Hydrological projections for New Zealand rivers under climate change

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Contents

Tables

Figures

Executive summary

The climate is changing and with it so are global and region water cycles. The elevation of atmospheric concentrations of greenhouse gasses, due largely to emissions by human activity since the Industrial Revolution, has warmed the planet and changed atmospheric circulation patterns. This has in turn altered amounts and timing of precipitation, river flows, and other hydrological conditions globally. While natural variability in the water cycle remains an important feature of the climate system, the effects of climate change are becoming important and are expected to become more so over the course of the century. This is a growing concern to New Zealand given the centrality of freshwater to our social, cultural, economic, and environmental well-being.

This report examines the potential impacts of climate change on hydrological conditions at 20 river mouths around the country. River hydrology is simulated from 1971-2099 under climate conditions derived from six Global Climate Models and four scenarios of future greenhouse gas emissions, taken from the IPCC Fifth Assessment. Climate projections have been downscaled to a resolution useful for hydrological simulations, as described in a companion report. A suite of 13 hydrological variables are examined, together describing seasonal variations in average conditions as well as high and low flow extremes. Differences between baseline conditions (1986-2005) and mid-century (2031-2050) or late-century (2080-2099) are examined for any patterns with the different emissions scenarios that would suggest a climate change effect.

Few hydrological changes are discernible by mid-century. By late-century, the North Island rivers considered in this study are generally projected to experience declines in many flow characteristics – seasonal and annual means as well as mean annual low flow. The South Island rivers are generally projected to experience increases in seasonal and annual mean flows as well as the mean annual flood. The north-east part of the South Island and the southern and mid-western parts of the North Island are transitional zones between the two large-scale areas of decreases and increases. The most robust results across the 20 rivers are changes in mean winter flow (whether increases or decreases) and in the mean annual flood (in the South Island).

It is important to bear in mind that these results apply only to the 20 river mouths studied. While regional patterns have emerged, a thorough understanding of hydrological changes elsewhere, including in sub-catchments of the 20 rivers, would require more extensive modelling. Some of this research has been carried out by an earlier report, which we recommend be read in tandem with this one. We also advise caution in interpretation of the numerical significance of the results. No statistical tests have been applied to the data nor have any hydrological changes been assessed for their practical relevance locally.

Summary of Findings

Hydrological projections for 20 rivers around New Zealand have been developed under the climate change forcings of six Global Climate Models (GCMs), dynamically downscaled and bias-corrected for use across New Zealand, and four Representative Concentration Pathways (RCPs). The GCM projections are taken from the IPCC Fifth Assessment. The RCPs represent alternative policy and behavioral choices over the coming century and corresponding global greenhouse gas emissions, including one mitigation pathway, two stabilisation pathways, and one very high emissions pathway. Hydrological conditions are simulated using the national hydrological model TopNet.

Effects of climate change are inferred from differences in hydrological conditions between an historical 'baseline' time period (1986-2005) and two future time-periods: 'mid-century' (2031-2050) and 'late-century' (2080-2099). The hydrological variables analysed include:

- Mean annual and seasonal discharge.
- Mean annual flood (MAF).
- Mean annual 7-day low flow (MALF).
- The frequency of flows that exceed three times the historical median flow (FRE3).
- Flow exceedance percentiles corresponding to 5% (a high flow), 25%, 50% (the median flow), 75% and 95% (a low flow).

The directions of the hydrological changes for each river, along with the list of rivers, are summarised in Table 1. The main findings are as follows:

1. There is a distinct spatial pattern in the rivers from increases in river flow statistics over most of the South Island, to decreases in river flow statistics over most of the North Island, with a transitional region straddling the top of the South and bottom of the North Islands.
2. The season with the most discernable changes in mean flow is winter, with all of the South Island exhibiting increases and over a third of the studied North Island rivers exhibiting decreases.
3. Spring flows decrease in five of the 11 studied North Island rivers.
4. MALF decreases in all North Island rivers, as well as a single South Island river (Buller).
5. MAF increases in all but one South Island river (Awatere) but in only the Waikato in the North Island.
6. FRE3 decreases in five of the 11 North Island rivers studied, and in seven of the 9 South Island rivers.
7. Rivers whose baseline exceedance flows of 5% and of 25% show increases in frequency are identical to those with increases in MAF.
8. The Haast River stands out as exhibiting the most number of changing hydrological conditions, all showing increased flows except for low flow conditions.

9. The Waiapu and Tukituki Rivers exhibit the greater number of decreasing hydrological variables, with apparent decreases in all but mean summer flow, MAF, and the frequency of flows above the baseline 5% exceedance flow.
10. The Awatere River exhibits the fewest changes, with an increase in only mean winter flow.
11. The Waiongana is the only North Island river to exhibit an increase in flow variables – mean winter flow; all others exhibit decreases.
12. Very few hydrological changes are apparