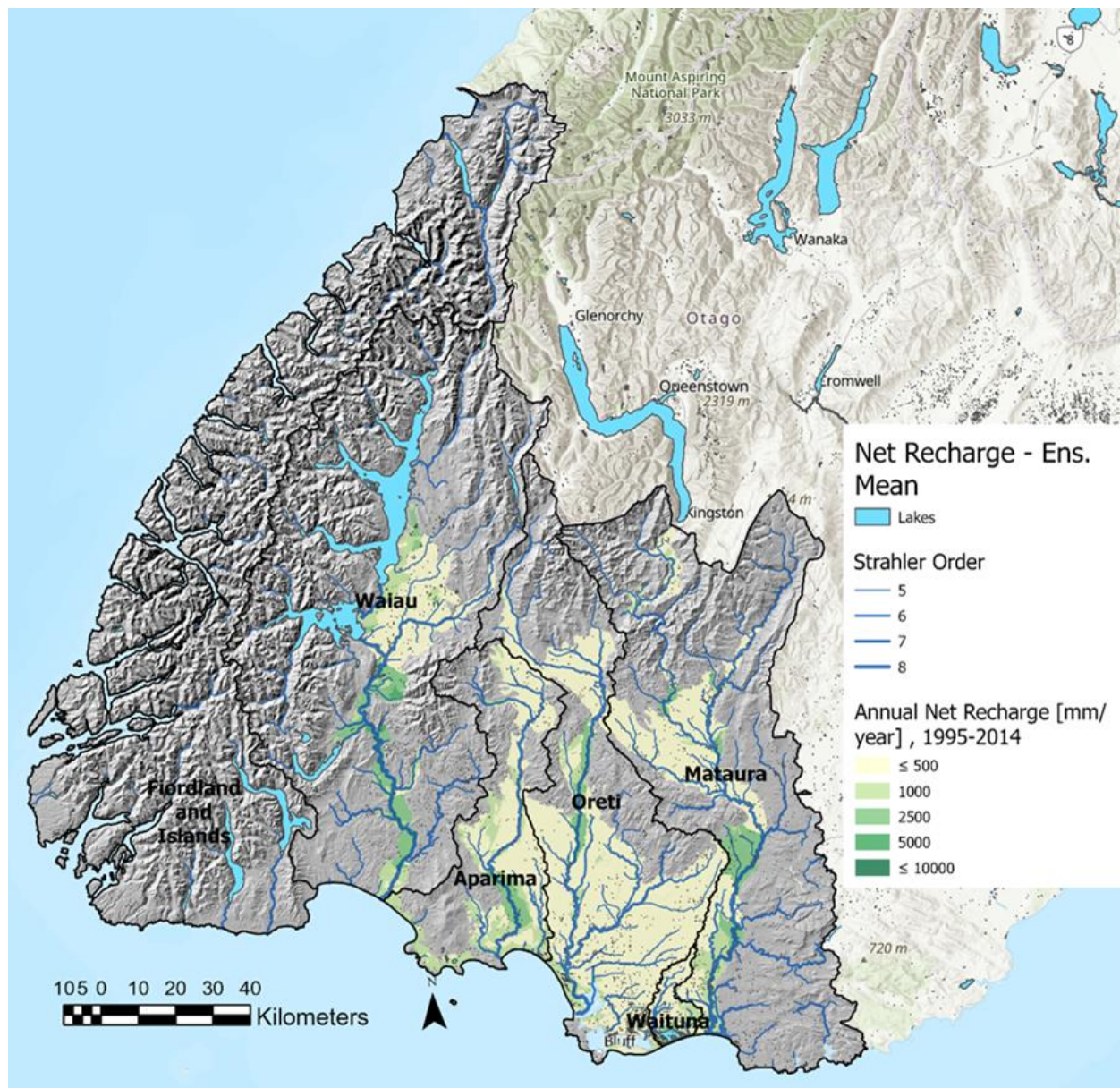
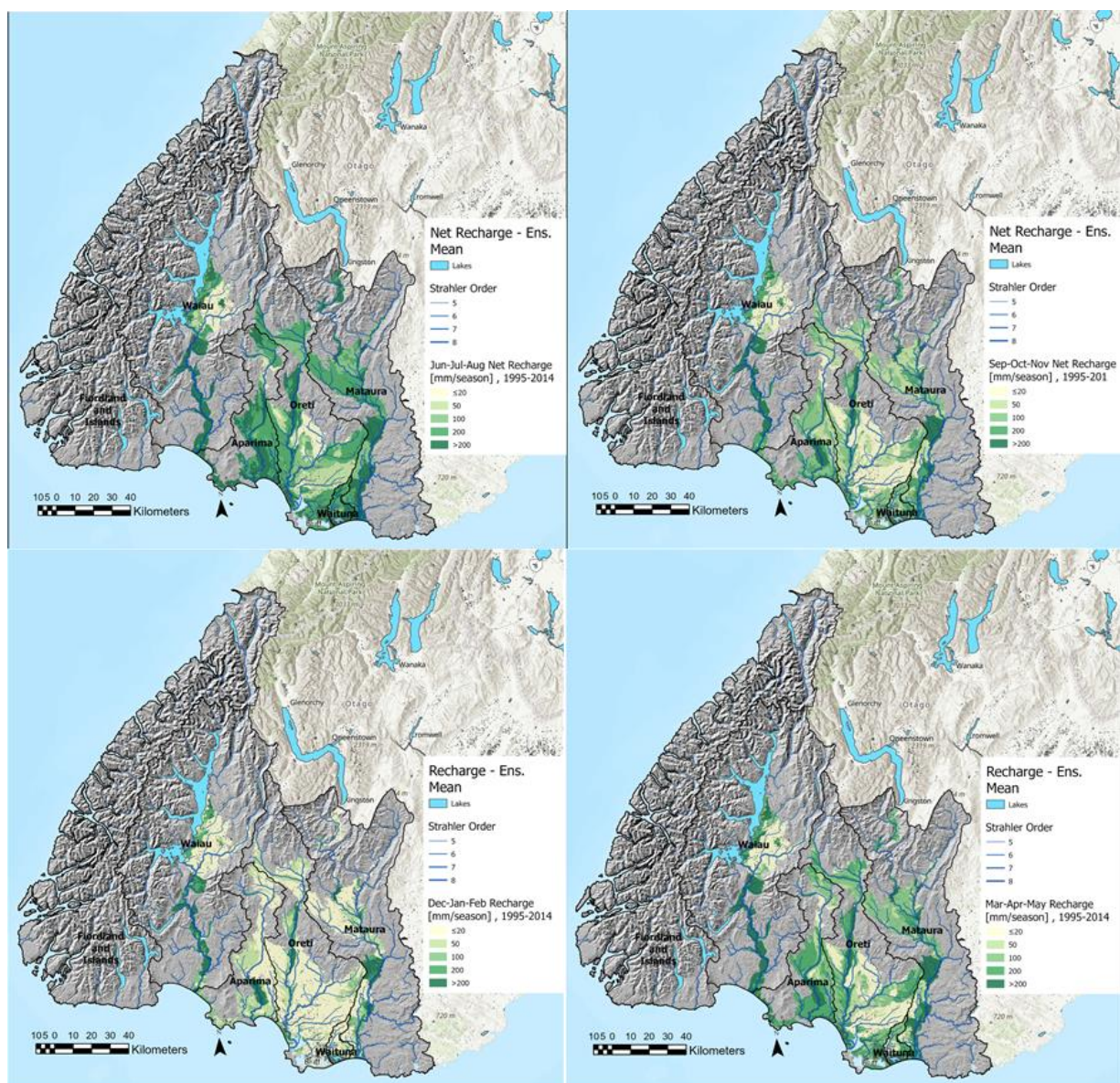


Figure 3-36: Multi-model average historical annual land surface recharge over Southland's shallow aquifers.



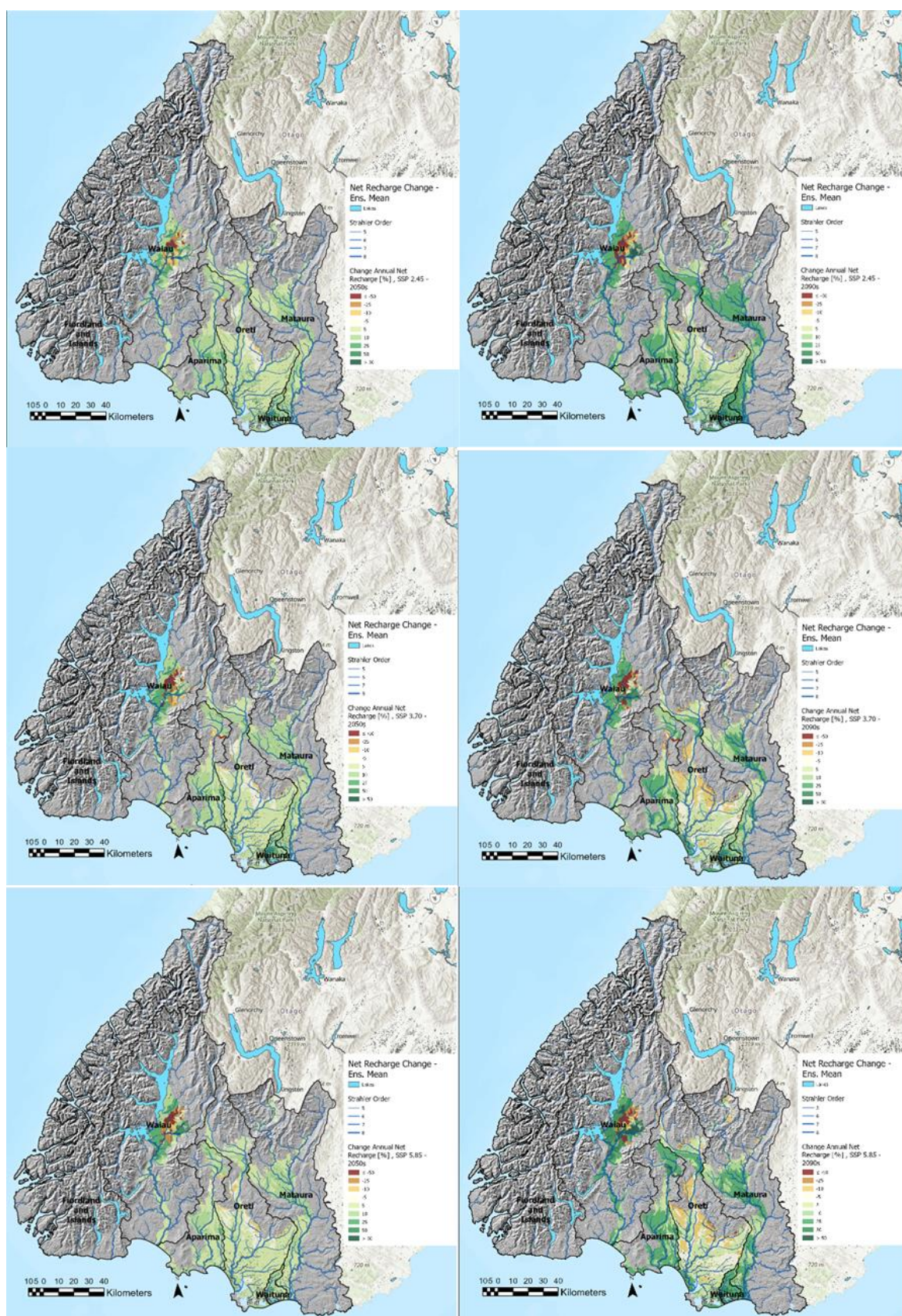


Figure 3-38: Change in multi-model average annual land surface recharge over Southland's shallow aquifers. Change in multi-model average annual land surface recharge for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

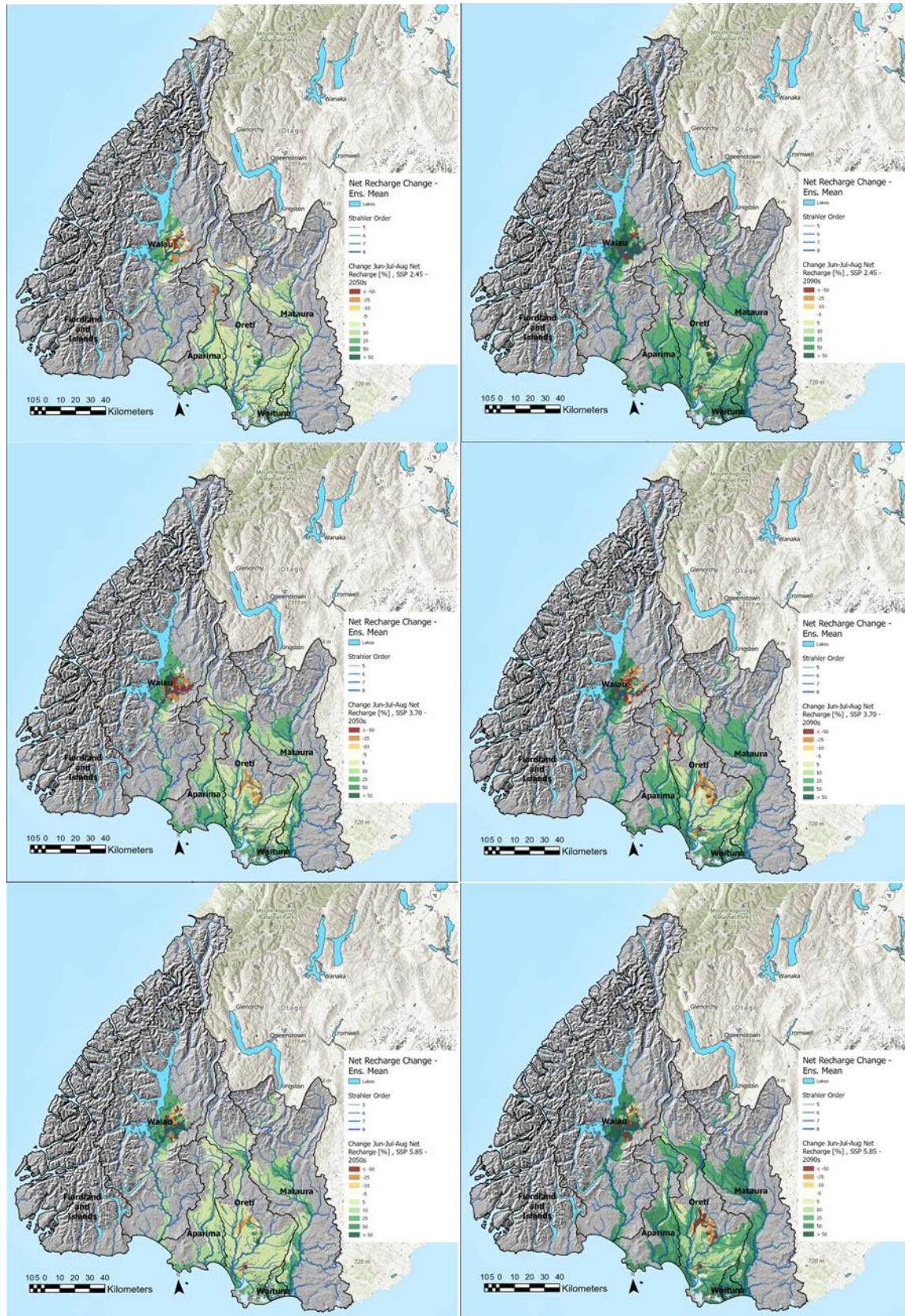


Figure 3-39: Change in multi-model average June-July-August (winter) land surface recharge over Southland's shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

3.15 Extreme events

3.15.1 Flood magnitude

Bakker (2025) identified that the analysis of flood frequency requires bias correcting the CMIP6 modelling chain to match observed flood frequency using the TopNet hydrological model. This additional bias correction (i.e., in addition to the water resource bias correction carried out as part of this project) can be carried out by correcting the volume of precipitation and/or the infiltration excess runoff catchment scale parameters. As a result, the analysis presented in this section is illustrative of the impact of climate change on flood magnitude across the Southland region. Figure 3-41 presents GCM-specific and pooled GCM hindcast annual daily maxima and annual hourly maxima flood frequency for Irthing Stream at Ellis Road. The flood frequency is typical of the flood frequency estimated across all locations of interest presented in Appendix E. While the flood frequencies were generated based on 20-year annual time series of daily and hourly peak discharge, the flood frequency is represented up to a 1:200-year Annual Recurrence Interval (ARI) (or a 0.005 Annual Exceedance Probability, AEP) at the request of Environment Southland. For each location and for each GCM, the flood frequency was optimised using R (R Core Team 2021 in association with the ‘extRemes’ package (Gilleland and Katz 2016) and selecting the Bayesian optimisation method). For clarity, the uncertainty associated with each GCM-derived flood frequency is not represented. No attempt was made to harmonise the GCM derived EVD Type (i.e., Weibull, Gumbel or Fréchet - see Volume 1 Section 3.3.4) at each location across GCMs to provide flood frequency developed using consistent EVD type at each location.

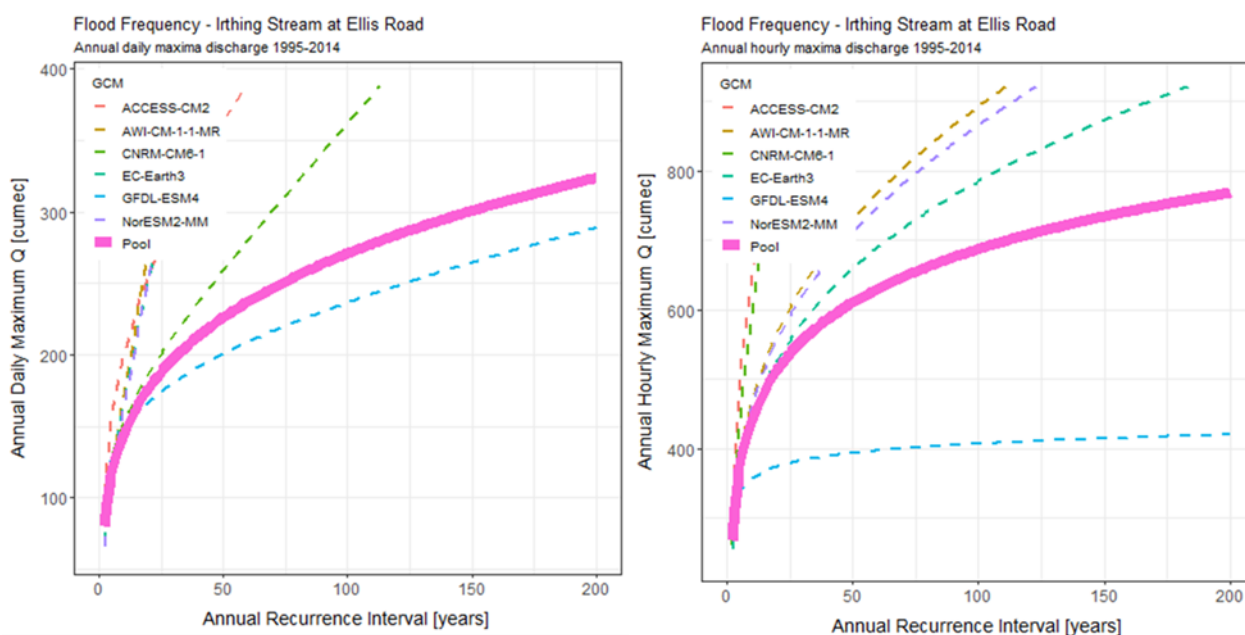


Figure 3-41: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for Irthing Stream at Ellis Road. Flood frequency curves are presented at nzsegement 15334924 for each CMIP6 GCM and the pooled GCM over the period 1995–2014.

Analysis of GCM-specific and pooled GCM flood frequency indicates that:

- For the majority of locations, the EVD (across all GCM) is generally of Type II (Fréchet distribution). This is consistent with storm rainfall EVDs in Southland. However, for each location there is at least one GCM generating EVD Type III (Weibull distribution), indicating the possibility of extreme floods to be capped (bound upper tail distribution).

- For a few locations, the majority of the EVD distribution type are associated with EVD Type III (bound tail distribution) resulting in extreme floods being capped (e.g., Winton Stream at Winton Township). The difference in EVD type at each location seems to be associated with the timing of the GCM precipitation, rather than the location itself. However, we were not able to identify any consistency across each FMU as different combinations of GCMs will generate different EVD Type at each location.
- Flood frequency distribution parameters are different when calculated using daily or hourly maxima, with hourly maxima derived flood frequency location and scale parameters (characterising flood magnitude and intra-annual variability) larger than those derived from daily maxima for both GCM-specific and pooled GCM.
- Hourly maxima derived flood frequency shape parameter (characterising how extreme floods may be) is generally larger than the corresponding daily maxima distribution shape parameter (19 of the 27 reporting locations).
- Hourly maxima flood magnitude is larger than daily maxima flood magnitude for the same AEP for both GCM-specific and pooled GCM.
- For a majority of locations, the pooled GCM flood magnitudes are smaller than the corresponding flood magnitude generated for the majority of the GCMs (at least four of six – see Figure 3-41). This behaviour is observed for event return periods larger than 1:10 year ARI. This result may be due to the small sample of the annual time series available for each GCM (20 members compared to 120 members of the pooled GCM).
- Simulated flood frequency at each site (GCM-specific or pooled GCM) is likely to be different than flood frequency derived by Environment Southland. Three main reasons could explain this result. Firstly, the simulated annual maxima flood frequency is generated using a 20-year period (1995–2014), whereas Environment Southland’s annual maxima flood frequencies will be generated using the whole record of observations available at each site. Secondly, CMIP6’s GCMs are free-running and as such observed and simulated precipitation are generally weakly correlated over the same time period. As a result, the annual time series of daily/hourly maxima may not be similar to the observed annual time series of daily/hourly maxima. Thirdly, Bakker (2025) identified that bias correcting the CMIP6 modelling chain to match observed flood frequency requires an additional bias correction of the volume of precipitation parameter using the TopNet hydrological model.

While no bias correction targeting the reproduction of historical observed flood frequency was completed as part of this project, analysis of the potential impact of climate change on flood magnitude was completed to provide advice to Environment Southland’s river engineering team. Caution is recommended when using site results presented hereafter for site specific analysis and detailed design of flood infrastructure.

Figure 3-42 to Figure 3-44 present three contrasting, but typical, behaviours associated with the change in annual daily maxima pooled GCM flood frequency (and their associated 95% confidence interval) under different warming scenarios by mid-century (2050s) and end of century (2090s).

- Figure 3-42 presents the historical and projected annual daily maxima pooled GCM flood frequency for the Aparima at Thornbury Bridge. The behaviour of the flood frequency projected at this location is characteristic of locations (Aparima River at

Thornbury Bridge and Waikaka at Gore Township) at which flood magnitude is projected to generally increase with warming and time across the different return periods considered.

- Figure 3-43 presents the annual daily maxima pooled GCM flood frequency for Kingswell Creek at Invercargill City. The behaviour of the flood frequency projected at this location is characteristic of locations (four locations over 27) at which flood magnitude is projected to increase with warming only for the 2050s or the 2090s period.
- Figure 3-44 presents the annual daily maxima pooled GCM flood frequency for the Waiau River at Tutapere. The behaviour of the flood frequency projected at this location is characteristic of the majority of the locations considered (78% of the locations) at which flood magnitude is not projected to increase consistently with warming and/or time.

Appendix E presents for each of the 27 reporting locations hourly and daily pooled maxima flood frequency for four warming scenarios for 2050s (2014–2060) and 2090s (2081–2098) time periods, daily and hourly pooled maxima distribution parameters frequency for four warming scenarios for 2050s (2014–2060) and 2090s (2081–2098) time periods and projected changes in pooled daily maxima flood magnitude for seven return periods (1:2.33, 5, 10, 20, 50, 100, and 200 year ARI).

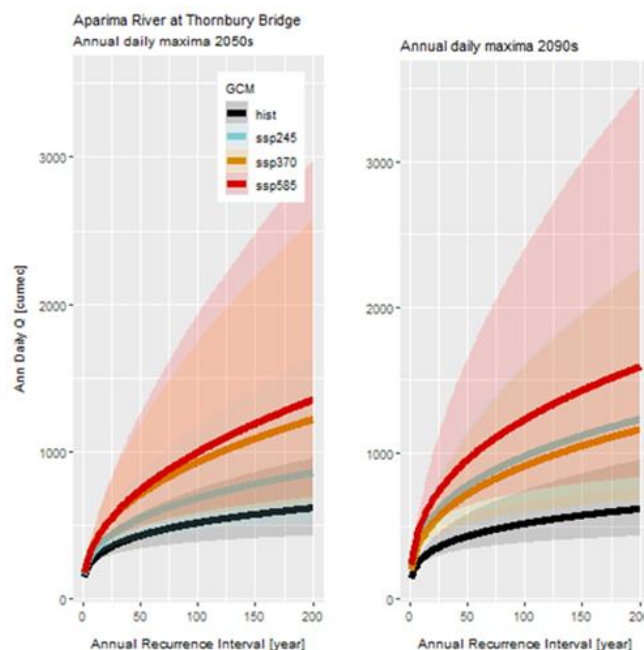


Figure 3-42: GCM pooled annual daily maxima flood frequency for the Aparima River at Thornbury Bridge for four warming scenarios. Pooled flood frequency presented at nzsegment 1544050 for the historical, SSP2-45, SSP3-70 and SSP5-8.5 warming scenarios and 2050s (2014–2060) and 2090s (2081–2098) time periods.

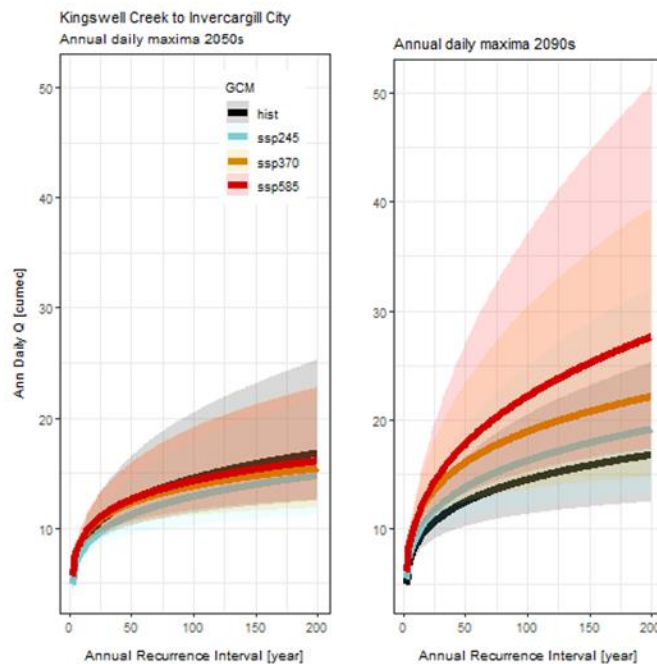


Figure 3-43: GCM pooled annual daily maxima (left panel) and annual hourly maxima flood frequency for Kingswell Creek at Invercargill City for four warming scenarios. Pooled flood frequency presented at nzsegment 15205799 for the historical, SSP2-45, SSP3-70 and SSP5-8.5 warming scenarios and 2050s (2014–2060) and 2090s (2081–2098) time periods.

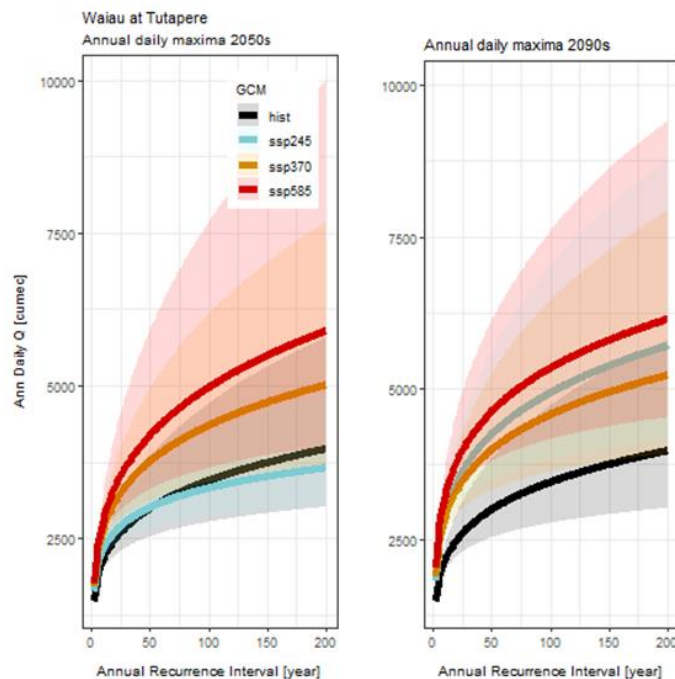


Figure 3-44: GCM pooled annual daily maxima (left panel) and annual hourly maxima flood frequency for Waiau River and Tutapere for four warming scenarios. Pooled flood frequency presented at nzsegment 15444806 for the historical, SSP2-4.5, SSP3-7.0 and SSP5-8.5 warming scenarios and 2050s (2014–2060) and 2090s (2081–2098) time periods.

Analysis of climate change impact on the annual daily maxima pooled GCM flood frequency distribution indicates:

- Location and scale parameters of the EVD distribution are projected to generally increase with time and warming for most of the locations. This indicates that flood magnitudes are expected to increase with time and warming across all return periods, and that the intra-annual variability of the floods is projected increase.
- However, for all but one location (Otautau Stream at Otautau Township), the EVD shape parameter is not expected to increase with warming and time. This indicates that extreme floods (i.e., associated with rare events) may not be larger under future warming conditions. This result is a-priori unexpected and could be since no bias correction was completed as part of the model development or be associated with hydrological processes conceptualisation and parameterisation with the Topnet model used as part of this study. Further investigations are recommended.

3.15.2 Probable Maximum Flood

As part of the analysis, modelled historic and projected changes to future Probable Maximum flood (PMF) are generated using the updated storm catalogue available within the Dam Safety Hydrology Group (DSHG) PMP tool (Bodeker et al. 2023). The PMPs are generated for 12 and 24 hrs storm durations. The change in PMP rainfall depth for different temperature changes and storm durations are summarised across Southland in Volume 2 – Figure 1-88, for warming of +1.0°C, +2.0°C and +3.0°C above current warming level. Location specific PMP rainfall depth associated with 12hr and 24hr storm event duration is shown in Table 3-35 .

Table 3-35: Historical PMP rainfall depth estimation for 12hr and 24 hr storm event duration (mm). PMP estimation generated using DSHG updated storm catalogue (Updated, Bodeker et al. 2023).

FMU	Location	Rainfall depth [mm]	
		12hr	24hr
Mataura	Mataura catchment to Cattle Flat Township	288	414
	Mataura River at Gore Township	229	326
	Mataura Catchment to Wyndham Catchment Township	214	302
	Waikaia Catchment to Waikaia Township	312	460
	Waikaka Stream to Gore Township	264	356
	Waikawa Catchment	229	356
	Waimea Catchment	267	362
	Waituna Catchment	277	354
	Mokoreta Catchment	260	337
	Waikaia Catchment	291	351
Oreti	Makarewa Catchment	247	321
	Oreti Catchment to Lumsden Township	290	415
	Oreti Catchment to Winton Township	264	372

FMU	Location	Rainfall depth [mm]	
		12hr	24hr
Aparima	Oreti Catchment to Wallacetown	248	345
	Waihopai River to Invercargill City	278	358
	Otepuni Stream to Invercargill City	288	368
	Kingswell Creek at Invercargill City	290	369
	Irthing Stream at Ellis Road	307	438
	Winton Stream to Winton Township	281	370
	Aparima River to Otautau Township	298	423
	Otautau Stream to Otautau Township	282	383
	Aparima River at Thornbury Bridge	276	385
	Whitestone Catchment	300	417
Waiau	Upukerora Catchment	309	434
	Mararoa Catchment	286	405
	Orauea Catchment	283	391
	Waiau River at Tutapere	229	356

To enable the calculation of the flood magnitude associated with the PMP event (referred as the Probable Maximum Flood (PMF)) through the modelling chain, the timing of the 12hr and 24hr event annual maximum rainfall total is identified for each General Circulation Models (GCMs) over the period 1995-2014 (see Table 3-36 for 24hr storm duration event and Table 3-37 for 12hr storm duration event).

Analysis of the PMP timing associated with 12hr and 24 hr duration storm event indicates:

- For all locations, the timing (month of occurrence) of the annual maxima rainfall total associated with a 12hr storm event duration does not generally coincide with the month of occurrence of the annual maxima rainfall total associated with a 24hr storm event duration.
- Further analysis of the timing of the PMP indicates that, for the same storm event duration, the timing associated with the maximum annual rainfall total is different across each GCM.
- The largest maximum annual rainfall event for 12hr and 24hr storm event is generally occurring during November to March period. However, for 75% of the locations (22 over 26), PMP are projected to occur during the period April to October for at least one of the GCMs. This could indicate that potentially large changes in maximum annual discharge are to be expected for at least one of the six GCMs for both storm event durations considered (see Volume 2 Section 1-8-1 for further details).

Historical PMFs associated with a 12hr and 24hr PMP storm event are presented as multi-model ensemble average and its associated range (see Volume 2 Section 1.8.1 for further details) in Table 3-38. PMF magnitudes are reported as integers rounded to the nearest value. As no bias correction was carried out to represent historical flood frequency or historical PMF at each location, caution is recommended in interpreting the absolute values associated with the 12hr and 24hr storm duration PMF. The information provided hereafter aims to describe the variability of the historical PMF across the GCMs and storm event duration, rather than to represent the absolute value of the PMF for the different storm duration events.

Table 3-36: Timing of the historical maximum annual 24hr rainfall total over the period 1995-2014 for each CMIP6's GCMs. Timing of the maximum annual 24hr rainfall total is provided by its month for each GCM.

FMU	Location	ACCESS-CM2	AWI-CM-1-1-MR	CNRM-CM6-1	EC-Earth3	GFDL-ESM4	NorESM2-MM
Mataura	Mataura catchment to Cattle Flat Township	March	November	January	July	June	November
	Mataura River at Gore Township	March	November	January	July	March	November
	Mataura Catchment to Wyndham Catchment Township	January	November	January	July	March	November
	Waikaia Catchment to Waikaia Township	March	November	October	January	March	November
	Waikaka Stream to Gore Township	January	November	December	December	March	November
	Waikawa Catchment	March	May	December	February	December	November
	Waimea Catchment	January	November	December	December	November	November
	Waituna Catchment	March	May	December	February	January	January
	Mokoreta Catchment	March	November	December	July	December	November
	Waikaia Catchment	March	November	January	July	March	November
Oreti	Makarewa Catchment	March	May	December	January	January	January
	Oreti Catchment to Lumsden Township	March	November	January	July	April	February
	Oreti Catchment to Winton Township	October	November	January	September	March	February
	Oreti Catchment to Wallacetown	January	November	January	March	March	February

FMU	Location	ACCESS-CM2	AWI-CM-1-1-MR	CNRM-CM6-1	EC-Earth3	GFDL-ESM4	NorESM2-MM
Aparima	Waihopai River to Invercargill City	March	May	December	February	January	January
	Otepuni Stream to Invercargill City	March	May	December	February	March	January
	Kingswell Creek at Invercargill City	March	May	December	February	January	January
	Irthing Stream at Ellis Road	November	November	January	July	March	November
	Winton Stream to Winton Township	January	May	December	March	March	January
	Aparima River to Otautau Township	January	October	January	September	June	January
	Otautau Stream to Otautau Township	January	February	December	December	January	January
Waiau	Aparima River at Thornbury Bridge	January	October	January	September	March	January
	Whitestone Catchment	March	February	January	January	April	February
	Upukerora Catchment	March	November	January	December	May	March
	Mararoa Catchment	March	November	January	December	May	February
	Orauea Catchment	November	February	February	February	January	January
	Waiau River at Tutapere	January	October	January	February	April	February

Table 3-37: Timing of the historical maximum 12hr rainfall total over the period 1995-2014 for each CMIP6's GCMs. Timing of the maximum annual 12hr rainfall total is provided by its month for each GCM.

FMU	Location	ACCESS-CM2	AWI-CM-1-1-MR	CNRM-CM6-1	EC-Earth3	GFDL-ESM4	NorESM2-MM
Mataura	Mataura catchment to Cattle Flat Township	February	January	February	January	February	November
	Mataura River at Gore Township	February	November	February	January	April	November

FMU	Location	ACCESS- CM2	AWI-CM- 1-1-MR	CNRM- CM6-1	EC-Earth3	GFDL- ESM4	NorESM2- MM
Oreti	Mataura Catchment to Wyndham Catchment Township	February	November	December	December	April	November
	Waikaia Catchment to Waikaia Township	February	November	March	January	February	November
	Waikaka Stream to Gore Township	January	November	December	December	April	November
	Waikawa Catchment	March	May	December	February	December	November
	Waimea Catchment	January	December	February	March	November	November
	Waituna Catchment	March	May	December	February	January	February
	Mokoreta Catchment	March	May	December	December	December	November
	Waikaia Catchment	February	November	March	January	February	November
	Makarewa Catchment	January	May	December	March	November	March
	Oreti Catchment to Lumsden Township	February	November	January	January	April	February
	Oreti Catchment to Winton Township	January	February	February	September	April	March
	Oreti Catchment to Wallacetown	January	February	February	March	March	March
	Waihopai River to Invercargill City	March	February	December	February	March	February
	Otepun Stream to Invercargill City	March	May	December	February	March	February
	Kingswell Creek at Invercargill City	March	May	December	February	March	March
Aparima	Irthing Stream at Ellis Road	February	November	January	January	April	February
	Winton Stream to Winton Township	January	February	February	March	November	March
	Aparima River to Otautau Township	January	February	February	September	March	March
	Otautau Stream to Otautau Township	January	February	January	March	January	February

FMU	Location	ACCESS-CM2	AWI-CM-1-1-MR	CNRM-CM6-1	EC-Earth3	GFDL-ESM4	NorESM2-MM
Waiau	Aparima River at Thornbury Bridge	January	February	February	September	March	March
	Whitestone Catchment	March	February	February	February	April	February
	Upukerora Catchment	March	February	January	February	March	February
	Mararoa Catchment	March	February	February	February	March	March
	Orauea Catchment	January	October	November	February	January	February
	Waiau River at Tutapere	January	February	February	September	March	February

Table 3-38: Multi-model ensemble average and associated range for the peak discharge associated with 12 hr and 24 hr return period PMPs. Range calculated across the six GCMs for each PMP event.

FMU	Location	Modelled PMF (m ³ s ⁻¹)	
		12 hr	24 hr
Mataura	Mataura catchment to Cattle Flat Township	1798 [538 – 2741]	1213 [513 – 1961]
	Mataura River at Gore Township	5206 [1087 – 7284]	3326 [1052 – 4675]
	Mataura Catchment to Wyndham Catchment Township	5699 [1135 – 7701]	3842 [1140 – 5330]
	Waikaia Catchment to Waikaia Township	2057 [466 – 2815]	1444 [510 – 1959]
	Waikaka Stream to Gore Township	874 [304 - 1198]	663 [288 – 840]
	Waikawa Catchment	324 [72 – 477]	278 [115 – 409]
	Waimea Catchment	684 [87 – 1088]	634 [219 – 784]
	Waituna Catchment	388 [335 – 442]	250 [169 – 351]
	Mokoreta Catchment	1238 [369 -1524]	538 [307 – 707]
	Waikaia Catchment	6114 [1270 – 8577]	3453 [1247 – 5863]
Oreti	Makarewa Catchment	2667 [2556 – 2801]	1770 [1593 – 2009]
	Oreti Catchment to Lumsden Township	2933 [2565 – 3217]	1687 [657 – 2407]

FMU	Location	Modelled PMF (m ³ s ⁻¹)	
		12 hr	24 hr
Aparima	Oreti Catchment to Winton Township	3495 [2886 – 3955]	2576 [1874 – 3094]
	Oreti Catchment to Wallacetown	4370 [4004 – 4725]	3308 [2437 – 3883]
	Waihopai River to Invercargill City	477 [454 – 499]	326 [221 – 389]
	Otepuni Stream to Invercargill City	75 [70 -79]	52 [36 -71]
	Kingswell Creek at Invercargill City	50 [39 – 55]	30 [24 – 43]
	Irthing Stream at Ellis Road	1264 [1163 – 1360]	590 [227 -855]
	Winton Stream to Winton Township	320 [307 -338]	225 [204 – 239]
	Aparima River to Otautau Township	1424 [896 – 1932]	1215 [888 – 1488]
	Otautau Stream to Otautau Township	385 [336 – 492]	393 [308 – 479]
	Aparima River at Thornbury Bridge	2948 [1689 – 3833]	1681 [1401 – 1986]
Waiau	Whitestone Catchment	872 [779 – 928]	595 [404 – 763]
	Upukerora Catchment	340 [172 -536]	245 [116 - 431]
	Mararoa Catchment	2490 [1932 – 2811]	1746 [881 – 2325]
	Orauea Catchment	961 [528 – 1164]	676 [552 – 846]
	Waiau River at Tutapere	3636 [2101 – 5302]	4454 [2354 – 7526]

Modelling of the climate change impacts on the 12hr and 24hr PMP event follows the assumptions described in Volume 2 – Section 1.8.1. Projected changes in PMP rainfall depth for all storm event return periods are generated using nominal annual average temperature changes representative of Southland’s projected mean annual temperature changes (see Volume 2 Section 1.8.1). The changes in PMF magnitude associated with 12hr and 24 hr PMP storm durations for different temperature changes are summarised across all locations as a Southland-wide average and an FMU-wide average in Table 3-39. Location specific projected changes in maximum peak discharge associated with 12 hr and 24 hr storm duration PMP and three warming scenarios are presented as multi-model ensemble average and its associated range in Table 3-40 (12hr storm duration rainfall event) and Table 3-41 (24hr storm duration rainfall event).

Table 3-39: Southland and FMU projected average changes in annual maximum discharge with temperature for 12hr and 24 hr duration PMP event (% , relative to 1995-2014).

	12hr duration event			24hr duration event		
	+1.0°C	+2.0°C	+3.0°C	+1.0°C	+2.0°C	+3.0°C
Southland	19	36	52	18	35	49
Aparima	17	35	55	14	28	43
Mataura	29	54	78	23	44	63
Waituna	[-]	[-]	[-]	[-]	[-]	[-]
Oreti	10	19	30	13	26	42
Waiau	13	27	41	15	30	45
Fiordland	[-]	[-]	[-]	[-]	[-]	[-]

Table 3-40: Location specific projected changes in in annual maximum discharge with temperature for 12hr duration PMP event (% , relative to 1995-2014). Range calculated across the six GCMs.

FMU	Location	Change in annual maximum discharge (PMF) with temperature for 12hr duration PMP event (%)		
		+1.0°C	+2.0°C	+3.0°C
Mataura	Mataura catchment to Cattle Flat Township	17 [9 – 29]	48 [19 – 150]	82 [29 – 277]
	Mataura River at Gore Township	18 [9 – 43]	53 [19 – 184]	87 [29 – 325]
	Mataura Catchment to Wyndham Catchment Township	18[10 – 45]	58 [20 – 225]	91 [30 – 357]
	Waikaia Catchment to Waikaia Township	14 [7 – 32]	33 [7 – 32]	69 [20 – 246]
	Waikaka Stream to Gore Township	39 [9 – 179]	66 [19 – 281]	87 [28 – 344]
	Waikawa Catchment	59 [27 – 173]	73 [27 – 257]	75 [27 – 271]
	Waimea Catchment	62 [10 – 203]	82 [13 – 260]	99 [16 – 300]
	Waituna Catchment	44 [36 – 53]	61 [50 – 73]	77 [64 – 93]
	Mokoreta Catchment	11 [-6 – 61]	37 [4 – 170]	54 [13 – 222]
Oreti	Waikaia Catchment	11 [8 – 15]	27 [17 -64]	62 [25 – 223]
	Makarewa Catchment	9 [9– 10]	19 [18 – 20]	27 [26 – 29]
	Oreti Catchment to Lumsden Township	10 [9 – 14]	20 [17 – 28]	30 [26 – 41]
	Oreti Catchment to Winton Township	11 [10 – 16]	23 [19 – 31]	34 [29 – 49]
	Oreti Catchment to Wallacetown	11 [10 – 11]	21 [20 – 23]	32 [29 – 34]
	Waihopai River to Invercargill City	10 [10 – 10]	20 [20 – 21]	31 [30 – 31]

FMU	Location	Change in annual maximum discharge (PMF) with temperature for 12hr duration PMP event (%)		
		+1.0°C	+2.0°C	+3.0°C
Aparima	Otepuni Stream to Invercargill City	6 [6 – 6]	16 [15 – 16]	32 [31 – 33]
	Kingswell Creek at Invercargill City	11 [11 – 11]	22 [22 – 22]	24 [22 – 33]
	Irthing Stream at Ellis Road	10 [9 – 12]	10 [9 – 13]	29 [27 – 33]
	Winton Stream to Winton Township	9 [8-10]	19 [17 – 20]	28 [26 -29]
	Aparima River to Otautau Township	18 [12 – 31]	37 [23 - 71]	60 [35 – 133]
	Otautau Stream to Otautau Township	18 [12 – 22]	37 [28 – 43]	56 [42 – 65]
	Aparima River at Thornbury Bridge	16 [11 – 25]	31 [21 – 49]	48 [32 – 85]
Waiau	Whitestone Catchment	10 [9 – 12]	19 [18 – 24]	29 [27 – 35]
	Upukerora Catchment	17 [13 -24]	35 [25 - 50]	54 [38 – 79]
	Mararoa Catchment	9 [9 – 10]	18 [18 – 19]	28 [27 – 29]
	Orauea Catchment	14 [11 – 23]	29 [22 – 48]	43 [33 – 73]
	Waiau River at Tutapere	17 [13 – 23]	34 [26 – 47]	51 [40 – 70]

Table 3-41: Location specific projected changes in in annual maximum discharge with temperature for 24hr duration PMP event (% relative to 1995-2014). Range calculated across the six GCMs.

FMU	Location	Change in annual maxima discharge (PMF) with temperature for 24hr duration PMP event (%)		
		+1.0°C	+2.0°C	+3.0°C
Mataura	Mataura catchment to Cattle Flat Township	23 [10– 44]	47 [20– 88]	74 [30 – 144]
	Mataura River at Gore Township	21 [11– 32]	48 [22 – 104]	76 [33 – 186]
	Mataura Catchment to Wyndham Catchment Township	18 [7– 33]	36 [13 – 186]	52 [20 – 99]
	Waikaia Catchment to Waikaia Township	26 [8 – 102]	46 [15 – 175]	62 [20 – 246]
	Waikaka Stream to Gore Township	39 [9 – 179]	66 [19 – 281]	87 [22 – 220]
	Waikawa Catchment	41 [28 – 58]	49 [28 – 108]	51 [27 – 118]
	Waimea Catchment	32 [11 – 131]	48 [21 – 177]	63 [30– 211]
	Waituna Catchment	13 [10 – 17]	26 [22 – 37]	40 [33 – 56]

FMU	Location	Change in annual maxima discharge (PMF) with temperature for 24hr duration PMP event (%)		
		+1.0°C	+2.0°C	+3.0°C
Oreti	Mokoreta Catchment	5 [3– 7]	19 [11 – 26]	35 [19 – 51]
	Waikaia Catchment	23 [6 – 71]	48 [13 -154]	80 [19 – 237]
	Makarewa Catchment	10 [9– 10]	19 [18 – 20]	29 [27– 30]
	Oreti Catchment to Lumsden Township	22 [10 – 65]	45 [19 – 28]	30 [26 – 41]
	Oreti Catchment to Winton Township	11 [10 – 16]	23 [19 – 121]	66 [29 – 191]
	Oreti Catchment to Wallacetown	10 [10 – 11]	20 [18 – 22]	30 [27 – 32]
	Waihopai River to Invercargill City	10 [9 – 11]	20 [19 – 22]	30 [27 – 32]
	Otepuni Stream to Invercargill City	7 [6 - 7]	17 [16 – 17]	32 [31 – 34]
	Kingswell Creek at Invercargill City	11 [11 – 12]	22 [22 – 23]	33 [32 – 34]
	Irthing Stream at Ellis Road	23 [10 – 48]	48 [9 – 129]	91 [30 – 242]
Aparima	Winton Stream to Winton Township	9 [9 -10]	18 [17 – 20]	27 [26 -29]
	Aparima River to Otautau Township	15 [7 – 35]	31 [14 - 75]	49 [21 – 123]
	Otautau Stream to Otautau Township	13 [9 – 16]	25 [17 – 32]	38 [25 – 48]
	Aparima River at Thornbury Bridge	14 [8 – 23]	28 [15 – 47]	43 [23 – 74]
Waiau	Whitestone Catchment	13 [9 – 30]	24 [18 – 49]	33 [27 – 63]
	Upukerora Catchment	21 [8 -58]	46 [20 - 113]	70 [30 – 168]
	Mararoa Catchment	15 [9 – 40]	27 [18 – 67]	40 [27 – 94]
	Orauea Catchment	12 [10 – 21]	28 [20 – 37]	42 [29 – 59]
	Waiau River at Tutapere	13 [10 – 16]	28 [20 – 37]	42 [29 – 59]

Analysis of the change in annual PMF associated with 12hr and 24 hr duration PMP indicates:

- PMF is expected to increase with warming as follows:
 - Under a 1°C warming, most FMUs except for Mataura are projected to experience a PMF increase between 10 and 20% independently of the storm duration.
 - Spatial difference in PMF changes is found between FMUs for warming larger than 1°C.
- Changes in PMF across different storm durations generally follow the same pattern as rainfall depth changes predicted by the HIRDS tool – larger percentage increases occur

for shorter-duration storms. However, this pattern does not appear in the Oreti and Waiau FMUs, where PMF increases become larger for longer storm durations. This unexpected trend may be due to the use of the DSHG tool and the way climate-change adjustments were applied when the PMP values were originally derived.

- The Mataura FMU shows the largest PMF increase in the region, with flows expected to rise by an average of at least 60% under a 3°C warming scenario. This strong response is likely linked to winter PMP conditions, for which significant snow storage exists at the start of the storm. Under warmer conditions, both increased rainfall and enhanced snowmelt amplify runoff, which may explain the large PMF increases observed upstream of Wyndham Township for the Mataura River. Although similar behaviour might be expected in the Waiau FMU, the projected PMF increase is smaller because snow storage remains during the PMP event even under a +3.0°C warming (see Section 2.2) or because upstream hydro-electric lakes partially buffer the flood response.
- While the results are aligned with our understanding that the frequency of extreme rainfall events is expected to increase with warming scenario and time, the spatial distribution of the changes in PMF does not mimic the spatial distribution of the maximum annual 1-day and 5-day rainfall. Further investigation is needed to better understand the underlying changes and to further characterise rarer rainfall events.

4 Stream water temperature

This section covers the projected differences in stream water temperature between the baseline period (1995–2015) and two future periods. These are mid-century (2041–2060) and late-century (2081–2098).

Modelled historic annual average and seasonal average stream water temperature are illustrated in Figure 4-1 and Figure 4-3. Projected changes in annual average stream temperature are illustrated in Figure 4-3, while projected changes in the September-October-November (spring) and January-February-March (late summer) stream temperature are illustrated in Figure 4-4 and Figure 3-40, with Appendix F presenting projected changes in winter and autumn stream temperature. FMU-wide average projected changes in annual and seasonal average flows (generated across each FMU) are summarised in Table 4-1 to Table 4-3 and Appendix F.

Table 4-1: Projected mean annual stream temperature changes (°C, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	1.4	2.3	1.6	3.2	1.3	3.7
Aparima	1.5	2.3	1.6	3.2	1.4	3.8
Fiordland and Islands	1.4	2.3	1.6	3.1	1.3	3.6
Mataura	1.4	2.3	1.6	3.2	1.4	3.7
Oreti	1.5	2.3	1.6	3.2	1.4	3.8
Waiau	1.4	2.3	1.6	3.1	1.4	3.7
Waituna	1.6	2.5	1.7	3.5	1.4	4.0

Table 4-2: Projected mean September-October-November (spring) stream temperature changes (°C, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	1.2	1.9	1.4	2.7	1.2	3.3
Aparima	1.3	2.0	1.5	2.8	1.3	3.5
Fiordland and Islands	1.2	1.9	1.4	2.6	1.1	3.2
Mataura	1.3	2.0	1.4	2.8	1.2	3.4
Oreti	1.3	2.0	1.5	2.8	1.3	3.4
Waiau	1.2	1.9	1.4	2.7	1.2	3.3
Waituna	1.4	2.2	1.5	3.1	1.3	3.7

Table 4-3: Projected mean December-January-February (summer) stream temperature changes (°C, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	1.4	2.3	1.6	3.2	1.3	3.7
Aparima	1.5	2.3	1.6	3.2	1.4	3.8

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Fiordland and Islands	1.4	2.3	1.6	3.1	1.3	3.6
Mataura	1.4	2.3	1.6	3.2	1.4	3.7
Oreti	1.5	2.3	1.6	3.2	1.4	3.8
Waiau	1.4	2.3	1.6	3.1	1.4	3.7
Waituna	1.6	2.5	1.7	3.5	1.4	4.0

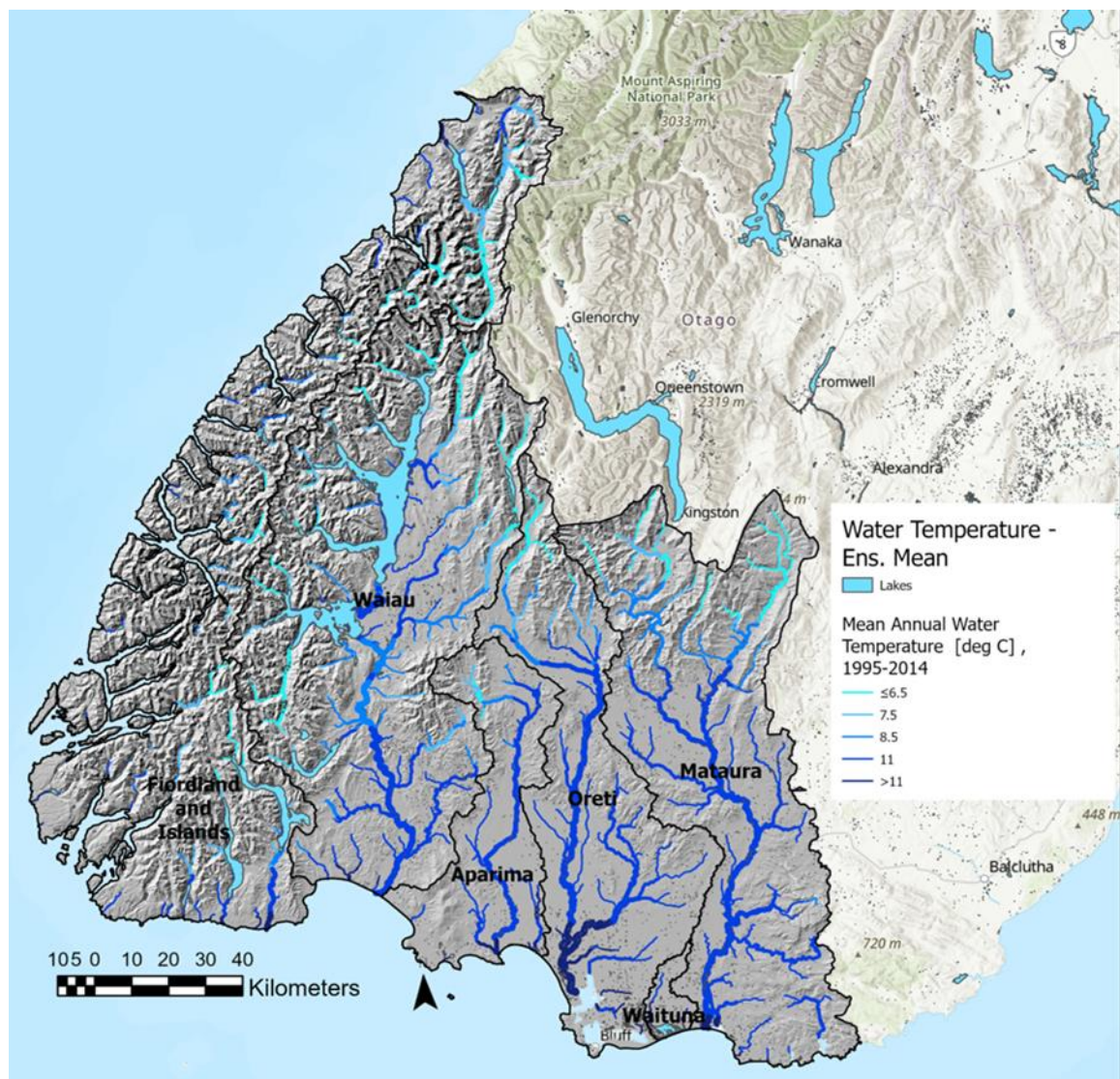


Figure 4-1: Historical multi-model annual average stream water temperature. The stream water temperature is generated using DN2.4.

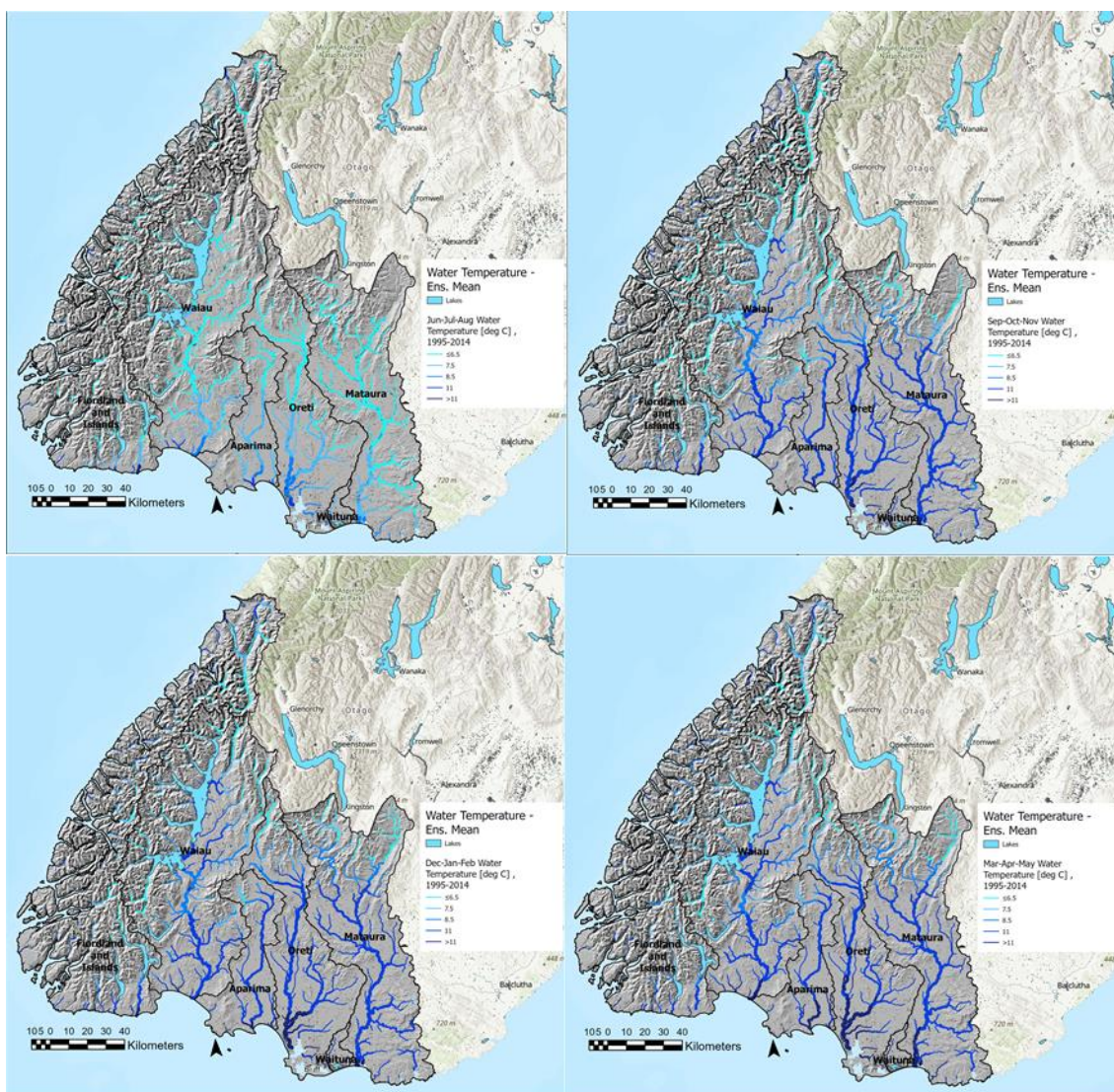


Figure 4-2: Historical multi-model seasonal average stream water temperature.

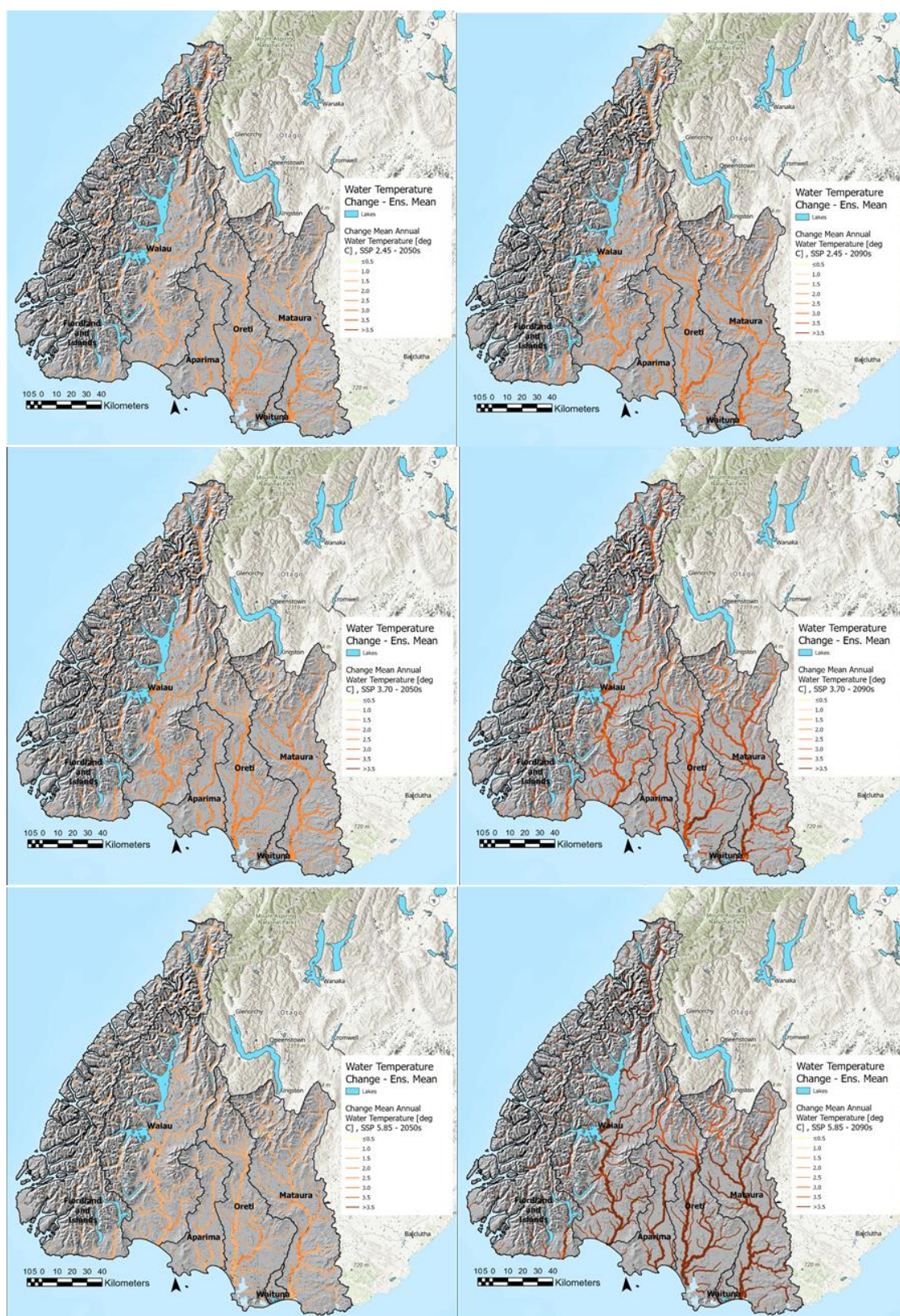


Figure 4-3: Change in multi-model annual average stream water temperature. Change in multi-model average annual stream water temperature is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

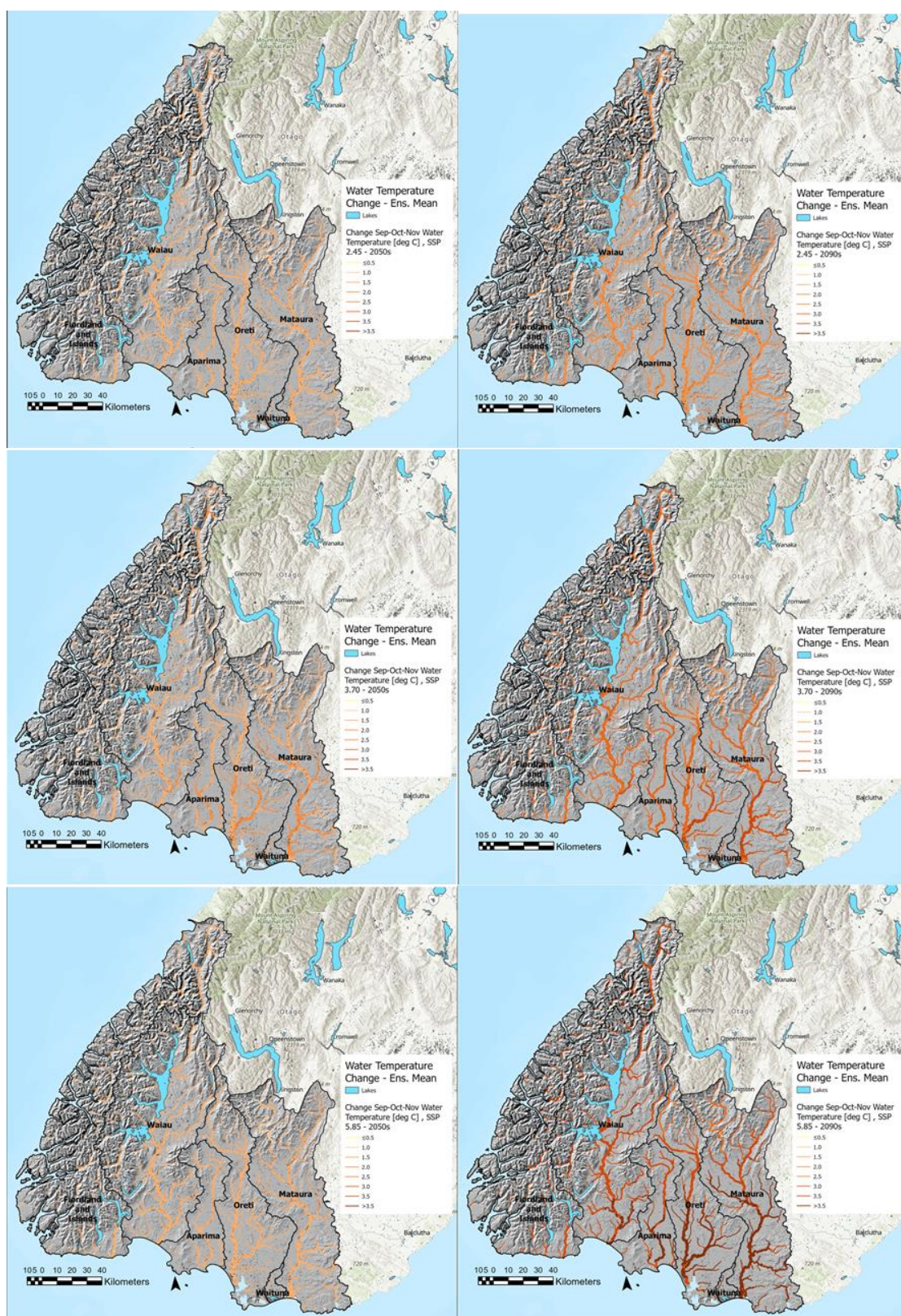
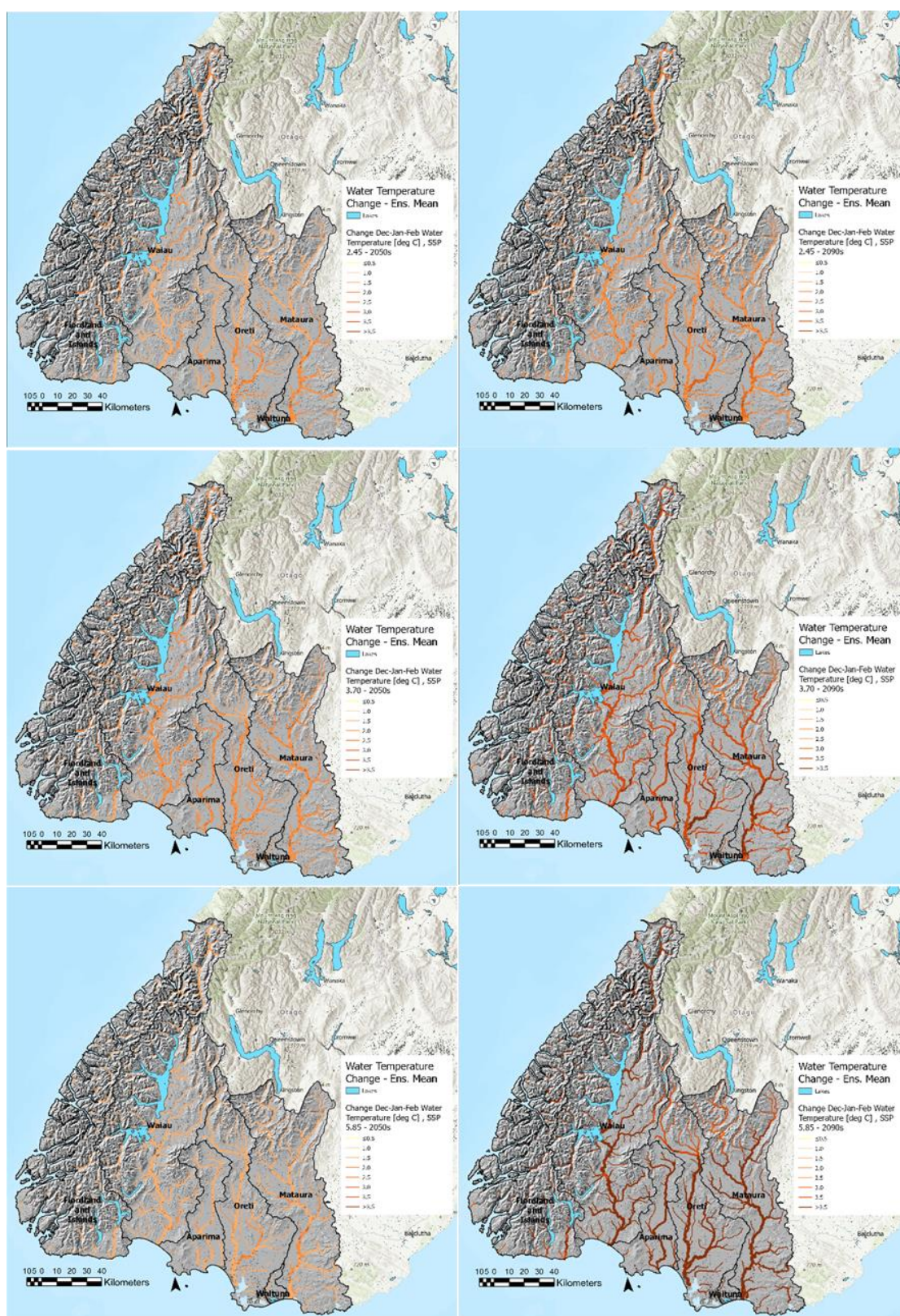


Figure 4-4: Change in multi-model ensemble September-October-November (spring) stream water temperature. Change in multi-model average annual stream water temperature is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).



5 Discussion

5.1 Bias Correction

The accuracy of the bias correction of historical flows generated under CMIP6 was assessed as follows:

- Accuracy of the bias correction process was assessed using daily flow time series.
- Due to the low temporal correlation between the simulated historical climate under climate change projections and weather observations, the accuracy of the bias corrected historical streamflow simulations was assessed using the average daily flow simulations (i.e., the average flows observed for every day of the year, e.g., average flows on 1 February).
- Bias correction accuracy was assessed by comparison of the absolute value of four hydrological metrics (Q95, Qmean, AnnQ25 and Q7dayMALF) characterising low to mid-range hydrological regime.
- This was supplemented by assessing the bias correction accuracy using nine statistical scores commonly used to assess hydrological model accuracy across flow regimes.

Analysis of the spatial distribution of the bias corrected parameters indicates:

- Under the current hydrological model assumptions, the precipitation volume generated by CCAM needs to be reduced for the upper reaches within each FMU (except for the Waiau FMU) and to be increased in the lower reaches. This spatial pattern in the bias correction likely reflects the impacts of regional surface water/groundwater interaction, with regional groundwater recharge occurring in the upper reaches and regional groundwater discharge occurring in the lower coastal reaches or downstream areas of regional groundwater systems (e.g., Mataura at Gore).
- Snow accumulation temperature threshold parameter requires to be augmented across Southland. This indicated that the current air temperature dataset generated by the CCAM model tends to be too warm to mimic MODIS-derived catchment scale snow cover areas.
- Spatial distribution of the catchment scale plant available water bias correction is variable. Results show that the bias correction parameter needs to be assigned its minimum or maximum permitted value for a large number of subbasins. This may indicate that there are important hydrological processes not represented within the model (e.g., surface/groundwater interaction through region groundwater movement).

Analysis of the bias correction outcomes indicates:

- The bias correction method implemented in this project reproduces average flow metrics low flow metrics for most of the natural flow locations (see Table 1-1).
- The simple cryospheric bias correction reproduces seasonal dynamics and timing of the snow cover area in terms of timing and magnitude of snow accumulation and snow melt.

- Despite carrying out bias correction of the cryospheric processes, the reproduction of low flow metrics is not satisfactory. This suggests an interplay between catchment-scale vadose zone parameters (related to soil characteristics – see Volume 1 Table 3-6) which control soil moisture, land surface recharge processes and groundwater discharge, and the catchment-scale infiltration excess runoff parameter that effectively reduces the modelled amount of precipitation infiltrating in the watershed vadose zone.
- Conventional statistical scores used to assess average bias (Pbias), timing of the hydrological simulation (VE) and reproduction of the average hydrological regime (D) are adequate to good across all natural flow sites.
- Statistical scores used to assess the accuracy of the hydrological simulations (e.g., NS and NSLog) are poor to extremely poor. This is thought to be partially due to, in addition to misrepresentation or non-representation of important hydrological processes by the hydrological model, large variations in magnitude and timing of the precipitation that largely control the ability of any hydrological model to mimic observed discharge time series. While Zammit et al (2024) demonstrated that good statistical scores can be achieved using similar bias correction method for headwater catchments, the transfer of similar methodology to larger snow affected catchment does not produce the expected outcomes.

Future improvements in the ability of the TopNet modelling suite to reproduce mid-range to low flow hydrological characteristics are required (or use of better catchment models are required) and could potentially be achieved through:

1. improved parametrisation of the infiltration excess runoff processes and its interplay with groundwater discharge processes.
2. Improved parametrisation of the groundwater conceptualisation and parametrisation of TopNet-GW (Yang et al. 2019, Griffiths et al. 2022) to better represent river/groundwater exchanges and the impacts of regional groundwater movements on flow regimes in low land catchments (see McMillan et al. 2016).
3. Refinement of the bias-correction method when applied to large river catchments.

5.2 Cryosphere

Seasonal snowfall volume across Southland’s Mountain domain is projected to decrease across most of the seasons but summer, with largest decrease by the end of the century under very high (SSP5-8.5) greenhouse gas concentration scenario. Despite precipitation projected to increase for the winter and spring seasons (up to 24% by the end of century under SSP5-8.5), the largest increase in air temperature is projected for winter and spring seasons resulting in a decrease in the seasonal snowfall volume. Summer snowfall volume is projected to increase across Southland’s Mountain domain at low elevations. However, this increase is minimal (in term of snowfall volume) and reflects the fact that snowfall occurs at temperature below snow accumulation threshold (that may be occurring at night).

Snow volumes across Southland’s Mountain domain are projected to decrease at annual and seasonal time scale with largest decrease by the end of the century under very high (SSP5-8.5) greenhouse gas concentration scenario (by at least 90%). Changes in snow volume are an extension of the changes in snowfall volume and indicates that a large portion of Southland’s Mountain domain

is likely to be snow free by the end of the century under very high greenhouse gas concentration scenario.

The average annual number of snow days across Southland's Mountain domain is projected to decrease with largest decrease by the end of the century under very high (SSP5-8.5) greenhouse gas concentration scenario (by at least 60 days across the Garvie Mountain in the Maitua FMU). Changes in annual average number of snow days are an extension of the changes in snowfall volume. At seasonal time scales, changes in the average seasonal number of snow days are projected to be limited (by up to 10 days) in winter by the end of the century under very high (SSP5-8.5) greenhouse gas concentration scenario. Change in the winter average number of snow days reflects a combination of the change in winter precipitation (increase) and air temperature (warming).

Snow melt volume across Southland's Mountain domain is projected to decrease in winter and spring with largest decrease by the end of the century under very high (SSP5-8.5) greenhouse gas concentration scenario. However, increases in snow melt volume are projected in winter at the highest elevations by mid-century across all greenhouse gas emission scenarios, with persisting small pockets of increased snow melt by the end of the century (likely aligning with permanent snow presence within Southland's Mountain domain). The projected reduction in snowmelt volume in winter and spring is an extension of the increase of warming resulting in a decrease of snow volume and associated snow melt. Reduction in snow melt volume may signal potential shift in hydrological regime for Southland's rivers due to a reduction in snow melt contribution during spring to sustain environmental flow and current water resource uses across the Southland region.

Snow line elevation across Southland's Mountain domain is projected to increase with largest increase by the end of the century under very high (SSP5-8.5) greenhouse gas concentration scenario (up to 800 m for the Eyre Mountains). Changes in snow elevation are an extension of the warming and associated changes in snowfall volume. This indicates that some of Southland's mountain domain is likely to have snow cover less than 90 days (duration threshold used to estimate the position of the snow line) by the end of the century under very high greenhouse gas concentration scenario.

All models project a decrease to snowfall volume (seasonally), snow volume (annual and seasonal), snow days (annual and all seasons except winter) and snow melt volume for each future period and SSP scenario, which provides a high degree of confidence that snow occurrence will be rarer as future warming occurs. There is uncertainty as to the precise amount of reduction in snow metrics that will occur under each SSP, therefore the multi-model (ensemble) average values presented in Section 2 are the most appropriate estimate for projected changes across Southland's mountain domain.

The multi-model (ensemble) winter average projected snow day changes presented obscures significant variations between the individual models run under each SSP. As a result, there could be little agreement among all the models as to the direction of the projected winter snow day changes (increase or decrease). The general lack of agreement between models, mainly during the winter season means that uncertainty remains as to the direction of projected number of snow days changes during winter season. Greater confidence can be placed on projections under which the majority of the models (e.g., five of the six models) project the same direction of change.

5.3 Hydrological metrics

5.3.1 High flow metrics

The magnitude of the Mean Annual Flood, which is the approximate natural streambank full flow, is projected to increase across almost all Southland rivers, with at least 95% of the reaches affected. The largest increases are expected by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas scenarios, reaching up to 42% across Southland (68% for the Aparima FMU). A small number of reaches in each FMU may see decreases, such as up to 5 percent in the Maitava FMU. These changes reflect shifts in air temperature, annual precipitation, daily rainfall extremes, and more frequent heavy rainfall events, because a warmer atmosphere holds more water (Clausius–Clapeyron relationship). Overall, the increase in Mean Annual Flood magnitude suggests a greater risk of riverine flooding across Southland rivers.

The magnitude of Q5, which is the river flow exceeded five percent of the time, shows a similar pattern to the Mean Annual Flood. It is projected to increase across most Southland rivers, affecting up to 94% of reaches. The largest increases are expected by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas scenarios, with rises of up to 20% across Southland (32% for the Waituna FMU). Some reaches may see decreases in Q5 magnitude in each FMU, such as up to 10% in the Maitava and Waiau FMUs. The differences between changes in Mean Annual Flood and Q5 magnitudes suggest a possible shift in the distribution of high flows under warming conditions.

The magnitude of Q25, which is the river flow exceeded twenty-five percent of the time, shows a similar pattern to Q5. It is projected to increase across most Southland rivers, affecting up to 72% of reaches. The largest increases are expected by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas scenarios, with rises of up to 9% across Southland (22% for the Waituna FMU). A substantial number of reaches may see decreases in Q25 magnitude in each FMU, with the exception of the Waituna FMU, ranging from 10% in Fiordland FMU and up to 48 % in the Maitava FMU. The differences between changes in Mean Annual Flood and Q25 magnitudes suggest a possible shift in the distribution of high to medium flows under warming conditions.

Changes in the average number of Fre3 events, defined using a three- or five-day gap between events, are projected to vary across Southland rivers by location, time, and warming scenario. At the annual scale, little change is expected across FMUs under most scenarios. However, by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas scenarios, Fre3 events may increase by more than one event in Fiordland and Waiau FMUs, while decreases are projected for up to 15% of Southland's river reaches, rising to 32% when a five-day gap is used. Larger variations are projected in the Aparima–Oreti and Maitava FMUs, with decreases of up to 10 events for the Aparima–Oreti and Maitava Rivers. At the seasonal scale, different spatial patterns appear. During winter and autumn, decreases in the average number of Fre3 events are projected for up to 30% of Southland's river reaches, with the largest decrease projected in the Oreti FMU (at least 47% of the river reaches). During spring and winter, decreases in the average number of Fre3 events are projected for at least half of Southland's river reaches, mainly affecting the Fiordland (up to 83% of the river reaches) and Waiau (up to 70% of the river reaches) FMUs. Overall, differences in the magnitude and spatial distribution of changes in Q5 and Fre3 events highlight shifts in high-flow hydrological regimes under warming scenarios.

The large majority of the models project increases in mean annual flood and Q5 and Q25 for each future period and SSP scenario, which provides a high degree of confidence that the magnitude of high flow metrics will increase with future warming. There is uncertainty as to the precise amount of

warming that will occur under each SSP, therefore the multi-model (ensemble) average values presented in Section 3 are the most appropriate estimate for projected changes across Southland. The uncertainty as to the direction and amount of change under each SSP means the multi-model (ensemble) average values are the most appropriate estimate for projected Fre3 changes across Southland. Nevertheless, the spread of model results under each SSP implies that these projections should be interpreted carefully.

5.3.2 Water resources metrics

The magnitude of mean flow is projected to increase across almost all Southland rivers, affecting at least 90% of reaches. The largest increases are expected by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas scenarios, with an average rise of 15% across Southland rivers. However, mean flow is projected to decrease in some areas within each FMU, such as up to 16% in the Waiau FMU and 23% in the Maitava FMU. These changes reflect shifts in annual precipitation, earlier and faster snowmelt, and increased glacier melt in glacierised catchments. This likely indicates an intensification of Southland's river hydrological regimes under warming, leading to greater variability and potential changes in timing (not assessed in this study).

Changes in annual flows were considered in terms of changes in mean annual flows (more sensitive to extreme) and median annual flows. Across most of Southland rivers, mean annual flow is projected to increase, with the greatest projected increases occurring for the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas concentration scenarios (average increase of 15% across Southland rivers). A notable difference is the lower Maitava River, for which by the end of the century under a very high greenhouse gas concentration scenario, median annual flows are projected to increase by 10%, while mean annual flows are projected to increase only by up to five %. The magnitude of the mean annual flow is projected to decrease in some areas within each FMU (e.g., up to 17% of the reaches in the Maitava and Waiau FMUs). Overall, changes in median annual flows generally follow the same pattern as changes in mean annual flows, but with smaller increases or decreases.

Seasonal average flows are projected to increase across nearly all Southland rivers in every season except summer. The largest increases are expected by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas scenarios, with average rises of at least 30% across Southland rivers. In contrast, the direction of change in summer flows is projected to vary with time and emissions scenario, while the magnitude of change is limited to a range of -5% to 5%. Regardless of time or emissions scenario, summer flows are projected to decrease in the Waiau and Fiordland FMUs, and in the Maitava FMU by the end of the century under high scenarios and mid-century under very high scenario. Summer flows in the Aparima and Oreti FMUs are projected to increase regardless of time and scenarios. Interestingly, the largest summer flow decreases occur under high scenarios rather than very high scenarios. The magnitude of summer flow is projected to decrease for the majority of river reaches within each FMU (except for the Aparima and Oreti FMUs), ranging from up to 71% in the Fiordland FMU to 83% in the Waituna and Maitava FMUs. Overall, these changes in seasonal average flows suggest a significant shift in Southland river hydrological regimes under warming, with clear spatial differences across FMUs.

The magnitude of the annual Q25 is projected to increase across nearly all Southland rivers (at least 75%), with the greatest increases by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas concentration scenarios (average increase of 15.0% across Southland rivers). However, the magnitude of annual Q25 is projected to decrease in some areas in each FMU (up to 26% in the Maitava FMU). Interestingly, the magnitude of the annual Q25 is projected to

increase (by up to 10 percent) for all FMU river main stem rivers under very high (SSP5-8.5) greenhouse gas concentration scenario. These changes reflect changes in seasonal flows and may indicate broader changes in Southland's high flow to mid-range hydrological regimes.

Changes in the magnitude of Q75, which is the river flow exceeded seventy-five percent of the time, show a different spatial pattern to the mean flow and annual Q25. It is projected to decrease by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas scenarios, with average decrease up to 6% across Southland rivers (up to 20% for the Oreti FMU). However, Q75 is projected to increase across the Fiordland FMU, and to a lesser extent the Aparima and Waituna FMUs, by up to 10%. The magnitude of Q75 is projected to decrease for more than half of the river reaches in Southland, ranging from 25% of the river reaches in the Fiordland FMU up to over 86% of the river reaches within the Maitua-Oreti and Waiau FMUs.

Changes in the magnitude of the Q95, which is the river flow exceeded ninety-five percent of the time, show similar spatial pattern to Q75. It is projected decrease by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas scenarios, with average decrease up to 6% across Southland rivers (by at least 13% for the Oreti-Waiau and Maitua FMUs under SSP3-7.0). However, Q95 is projected to increase only across the Fiordland FMU by up to 6%. The magnitude of Q95 is projected to decrease for 60% of the river reaches in Southland, ranging from 28% of the river reaches in the Fiordland FMU up to over 90% of the river reaches within the Maitua-Oreti and Waiau FMUs.

Changes in the magnitude of the mean annual 7-day low flow vary across Southland rivers in both direction and magnitude. At FMU scale, the largest decrease is projected for the Waiau FMU by mid-century under the high (SSP3-7.0) scenario, at -11%. The largest increase is projected for the Aparima and Waituna FMUs by the end of the century under the low (SSP2-4.5) scenario, at +50%. By the end of the century, the magnitude of the mean annual 7-day low flow is projected to decrease over time across all FMUs except for the Aparima and Maitua FMUs. Spatial analysis shows a decrease of at least 23% for most reaches in the Oreti and Maitua main stems by mid-century under the high emissions scenario. As with mean flows, decreases are projected in parts of every FMU, reaching more than 60% of river reaches in all FMUs except the Waituna FMU (up to 46%). Combined with changes in Q75 and Q95, these shifts point to significant changes in low-flow hydrological regimes across Southland rivers under warming. This suggests river water will be less consistently available to meet environmental or water-use needs in the future.

Changes in flow reliability, defined as the fraction of time that flow is equal to or below the NES for Environmental Flows and Water Levels, vary across Southland rivers in both direction and size. At FMU scale, the largest decrease is projected for the Aparima and Maitua FMUs by the end of the century under the low (SSP2-4.5) scenario, at -0.05, as well as the Waituna FMU, at -0.08. The largest increase is projected for the Waiau FMU by the end of the century under all warming scenarios, at +0.02. Spatial analysis shows that flow reliability is projected to fall across at least 69% of reaches in every FMU, with the biggest decrease in the Aparima-Oreti and Maitua main stems, up to 0.08, by the end of the century under the moderate (SSP2-4.5) scenario. These changes suggest river water will be less consistently available to meet environmental or water-use needs under future warming, reflecting a shift towards greater variability and uncertainty in water regimes.

Changes in water supply reliability, defined as the fraction of time river flow is too low during the irrigation season, vary across Southland rivers in both direction and size. At FMU scale, the largest decrease is projected for the Aparima and Maitua FMUs by the end of the century under the low (SSP2-4.5) scenario, at -0.05 as well as the Waituna FMU, at -0.07. The largest increase is projected

for the Waiau FMU by the end of the century under the low and very high (SSP5-8.5) scenarios, at +0.01. Spatial analysis shows that water supply reliability is projected to decline for at least 80% of the reaches in every FMU, with decreases of up to 0.1 for most main stems by the end of the century under the very high emissions scenario. These changes mirror the projections for flow reliability and suggest that river water will be less consistently available to meet irrigation demand, likely increasing the frequency of water shortages during the irrigation season under future warming.

Projected changes in land surface recharge vary in both direction and magnitude across Southland's shallow aquifers. At the annual scale, recharge is projected to decrease in the Oreti FMU by up to 6% under high (SSP3-7.0) and very high (SSP5-8.5) scenarios. Conversely, recharge is projected to increase for other FMUs under all scenarios, reaching up to 12.6% (Aparima FMU) and 17% (Waituna FMU) by the end of the century under the very high scenario. At the seasonal scale, recharge is projected to rise in autumn and winter across all FMUs under all scenarios, except for small pockets in the Oreti and Waiau FMUs. In summer, recharge is projected to fall by up to 50% across most shallow aquifers in the Oreti (except Five Rivers), Waituna, and lower Maitara FMUs under high and very high emissions scenarios. In spring, decreases in recharge are limited to parts of the lower Oreti and Waiau aquifers under the very high emissions scenario. Overall, reductions in spring and summer recharge point to increasing risks of hydrological and agricultural drought, water scarcity (such as access to groundwater for drinking water in the lower Maitara), and ecosystem stress. These changes suggest greater variability and reduced resilience of groundwater resources in the Oreti, Waituna, and lower Maitara FMUs under future warming.

5.3.3 Flood metrics

Flood magnitude projections under climate change were assessed using a stationary assumption and pooled GCM 20-year annual maxima time series, equivalent to 120 years. Results show that maximum daily and hourly annual peak discharge is generally projected to increase with time, warming, and return period across Southland rivers. However, the size of the changes varies by location and scenario. The maximum daily annual peak discharge is projected to rise consistently with time and warming for only three of the locations considered (Aparima at Thornbury Bridge, Aparima River at Thornbury Bridge and Waikaka at Gore Township). This aligns with projected changes in maximum annual 1-day and 5-day rainfall totals across Southland. In contrast, for most sites (78% of the locations considered), flood magnitude does not generally increase with warming or time. At these sites, the largest increase occurs under the high (SSP3-7.0) scenario and does not rise further with warming. Site analysis suggests this may be linked to the pooled GCM annual daily maxima EVD being Type III, which caps extreme floods due to its bound tail distribution. Because of the limited sample size and the need for additional bias correction to support flood magnitude analysis, caution is needed when interpreting these projected changes in annual daily peak floods. Even greater caution is required for annual hourly peak floods, given the constraints of hourly climate input resolution.

The magnitude of peak daily discharge linked to 12hr and 24-hour Probable Maximum Precipitation (12hr and 24 hr PMF) is projected to increase with warming. Under 1°C warming, most FMUs, except Maitara, show an increase between 10% and 20% in 12hr and 24 hr PMFs. Spatial differences become more pronounced for warming above 2°C, with the largest changes projected for the Maitara FMU. This pattern likely reflects the influence of winter PMP events, where warming shifts precipitation phase from snow to rain, amplifying hydrological responses. While these results align with expectations that extreme rainfall events become more frequent under climate change, the spatial distribution of changes in PMF (12hr and 24hr event duration) does not match that of maximum annual 1-day or 5-day rainfall. Changes in PMF across different storm durations generally

follow the same pattern as rainfall depth changes predicted by the HIRDS tool, while changes in PMF for some locations are predicted to increase with storm duration. The latter may be due to the use of the DSHG tool and the way climate-change adjustments were applied when the PMP values were originally derived. Further investigation is needed to understand these changes and better characterise the impacts of rarer rainfall events.

5.3.4 Stream Temperature

Stream temperature is projected to increase uniformly across Southland rivers with time and warming, at both annual and seasonal time scale. Spatially, the largest increases are projected to occur under high (SSP-3-7.0) and very-high (SSP5-8.5) greenhouse gas concentration scenarios at the outlets of the main river stems (up 4°C), while the lowest increases are projected in the upper reaches FMUs (up to 1°C). Due to the stream temperature model formulation (based only on air temperature), projected changes in stream temperature directly reflect changes in air temperature at both annual and seasonal time scale. Those changes signal greater stress on freshwater ecosystems, reduced water quality, and challenges for human use, making rivers less resilient to warming (Kaushal et al. 2010).

6 Acknowledgements

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7 Glossary of abbreviations and terms

Anthropogenic	Originating in human activity
ARI	Average recurrence interval. The average time interval (averaged over a very long time period and many "events") that is expected to elapse between recurrences of an infrequent event
Bias-corrected	The process of using observations (e.g., data from existing climate stations, or streamflow stations) to calibrate climate model or climate-hydro modelling chain simulations. This ensures climate model or hydrological output resemble a given location's climate and weather/ hydrological characteristics appropriately
CCAM	Conformal Cubic Atmospheric Model, which uses dynamical downscaling to simulate climate and weather at finer resolutions than GCMs. Developed by CSIRO in Australia
Climate variable	An element of the climate that is liable to vary or change, e.g., temperature, rainfall.
CMIP5	Fifth Coupled Model Intercomparison Project. This project involved a number of experiments with coupled atmosphere-ocean global climate models, most of which were reported on in the IPCC Fifth Assessment Report, Working Group I
CMIP6	Sixth Coupled Model Intercomparison Project. This project involved a number of experiments with coupled atmosphere-ocean global climate models, most of which were reported on in the IPCC Sixth Assessment Report, Working Group I
Downscaling	Deriving local climate information from larger-scale model or observational data. Two main methods exist – statistical and dynamical. Statistical methods develop statistical relationships between large-scale atmospheric variables (e.g., circulation and moisture variations) and local climate variables (e.g., rainfall variations). Dynamical methods use the output of a regional climate/weather model driven by a larger-scale global model
Ensemble	Referring here to the collection of six GCMs that were selected for downscaling and bias-correction in New Zealand
GCMs	Global Climate Models
IPCC	Intergovernmental Panel on Climate Change. This body was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to objectively assess scientific, technical and socioeconomic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. One of its major outputs is regular assessments of the climate system and our knowledge of climate change, known as Assessment Reports

Radiative forcing	The difference between the energy entering our atmosphere and the energy leaving it. If the number is greater than zero, our atmospheric temperature can increase
RCPs	Representative Concentration Pathways. These comprise scenarios used in CMIP5 modelling. They describe four possible climate futures represented by the concentration of greenhouse gases in the atmosphere, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W m ² , respectively)
Seven-station series	This refers to seven long-term temperature records used to assess New Zealand's warming on the century time-scale. The sites are located in Auckland, Wellington, Masterton, Nelson, Hokitika, Lincoln, and Dunedin.
SSPs	Shared Socioeconomic Pathways. These comprise scenarios of projected socioeconomic global changes up to 2100, used in CMIP6 modelling
SST	Sea-surface temperature. The temperature of the uppermost layer of the ocean

Appendix A Bias corrected hindcast daily average hydrographs

Aparima at Thornbury

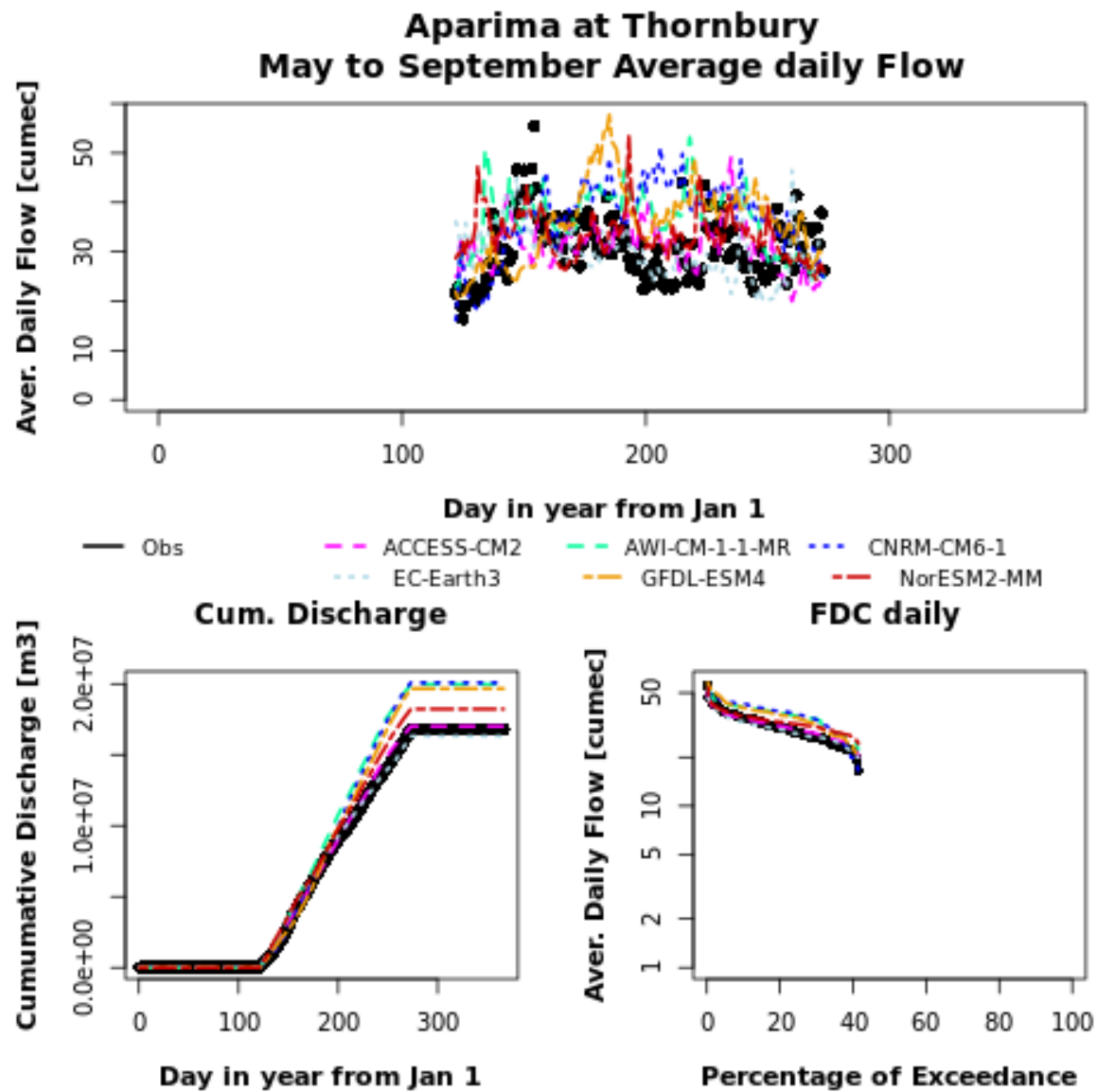


Figure A-1: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Aparima at Thornbury. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

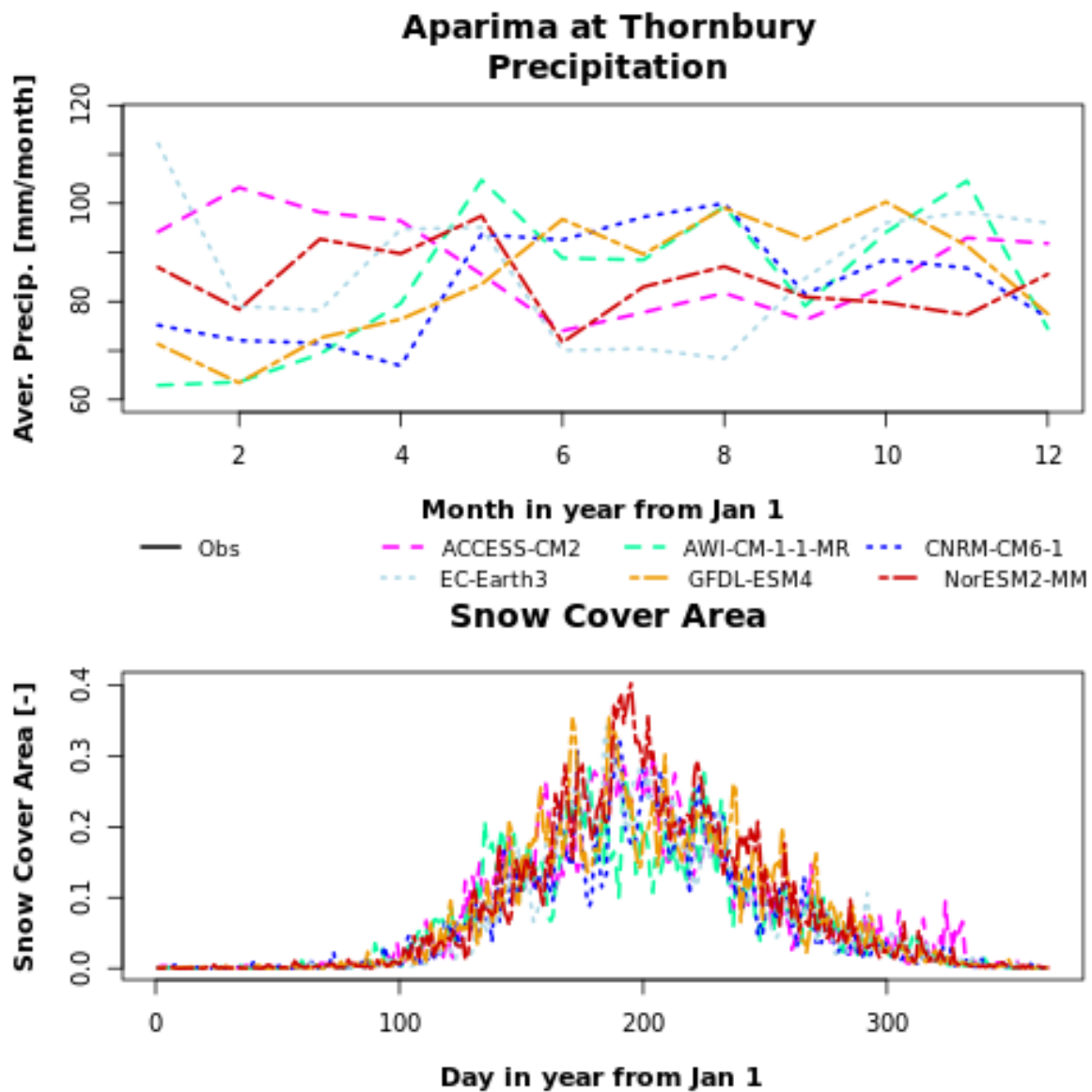


Figure A-2: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Aparima at Thornbury. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

Oreti at Three Kings

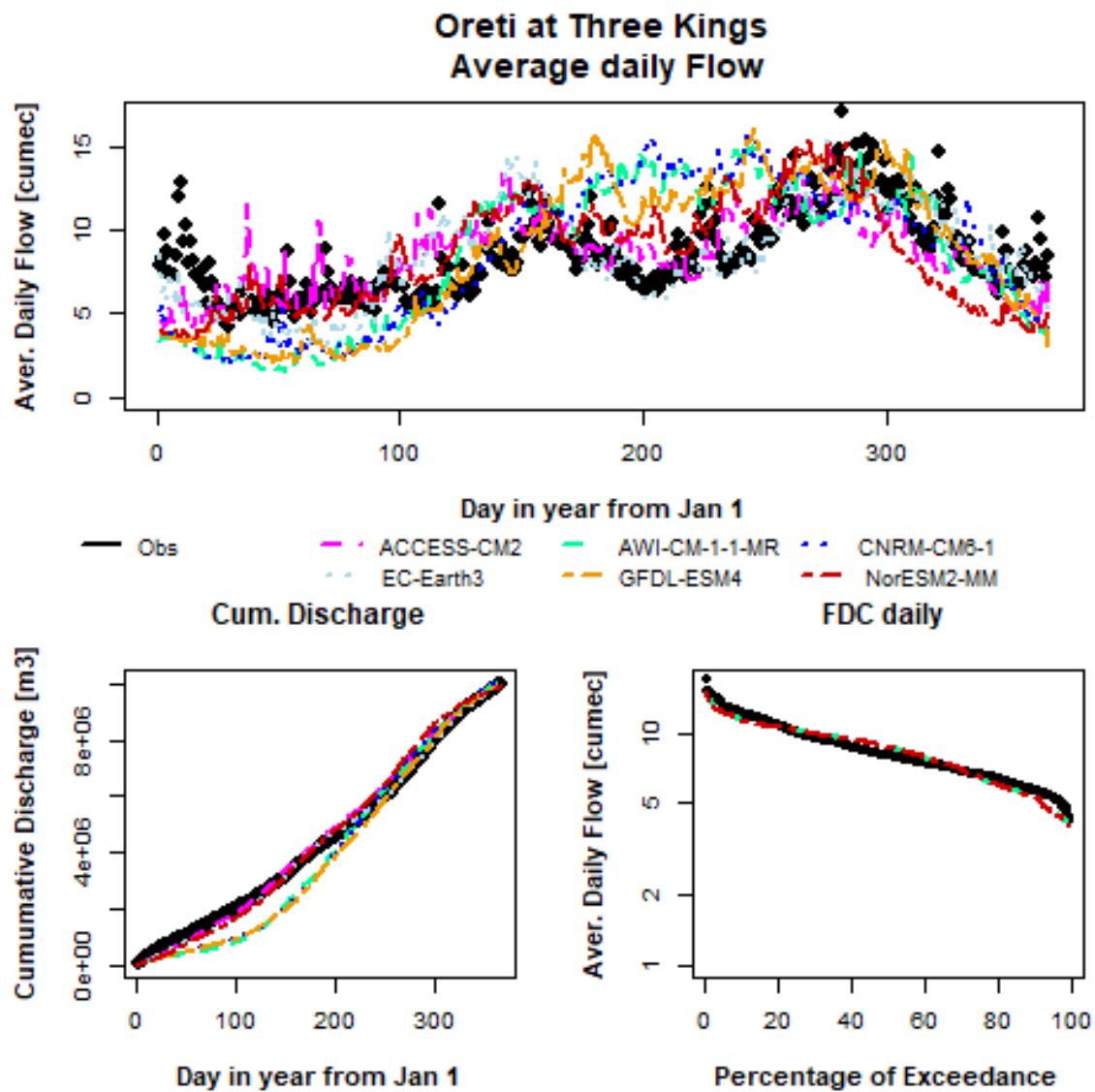


Figure A-3: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Oreti at Three Kings. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014.

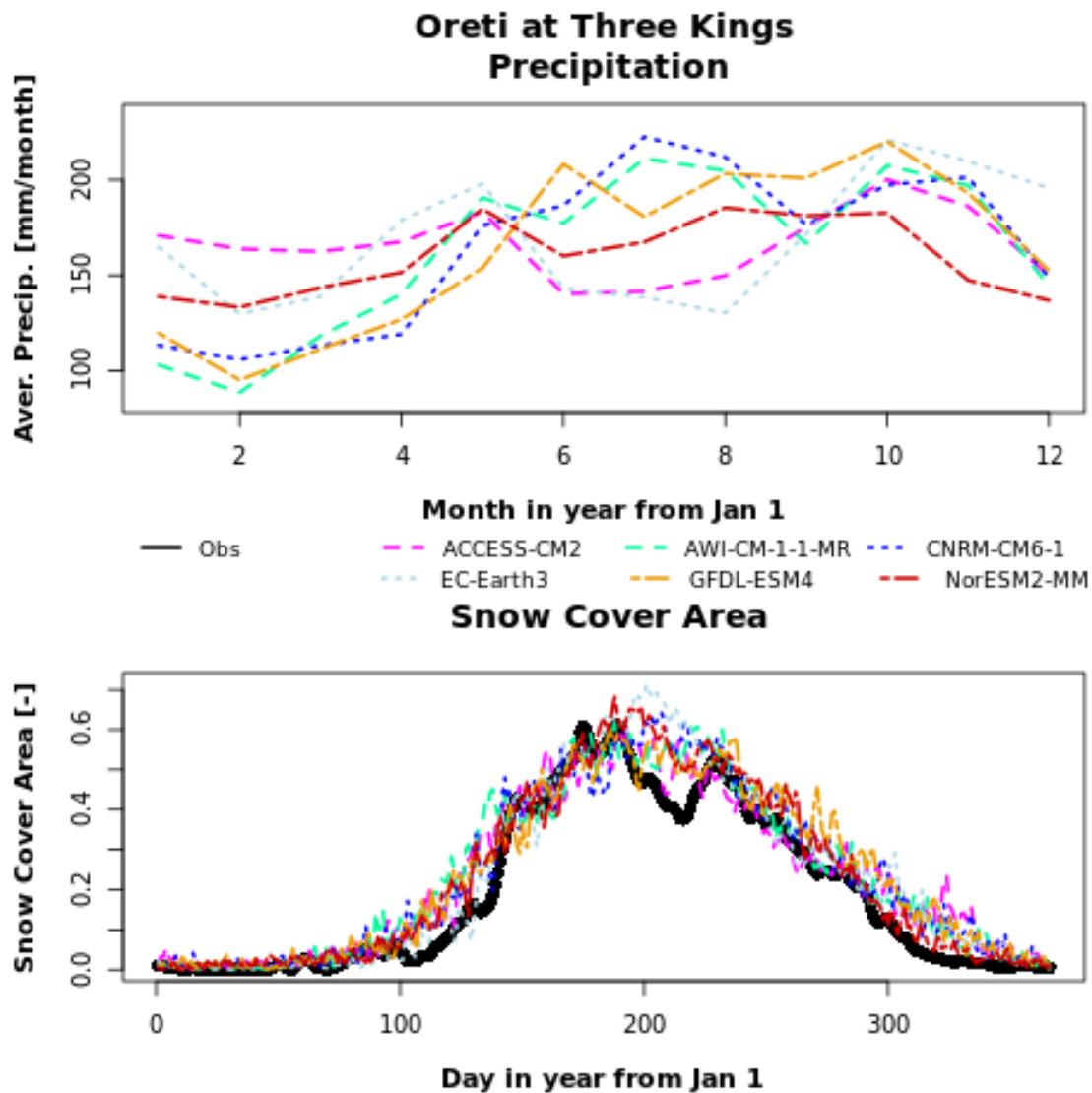


Figure A-4: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Oreti at Three Kings. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

Lyvia Creek at Deep Cove

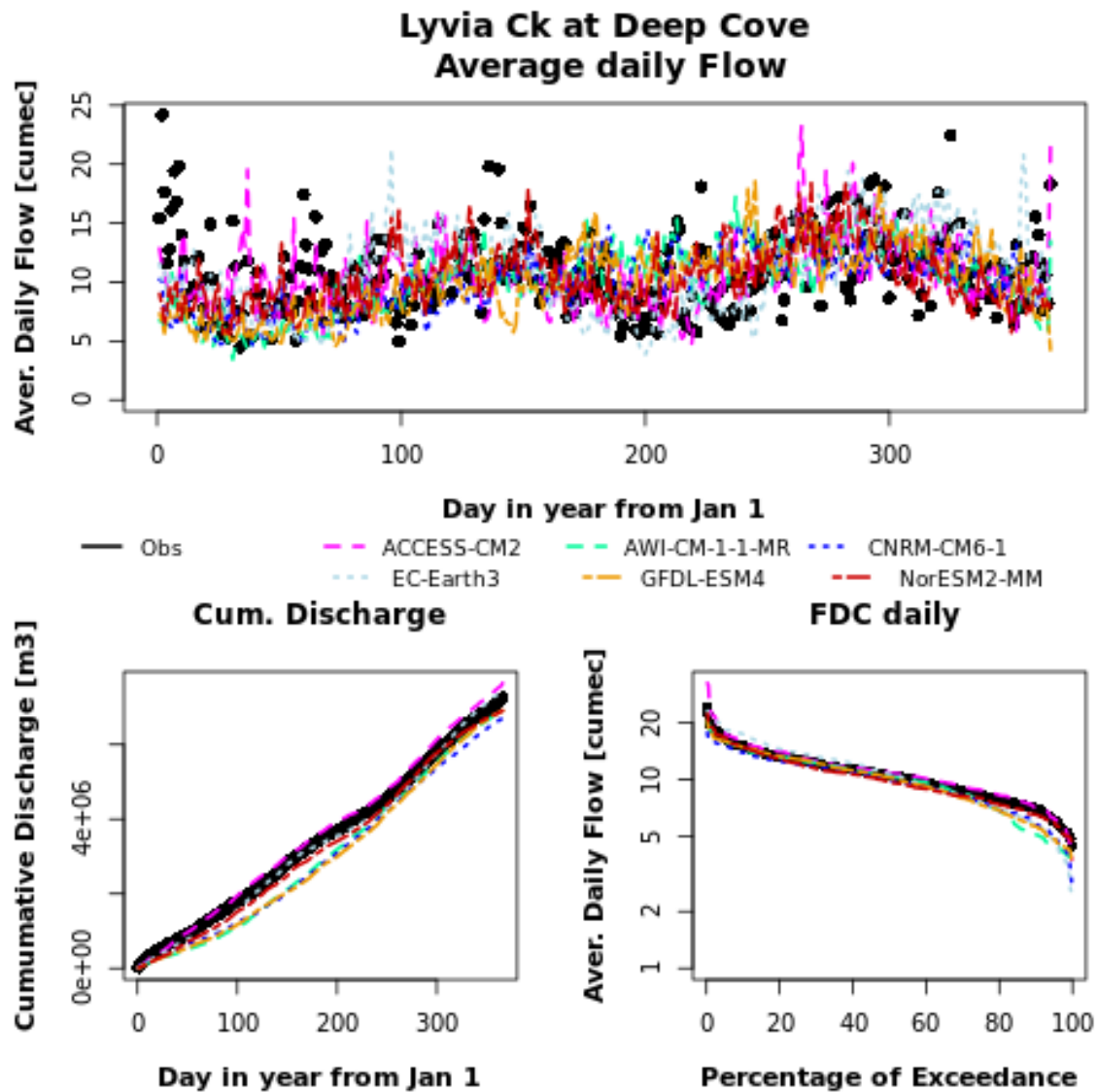


Figure A-5: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for Lyvia Creek at Deep Cove. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

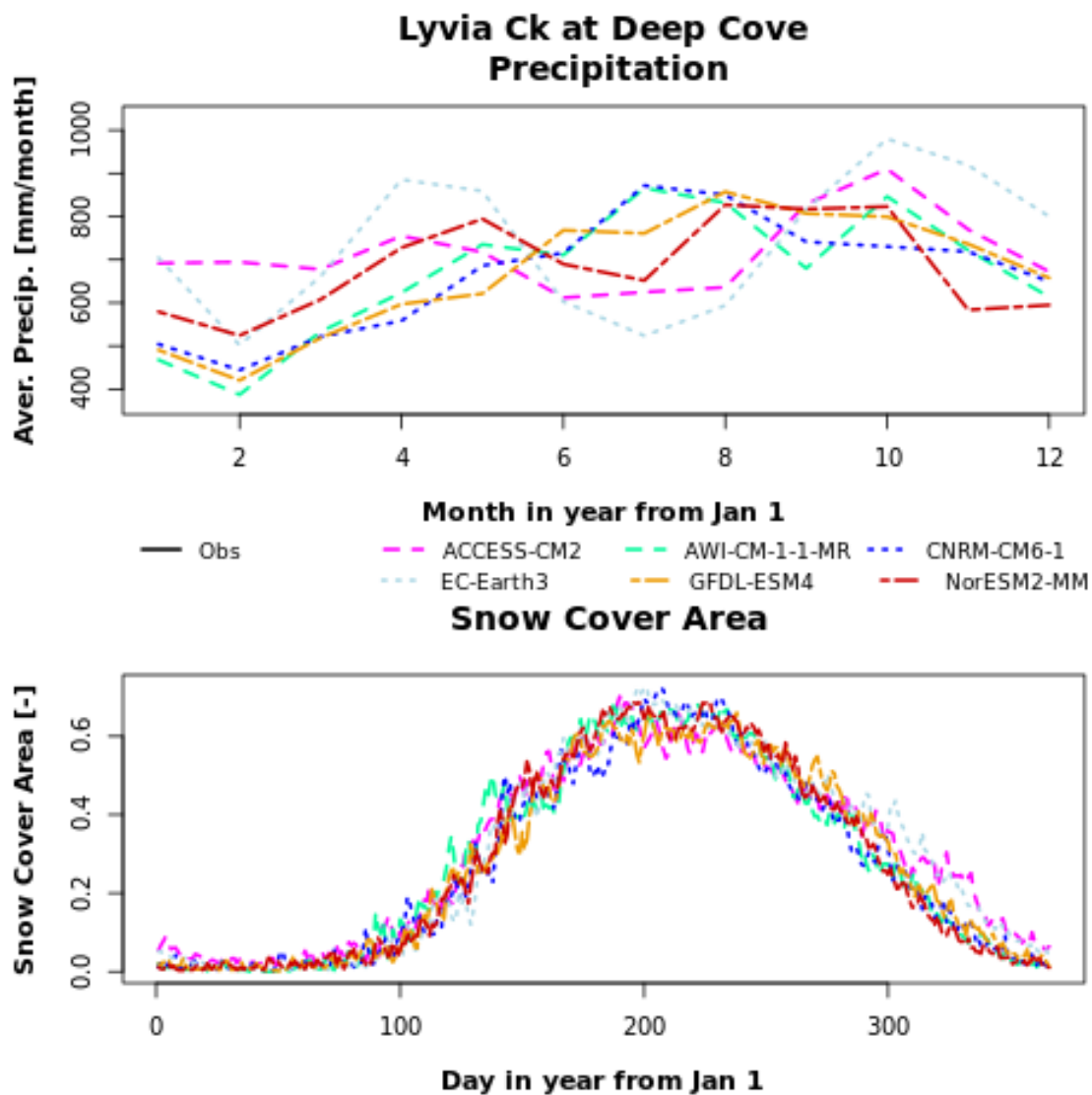


Figure A-6: Hindcast bias corrected monthly average precipitation and daily average snow cover area for Livia Creek at Deep Cove. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

Mataura at Parawa

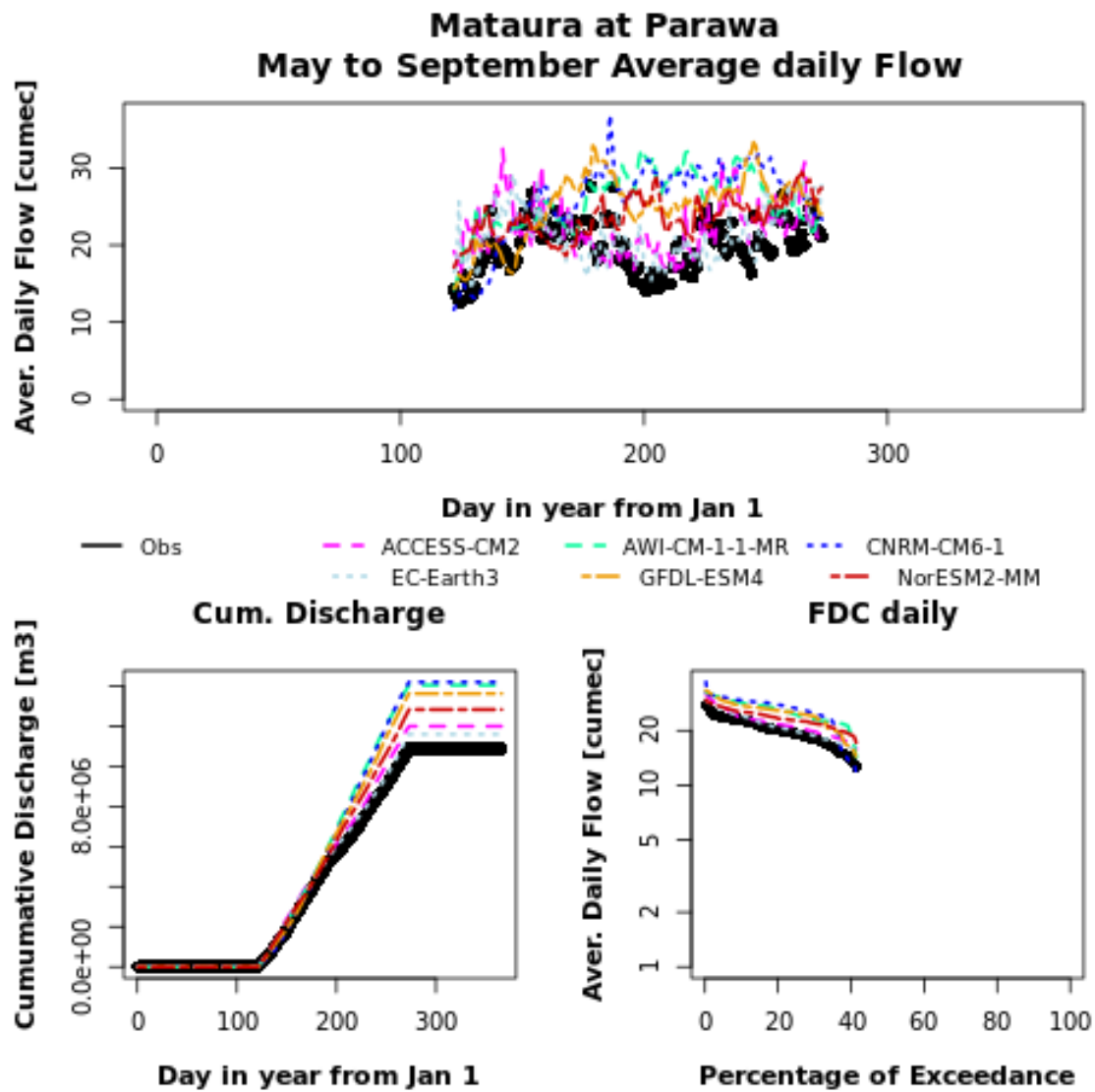


Figure A-7: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Mataura at Parawa. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

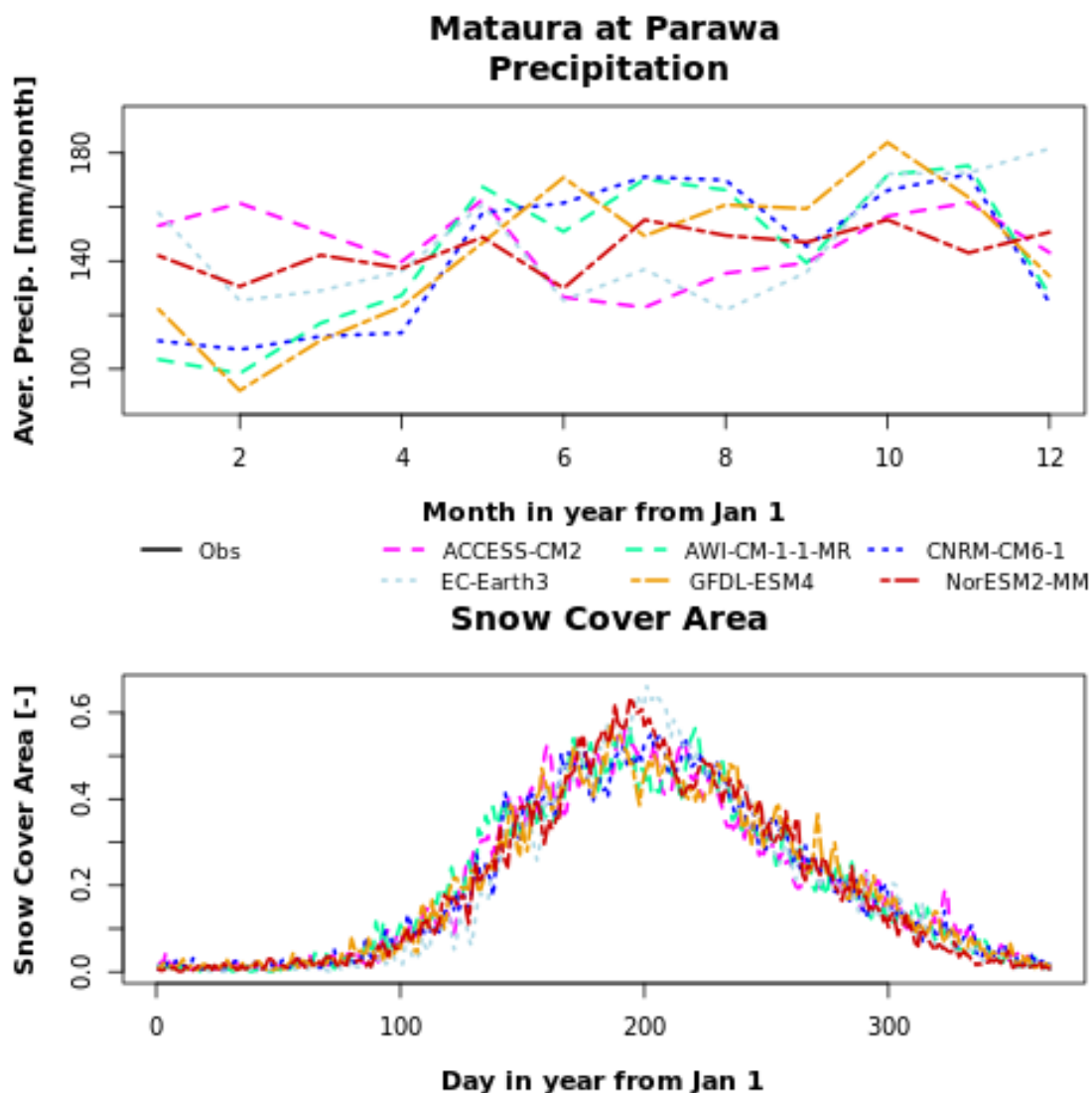


Figure A-8: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Matura at Parawa. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

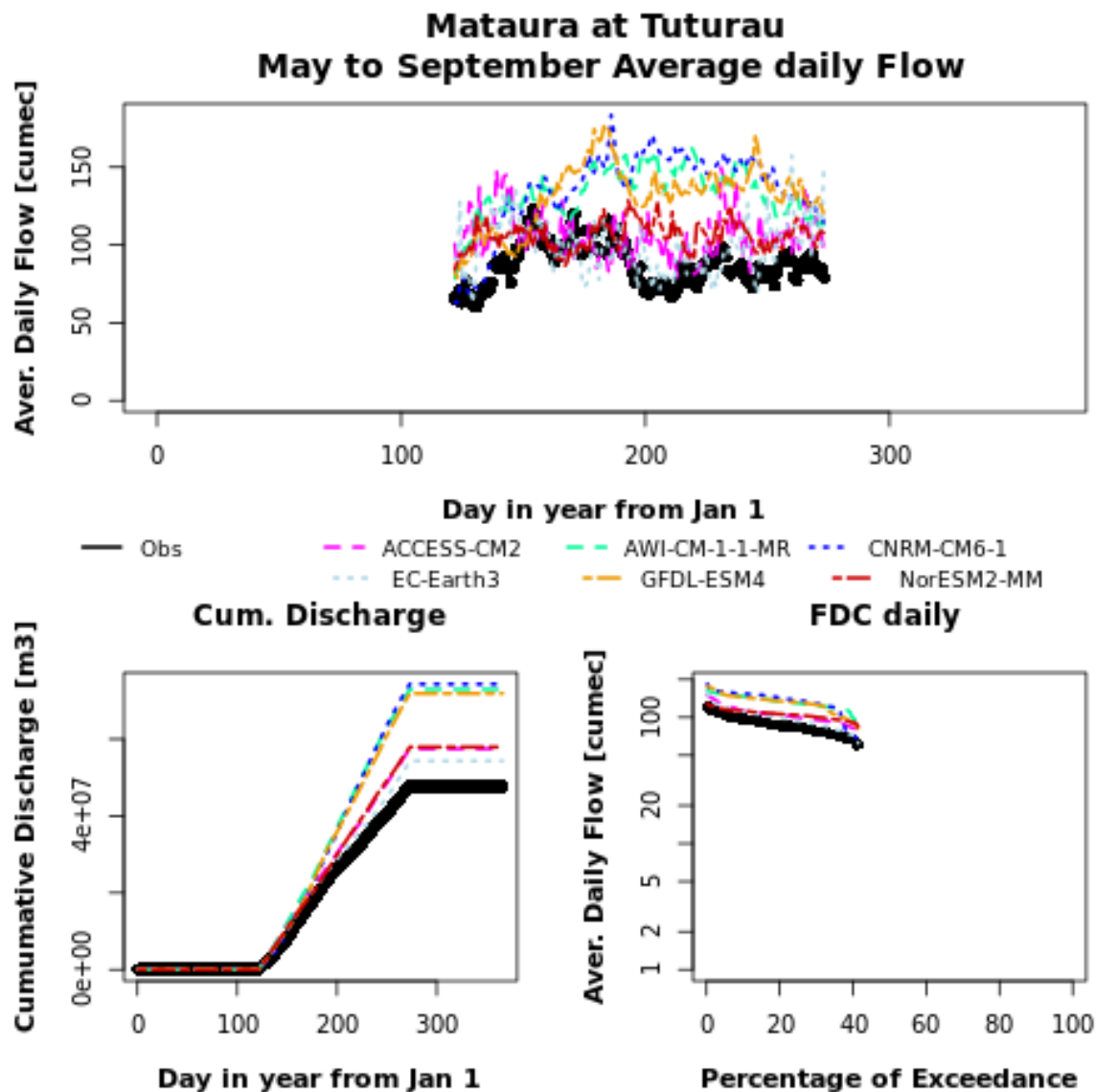


Figure A-9: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Mataura at Tukurau. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

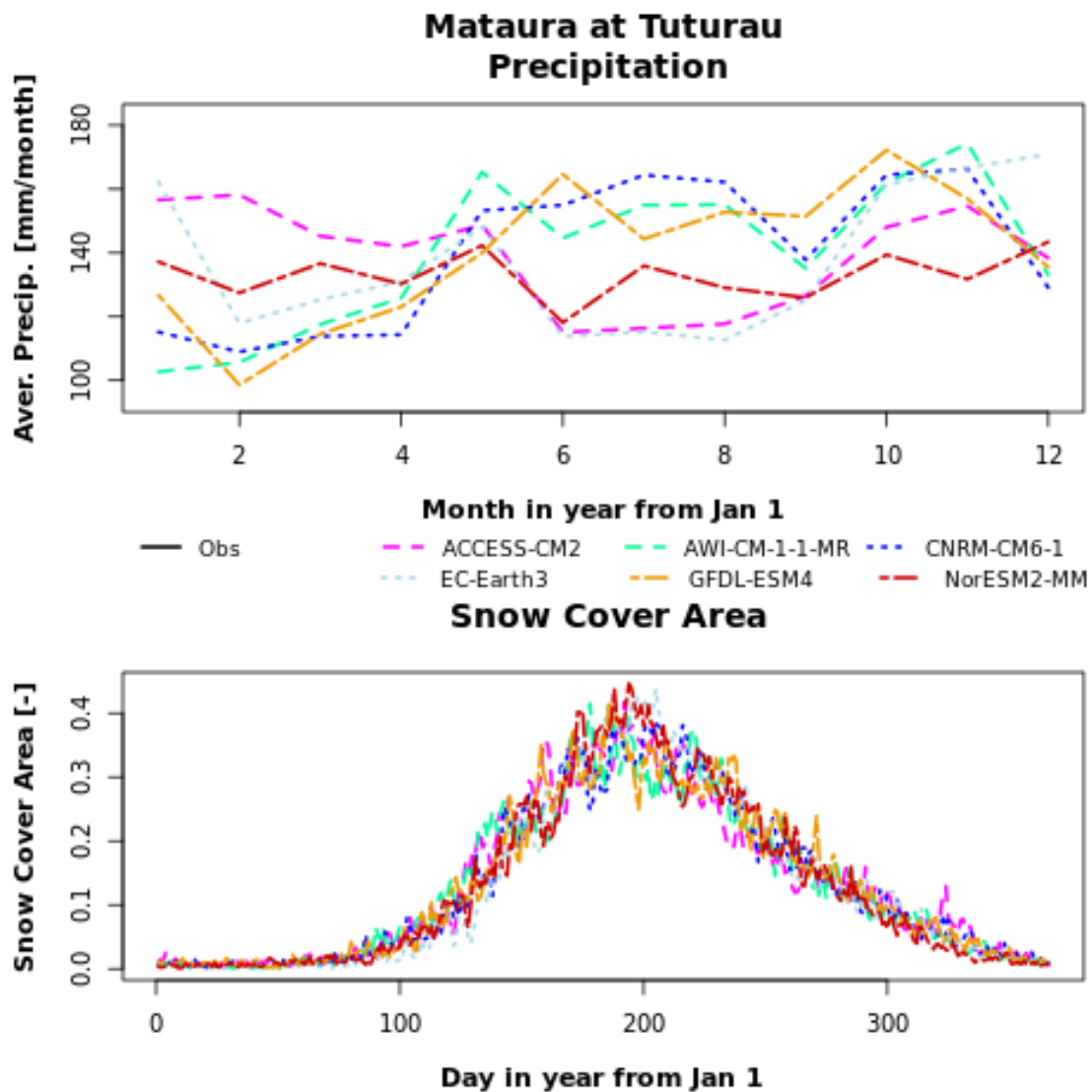


Figure A-10: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Mataura at Tukurau. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

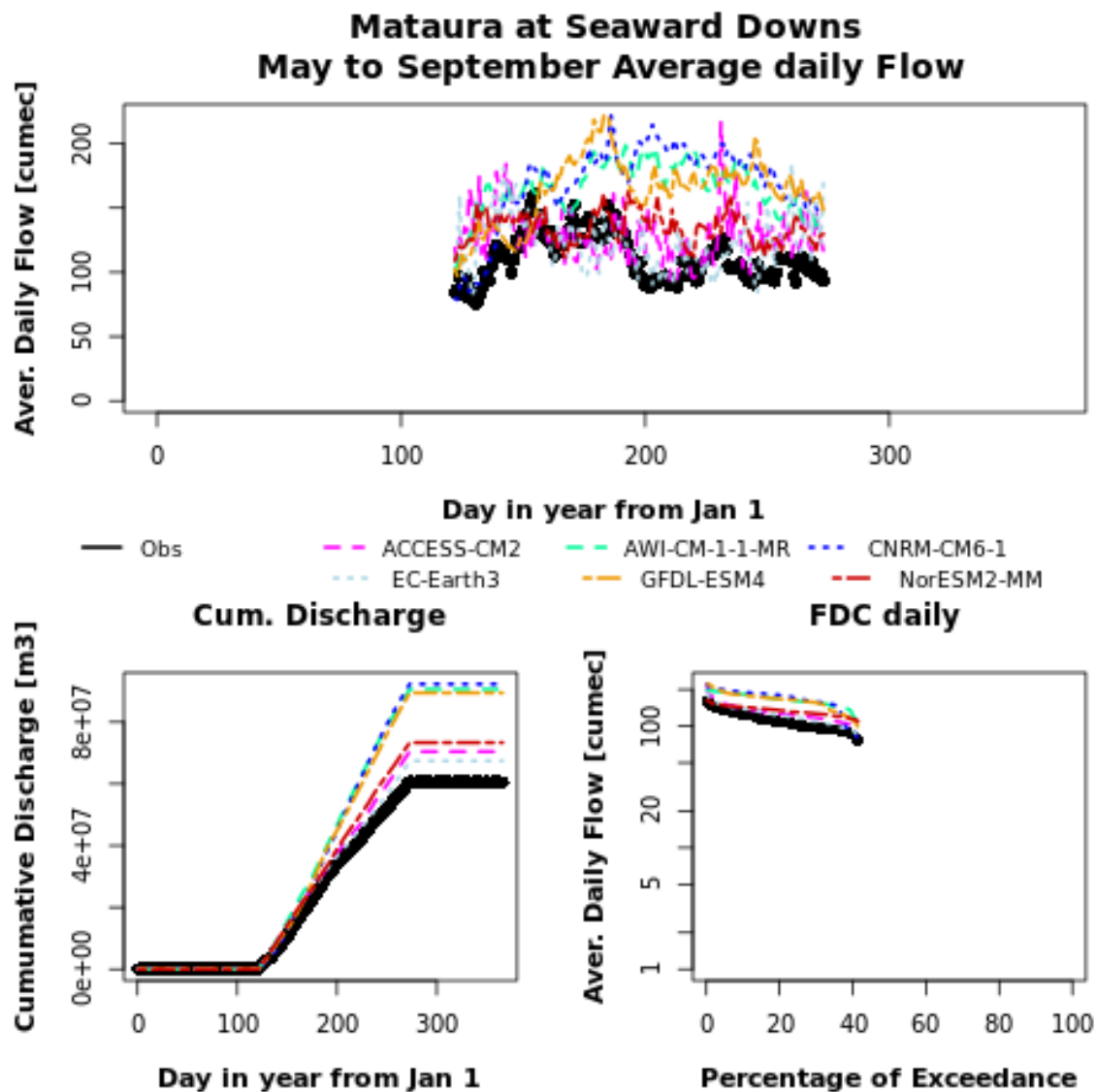


Figure A-11: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Mataura at Seaward Downs. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

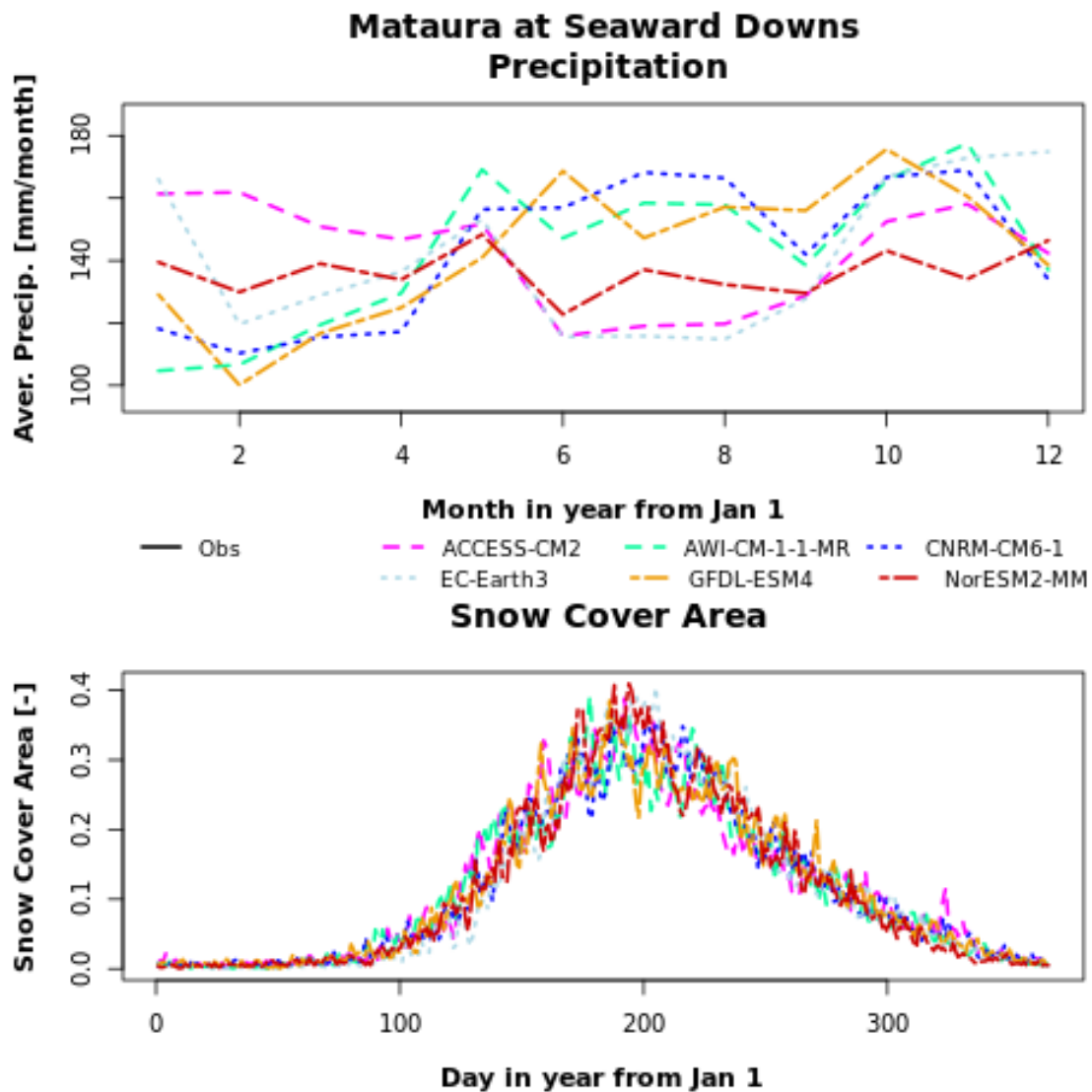


Figure A-12: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Matura at Seaward Downs. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

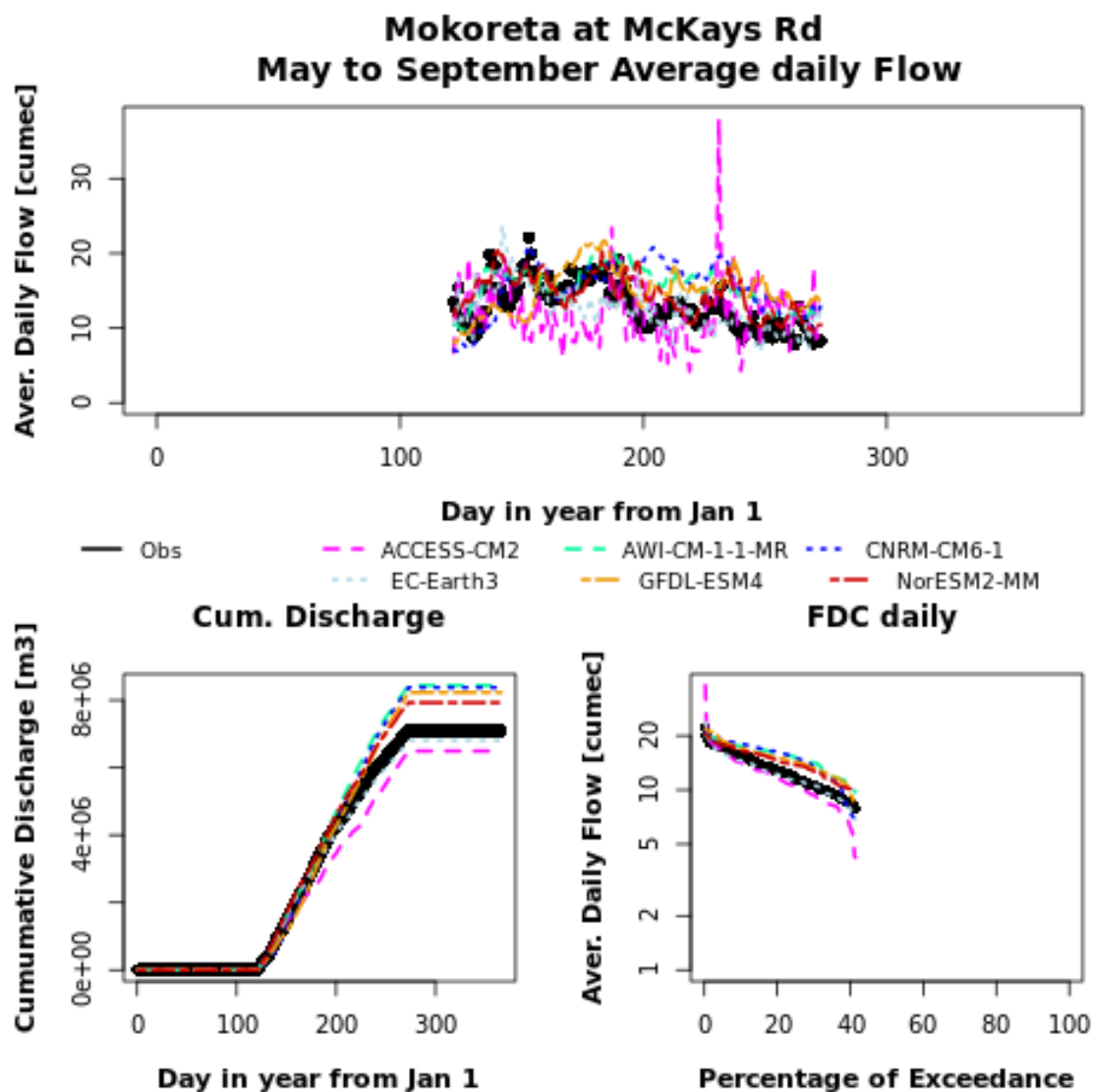


Figure A-13: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Mokoreta at McKays Road. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

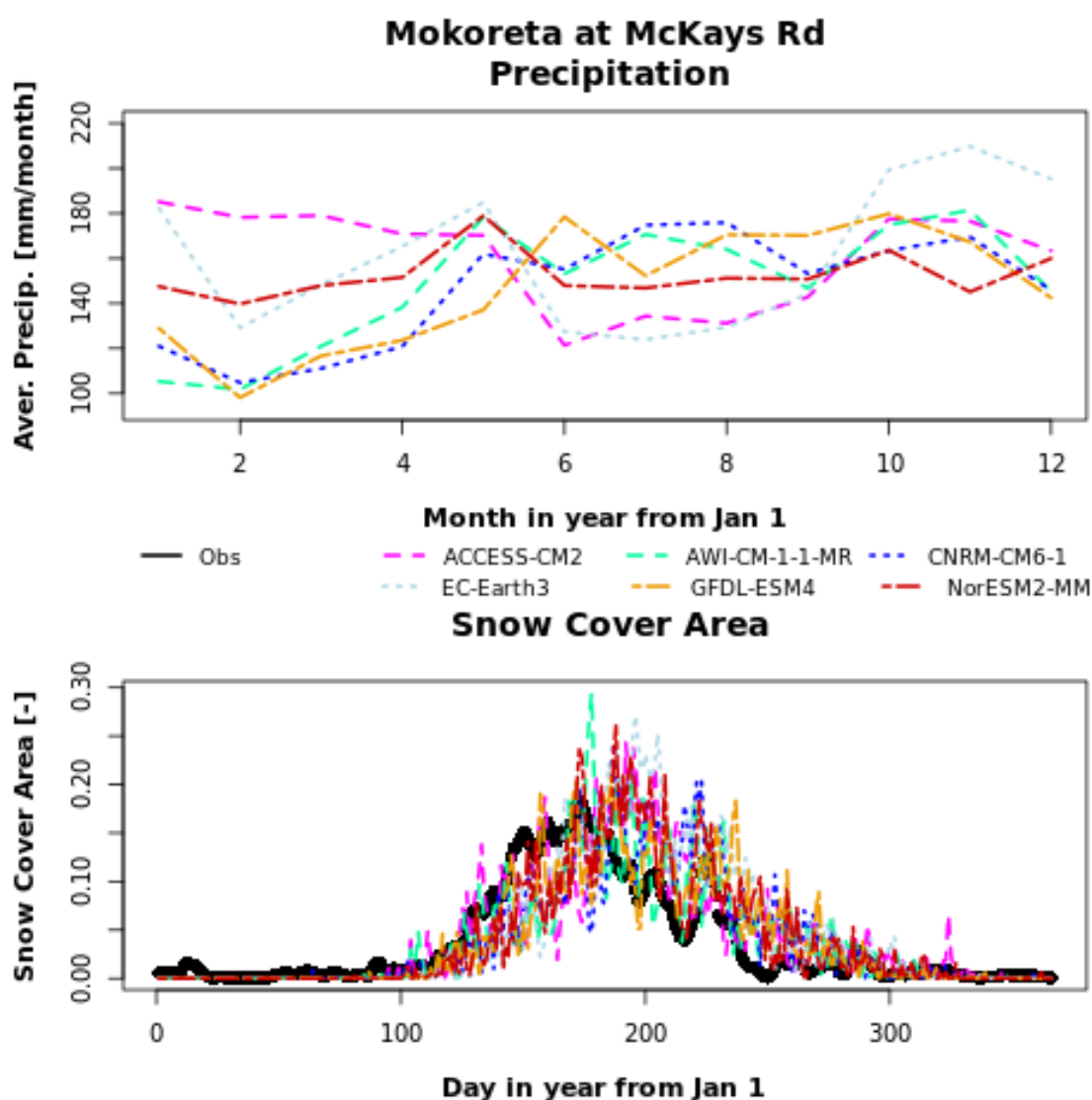


Figure A-14: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Mokoreta at McKays Road. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

Waikaka Stream at Willowbank

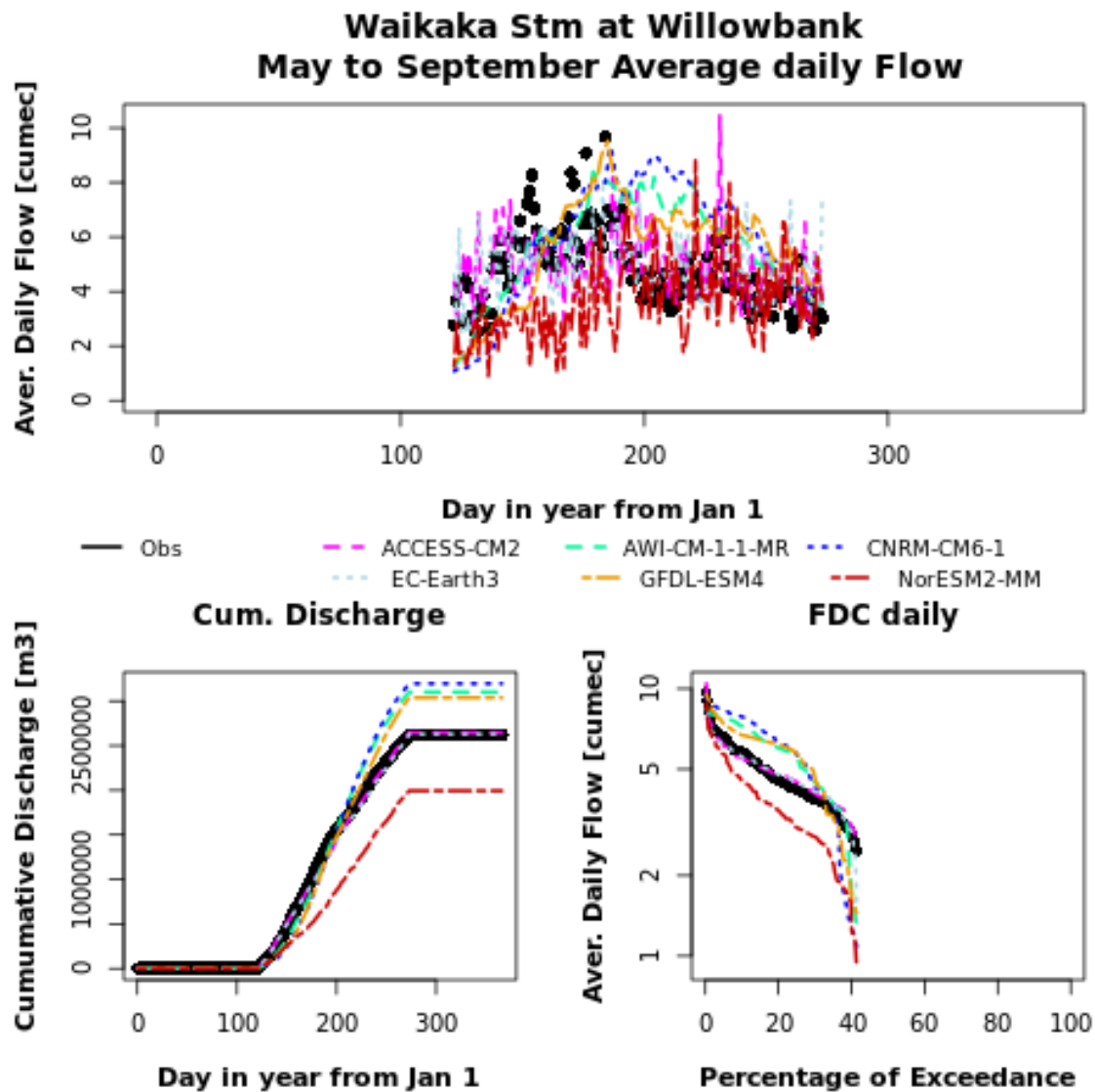


Figure A-15: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Waikaka Stream at Willowbank. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

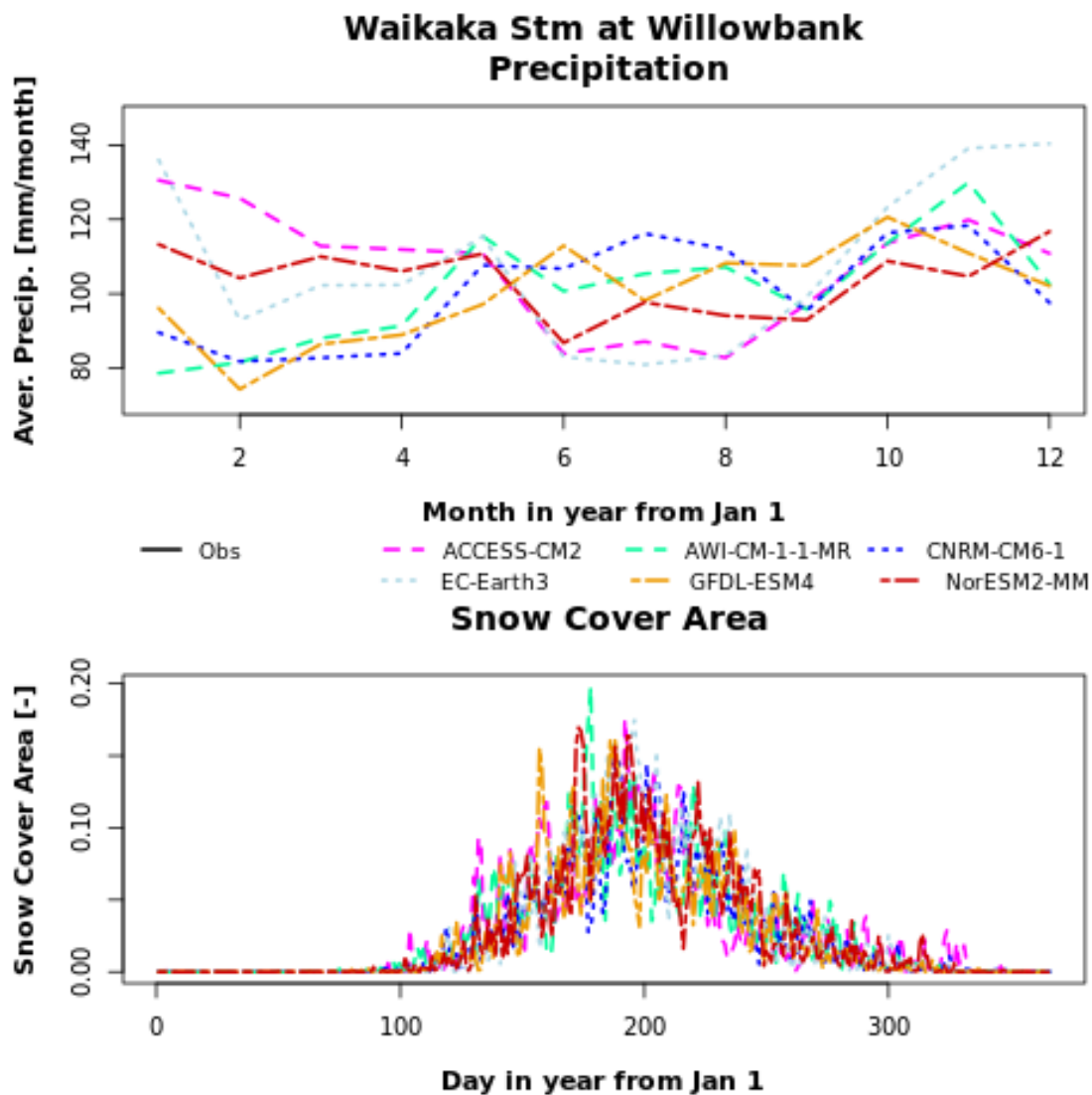


Figure A-16: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Waikaka Stream at Willowbank. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

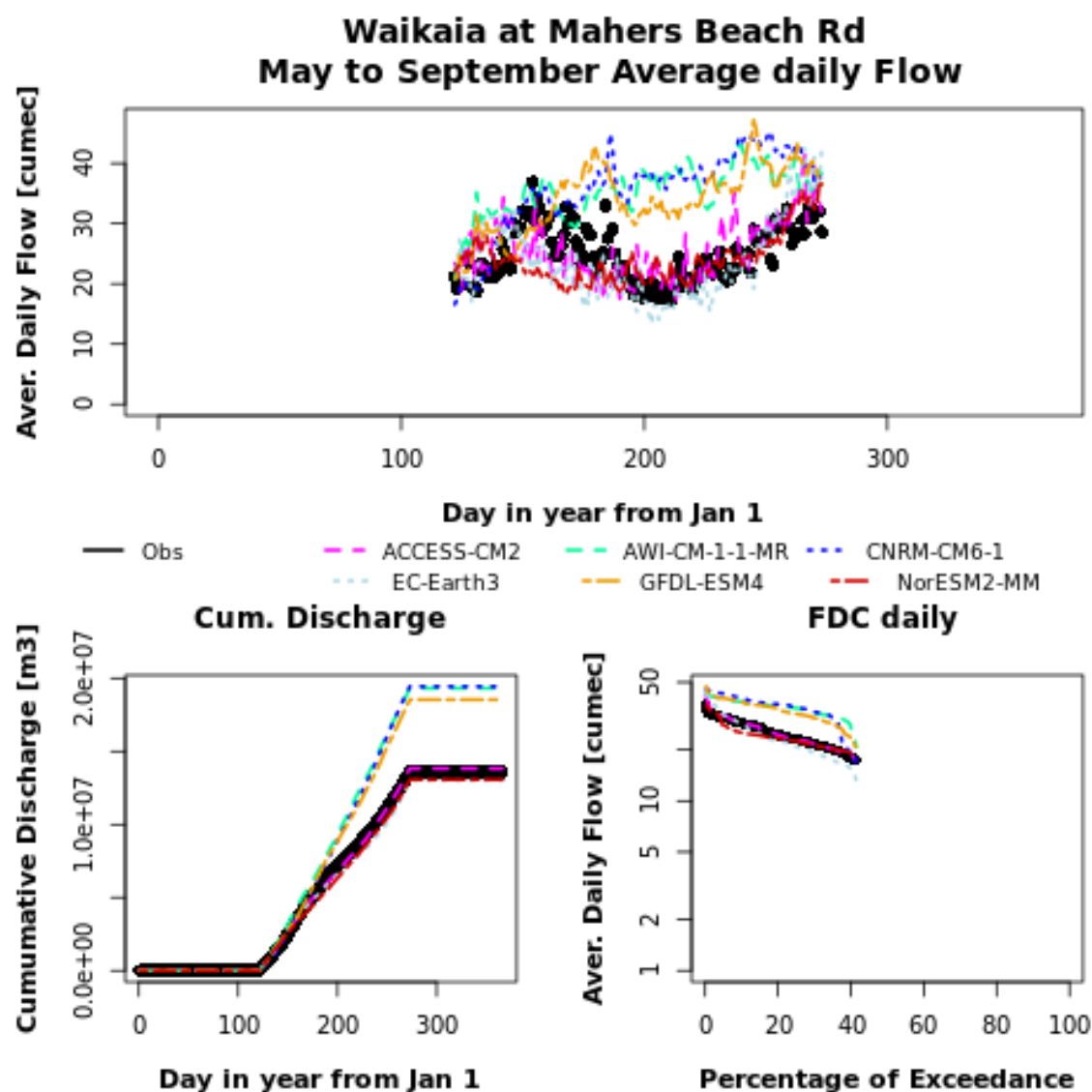


Figure A-17: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Waikaia at Mahers Beach Road. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

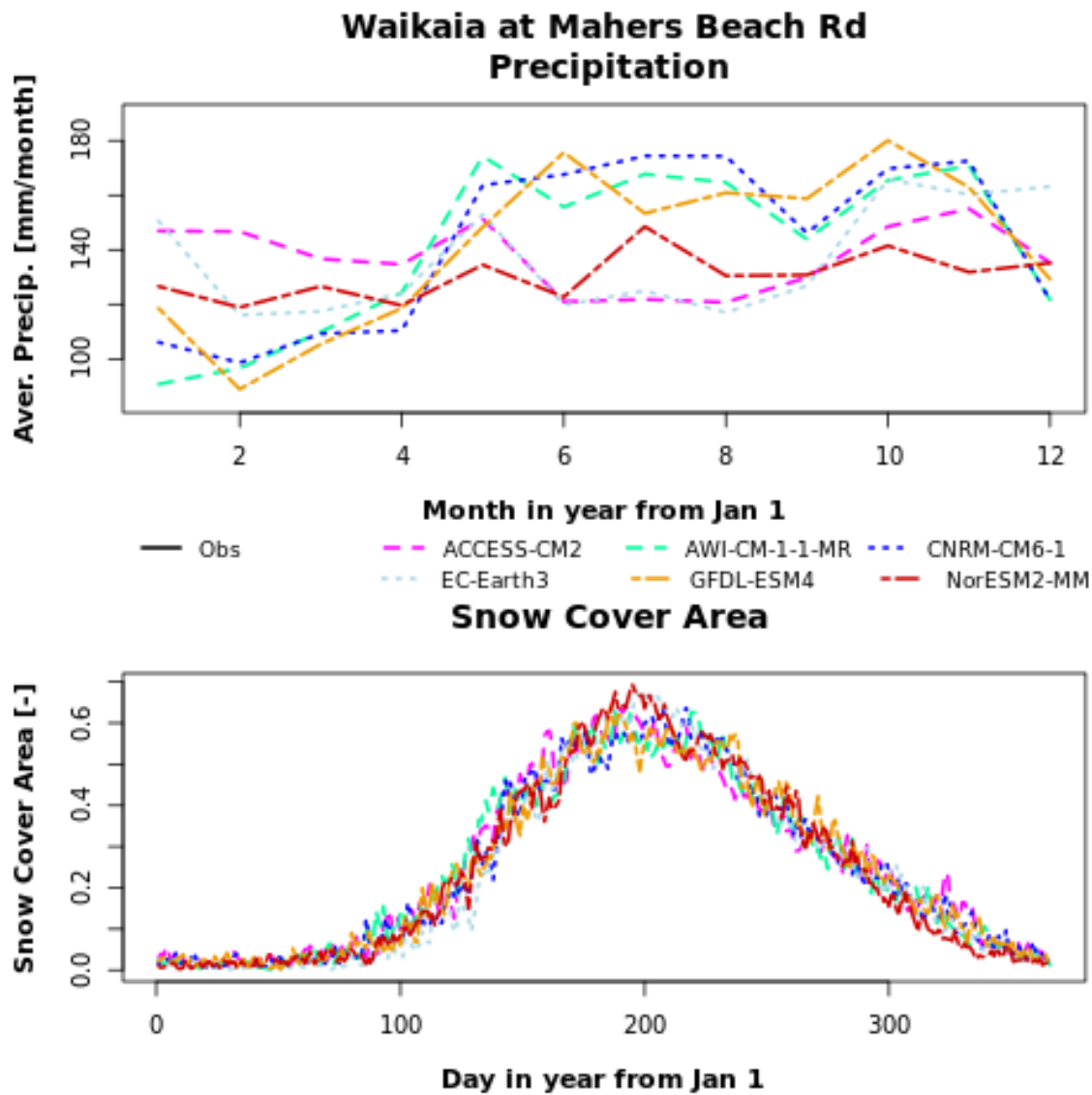


Figure A-18: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Waikaia at Mahers Beach Road. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

Rowallan Burn at Old Mill

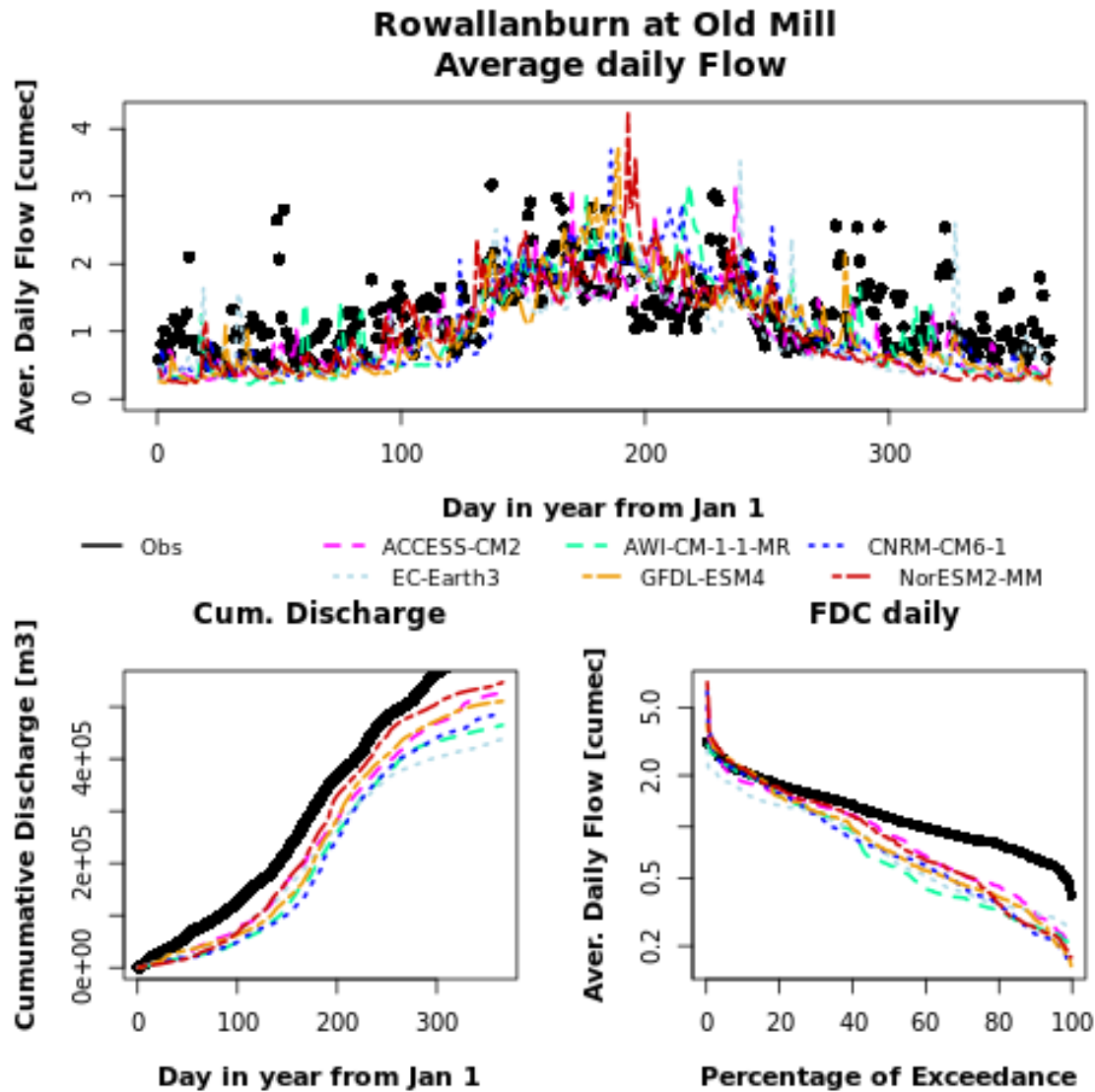


Figure A-19: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for Rowallan Burn at Old Mill. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

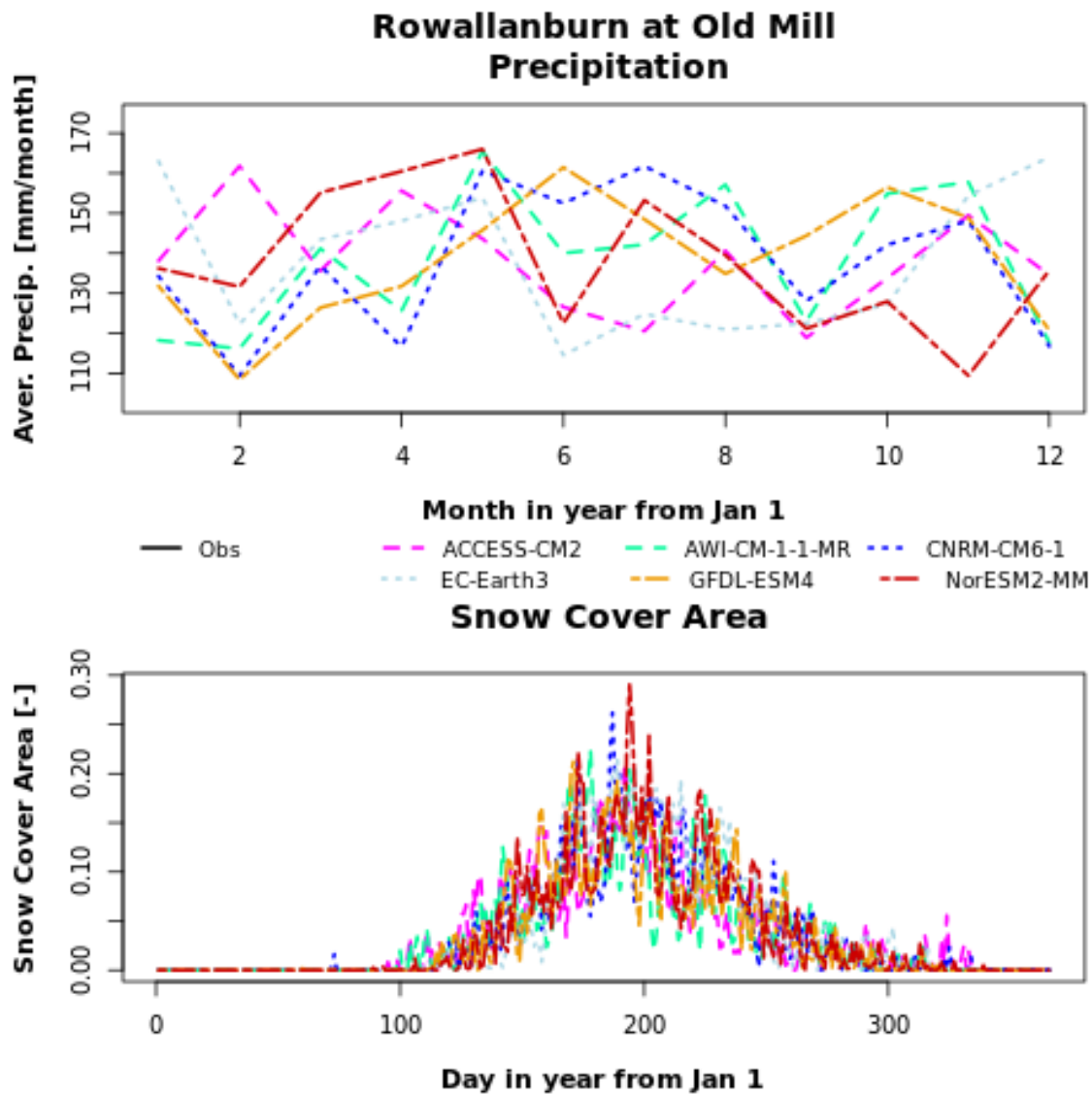


Figure A-20: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Rowallan Burn at Old Mill. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

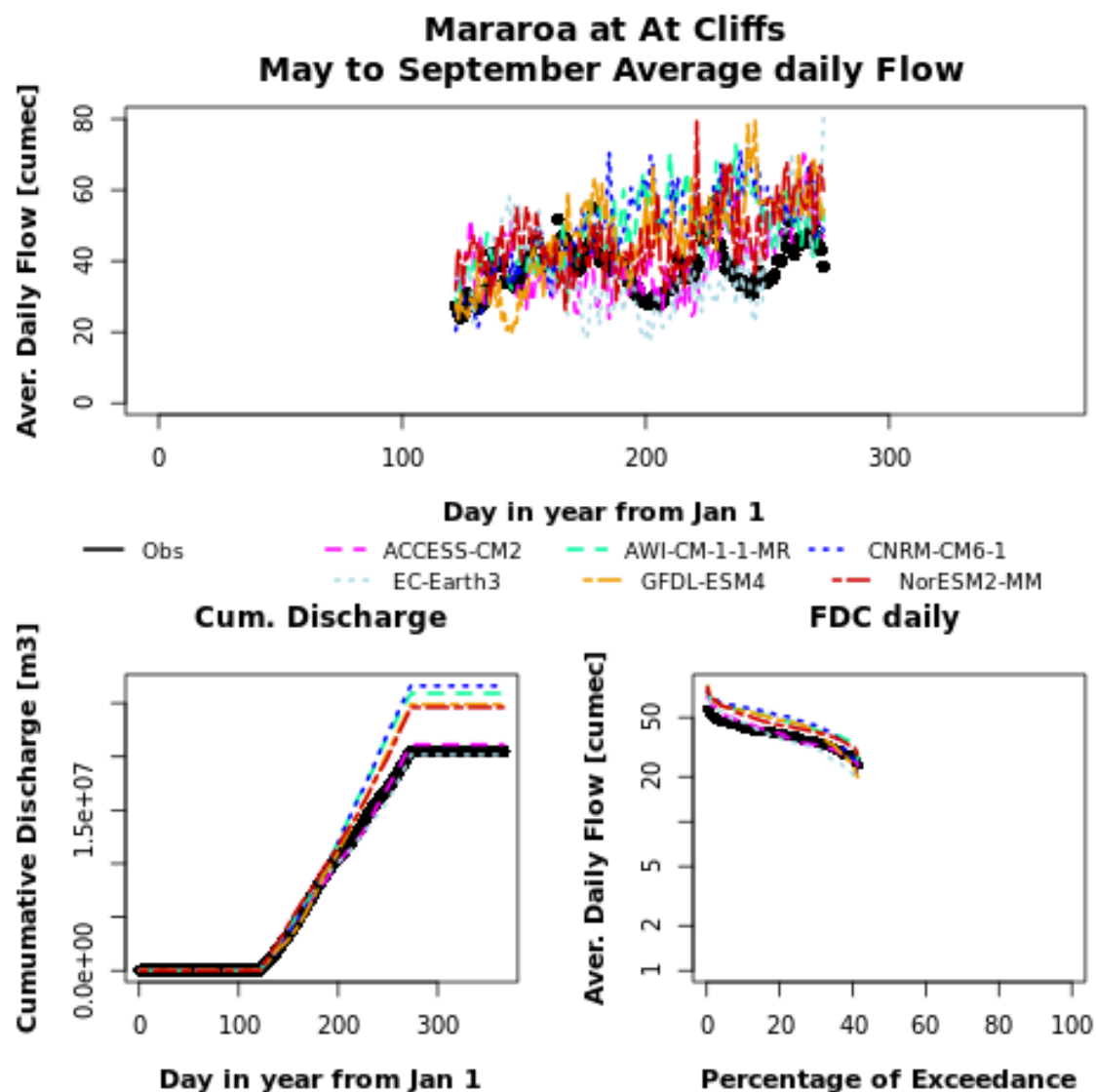


Figure A-21: Hindcast bias corrected daily average hydrograph, cumulative hydrograph and flow duration curve for the Mararoa at Cliffs. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

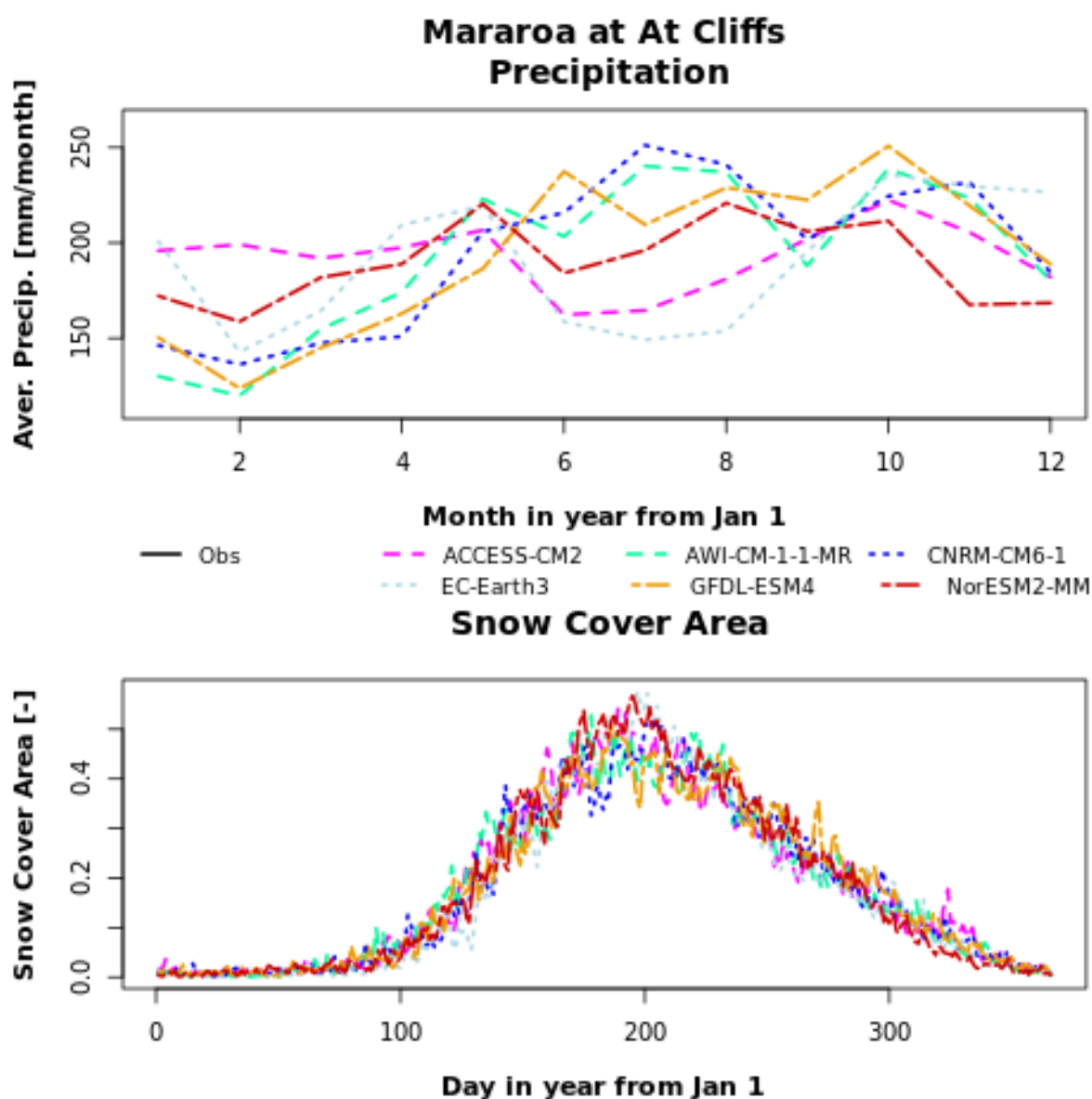


Figure A-22: Hindcast bias corrected monthly average precipitation and daily average snow cover area for the Maraora at Cliffs. Hindcast simulations presented for observed and the six CMIP6's GCMs over the period 1995–2014 hydrological years.

Appendix B Cryosphere

Change in snowfall volume

Changes are provided at seasonal time scale

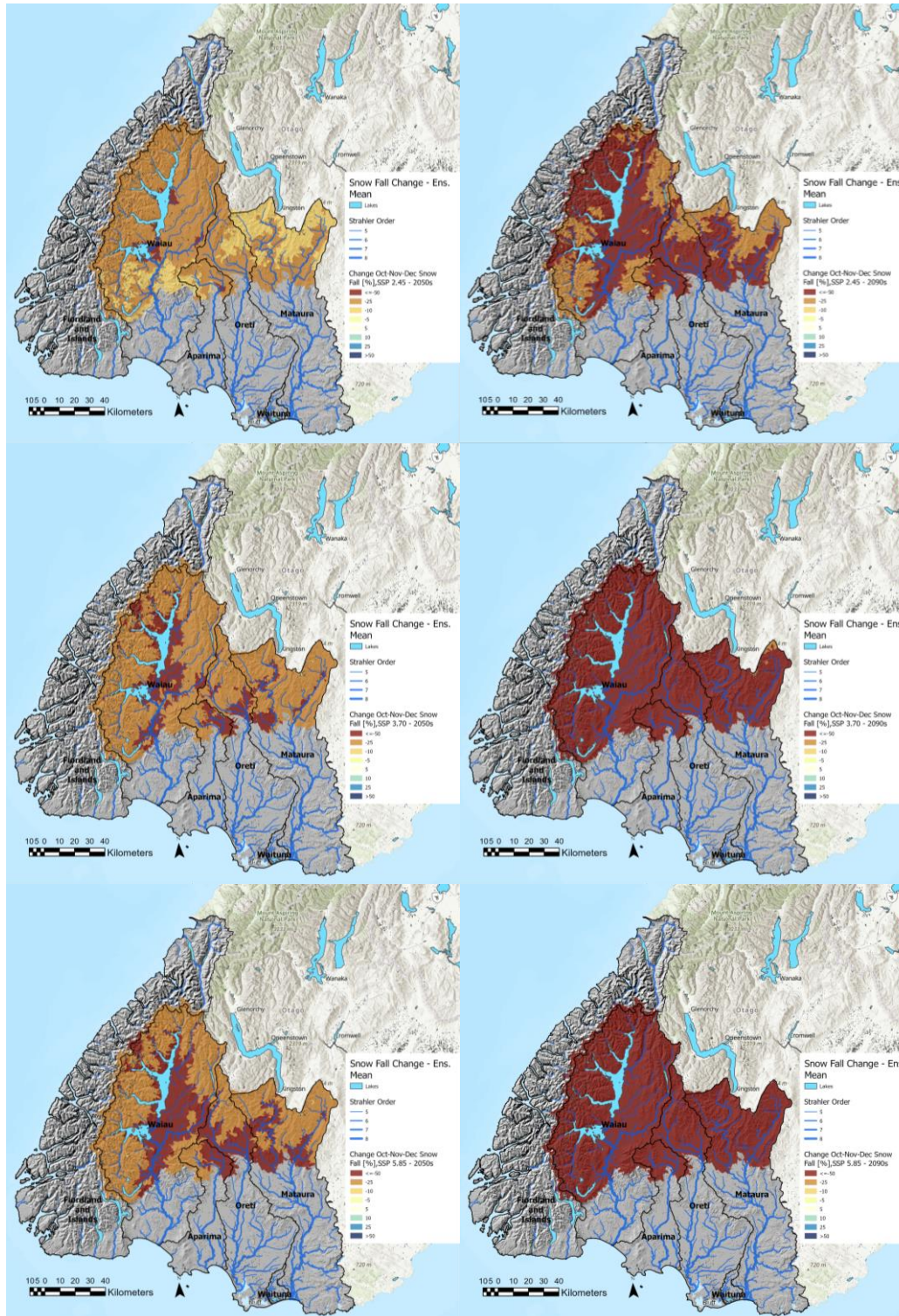


Figure B-1: Change in multi-model October-November-December (late spring) snowfall (based on snow year). Change in multi-model average seasonal snowfall is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

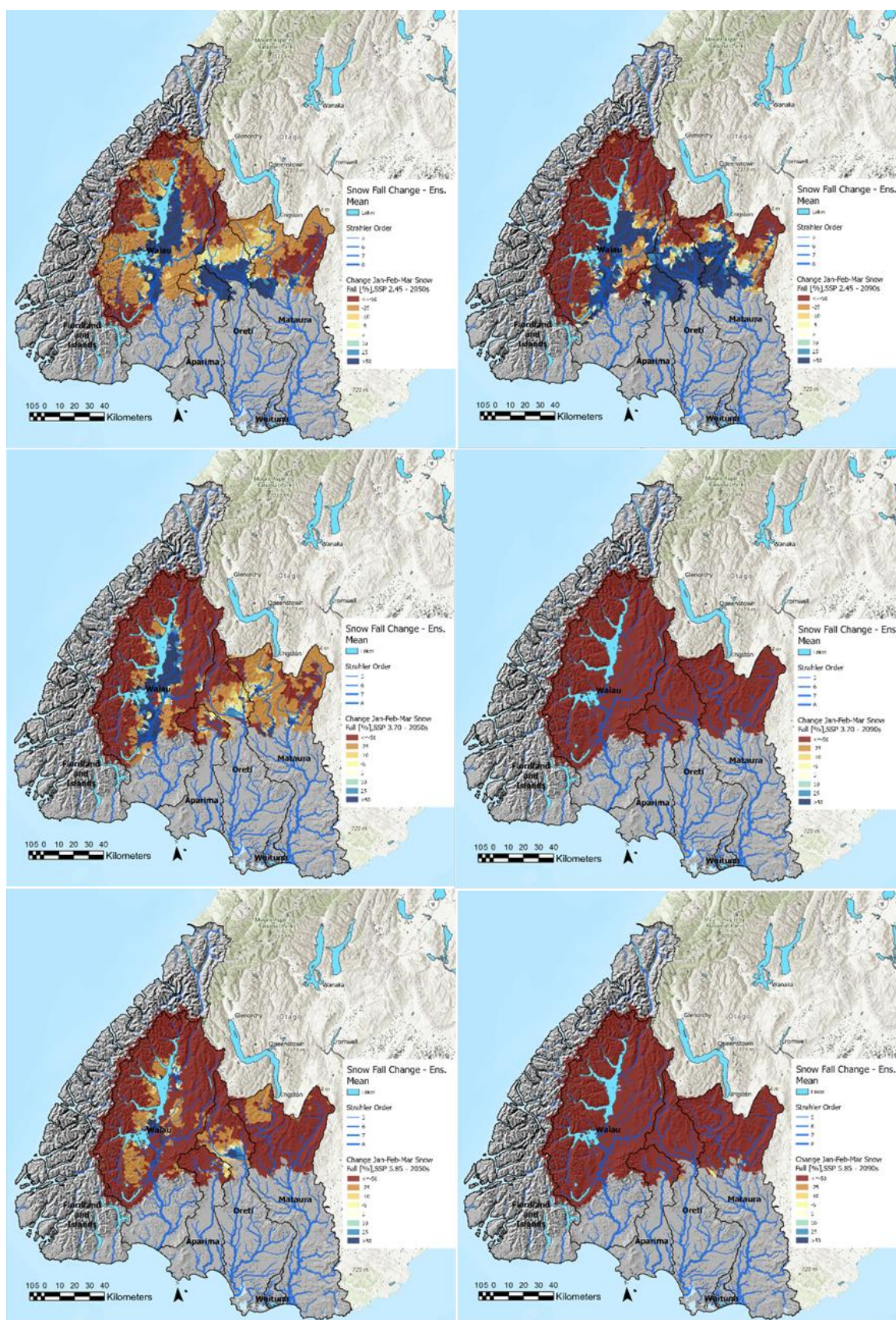


Figure B-2: Change in multi-model January-February-March (late summer) snowfall (based on snow year). Change in multi-model average seasonal snowfall is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

Seasonal Snow Volume

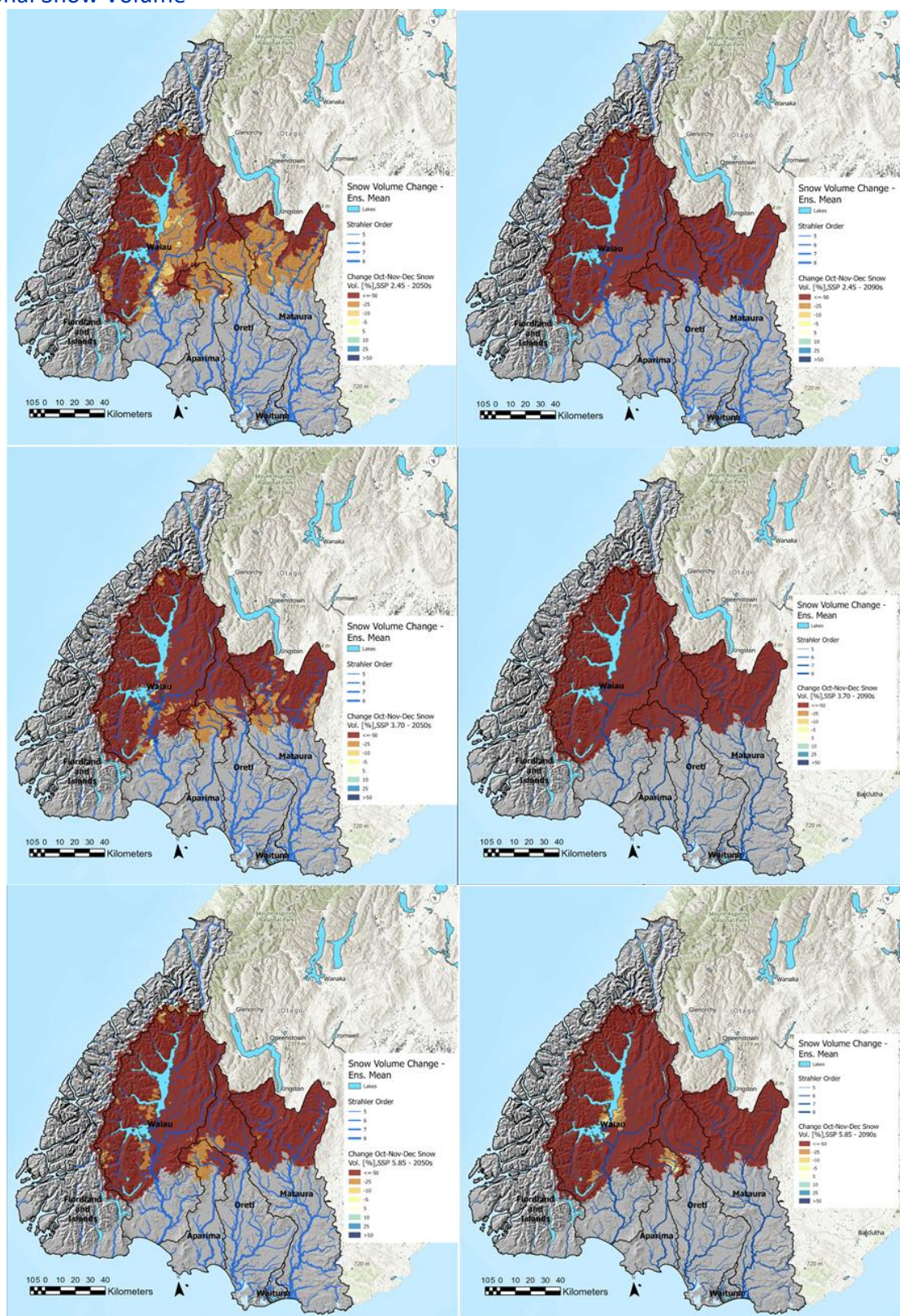


Figure B-3: Change in multi-model average October-November-December (late spring) snow volume (calculated based on snow year). Change in multi-model seasonal average annual snow volume is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

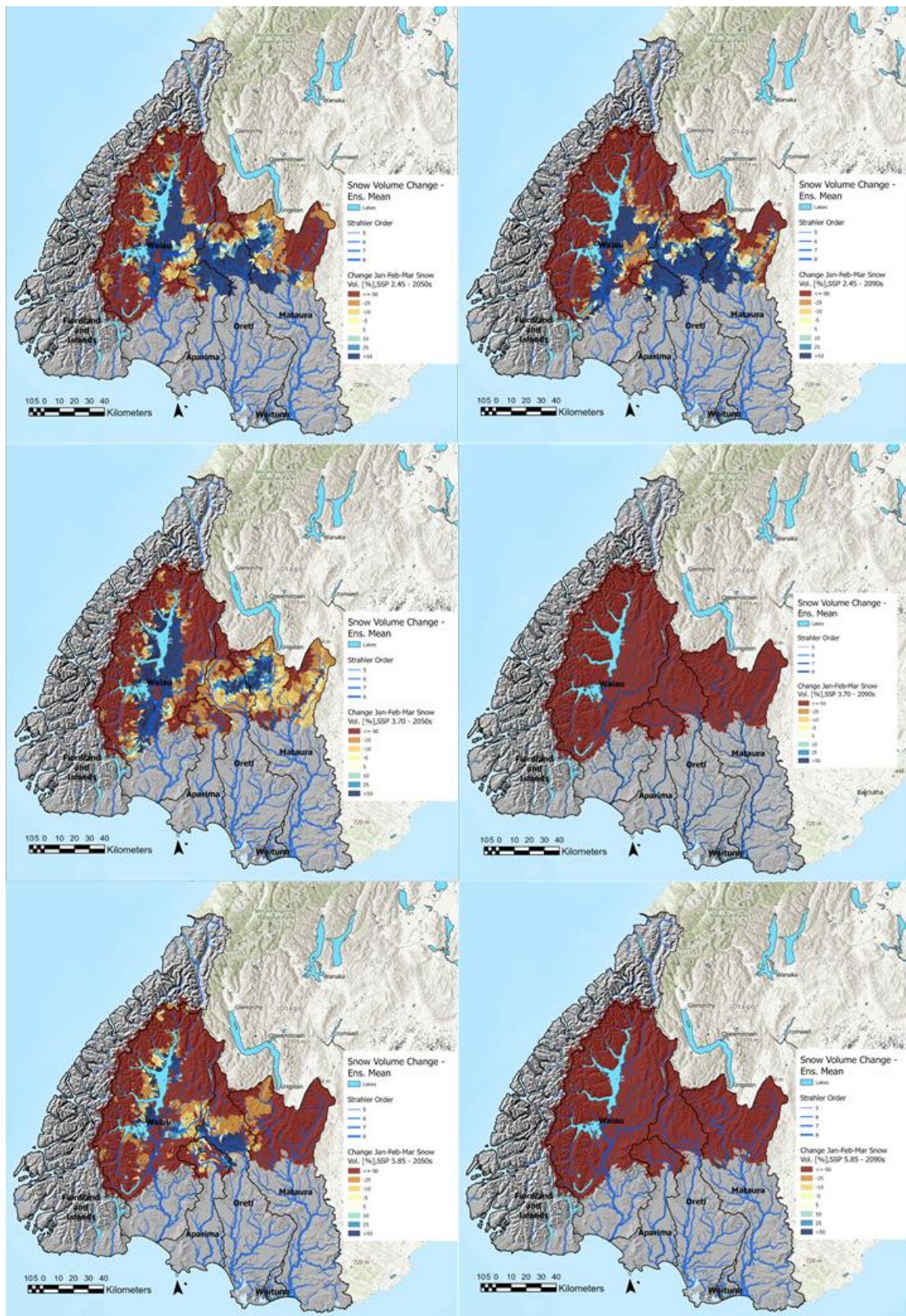


Figure B-4: Change in multi-model average January-February-March (late summer) snow volume (based on snow year). Change in multi-model average seasonal snow volume is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

Number of Snow days

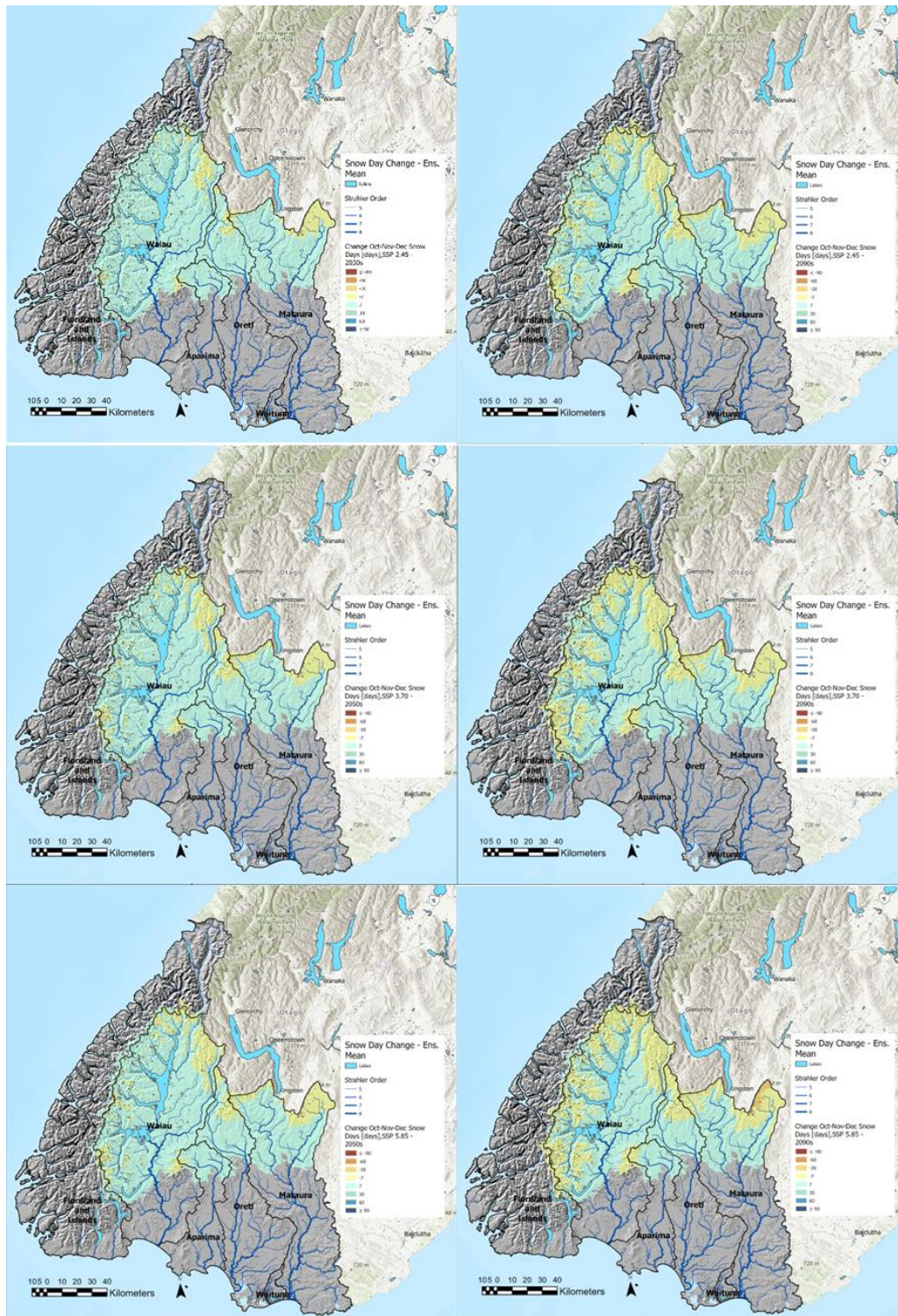


Figure B-5: Change in multi-model October-November-December snow days (based on snow year). Change in multi-model average seasonal snow days is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

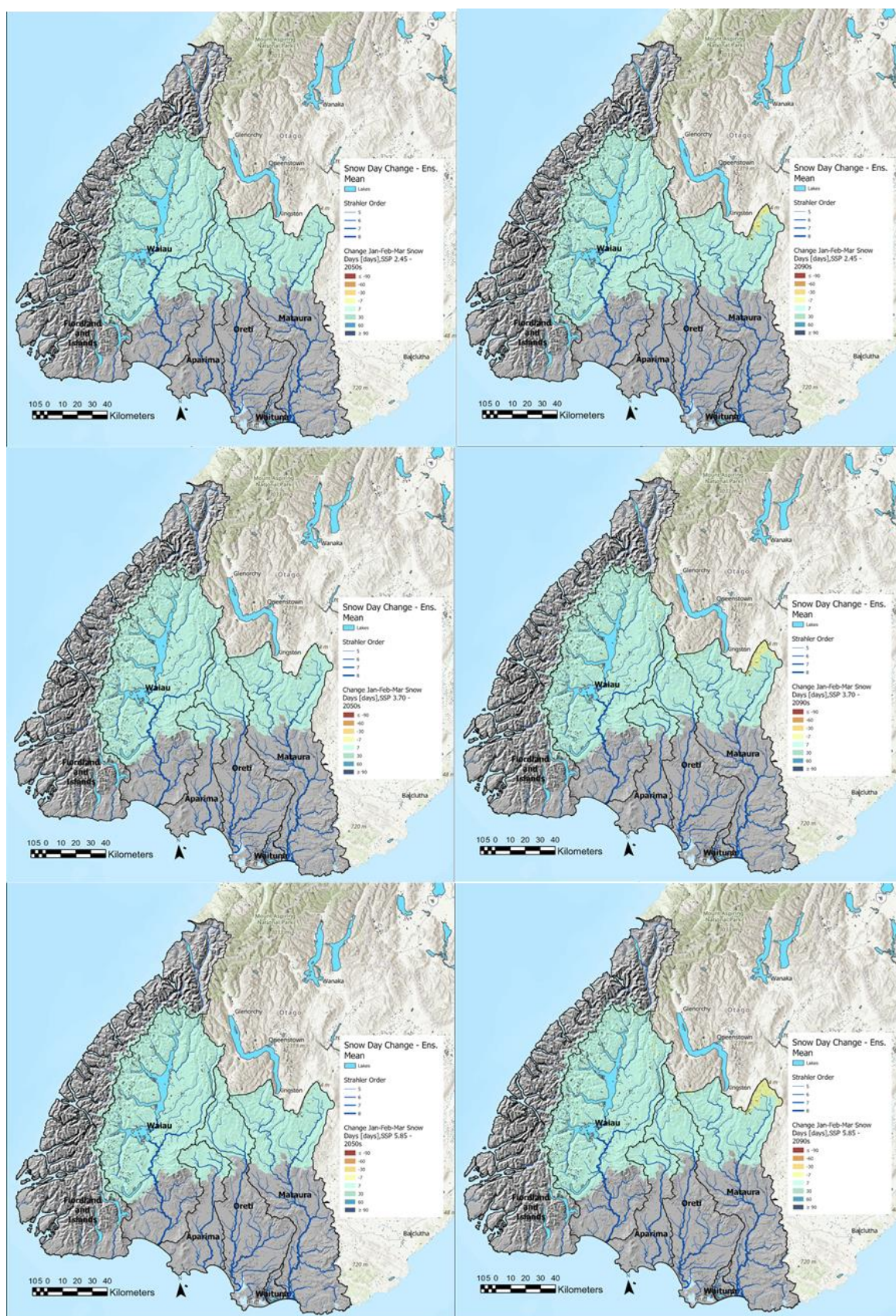


Figure B-6: Change in multi-model January-February-March (late summer) snow days (based on snow year). Change in multi-model average seasonal snow days is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

Snow melt

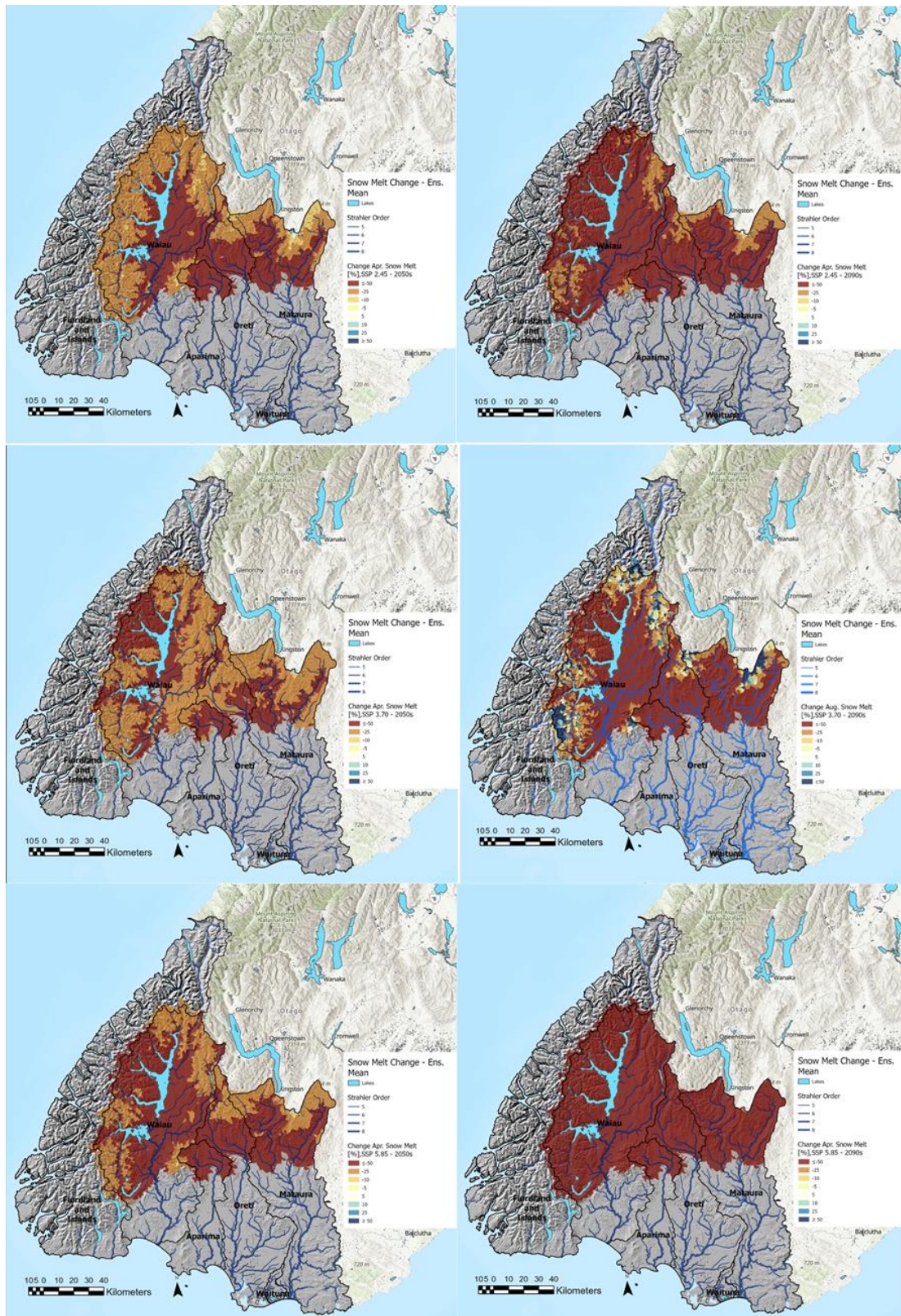


Figure B-7: Change in multi-model average April snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

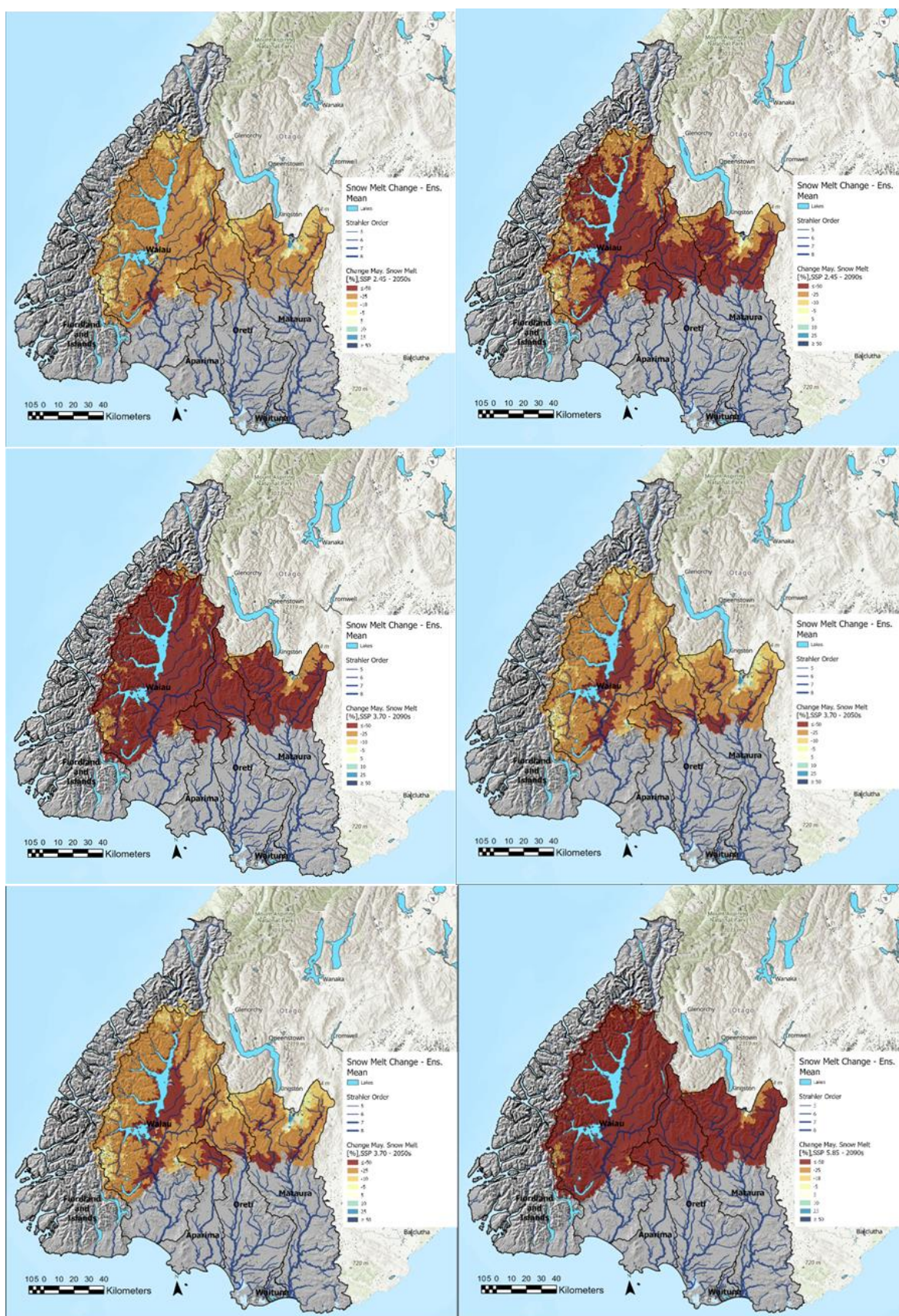


Figure B-8: Change in multi-model average May snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

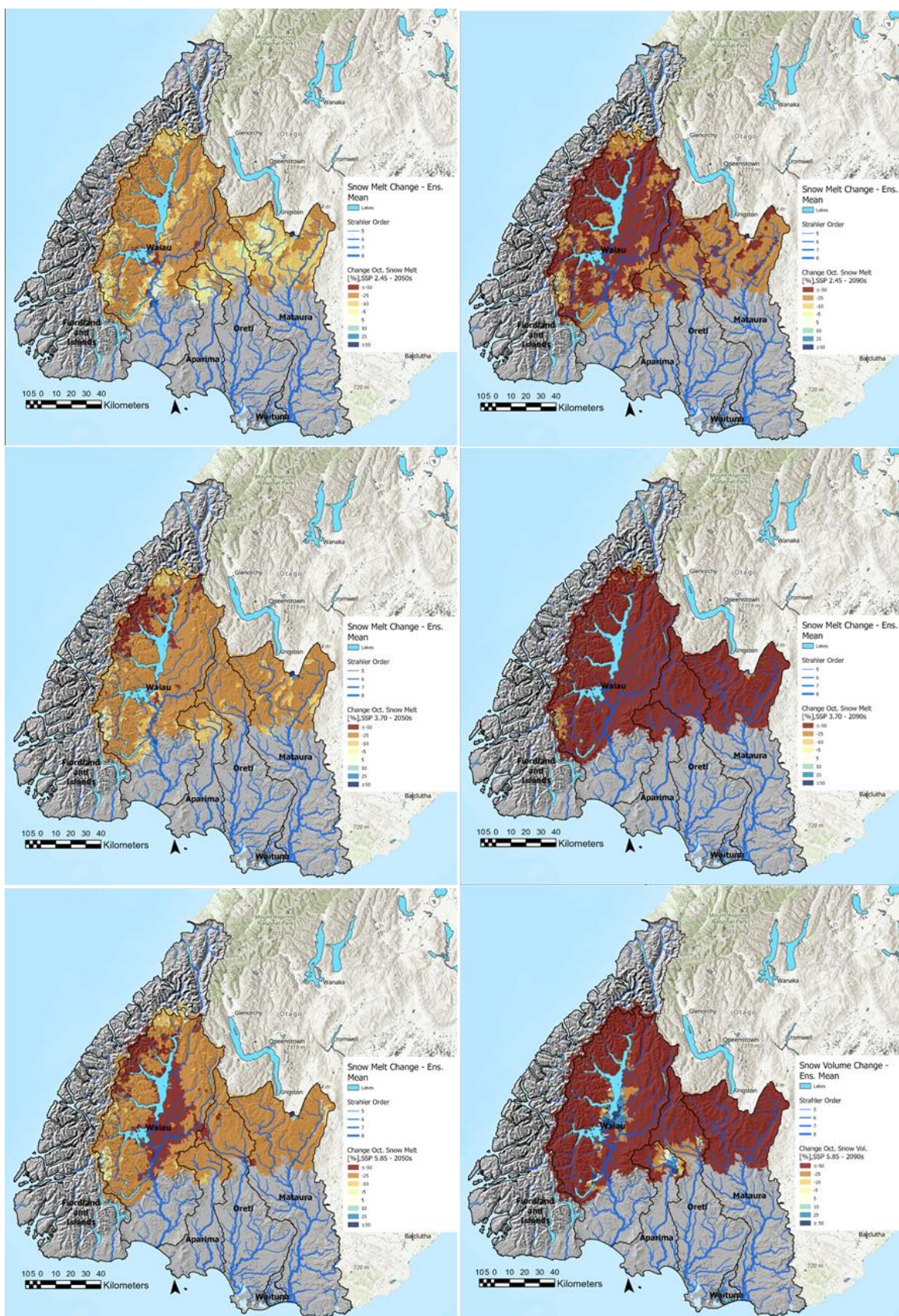


Figure B-9: Change in multi-model average October snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

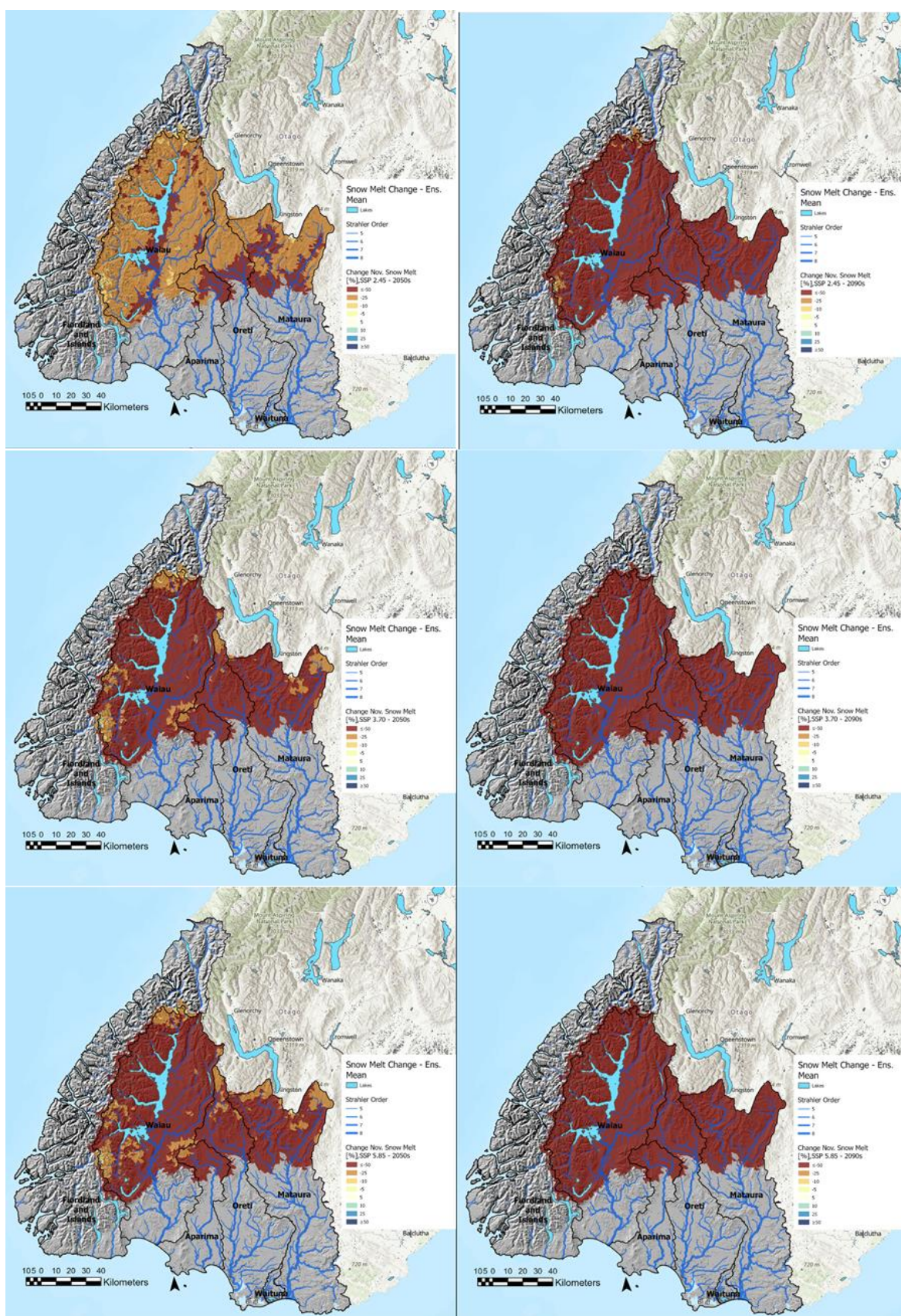


Figure B-10: Change in multi-model average November snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

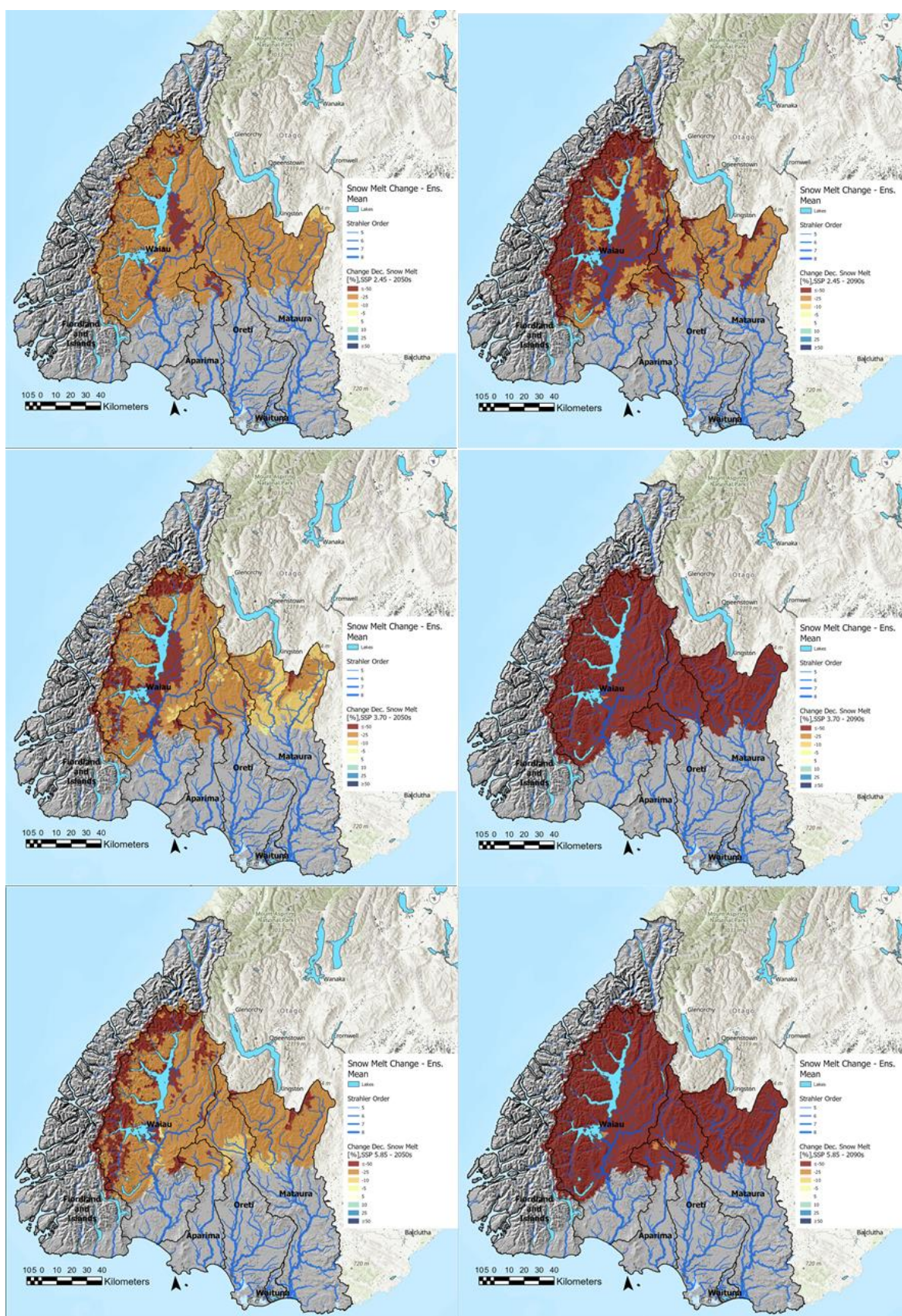


Figure B-11: Change in multi-model average December snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

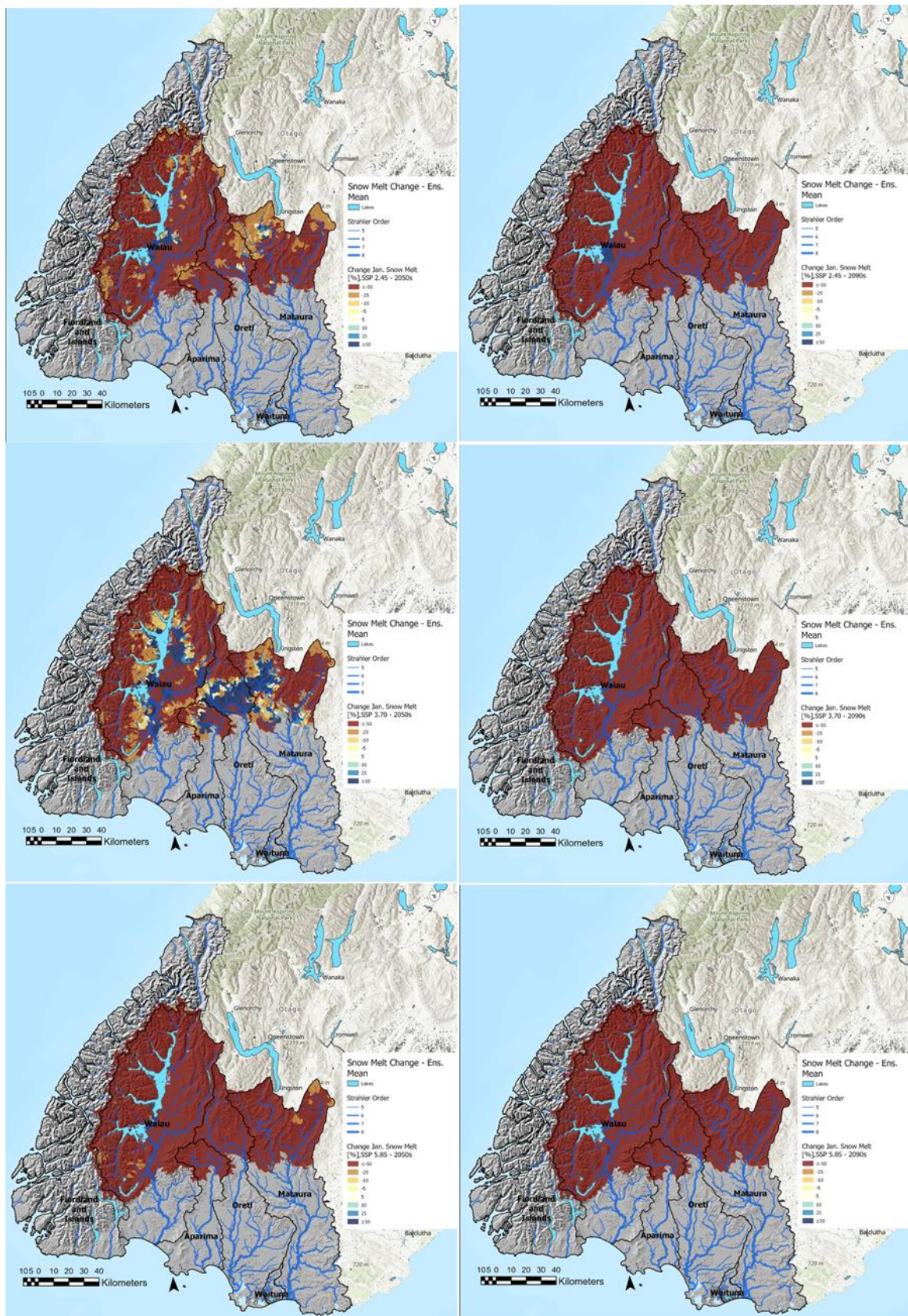


Figure B-12: Change in multi-model average January snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

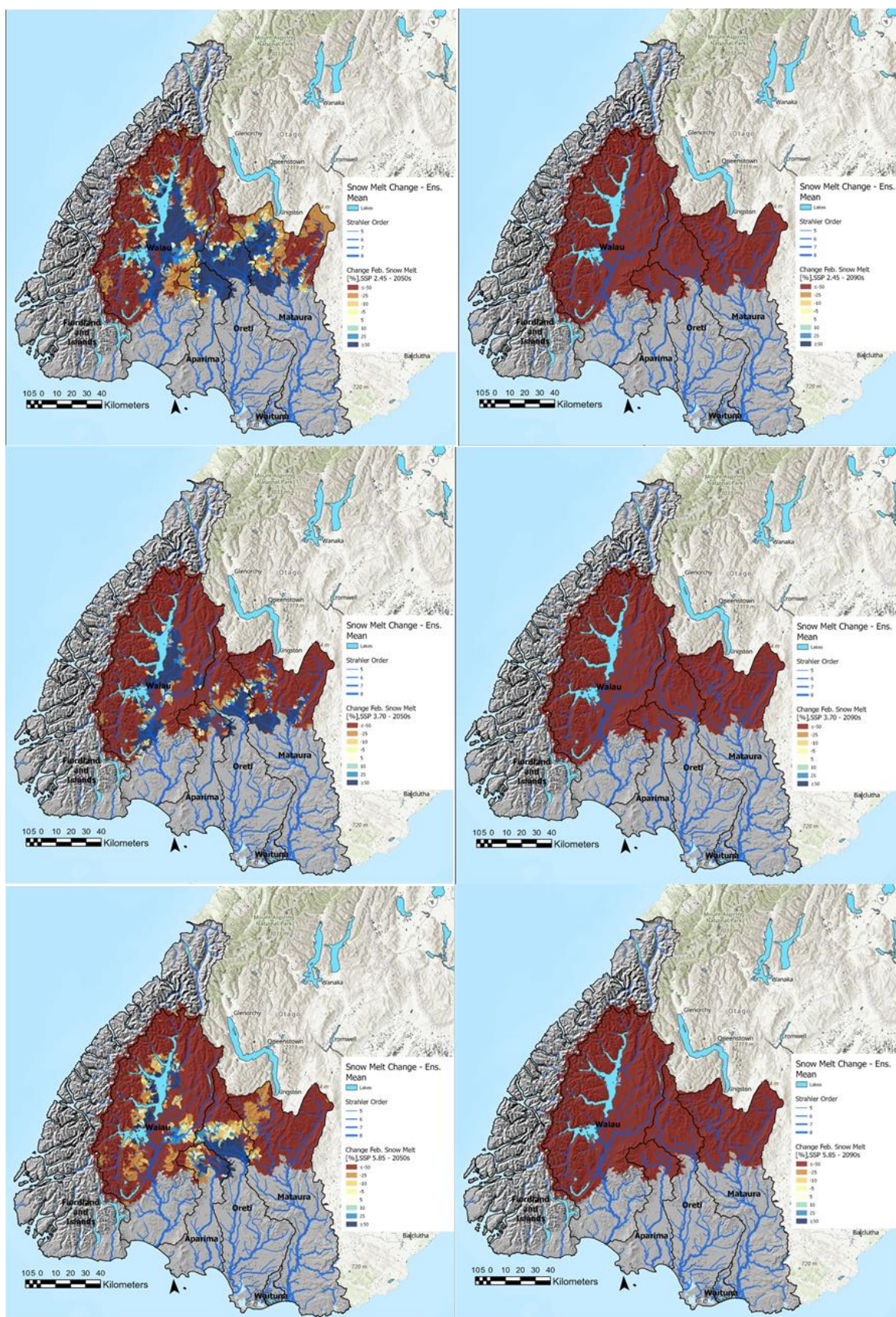


Figure B-13: Change in multi-model average February snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

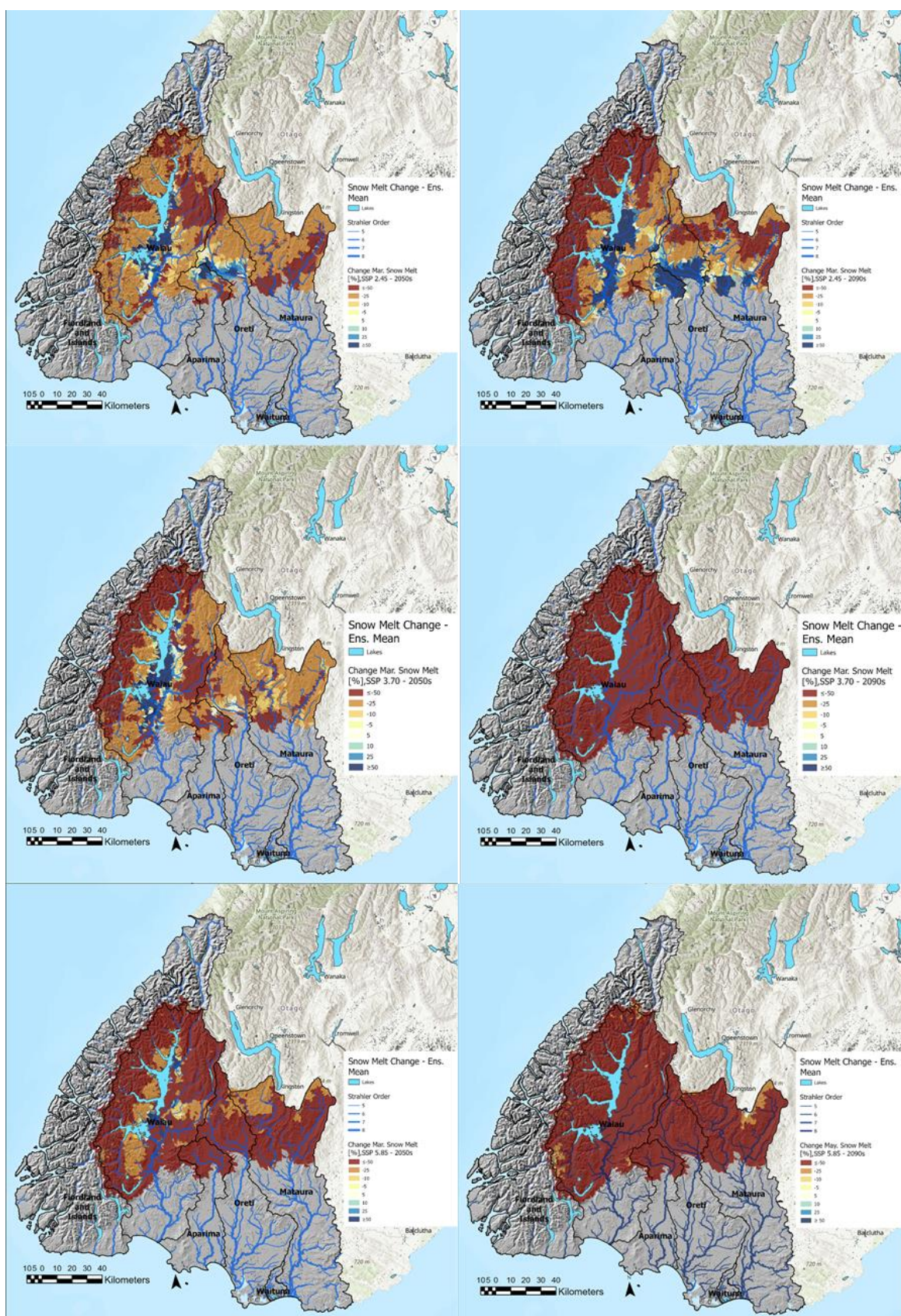


Figure B-14: Change in multi-model average March snow melt. Change in multi-model monthly snow melt is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

Appendix C High flow metrics

Hourly Mean Annual Flood

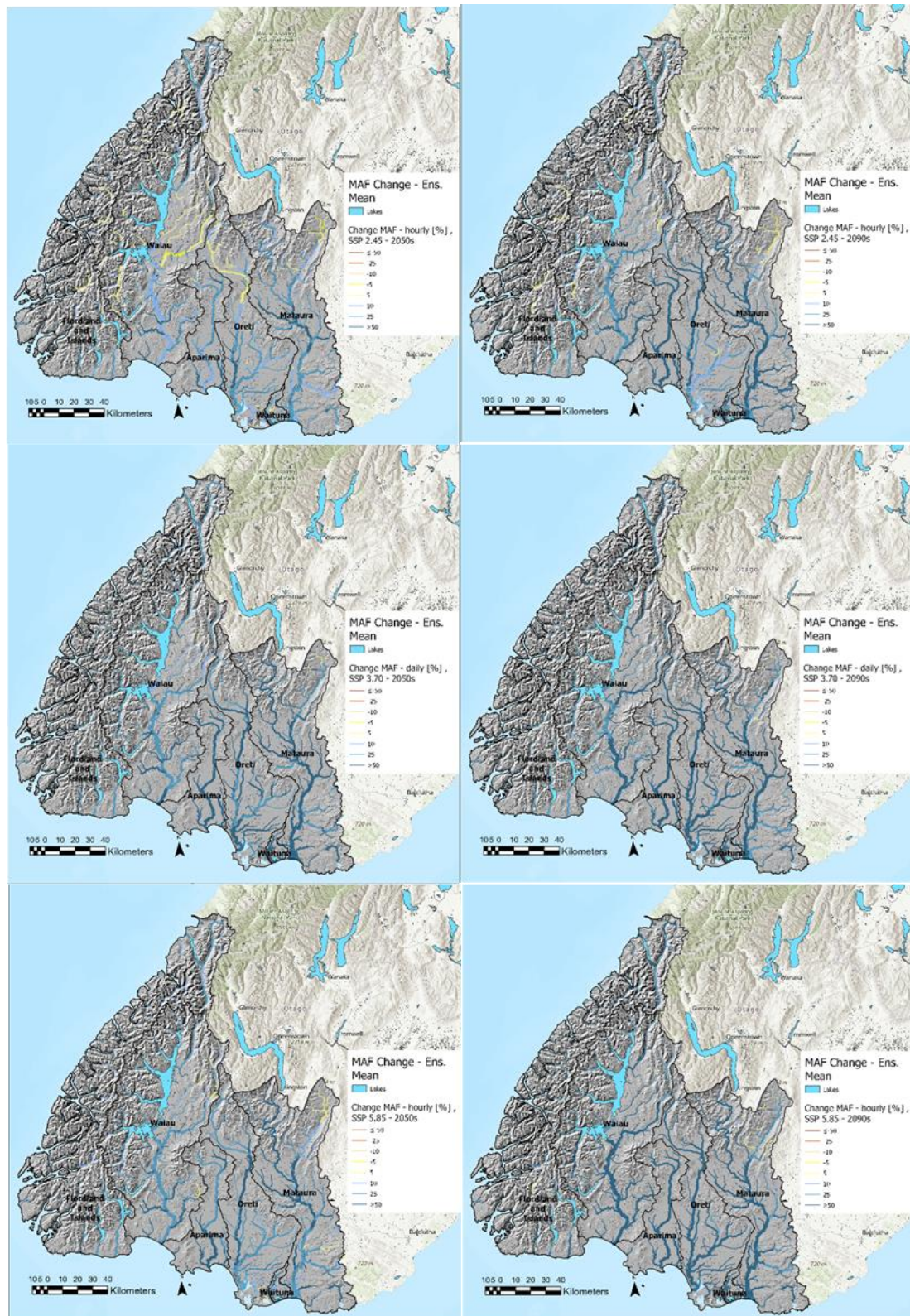


Figure C-1: Change multi-model average hourly mean annual flood. Change in multi-model average hourly mean annual flood for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panel).

Fre3 events

Fre3 events calculated using 3-days gap

Table C-1: Projected changes in spring average number of Fre3 events with 3-day gaps (average no. of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.1	0.2	0.1	0.2	0.1	0.3
Aparima	0.1	0.3	0.2	0.4	0.2	0.4
Fiordland and Islands	0.2	0.3	0.2	0.4	0.2	0.4
Mataura	0.1	0.1	0.1	0.1	0.1	0.2
Oreti	0.1	0.2	0.0	0.1	0.1	0.2
Waiau	0.0	0.1	0.1	0.1	0.0	0.0
Waituna	0.1	0.0	0.1	0.1	0.2	0.3

Table C-2: Projected changes in autumn average number of Fre3 events with 3-day gaps (average no. of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.1	0.1	0.0	0.1	0.0	0.1
Aparima	0.1	0.2	0.0	0.2	0.0	0.3
Fiordland and Islands	0.0	0.1	-0.1	0.0	0.0	0.0
Mataura	0.2	0.1	0.1	0.3	0.1	0.2
Oreti	0.1	0.2	0.1	0.2	0.1	0.4
Waiau	0.1	0.1	-0.1	0.1	0.0	0.1
Waituna	0.1	0.1	0.1	0.3	0.1	0.3

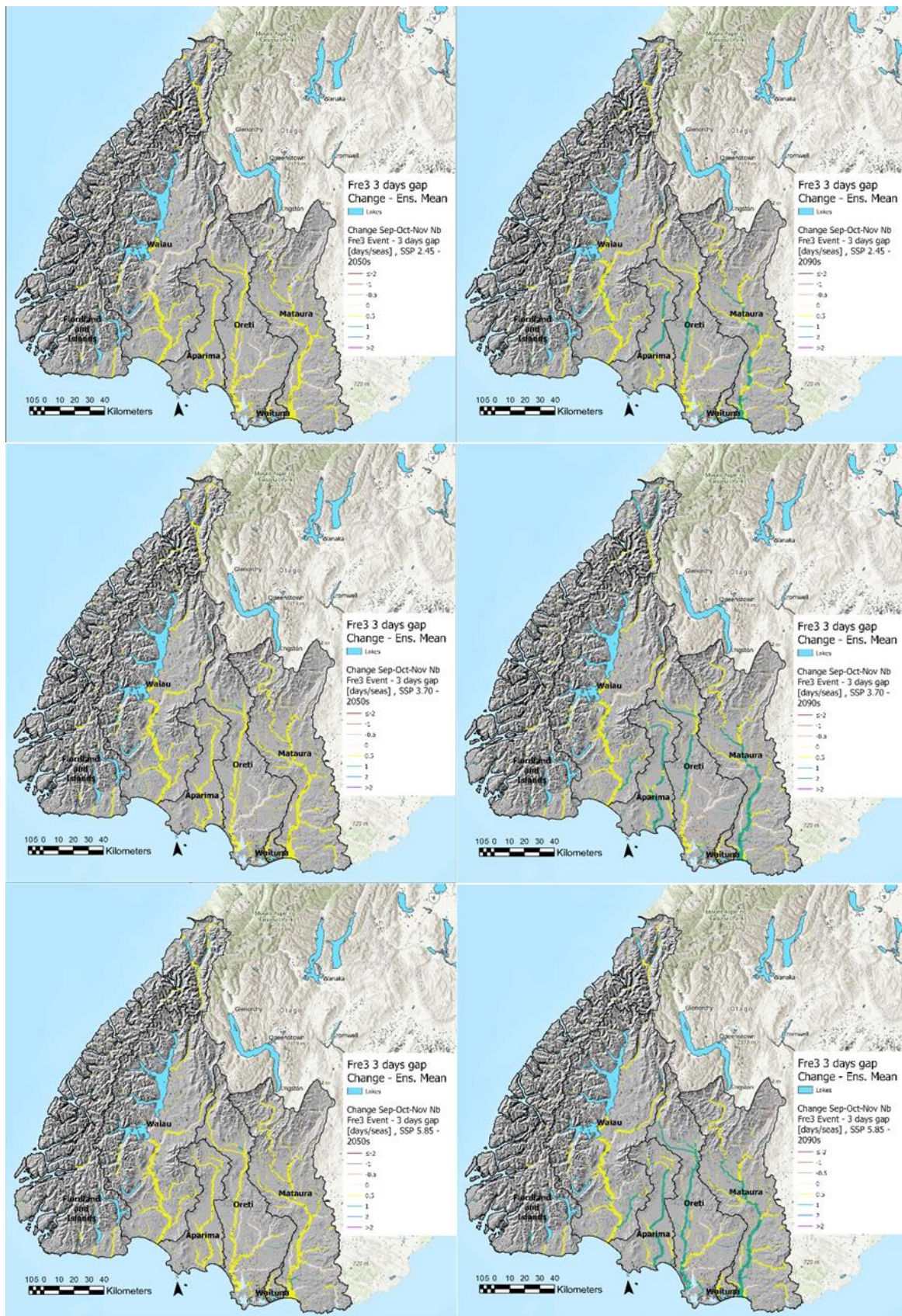


Figure C-2: Change in multi-model average number of Fre3 events with 3 days gap during September-October-November (spring, based on hydrological year). Change in multi-model average seasonal number of Fre3 events is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

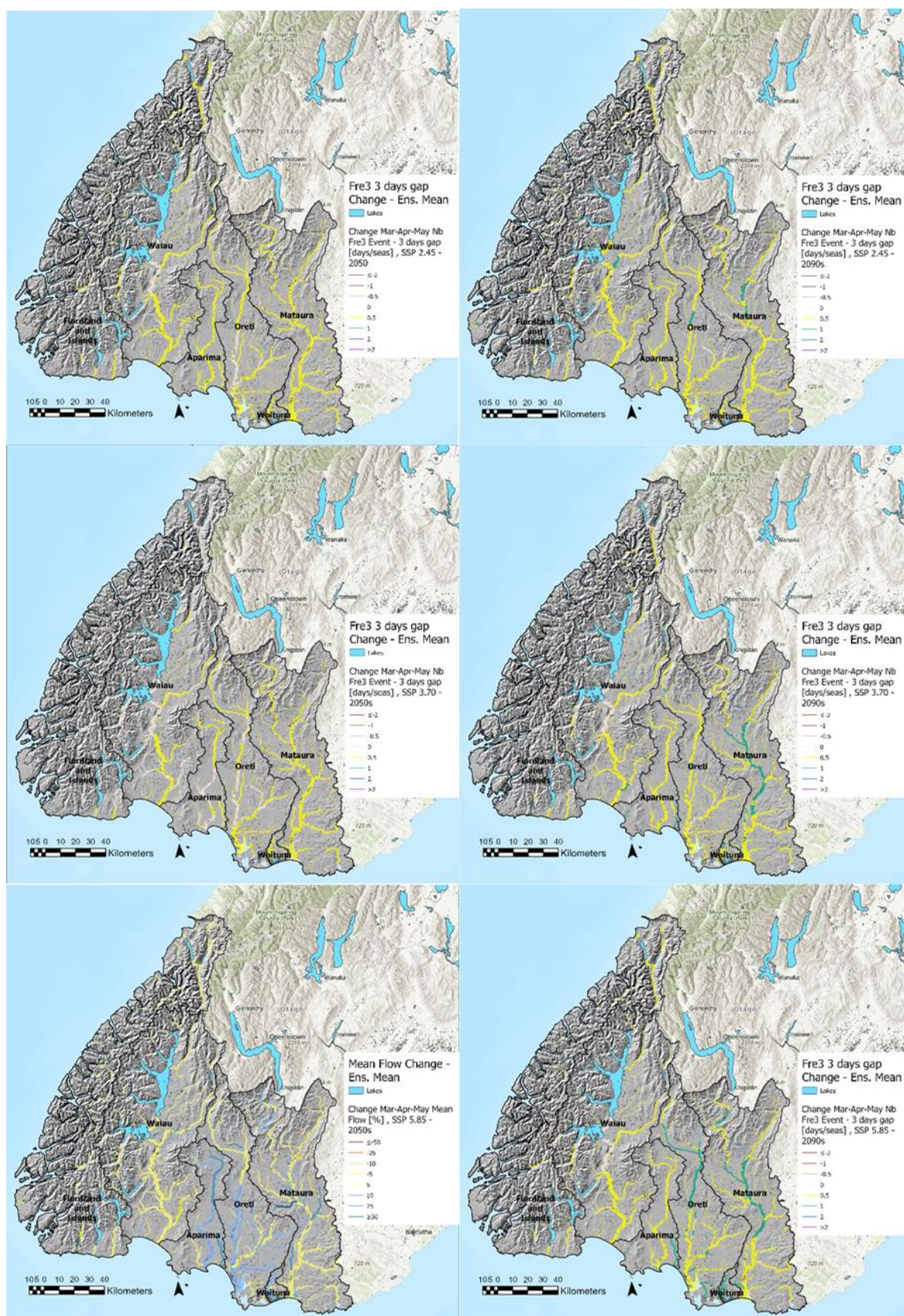


Figure C-3: Change in multi-model average number of Fre3 events with 3 days gap during March-April-May (autumn, based on hydrological year). Change in multi-model average seasonal number of Fre3 events is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Fre3 events calculated using 5-days gap

Table C-3: Projected changes in annual average number of Fre3 events with 5-day gaps (average no. of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.2	0.5	0.2	0.5	0.3	0.6
Aparima	0.4	0.7	0.4	0.9	0.3	1.2
Fiordland and Islands	0.1	0.6	0.1	0.5	0.4	0.6
Mataura	0.2	0.4	0.2	0.5	0.2	0.7
Oreti	0.2	0.4	0.1	0.4	0.2	0.5
Waiau	0.2	0.5	0.2	0.3	0.3	0.5
Waituna	0.1	0.0	0.0	0.4	0.2	0.6

Table C-4: Projected changes in winter average number of Fre3 events with 5-day gaps (average no. of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.1	0.3	0.2	0.2	0.2	0.2
Aparima	0.2	0.2	0.1	0.2	0.1	0.2
Fiordland and Islands	0.1	0.4	0.3	0.3	0.2	0.4
Mataura	0.1	0.2	0.1	0.1	0.1	0.1
Oreti	0.0	0.1	-0.1	0.0	0.0	-0.2
Waiau	0.2	0.3	0.3	0.3	0.2	0.3
Waituna	0.1	0.1	0.0	0.0	0.1	0.0

Table C-5: Projected changes in spring average number of Fre3 events with 5-day gaps (average no. of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.3	0.3	0.3	0.3	0.2	0.3
Aparima	0.2	0.3	0.2	0.4	0.2	0.3
Fiordland and Islands	0.2	0.4	0.2	0.4	0.2	0.4
Mataura	0.3	0.3	0.3	0.3	0.3	0.3
Oreti	0.3	0.3	0.3	0.3	0.3	0.3
Waiau	0.2	0.2	0.2	0.1	0.2	0.1
Waituna	0.4	0.3	0.4	0.4	0.4	0.4

Table C-6: Projected changes in summer average number of Fre3 events with 5-day gaps (average no. of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.1	0.2	0.1	0.2	0.2	0.3
Aparima	0.1	0.2	0.2	0.3	0.2	0.4
Fiordland and Islands	0.1	0.1	0.0	0.1	0.2	0.1
Mataura	0.2	0.3	0.3	0.4	0.3	0.5
Oreti	0.3	0.3	0.3	0.5	0.3	0.5
Waiau	0.1	0.1	0.1	0.1	0.1	0.2
Waituna	0.2	0.3	0.3	0.5	0.4	0.6

Table C-7: Projected changes in autumn average number of Fre3 events with 5-day gaps (average no. of events per year, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	0.3	0.3	0.2	0.3	0.3	0.3
Aparima	0.2	0.3	0.1	0.3	0.1	0.4
Fiordland and Islands	0.2	0.3	0.1	0.2	0.2	0.2
Mataura	0.4	0.4	0.4	0.5	0.3	0.5
Oreti	0.4	0.5	0.4	0.5	0.4	0.6
Waiau	0.2	0.2	0.1	0.2	0.2	0.2
Waituna	0.4	0.4	0.3	0.5	0.4	0.6

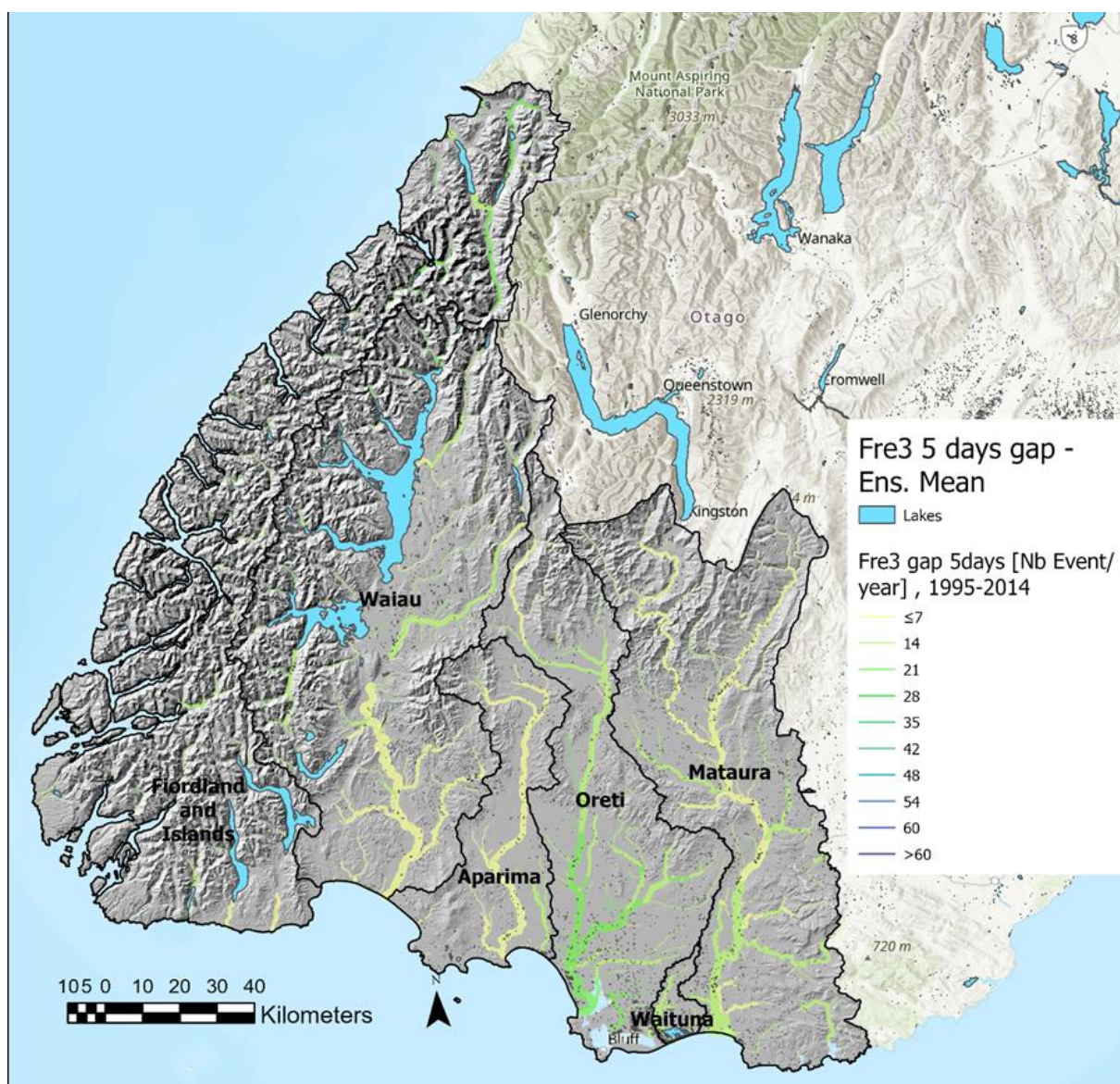


Figure C-4: Historical multi-model average number of Fre3 events per year with 5-days gap (based on hydrological year).

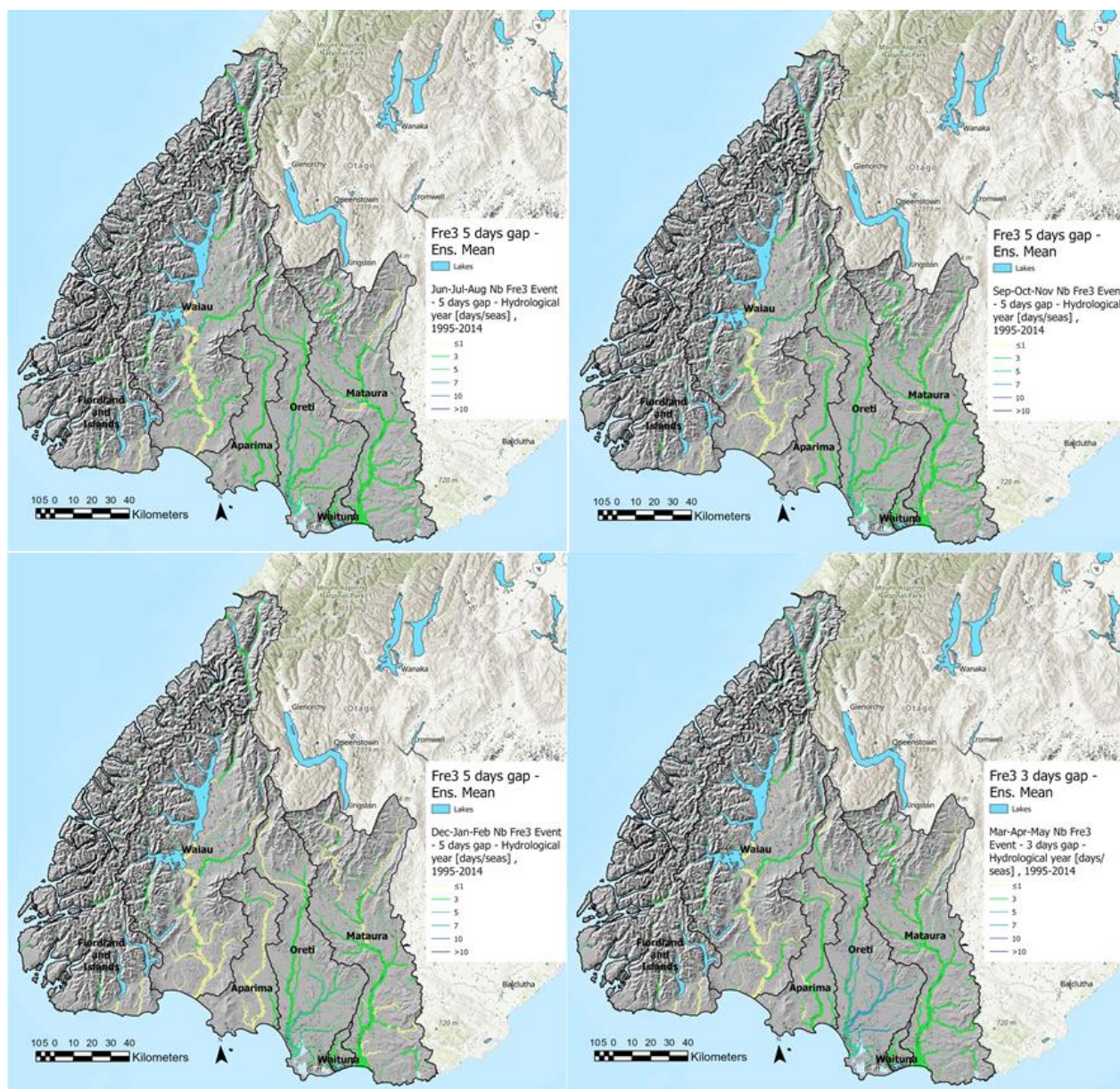


Figure C-5: Historical multi-model average seasonal number of Fre3 events with 5-days gap (based on hydrological year).

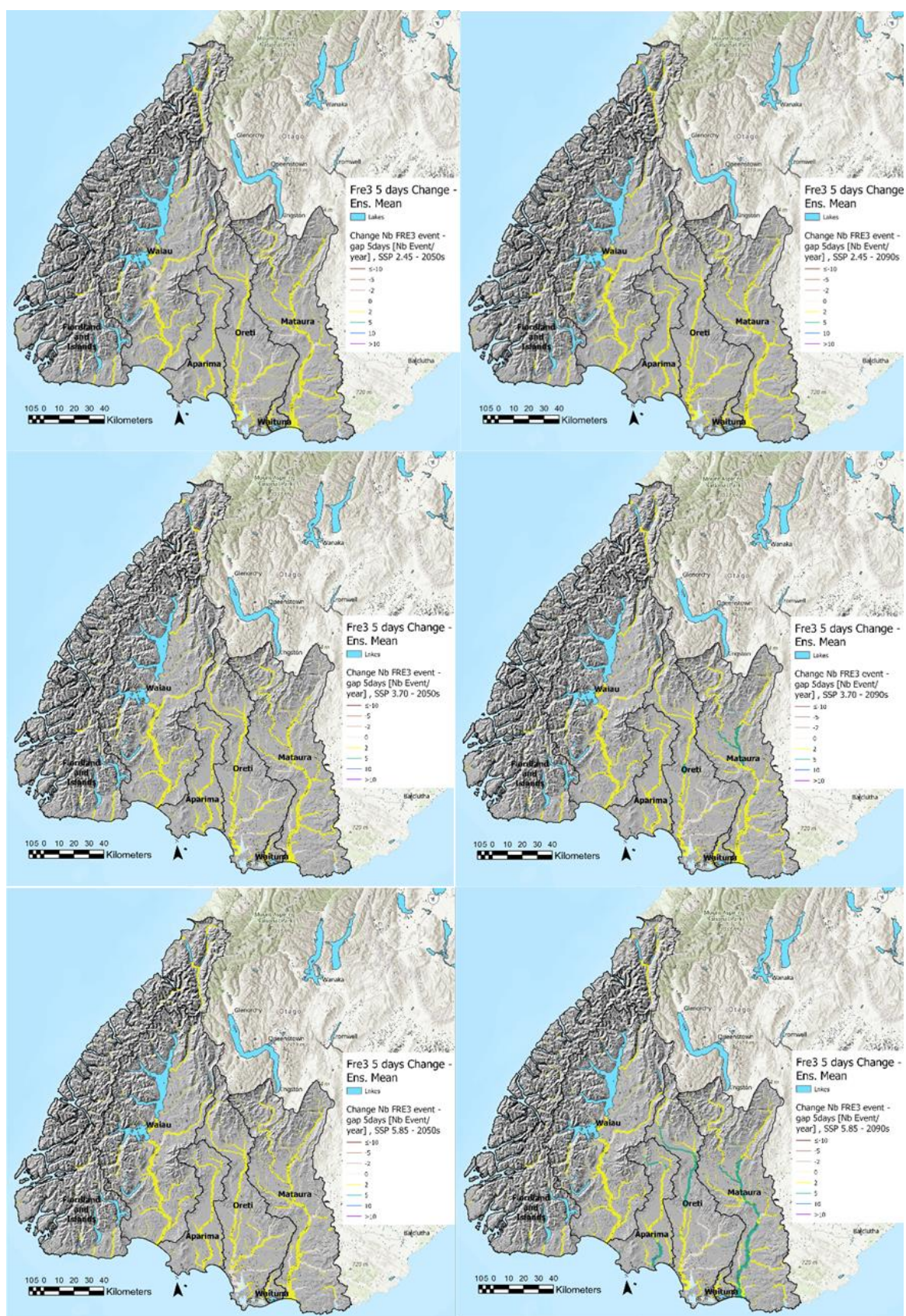


Figure C-6: Change in multi-model average number of Fre3 events per year with 5-days gap (based on hydrological year). Change in multi-model average annual number of Fre3 events is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

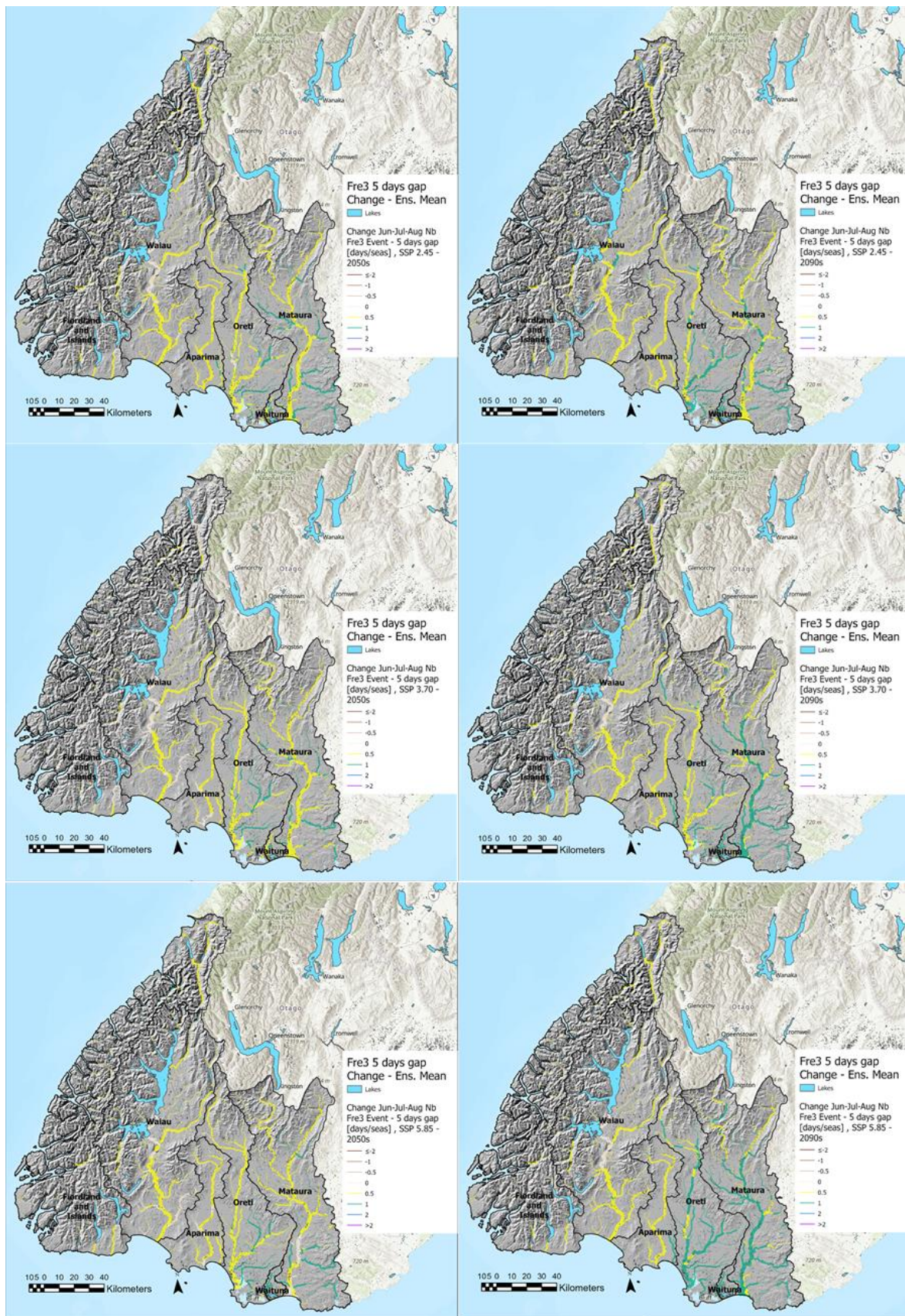


Figure C-7: Change in multi-model average number of Fre3 events during June-July-August (winter) with 5-days gap (based on hydrological year). Change in multi-model average seasonal number of Fre3 events is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

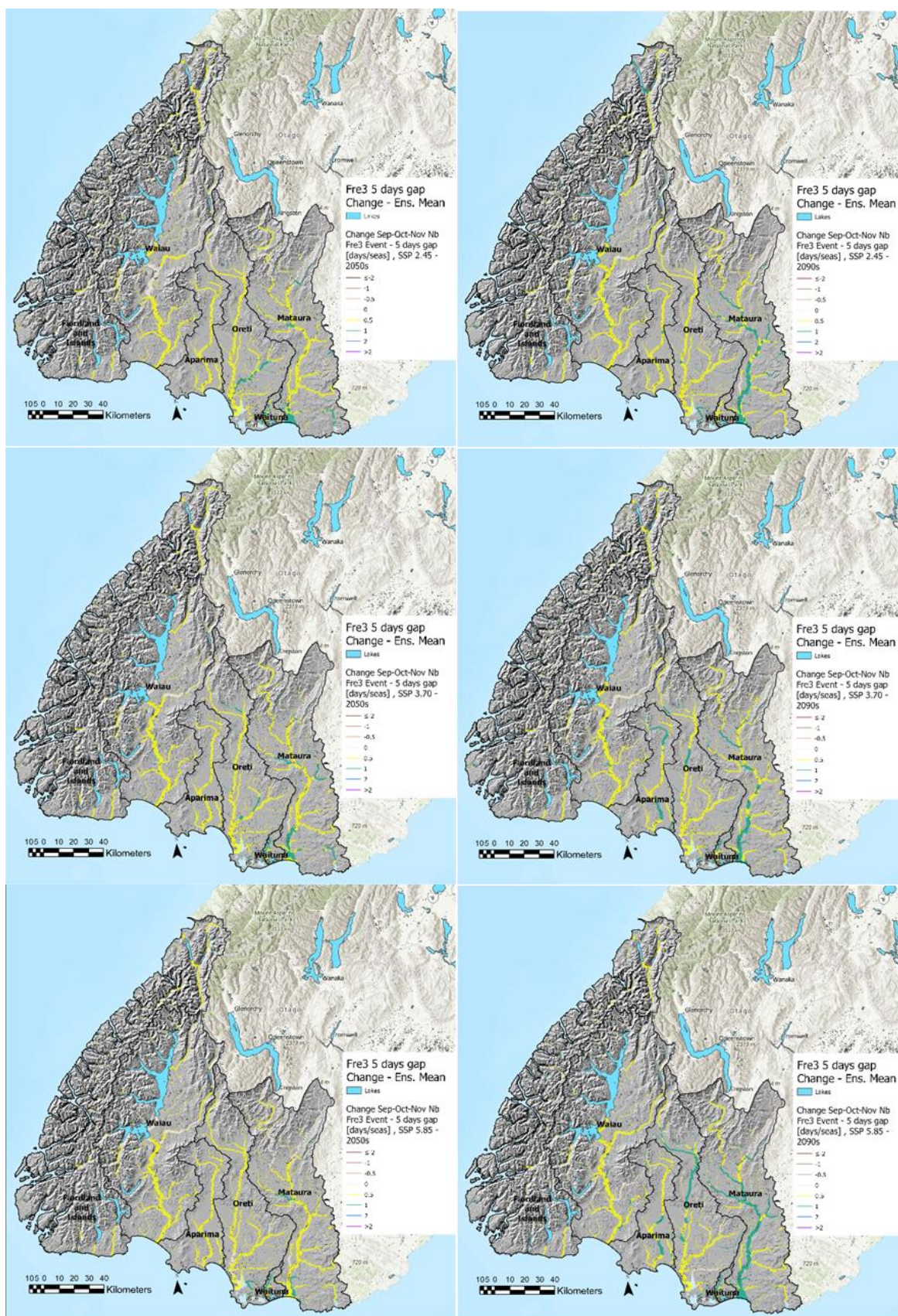


Figure C-8: Change in multi-model average number of Fre3 events during September-October-November (spring) with 5-days gap (based on hydrological year). Change in multi-model average seasonal number of Fre3 events for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

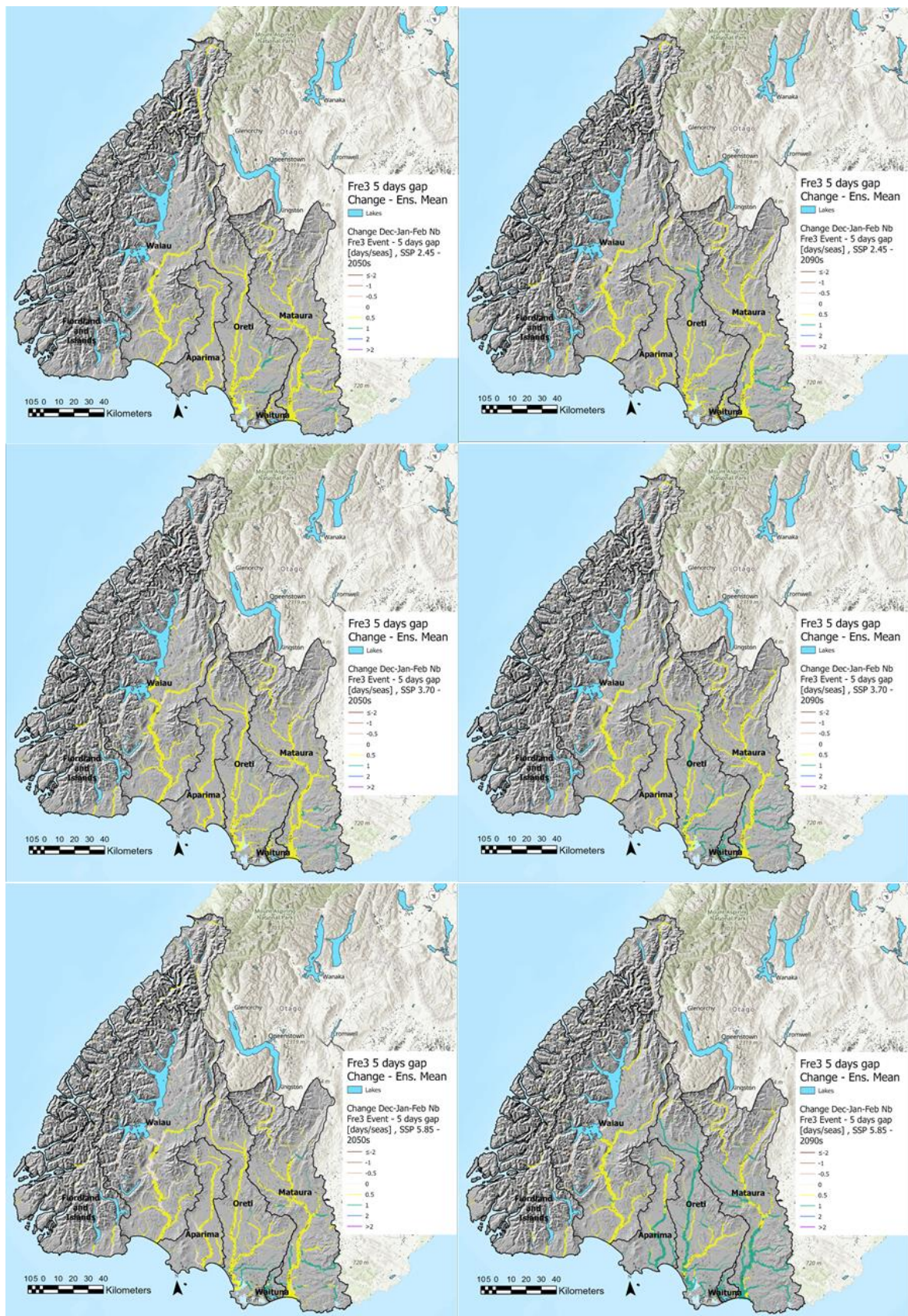


Figure C-9: Change in multi-model average number of Fre3 events during December-January-February (summer) with 5-days gap (based on hydrological year). Change in multi-model average seasonal number of Fre3 events is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

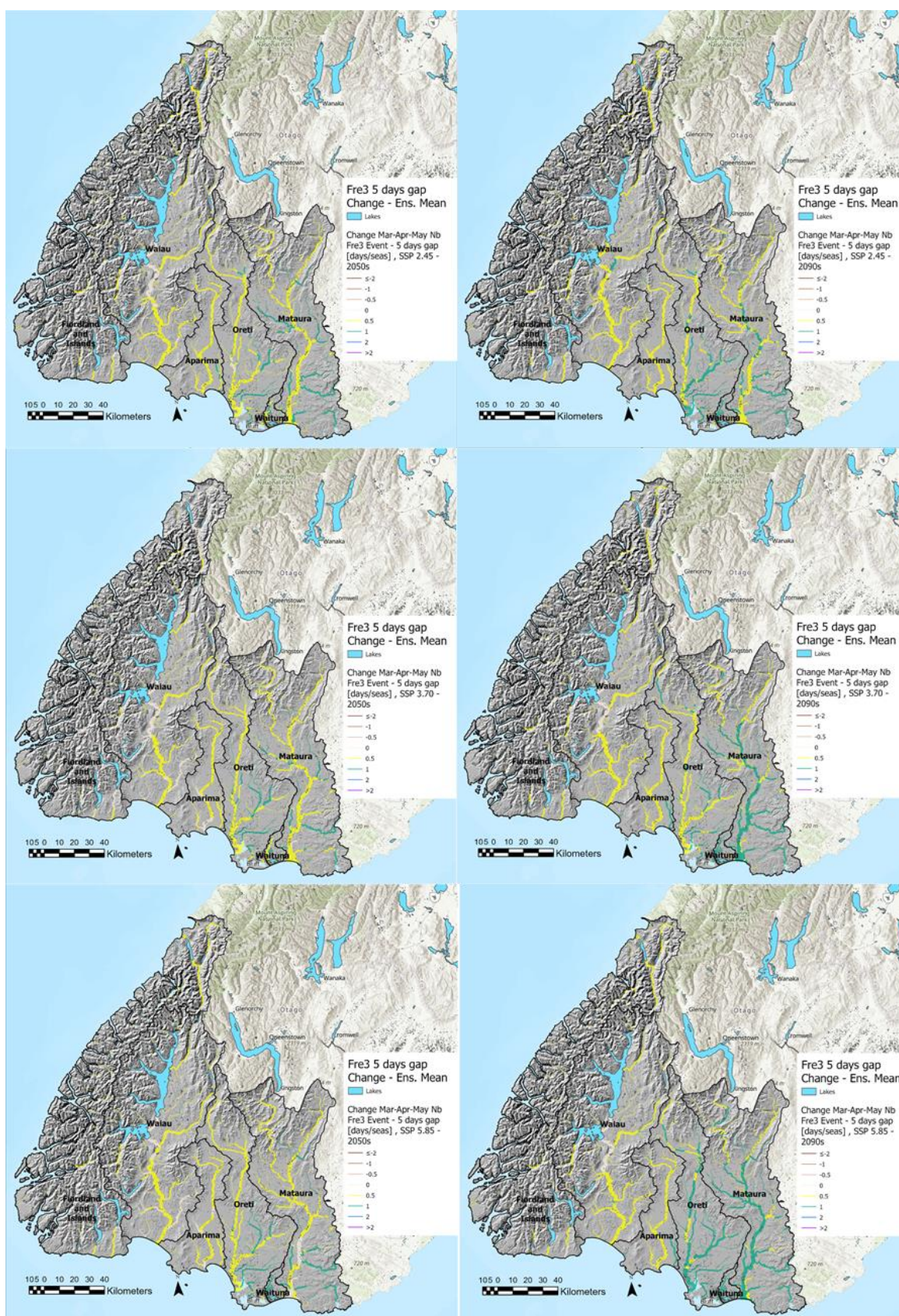


Figure C-10: Change in multi-model average number of Fre3 events during March-April-May (autumn) with 5-days gap (based on hydrological year). Change in multi-model average seasonal number of Fre3 events is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Appendix D Water resources metrics

Mean discharge hydrological year

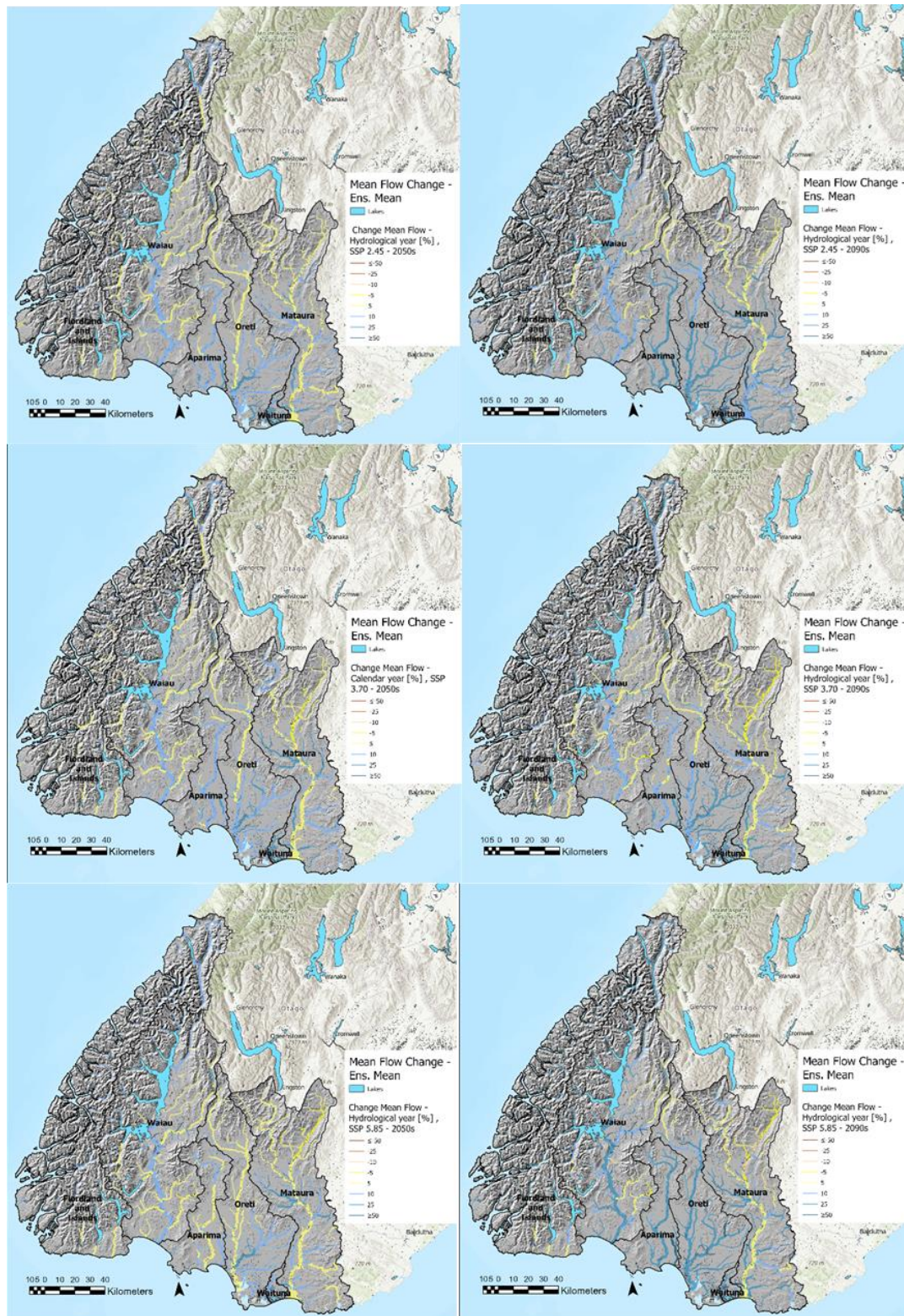


Figure D-1: Change multi-model average mean discharge calculated on hydrological year. Change in multi-model average mean discharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Table D-1: FMU scale projected changes in mean discharge calculated on hydrological year (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	6.3	11.9	5.7	8.5	6.2	13.6
Aparima	9.4	18.8	6.2	10.3	4.8	19.2
Fiordland and Islands	4.9	8.1	4.1	7.4	6.8	11.4
Mataura	5.9	12.3	6.0	5.7	4.6	9.6
Oreti	8.4	15.5	7.5	13.5	7.0	19.0
Waiau	5.5	11.8	5.7	7.6	6.1	14.0
Waituna	10.8	21.4	10.7	17.2	8.2	22.0

Median Annual flows

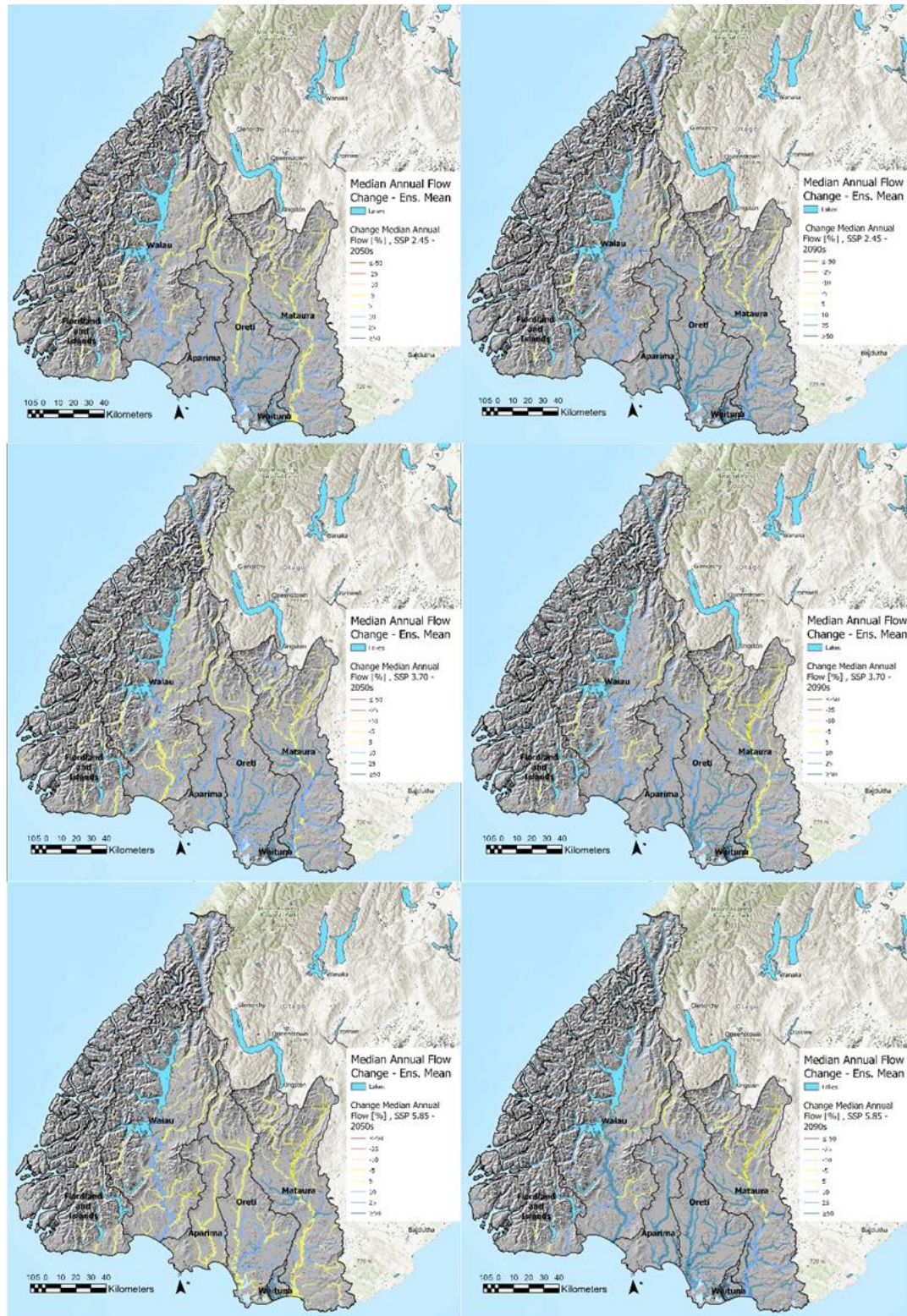


Figure D-2: Change multi-model average median annual flows. Change in multi-model average median annual flow is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Table D-2: FMU scale projected changes in median annual flow (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	6.6	11.7	6.6	10.2	5.3	14.7
Aparima	9.1	17.4	7.5	11.4	2.3	18.5
Fiordland and Islands	4.5	7.7	4.6	9.0	6.7	11.7
Mataura	6.0	12.1	6.9	7.4	3.3	11.9
Oreti	8.9	15.9	8.5	14.4	4.4	20.3
Waiau	7.7	11.7	6.7	10.1	6.2	15.2
Waituna	10.8	23.1	14.0	19.4	7.4	26.3

Table D-3: Location specific projected changes in median annual flow (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	0.9	1.4	1.5	1.2	-3.2	-0.6
Mataura River at Gore Township	3.6	3.9	4.3	1.1	0.6	3.4
Mataura Catchment to Wyndham Catchment Township	4.3	6.9	5.1	3.3	2.0	7.1
Waikaia Catchment to Waikaia Township	-1.0	0.2	-6.4	-3.7	-8.1	-7.9
Waikaka Stream to Gore Township	7.9	11.9	11.8	7.1	10.9	18.9
Waikawa Catchment	6.4	10.1	9.8	9.5	3.6	10.1
Waimea Catchment	11.8	22.9	16.8	10.3	13.4	17.4
Waituna Catchment	8.4	23.2	13.2	20.4	9.1	25.9
Mokoreta Catchment	8.7	13.0	10.8	9.2	7.3	14.2
Waikaia Catchment	-1.9	-0.4	-4.8	-5.9	-6.5	-6.1
Makarewa Catchment	11.4	14.0	13.1	14.0	9.6	24.9
Oreti Catchment to Lumsden Township	2.2	3.3	3.2	3.6	-1.7	11.1
Oreti Catchment to Winton Township	3.3	11.5	6.4	9.0	2.6	16.8
Oreti Catchment to Wallacetown	5.7	13.1	7.6	11.3	3.3	17.0
Waihopai River to Invercargill City	8.3	17.7	8.0	17.0	6.5	23.3
Otepuni Stream to Invercargill City	8.5	17.4	7.1	14.4	3.4	20.8
Kingswell Creek at Invercargill City	7.1	15.5	9.1	15.7	7.3	28.0
Irthing Stream at Ellis Road	3.0	4.0	2.5	3.6	-5.2	14.2
Winton Stream to Winton Township	11.0	22.3	12.0	15.4	6.8	20.1
Aparima River to Otautau Township	6.0	14.8	9.2	9.9	3.9	20.4
Otautau Stream to Otautau Township	7.0	19.0	9.9	15.3	2.5	15.7
Aparima River at Thornbury Bridge	7.7	15.8	8.9	12.2	2.8	16.7
Whitestone Catchment	8.0	16.5	3.9	11.2	7.4	17.6
Upukerora Catchment	2.3	10.3	3.5	9.4	2.8	6.7
Mararoa Catchment	4.2	9.1	1.5	6.7	3.8	6.5

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Orauea Catchment	10.9	9.1	8.4	10.8	-0.1	10.1
Waiau River at Tutapere	6.5	9.0	4.4	10.1	7.6	12.6

Seasonal Average Flows

Hydrological year

Table D-4: Location specific projected changes in winter seasonal flow (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	5.4	-0.3	3.5	-3.9	-2.2	-1.8
Mataura River at Gore Township	3.3	0.8	0.9	-4.4	-6.6	-6.0
Mataura Catchment to Wyndham Catchment Township	5.9	6.1	3.9	2.2	-4.1	-2.8
Waikaia Catchment to Waikaia Township	1.0	-5.7	-5.5	-12.7	-12.1	-13.3
Waikaka Stream to Gore Township	6.6	19.5	7.5	8.4	7.0	4.0
Waikawa Catchment	11.3	15.0	7.3	10.5	-3.0	8.1
Waimea Catchment	31.6	32.0	19.4	25.3	0.6	16.9
Waituna Catchment	6.6	14.4	11.2	15.9	-2.0	9.6
Mokoreta Catchment	9.2	14.8	8.7	11.0	-2.5	2.4
Waikaia Catchment	-2.6	-8.0	-6.9	-15.6	-14.0	-17.3
Makarewa Catchment	-2.4	17.7	1.4	21.8	-1.0	13.2
Oreti Catchment to Lumsden Township	6.7	17.5	13.8	11.7	6.4	18.5
Oreti Catchment to Winton Township	7.1	10.5	9.1	15.5	4.0	17.0
Oreti Catchment to Wallacetown	7.8	11.3	10.1	17.4	4.4	18.2
Waihopai River to Invercargill City	9.7	11.6	7.6	20.9	0.9	16.7
Otepuni Stream to Invercargill City	8.3	13.4	14.9	22.2	0.3	20.3
Kingswell Creek at Invercargill City	7.7	12.7	14.3	27.6	2.2	23.3
Irthing Stream at Ellis Road	22.8	31.1	25.0	25.8	17.3	34.2
Winton Stream to Winton Township	16.0	21.7	14.9	33.6	0.9	33.5
Aparima River to Otautau Township	9.0	11.8	9.3	13.8	5.0	21.2
Otautau Stream to Otautau Township	13.8	6.0	7.7	7.9	-6.1	20.9
Aparima River at Thornbury Bridge	7.5	9.6	7.7	12.4	2.7	19.0
Whitestone Catchment	-13.4	-10.0	-17.6	-9.4	-12.3	4.1
Upukerora Catchment	-7.0	4.2	5.0	-8.5	-4.8	-1.8
Mararoa Catchment	-15.0	-10.7	-15.1	-16.2	-14.0	-12.4
Orauea Catchment	11.5	8.7	13.9	7.0	0.8	16.2
Waiau River at Tutapere	-4.9	-1.1	-1.7	-6.4	-5.7	-3.9

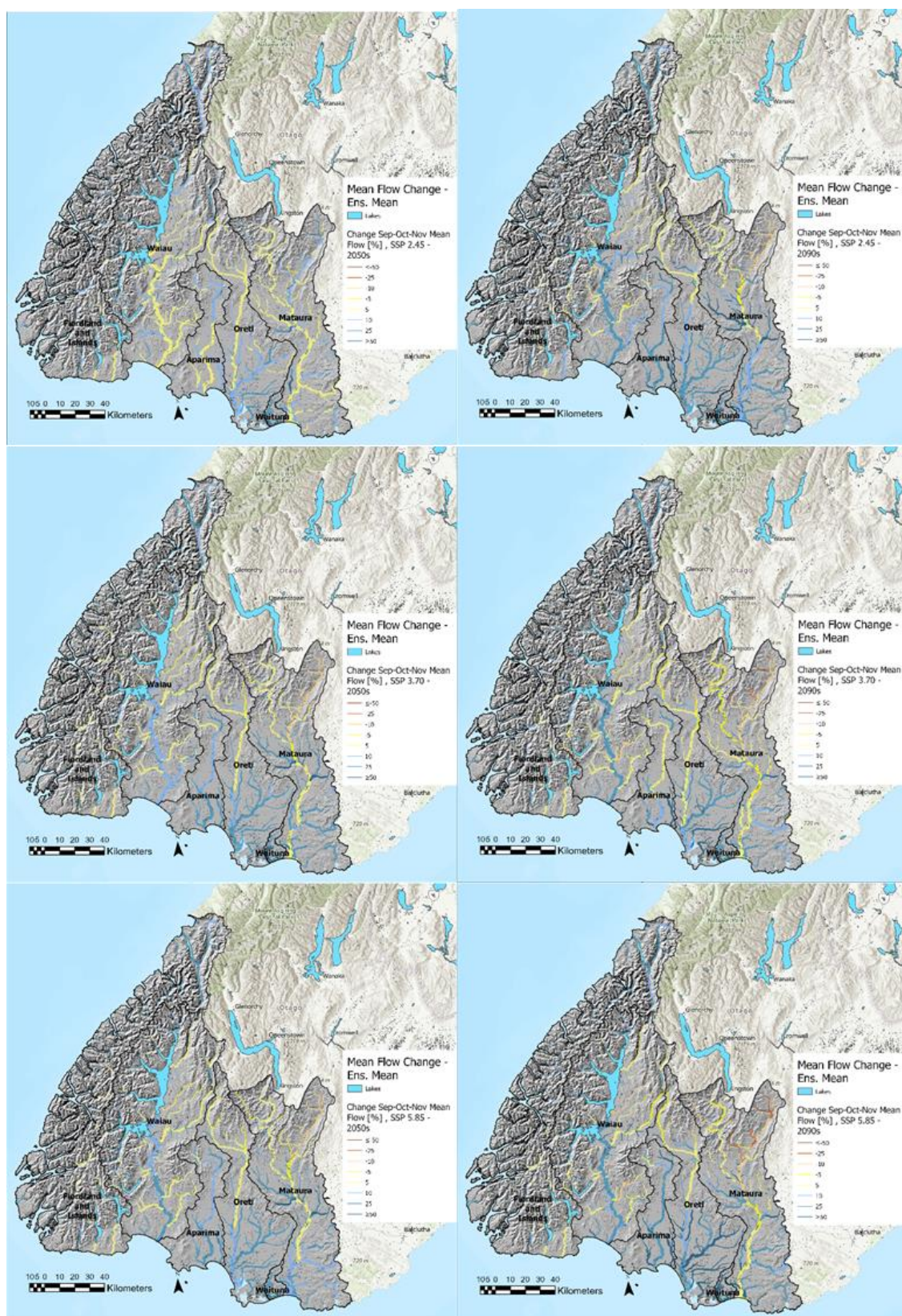


Figure D-3: Change multi-model average September-October-November (spring) mean discharge calculated on hydrological year. Change in multi-model average seasonal mean discharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Table D-5: Location specific projected changes in spring seasonal flow (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	0.4	12.7	3.0	3.9	1.3	8.4
Mataura River at Gore Township	1.7	15.2	4.9	5.7	1.5	7.0
Mataura Catchment to Wyndham Catchment Township	3.1	17.0	4.2	4.6	2.4	5.3
Waikaia Catchment to Waikaia Township	6.3	1.2	-2.1	-4.8	-5.8	-8.3
Waikaka Stream to Gore Township	1.6	11.3	-5.4	3.9	5.9	9.9
Waikawa Catchment	7.6	9.0	-0.7	3.5	1.5	0.4
Waimea Catchment	3.5	23.6	5.8	9.0	3.0	19.1
Waituna Catchment	7.1	14.5	5.8	19.0	3.3	17.7
Mokoreta Catchment	2.5	7.2	-2.2	2.0	-0.5	-1.2
Waikaia Catchment	5.7	6.5	0.4	0.6	-2.8	-0.9
Makarewa Catchment	7.4	18.4	4.8	12.0	3.5	14.3
Oreti Catchment to Lumsden Township	-4.0	8.5	1.3	-2.0	-2.2	3.1
Oreti Catchment to Winton Township	3.0	15.6	4.0	4.8	0.6	6.5
Oreti Catchment to Wallacetown	4.3	17.2	4.6	6.0	1.2	7.9
Waihopai River to Invercargill City	14.1	24.9	7.7	14.5	5.8	20.3
Otepuni Stream to Invercargill City	13.4	20.4	7.9	17.3	7.3	23.7
Kingswell Creek at Invercargill City	13.9	25.1	11.0	23.6	10.5	20.8
Irthing Stream at Ellis Road	-1.3	13.5	4.5	3.6	0.9	7.7
Winton Stream to Winton Township	5.2	20.1	6.2	10.3	1.6	9.2
Aparima River to Otautau Township	3.2	21.3	1.9	6.3	2.9	11.1
Otautau Stream to Otautau Township	7.5	24.0	1.8	6.0	-1.9	8.9
Aparima River at Thornbury Bridge	3.2	19.2	1.5	5.1	0.6	9.1
Whitestone Catchment	1.5	21.6	2.5	8.5	9.8	14.5
Upukerora Catchment	1.0	14.9	-0.6	3.4	2.1	5.0
Mararoa Catchment	1.8	13.1	-1.3	4.5	2.9	5.5
Orauea Catchment	-3.2	13.1	-4.2	-3.0	-7.4	0.7
Waiau River at Tutapere	1.4	11.4	-0.4	7.6	1.7	10.7

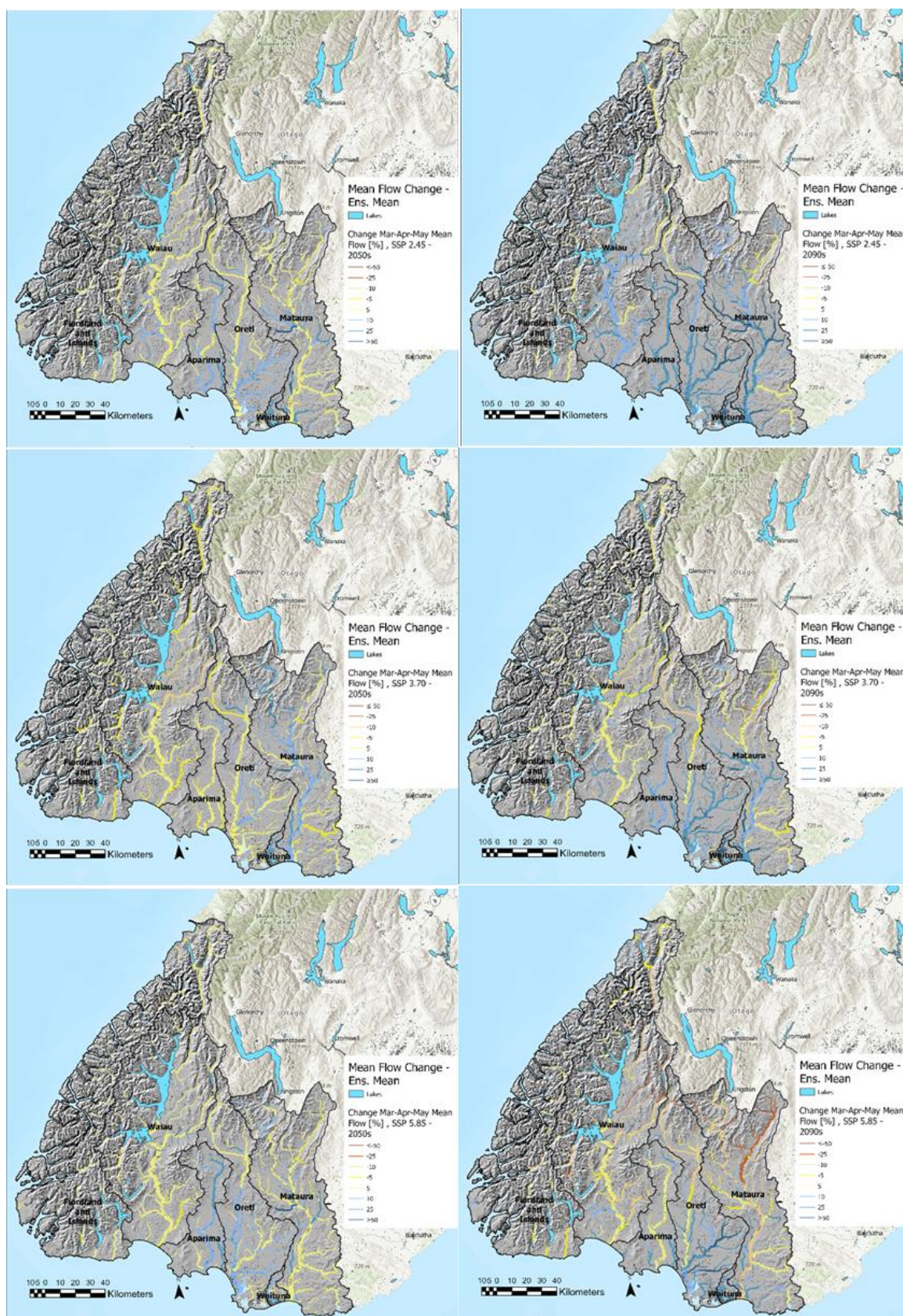


Figure D-4: Change multi-model average March-April-May (autumn) mean discharge calculated on hydrological year. Change in multi-model average seasonal mean discharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Table D-6: Location specific projected changes in autumn seasonal flow (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Mataura catchment to Cattle Flat Township	-5.1	-0.5	-7.4	-16.8	-11.7	-17.5
Mataura River at Gore Township	-4.1	-4.3	-5.7	-21.0	-11.7	-22.3
Mataura Catchment to Wyndham Catchment Township	-0.8	-0.9	-1.3	-15.4	-7.4	-13.4
Waikaia Catchment to Waikaia Township	-12.9	-18.8	-19.8	-28.4	-19.5	-31.8
Waikaka Stream to Gore Township	4.0	15.4	19.0	-1.8	3.1	-0.5
Waikawa Catchment	1.6	5.9	8.5	-4.6	-5.6	5.0
Waimea Catchment	5.4	23.4	22.4	-4.2	11.3	0.6
Waituna Catchment	3.8	15.1	12.2	6.0	1.0	20.1
Mokoreta Catchment	3.2	8.1	12.3	-5.1	-3.2	5.2
Waikaia Catchment	-11.4	-17.5	-12.8	-30.1	-17.6	-35.5
Makarewa Catchment	21.7	18.6	14.8	15.0	14.6	22.2
Oreti Catchment to Lumsden Township	-3.0	2.6	-11.2	-17.0	-9.4	-13.2
Oreti Catchment to Winton Township	1.1	6.3	-4.1	-10.3	-2.3	-1.8
Oreti Catchment to Wallacetown	2.1	7.7	-2.4	-8.3	-1.0	1.8
Waihopai River to Invercargill City	9.5	17.5	7.4	8.9	10.8	25.8
Otepuni Stream to Invercargill City	21.2	22.8	7.6	10.5	15.3	30.5
Kingswell Creek at Invercargill City	11.4	18.0	10.3	10.7	6.3	28.8
Irthing Stream at Ellis Road	2.3	11.5	-9.2	-12.2	-3.9	-12.2
Winton Stream to Winton Township	10.7	18.0	9.4	2.9	12.4	21.4
Aparima River to Otautau Township	1.9	7.7	-0.6	-8.8	-0.9	-1.2
Otautau Stream to Otautau Township	1.1	12.0	2.8	8.9	10.6	4.5
Aparima River at Thornbury Bridge	-0.3	8.9	0.3	-4.1	0.6	4.0
Whitestone Catchment	-6.2	1.2	-10.6	-16.7	-7.8	-13.4
Upukerora Catchment	-9.1	-11.1	-11.3	-21.3	-16.0	-25.5
Mararoa Catchment	-7.8	-5.7	-11.6	-19.3	-12.2	-19.6
Orauea Catchment	1.0	12.7	0.3	-2.8	2.0	-6.8
Waiau River at Tutapere	1.2	2.6	-0.4	-4.4	-3.8	-4.1

Calendar year

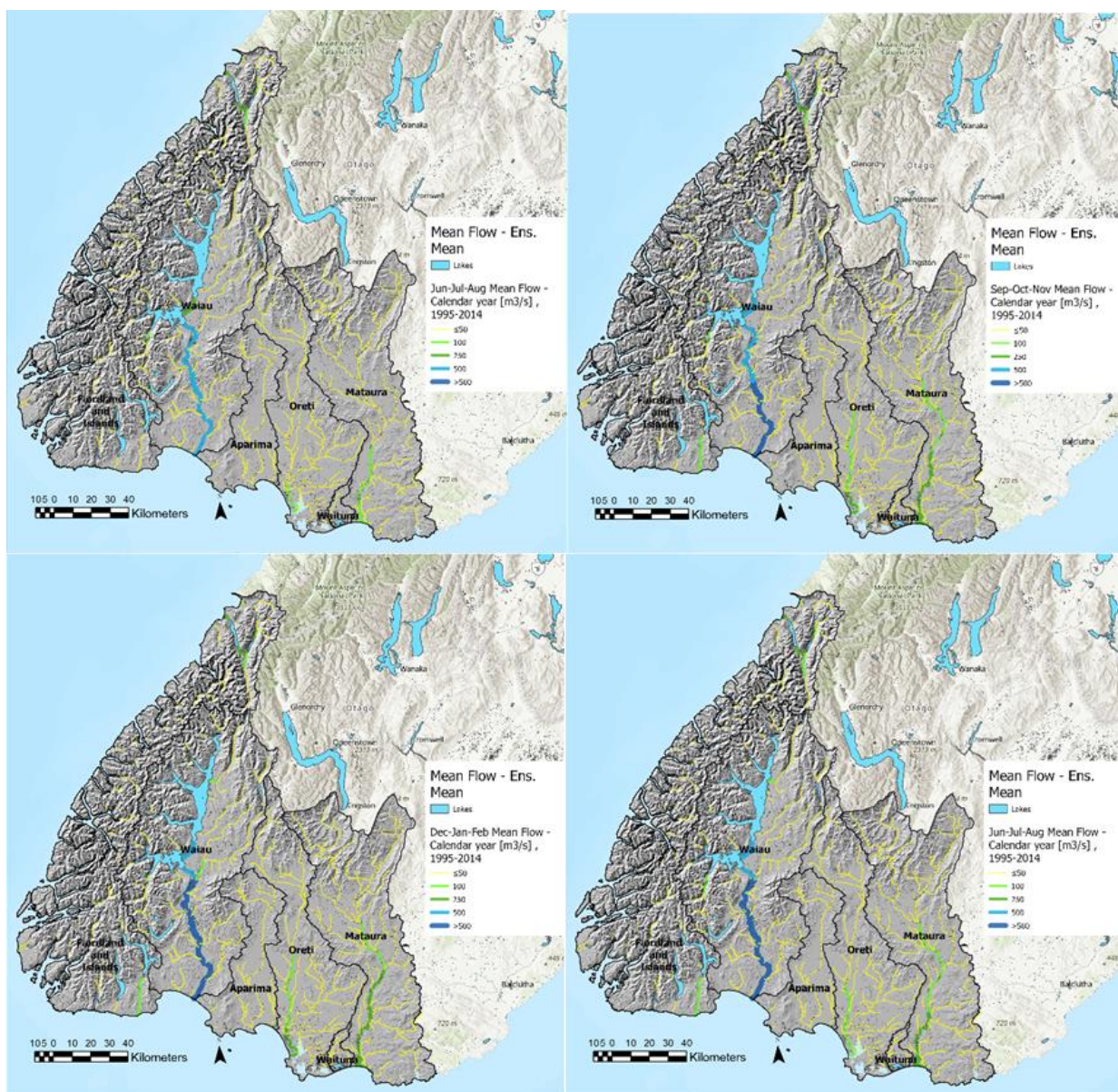


Figure D-5: Multi-model ensemble average seasonal discharge calculated on calendar year.

Add seasonal tables

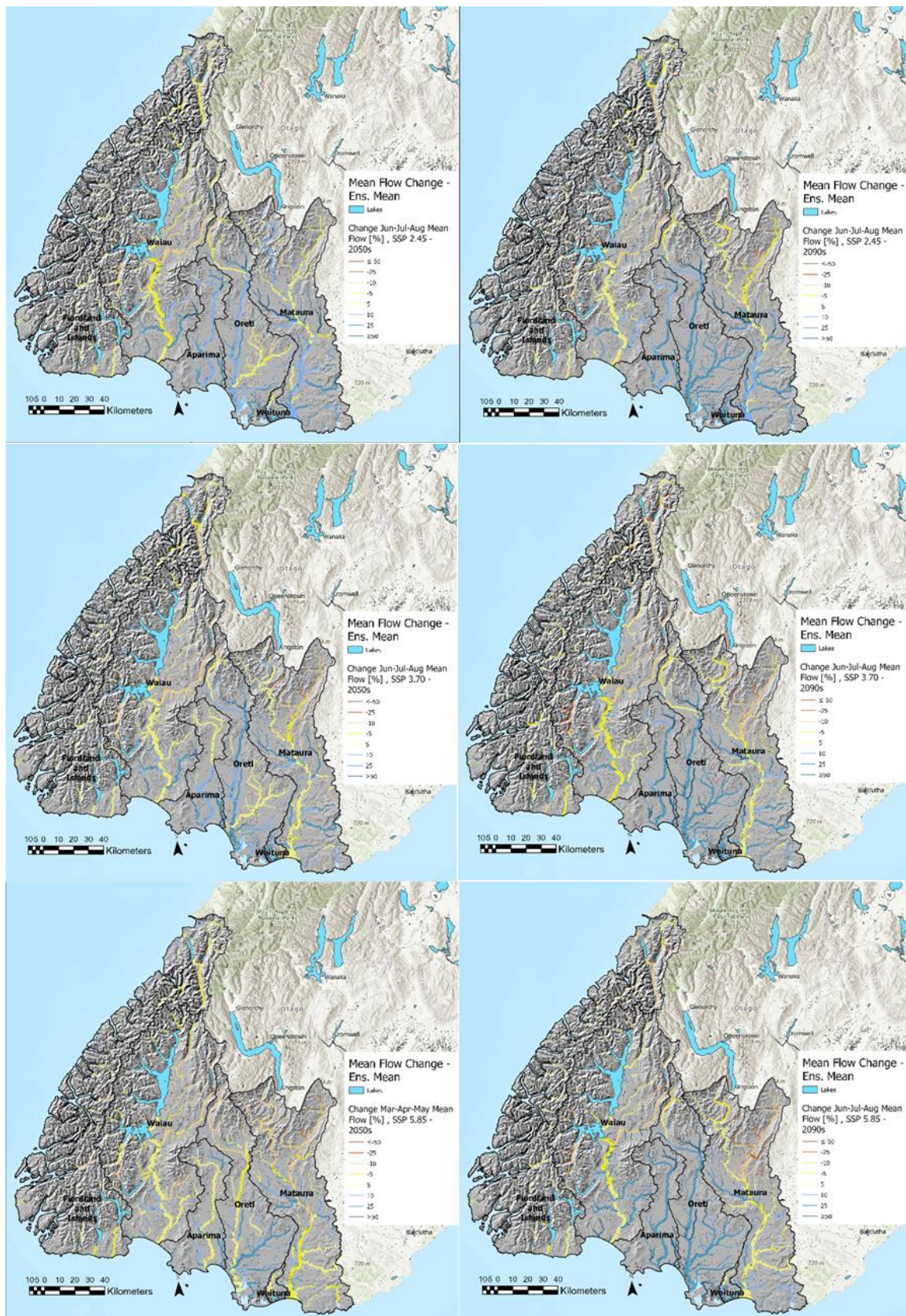


Figure D-6: Change multi-model average June-July-August (winter) mean discharge calculated on calendar year. Change in multi-model average seasonal mean discharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

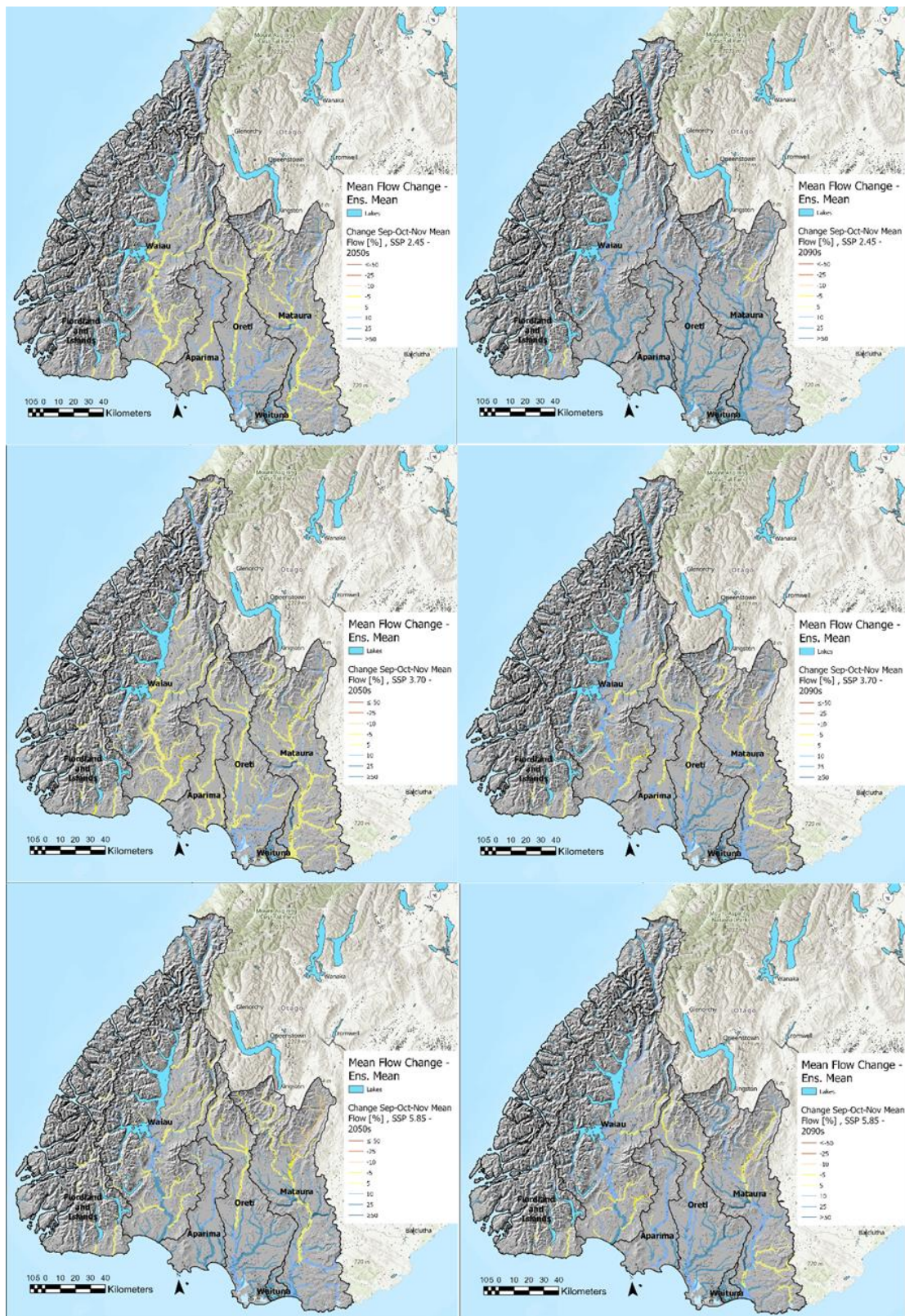


Figure D-7: Change multi-model average September-October-November (spring) mean discharge calculated on calendar year. Change in multi-model average seasonal mean discharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

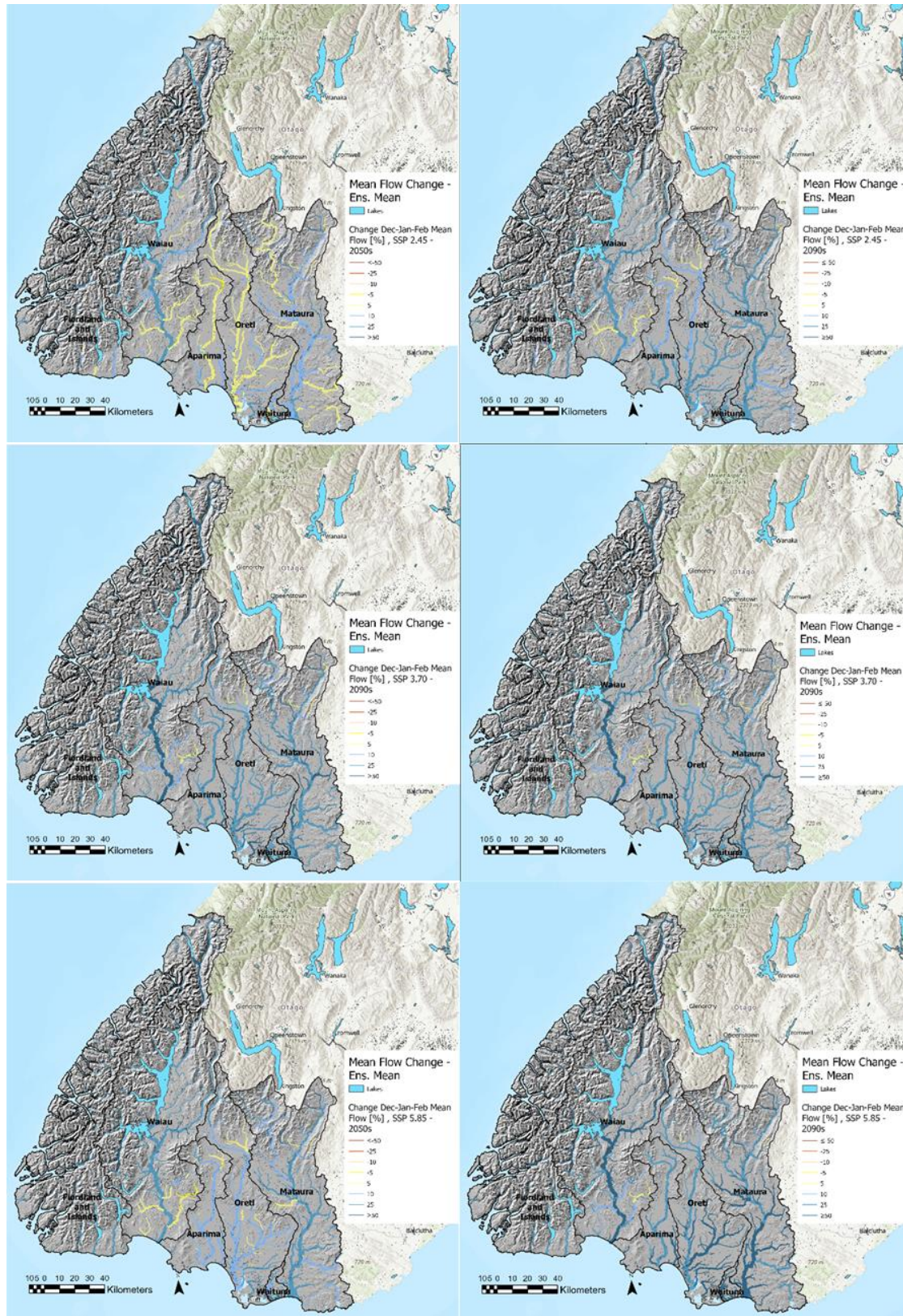


Figure D-8: Change multi-model average December-January-February (summer) mean discharge calculated on calendar year. Change in multi-model average seasonal mean discharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

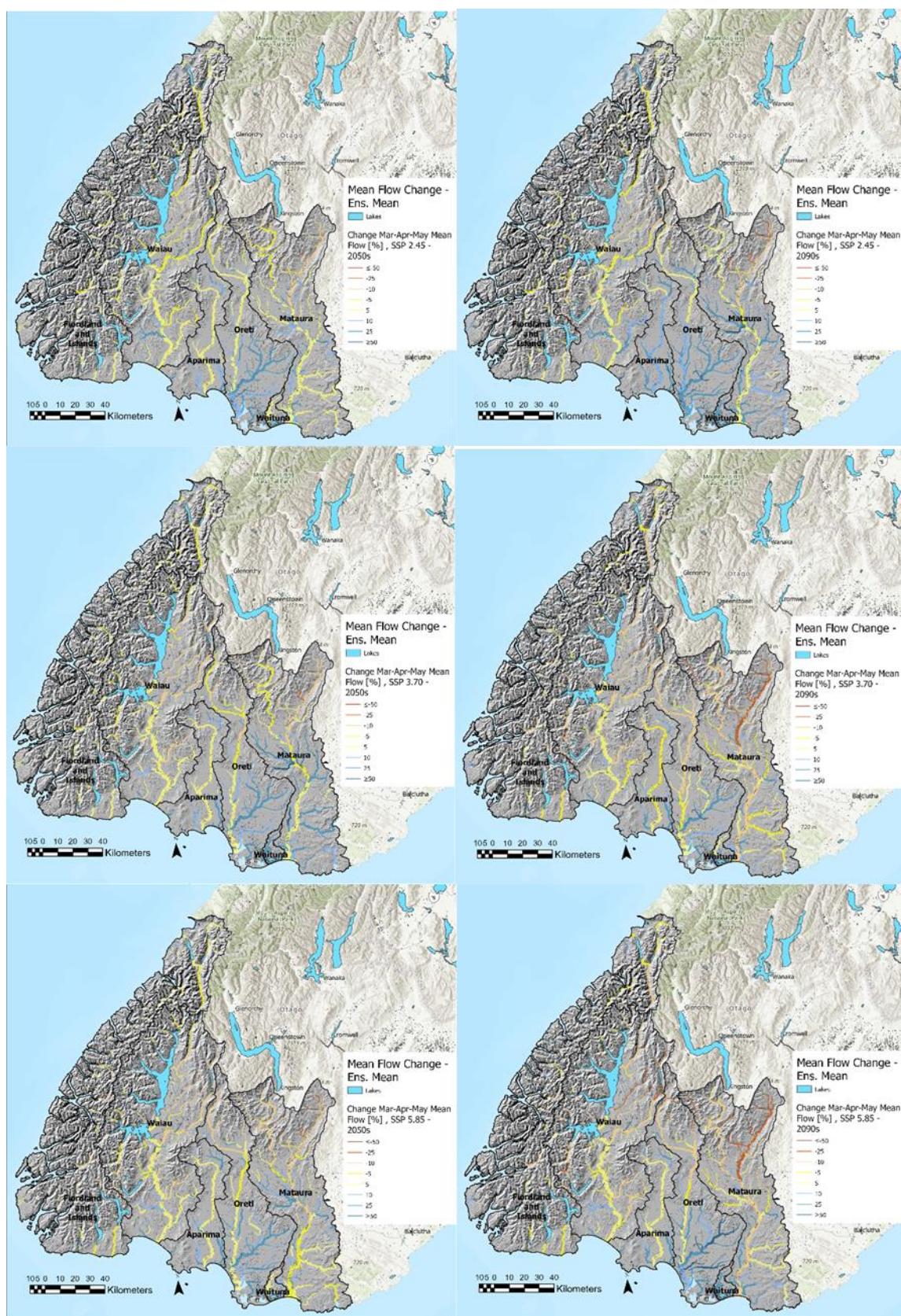


Figure D-9: Change multi-model average March-April-May (autumn) mean discharge calculated on calendar year. Change in multi-model average seasonal mean discharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Land surface recharge

Seasonal time scale

Table D-7: Projected changes in September-October-November (spring) land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	10.3	20.5	6.0	14.6	8.0	14.9
Aparima	15.0	24.9	10.0	19.5	11.6	28.7
Fiordland and Islands	9.3	19.1	7.9	17.6	9.9	20.3
Mataura	12.2	27.4	7.1	16.1	7.9	12.9
Oreti	14.3	20.0	4.2	10.9	6.3	0.8
Waiau	4.5	13.2	1.1	7.1	4.7	11.0
Waituna	23.1	40.9	14.8	33.9	13.4	36.0

Table D-8: Projected changes in March-April-May (autumn) land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	1.2	5.2	-6.5	-7.5	-2.4	-7.9
Aparima	2.9	17.9	-6.7	-3.8	3.4	2.1
Fiordland and Islands	1.0	5.9	-2.3	-2.9	0.3	-0.9
Mataura	2.7	6.1	-4.5	-7.4	-2.0	-12.2
Oreti	2.9	-3.6	-15.0	-19.5	-12.1	-23.5
Waiau	-2.6	6.2	-7.9	-6.1	-2.4	-7.5
Waituna	10.7	-1.0	-15.2	-21.1	-1.4	-5.9

Table D-9: Shallow aquifers projected changes in June-July-August (winter) land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Awarua	4.0	23.1	8.2	17.3	7.8	27.6
Blackmount	4.0	14.8	6.7	10.8	2.7	17.3
Castlerock	5.2	25.4	11.6	18.5	9.5	29.9
Cattle Flat	-2.8	16.2	7.6	12.6	5.8	17.0
Central Plains	1.2	17.2	7.1	12.6	4.3	16.0
Centre Hill	-5.9	-1.9	-3.7	-5.4	-2.9	-0.1
Croydon	-0.8	19.9	8.6	20.3	10.0	33.4
Dipton	-4.1	6.9	2.6	-0.1	-1.1	-1.1

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Edendale	1.8	17.0	8.3	15.7	7.2	24.0
Five Rivers	-8.5	3.3	-0.7	-1.5	0.1	5.5
Knapdale	-1.4	19.4	7.4	19.4	8.8	31.5
Longridge	-1.9	18.5	8.3	18.5	7.7	28.2
Lower Aparima	5.9	20.5	11.7	19.0	6.0	28.5
Lower Maitara	1.7	20.2	9.2	18.6	8.4	27.3
Lower Oreti	-0.1	13.4	-2.8	-1.8	-2.5	-1.1
Makarewa	3.4	16.4	-2.7	-6.4	0.7	-2.4
Orepuki	9.7	27.4	19.3	29.6	11.4	31.0
Oreti	4.3	24.5	12.1	19.5	9.5	30.9
Riversdale	0.6	19.1	9.5	19.7	9.4	31.8
Te Anau	-3.0	26.3	-3.1	6.0	8.8	24.5
Te Waewae	7.5	23.6	15.8	19.5	7.5	23.7
Tiwai	10.1	27.9	18.2	28.8	8.3	34.1
Upper Aparima	-1.7	11.6	2.9	0.8	1.9	21.1
Upper Maitara	-5.8	8.2	4.2	5.5	1.9	7.5
Waihopa	4.1	8.0	1.7	3.6	0.3	6.6
Waimatuku	5.5	22.5	12.2	20.4	7.4	26.5
Waimea Plains	-3.7	17.1	7.0	15.5	5.3	21.9
Waipounamu	5.3	22.7	16.6	23.3	13.6	39.5
Wendon	-1.2	16.4	10.9	11.2	7.8	16.7
Wendonside	3.7	20.9	14.3	19.1	10.8	31.8

Table D-10: Shallow aquifers projected changes in September-October-November (spring) land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Awarua	24.0	37.7	15.6	29.3	14.2	28.2
Blackmount	8.1	21.0	11.3	9.3	5.5	14.2
Castlerock	13.3	35.4	15.3	14.0	16.3	24.3
Cattle Flat	9.4	25.8	2.7	15.1	6.6	8.8
Central Plains	13.9	19.1	4.3	14.4	6.9	8.6
Centre Hill	4.1	9.0	-4.4	12.2	8.3	-6.0
Croydon	16.0	35.5	14.5	24.8	18.9	32.5

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Dipton	-0.8	5.1	-5.6	-7.8	-4.1	-15.6
Edendale	19.6	30.5	12.1	24.7	15.0	26.0
Five Rivers	8.1	10.8	-0.1	10.8	4.8	-0.3
Knapdale	19.1	42.1	17.9	27.9	20.2	35.7
Longridge	18.7	47.3	18.1	26.5	15.5	27.2
Lower Aparima	18.4	30.1	15.8	28.6	14.7	31.1
Lower Maitara	17.4	30.1	9.6	21.8	11.9	21.8
Lower Oreti	12.7	19.7	0.9	0.7	-0.1	-6.6
Makarewa	25.6	35.7	1.8	14.5	10.2	-5.3
Orepuki	25.6	35.4	14.6	31.7	14.5	27.5
Oreti	13.3	35.7	14.3	15.3	14.6	25.4
Riversdale	13.7	36.8	15.8	20.4	15.7	25.2
Te Anau	0.9	20.1	-8.7	6.5	11.6	23.3
Te Waewae	11.4	17.8	4.1	17.4	5.8	14.7
Tiwai	39.0	43.6	24.9	44.4	22.1	46.8
Upper Aparima	7.1	17.7	6.2	7.3	7.9	31.1
Upper Maitara	-4.3	9.6	-0.9	2.3	-1.8	-2.1
Waihopai	15.5	16.2	14.1	17.2	9.2	6.2
Waimatuku	20.0	29.8	11.8	28.2	16.3	30.5
Waimea Plains	20.0	44.6	10.8	27.2	9.1	21.9
Waipounamu	19.1	39.6	13.8	25.0	13.0	28.2
Wendon	2.6	27.5	5.1	7.6	5.5	5.2
Wendonside	18.1	38.0	10.0	20.6	10.0	19.3

Table D-11: Shallow aquifers projected changes in December-January-February (summer) land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Awarua	-18.9	3.6	14.0	-23.9	1.2	-1.1
Blackmount	5.5	14.1	17.4	10.6	2.9	21.2
Castlerock	-2.9	5.7	12.3	-2.8	-6.0	12.3
Cattle Flat	-5.2	-11.9	14.0	-3.8	-2.6	-4.9
Central Plains	-5.7	-14.7	0.4	-22.1	-12.3	-13.6
Centre Hill	-29.3	-31.5	-22.1	-42.1	-27.3	-28.9
Croydon	12.3	9.9	9.7	8.9	5.0	24.1
Dipton	-14.2	-26.5	-14.0	-30.5	-25.3	-33.6
Edendale	-28.1	-19.7	-13.0	-34.8	-19.3	-10.7
Five Rivers	-15.0	-12.6	-3.6	-25.9	-25.3	-15.2
Knapdale	18.6	13.6	16.4	-0.3	14.9	24.1
Longridge	13.0	10.4	22.9	-19.5	-0.2	24.8
Lower Aparima	8.2	6.1	17.4	1.8	1.6	22.8
Lower Maitara	-15.6	2.4	3.9	-19.1	-3.3	5.5
Lower Oreti	-4.8	-13.2	-2.8	-26.4	-3.2	-25.7
Makarewa	19.4	2.8	22.9	-15.9	3.5	-22.1
Orepuki	0.5	2.4	8.0	-7.7	0.7	13.1
Oreti	-3.3	8.0	18.5	-4.3	-2.8	19.0
Riversdale	11.0	3.8	5.7	-1.3	-3.9	11.1
Te Anau	2.8	8.7	10.4	-8.6	-2.4	11.1
Te Waewae	-0.3	0.3	10.2	-1.2	0.4	15.5
Tiwai	4.9	11.3	9.6	12.6	3.1	26.6
Upper Aparima	28.6	11.6	38.7	14.9	8.3	39.6
Upper Maitara	-15.6	-31.7	-18.3	-41.6	-38.8	-36.3
Waihopai	-37.6	-24.6	20.8	-45.9	-13.3	-58.0
Waimatuku	5.7	1.0	11.4	-10.2	-6.7	20.0
Waimea Plains	6.9	32.4	41.4	-16.1	10.7	48.7
Waipounamu	4.6	7.4	11.3	6.1	-2.2	12.5
Wendon	21.9	3.1	44.9	-10.2	28.6	-0.3
Wendonside	4.1	0.8	8.7	-2.2	-4.6	7.1

Table D-12: Shallow aquifers projected changes in March-April-May (autumn) land surface recharge (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Awarua	9.1	1.8	-10.3	-16.8	-3.1	-9.0
Blackmount	-1.3	11.3	-7.0	-0.1	-4.1	-5.2
Castlerock	1.0	16.4	-3.5	2.9	-1.9	-3.0
Cattle Flat	-0.1	2.7	-8.2	-8.6	-7.4	-14.7
Central Plains	0.9	0.6	-8.9	-11.3	-5.2	-14.1
Centre Hill	-8.0	-6.7	-17.5	-24.9	-12.8	-25.5
Croydon	6.8	19.1	1.4	9.7	6.8	9.8
Dipton	-5.6	-6.4	-11.8	-21.0	-9.5	-23.7
Edendale	3.9	3.3	-9.7	-8.7	-5.4	-17.0
Five Rivers	-6.8	-2.9	-13.9	-15.8	-14.6	-22.5
Knapdale	7.7	21.6	2.9	6.6	8.0	6.4
Longridge	6.8	19.3	5.1	3.6	9.5	3.4
Lower Aparima	2.2	10.6	-4.7	1.9	-3.7	-1.2
Lower Mataura	7.6	10.0	-3.2	-2.9	-2.5	-4.3
Lower Oreti	13.1	18.1	-11.9	-6.5	-8.3	-28.2
Makarewa	11.5	-5.1	-25.0	-27.2	-17.7	-31.7
Orepuki	1.9	10.0	-4.6	-0.2	-3.8	-2.6
Oreti	3.3	17.9	-1.2	4.9	1.0	-1.9
Riversdale	4.3	16.5	3.8	5.1	5.9	7.7
Te Anau	-8.7	3.9	-16.2	-16.5	-0.9	-17.8
Te Waewae	-1.1	10.0	-6.2	-2.5	-3.4	-6.1
Tiwai	8.6	13.7	-1.0	8.2	0.6	5.2
Upper Aparima	2.5	35.8	-12.3	-10.6	15.0	12.9
Upper Mataura	-8.5	-11.2	-14.0	-21.4	-11.8	-27.7
Waihopai	-3.6	-14.0	-20.3	-28.3	-15.3	-32.3
Waimatuku	4.6	9.5	-6.1	0.4	-2.8	-1.0
Waimea Plains	7.0	16.4	2.4	2.2	7.1	-6.9
Waipounamu	1.9	15.4	0.3	4.8	2.1	0.3
Wendon	-1.1	-2.4	-13.1	-15.6	-9.1	-28.0
Wendonside	-1.4	9.4	-4.4	-2.4	-2.9	-8.4

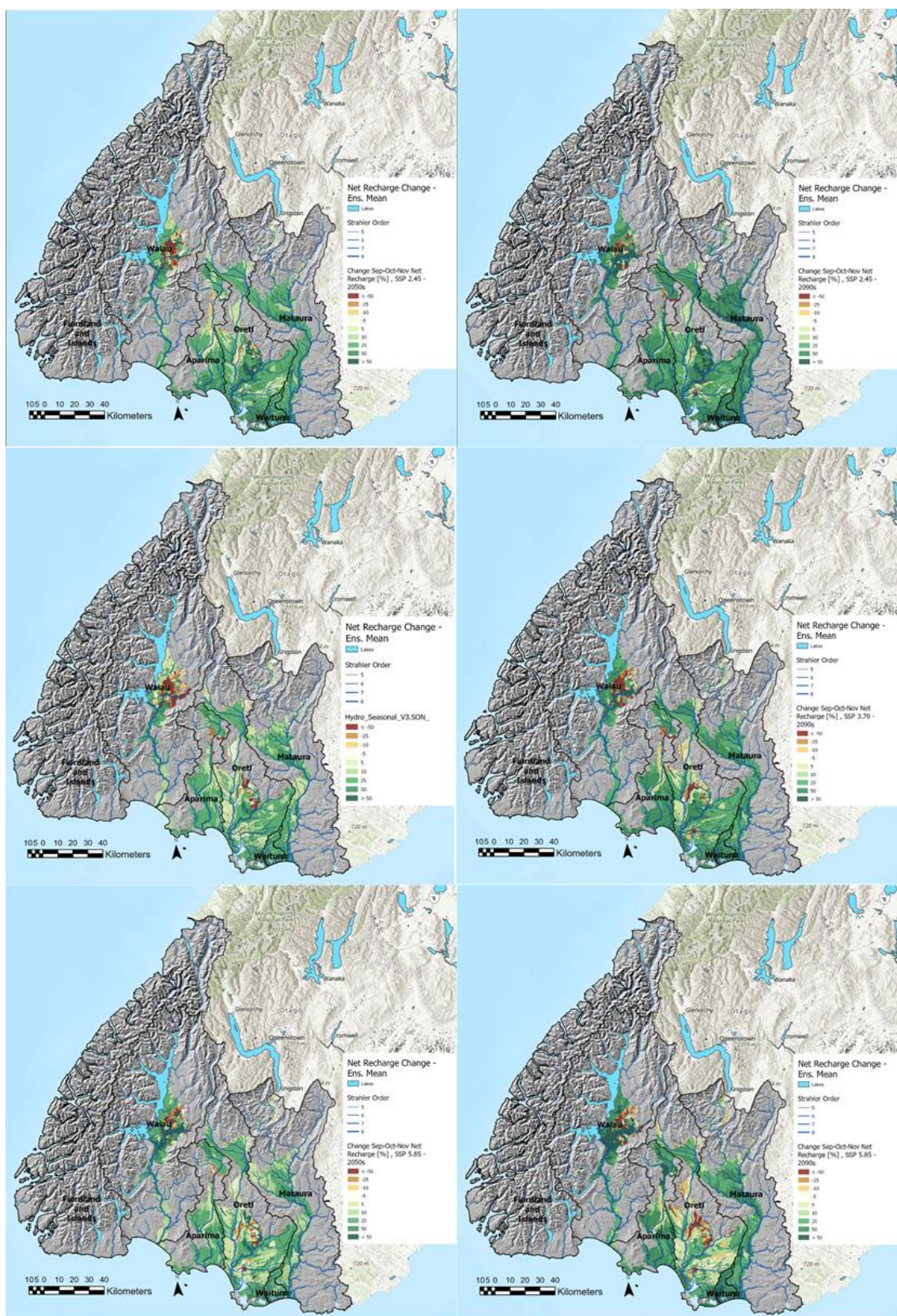


Figure D-10: Change multi-model average September-October-November (spring) land surface recharge calculated on hydrological year. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

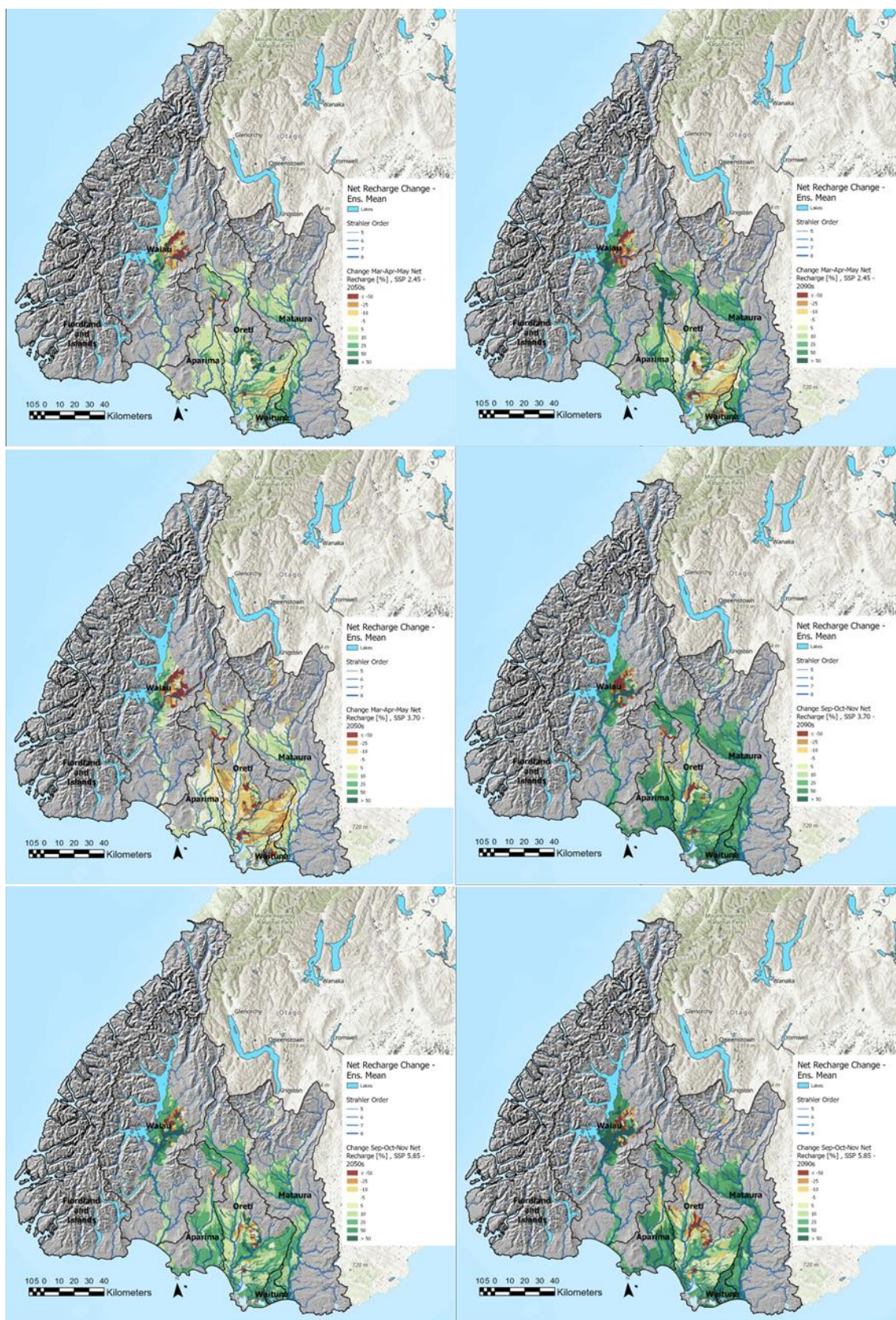


Figure D-11: Change multi-model average March-April-May (autumn) land surface recharge calculated on hydrological year. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Monthly time scale

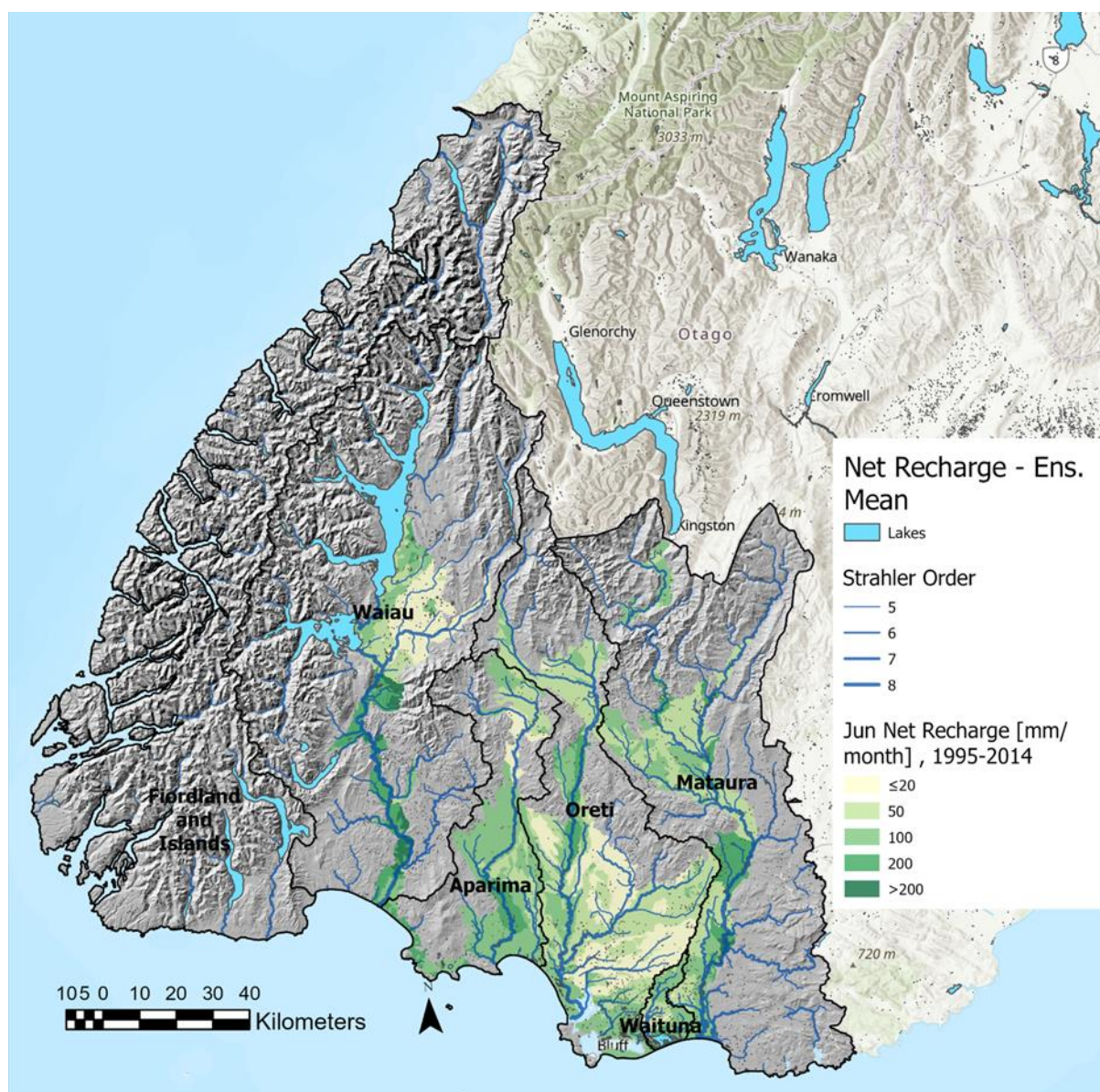


Figure D-12: Historical multi-model average June land surface recharge over Southland's shallow aquifers.

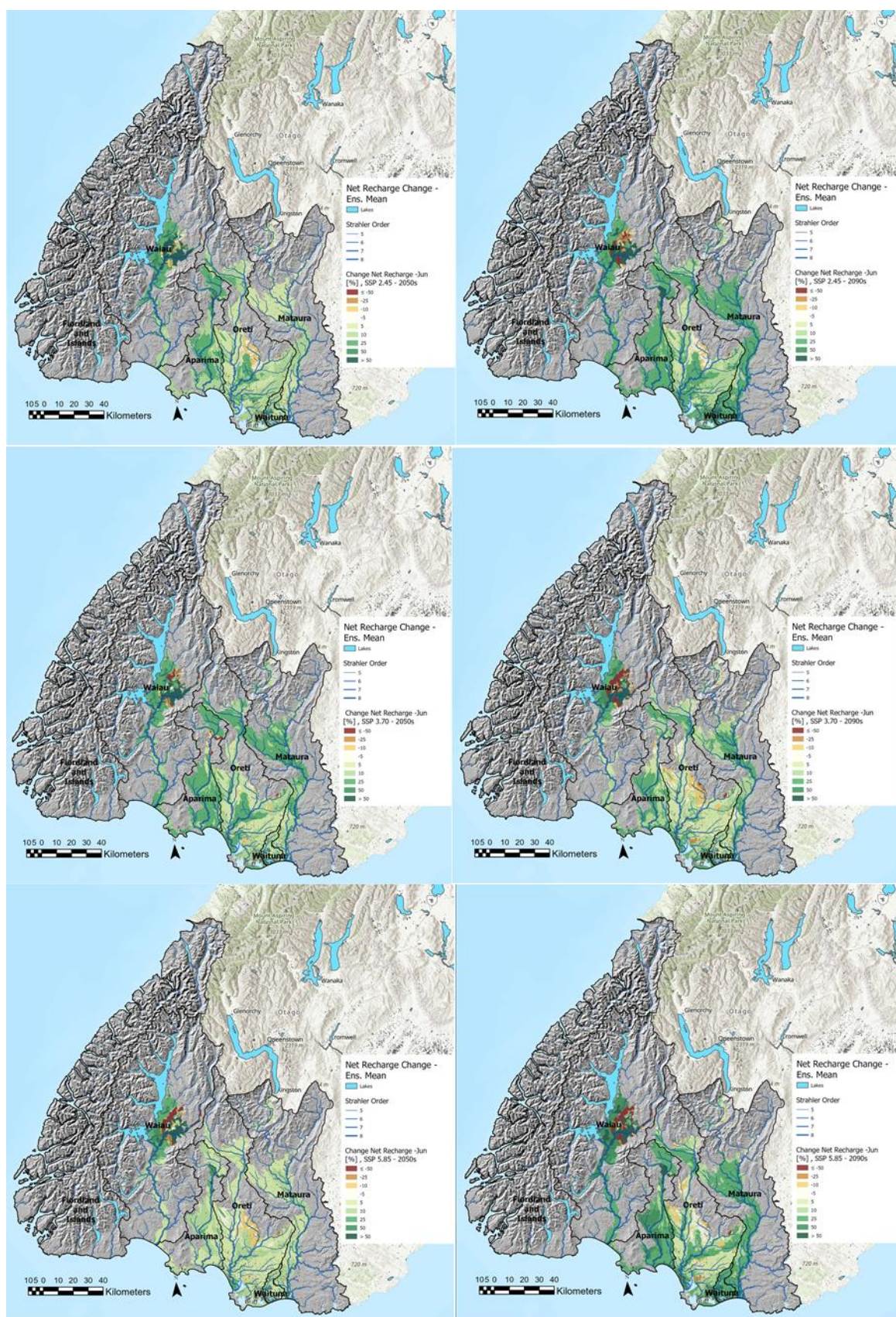


Figure D-13: Change multi-model average June land surface recharge over Southland’s shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

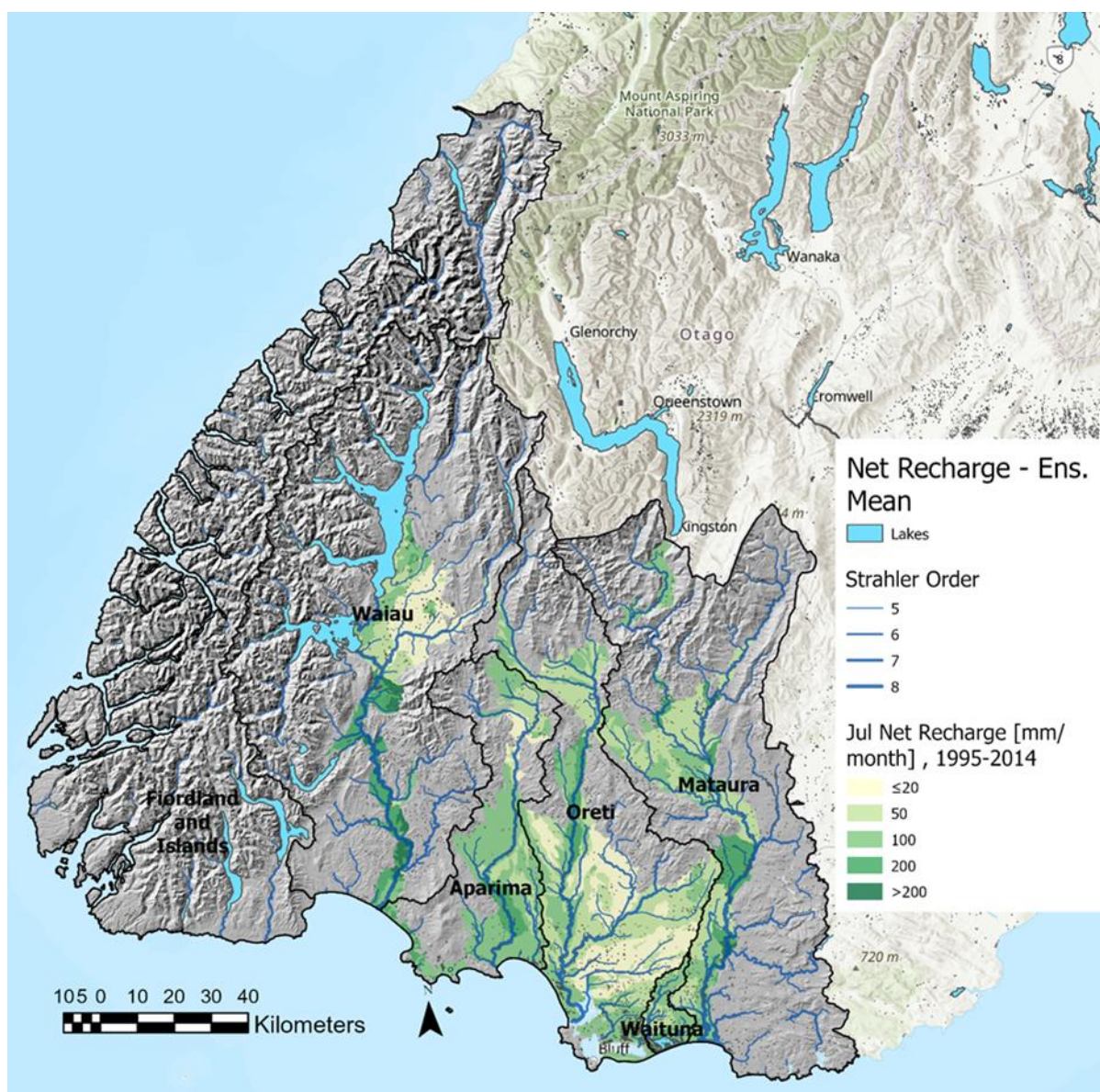


Figure D-14: Historical multi-model average July land surface recharge over Southland's shallow aquifers.

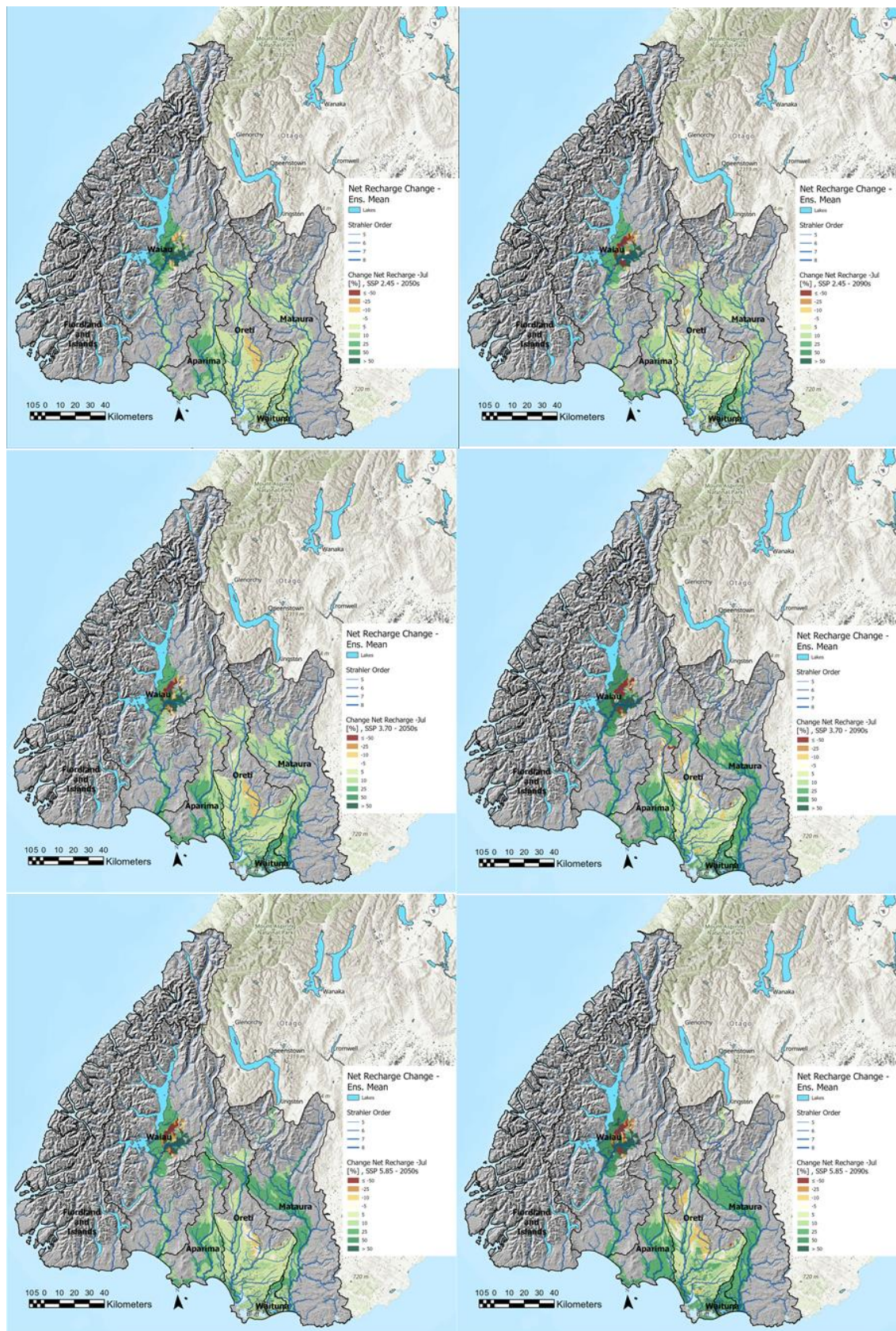


Figure D-15: Change multi-model average July land surface recharge over Southland’s shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

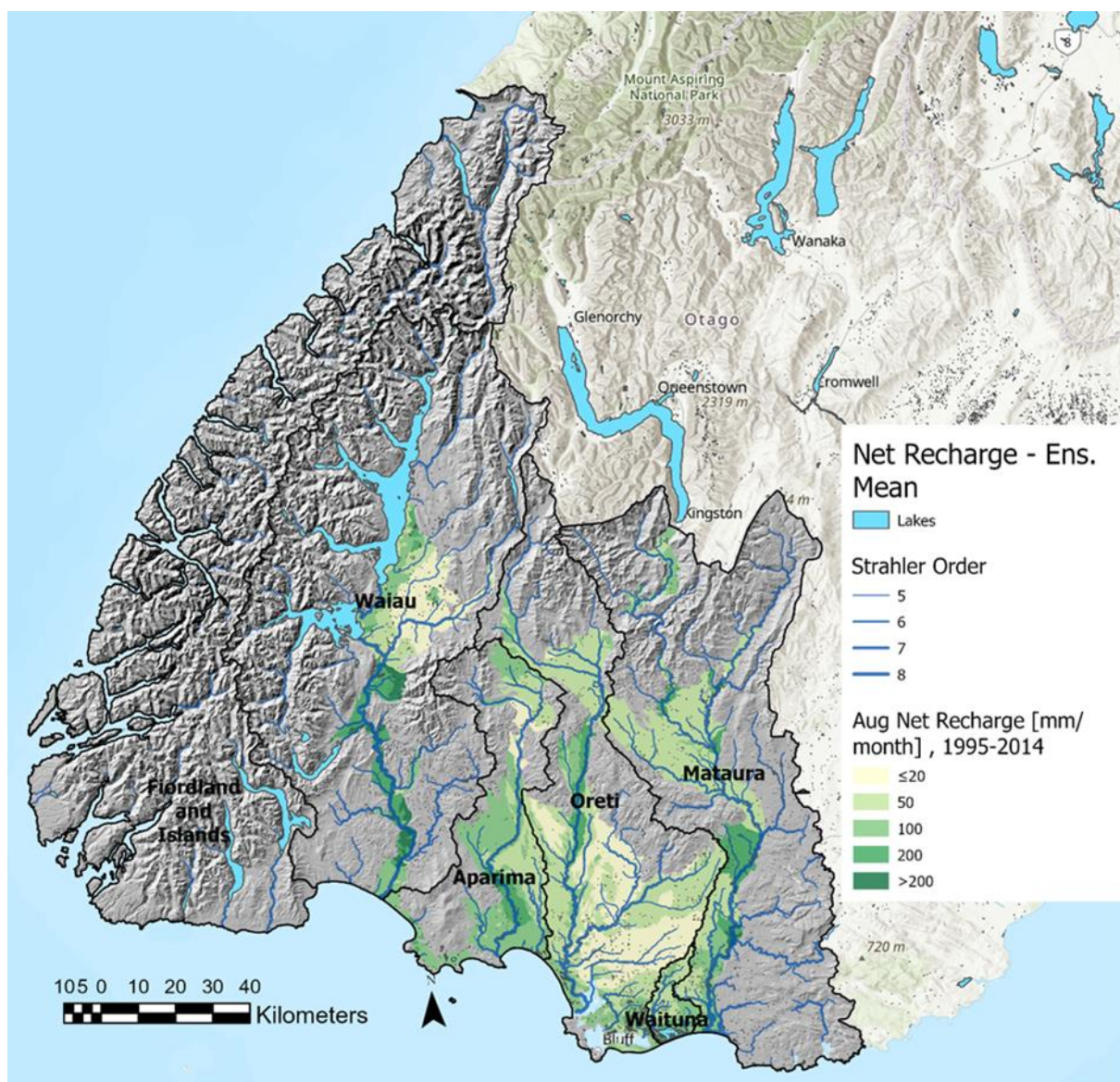


Figure D-16: Historical multi-model average August land surface recharge over Southland's shallow aquifers.

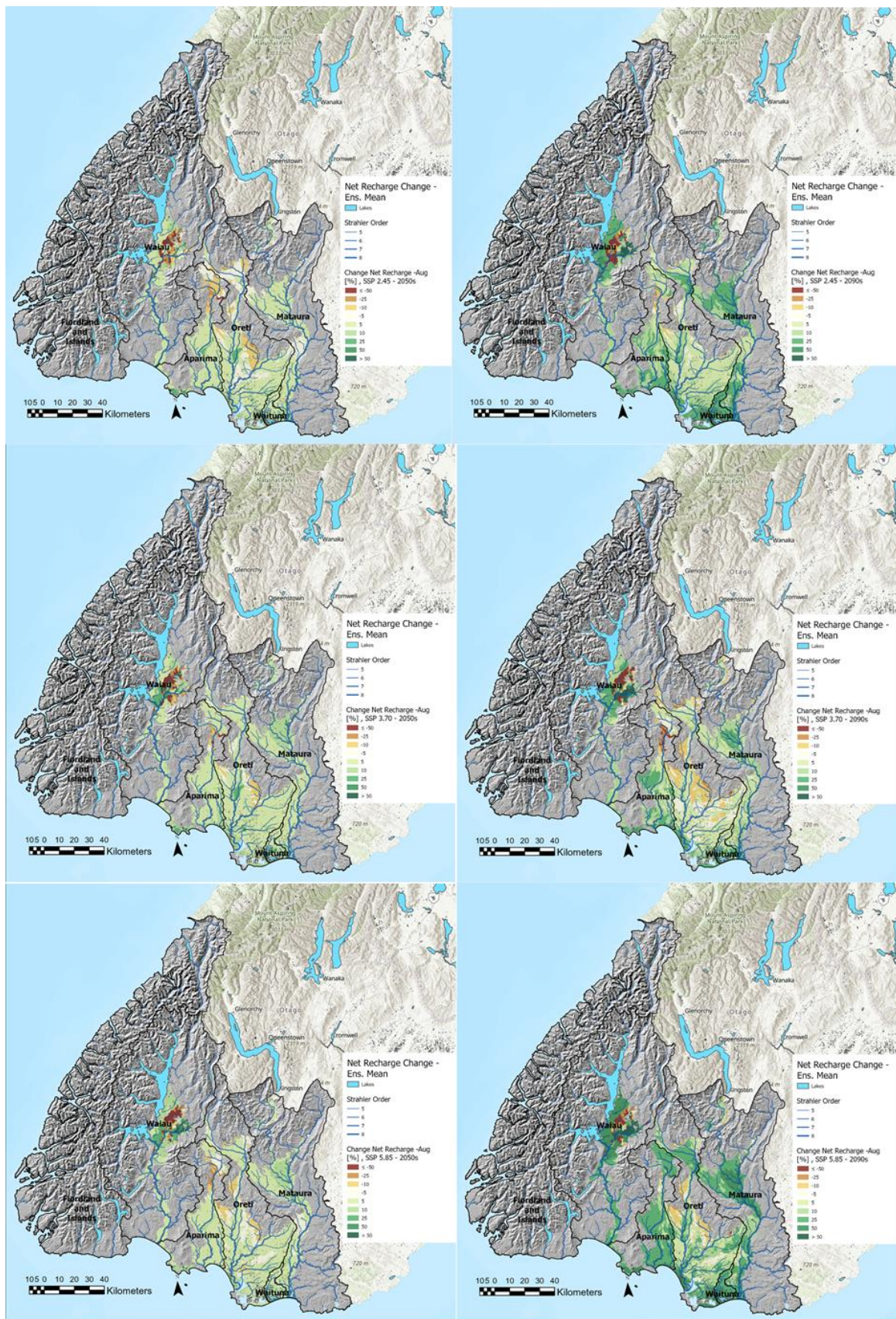


Figure D-17: Change multi-model average August land surface recharge over Southland's shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

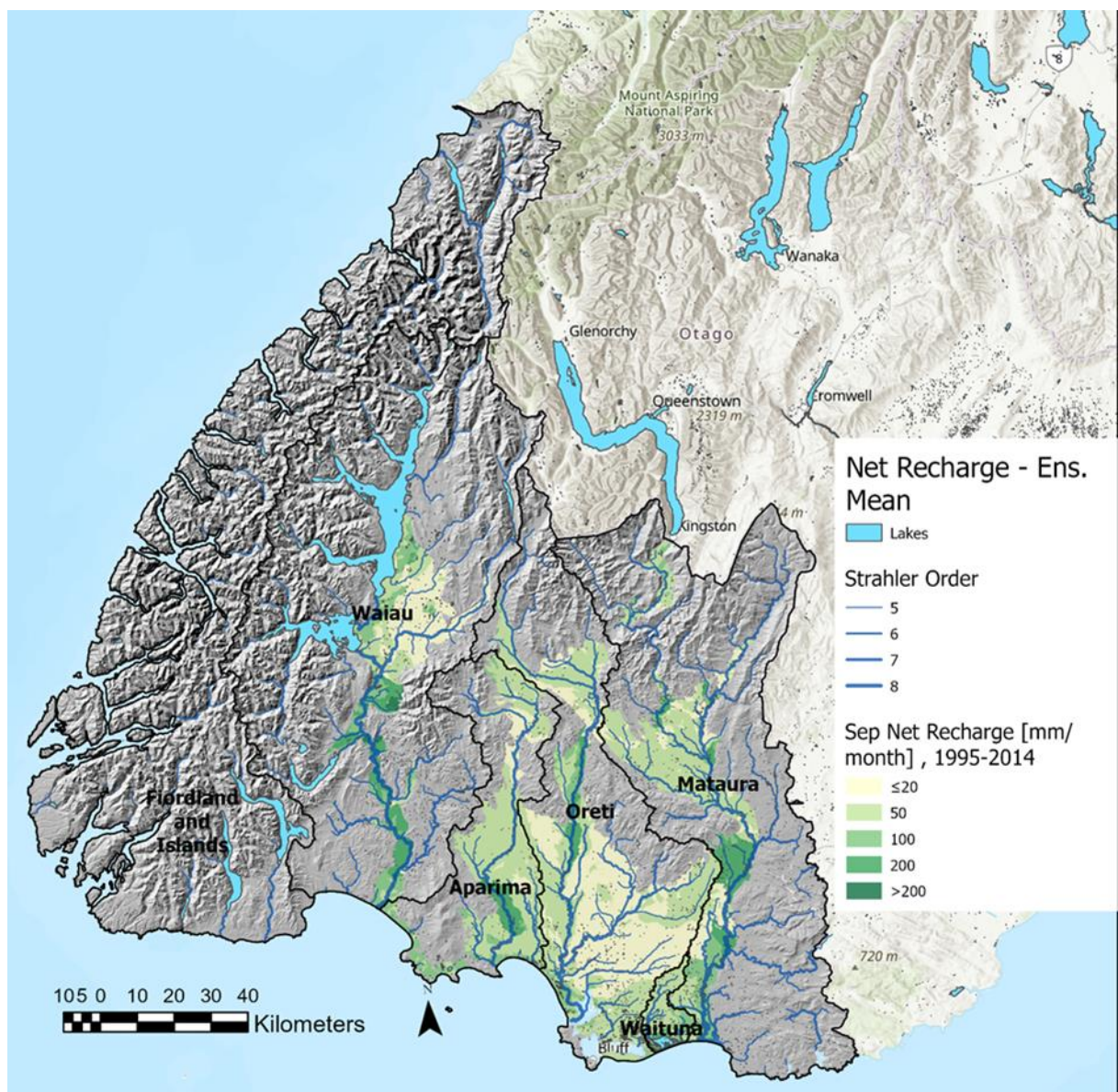


Figure D-18: Historical multi-model average September land surface recharge over Southland's shallow aquifers.

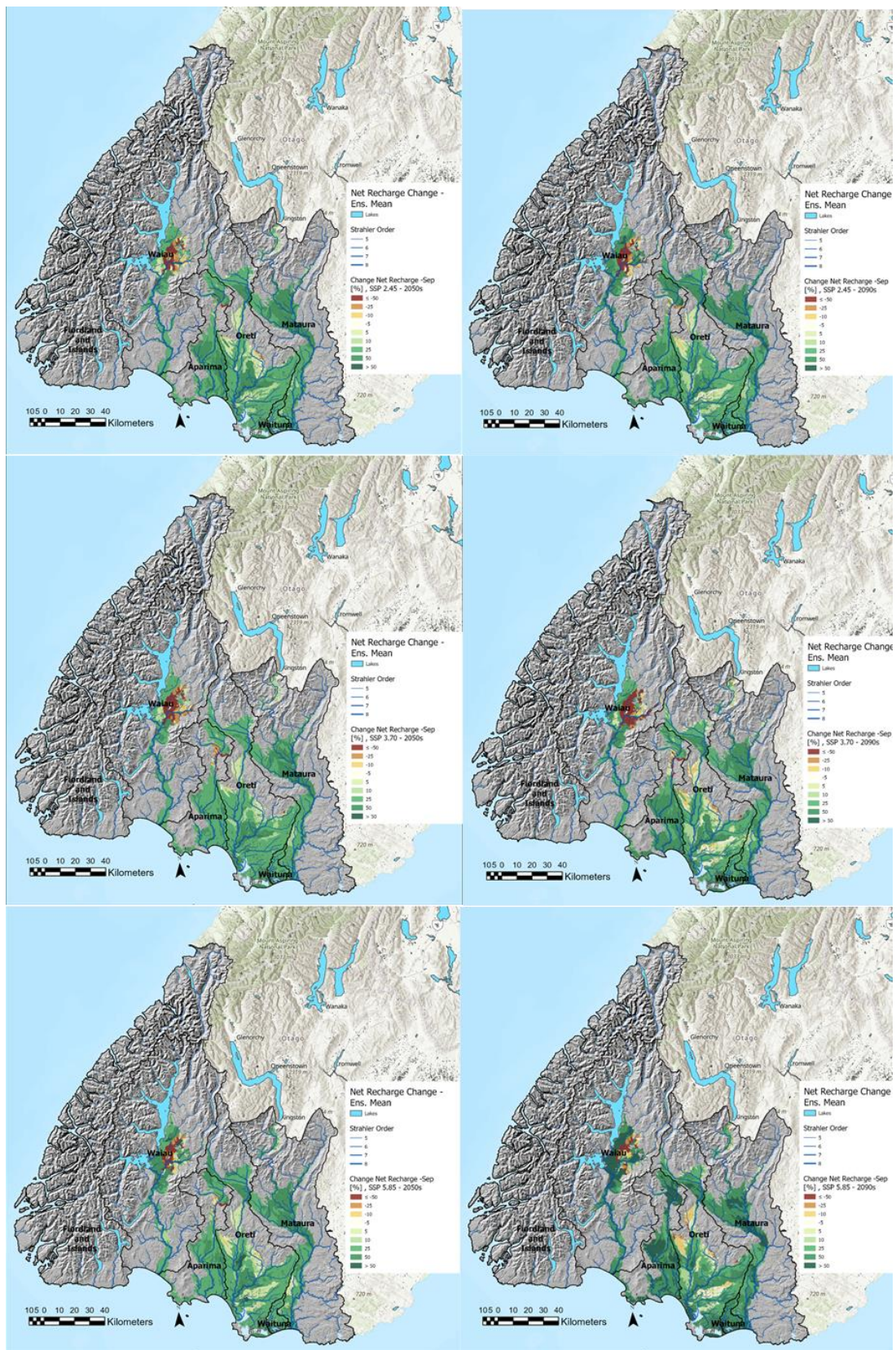


Figure D-19: Change multi-model average September land surface recharge over Southland's shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

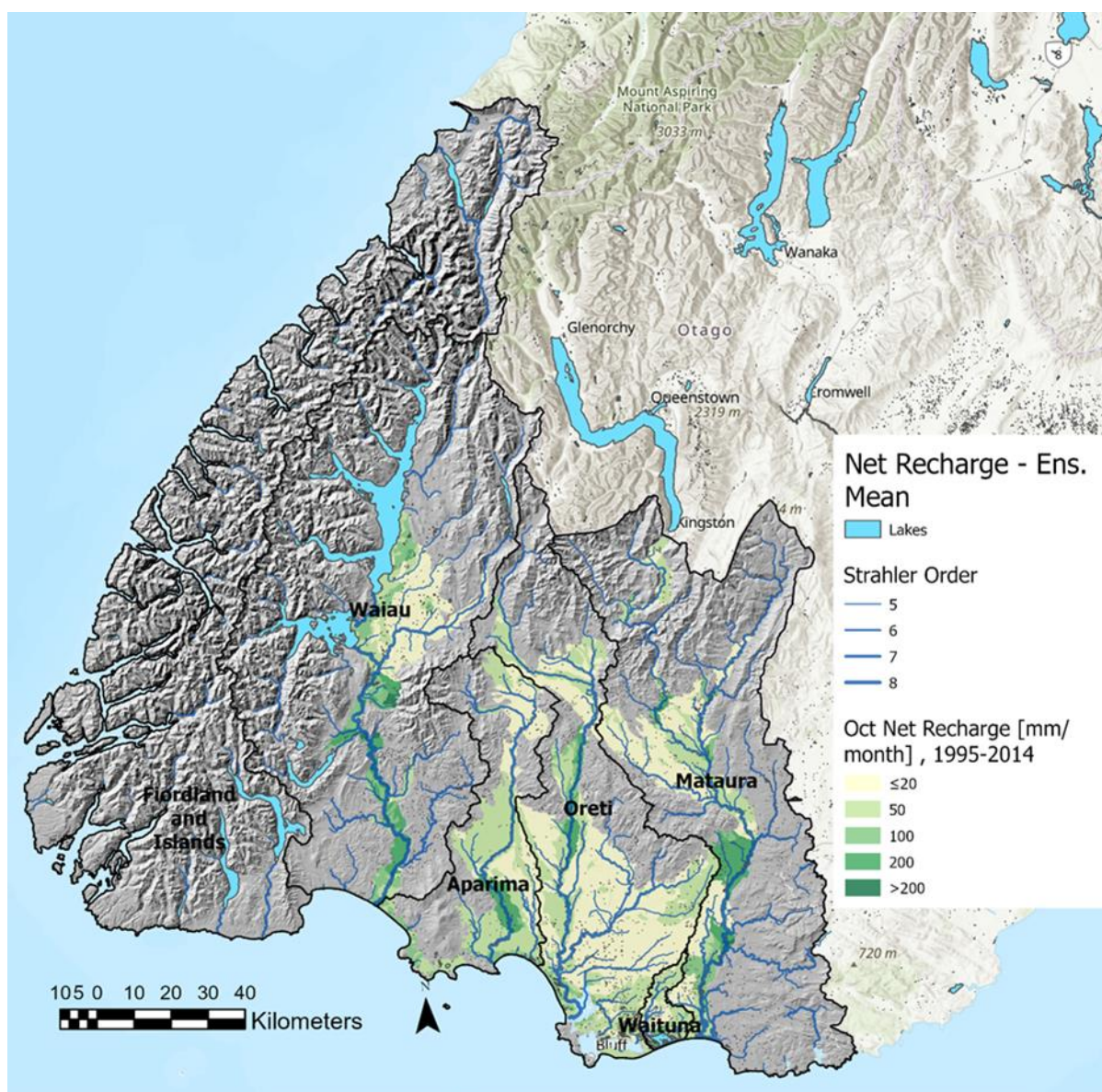


Figure D-20: Historical multi-model average October land surface recharge over Southland's shallow aquifers.

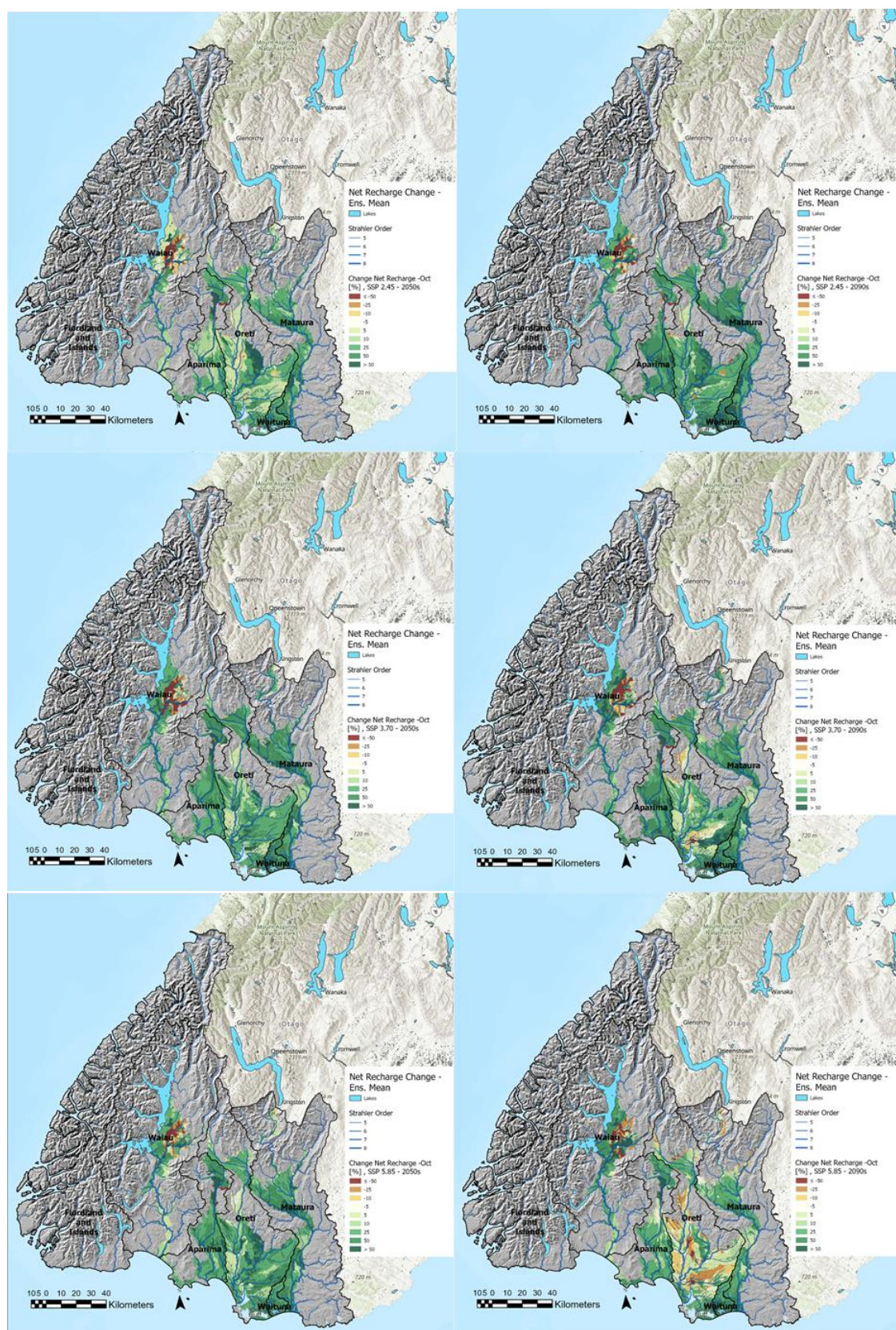


Figure D-21: Change multi-model average October land surface recharge over Southland's shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

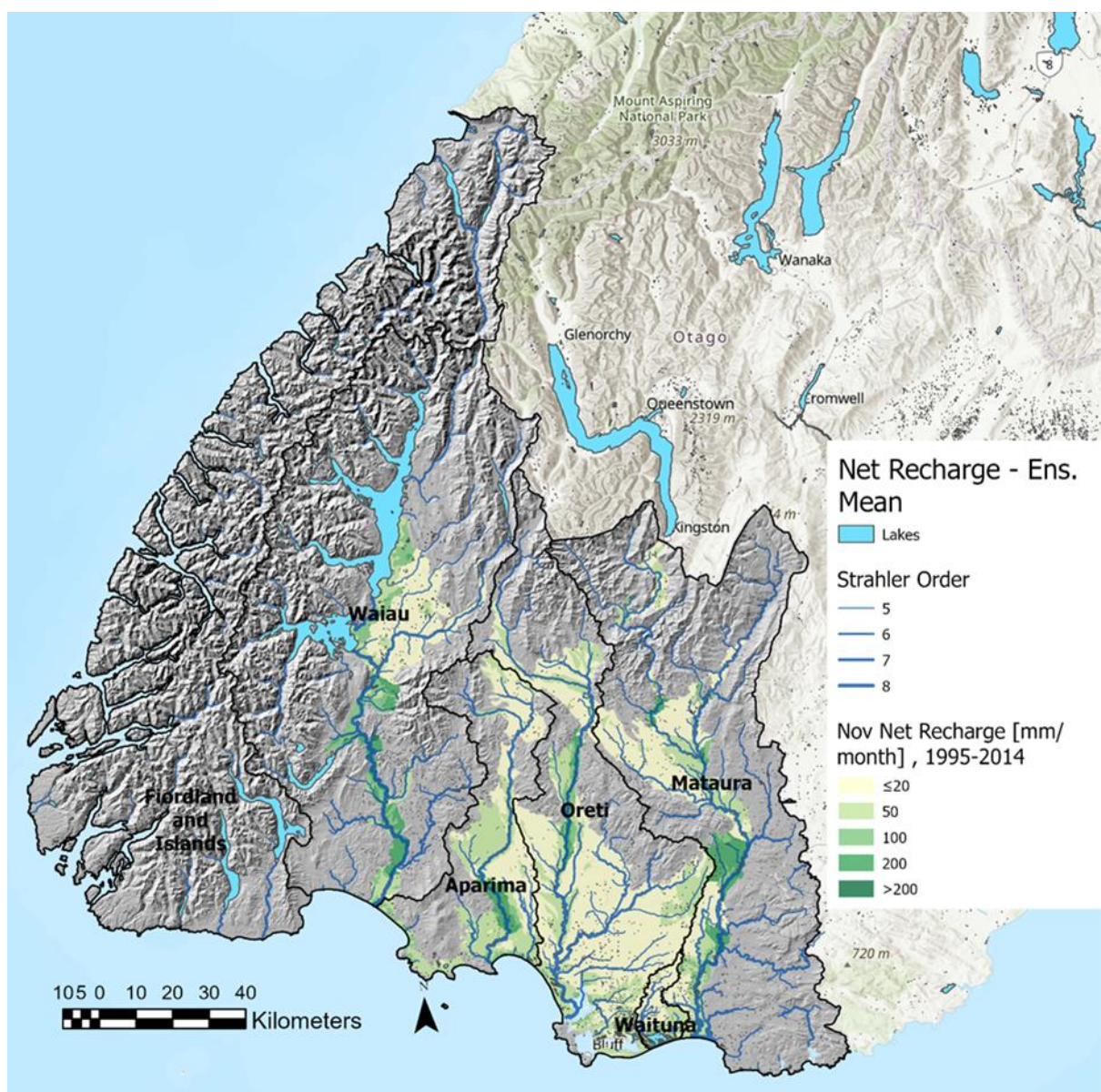


Figure D-22: Historical multi-model average November land surface recharge over Southland's shallow aquifers.

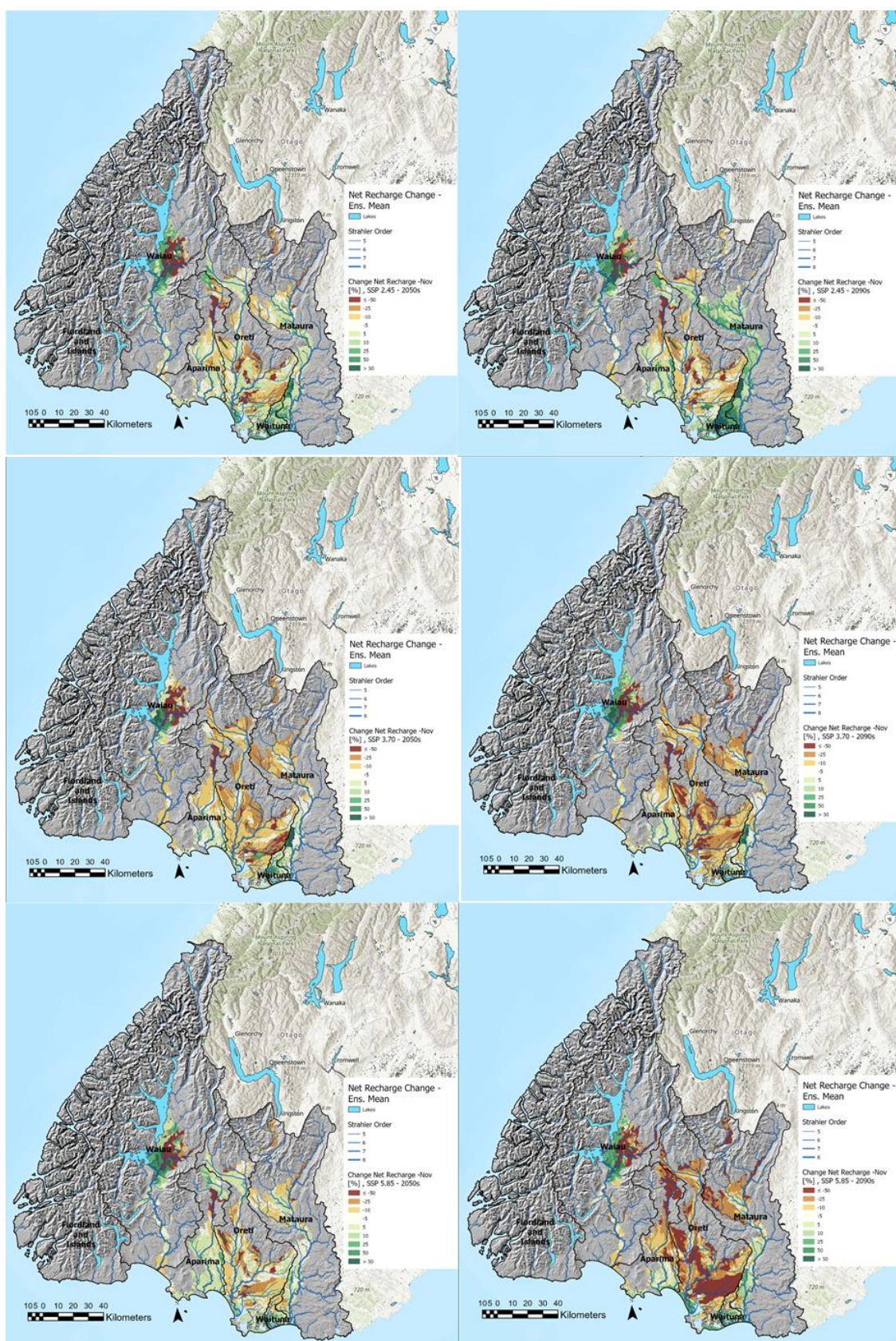


Figure D-23: Change multi-model average November land surface recharge over Southland’s shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

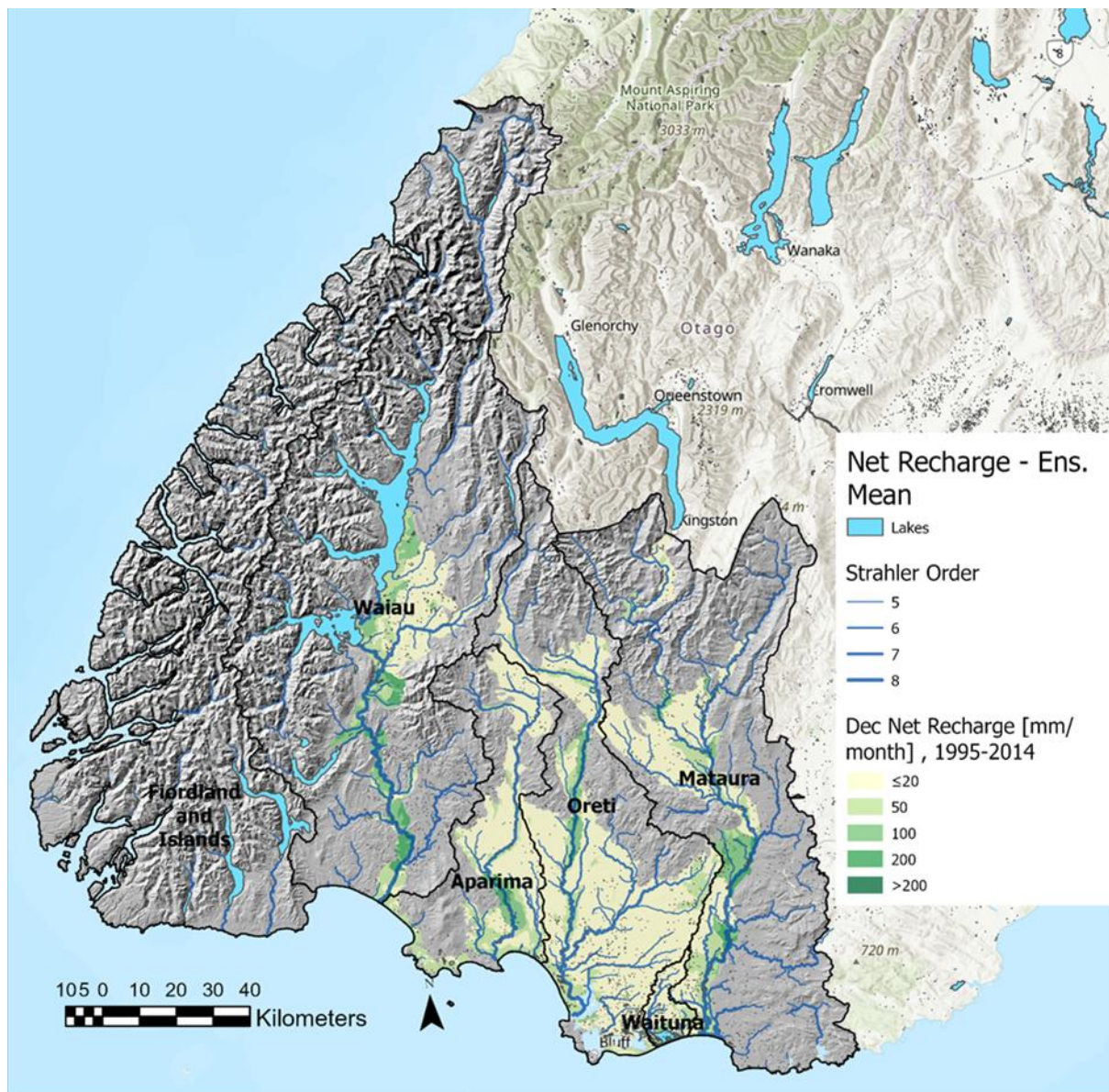


Figure D-24: Historical multi-model average December land surface recharge over Southland's shallow aquifers.

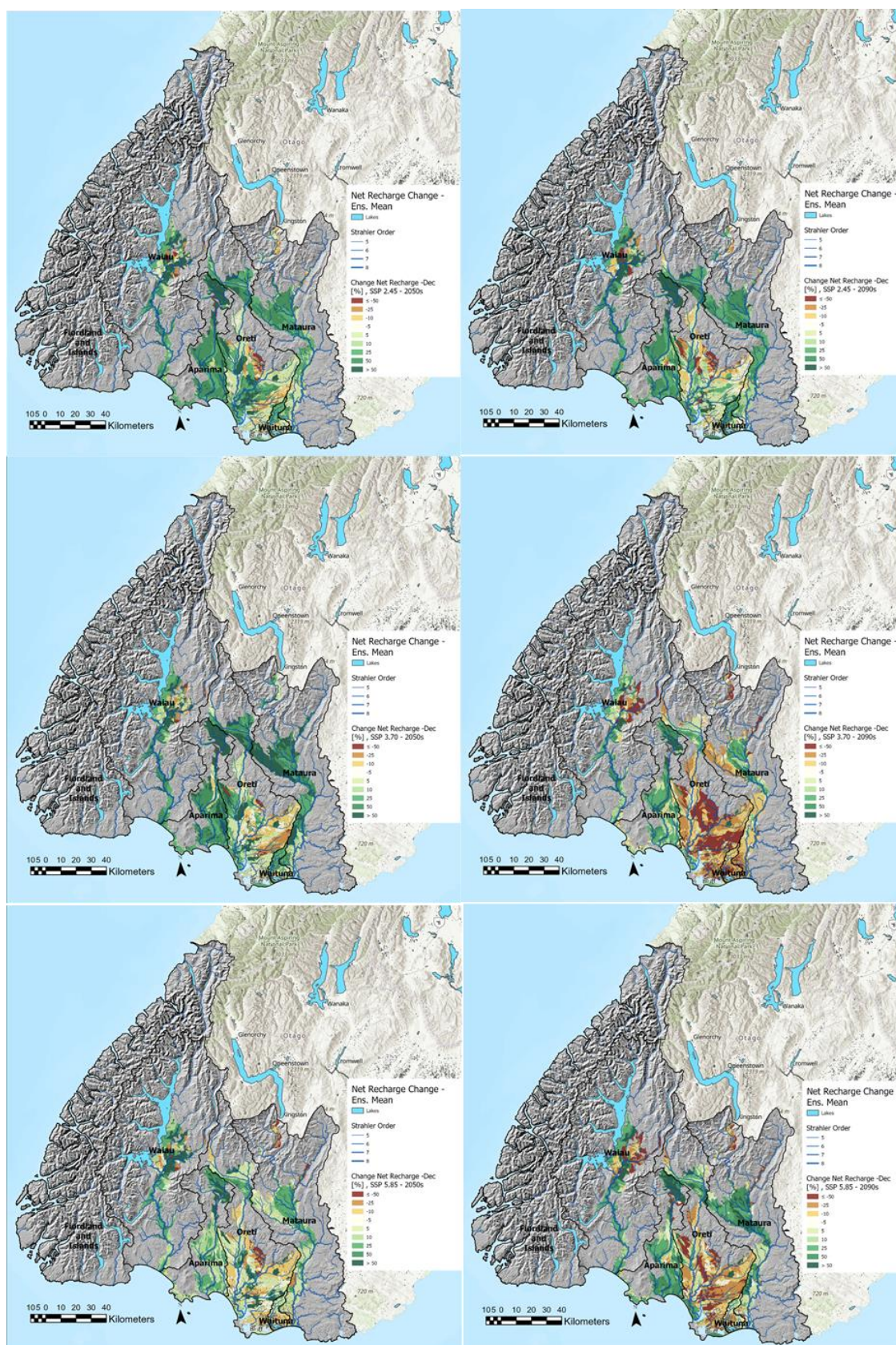


Figure D-25: Change multi-model average December land surface recharge over Southland’s shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

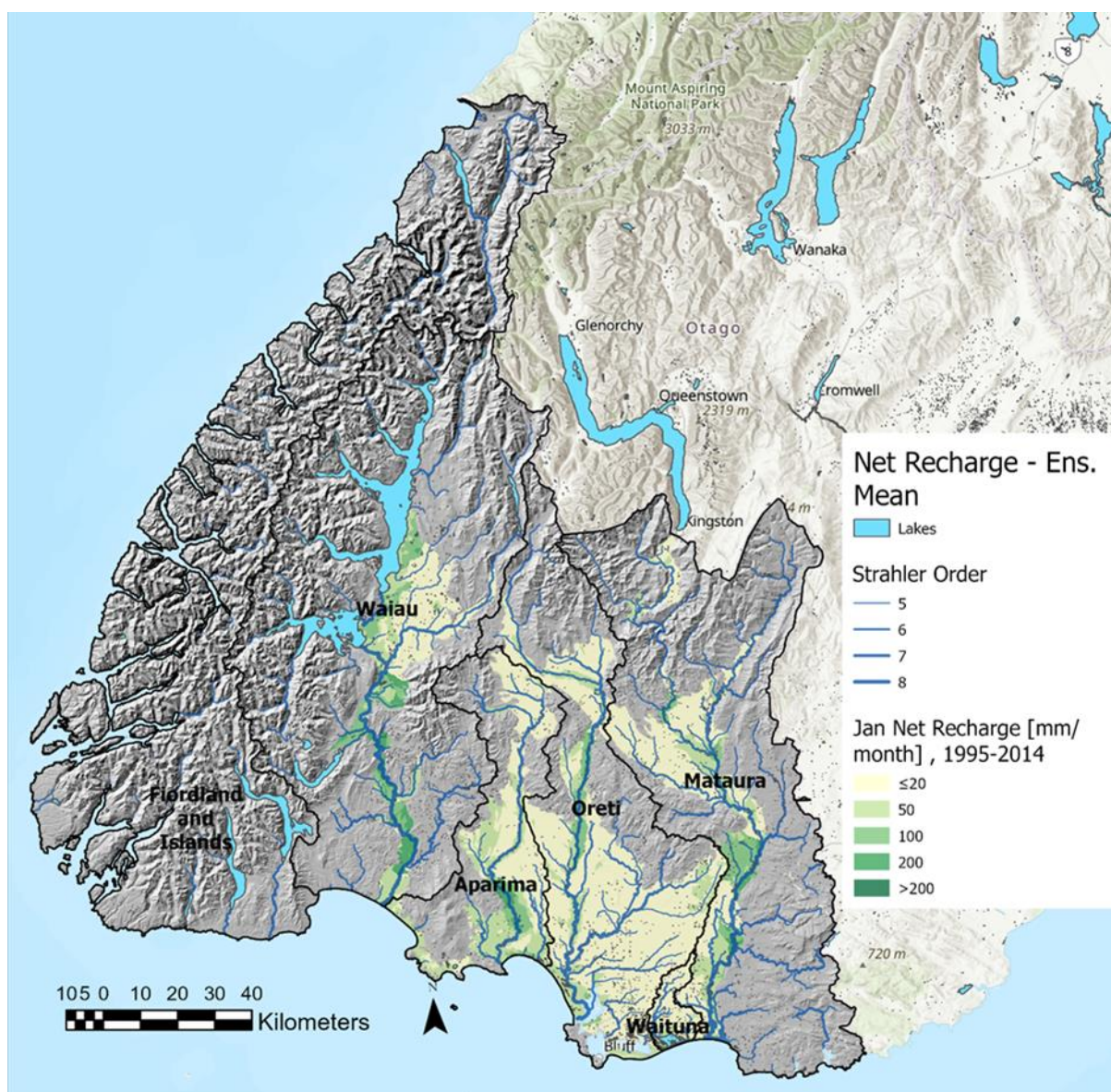


Figure D-26: Historical multi-model average January land surface recharge over Southland's shallow aquifers.

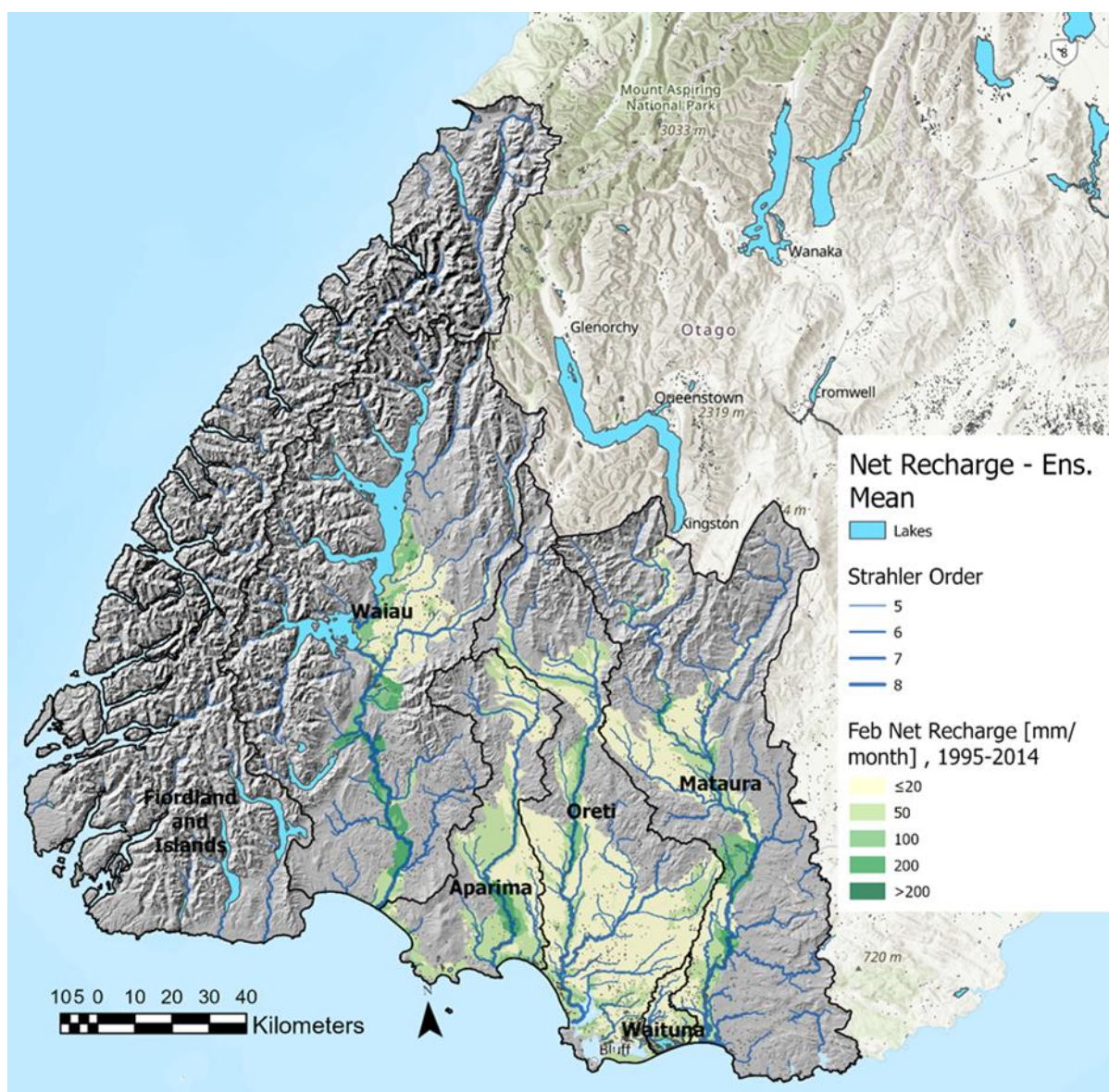


Figure D-28: Historical multi-model average February land surface recharge over Southland's shallow aquifers.

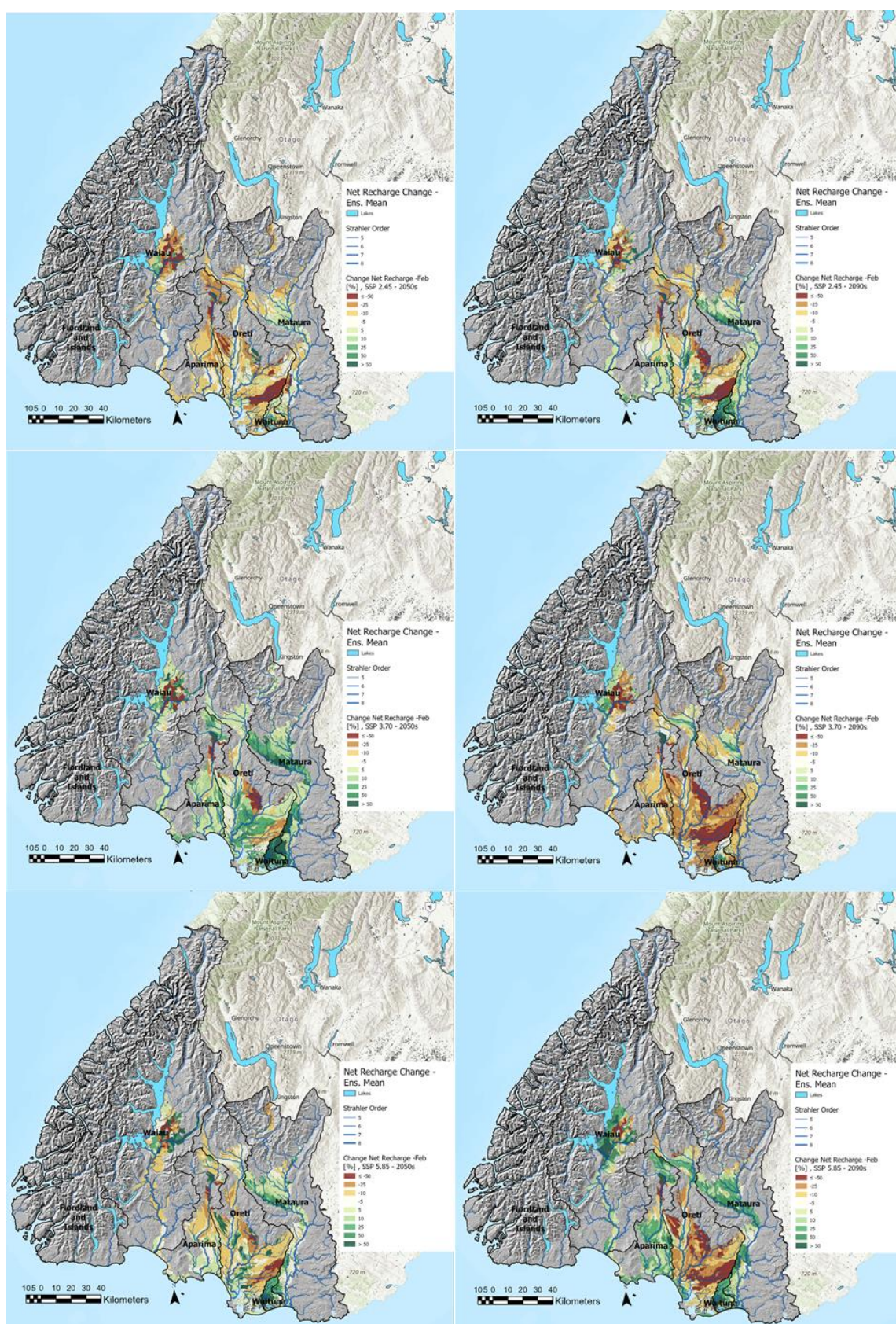


Figure D-29: Change multi-model average February land surface recharge over Southland’s shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

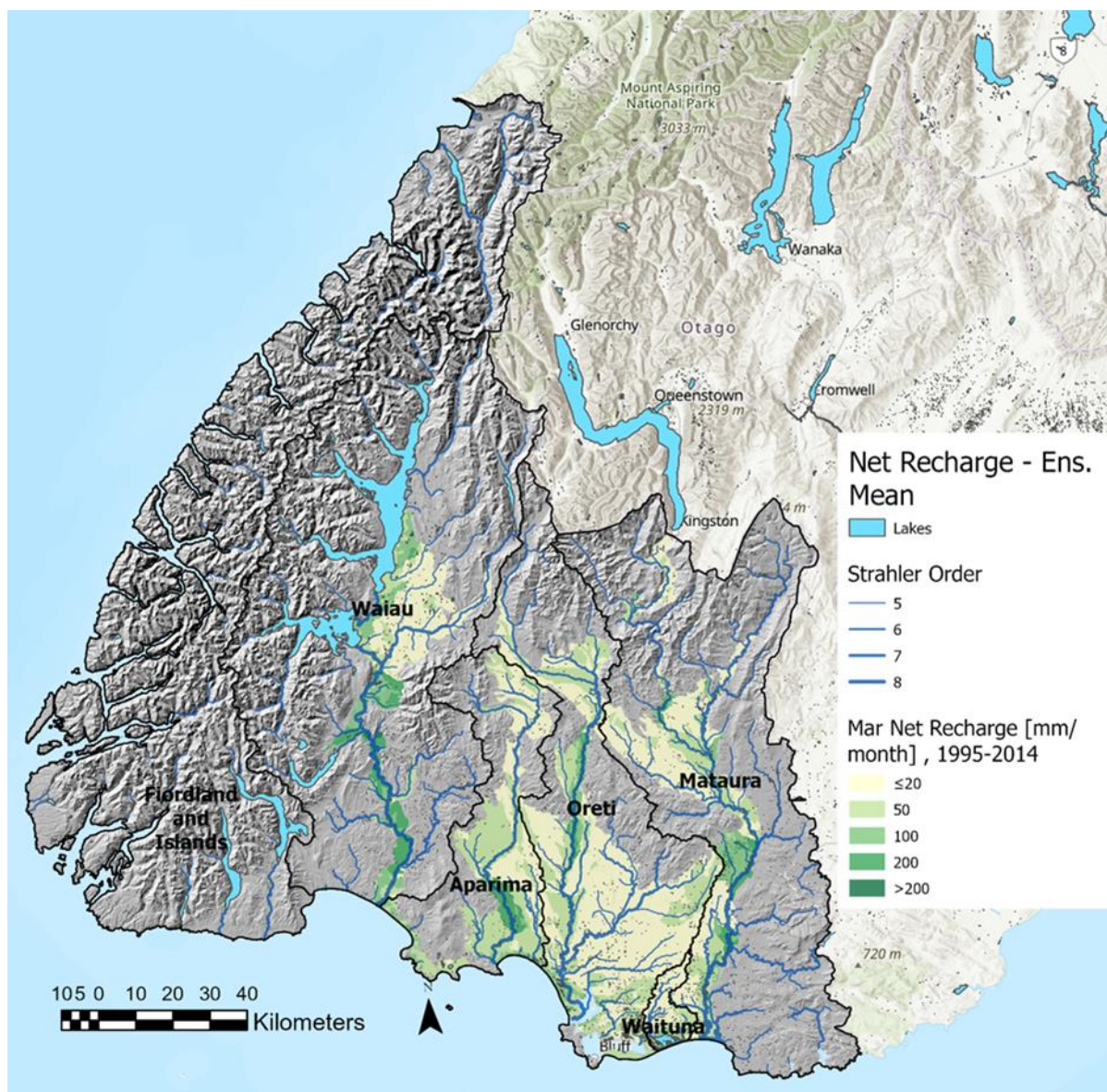


Figure D-30: Historical multi-model average March land surface recharge over Southland's shallow aquifers.

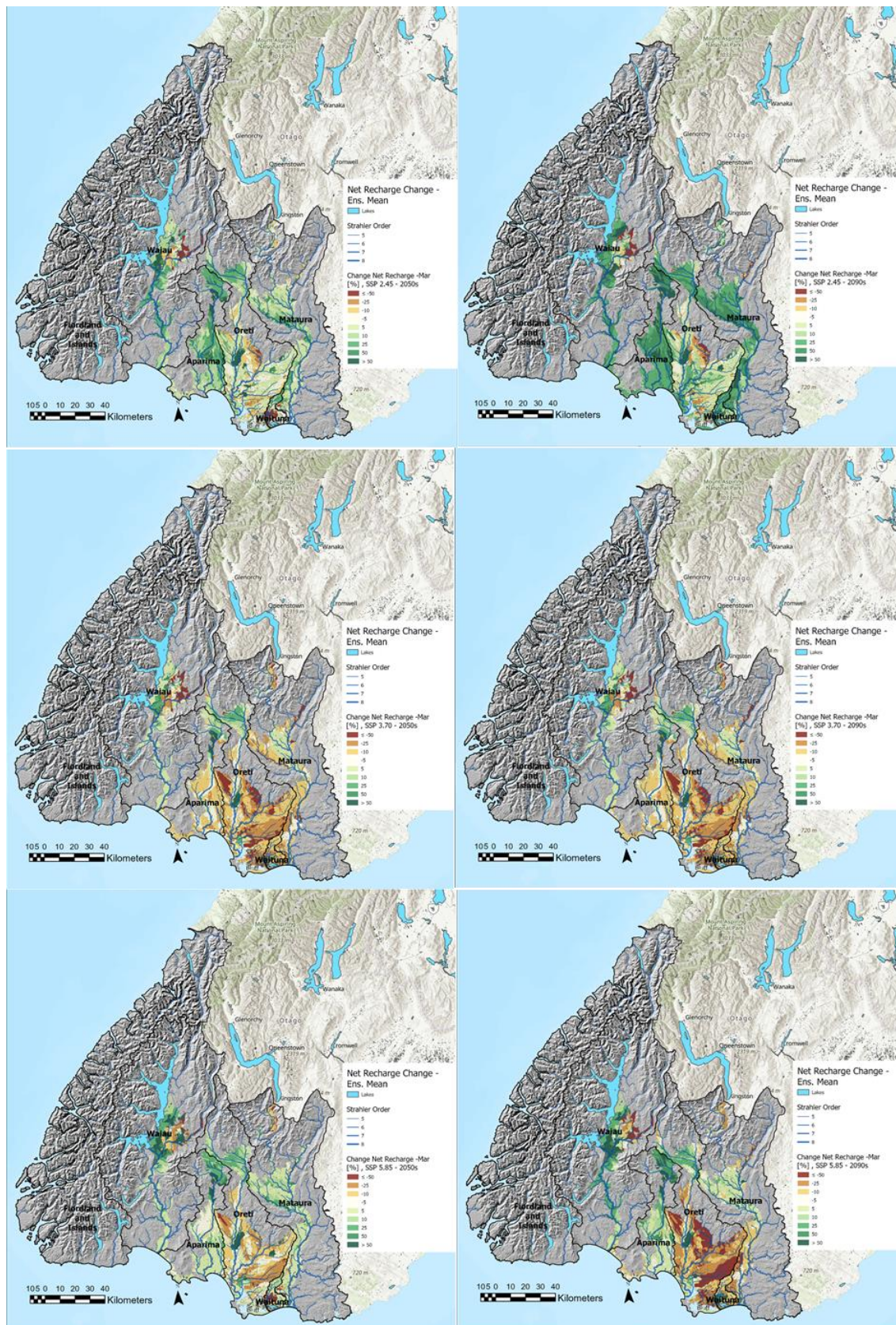


Figure D-31: Change multi-model average March land surface recharge over Southland’s shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

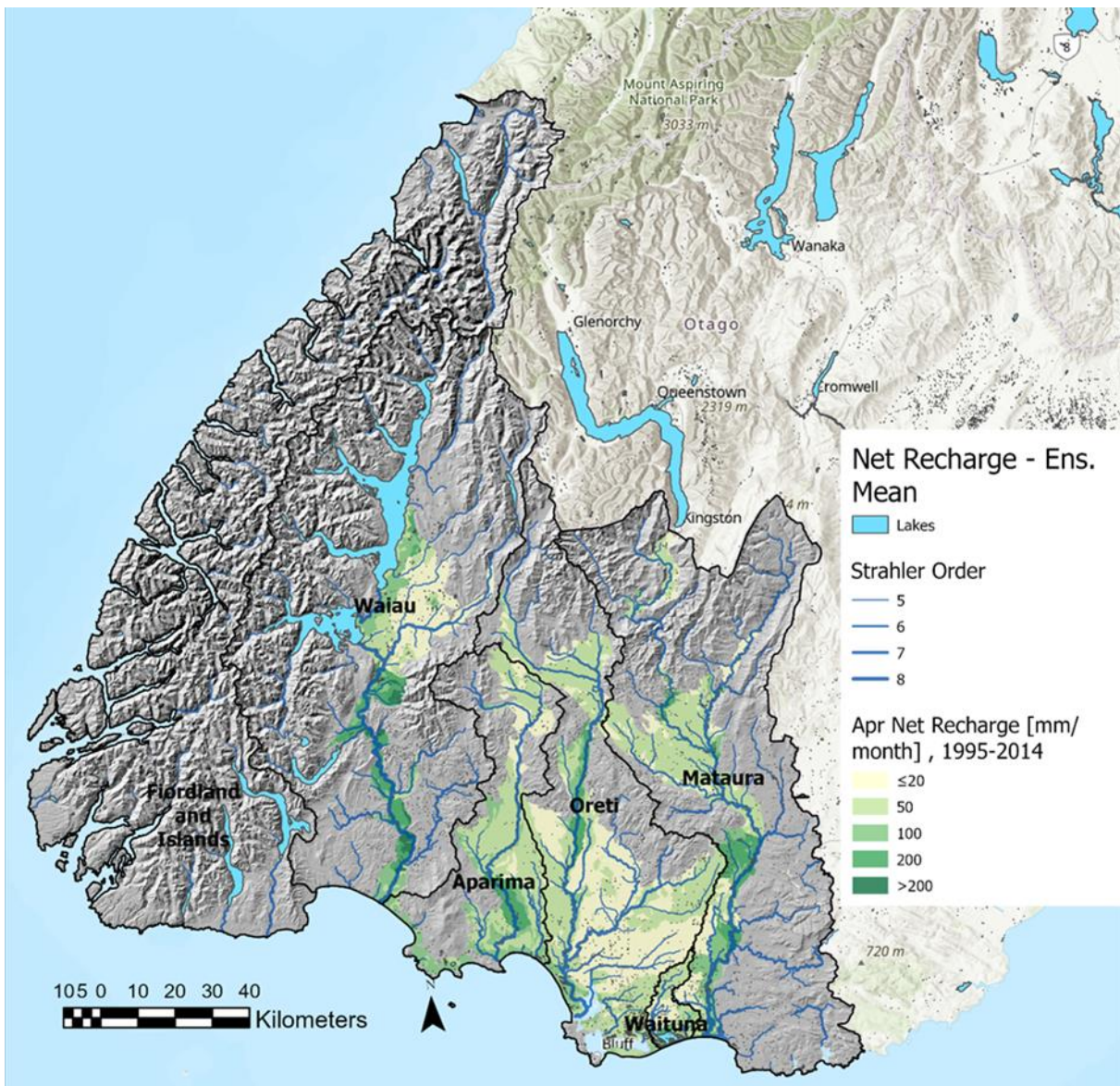


Figure D-32: Historical multi-model average April land surface recharge over Southland's shallow aquifers.

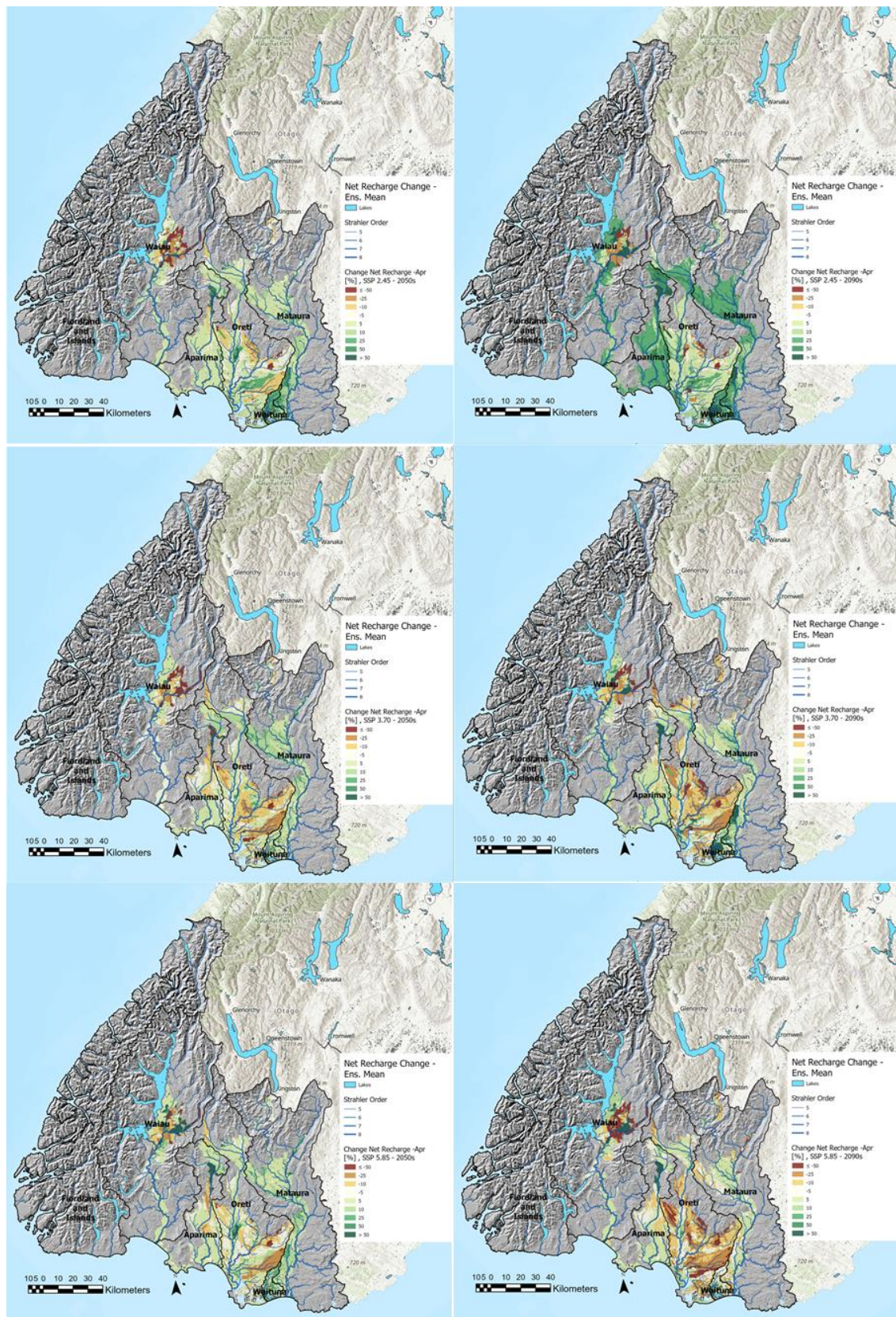


Figure D-33: Change multi-model average April land surface recharge over Southland’s shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

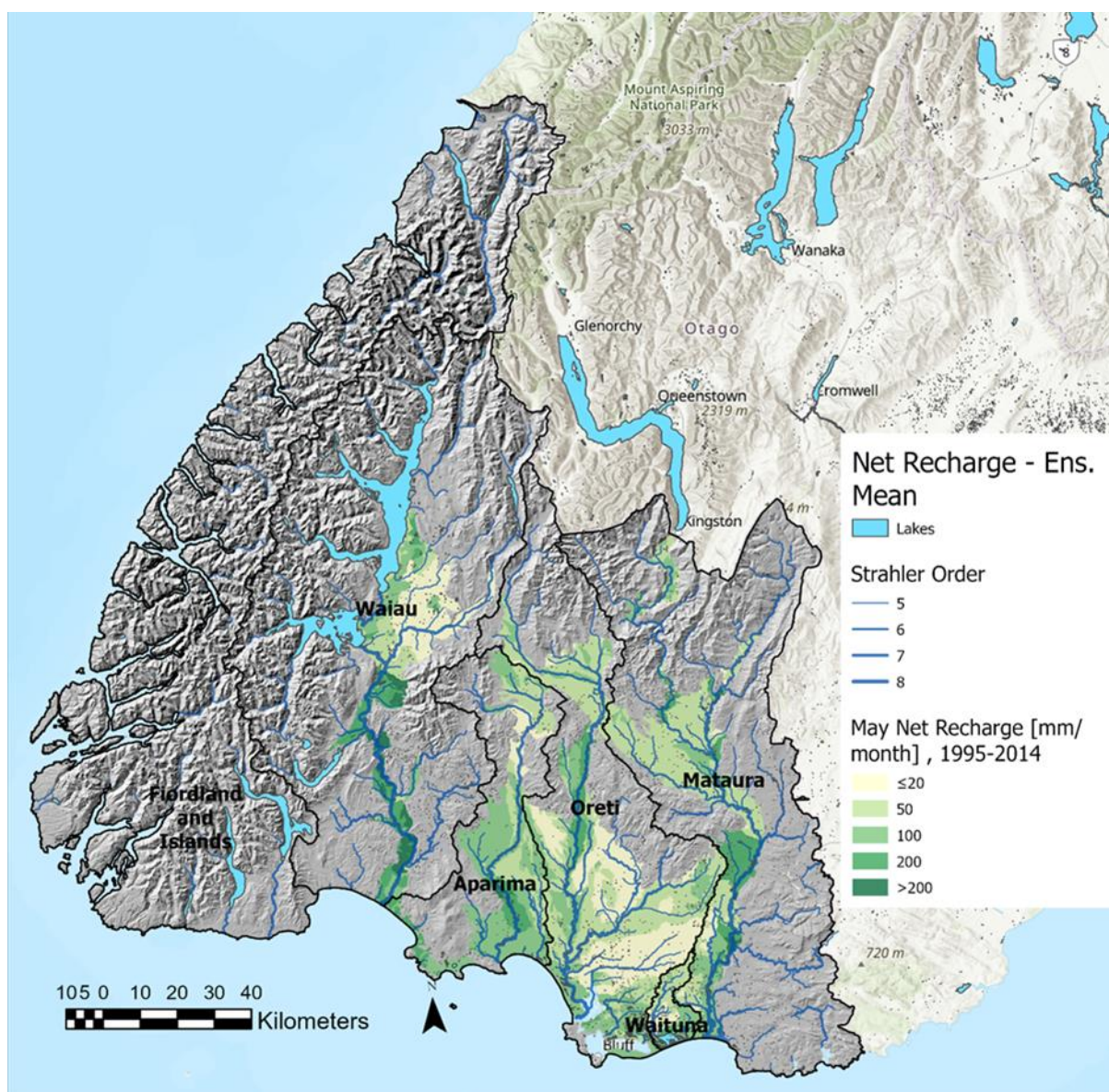


Figure D-34: Historical multi-model average May land surface recharge over Southland's shallow aquifers.

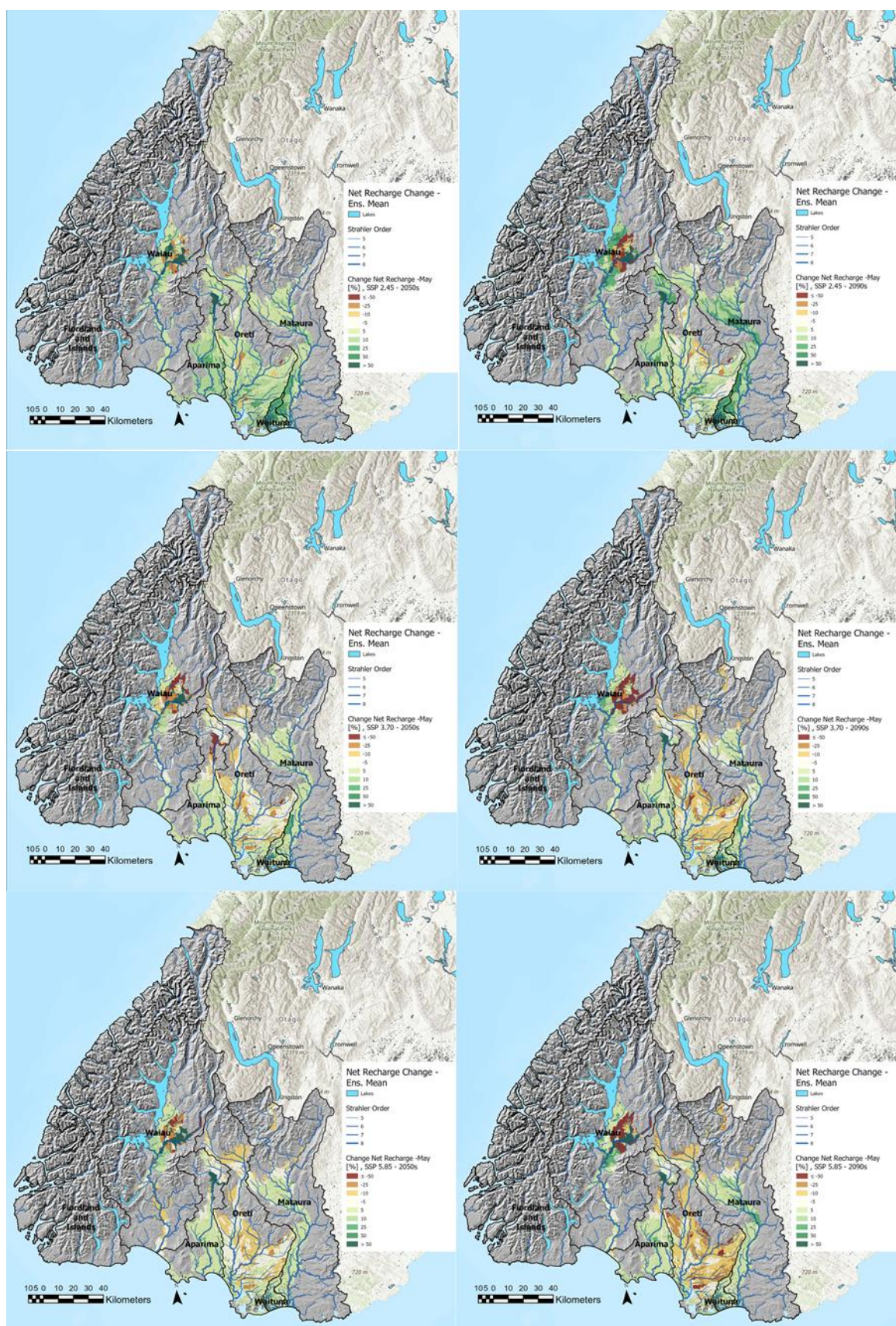


Figure D-35: Change multi-model average May land surface recharge over Southland’s shallow aquifers. Change in multi-model average seasonal land surface recharge is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

Appendix E Hydrological extremes

Aparima FMU

Aparima at Thornbury Bridge

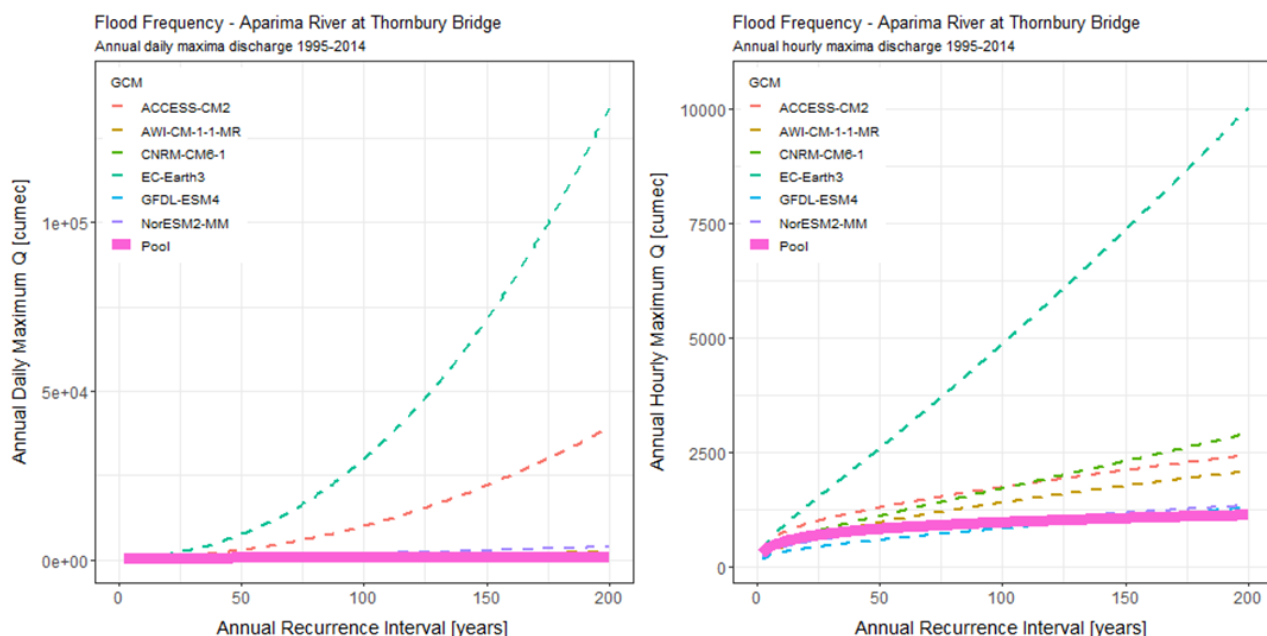


Figure E-1: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for Aparima River at Thornbury Bridge. Flood frequency generated nzsegment 1544050 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

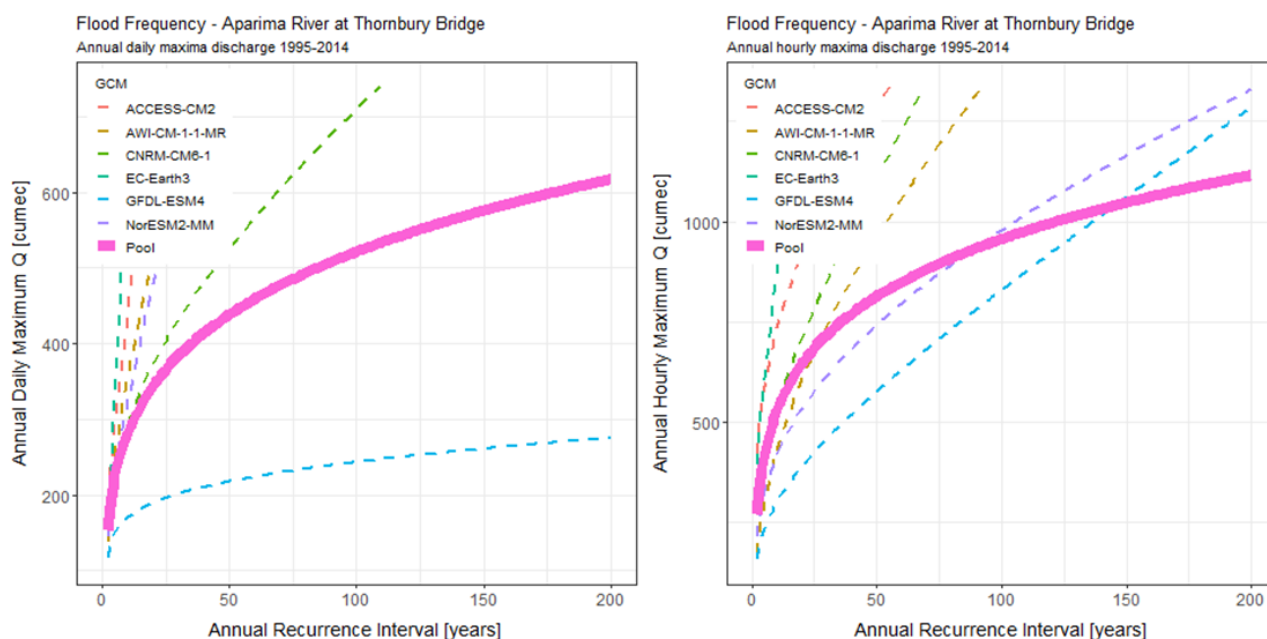


Figure E-2: Scaled simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for Aparima River at Thornbury Bridge. Flood frequency generated nzsegment 1544050 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

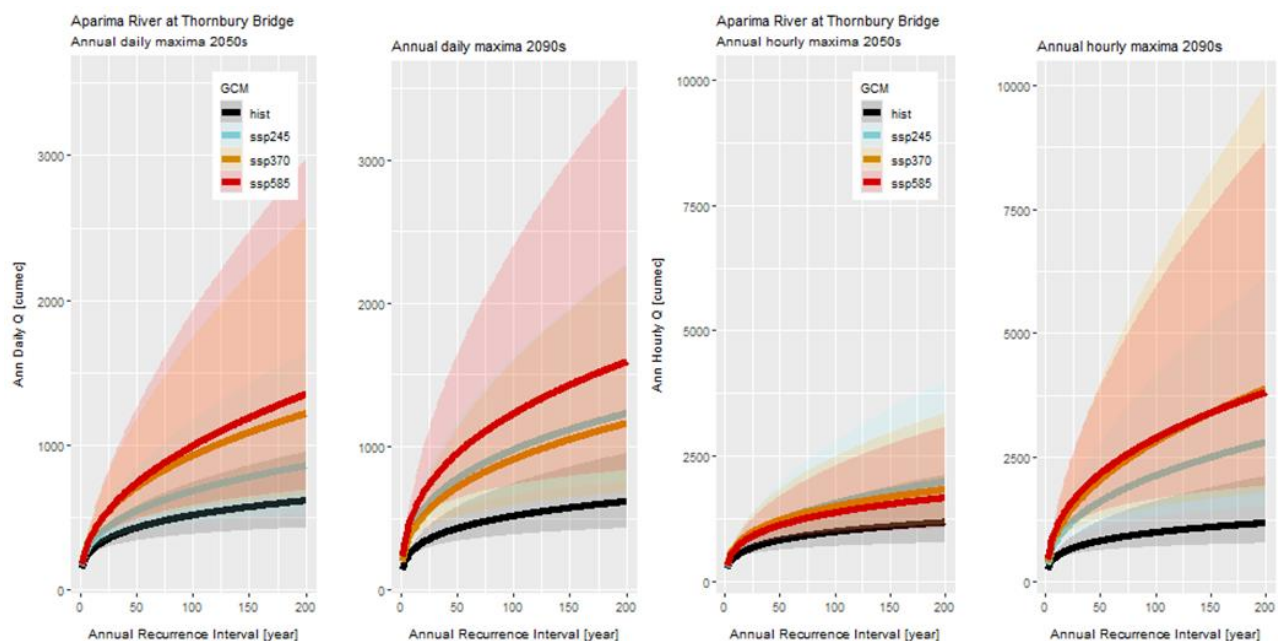


Figure E-3: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for Aparima River at Thornbury Bridge for four warming scenarios. Pooled flood frequency presented at nzsegment 1544050 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-1: Pooled multi-model daily maxima flood distribution parameters for Aparima River at Thornbury Bridge. Daily maxima flood extreme event distribution generated using General Extreme Value distribution under stationarity assumption at nzsegment 1544050 for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3\cdot\text{s}^{-1}$]	Scale [$\text{m}^3\cdot\text{s}^{-1}$]	Shape [-]
Historical	2004	137.7	55.5	0.160
SSP2-4.5	2050	145.1	53.1	0.289
	2090	167.2	79.2	0.301
SSP3-7.0	2050	156.4	68.9	0.312
	2090	177.0	71.4	0.287
SSP5-8.5	2050	152.7	60.9	0.390
	2090	195.1	99.6	0.293

Table E-2: Pooled multi-model hourly maxima flood distribution parameters for Aparima River at Thornbury Bridge. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 1544050 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
Historical	2004	214.4	112.9	0.152
SSP2-4.5	2050	247.6	123.5	0.310
	2090	287.4	157.8	0.327
SSP3-7.0	2050	297.2	158.8	0.189
	2090	323.9	182.2	0.376
SSP5-8.5	2050	271.5	143.8	0.189
	2090	362.3	225.4	0.326

Table E-3: Projected changes in pooled multi-model daily maxima flood magnitude for Aparima River at Thornbury Bridge (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	4.2	26.8	16.8	29.5	12.2	50.5
5-year level	5.6	37.0	24.5	34.2	19.7	65.4
10-year level	9.0	46.9	33.0	40.2	30.0	79.0
20-year level	13.6	57.8	43.2	47.7	43.6	93.8
50-year level	21.7	74.5	59.5	59.8	67.3	116.4
100-year level	29.1	89.1	74.5	70.8	90.5	136.6
200-year level	37.9	105.7	92.5	83.7	119.5	160.2

Table E-4: Projected changes in pooled multi-model hourly maxima flood magnitude for Aparima at Thornbury Bridge (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	15.3	37.2	39.5	56.3	27.1	79.0
5-year level	19.7	46.7	41.7	71.4	28.7	97.8
10-year level	26.0	57.4	43.9	89.1	30.5	116.2
20-year level	34.0	70.1	46.4	111.0	32.5	136.8
50-year level	47.1	90.2	50.1	147.6	35.4	168.9
100-year level	59.0	108.3	53.2	182.8	37.8	197.9
200-year level	73.0	129.3	56.7	226.5	40.4	232.0

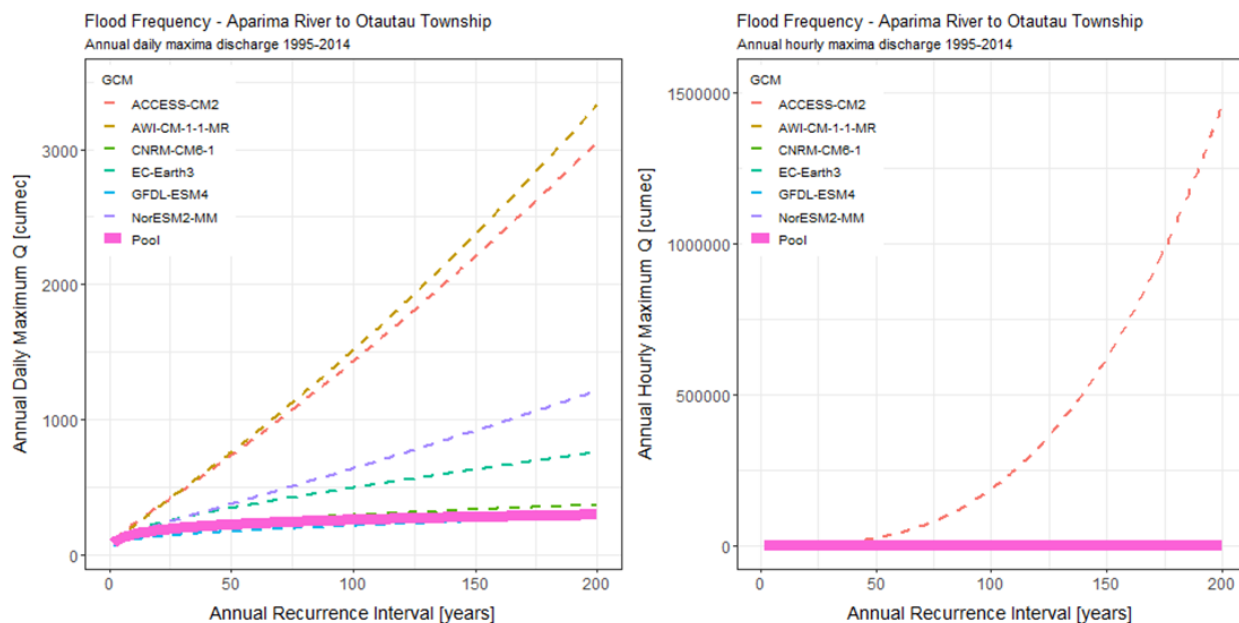


Figure E-4: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Aparima River at Otautau Township. Flood frequency generated at nzsegment 15438598 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

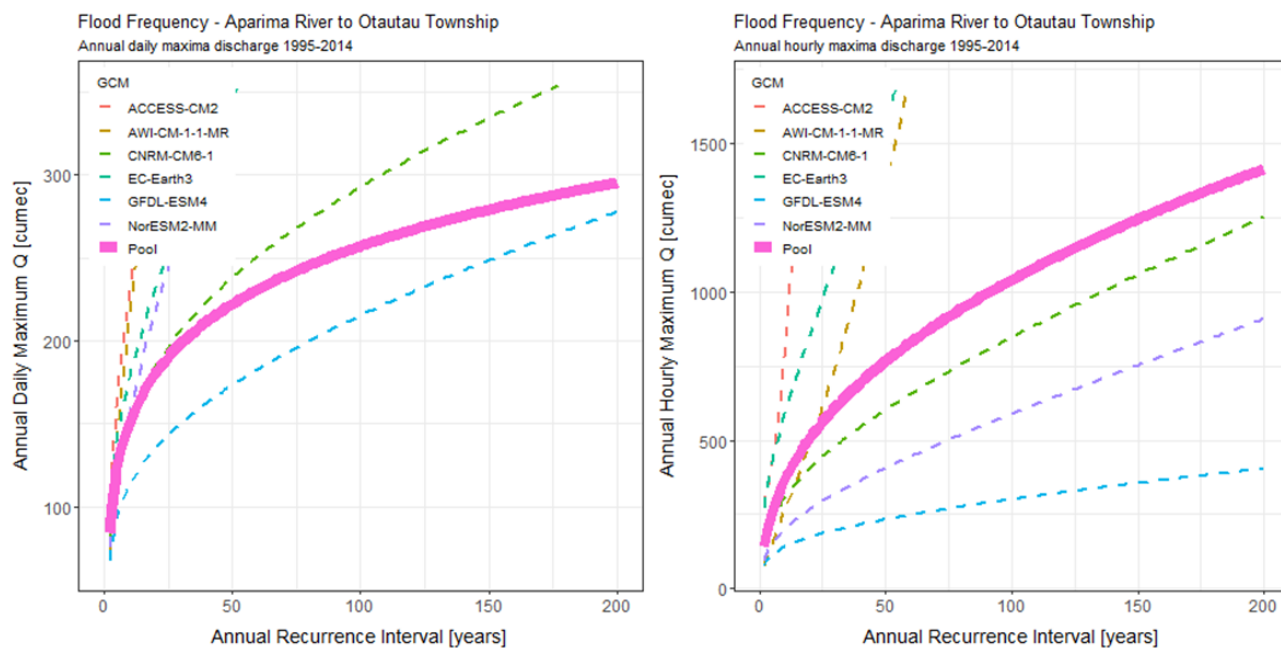


Figure E-5: Scaled simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Aparima River at Otautau Township. Flood frequency generated at nzsegment 15438598 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

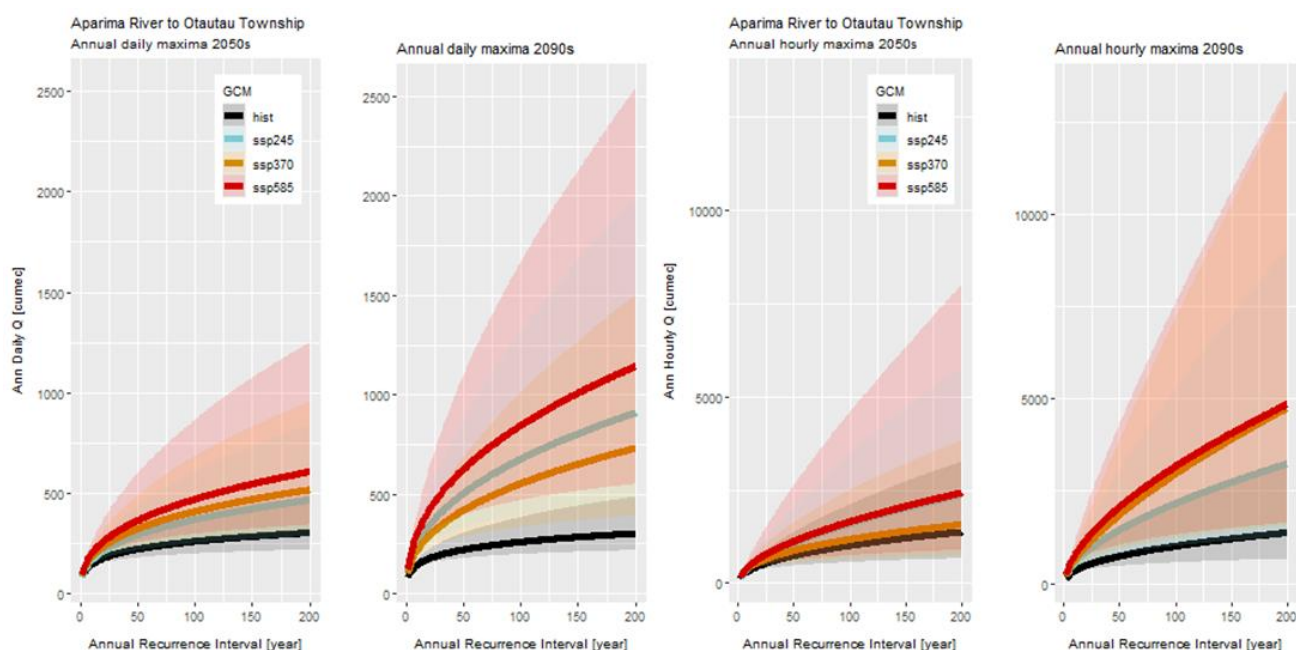


Figure E-6: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Aparima River at Otautau Township for four warming scenarios. Pooled flood frequency presented at nzsegment 15438598 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-5: Pooled multi-model daily maxima flood distribution parameters for the Aparima River at Otautau Township. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15438598 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Historical	2004	69.2	29.4	0.131
SSP2-4.5	2050	72.6	29.8	0.285
	2090	87.7	46.0	0.364
SSP3-7.0	2050	78.5	33.1	0.284
	2090	85.8	38.3	0.350
SSP5-8.5	2050	83.0	35.2	0.315
	2090	101.2	57.1	0.368

Table E-6: Pooled multi-model hourly maxima flood distribution parameters the Aparima River at Otautau Township. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15438598 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
Historical	2004	111.7	69.0	0.367
SSP2-4.5	2050	122.5	73.7	0.504
	2090	153.5	100.4	0.495
SSP3-7.0	2050	148.4	86.5	0.332
	2090	153.8	101.3	0.595
SSP5-8.5	2050	138.7	84.8	0.446
	2090	184.0	133.6	0.529

Table E-7: Projected changes in pooled multi-model daily maxima flood magnitude for the Aparima River at Otautau Township (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	5.2	35.2	14.4	27.1	21.3	59.0
5-year level	9.0	52.7	19.2	37.0	27.7	83.3
10-year level	14.3	70.9	25.4	49.0	36.2	107.7
20-year level	20.9	92.4	33.2	64.0	46.7	136.0
50-year level	31.9	127.3	45.7	88.9	64.2	181.8
100-year level	41.8	160.0	57.1	112.5	80.5	224.6
200-year level	53.4	199.6	70.4	141.1	100.0	276.7

Table E-8: Projected changes in pooled multi-model hourly maxima flood magnitude for the Aparima at Otautau Township (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	10.1	41.4	30.3	43.4	24.7	75.8
5-year level	15.4	51.4	26.8	60.4	28.4	96.8
10-year level	22.4	62.2	24.1	81.0	33.6	117.6
20-year level	31.2	75.0	21.6	106.9	40.3	141.4
50-year level	45.3	95.3	18.6	150.7	51.7	178.8
100-year level	57.9	113.7	16.5	193.0	62.6	212.6
200-year level	72.4	135.2	14.5	244.8	76.1	252.1

Otautau Stream at Otautau Township

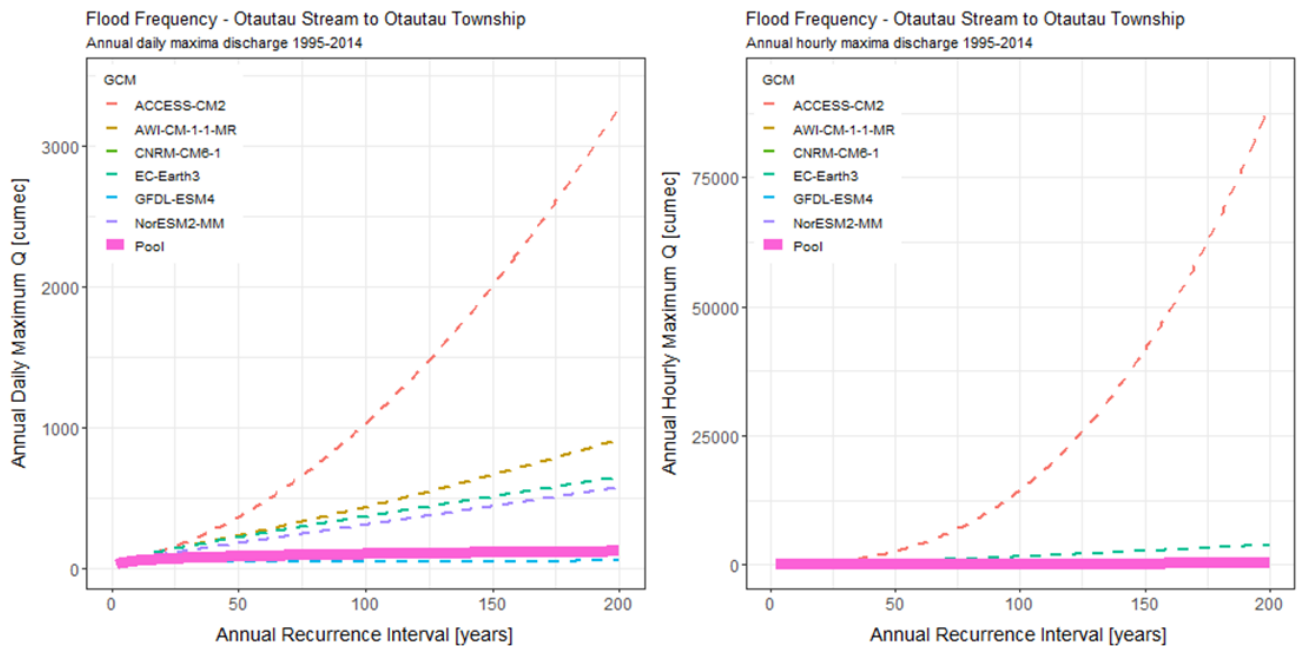


Figure E-7: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for Otautau Stream at Otautau Township. Flood frequency generated at nzsegment 15061126 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

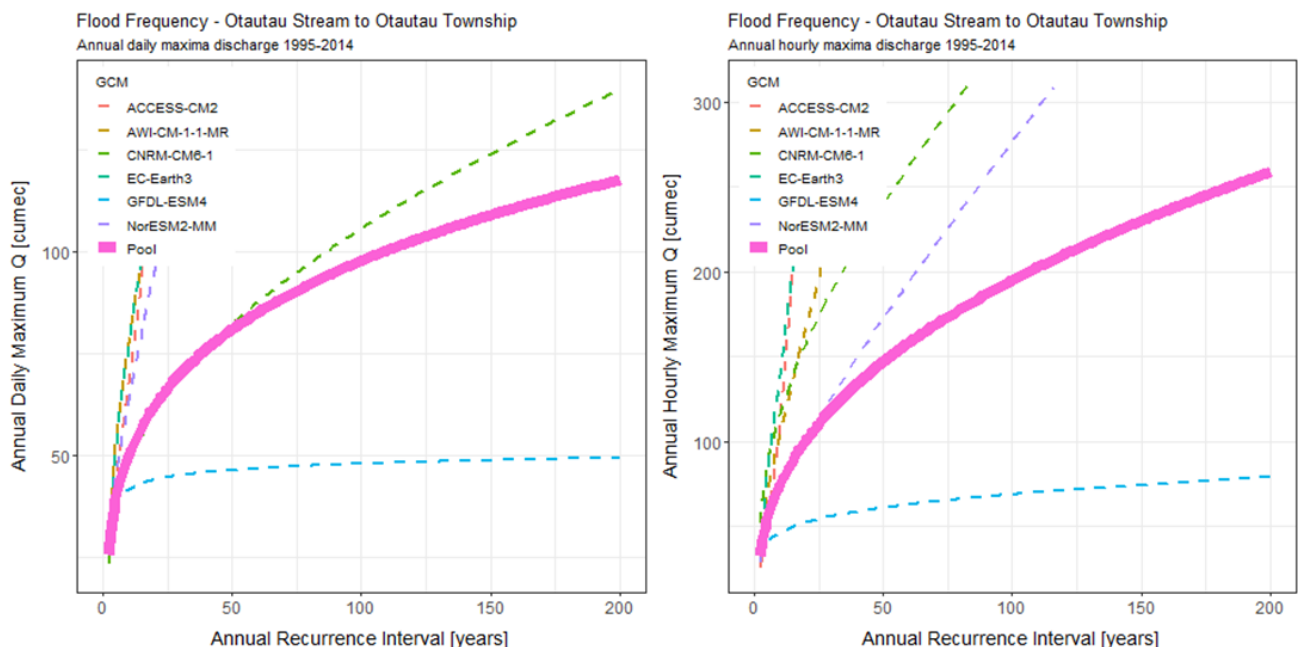


Figure E-8: Scaled simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for Otautau Stream at Otautau Township. Flood frequency generated at nzsegment 15061126 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

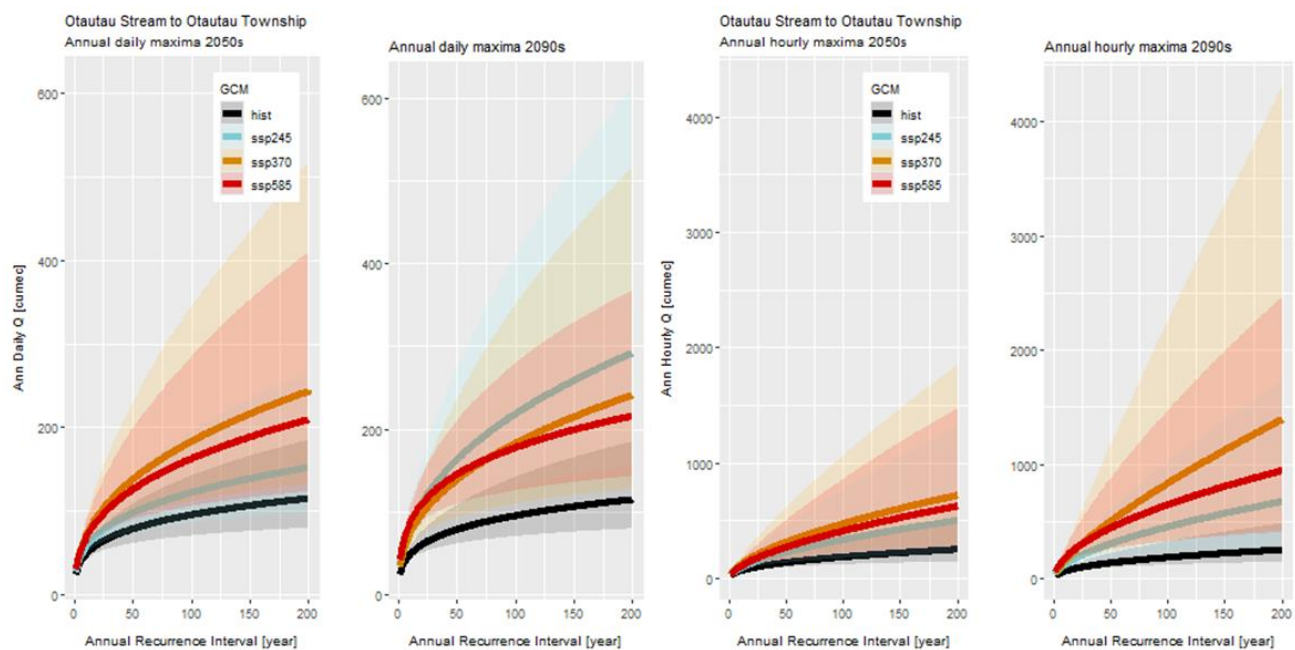


Figure E-9: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for Otautau Stream at Otautau Township for four warming scenarios. Pooled flood frequency presented at nzsegment 15061126 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-9: Pooled multi-model daily maxima flood distribution parameters for Otautau Stream at Otautau Township. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15061126 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Historical	2004	21.5	9.5	0.202
SSP2-4.5	2050	24.1	10.8	0.256
	2090	29.9	14.8	0.366
SSP3-7.0	2050	26.3	12.9	0.351
	2090	29.1	12.8	0.344
SSP5-8.5	2050	26.8	12.7	0.311
	2090	35.3	18.2	0.202

Table E-10: Pooled multi-model hourly maxima flood distribution parameters for Otautau Stream at Otautau Township. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15061126 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Historical	2004	25.7	12.2	0.392
SSP2-4.5	2050	30.1	15.0	0.512
	2090	36.9	20.9	0.505
SSP3-7.0	2050	34.1	20.1	0.532
	2090	39.3	23.6	0.648
SSP5-8.5	2050	31.5	16.4	0.557

	Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
2090	47.9	33.5	0.467

Table E-11: Projected changes in pooled multi-model daily maxima flood magnitude for Otautau Stream at Otautau Township (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	12.7	44.0	26.3	36.5	27.5	69.7
5-year level	14.7	55.8	35.4	42.2	33.7	75.6
10-year level	17.1	68.4	45.2	49.9	40.3	78.8
20-year level	19.8	83.1	56.6	59.6	47.9	81.3
50-year level	24.1	106.6	74.8	75.9	59.6	83.8
100-year level	27.8	128.0	91.4	91.0	69.9	85.5
200-year level	31.9	153.1	110.8	108.9	81.7	87.2

Table E-12: Projected changes in pooled multi-model hourly maxima flood magnitude for Otautau Stream at Otautau Township (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	19.7	51.5	42.0	66.4	27.2	109.0
5-year level	27.1	66.1	59.3	97.5	38.9	139.9
10-year level	35.7	79.9	76.0	133.2	52.2	163.2
20-year level	46.2	95.3	94.9	178.6	68.3	185.7
50-year level	63.3	119.1	124.6	258.8	94.4	216.5
100-year level	79.0	140.3	151.4	340.2	118.4	242.2
200-year level	97.6	164.9	183.0	445.8	146.7	270.7

Oreti
Makarewa Catchment

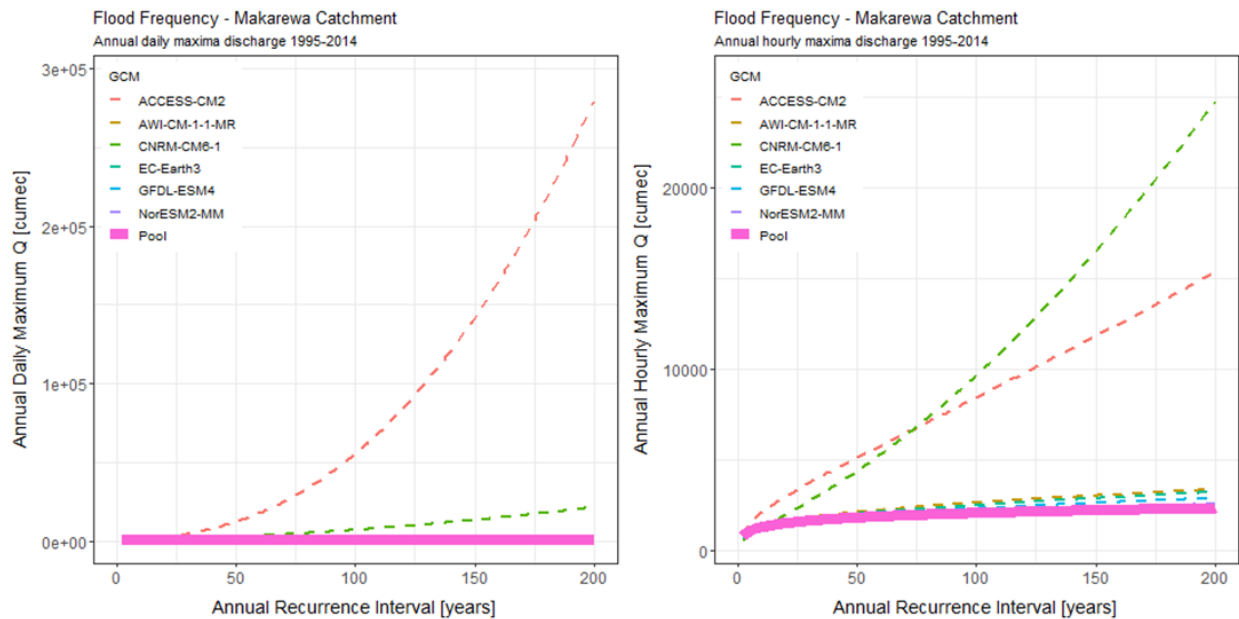


Figure E-10: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Makarewa Catchment. Flood frequency generated at nzsegment 15441846 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

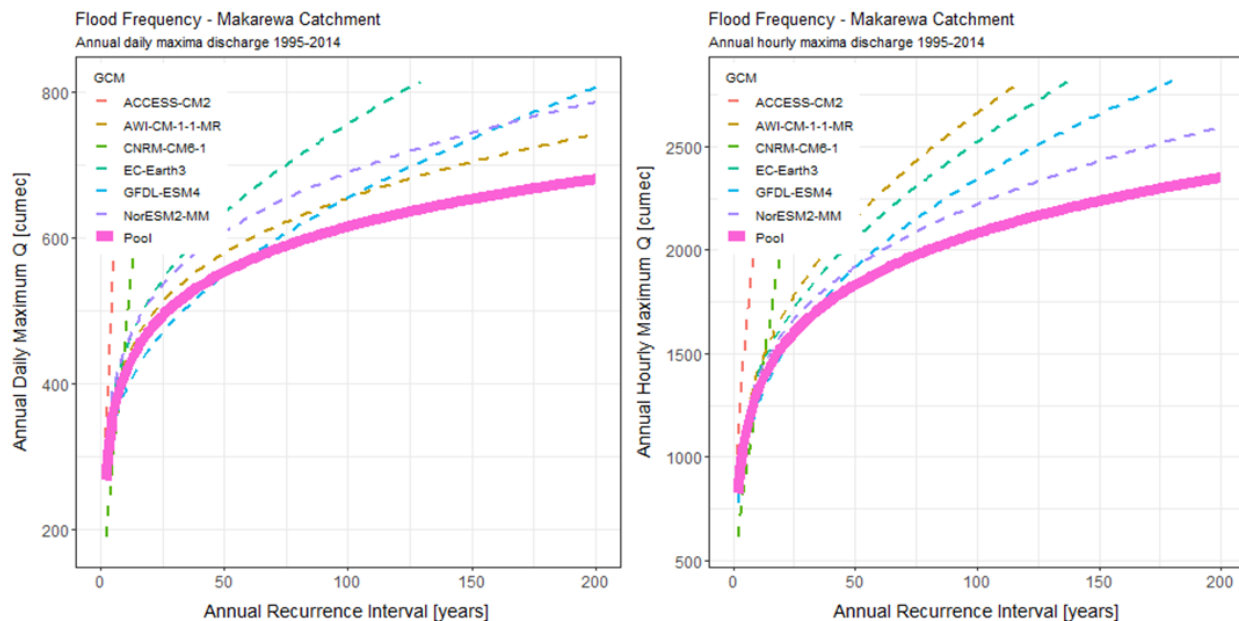


Figure E-11: Scaled simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Makarewa Catchment. Flood frequency generated at nzsegment 15441846 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

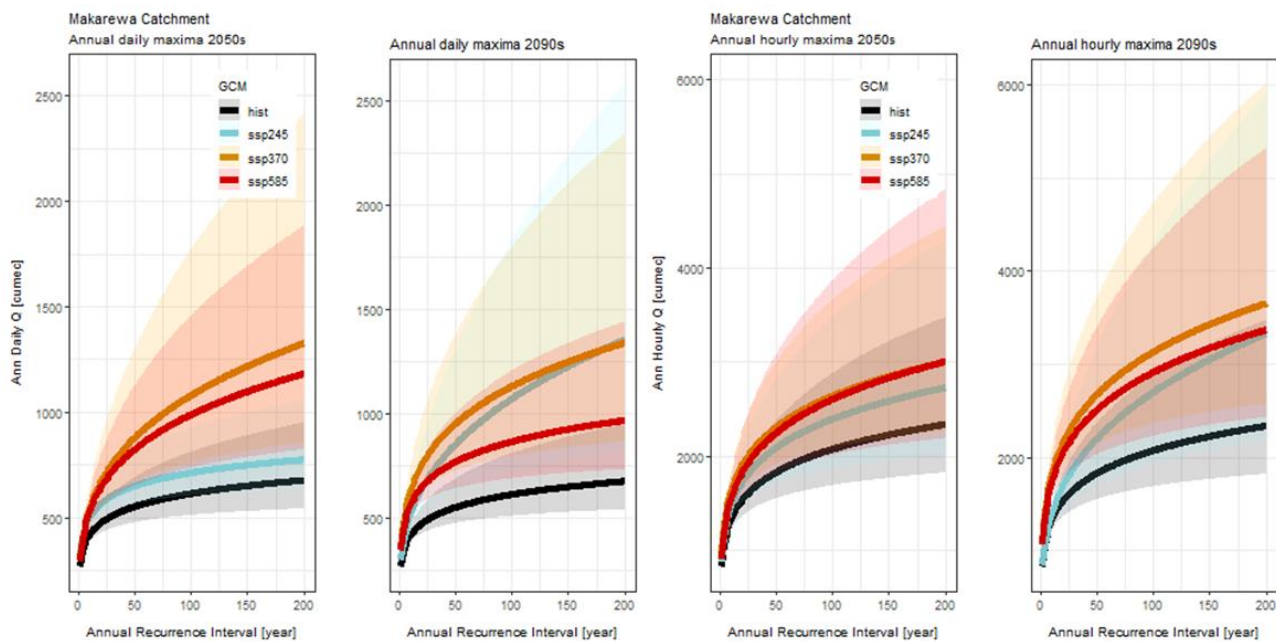


Figure E-12: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Makarewa Catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15441846 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-13: Pooled multi-model daily maxima flood distribution parameters for the Makarewa Catchment. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15441846 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	242.3	74.8	0.025
SSP2-4.5	2050	277.5	103.4	-0.046
	2090	273.7	71.7	0.321
SSP3-7.0	2050	265.2	89.5	0.253
	2090	314.6	111.1	0.172
SSP5-8.5	2050	261.0	91.9	0.206
	2090	306.0	107.3	0.044

Table E-14: Pooled multi-model hourly maxima flood distribution parameters for the Makarewa Catchment. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15441846 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	747.5	230.1	0.085
SSP2-4.5	2050	769.9	274.8	0.092
	2090	778.0	189.1	0.293
SSP3-7.0	2050	861.0	301.9	0.093

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	965.2	310.7	0.155
	2050	799.1	282.0	0.124
	2090	944.1	294.3	0.140

Table E-15: Projected changes in pooled multi-model daily maxima flood magnitude for the Makarewa Catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	17.7	11.7	12.3	33.7	11.0	29.0
5-year level	19.8	15.6	20.2	41.7	18.6	32.4
10-year level	19.9	23.3	29.5	49.7	26.4	34.8
20-year level	19.2	34.4	40.7	58.6	35.3	36.8
50-year level	17.6	54.5	58.9	72.3	48.9	39.3
100-year level	16.1	74.6	75.7	84.2	60.8	41.1
200-year level	14.3	99.8	95.7	97.6	74.3	43.0

Table E-16: Projected changes in pooled multi-model hourly maxima flood magnitude the Makarewa Catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	5.6	1.5	17.7	30.5	9.5	26.9
5-year level	8.7	1.7	20.8	33.6	13.3	28.7
10-year level	10.6	5.0	22.7	36.9	16.3	30.9
20-year level	12.3	10.3	24.3	40.6	19.0	33.4
50-year level	14.1	20.3	26.1	46.2	22.7	37.2
100-year level	15.4	30.2	27.3	51.0	25.6	40.5
200-year level	16.7	42.4	28.4	56.3	28.5	44.1

Oreti Catchment to Lumsden Township

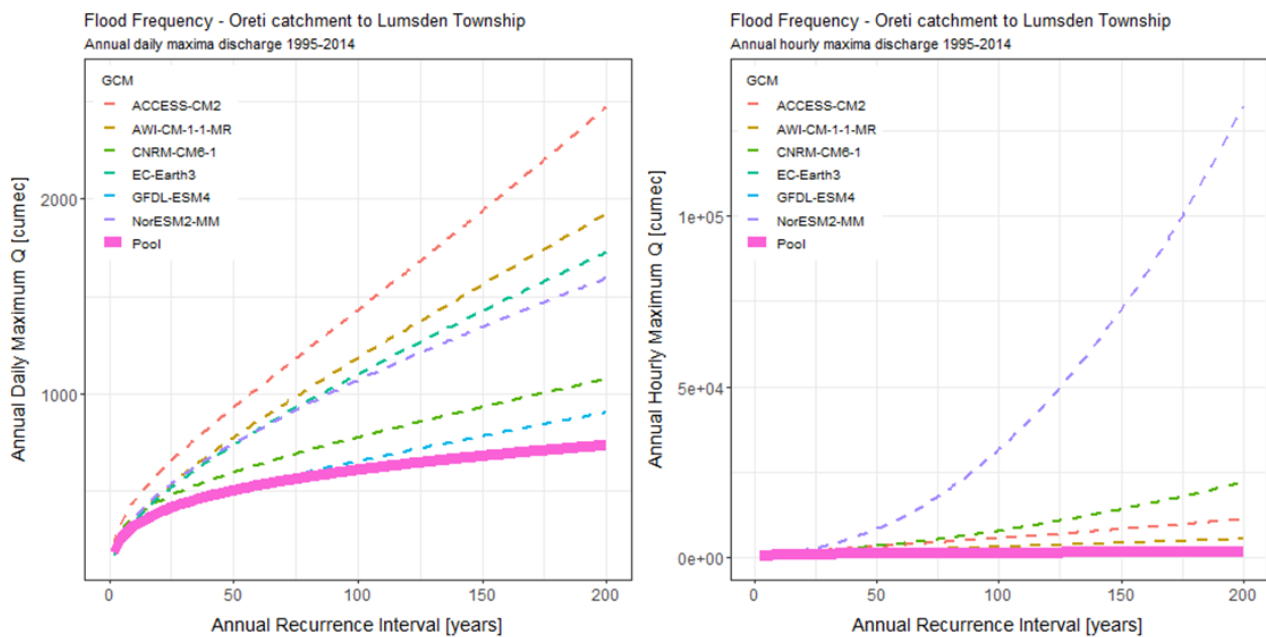


Figure E-13: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood magnitude for the Oreti Catchment at Lumsden. Flood magnitude generated at nzsegment 15335300 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

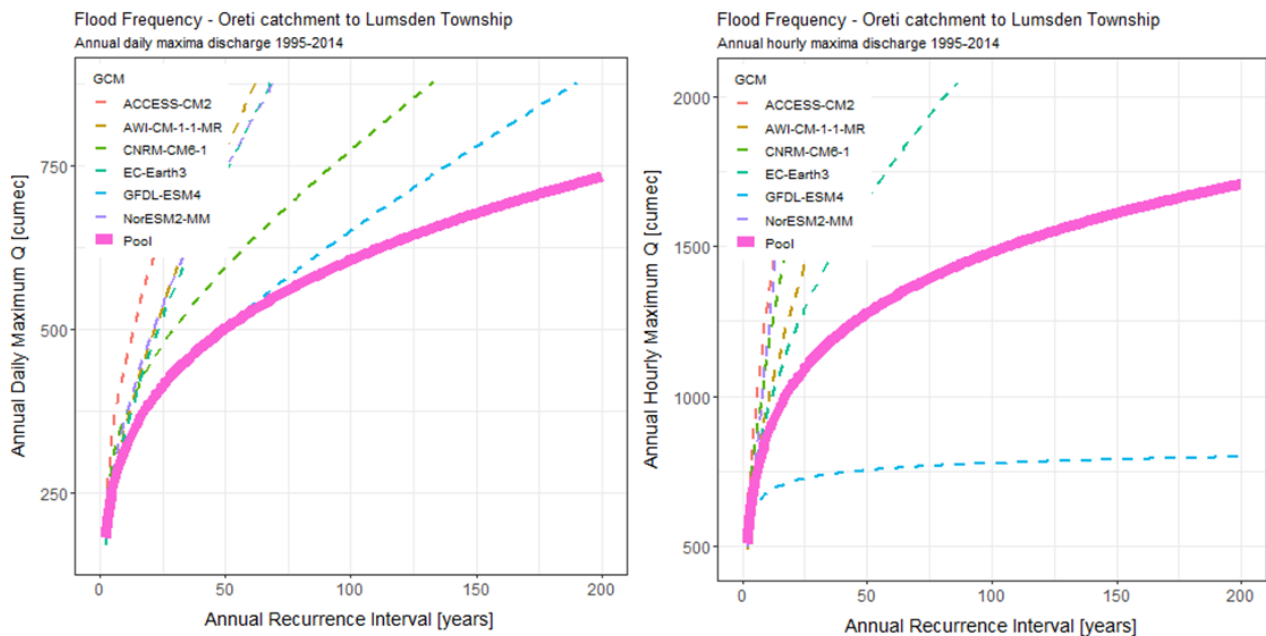


Figure E-14: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Oreti Catchment at Lumsden. Flood frequency generated at nzsegment 15335300 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

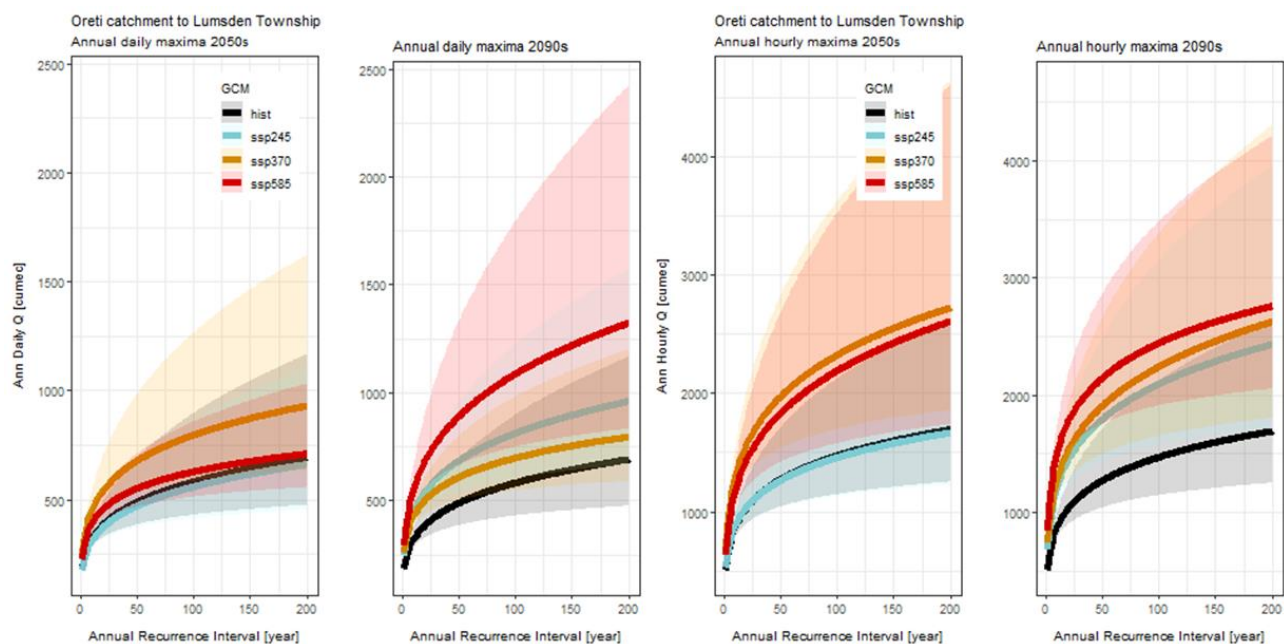


Figure E-15: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Oreti Catchment at Lumsden for four warming scenarios. Pooled flood frequency presented at nzsegment 15335300 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-17: Pooled multi-model daily maxima flood distribution parameters for the Oreti Catchment at Lumsden. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15335300 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	162.8	55.2	0.189
SSP2-4.5	2050	158.9	54.0	0.179
	2090	217.3	81.7	0.174
SSP3-7.0	2050	218.1	88.1	0.129
	2090	228.4	78.4	0.098
SSP5-8.5	2050	200.1	77.2	0.071
	2090	255.0	99.4	0.219

Table E-18: Pooled multi-model hourly maxima flood distribution parameters for the Oreti Catchment at Lumsden. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15335300 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	448.4	163.0	0.119
SSP2-4.5	2050	469.9	159.4	0.111
	2090	597.1	231.0	0.129
SSP3-7.0	2050	589.3	263.2	0.132

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	653.5	228.3	0.154
	2050	549.3	223.5	0.172
	2090	714.8	330.9	0.043

Table E-19: Projected changes in pooled multi-model daily maxima flood magnitude for the Oreti Catchment at Lumsden (% relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	-2.4	35.9	37.9	40.0	25.0	61.0
5-year level	-2.6	38.3	40.8	37.4	24.6	67.1
10-year level	-2.9	39.4	41.3	34.0	22.1	71.8
20-year level	-3.2	39.9	40.6	30.1	18.6	76.2
50-year level	-3.6	39.9	38.7	24.4	12.8	82.0
100-year level	-3.9	39.5	36.8	19.8	7.9	86.5
200-year level	-4.3	38.8	34.5	15.0	2.7	91.3

Table E-20: Projected changes in pooled multi-model hourly maxima flood magnitude for the Oreti Catchment at Lumsden (% relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	3.5	34.8	36.9	45.0	25.5	66.4
5-year level	2.0	36.8	43.4	45.1	30.2	71.4
10-year level	1.0	38.2	47.5	46.1	34.2	72.3
20-year level	0.2	39.5	50.9	47.5	38.3	71.4
50-year level	-0.6	41.1	54.9	50.1	44.0	68.8
100-year level	-1.1	42.4	57.8	52.4	48.7	66.1
200-year level	-1.6	43.7	60.7	55.1	53.9	62.9

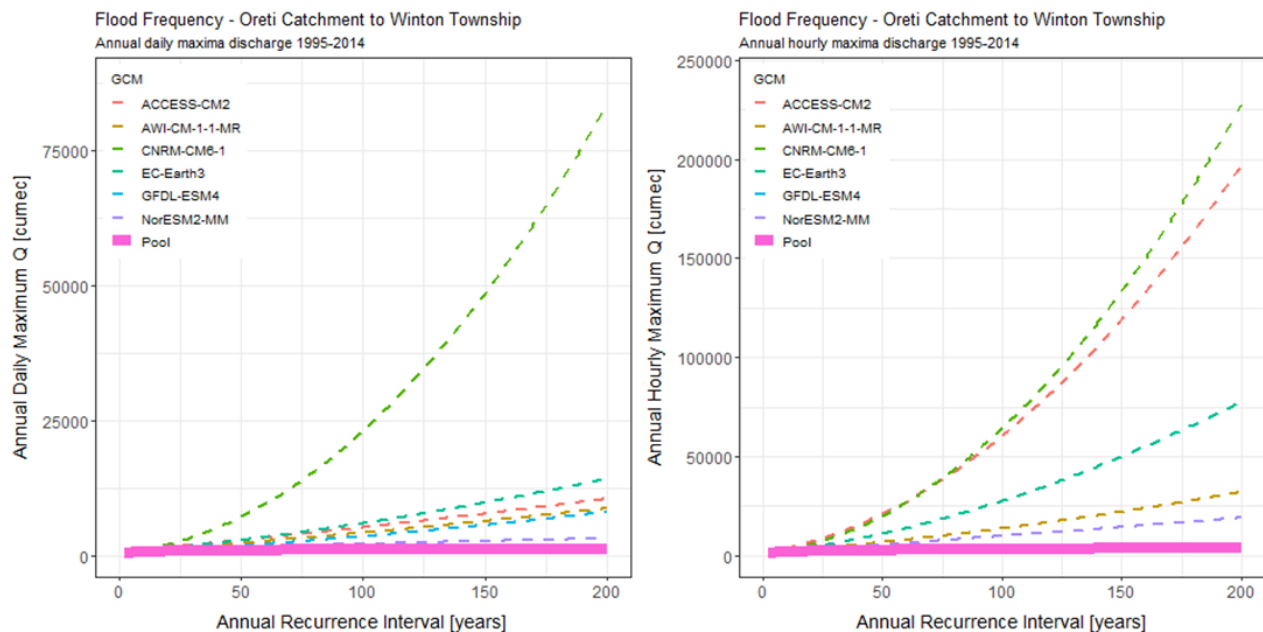


Figure E-16: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Oreti Catchment at Winton Township. Flood frequency generated for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

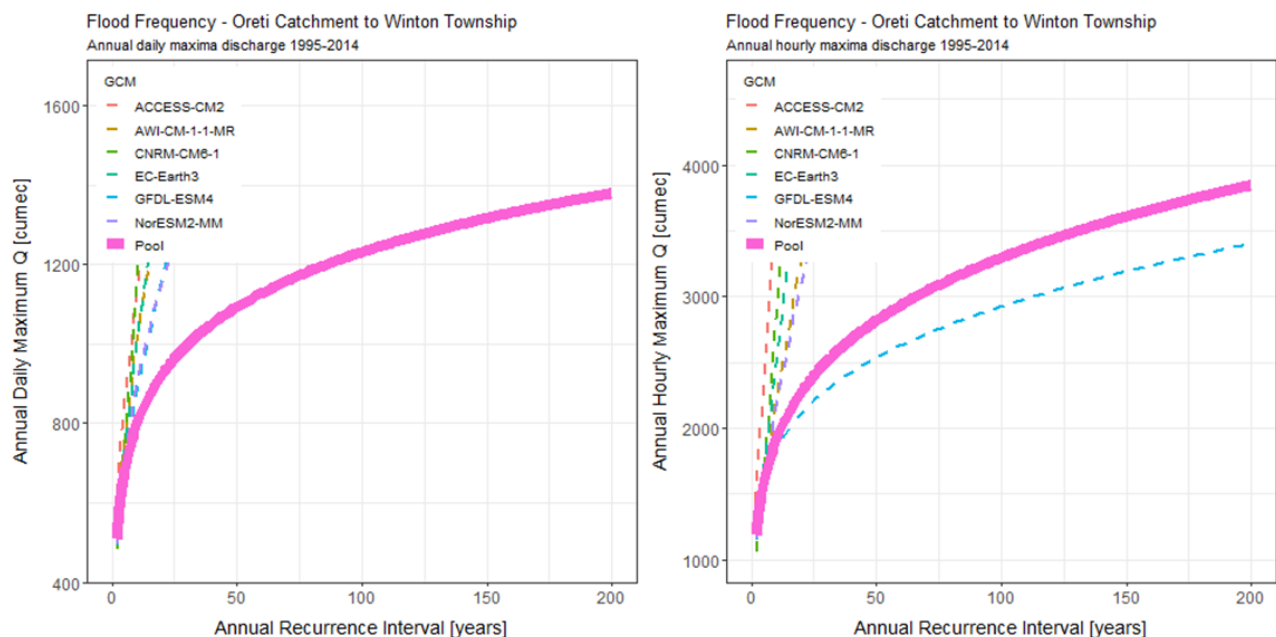


Figure E-17: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Oreti Catchment at Winton Township. Flood frequency generated for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

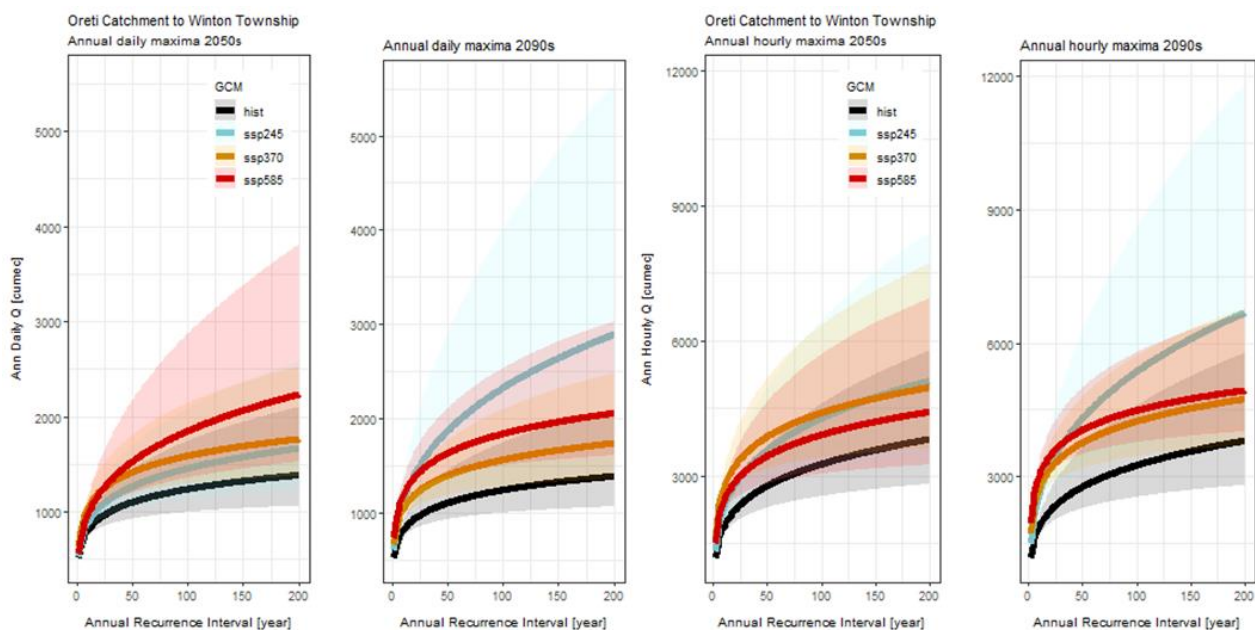


Figure E-18: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Oreti Catchment at Winton Township for four warming scenarios. Pooled flood frequency presented at nzsegment 15445670 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-21: Pooled multi-model daily maxima flood distribution parameters for the Oreti Catchment at Winton Township. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15445670 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	464.6	142.3	0.060
SSP2-4.5	2050	474.9	159.4	0.110
	2090	534.3	185.0	0.271
SSP3-7.0	2050	558.4	206.6	0.025
	2090	587.2	186.6	0.044
SSP5-8.5	2050	494.5	159.7	0.230
	2090	641.5	225.9	0.050

Table E-22: Pooled multi-model hourly maxima flood distribution parameters for the Oreti Catchment at Winton Township. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15445670 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	1054.8	296.9	0.184
SSP2-4.5	2050	1186.1	390.6	0.204
	2090	1341.3	396.3	0.292
SSP3-7.0	2050	1437.7	547.4	0.055

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	1521.7	509.2	0.055
	2050	1339.7	456.8	0.070
	2090	1732.6	578.9	0.009

Table E-23: Projected changes in pooled multi-model daily maxima flood magnitude the Oreti Catchment at Winton Township (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	4.0	18.6	23.8	27.0	8.2	41.2
5-year level	6.8	27.6	27.1	27.4	13.5	44.4
10-year level	9.3	37.8	28.4	27.3	19.7	46.1
20-year level	11.7	49.9	28.8	27.1	27.1	47.1
50-year level	14.9	69.4	28.7	26.5	38.7	47.9
100-year level	17.5	87.3	28.1	25.9	49.1	48.1
200-year level	20.2	108.4	27.2	25.2	61.0	48.1

Table E-24: Projected changes in pooled multi-model hourly maxima flood magnitude for the Oreti Catchment at Winton Township (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	15.4	28.7	42.3	47.3	30.2	67.3
5-year level	19.4	33.3	46.3	47.8	31.6	66.2
10-year level	22.4	38.6	46.1	45.5	30.4	61.7
20-year level	25.2	45.1	44.0	41.9	28.0	55.6
50-year level	28.7	55.4	39.4	35.7	23.8	45.9
100-year level	31.3	64.7	35.0	30.3	20.0	37.9
200-year level	34.1	75.4	30.2	24.5	15.9	29.6

Oreti Catchment at Wallacetown

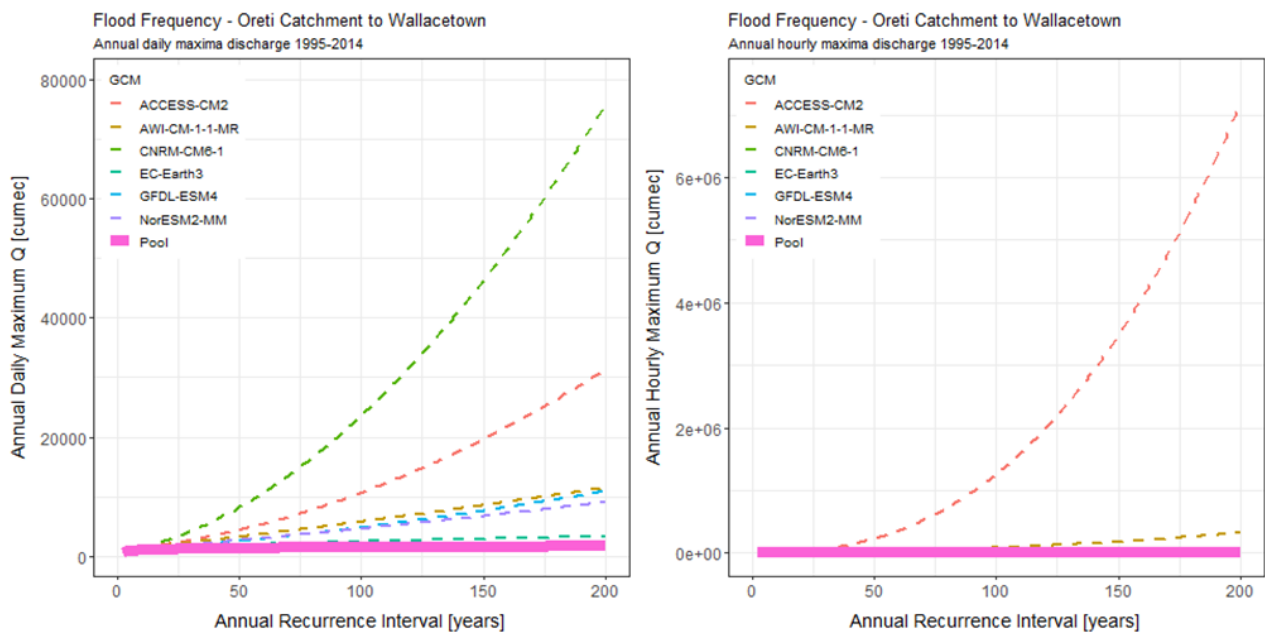


Figure E-19: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood magnitude for the Oreti Catchment at Wallacetown. Flood frequency generated presented at nzsegment 15446374 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

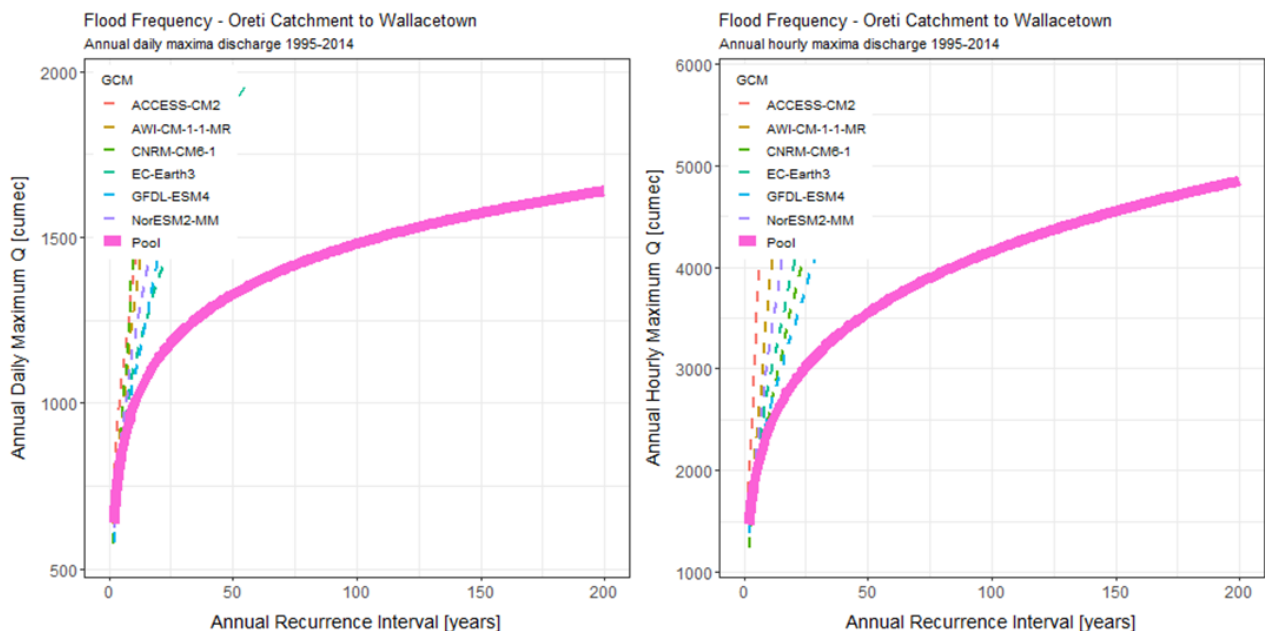


Figure E-20: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Oreti Catchment at Wallacetown. Flood frequency generated presented at nzsegment 15446374 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

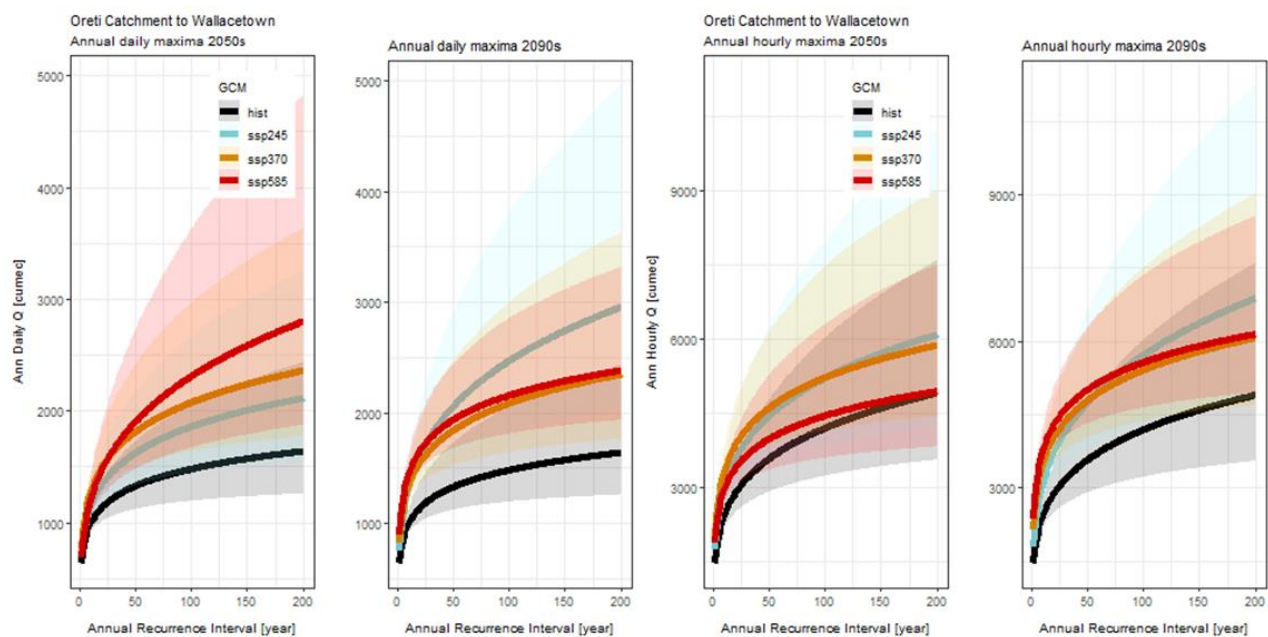


Figure E-21: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Oreti Catchment at Wallacetown for four warming scenarios. Pooled flood frequency presented at nzsegment 15446374 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-25: Pooled multi-model daily maxima flood distribution parameters for the Oreti Catchment at Wallacetown Daily maxima flood extreme event distribution generated using General Extreme Value distribution presented at nzsegment 15446374 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	572.7	180.9	0.024
SSP2-4.5	2050	606.3	214.3	0.087
	2090	665.6	225.1	0.209
SSP3-7.0	2050	672.4	238.8	0.091
	2090	734.4	242.3	0.067
SSP5-8.5	2050	605.5	197.3	0.235
	2090	785.3	282.8	0.015

Table E-26: Pooled multi-model hourly maxima flood distribution parameters for the Oreti Catchment at Wallacetown. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution presented at nzsegment 15446374 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	1315.5	395.4	0.174
SSP2-4.5	2050	1519.8	537.7	0.147
	2090	1621.1	478.0	0.235
SSP3-7.0	2050	1760.6	635.7	0.058

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	1899.0	644.0	0.062
	2050	1663.2	542.6	0.034
	2090	2093.2	714.5	0.016

Table E-27: Projected changes in pooled multi-model daily maxima flood frequency for the Oreti Catchment at Wallacetown (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	8.2	18.6	20.1	29.4	7.3	40.0
5-year level	11.9	25.2	24.4	31.6	13.2	43.0
10-year level	15.0	32.6	28.1	33.6	20.4	44.4
20-year level	18.1	41.3	31.6	35.7	29.1	45.2
50-year level	22.3	54.8	36.4	38.5	43.2	45.6
100-year level	25.5	66.6	40.1	40.8	55.9	45.6
200-year level	28.9	80.1	43.9	43.1	70.8	45.2

Table E-28: Projected changes in pooled multi-model hourly maxima flood frequency for the Oreti Catchment at Wallacetown (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	18.5	23.2	37.2	46.4	27.2	61.2
5-year level	21.6	24.5	38.3	46.0	25.3	59.3
10-year level	23.0	26.4	36.7	43.5	21.8	54.9
20-year level	23.7	28.9	33.8	39.9	17.5	49.0
50-year level	24.2	32.9	28.8	34.0	11.2	40.1
100-year level	24.2	36.4	24.4	29.1	6.0	32.8
200-year level	24.1	40.3	19.7	23.8	0.7	25.3

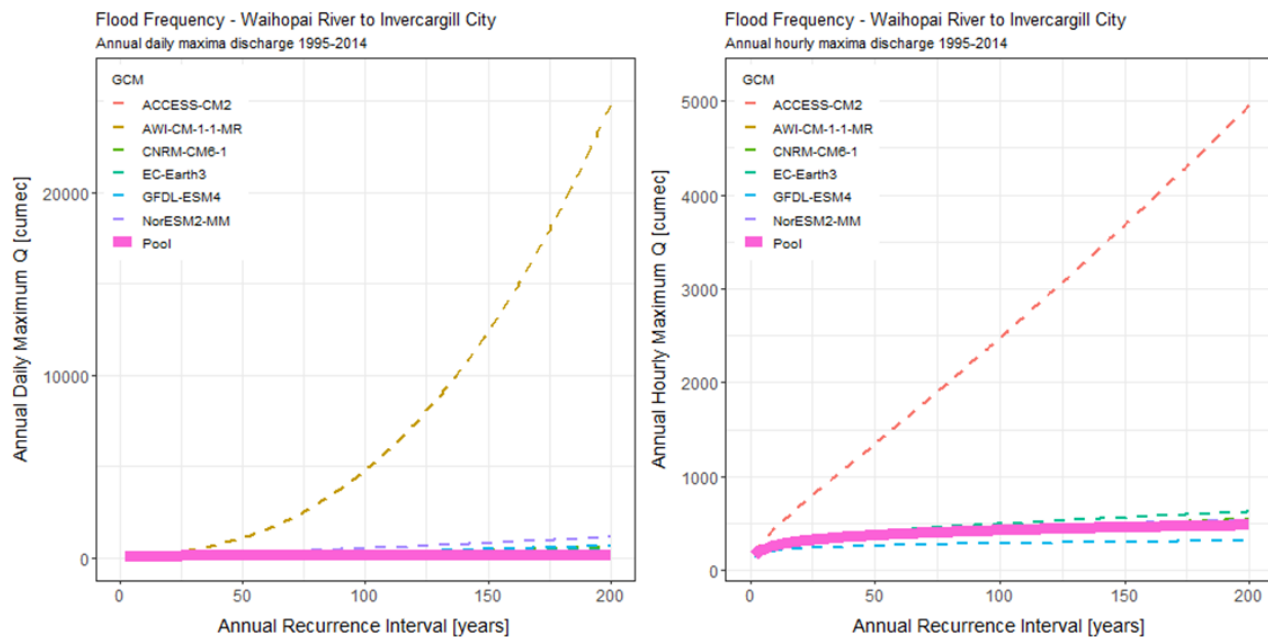


Figure E-22: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waihopai River at Invercargill City. Flood frequency generated presented at nzsegment 15439446 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

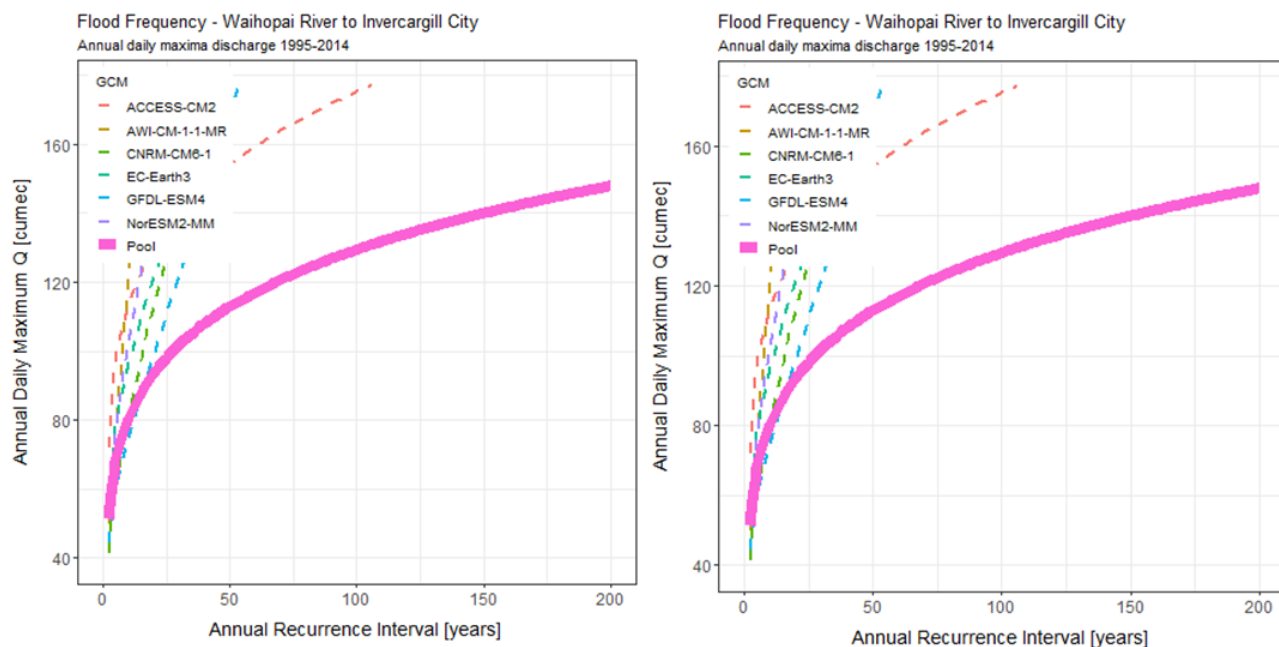


Figure E-23: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waihopai River at Invercargill City. Flood frequency generated at nzsegment 15439446 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

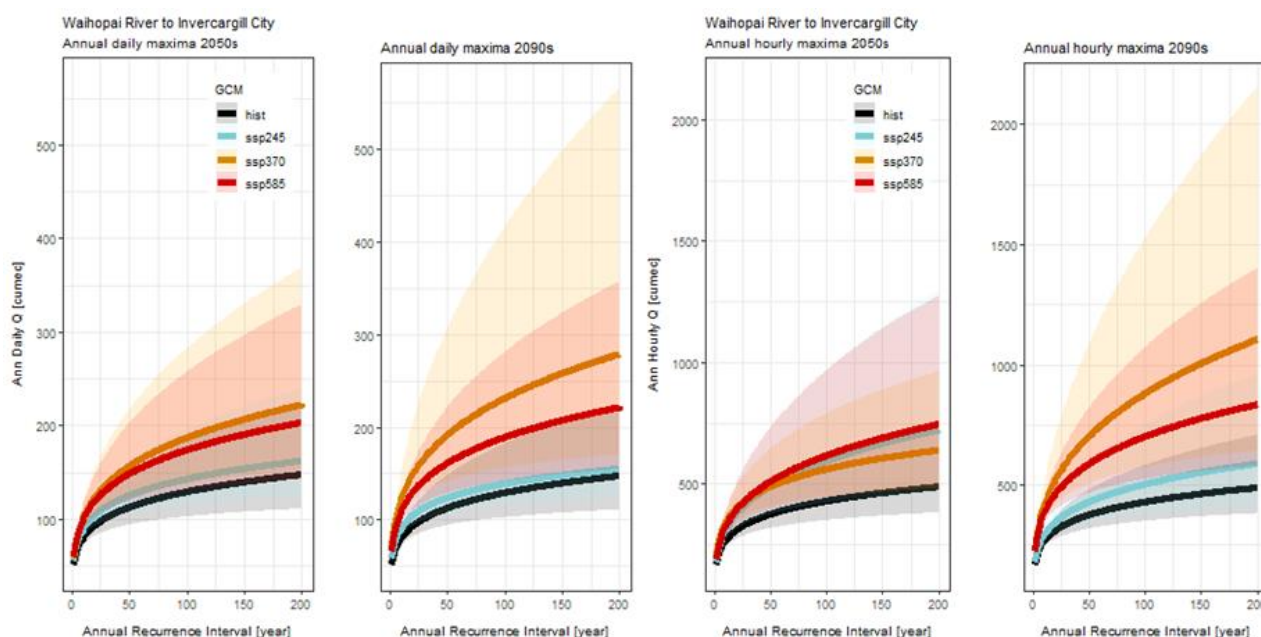


Figure E-24: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Waihopai River at Invercargill City for four warming scenarios. Pooled flood frequency presented at nzsegment 15439446 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-29: Pooled multi-model daily maxima flood distribution parameters for the Waihopai River at Invercargill City. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15439446 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	46.5	12.9	0.126
SSP2-4.5	2050	50.5	15.3	0.103
	2090	52.4	16.2	0.057
SSP3-7.0	2050	51.4	17.9	0.188
	2090	61.8	21.1	0.197
SSP5-8.5	2050	53.2	17.3	0.156
	2090	59.8	17.8	0.172

Table E-30: Pooled multi-model hourly maxima flood distribution parameters for the Waihopai River at Invercargill City. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15439446 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	149.7	45.7	0.112
SSP2-4.5	2050	158.2	51.0	0.228
	2090	163.6	46.4	0.175
SSP3-7.0	2050	180.3	64.2	0.096

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	197.0	68.8	0.278
	2050	168.0	52.6	0.230
	2090	199.7	64.3	0.199

Table E-31: Projected changes in pooled multi-model daily maxima flood magnitude for the Waihopai River at Invercargill City (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	9.8	14.0	14.8	37.7	17.4	30.0
5-year level	11.0	14.4	21.4	45.5	21.6	33.0
10-year level	11.4	13.7	26.7	52.4	24.8	35.8
20-year level	11.4	12.3	31.9	59.5	27.8	38.7
50-year level	11.1	9.8	39.0	70.0	31.7	42.9
100-year level	10.6	7.5	44.6	78.9	34.6	46.3
200-year level	9.9	5.0	50.5	89.1	37.7	50.0

Table E-32: Projected changes in pooled multi-model hourly maxima flood magnitude for the Waihopai River at Invercargill City e (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	7.2	8.3	23.4	35.6	13.3	35.1
5-year level	11.3	8.4	26.6	45.0	16.9	39.2
10-year level	16.0	9.5	28.2	55.3	21.4	43.6
20-year level	21.6	11.2	29.3	67.4	26.9	48.6
50-year level	30.5	14.2	30.2	86.9	35.6	56.4
100-year level	38.5	17.2	30.5	104.8	43.5	63.2
200-year level	47.8	20.6	30.7	126.1	52.6	70.8

Otepunu Stream at Invercargill City

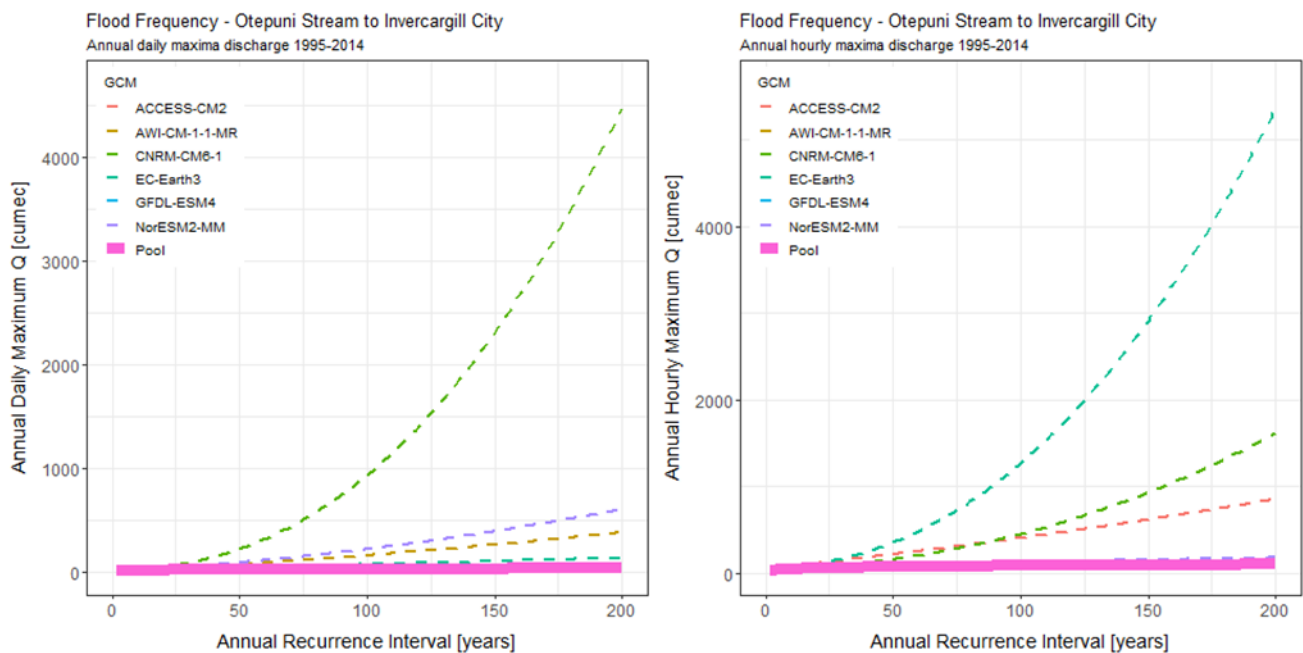


Figure E-25: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Otepunu Stream at Invercargill City. Flood frequency generated at nzsegment 15214983 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

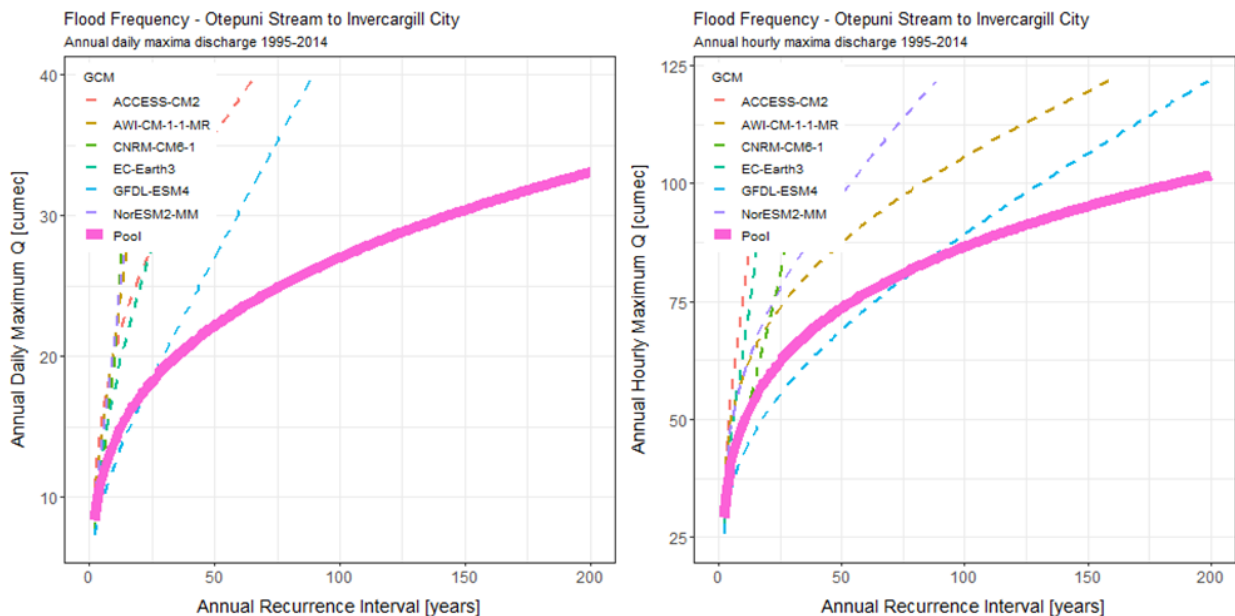


Figure E-26: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Otepunu Stream at Invercargill City. Flood frequency generated at nzsegment 15214983 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

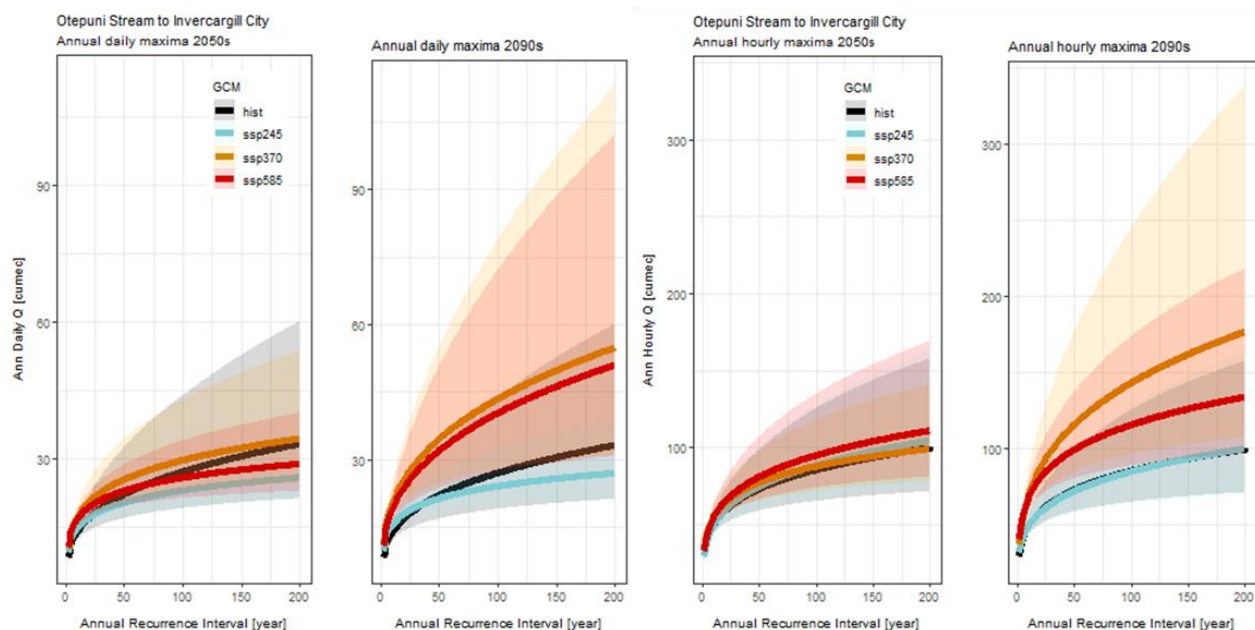


Figure E-27: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Otepun Stream at Invercargill City for four warming scenarios. Pooled flood frequency presented at nzsegment 15214983 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-33: Pooled multi-model daily maxima flood distribution parameters for the Otepun Stream at Invercargill City. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15214983 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	7.5	2.1	0.258
SSP2-4.5	2050	8.5	2.6	0.081
	2090	9.0	2.8	0.063
SSP3-7.0	2050	9.1	3.1	0.138
	2090	10.1	3.3	0.279
SSP5-8.5	2050	9.5	3.1	0.054
	2090	10.0	2.8	0.312

Table E-34: Pooled multi-model hourly maxima flood distribution parameters the Otepun Stream at Invercargill City. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15214983 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	26.4	8.6	0.152
SSP2-4.5	2050	26.8	8.1	0.191
	2090	29.5	7.0	0.206
SSP3-7.0	2050	30.7	10.0	0.086

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	32.9	12.3	0.246
	2050	29.7	9.1	0.173
	2090	36.1	12.1	0.134

Table E-35: Projected changes in pooled multi-model daily maxima flood magnitude for the Otepuni Stream at Invercargill City (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	12.9	19.6	23.3	37.0	27.1	32.8
5-year level	10.2	17.1	24.8	42.5	25.1	34.6
10-year level	5.8	12.2	23.4	46.7	20.2	37.0
20-year level	0.2	6.1	20.4	50.7	13.7	40.0
50-year level	-8.3	-3.2	14.6	56.1	3.5	44.7
100-year level	-15.2	-10.8	9.3	60.5	-4.8	48.9
200-year level	-22.3	-18.6	3.4	65.1	-13.3	53.4

Table E-36: Projected changes in pooled multi-model hourly maxima flood magnitude for the Otepuni Stream at Invercargill City (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	0.3	6.7	15.7	27.9	11.3	37.1
5-year level	0.0	2.1	14.0	34.8	10.5	37.5
10-year level	0.3	0.1	11.9	41.2	10.3	37.3
20-year level	1.0	-0.9	9.5	48.2	10.4	36.9
50-year level	2.3	-1.0	5.8	58.5	10.7	36.1
100-year level	3.5	-0.5	2.7	67.4	11.0	35.3
200-year level	4.9	0.5	-0.6	77.3	11.3	34.4

Kingswell Creek at Invercargill City

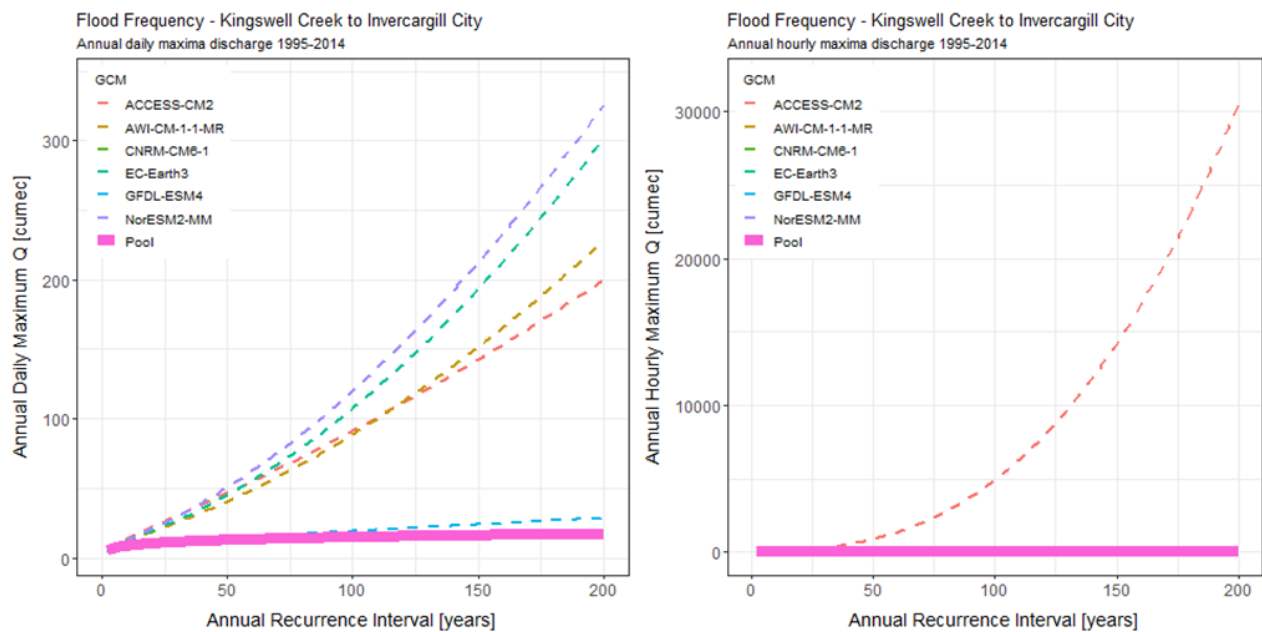


Figure E-28: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for Kingswell Creek at Invercargill City. Flood frequency generated presented at nzsegment 15205799 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

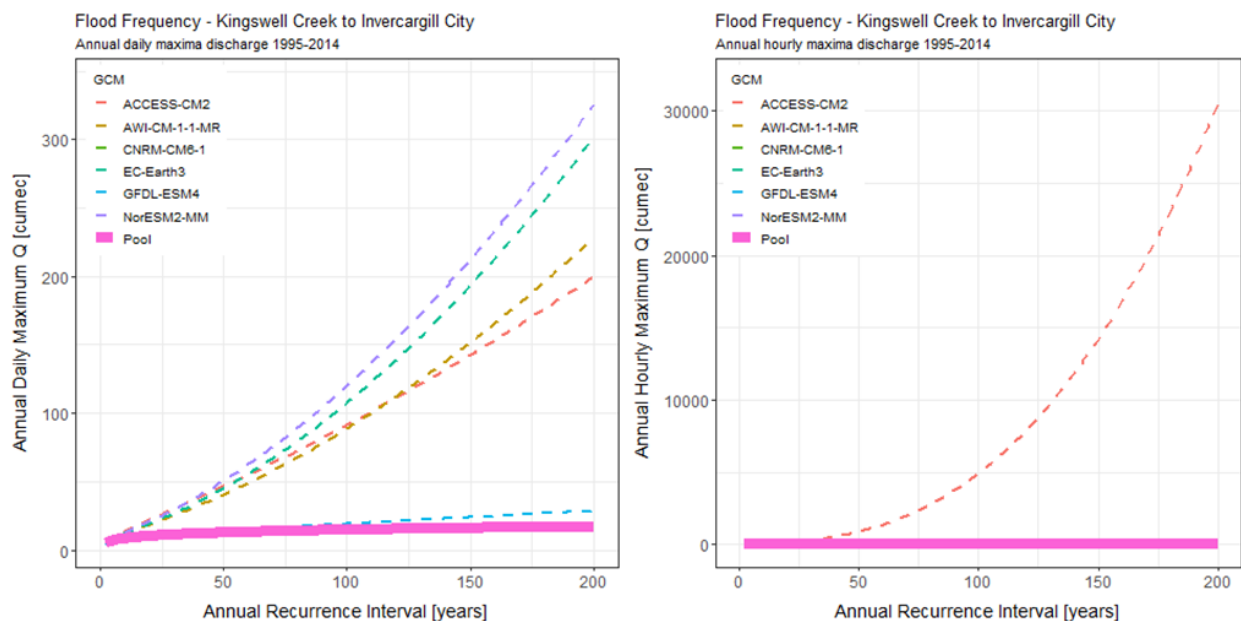


Figure E-29: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for Kingswell Creek at Invercargill City. Flood frequency generated presented at nzsegment 15205799 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

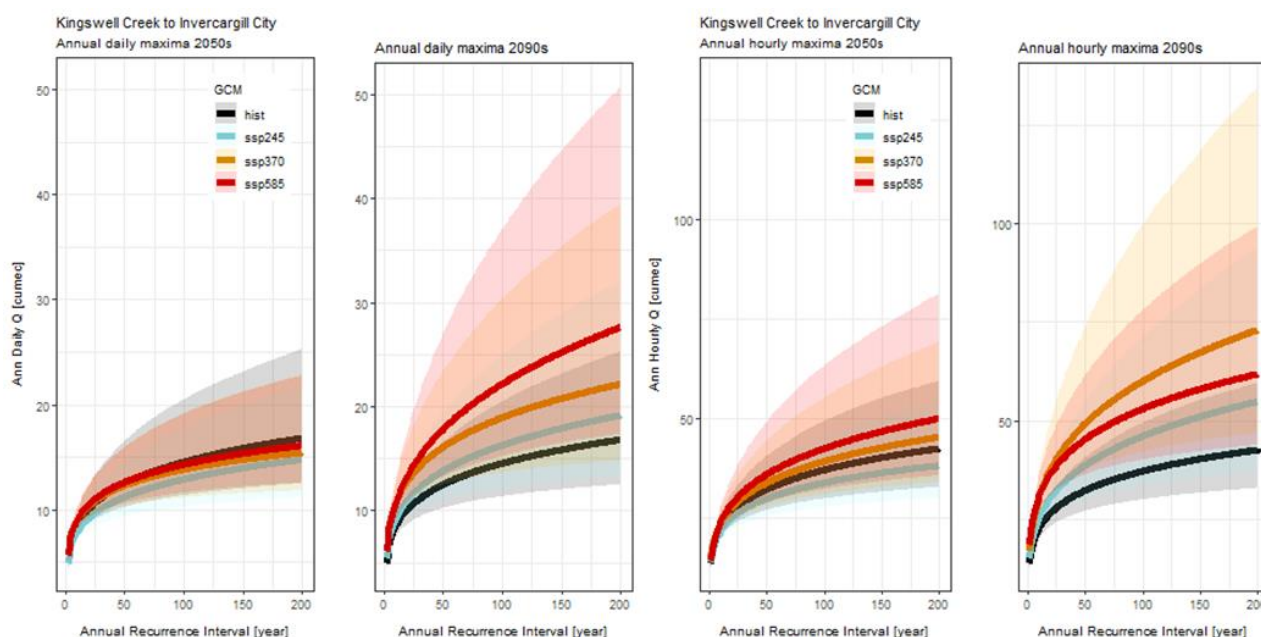


Figure E-30: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for Kingswell Creek at Invercargill City for four warming scenarios. Pooled flood frequency presented at nzsegment 15205799 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-37: Pooled multi-model daily maxima flood distribution parameters for Kingswell Creek at Invercargill City. Daily maxima flood extreme event distribution generated using General Extreme Value distribution presented at nzsegment 15205799 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	4.4	1.6	0.132
SSP2-4.5	2050	4.5	1.3	0.130
	2090	4.9	1.6	0.172
SSP3-7.0	2050	5.1	1.7	0.045
	2090	5.4	2.0	0.132
SSP5-8.5	2050	5.1	1.6	0.079
	2090	5.5	1.7	0.287

Table E-38: Pooled multi-model hourly maxima flood distribution parameters for Kingswell Creek at Invercargill City. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution presented at nzsegment 15205799 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	12.4	3.9	0.128
SSP2-4.5	2050	12.5	3.6	0.094
	2090	13.7	4.0	0.206
SSP3-7.0	2050	14.1	3.6	0.166

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	14.6	5.4	0.221
	2050	12.8	4.0	0.180
	2090	16.7	5.2	0.159

Table E-39: Projected changes in pooled multi-model daily maxima flood magnitude for Kingswell Creek at Invercargill City (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	-0.9	10.1	14.8	23.7	13.2	22.4
5-year level	-4.7	8.6	10.4	25.3	9.7	23.2
10-year level	-7.0	8.5	6.7	26.4	7.0	26.8
20-year level	-8.6	9.0	3.1	27.4	4.4	32.4
50-year level	-10.3	10.4	-1.4	28.9	1.0	42.6
100-year level	-11.3	11.9	-4.8	30.2	-1.6	52.4
200-year level	-12.1	13.9	-8.2	31.7	-4.2	64.2

Table E-40: Projected changes in pooled multi-model hourly maxima flood magnitude for Kingswell Creek at Invercargill City e (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	0.1	9.9	10.5	22.2	4.0	34.6
5-year level	-2.0	10.6	7.1	29.0	5.1	35.2
10-year level	-3.7	12.4	5.7	35.4	6.6	36.3
20-year level	-5.3	15.0	5.1	42.3	8.5	37.7
50-year level	-7.2	19.6	5.2	52.5	11.7	40.2
100-year level	-8.6	23.9	5.8	61.4	14.5	42.5
200-year level	-10.0	28.9	6.8	71.6	17.7	45.2

Irthing Stream at Ellis Road

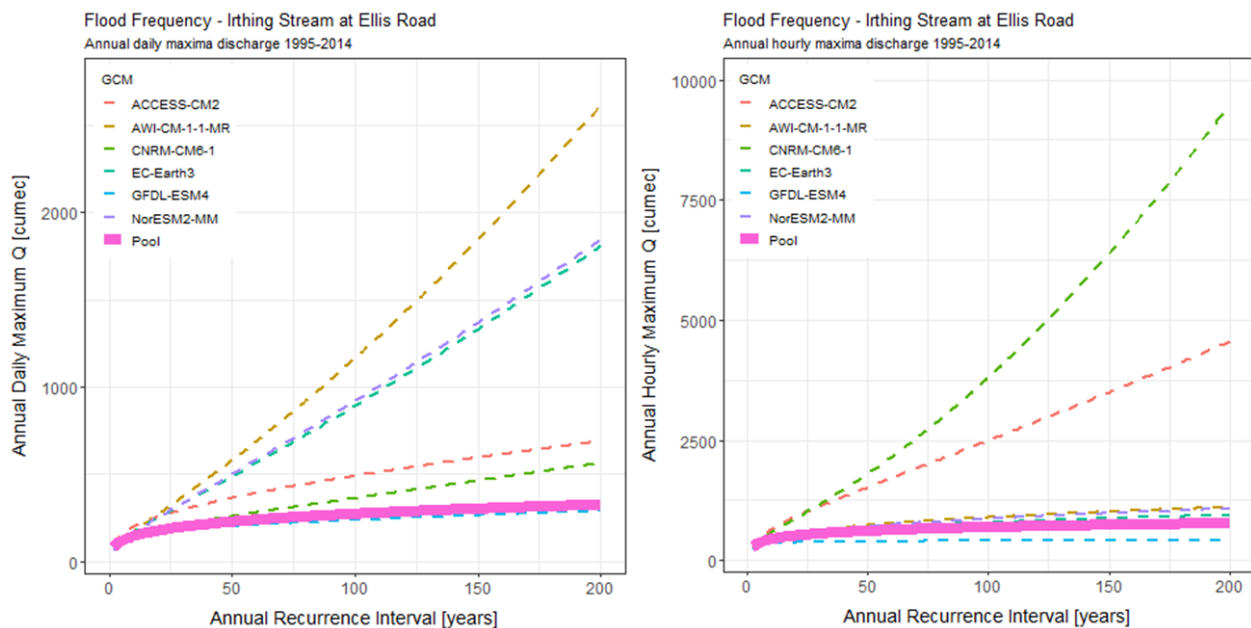


Figure E-31: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Irthing Stream at Ellis Road. Flood frequency generated at nzsegment 15334924 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

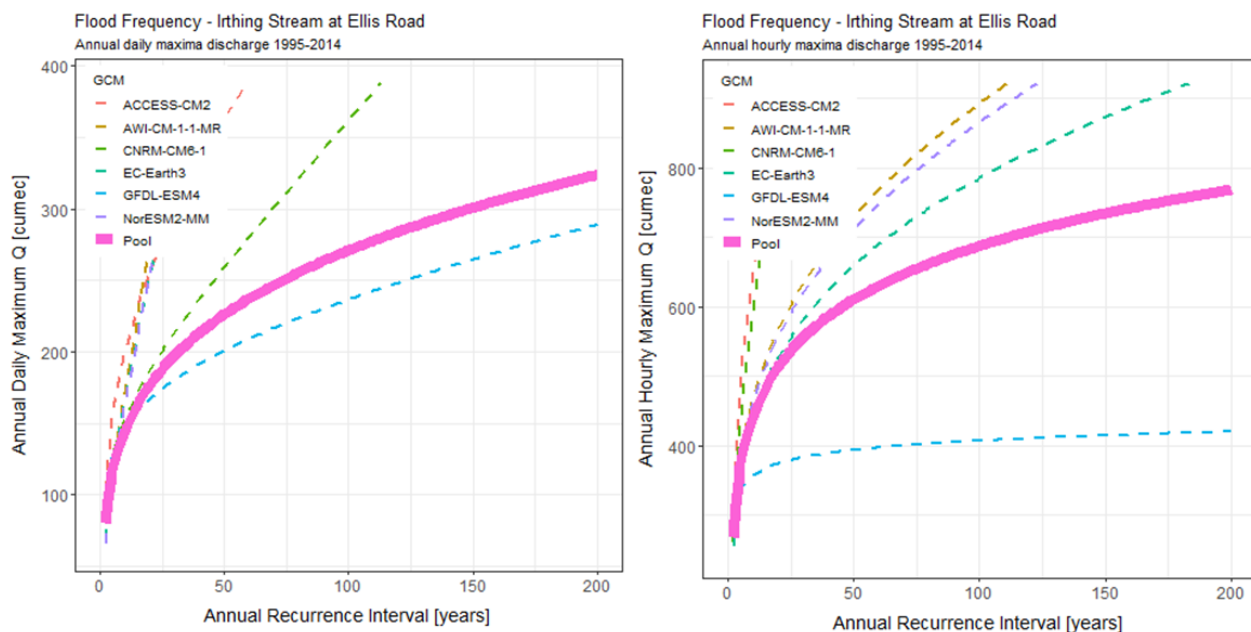


Figure E-32: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Irthing Stream at Ellis Road. Flood frequency generated at nzsegment 15334924 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

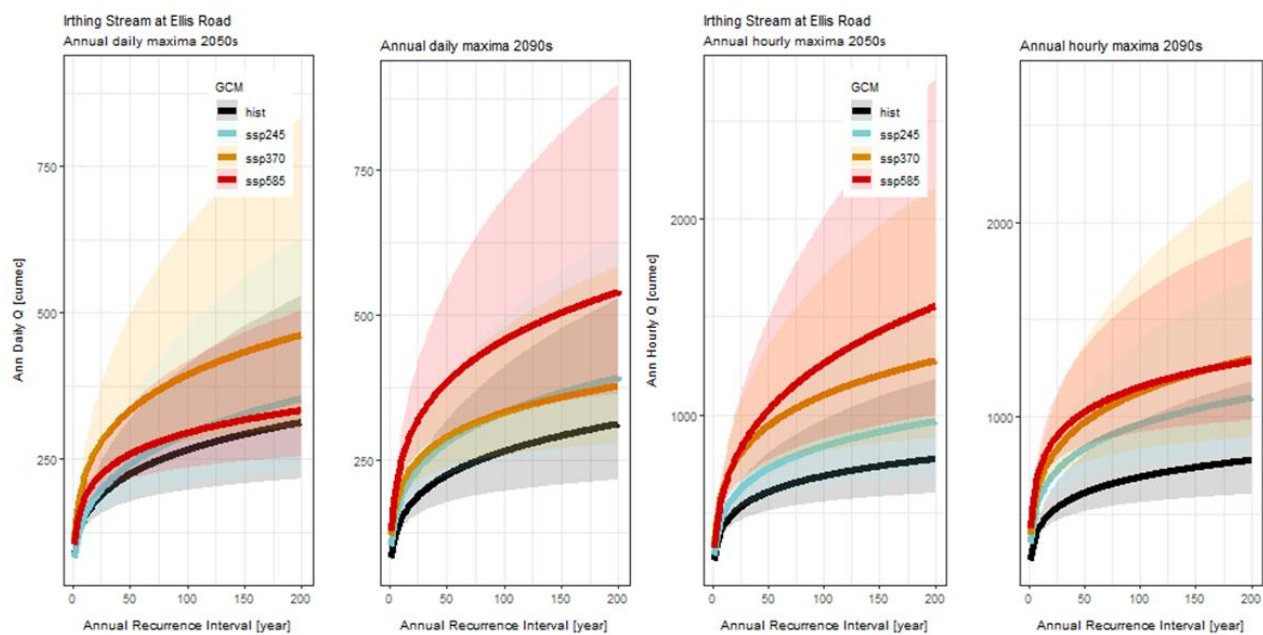


Figure E-33: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Irthing Stream at Ellis Road for four warming scenarios. Pooled flood frequency presented at nzsegment 15334924 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-41: Pooled multi-model daily maxima flood distribution parameters for the Irthing Stream at Ellis Road. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15334924 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	73.2	27.2	0.162
SSP2-4.5	2050	70.6	27.5	0.209
	2090	89.8	34.0	0.168
SSP3-7.0	2050	96.3	46.0	0.122
	2090	105.5	39.3	0.084
SSP5-8.5	2050	90.6	37.5	0.062
	2090	109.3	50.8	0.149

Table E-42: Pooled multi-model hourly maxima flood distribution parameters the Irthing Stream at Ellis Road. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15334924 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	228.7	84.9	0.061
SSP2-4.5	2050	250.4	96.5	0.105
	2090	309.5	108.1	0.101
SSP3-7.0	2050	297.1	130.3	0.107

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	341.5	125.1	0.111
	2050	274.5	112.3	0.242
	2090	363.4	160.8	0.018

Table E-43: Projected changes in pooled multi-model daily maxima flood magnitude for the Irthing Stream at Ellis Road (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	-2.5	23.2	38.1	43.5	25.6	56.1
5-year level	-0.3	23.9	44.2	41.0	25.2	63.1
10-year level	1.9	24.3	46.8	37.9	23.0	66.8
20-year level	4.1	24.7	48.0	34.4	20.0	69.2
50-year level	7.4	25.0	48.4	29.2	15.0	71.2
100-year level	10.1	25.2	48.1	25.1	10.9	72.0
200-year level	13.0	25.3	47.5	20.8	6.5	72.5

Table E-44: Projected changes in pooled multi-model hourly maxima flood magnitude the Irthing Stream at Ellis Road (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	10.5	34.2	34.6	49.4	23.5	64.0
5-year level	12.5	33.9	40.7	50.8	32.0	67.9
10-year level	14.4	34.5	45.3	52.9	41.2	69.0
20-year level	16.5	35.5	49.6	55.4	51.8	69.1
50-year level	19.4	37.5	55.3	59.5	68.3	68.2
100-year level	21.9	39.2	59.7	63.2	83.0	67.1
200-year level	24.6	41.3	64.3	67.4	99.9	65.6

Winton Stream to Winton Township

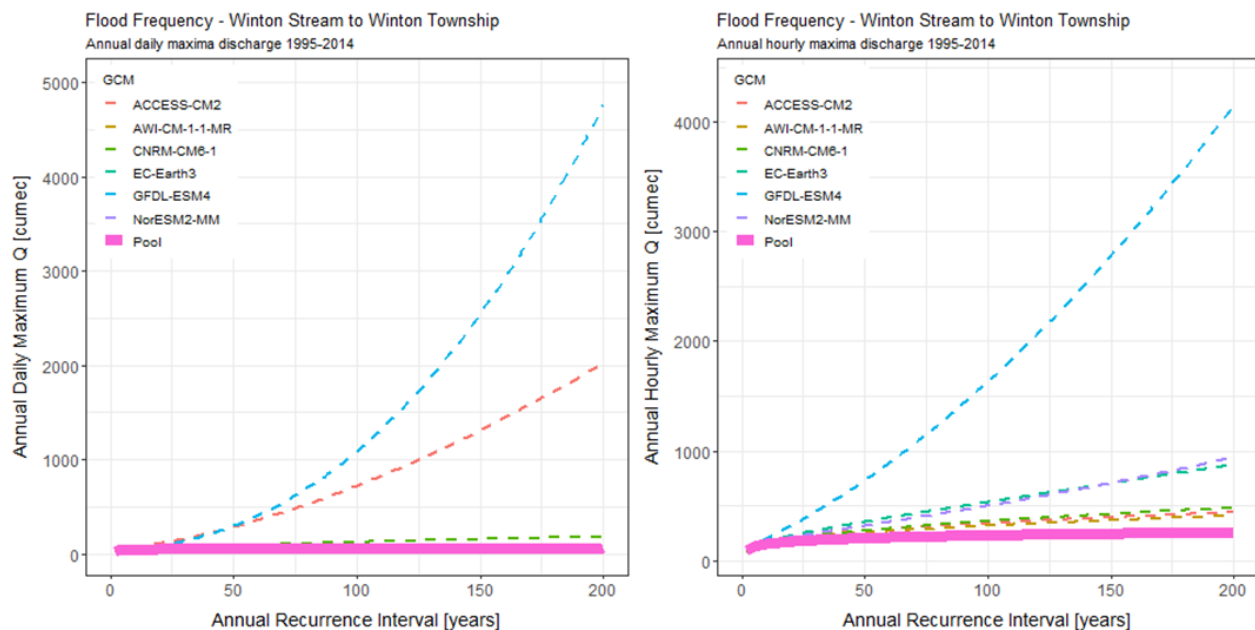


Figure E-34: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Winton Stream at Winton Township. Flood frequency generated at nzsegment 15425942 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

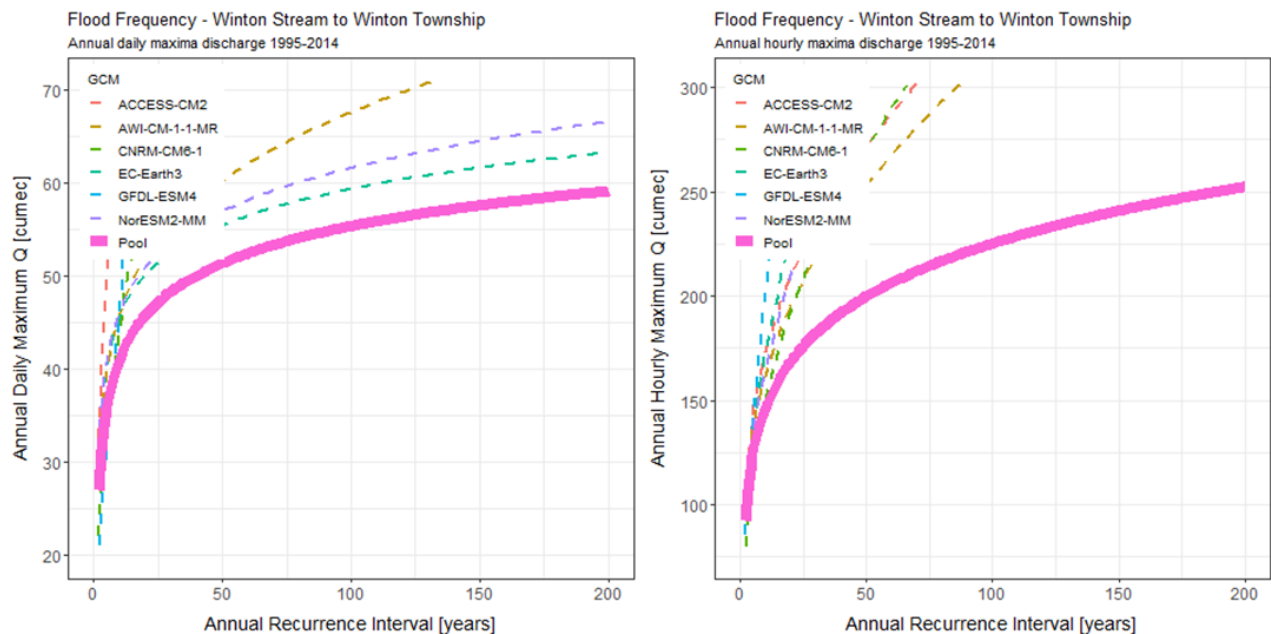


Figure E-35: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Winton Stream at Winton Township. Flood frequency generated at nzsegment 15425942 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

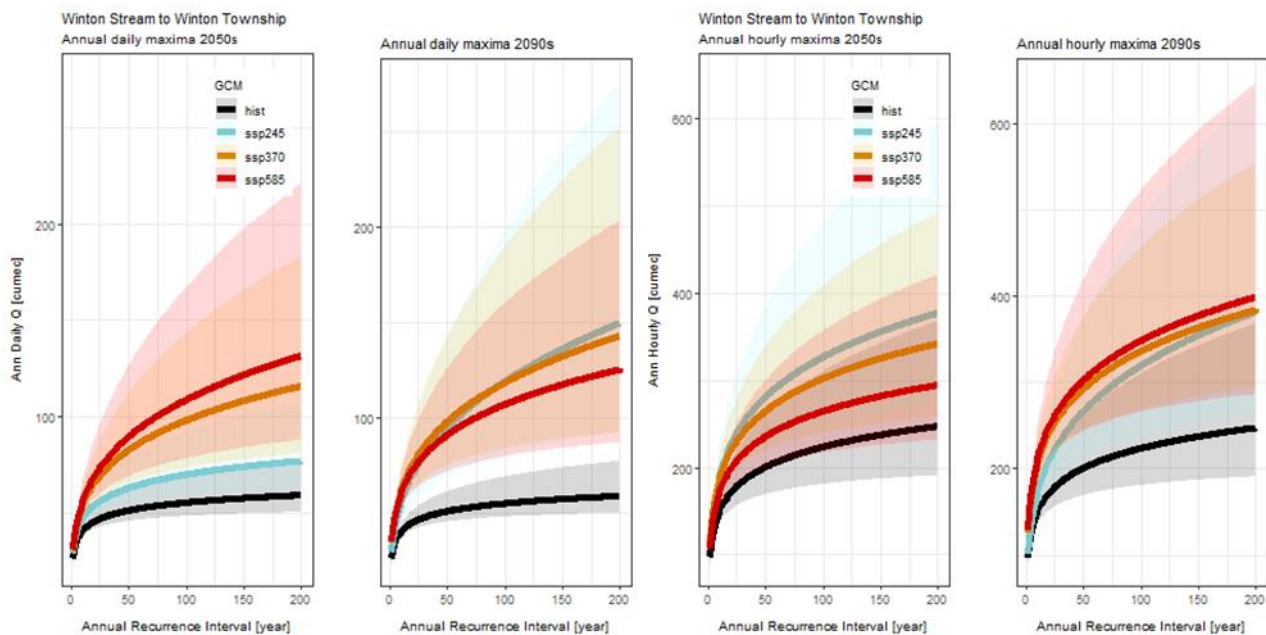


Figure E-36: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Winton Stream at Winton Township for four warming scenarios. Pooled flood frequency presented at nzsegment 15425942 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-45: Pooled multi-model daily maxima flood distribution parameters for the Winton Stream at Winton Township. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 115425942 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	23.7	8.5	-0.101
SSP2-4.5	2050	26.2	9.4	-0.002
	2090	26.7	9.2	0.289
SSP3-7.0	2050	27.2	9.7	0.177
	2090	31.2	10.7	0.213
SSP5-8.5	2050	27.6	9.6	0.228
	2090	31.0	11.1	0.151

Table E-46: Pooled multi-model hourly maxima flood distribution parameters the Winton Stream at Winton Township. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 154259424 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	86.7	27.4	0.024
SSP2-4.5	2050	93.1	37.6	0.112
	2090	90.1	28.4	0.213
SSP3-7.0	2050	100.7	34.9	0.086

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	111.8	36.2	0.116
	2050	94.4	33.0	0.040
	2090	114.9	37.7	0.109

Table E-47: Projected changes in pooled multi-model daily maxima flood magnitude for the Winton Stream at Winton Township (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	10.9	13.8	16.1	32.7	17.8	32.5
5-year level	13.2	23.5	23.3	41.1	26.3	39.9
10-year level	15.8	37.0	32.3	52.6	37.3	49.1
20-year level	18.6	54.6	43.3	67.0	51.3	60.1
50-year level	22.8	85.2	60.9	91.2	74.4	77.7
100-year level	26.2	115.2	76.8	113.9	96.0	93.4
200-year level	29.8	152.7	95.3	141.2	121.8	111.5

Table E-48: Projected changes in pooled multi-model hourly maxima flood magnitude the Winton Stream at Winton Township (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	12.6	4.9	18.3	30.0	10.8	34.0
5-year level	20.3	9.3	21.9	33.1	13.2	37.3
10-year level	26.4	14.9	24.9	36.5	14.7	40.9
20-year level	32.2	21.8	27.9	40.2	15.9	44.8
50-year level	40.0	32.9	31.9	45.7	17.3	50.7
100-year level	46.1	42.8	35.0	50.2	18.2	55.7
200-year level	52.4	54.3	38.2	55.1	19.0	61.1

Mataura

Mataura catchment at Cattle Flat Township

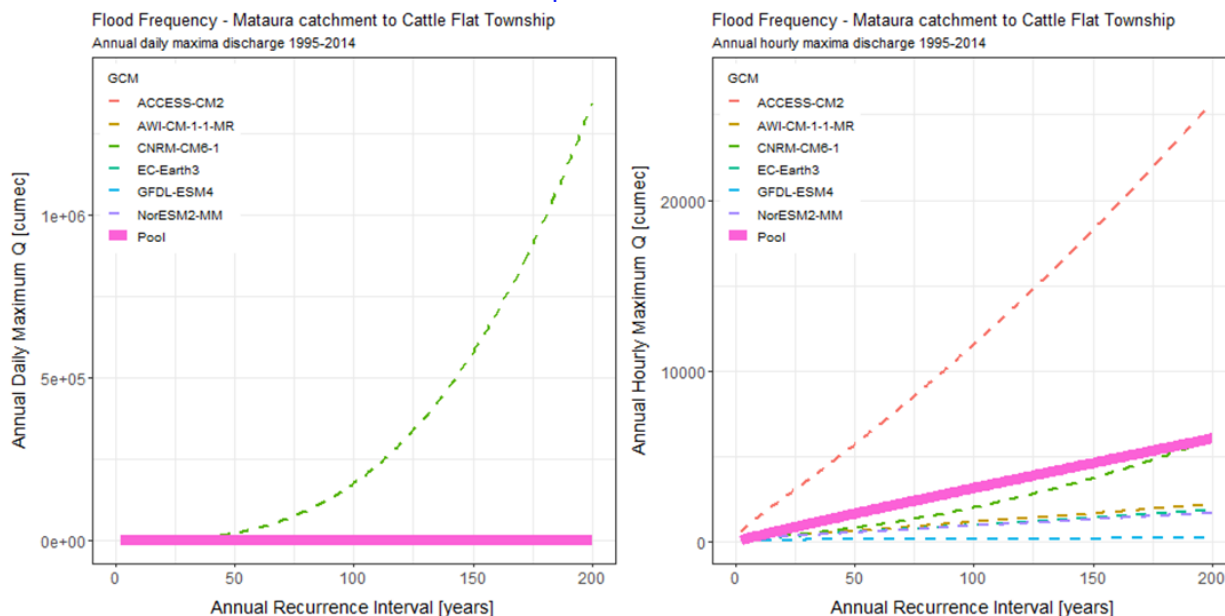


Figure E-37: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mataura catchment at Cattle Flat. Flood frequency generated at nzsegment 15330788 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

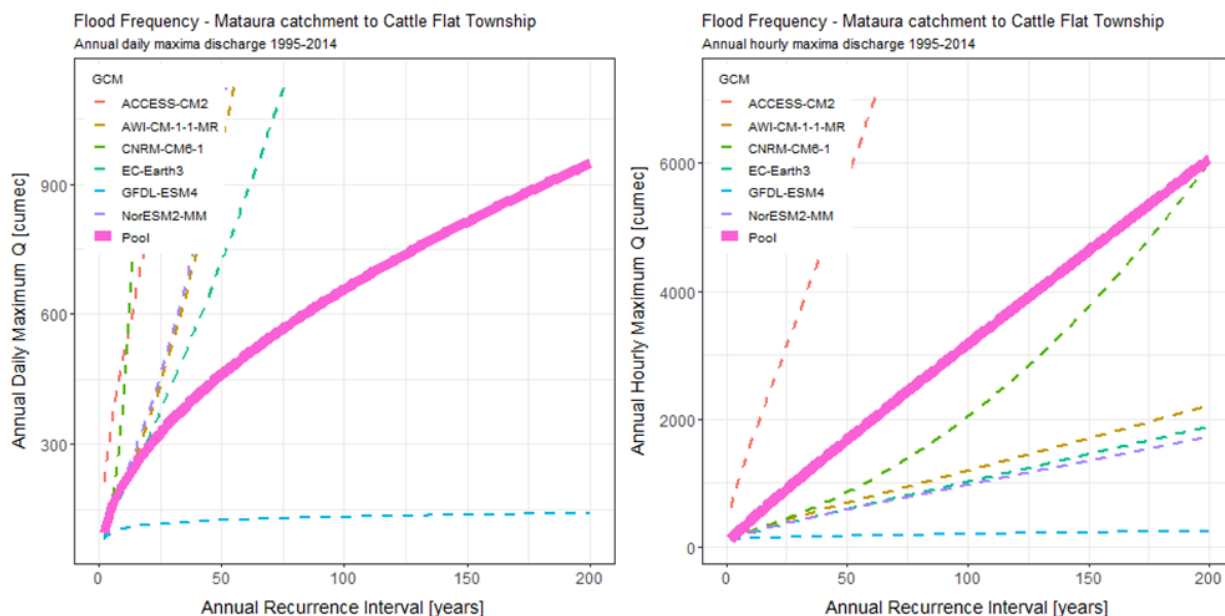


Figure E-38: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mataura catchment at Cattle Flat. Flood frequency generated at nzsegment 15330788 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

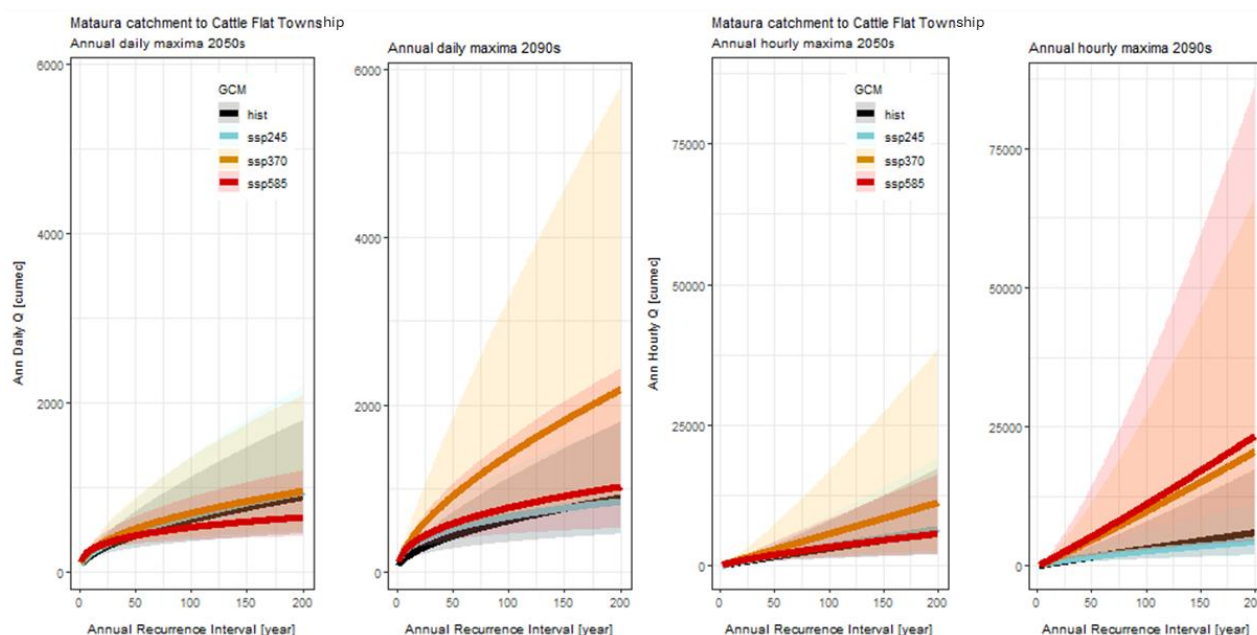


Figure E-39: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Mataura catchment at Cattle Flat for four warming scenarios. Pooled flood frequency presented at nzsegment 15330788 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-49: Pooled multi-model daily maxima flood distribution parameters for the Mataura catchment at Cattle Flat. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15330788 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	82.0	27.6	0.509
SSP2-4.5	2050	83.2	34.9	0.451
	2090	112.2	58.2	0.266
SSP3-7.0	2050	100.9	41.5	0.404
	2090	109.8	50.2	0.579
SSP5-8.5	2050	111.8	52.1	0.211
	2090	110.8	56.4	0.331

Table E-50: Pooled multi-model hourly maxima flood distribution parameters for the Mataura catchment at Cattle Flat. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15330788 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	94.1	42.0	0.880
SSP2-4.5	2050	101.3	55.6	0.826
	2090	134.0	85.4	0.632
SSP3-7.0	2050	128.5	73.4	0.867

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	140.3	89.1	0.976
	2050	132.5	81.9	0.704
	2090	155.4	105.4	0.946

Table E-51: Projected changes in pooled multi-model daily maxima flood magnitude for the Mataura catchment at Cattle Flat (% relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	5.7	47.8	27.3	43.6	43.0	45.9
5-year level	9.8	52.3	29.4	60.0	41.2	52.9
10-year level	11.0	47.1	27.8	74.3	31.7	51.3
20-year level	10.9	37.3	24.3	88.8	18.8	45.4
50-year level	9.6	21.0	18.1	109.2	0.0	34.2
100-year level	8.1	7.9	12.9	126.1	-13.9	24.6
200-year level	6.6	-4.8	7.6	144.6	-26.9	14.9

Table E-52: Projected changes in pooled multi-model hourly maxima flood magnitude for the Mataura catchment at Cattle Flat (% relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	13.3	53.9	46.1	66.7	51.8	88.3
5-year level	18.5	54.2	58.6	98.2	55.8	126.3
10-year level	19.3	42.0	65.9	124.8	48.7	156.2
20-year level	18.0	25.3	71.2	150.5	37.1	184.3
50-year level	14.7	2.6	77.3	184.9	19.8	222.2
100-year level	11.8	-13.1	82.1	212.6	7.2	253.8
200-year level	8.9	-26.9	87.6	242.7	-4.5	289.5

Mataura River at Gore Township

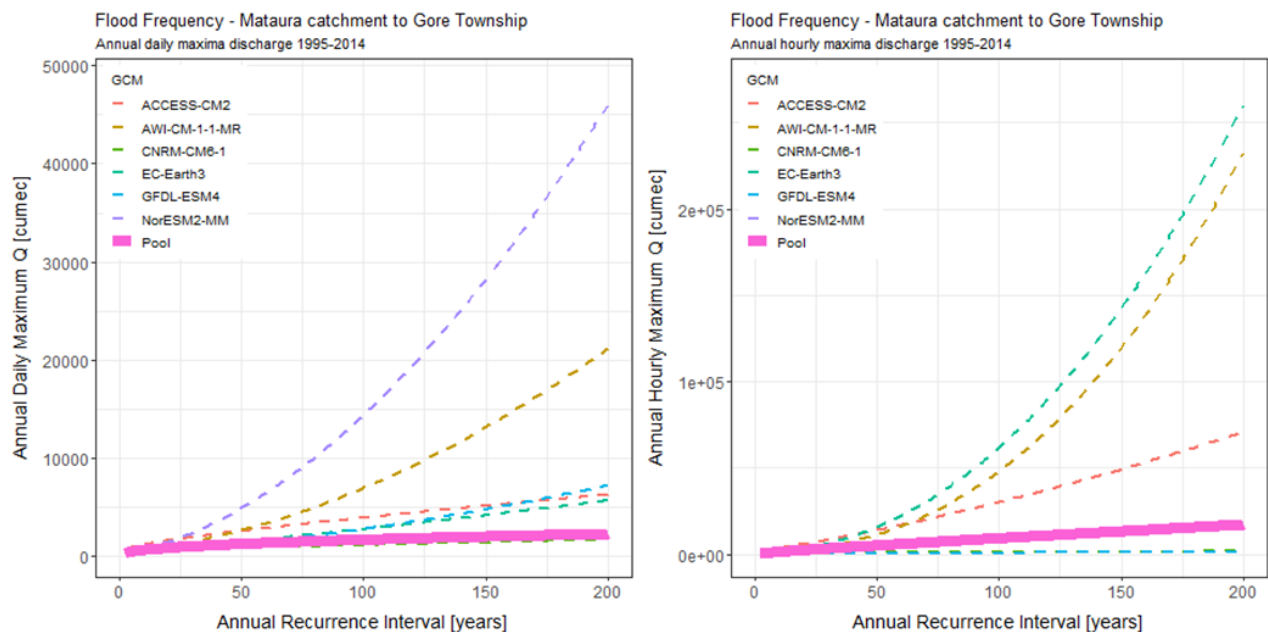


Figure E-40: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mataura Catchment at Gore Township. Flood frequency generated at nzsegment 15408285 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

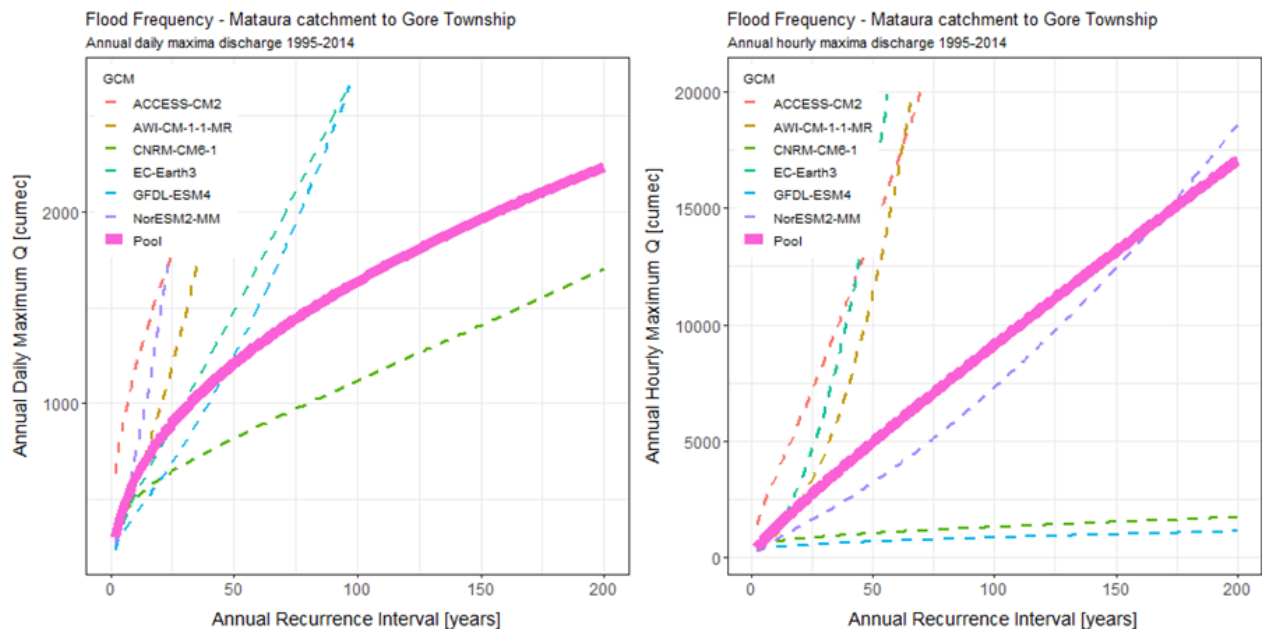


Figure E-41: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mataura Catchment at Gore Township. Flood frequency generated at nzsegment 15408285 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

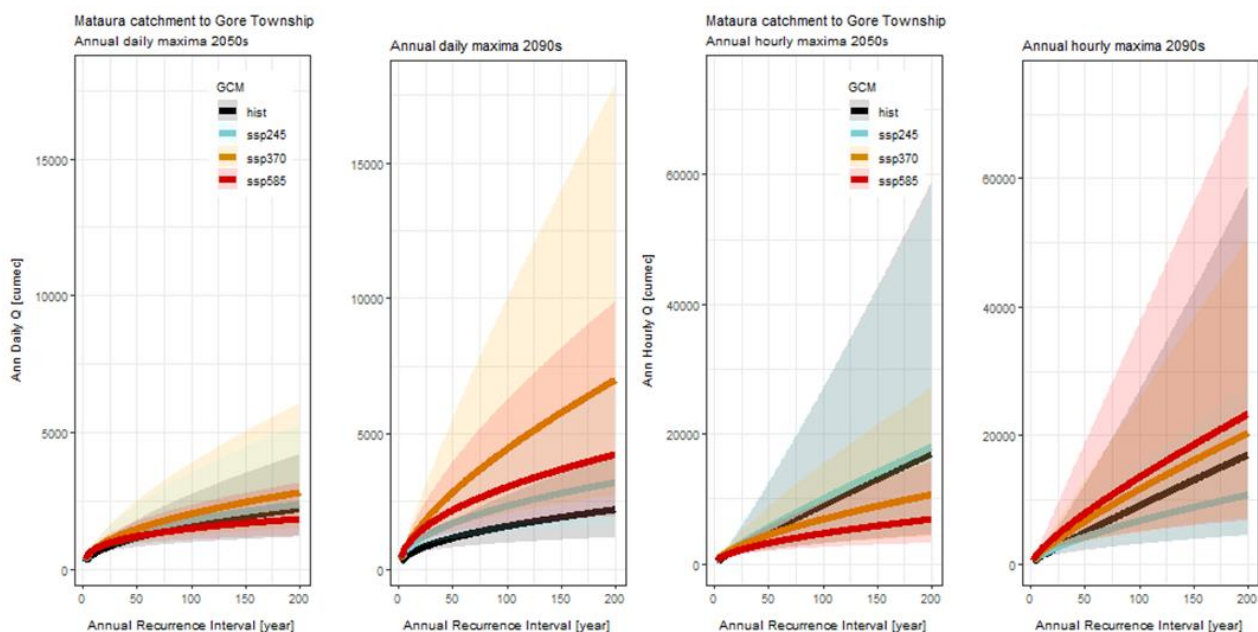


Figure E-42: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Mataura Catchment at Gore Township for four warming scenarios. Pooled flood frequency presented at nzsegment 15408285 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-53: Pooled multi-model daily maxima flood distribution parameters for the Mataura Catchment at Gore Township. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15408285 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	252.8	81.2	0.455
SSP2-4.5	2050	286.9	125.7	0.341
	2090	324.2	134.2	0.416
SSP3-7.0	2050	313.5	106.2	0.442
	2090	335.6	147.7	0.604
SSP5-8.5	2050	320.1	130.4	0.249
	2090	353.3	176.8	0.414

Table E-54: Pooled multi-model hourly maxima flood distribution parameters the Mataura Catchment at Gore Township. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15408285 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	326.9	149.3	0.802
SSP2-4.5	2050	371.2	196.4	0.755
	2090	430.7	214.2	0.624
SSP3-7.0	2050	482.5	259.6	0.567
	2090	458.5	243.2	0.756

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2050	422.8	219.7	0.502
	2090	518.7	336.7	0.683

Table E-55: Projected changes in pooled multi-model daily maxima flood magnitude for the Mataura Catchment at Gore Township (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	19.9	34.4	25.2	42.9	30.9	53.0
5-year level	24.9	41.4	26.3	63.5	30.3	69.1
10-year level	25.1	44.8	26.8	84.5	24.7	78.1
20-year level	22.9	46.5	27.1	108.5	16.5	84.0
50-year level	17.7	46.9	27.1	145.7	3.6	88.6
100-year level	12.8	46.3	27.0	178.8	-6.7	90.7
200-year level	7.4	45.3	27.0	216.9	-16.8	92.2

Table E-56: Projected changes in pooled multi-model hourly maxima flood magnitude for the Mataura Catchment at Gore Township (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	17.6	32.7	51.1	45.3	30.5	73.5
5-year level	20.6	26.0	43.5	48.9	19.4	84.0
10-year level	20.2	15.1	29.2	47.5	3.3	81.9
20-year level	18.1	2.6	12.5	43.4	-13.9	74.2
50-year level	13.8	-14.1	-9.3	35.3	-34.8	60.0
100-year level	9.9	-25.9	-24.1	27.9	-48.3	48.5
200-year level	5.8	-36.7	-37.1	19.8	-59.4	37.1

Mataura catchment at Wyndham catchment Township

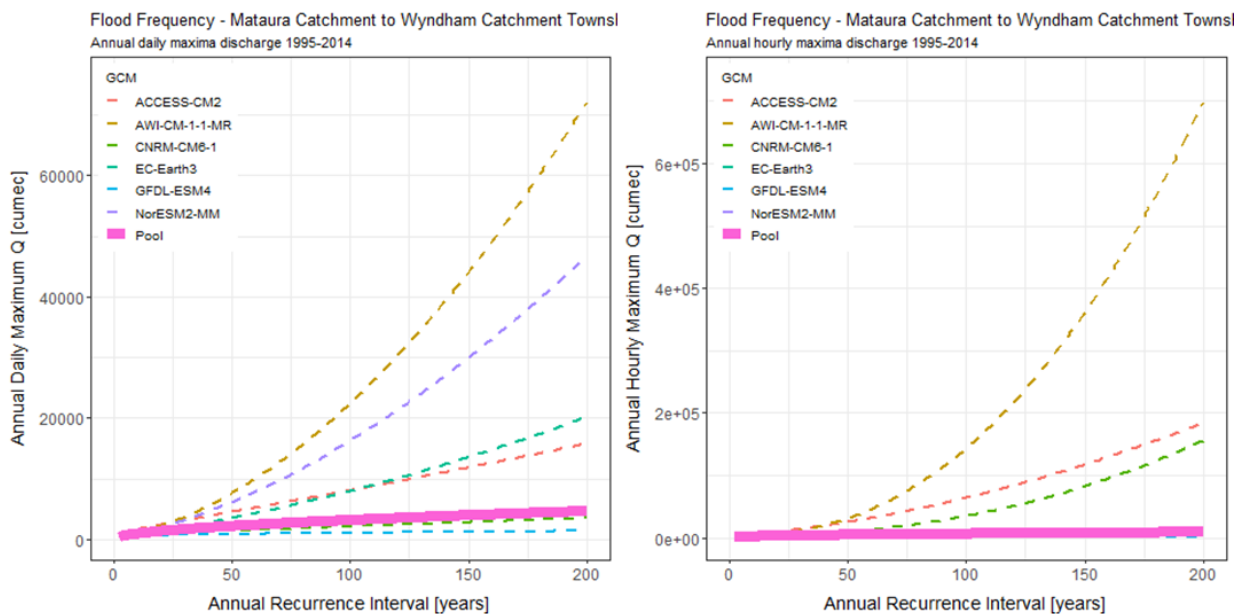


Figure E-43: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mataura catchment at Wyndham catchment Township. Flood frequency generated at nzsegment 15444038 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

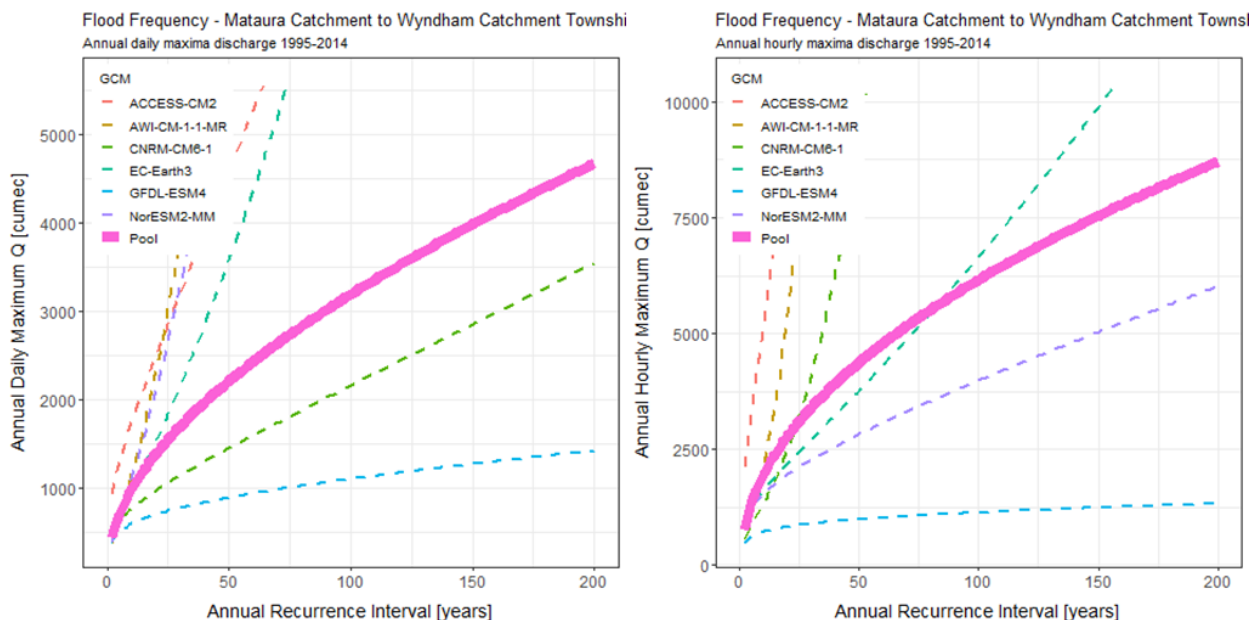


Figure E-44: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mataura catchment at Wyndham catchment Township. Flood frequency generated at nzsegment 15444038 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

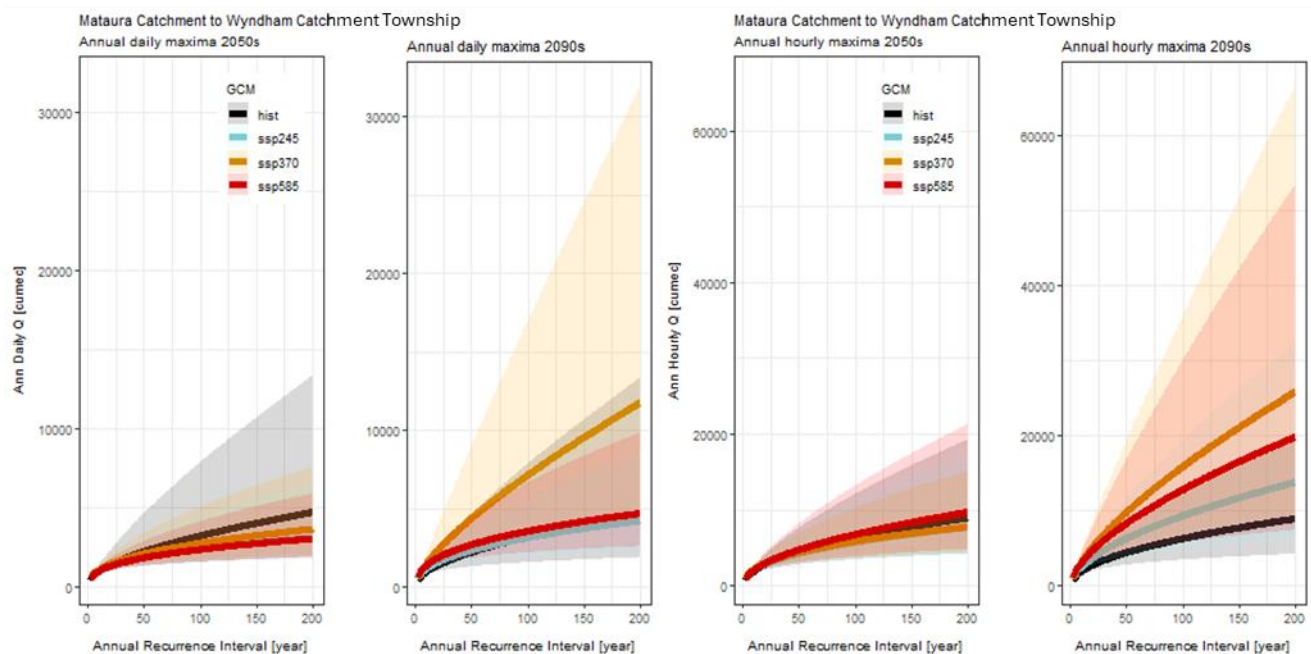


Figure E-45: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Mataura catchment at Wyndham catchment Township for four warming scenarios. Pooled flood frequency presented at nsegment 15444038 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-57: Pooled multi-model daily maxima flood distribution parameters for the Mataura catchment at Wyndham catchment Township. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nsegment 15444038 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	389.5	149.2	0.470
SSP2-4.5	2050	452.8	172.7	0.321
	2090	472.8	197.9	0.388
SSP3-7.0	2050	488.2	172.8	0.374
	2090	486.1	194.1	0.663
SSP5-8.5	2050	447.1	170.0	0.326
	2090	526.0	252.7	0.345

Table E-58: Pooled multi-model hourly maxima flood distribution parameters for the Mataura catchment at Wyndham catchment Township. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nsegment 15444038 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	653.4	334.2	0.458
SSP2-4.5	2050	756.9	381.4	0.371
	2090	828.9	412.3	0.518
SSP3-7.0	2050	798.9	417.4	0.352
	2090	837.6	482.7	0.635

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2050	744.6	331.5	0.481
	2090	945.3	483.7	0.561

Table E-59: Projected changes in pooled multi-model daily maxima flood magnitude for the Mataura catchment at Wyndham catchment Township (% relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	15.1	23.0	22.7	27.5	13.6	40.7
5-year level	9.5	22.2	16.6	37.9	8.2	42.7
10-year level	2.6	18.8	10.2	51.6	1.4	39.2
20-year level	-5.4	13.9	3.2	69.0	-6.4	32.6
50-year level	-16.7	5.4	-6.7	97.1	-17.8	20.9
100-year level	-25.6	-2.1	-14.6	121.8	-26.6	10.6
200-year level	-34.3	-10.2	-22.6	149.2	-35.4	-0.3

Table E-60: Projected changes in pooled multi-model hourly maxima flood magnitude for the Mataura catchment at Wyndham catchment Township (% relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	14.6	26.6	21.9	34.4	10.4	45.9
5-year level	10.7	28.5	18.0	49.6	7.2	52.0
10-year level	6.5	31.6	12.9	66.7	6.1	60.2
20-year level	1.9	35.7	7.2	87.3	5.9	70.6
50-year level	-4.4	42.2	-0.9	120.8	6.4	87.6
100-year level	-9.2	47.9	-7.2	151.7	7.2	103.2
200-year level	-13.9	54.3	-13.4	188.5	8.2	121.6

Waikaia catchment to Waikaia Township

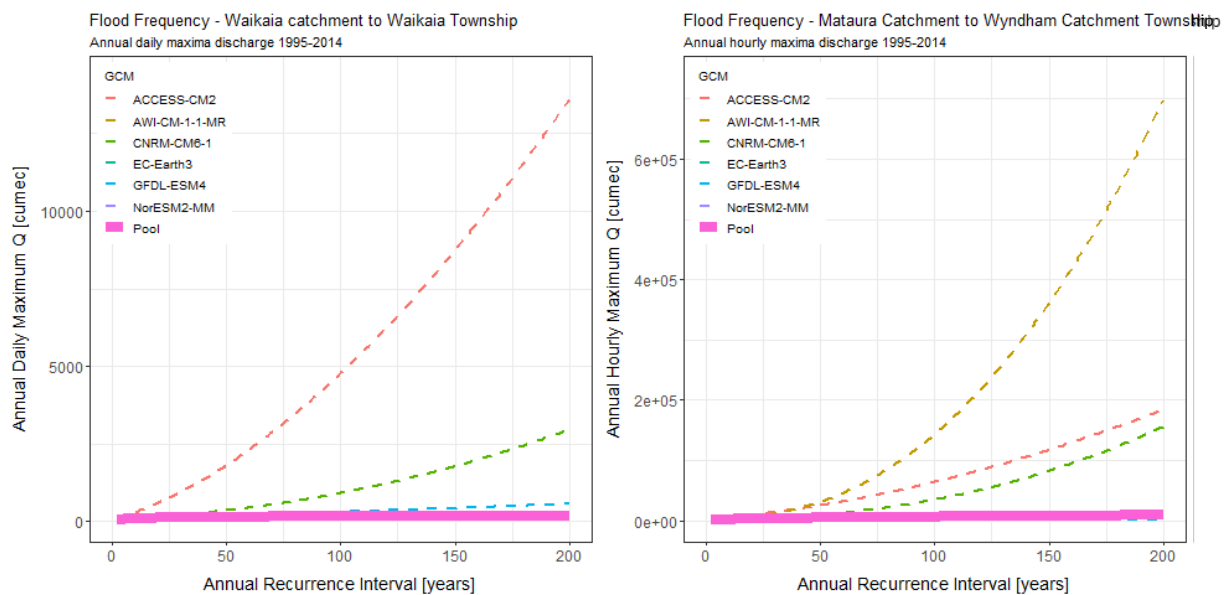


Figure E-46: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waikaia catchment at Waikaia Township. Flood frequency generated presented at nzsegment 15331068 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

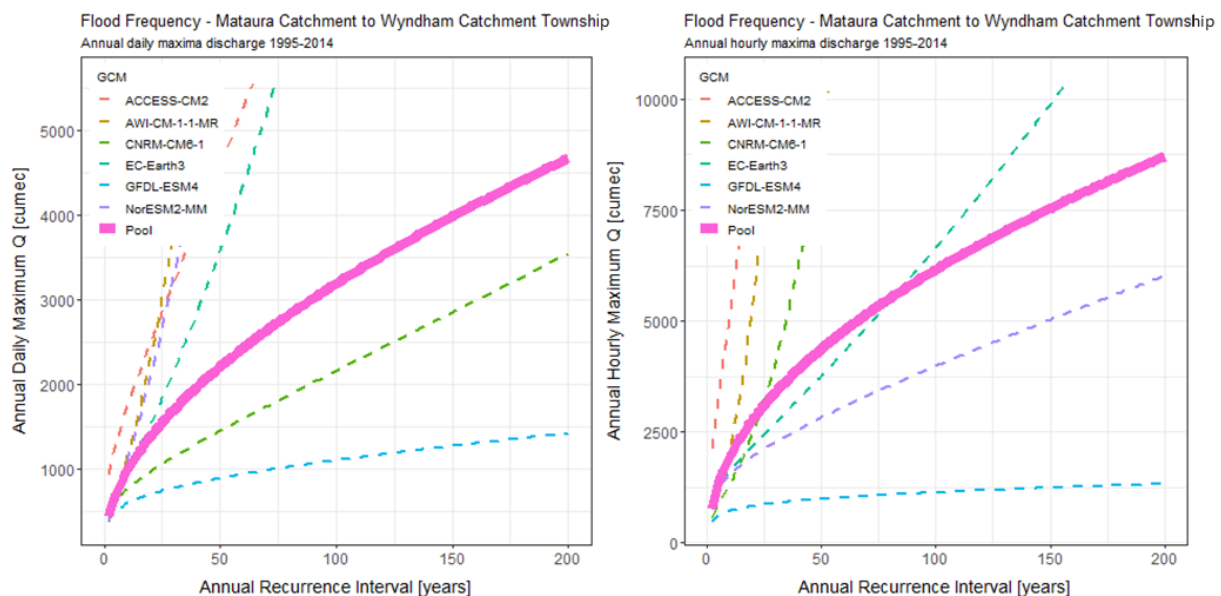


Figure E-47: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waikaia catchment at Waikaia Township. Flood frequency generated presented at nzsegment 15331068 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

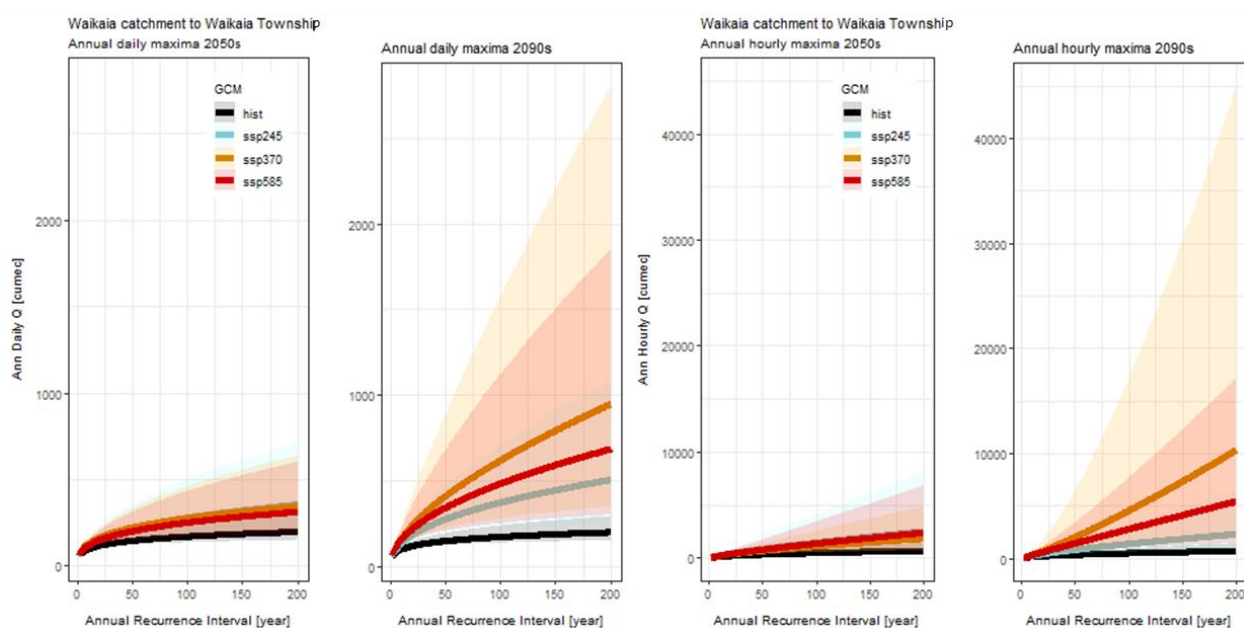


Figure E-48: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Waikaia catchment at Waikaia Township for four warming scenarios. Pooled flood frequency presented at nzsegment 15331068 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-61: Pooled multi-model daily maxima flood distribution parameters for the Waikaia catchment at Waikaia Township. Daily maxima flood extreme event distribution generated using General Extreme Value distribution presented at nzsegment 15331068 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	50.0	18.6	0.137
SSP2-4.5	2050	50.1	22.8	0.282
	2090	45.4	24.2	0.384
SSP3-7.0	2050	58.4	22.8	0.270
	2090	53.4	24.2	0.540
SSP5-8.5	2050	53.1	21.5	0.254
	2090	51.2	26.7	0.429

Table E-62: Pooled multi-model hourly maxima flood distribution parameters for the Waikaka Stream at Gore Township. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution presented at nzsegment 15331068 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	54.4	26.3	0.466
SSP2-4.5	2050	60.3	37.2	0.686
	2090	57.3	38.9	0.664
SSP3-7.0	2050	64.3	33.0	0.651

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	57.3	31.9	1.019
	2050	58.6	31.8	0.716
	2090	56.9	37.5	0.869

Table E-63: Projected changes in pooled multi-model daily maxima flood magnitude for the Waikaia catchment at Waikaia Township (% relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	-0.2	18.8	14.1	8.7	12.3	-0.2
5-year level	17.0	24.5	35.8	14.2	33.2	17.0
10-year level	34.3	30.9	64.0	20.0	55.8	34.3
20-year level	54.2	38.6	102.9	26.8	83.8	54.2
50-year level	86.6	50.9	177.9	37.4	132.3	86.6
100-year level	117.1	61.9	260.7	46.9	181.2	117.1
200-year level	154.2	74.8	377.1	58.1	244.7	154.2

Table E-64: Projected changes in pooled multi-model hourly maxima flood magnitude the Waikaia catchment at Waikaia Township (% relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	20.7	17.9	21.8	14.8	13.3	18.6
5-year level	42.5	41.7	33.4	54.8	29.9	56.3
10-year level	66.6	65.4	48.0	120.1	50.9	105.3
20-year level	96.4	92.7	66.4	227.0	78.5	173.7
50-year level	147.4	136.6	97.4	476.9	127.5	307.8
100-year level	197.6	177.6	126.6	809.5	177.1	457.7
200-year level	261.1	227.2	161.8	1361.2	240.8	669.5

Waikaka Stream at Gore Township

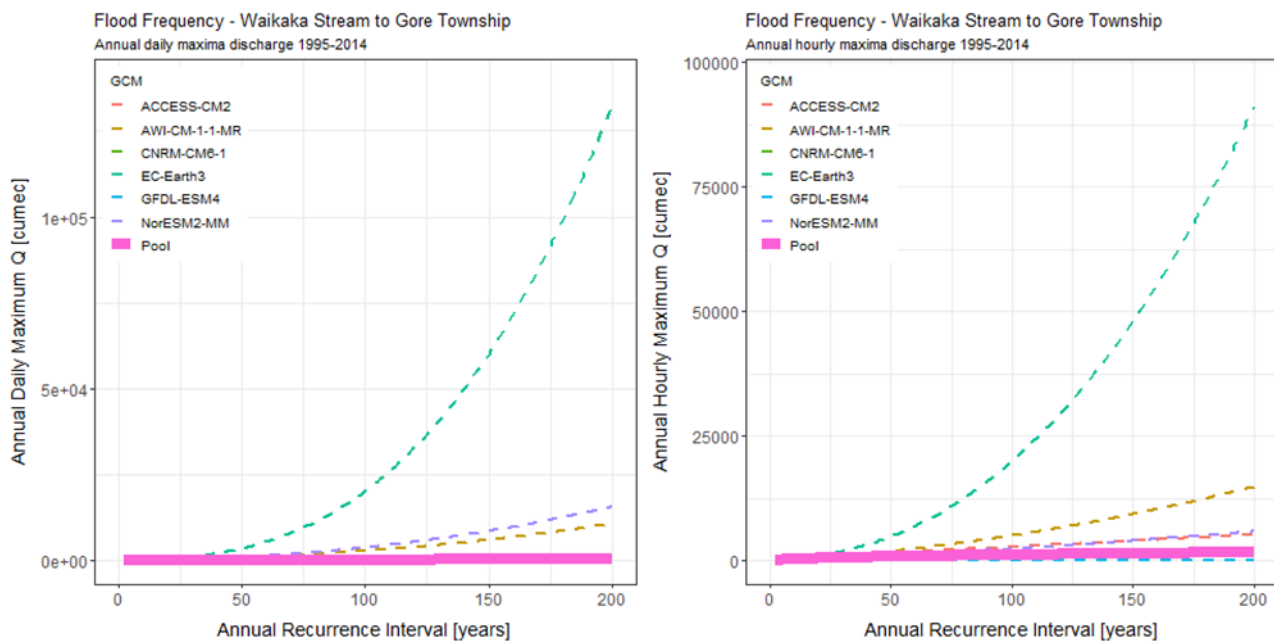


Figure E-49: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waikaka Stream at Gore Township. Flood frequency generated presented at nzsegment 15436622 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

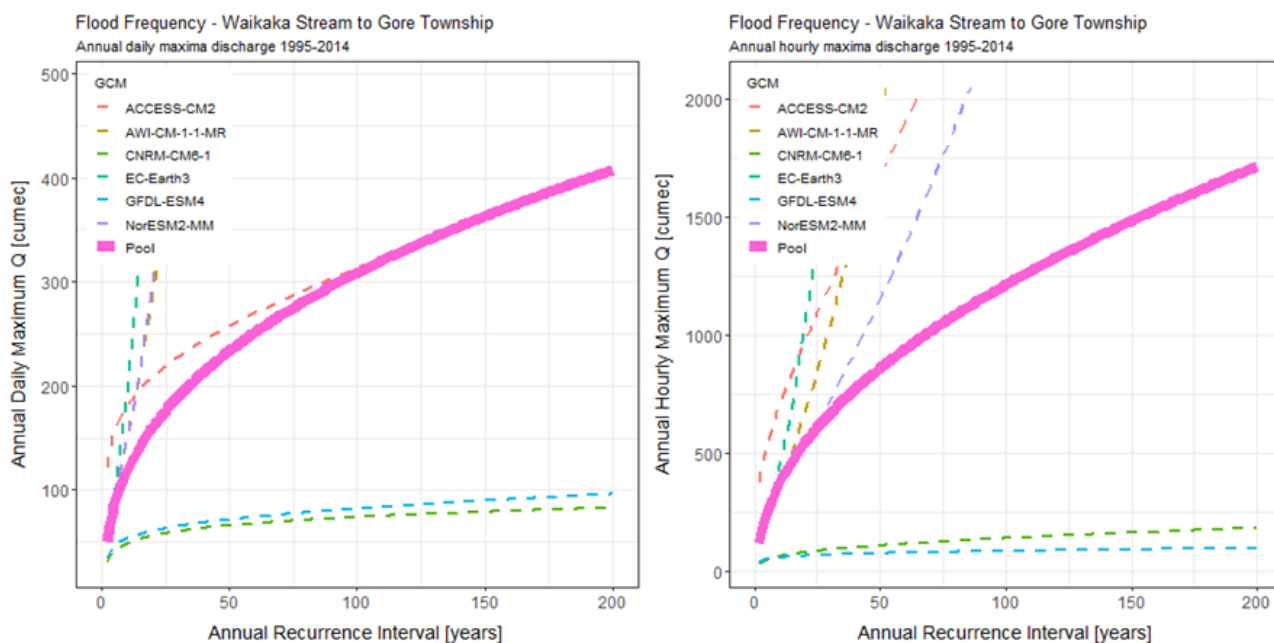


Figure E-50: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waikaka Stream at Gore Township. Flood frequency generated presented at nzsegment 15436622 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

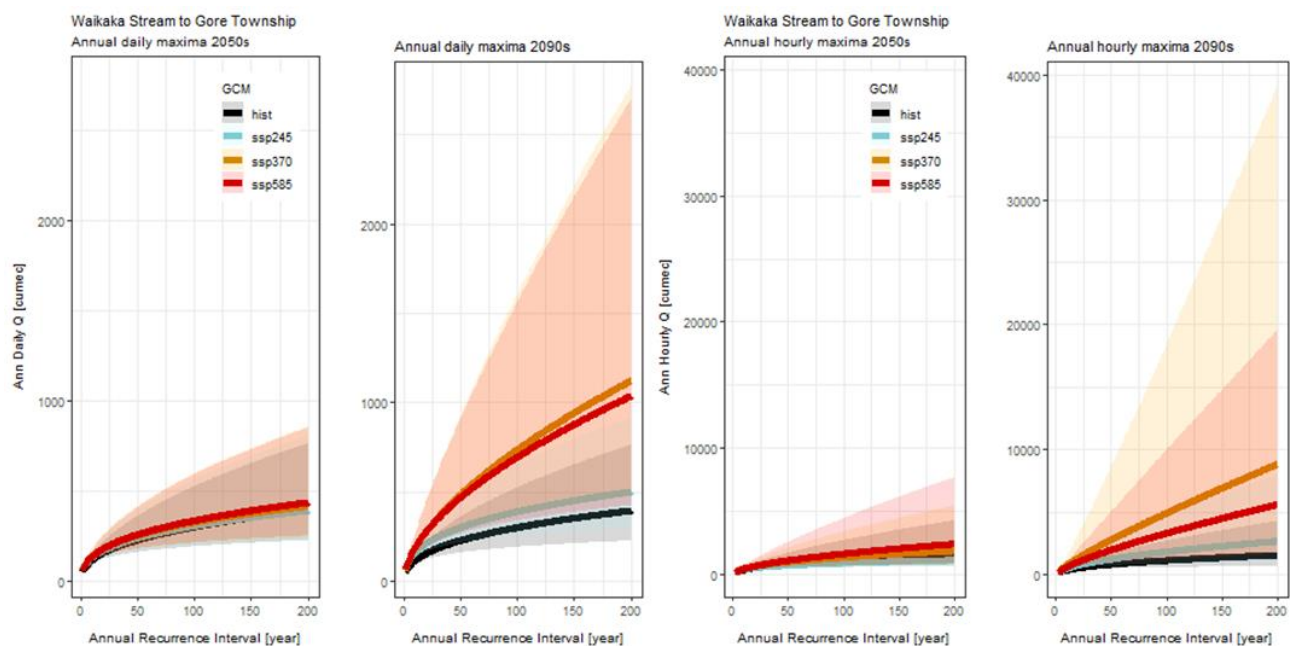


Figure E-51: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Waikaka Stream at Gore Township for four warming scenarios. Pooled flood frequency presented at nzsegment 15436622 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-65: Pooled multi-model daily maxima flood distribution parameters for the Waikaka Stream at Gore Township e. Daily maxima flood extreme event distribution generated using General Extreme Value distribution presented at nzsegment 15436622 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	42.1	22.3	0.340
SSP2-4.5	2050	49.1	26.3	0.276
	2090	56.2	32.1	0.303
SSP3-7.0	2050	50.8	28.1	0.275
	2090	49.1	30.1	0.547
SSP5-8.5	2050	49.4	26.2	0.317
	2090	54.3	31.5	0.508

Table E-66: Pooled multi-model hourly maxima flood distribution parameters for the Waikaka Stream at Gore Township. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution presented at nzsegment 15436622 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	97.2	81.9	0.347
SSP2-4.5	2050	122.3	102.5	0.172
	2090	121.5	100.6	0.436
SSP3-7.0	2050	119.9	100.8	0.326

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	127.4	121.2	0.648
	2050	106.4	88.4	0.431
	2090	118.5	95.9	0.633

Table E-67: Projected changes in pooled multi-model daily maxima flood magnitude for the Waikaka Stream at Gore Township (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	16.4	35.8	21.4	23.5	17.3	33.9
5-year level	14.4	36.7	20.1	39.3	16.5	46.3
10-year level	11.9	36.0	17.8	56.5	15.5	60.2
20-year level	9.1	34.5	15.1	77.3	14.4	77.0
50-year level	5.1	31.8	11.3	111.6	12.7	104.6
100-year level	2.0	29.3	8.2	144.0	11.4	130.4
200-year level	-1.1	26.5	5.2	183.2	10.0	161.5

Table E-68: Projected changes in pooled multi-model hourly maxima flood magnitude for the Waikaka Stream at Gore Township (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	23.3	25.5	23.0	42.1	9.9	24.0
5-year level	15.0	29.7	22.0	70.5	13.5	39.5
10-year level	6.7	35.1	21.1	104.7	18.1	60.7
20-year level	-1.7	41.4	20.3	150.4	23.9	88.7
50-year level	-12.6	51.4	19.5	236.6	33.6	139.0
100-year level	-20.6	60.2	19.1	330.9	42.8	190.2
200-year level	-28.3	70.2	19.1	462.1	54.0	256.6

Waikawa Catchment

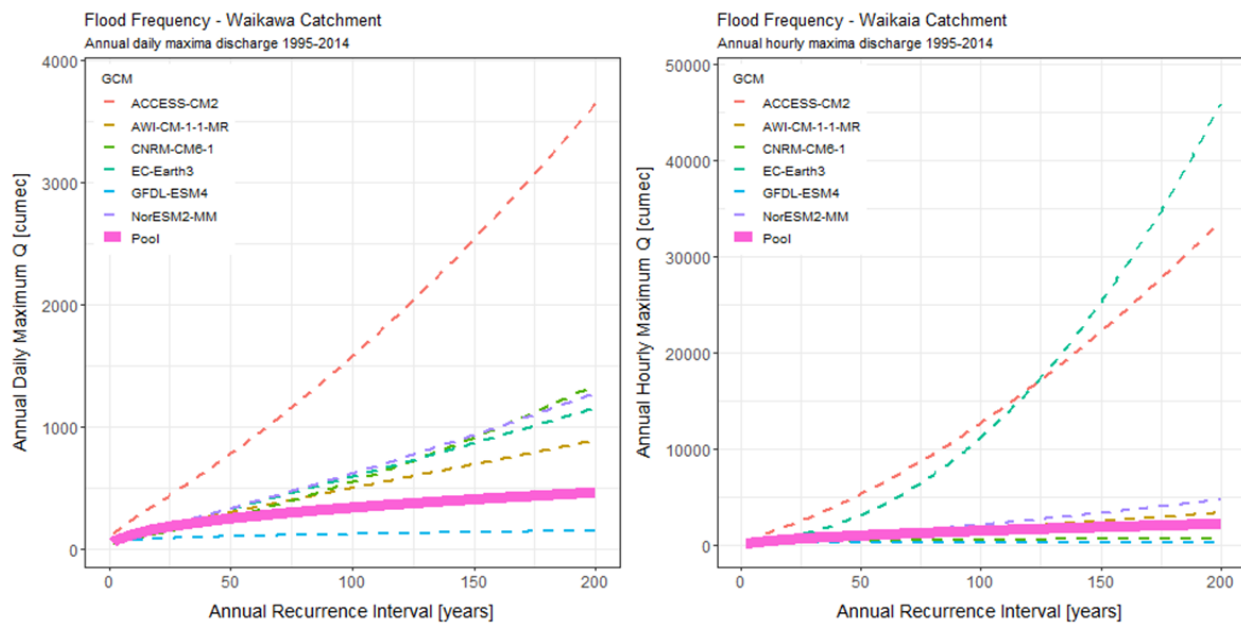


Figure E-52: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waikawa catchment. Flood frequency generated at nzsegment 15210887 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

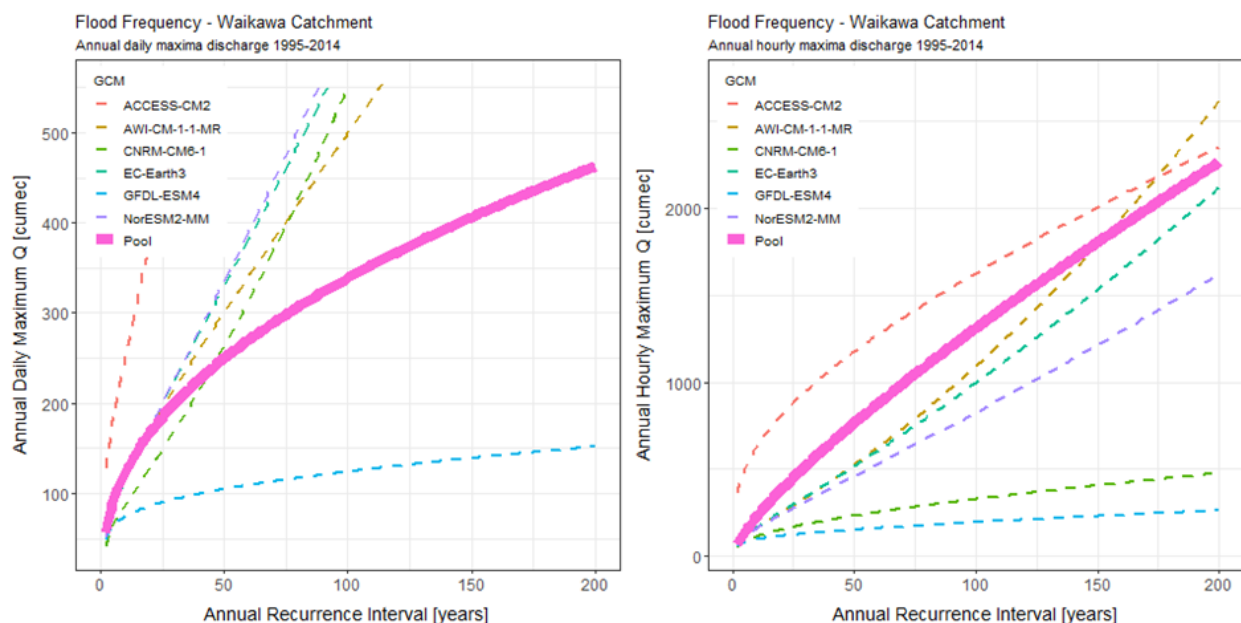


Figure E-53: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waikawa catchment. Flood frequency generated at nzsegment 15210887 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

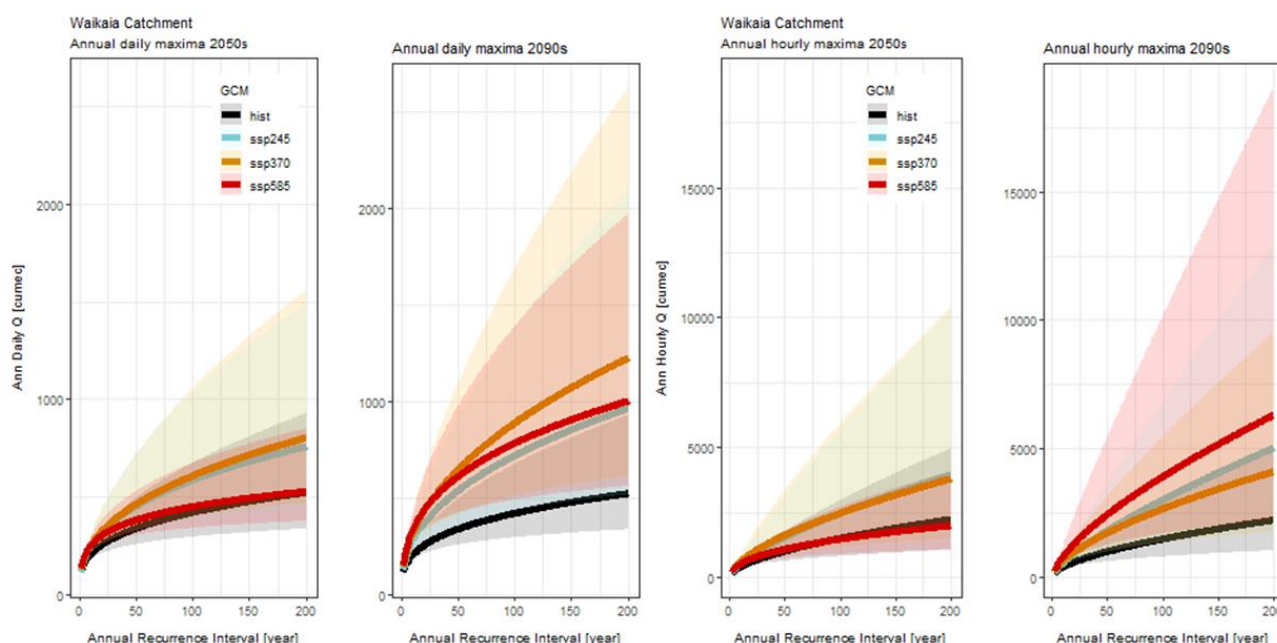


Figure E-54: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Waikawa catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15210887 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-69: Pooled multi-model daily maxima flood distribution parameters for the Waikawa catchment.

Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15210887 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	49.7	20.3	0.411
SSP2-4.5	2050	46.9	17.7	0.423
	2090	58.5	26.9	0.379
SSP3-7.0	2050	60.2	25.7	0.260
	2090	53.8	20.7	0.742
SSP5-8.5	2050	45.1	21.6	0.600
	2090	61.5	29.2	0.359

Table E-70: Pooled multi-model hourly maxima flood distribution parameters for the Waikawa catchment e. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15210887 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	141.1	62.2	0.539
SSP2-4.5	2050	144.4	80.4	0.616
	2090	155.7	79.8	0.683
SSP3-7.0	2050	194.3	95.3	0.554

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	195.9	98.7	0.579
	2050	181.7	97.3	0.381
	2090	197.0	131.7	0.599

Table E-71: Projected changes in pooled multi-model daily maxima flood magnitude for the Waikawa catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	-6.9	20.7	21.2	9.4	-4.5	27.7
5-year level	-8.4	23.1	17.0	21.5	6.8	30.5
10-year level	-9.1	23.6	11.1	42.0	19.4	30.6
20-year level	-9.5	23.3	4.4	73.0	34.7	29.5
50-year level	-9.7	22.0	-5.0	135.0	59.9	26.9
100-year level	-9.7	20.6	-12.2	204.3	83.3	24.3
200-year level	-9.6	19.1	-19.2	301.3	111.3	21.5

Table E-72: Projected changes in pooled multi-model hourly maxima flood magnitude the Waikawa catchment e (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	19.0	53.6	58.6	66.7	29.7	69.9
5-year level	22.3	60.2	66.8	110.1	51.8	90.9
10-year level	25.4	61.5	69.8	166.0	70.8	105.5
20-year level	28.6	60.8	70.8	241.3	90.3	118.5
50-year level	33.2	58.6	71.0	381.0	118.7	135.5
100-year level	37.0	56.6	71.1	529.7	143.3	149.6
200-year level	41.2	54.8	71.6	731.6	171.6	165.5

Waimea Catchment

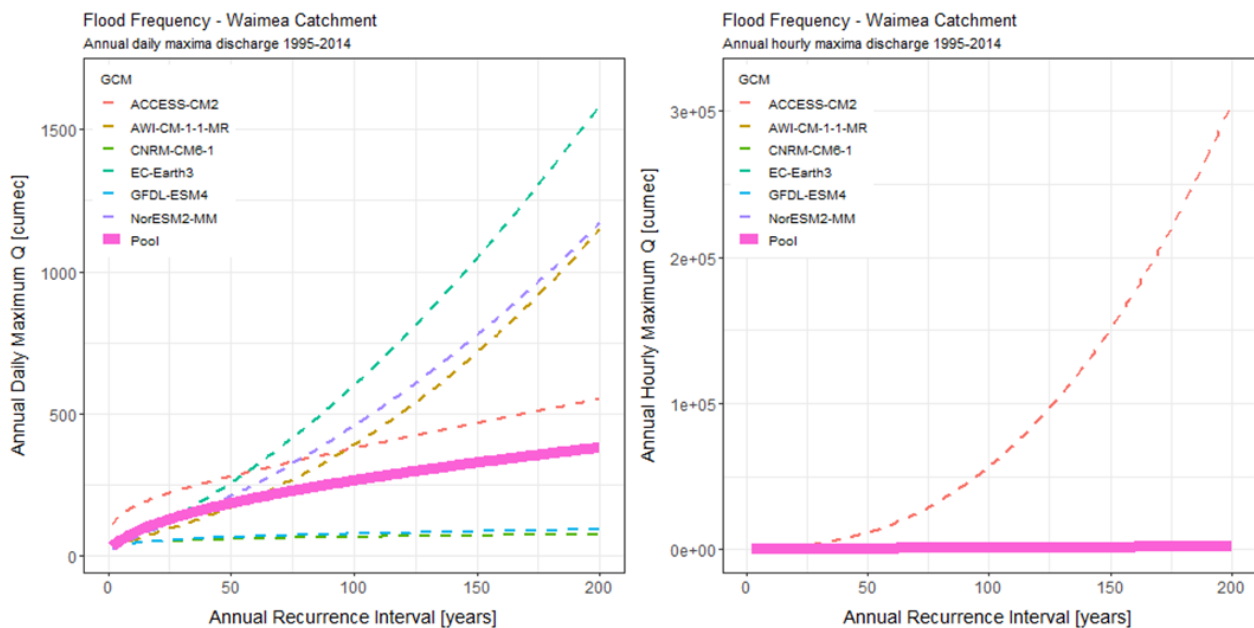


Figure E-55: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waimea catchment. Flood frequency generated at nzsegment 15403349 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

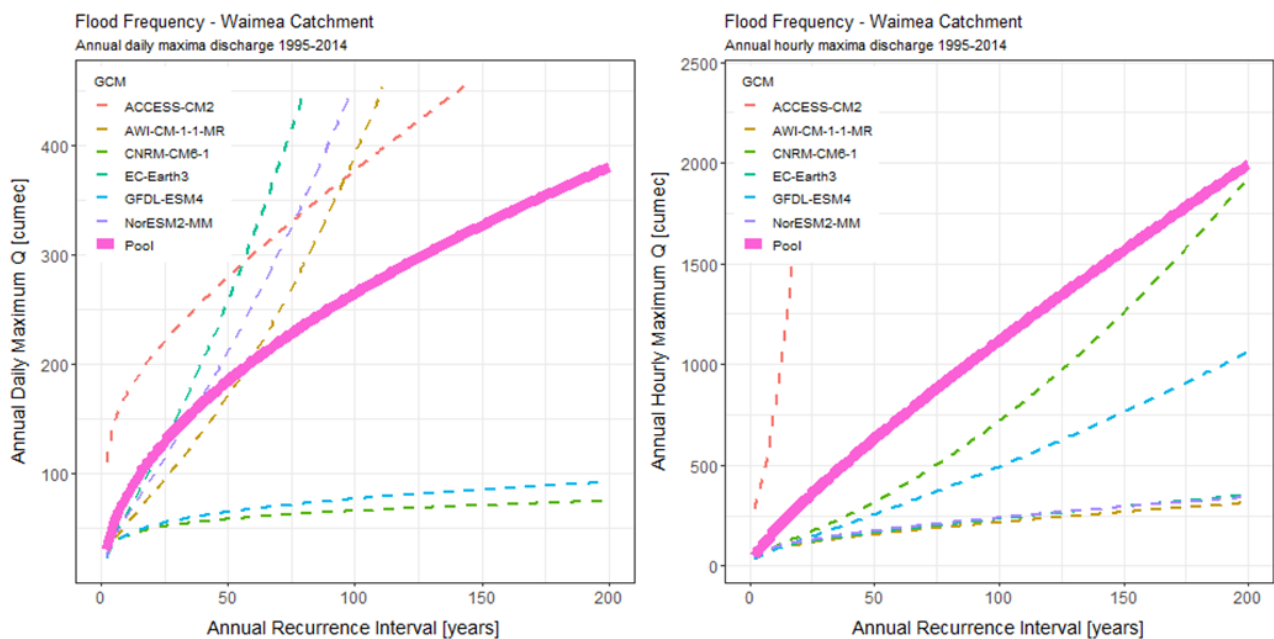


Figure E-56: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waimea catchment. Flood frequency generated at nzsegment 15403349 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

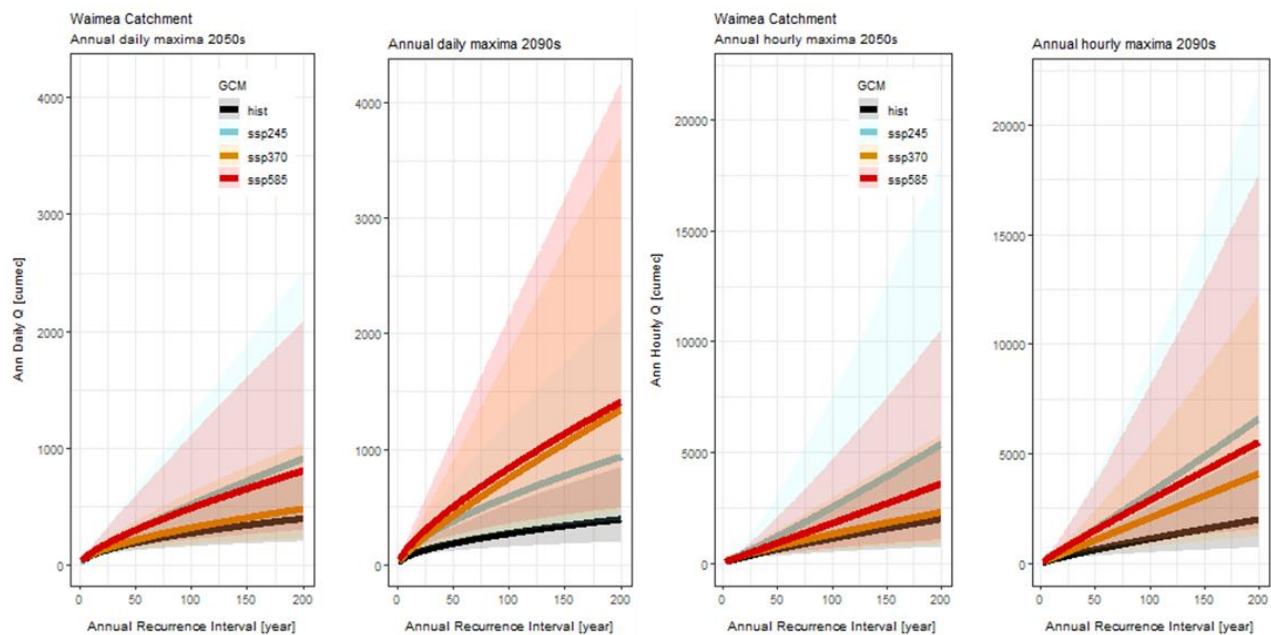


Figure E-57: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Waimea catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15403349 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-73: Pooled multi-model daily maxima flood distribution parameters for the Waimea catchment. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15403349 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	24.4	12.9	0.503
SSP2-4.5	2050	21.8	11.0	0.736
	2090	31.2	20.5	0.604
SSP3-7.0	2050	27.2	12.5	0.559
	2090	29.0	14.4	0.775
SSP5-8.5	2050	26.7	13.2	0.672
	2090	33.2	22.2	0.678

Table E-74: Pooled multi-model hourly maxima flood distribution parameters the Waimea catchment. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15403349 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	38.1	21.4	0.783
SSP2-4.5	2050	39.1	23.4	0.965
	2090	48.0	32.9	0.946
SSP3-7.0	2050	49.0	28.4	0.746
	2090	48.0	25.4	0.903

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2050	41.5	20.9	0.918
	2090	59.0	42.4	0.844

Table E-75: Projected changes in pooled multi-model daily maxima flood magnitude for the Waimea catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	-9.8	37.5	8.2	19.6	8.9	48.0
5-year level	-1.8	53.1	6.3	31.5	14.5	71.6
10-year level	10.5	66.6	7.0	50.5	23.7	95.4
20-year level	27.4	80.7	8.9	77.1	36.3	123.0
50-year level	58.1	100.8	12.8	125.9	57.9	167.0
100-year level	89.4	117.7	16.5	175.5	78.5	207.7
200-year level	129.8	136.3	20.8	239.1	103.2	256.4

Table E-76: Projected changes in pooled multi-model hourly maxima flood magnitude for the Waimea catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	6.4	36.5	29.3	25.1	6.8	68.5
5-year level	19.6	59.0	28.5	30.2	10.0	89.1
10-year level	36.2	82.2	26.5	38.9	17.4	104.9
20-year level	57.0	108.6	23.9	50.3	27.8	119.8
50-year level	92.0	149.5	20.2	68.9	45.1	140.4
100-year level	125.9	186.3	17.4	85.5	60.9	157.5
200-year level	168.5	229.5	14.8	104.5	79.1	176.7

Waituna Catchment

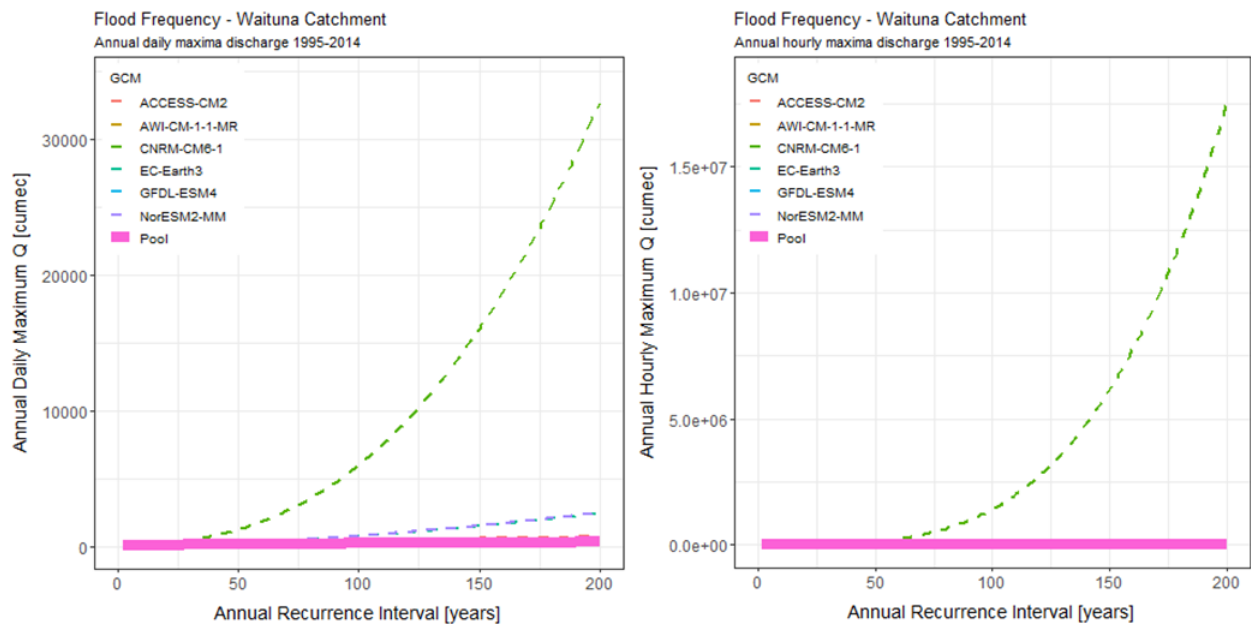


Figure E-58: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waituna catchment. Flood frequency generated at nzsegment 15207879 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

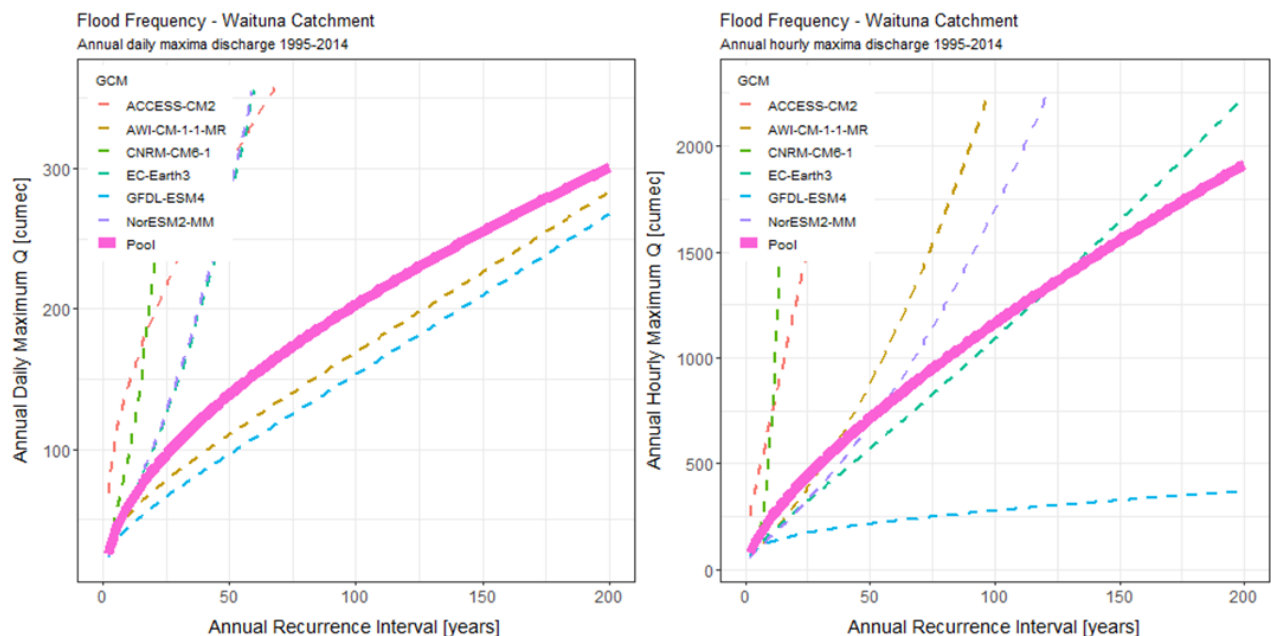


Figure E-59: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waituna catchment. Flood frequency generated at nzsegment 15207879 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

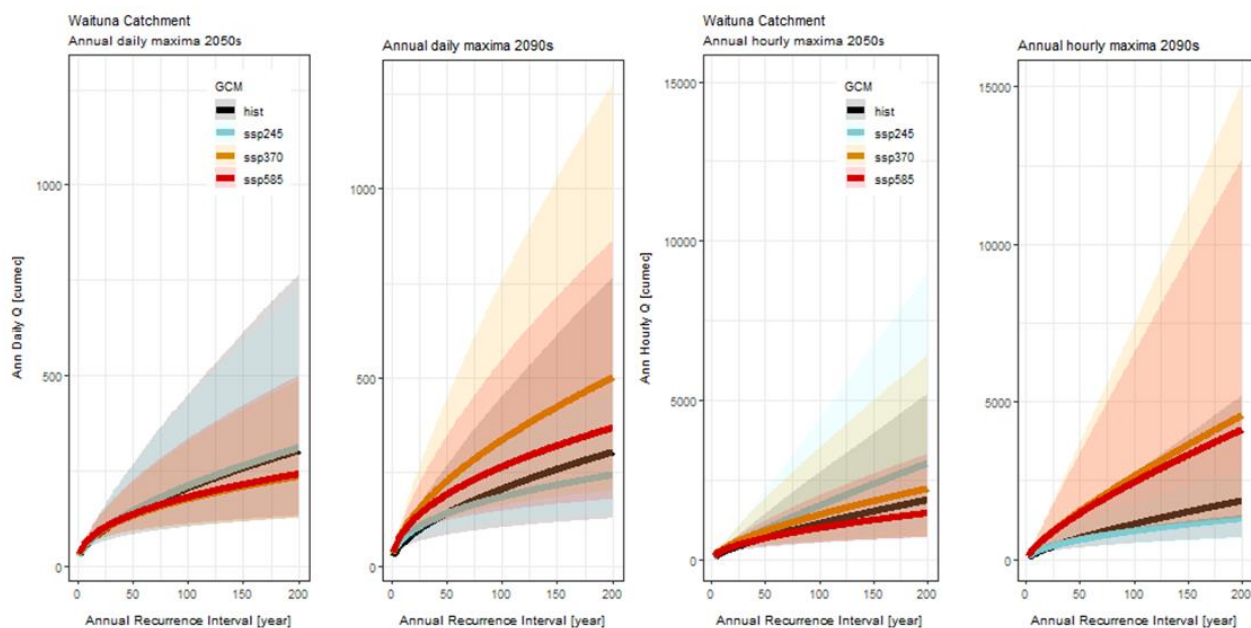


Figure E-60: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Waituna catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15207879 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-77: Pooled multi-model daily maxima flood distribution parameters for the Waituna catchment. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15207879 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3.\text{s}^{-1}$]	Scale [$\text{m}^3.\text{s}^{-1}$]	Shape [-]
Hindcast	2004	22.3	9.0	0.506
SSP2-4.5	2050	23.3	9.0	0.524
	2090	27.8	12.8	0.354
SSP3-7.0	2050	26.9	11.6	0.367
	2090	28.3	14.7	0.511
SSP5-8.5	2050	27.1	11.9	0.372
	2090	29.7	15.5	0.417

Table E-78: Pooled multi-model hourly maxima flood distribution parameters for the Waituna catchment. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15207879 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3.\text{s}^{-1}$]	Scale [$\text{m}^3.\text{s}^{-1}$]	Shape [-]
Hindcast	2004	63.2	31.5	0.662
SSP2-4.5	2050	68.2	33.9	0.751
	2090	81.0	47.5	0.471
SSP3-7.0	2050	88.4	50.4	0.573

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	97.8	64.6	0.690
	2050	84.0	45.8	0.508
	2090	102.7	68.2	0.655

Table E-79: Projected changes in pooled multi-model daily maxima flood magnitude for the Waituna catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	3.5	27.5	21.4	35.1	23.1	40.7
5-year level	2.9	25.3	18.1	45.3	20.3	46.1
10-year level	2.8	19.5	12.3	51.6	14.9	45.8
20-year level	2.9	11.6	5.1	56.3	7.8	42.5
50-year level	3.0	-0.6	-5.6	60.7	-3.0	35.4
100-year level	2.9	-10.3	-14.0	63.1	-11.5	28.6
200-year level	2.6	-20.0	-22.3	64.9	-20.2	21.1

Table E-80: Projected changes in pooled multi-model hourly maxima flood magnitude for the Waituna catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	8.6	31.7	43.9	68.2	34.3	76.4
5-year level	12.9	27.7	44.7	86.5	29.5	92.6
10-year level	18.9	18.7	41.6	99.0	21.2	101.5
20-year level	26.4	7.6	37.0	109.8	11.5	107.6
50-year level	38.5	-7.9	29.9	123.2	-2.2	113.3
100-year level	49.2	-19.3	24.3	133.6	-12.3	116.9
200-year level	61.4	-29.9	18.9	144.7	-22.0	120.3

Mokoreta catchment

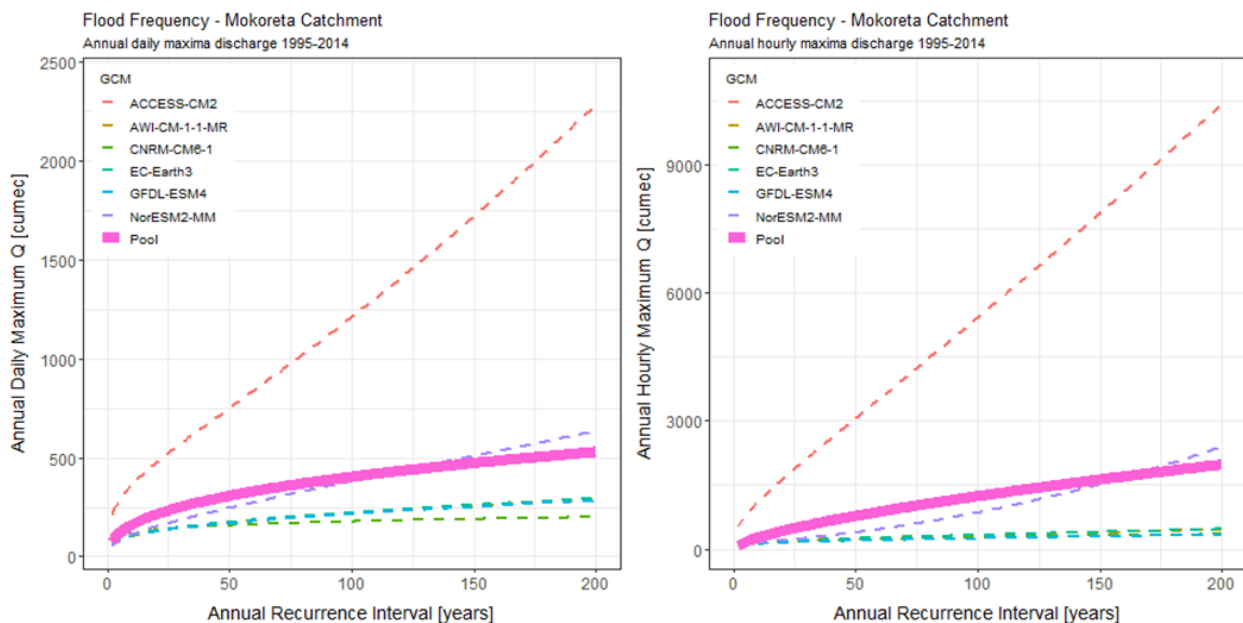


Figure E-61: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mokoreta catchment. Flood frequency generated at nzsegment 15445270 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

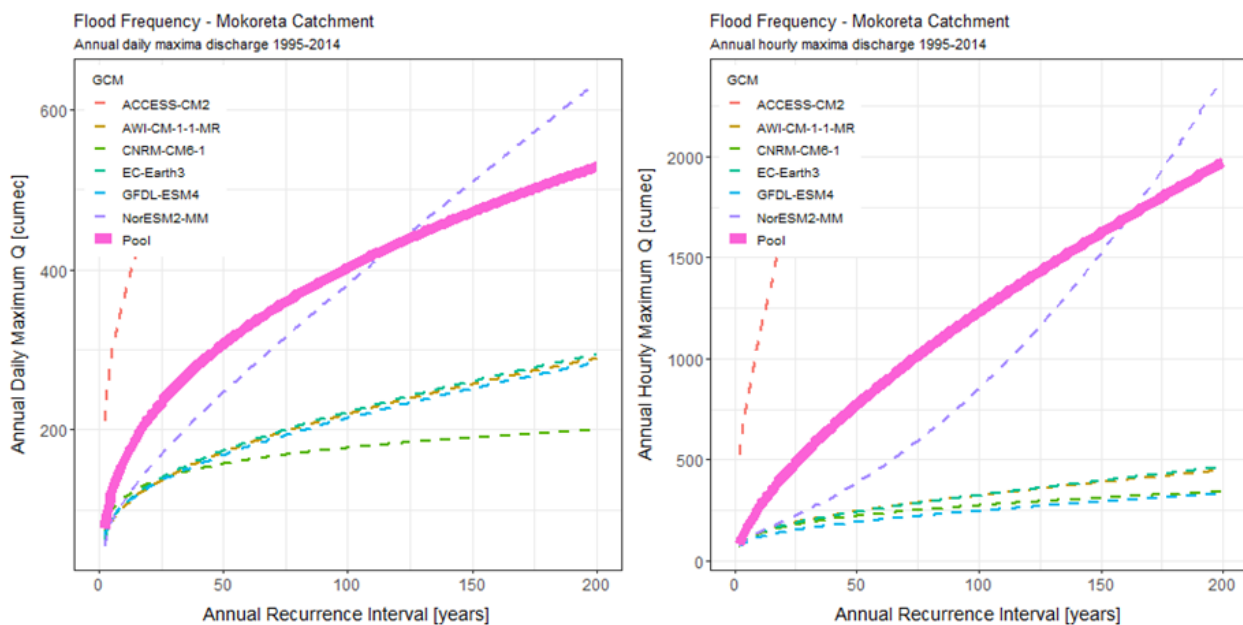


Figure E-62: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mokoreta catchment. Flood frequency generated at nzsegment 15445270 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

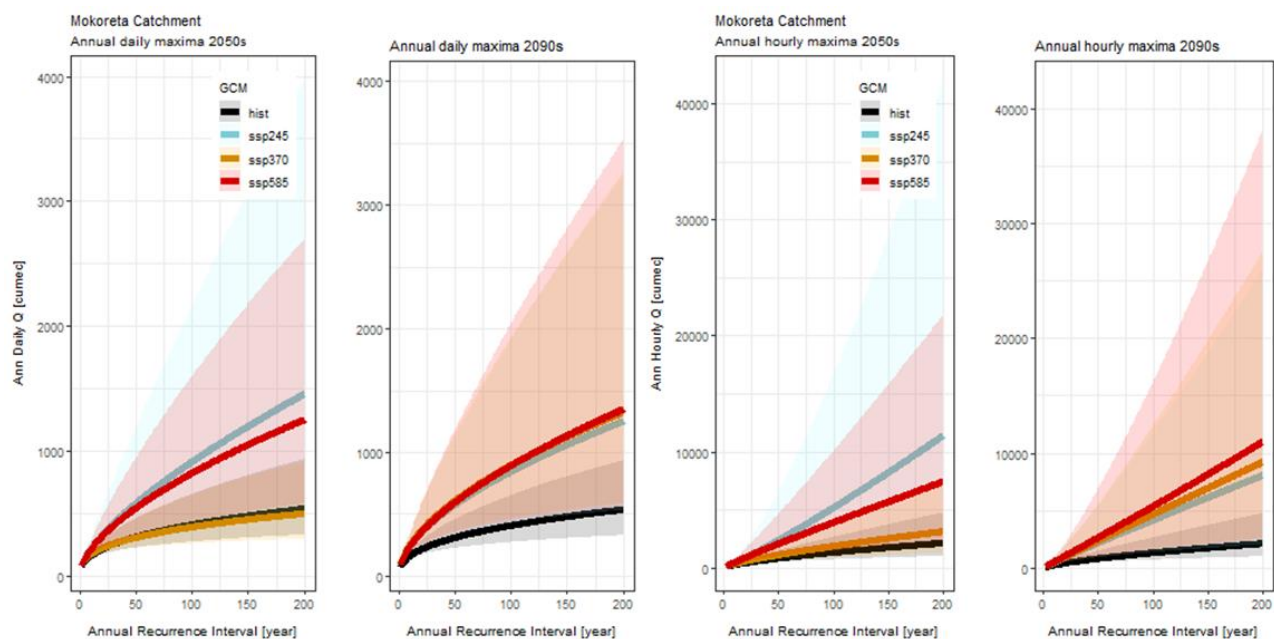


Figure E-63: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Mokoreta catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15445270 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-81: Pooled multi-model daily maxima flood distribution parameters for the Mokoreta catchment. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15445270 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	66.1	27.5	0.368
SSP2-4.5	2050	69.5	29.7	0.600
	2090	77.3	37.9	0.506
SSP3-7.0	2050	77.6	29.3	0.311
	2090	80.4	39.5	0.516
SSP5-8.5	2050	65.6	31.7	0.568
	2090	76.5	36.0	0.541

Table E-82: Pooled multi-model hourly maxima flood distribution parameters for the Mokoreta catchment. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15445270 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	73.0	40.4	0.653
SSP2-4.5	2050	73.7	39.1	1.020
	2090	91.9	60.4	0.843
SSP3-7.0	2050	90.6	48.8	0.692

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	90.8	58.8	0.892
	2050	85.0	58.1	0.849
	2090	92.0	60.4	0.904

Table E-83: Projected changes in pooled multi-model daily maxima flood magnitude for the Mokoreta catchment (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	7.4	22.5	14.7	27.7	4.1	20.5
5-year level	17.5	34.4	10.3	40.6	16.3	32.4
10-year level	31.7	46.8	6.6	54.2	30.1	46.1
20-year level	51.1	61.3	3.1	70.1	47.0	63.0
50-year level	86.5	84.7	-1.2	95.5	74.8	91.1
100-year level	122.9	106.4	-4.3	118.7	100.9	117.9
200-year level	170.4	132.3	-7.3	146.1	132.1	150.5

Table E-84: Projected changes in pooled multi-model hourly maxima flood magnitude for the Mokoreta catchment e (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	3.2	35.2	23.6	33.6	26.8	36.2
5-year level	22.0	57.2	24.9	58.2	49.4	63.6
10-year level	52.7	82.0	27.3	87.7	73.7	97.3
20-year level	98.2	112.6	30.6	124.9	102.6	141.4
50-year level	188.7	164.1	36.1	189.0	149.6	220.8
100-year level	289.8	214.1	40.9	251.8	193.6	303.2
200-year level	432.0	276.3	46.4	331.0	246.8	413.0

Waikaia Catchment

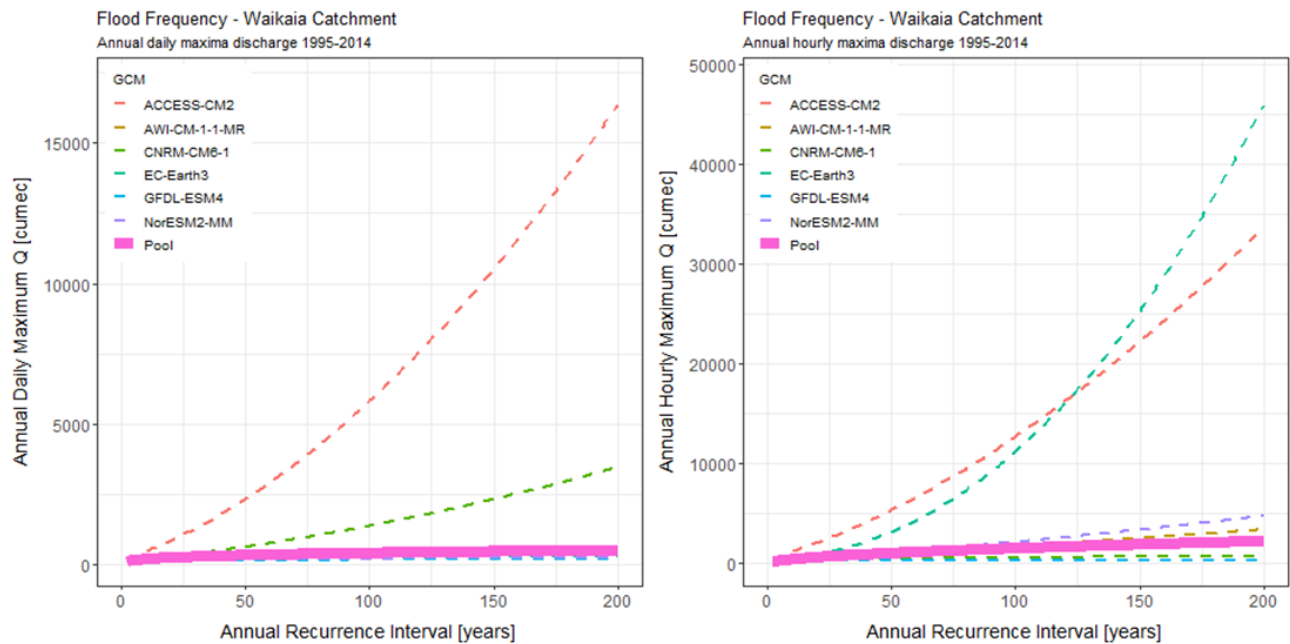


Figure E-64: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waikaia catchment. Flood frequency generated presented at nzsegment 15407605 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

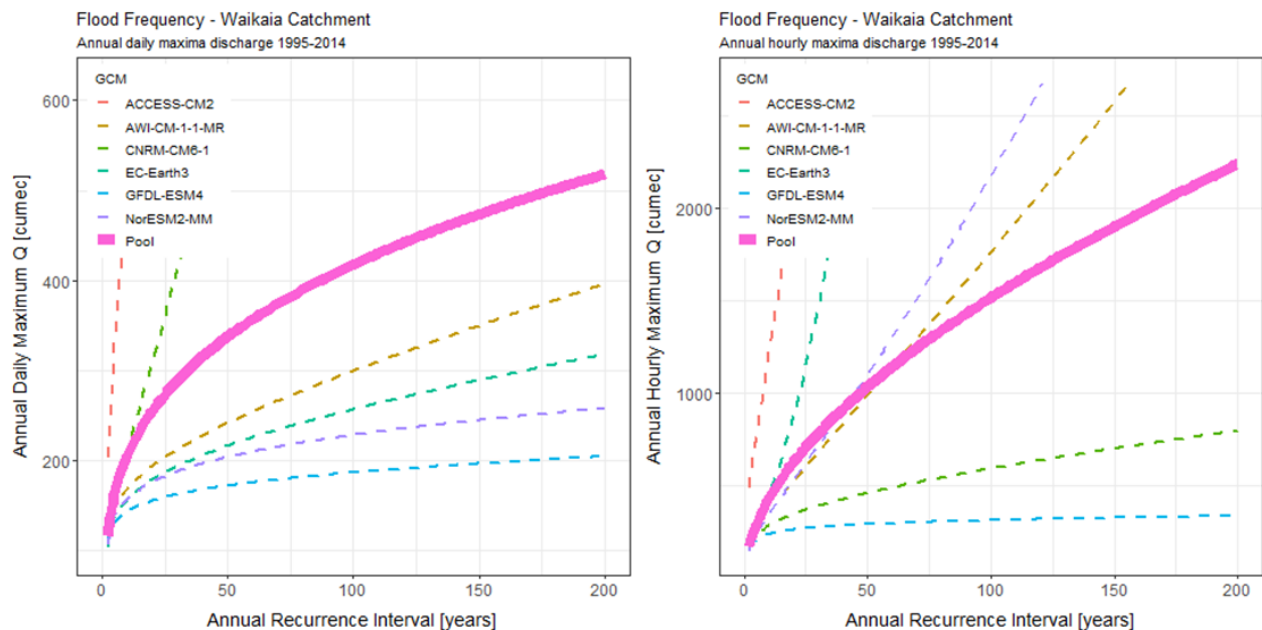


Figure E-65: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waikaia catchment. Flood frequency generated presented at nzsegment 15407605 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

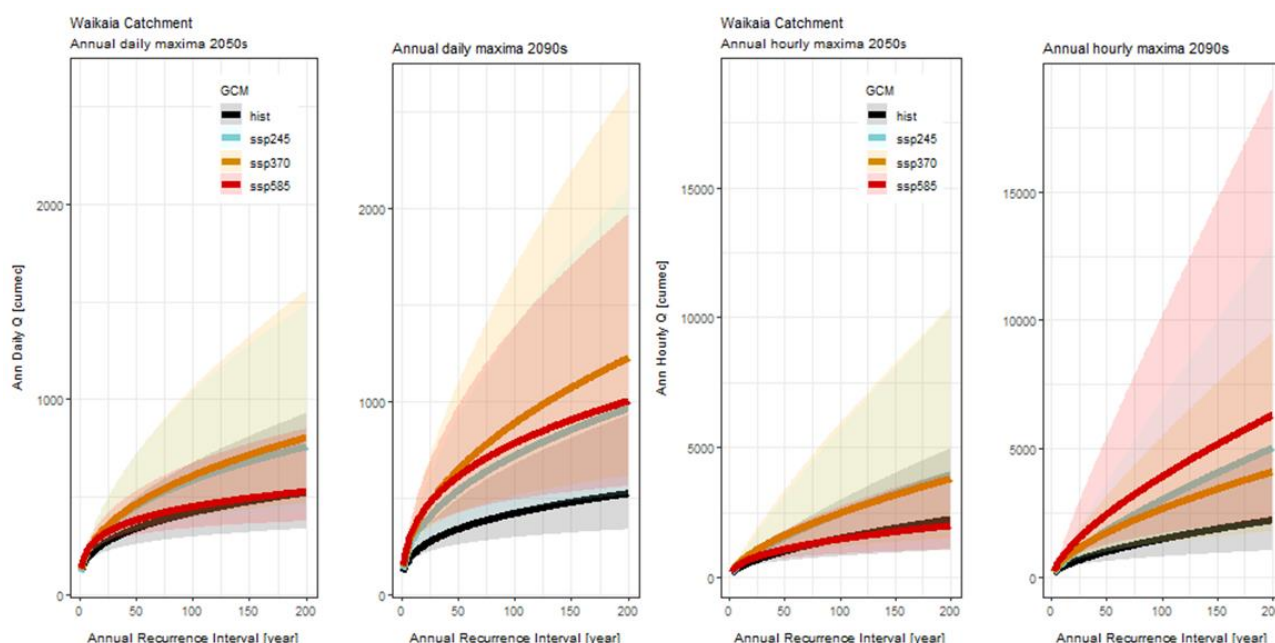


Figure E-66: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Waikaia catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15407605 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-85: Pooled multi-model daily maxima flood distribution parameters for the Waikaia catchment. Daily maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15407605 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	104.2	32.1	0.283
SSP2-4.5	2050	101.0	44.4	0.316
	2090	113.0	45.2	0.382
SSP3-7.0	2050	119.0	36.7	0.385
	2090	125.1	49.7	0.425
SSP5-8.5	2050	121.6	48.3	0.150
	2090	129.5	64.3	0.287

Table E-86: Pooled multi-model hourly maxima flood distribution parameters for the Waikaia catchment. Hourly maxima flood extreme event distribution generated using General Extreme Value distribution at nzsegment 15407605 under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	141.1	62.2	0.539
SSP2-4.5	2050	144.4	80.4	0.616
	2090	155.7	79.8	0.683
SSP3-7.0	2050	194.3	95.3	0.554

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	195.9	98.7	0.579
	2050	181.7	97.3	0.381
	2090	197.0	131.7	0.599

Table E-87: Projected changes in pooled multi-model daily maxima flood magnitude the Waikaia catchment (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	3.8	14.3	14.7	26.8	21.2	36.6
5-year level	13.4	24.7	17.8	39.9	23.4	52.4
10-year level	20.2	34.0	22.0	53.0	22.0	62.7
20-year level	26.3	44.0	27.4	67.7	18.7	70.9
50-year level	33.8	58.4	36.3	90.4	12.6	79.9
100-year level	39.3	70.5	44.4	110.5	7.0	85.8
200-year level	44.8	83.9	53.5	133.5	0.9	91.1

Table E-88: Projected changes in pooled multi-model hourly maxima flood magnitude the Waikaia catchment (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	9.3	15.8	41.5	43.9	33.5	57.2
5-year level	20.6	28.2	46.9	51.8	32.9	82.5
10-year level	30.3	41.5	51.0	58.2	27.3	101.5
20-year level	39.9	56.8	55.0	64.2	19.5	119.2
50-year level	53.4	80.5	60.3	72.1	7.5	142.6
100-year level	64.3	101.3	64.8	78.0	-1.9	161.4
200-year level	76.1	124.9	69.6	84.0	-11.1	182.0

Whitestone Catchment

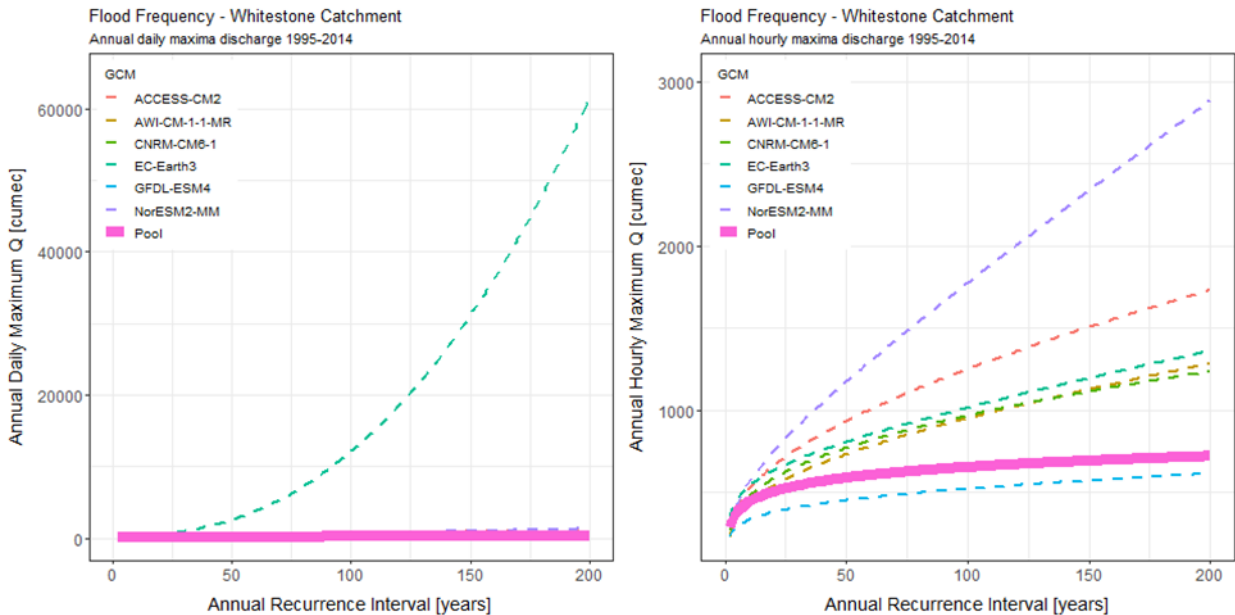


Figure E-67: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Whitestone Catchment. Flood frequency generated at nzsegment 15320684 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

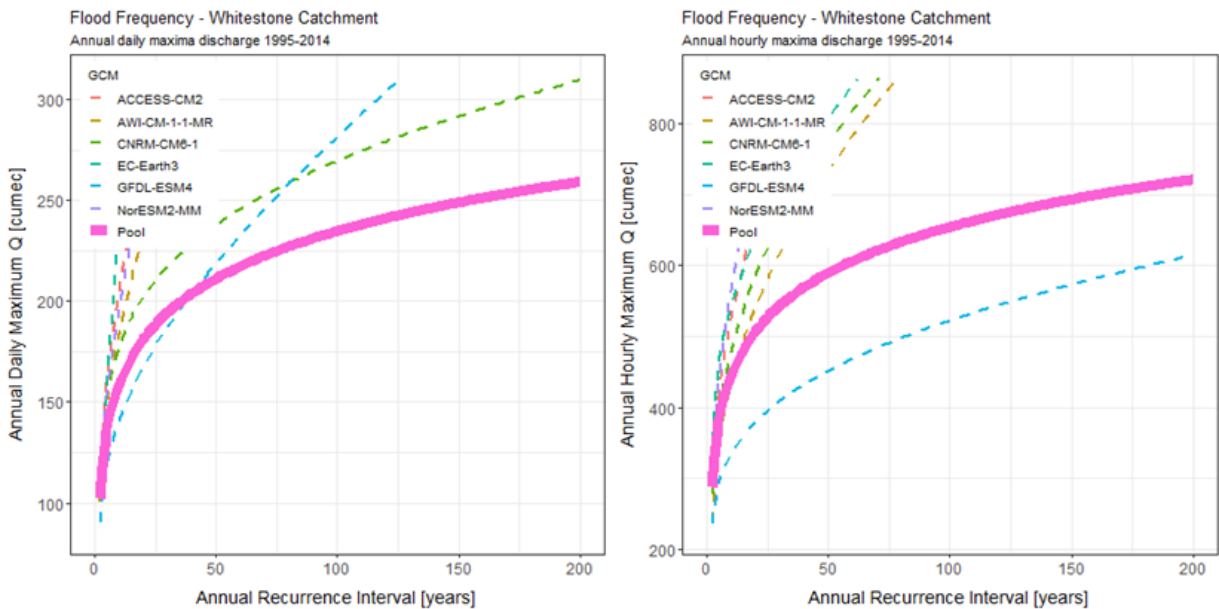


Figure E-68: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Whitestone Catchment. Flood frequency generated at nzsegment 15320684 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

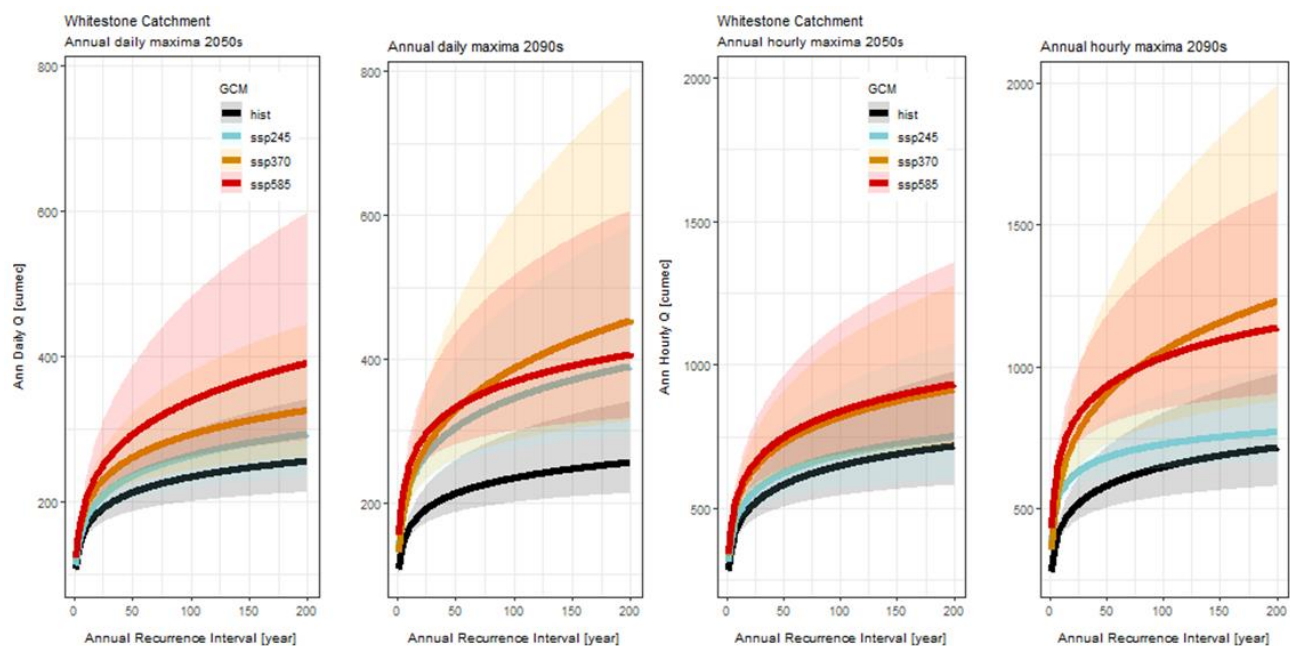


Figure E-69: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Whitestone Catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15320684 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-89: Pooled multi-model daily maxima flood distribution parameters for the Whitestone Catchment. Daily maxima flood extreme event distribution generated at nzsegment 15320684 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	96.5	29.5	0.002
SSP2-4.5	2050	103.0	30.0	0.057
	2090	122.3	39.3	0.078
SSP3-7.0	2050	108.9	34.7	0.054
	2090	116.5	38.1	0.159
SSP5-8.5	2050	108.6	35.2	0.133
	2090	136.3	49.9	-0.007

Table E-90: Pooled multi-model hourly maxima flood distribution parameters for the Whitestone Catchment. Hourly maxima flood extreme event distribution generated at nzsegment 15320684 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	252.7	77.8	0.036
SSP2-4.5	2050	279.0	88.1	-0.008
	2090	343.5	109.6	-0.130
SSP3-7.0	2050	300.1	95.3	0.062
	2090	314.1	109.2	0.148

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2050	303.7	103.4	0.040
	2090	381.3	139.8	-0.003

Table E-91: Projected changes in pooled multi-model daily maxima flood magnitude for for the Whitestone Catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	6.2	28.1	13.9	22.9	14.3	45.4
5-year level	6.5	31.2	15.9	28.7	18.7	49.8
10-year level	7.5	34.4	17.8	35.1	23.5	52.2
20-year level	8.7	37.9	19.8	42.6	29.0	54.0
50-year level	10.8	43.0	22.6	54.4	37.3	55.9
100-year level	12.6	47.3	24.9	64.8	44.5	57.2
200-year level	14.6	52.0	27.2	76.8	52.6	58.4

Table E-92: Projected changes in pooled multi-model hourly maxima flood magnitude for the Whitestone Catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	10.6	35.7	19.5	27.5	22.1	55.0
5-year level	10.1	32.2	20.8	33.6	24.4	58.5
10-year level	9.3	28.0	21.9	39.5	25.8	59.8
20-year level	8.4	23.4	23.1	45.8	26.9	60.2
50-year level	7.0	17.1	24.8	55.2	28.2	60.0
100-year level	5.8	12.3	26.1	63.0	29.1	59.5
200-year level	4.7	7.6	27.5	71.7	30.0	58.7

Upukerora Catchment

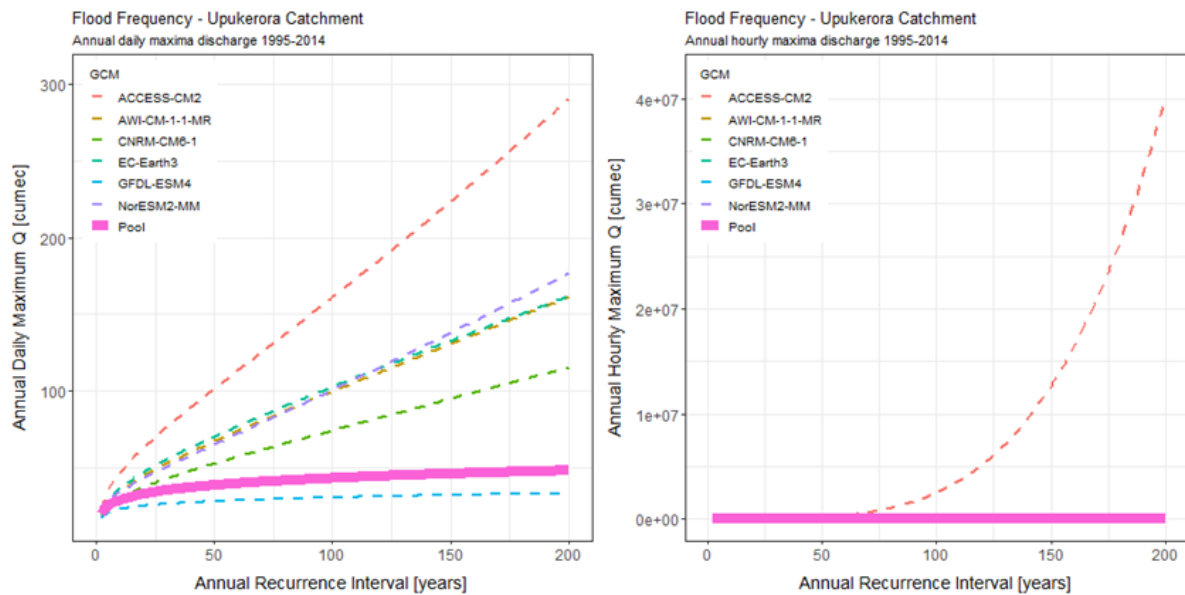


Figure E-70: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Upukerora Catchment. Flood frequency generated at nzsegment 15217459 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

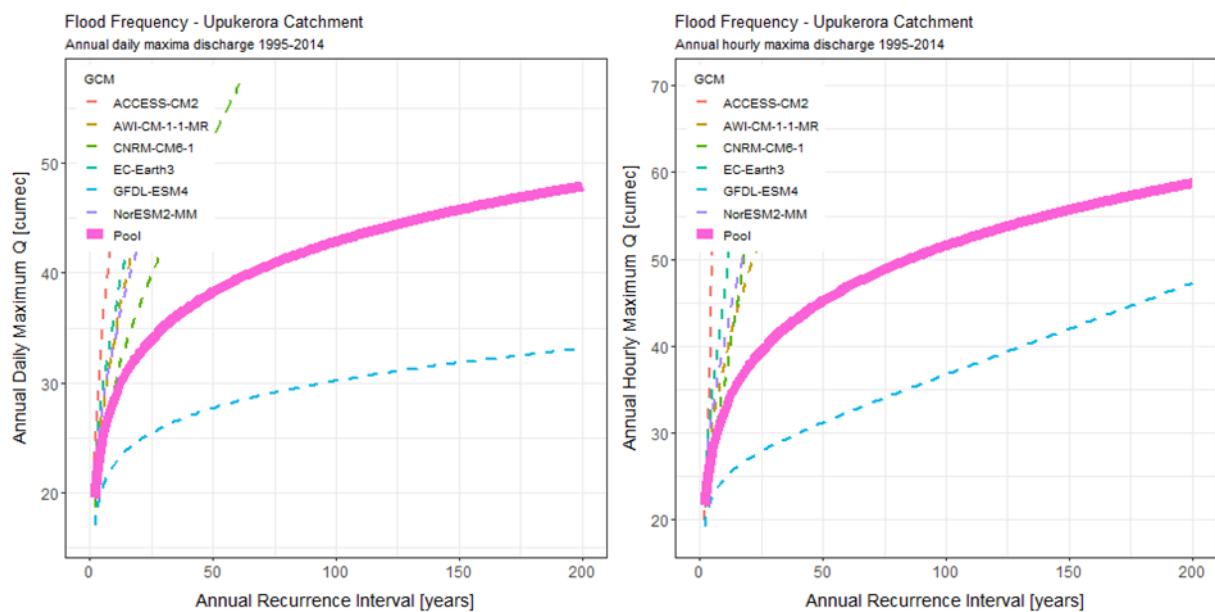


Figure E-71: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Upukerora Catchment. Flood frequency generated at nzsegment 15217459 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

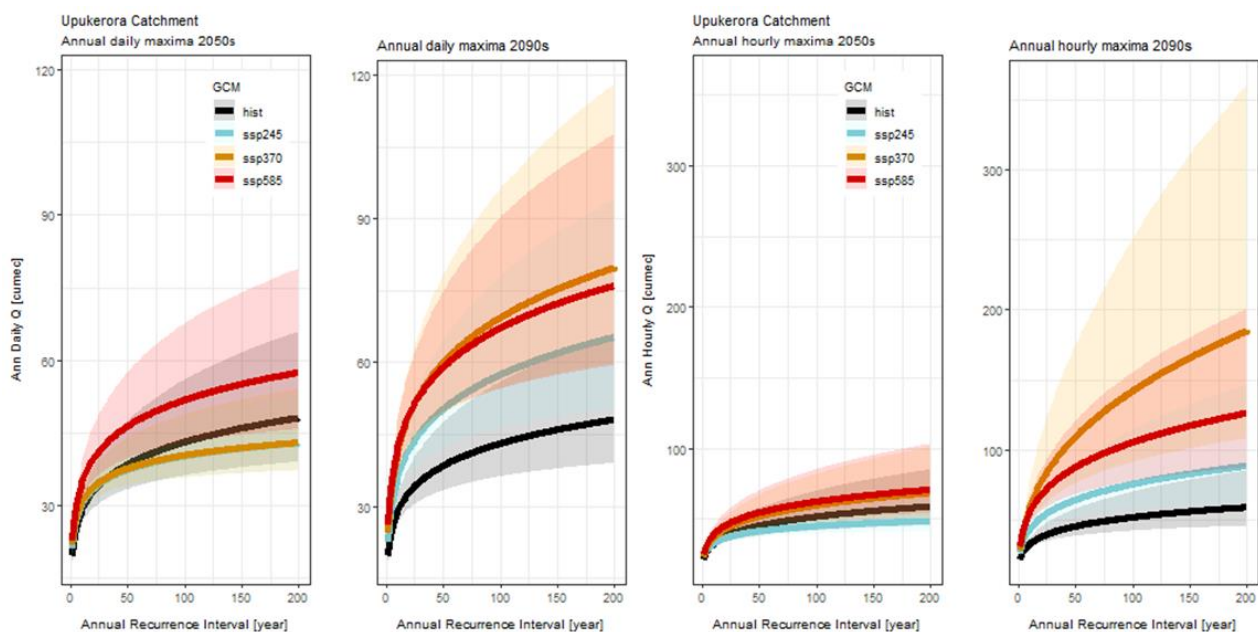


Figure E-72: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Upukerora Catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15217459 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-93: Pooled multi-model daily maxima flood distribution parameters for the Upukerora Catchment. Daily maxima flood extreme event distribution generated at nzsegment 15217459 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	18.1	4.3	0.092
SSP2-4.5	2050	19.0	5.4	-0.077
	2090	20.3	6.0	0.111
SSP3-7.0	2050	19.8	5.3	-0.083
	2090	21.5	7.6	0.121
SSP5-8.5	2050	20.5	5.9	0.052
	2090	23.3	7.5	0.094

Table E-94: Pooled multi-model hourly maxima flood distribution parameters for the Upukerora Catchment. Hourly maxima flood extreme event distribution generated at nzsegment 15217459 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	20.0	4.9	0.137
SSP2-4.5	2050	21.1	5.5	-0.025
	2090	23.7	7.2	0.169
SSP3-7.0	2050	21.7	5.7	0.144
	2090	24.6	10.0	0.340

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2050	22.5	6.5	0.110
	2090	27.1	9.9	0.209

Table E-95: Projected changes in pooled multi-model daily maxima flood magnitude for the Upukerora Catchment (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	6.7	15.6	10.3	25.8	16.0	33.9
5-year level	6.5	20.6	9.0	35.7	18.8	41.1
10-year level	4.5	24.1	6.3	42.7	20.0	45.7
20-year level	1.7	27.1	2.9	48.7	20.5	49.4
50-year level	-2.9	30.7	-2.2	55.9	20.5	53.3
100-year level	-6.8	33.3	-6.4	60.9	20.1	55.9
200-year level	-10.8	35.8	-10.6	65.8	19.5	58.1

Table E-96: Projected changes in pooled multi-model hourly maxima flood magnitude for the Upukerora Catchment (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	5.5	22.5	9.7	35.4	14.9	44.7
5-year level	3.6	28.1	11.3	57.8	17.8	58.4
10-year level	0.6	32.4	12.4	79.2	19.2	69.1
20-year level	-3.0	36.5	13.3	103.2	20.0	79.3
50-year level	-8.4	41.7	14.5	140.4	20.5	92.8
100-year level	-12.8	45.7	15.4	173.8	20.4	103.2
200-year level	-17.3	49.9	16.3	213.1	20.2	113.9

Mararoa Catchment

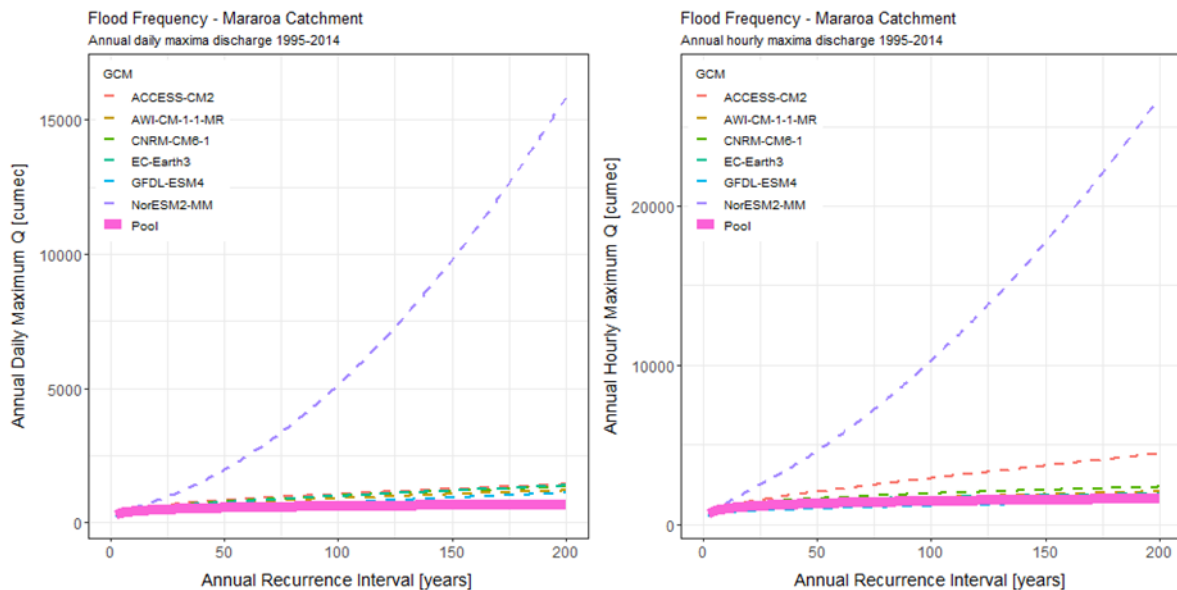


Figure E-73: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mararoa Catchment. Flood frequency generated at nzsegment 15334964 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

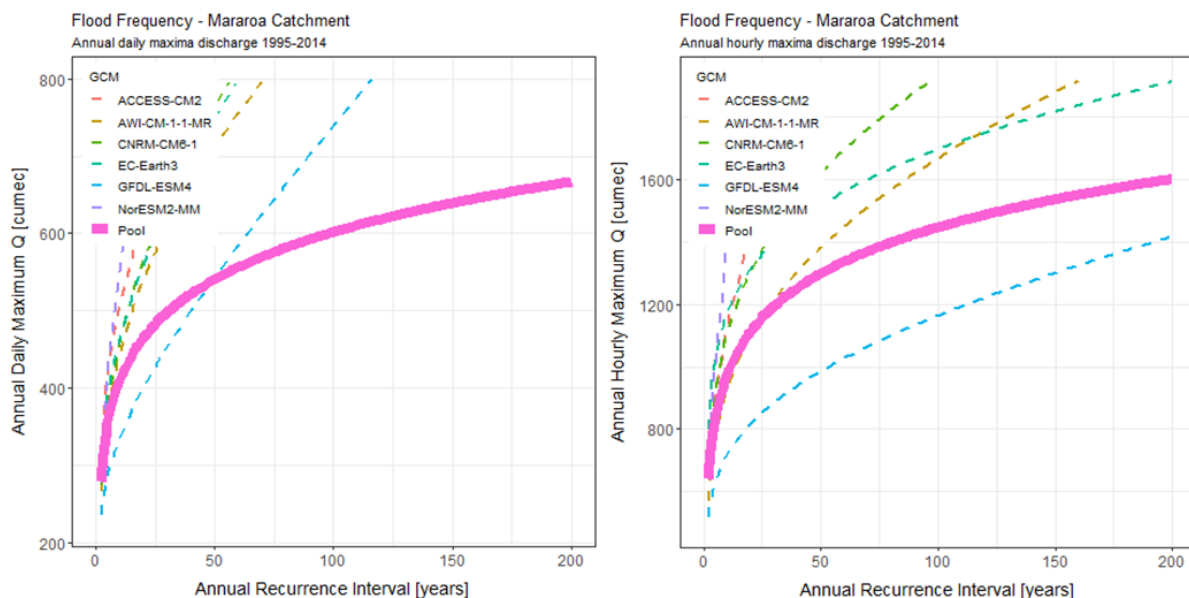


Figure E-74: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Mararoa Catchment. Flood frequency generated at nzsegment 15334964 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

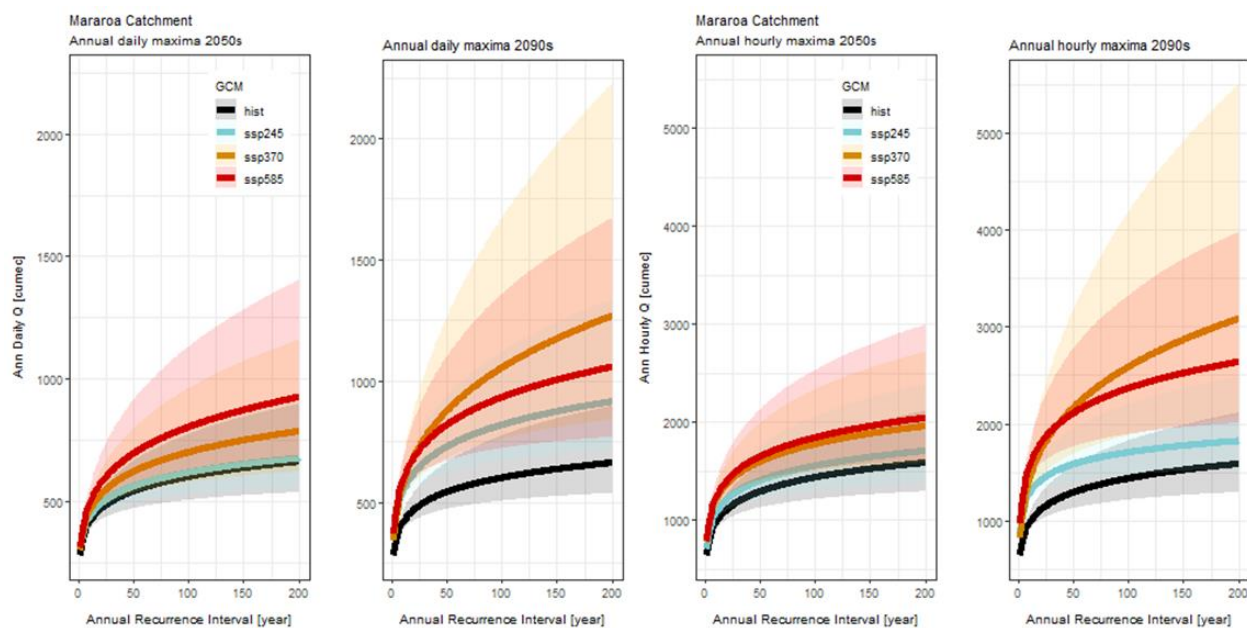


Figure E-75: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Mararoa Catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15334964 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-97: Pooled multi-model daily maxima flood distribution parameters for the Mararoa Catchment. Daily maxima flood extreme event distribution generated at nzsegment 15334964 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	259.8	65.5	0.047
SSP2-4.5	2050	276.3	69.1	0.026
	2090	316.2	91.5	0.066
SSP3-7.0	2050	276.7	73.4	0.088
	2090	307.1	88.6	0.224
SSP5-8.5	2050	285.3	76.3	0.149
	2090	328.9	103.8	0.084

Table E-98: Pooled multi-model hourly maxima flood distribution parameters for the Mararoa Catchment. Hourly maxima flood extreme event distribution generated at nzsegment 15334964 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3 \cdot \text{s}^{-1}$]	Scale [$\text{m}^3 \cdot \text{s}^{-1}$]	Shape [-]
Hindcast	2004	581.6	166.8	0.041
SSP2-4.5	2050	646.5	185.4	0.019
	2090	777.3	244.3	-0.094
SSP3-7.0	2050	691.7	219.6	0.024
	2090	728.7	239.4	0.193
SSP5-8.5	2050	704.4	223.1	0.035

	Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
2090	864.7	292.4	0.035

Table E-99: Projected changes in pooled multi-model daily maxima flood magnitude for the Mararoa Catchment (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	6.1	24.1	7.4	21.3	11.1	30.9
5-year level	5.6	27.4	9.1	28.7	14.4	36.9
10-year level	5.1	29.7	10.6	36.8	17.9	41.3
20-year level	4.4	31.7	12.3	46.3	22.0	45.4
50-year level	3.6	34.3	14.6	61.4	28.2	50.8
100-year level	2.9	36.1	16.5	75.1	33.6	55.0
200-year level	2.2	37.9	18.6	91.1	39.6	59.4

Table E-100: Projected changes in pooled multi-model hourly maxima flood magnitude for the Mararoa Catchment (% relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	11.1	34.7	20.7	28.9	22.9	52.4
5-year level	10.6	33.2	22.3	36.5	24.8	56.6
10-year level	10.1	30.5	23.0	44.5	25.9	59.1
20-year level	9.5	27.3	23.4	53.5	26.7	61.0
50-year level	8.8	22.4	23.6	67.5	27.6	63.1
100-year level	8.2	18.6	23.6	79.8	28.2	64.5
200-year level	7.6	14.8	23.5	94.0	28.8	65.9

Orauea Catchment

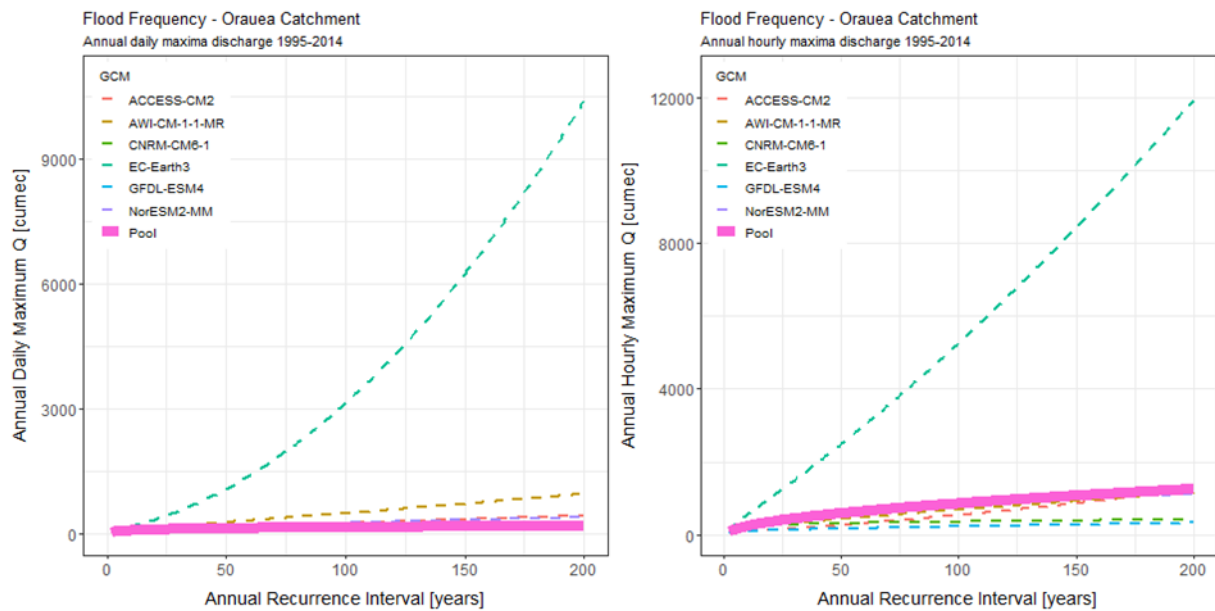


Figure E-76: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Orauea Catchment. Flood frequency generated at nzsegment 15443622 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

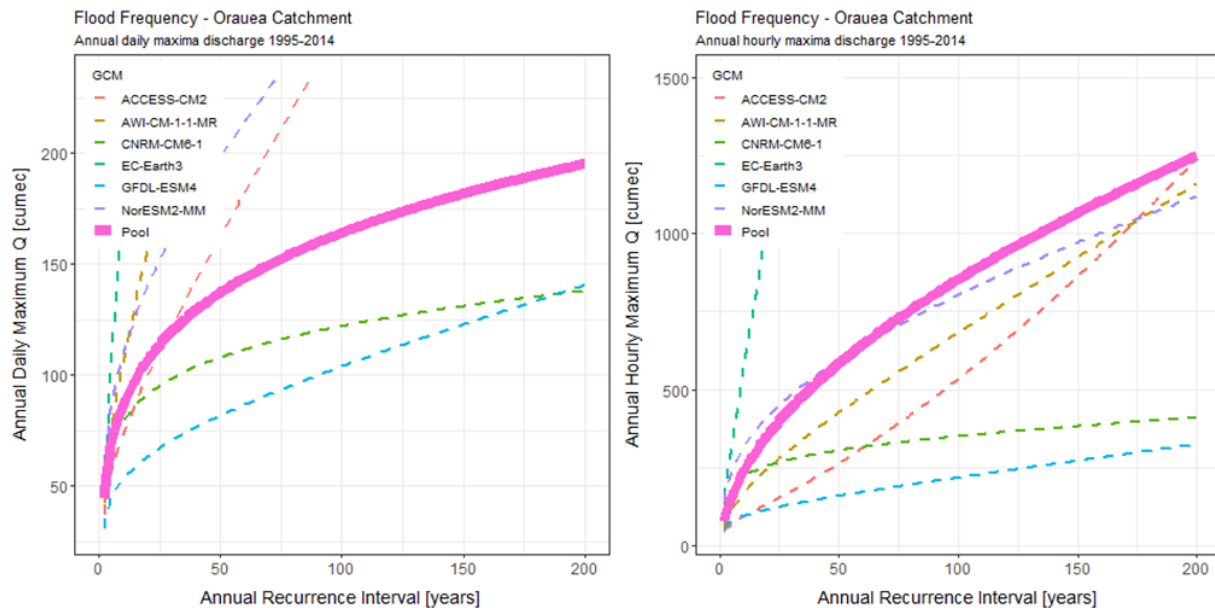


Figure E-77: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Orauea Catchment. Flood frequency generated at nzsegment 15443622 for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

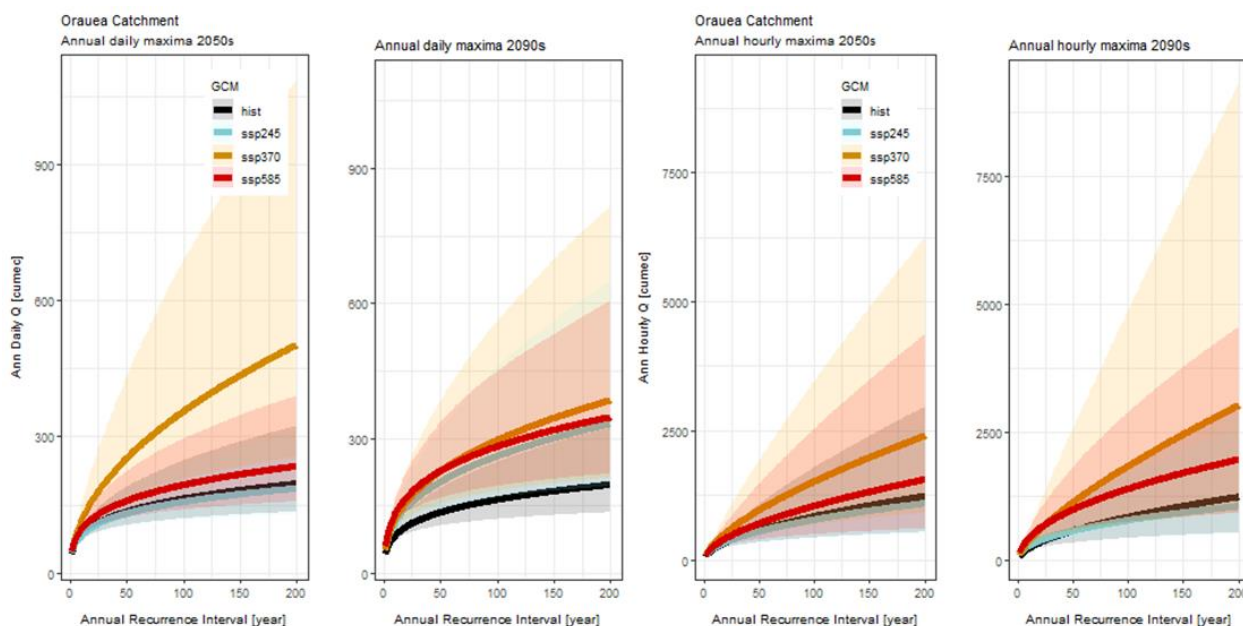


Figure E-78: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Orauea Catchment for four warming scenarios. Pooled flood frequency presented at nzsegment 15443622 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-101: Pooled multi-model daily maxima flood distribution parameters for the Orauea Catchment. Daily maxima flood extreme event distribution generated at nzsegment 15443622 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3.\text{s}^{-1}$]	Scale [$\text{m}^3.\text{s}^{-1}$]	Shape [-]
Hindcast	2004	36.2	16.9	0.192
SSP2-4.5	2050	38.3	16.6	0.168
	2090	45.2	21.0	0.293
SSP3-7.0	2050	39.5	19.0	0.454
	2090	44.5	22.8	0.315
SSP5-8.5	2050	41.8	19.2	0.209
	2090	51.3	27.5	0.226

Table E-102: Pooled multi-model hourly maxima flood distribution parameters for the Orauea Catchment. Hourly maxima flood extreme event distribution generated at nzsegment 15443622 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3.\text{s}^{-1}$]	Scale [$\text{m}^3.\text{s}^{-1}$]	Shape [-]
Hindcast	2004	62.6	41.3	0.490
SSP2-4.5	2050	72.8	46.7	0.417
	2090	89.5	54.1	0.357
SSP3-7.0	2050	79.0	53.7	0.591

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	82.5	57.0	0.622
	2050	74.6	50.3	0.484
	2090	118.8	81.6	0.430

Table E-103: Projected changes in pooled multi-model daily maxima flood magnitude for the Orauea Catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	4.1	25.5	11.9	26.7	15.3	46.8
5-year level	1.7	29.4	23.0	34.9	15.4	53.3
10-year level	0.1	34.3	37.1	43.2	15.9	57.9
20-year level	-1.3	40.3	55.2	52.7	16.5	62.1
50-year level	-3.0	50.0	86.5	67.2	17.6	67.5
100-year level	-4.1	58.7	117.0	80.2	18.5	71.6
200-year level	-5.2	68.7	154.9	95.0	19.4	76.0

Table E-104: Projected changes in pooled multi-model hourly maxima flood magnitude for the Orauea Catchment (% , relative to 1995-2014).

Annual Recurrence Interval (ARI)	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
2.33-year level	14.6	37.8	28.7	35.5	20.0	91.1
5-year level	10.4	27.8	35.7	45.8	20.6	88.7
10-year level	6.3	19.0	43.6	57.7	21.0	84.4
20-year level	2.2	10.6	52.9	72.2	21.6	79.1
50-year level	-3.2	0.1	67.2	95.9	22.7	71.4
100-year level	-7.3	-7.4	79.8	117.9	24.1	65.2
200-year level	-11.2	-14.4	94.0	144.1	25.9	58.8

Waiau River at Tuatapere

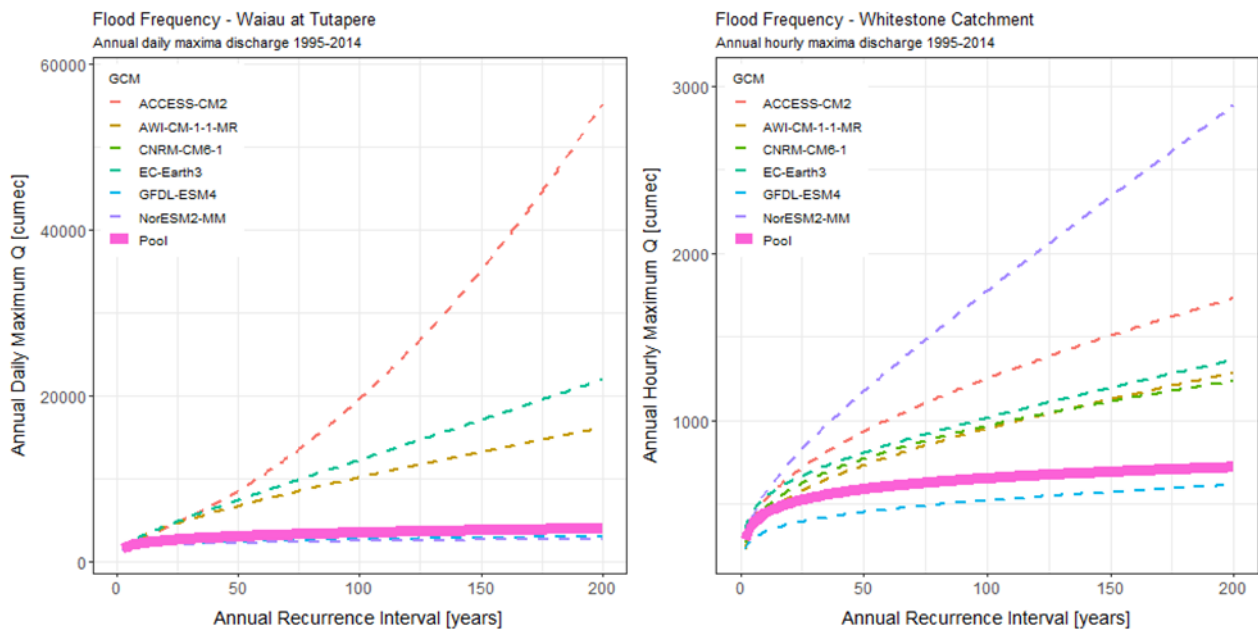


Figure E-79: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waiau River at Tuatapere. Flood frequency generated for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

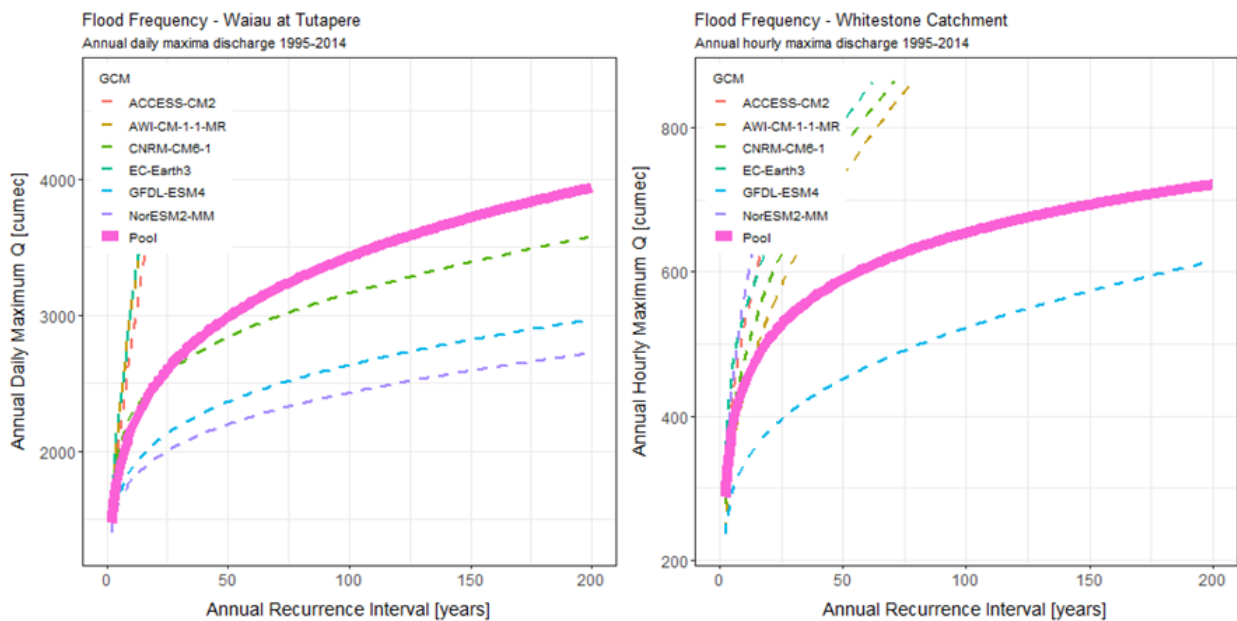


Figure E-80: Simulated annual daily maxima (left panel) and annual hourly maxima (right panel) flood frequency for the Waiau River at Tuatapere. Flood frequency generated for each CMIP6's GCM and the pooled GCM over the period 1995–2014.

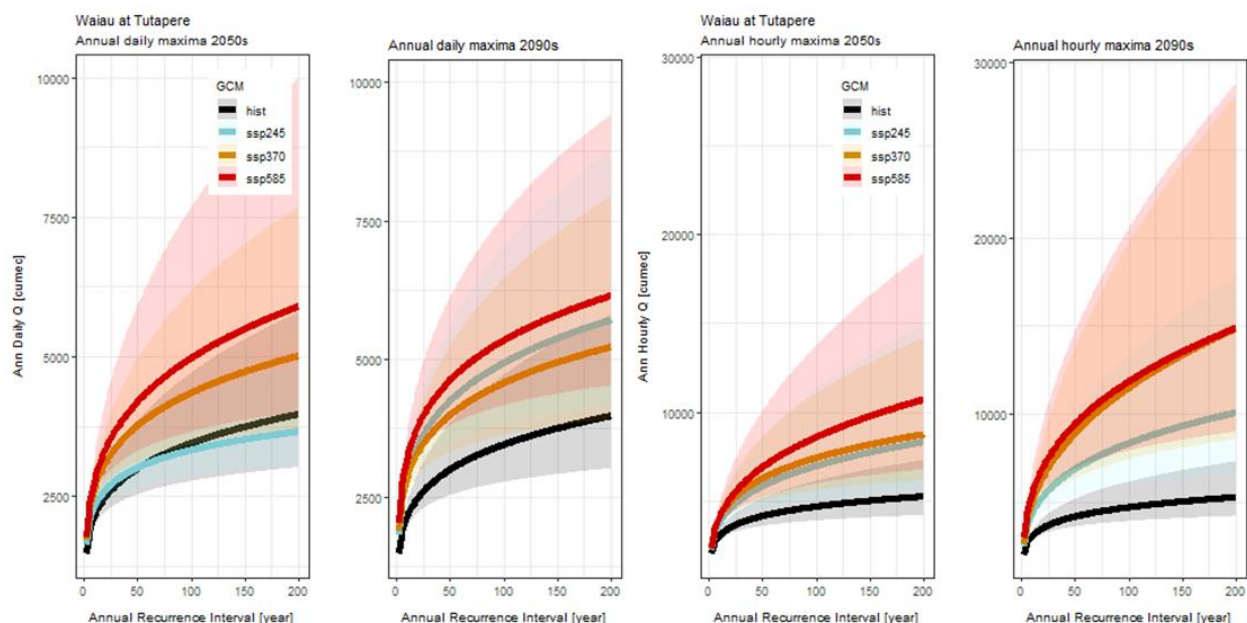


Figure E-81: GCM pooled annual daily maxima (left panel) and hourly maxima (right panel) for frequency for the Waiau River at Tutapere for four warming scenarios. Pooled flood frequency presented at nzsegment 15444806 for historical, SSP 2-4.5, SSP 3-7.0 and SSP 5-8.5 warming scenarios for 2050s (2041–2060) and 2090s (2081–2098).

Table E-105: Pooled multi-model daily maxima flood distribution parameters for the Waiau River at Tutapere. Daily maxima flood extreme event distribution generated at nzsegment 15444806 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3\cdot\text{s}^{-1}$]	Scale [$\text{m}^3\cdot\text{s}^{-1}$]	Shape [-]
Hindcast	2004	1373.2	285.5	0.177
SSP2-4.5	2050	1519.8	341.5	0.055
	2090	1644.2	481.0	0.150
SSP3-7.0	2050	1565.6	406.8	0.152
	2090	1726.9	430.6	0.137
SSP5-8.5	2050	1595.6	423.0	0.205
	2090	1823.4	531.3	0.138

Table E-106: Pooled multi-model hourly maxima flood distribution parameters for the Waiau River at Tutapere. Hourly maxima flood extreme event distribution generated at nzsegment 15444806 using General Extreme Value distribution under stationarity assumption for Hindcast, SSP2-4.5, SSP3-7.0 and SSP5-8.5 by mid-century (2050) and end of century (2090).

		Location [$\text{m}^3\cdot\text{s}^{-1}$]	Scale [$\text{m}^3\cdot\text{s}^{-1}$]	Shape [-]
Hindcast	2004	1857.0	495.9	0.087
SSP2-4.5	2050	2090.8	616.7	0.202
	2090	2231.8	720.9	0.227
SSP3-7.0	2050	2149.2	729.7	0.173

		Location [m ³ .s ⁻¹]	Scale [m ³ .s ⁻¹]	Shape [-]
SSP5-8.5	2090	2335.7	783.6	0.337
	2050	2119.7	650.5	0.286
	2090	2587.4	933.7	0.279

Table E-107: Projected changes in pooled multi-model daily maxima flood magnitude for the Waiau River at Tuatapere (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	11.2	25.1	17.1	28.4	19.9	38.5
5-year level	10.1	31.7	20.8	31.1	25.6	45.4
10-year level	8.0	35.7	22.9	32.4	30.0	49.2
20-year level	5.1	38.6	24.4	32.9	34.2	51.8
50-year level	0.4	41.3	25.6	32.8	39.8	53.8
100-year level	-3.5	42.7	26.1	32.2	44.1	54.5
200-year level	-7.8	43.7	26.3	31.4	48.6	54.6

Table E-108: Projected changes in pooled multi-model hourly maxima flood magnitude for the Waiau River at Tuatapere (% , relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
Annual Recurrence Interval (ARI)	2050	2090	2050	2090	2050	2090
2.33-year level	14.8	24.5	20.5	31.9	17.6	47.6
5-year level	19.7	32.9	28.3	46.0	26.0	63.5
10-year level	24.9	41.2	34.8	61.9	35.6	79.3
20-year level	31.0	50.5	41.4	81.2	47.1	97.4
50-year level	40.3	64.7	50.6	113.4	65.7	125.7
100-year level	48.6	77.0	58.1	144.0	82.8	151.5
200-year level	58.1	91.1	66.1	181.5	103.2	181.9

Appendix F Stream Temperature

Table F-1: Projected mean June-July-August (winter) stream temperature changes (°C, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	1.3	2.1	1.4	2.9	1.3	3.6
Aparima	1.4	2.3	1.5	3.1	1.4	3.9
Fiordland and Islands	1.3	2.1	1.3	2.9	1.3	3.5
Mataura	1.3	2.1	1.5	3.0	1.3	3.7
Oreti	1.3	2.2	1.5	3.1	1.4	3.8
Waiau	1.3	2.1	1.4	3.0	1.4	3.7
Waituna	1.5	2.4	1.7	3.3	1.4	4.1

Table F-2: Projected mean March-April-May (autumn) stream temperature changes (°C, relative to 1995-2014).

	SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090
Southland	1.7	2.5	1.7	3.4	1.6	4.0
Aparima	1.3	2.1	1.4	2.9	1.3	3.6
Fiordland and Islands	1.3	2.1	1.4	2.9	1.3	3.6
Mataura	1.3	2.1	1.4	2.9	1.3	3.6
Oreti	1.3	2.1	1.4	2.9	1.3	3.6
Waiau	1.3	2.1	1.4	2.9	1.3	3.6
Waituna	1.3	2.1	1.4	2.9	1.3	3.6

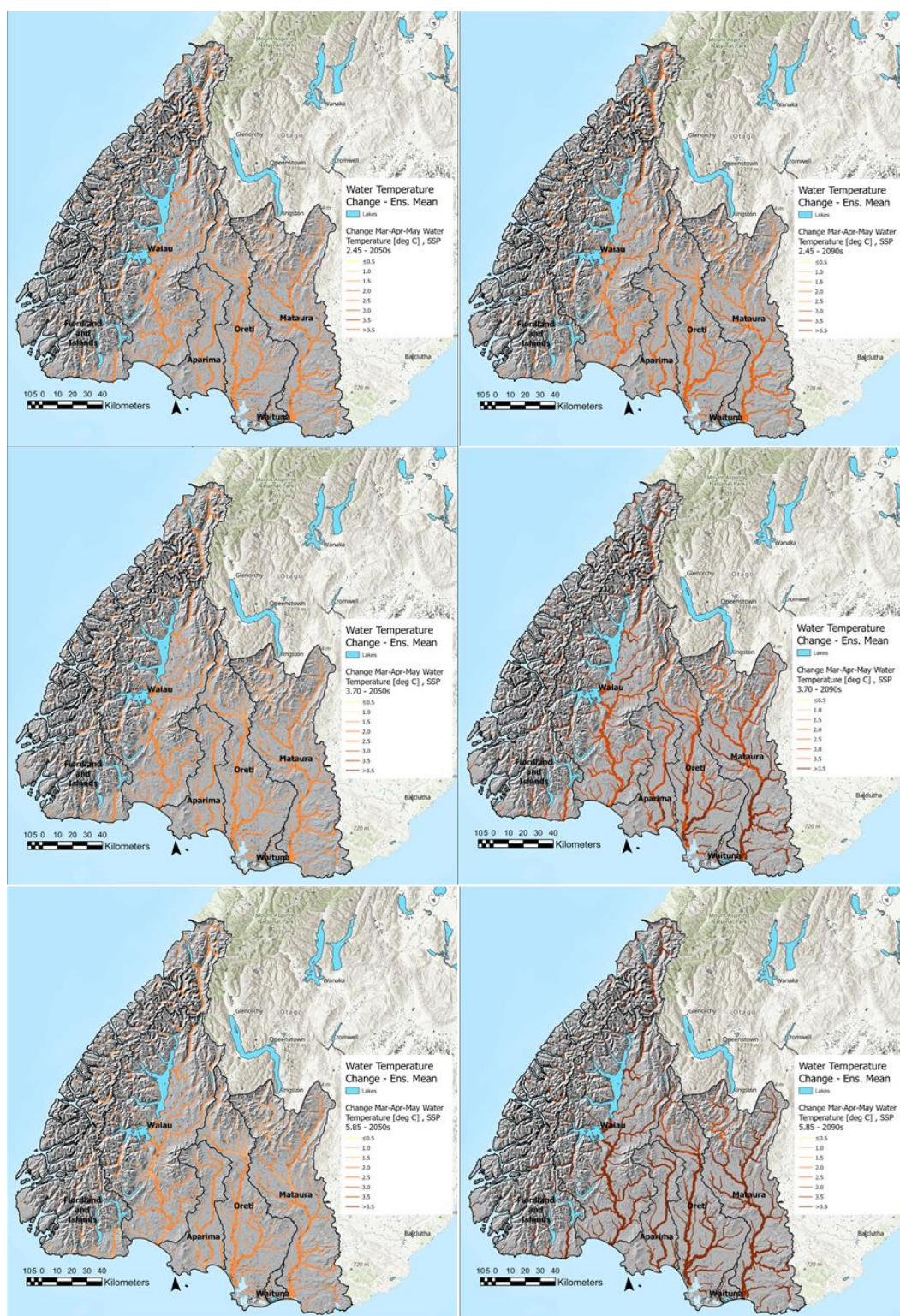


Figure F-1: Change in multi-model average March-April-May (autumn) stream water temperature. Change in multi-model average seasonal stream temperature is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 lower panel) by mid-century (left hand panels) and end of century (right hand panels).

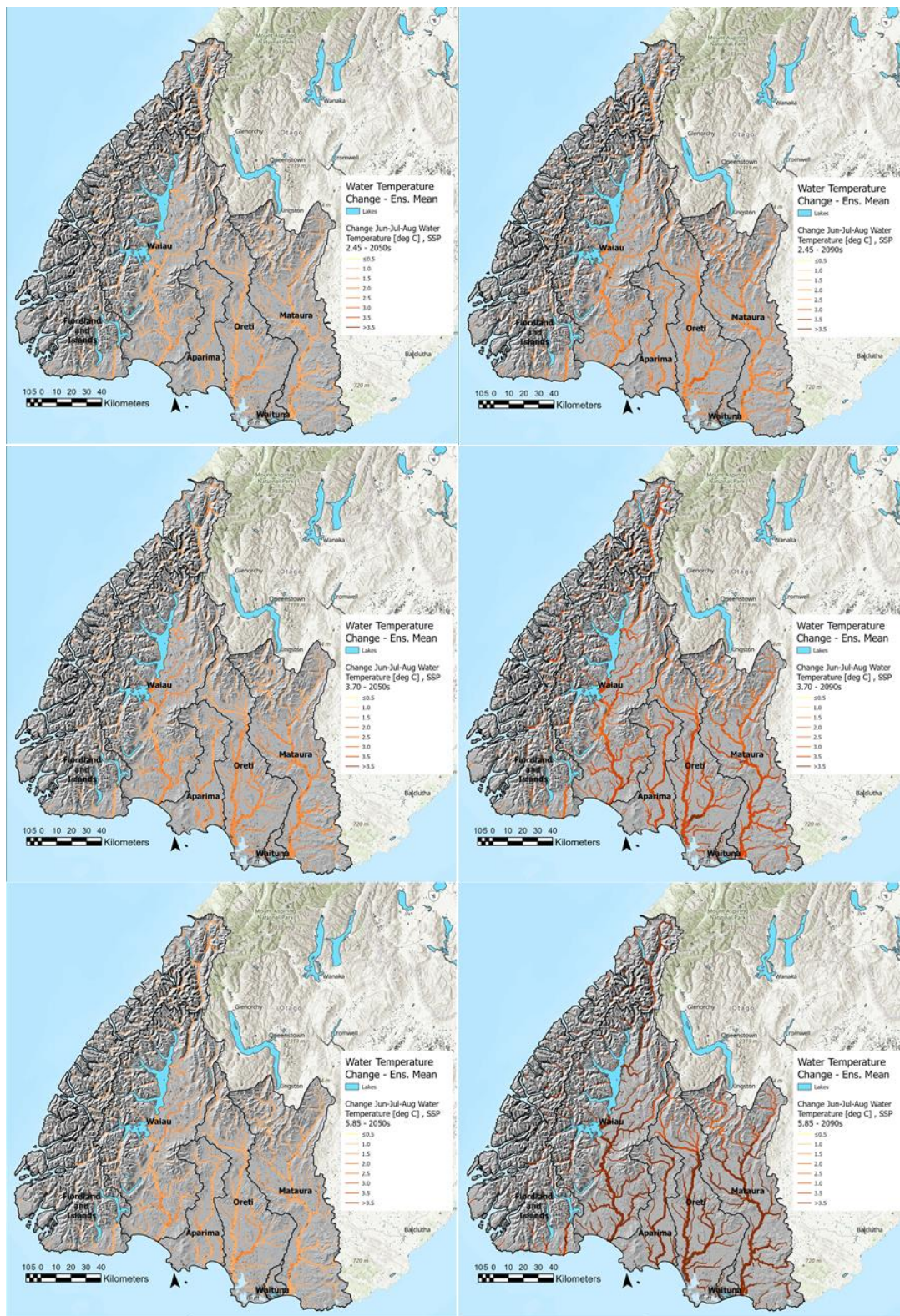


Figure F-2: Change in multi-model average June-July-August (winter) stream water temperature. Change in multi-model average seasonal stream water temperature is presented for SSP 2-4.5 (top panel), SSP 3-7.0 (middle panel) and SSP 5-8.5 (lower panel) by mid-century (left hand panels) and end of century (right hand panels).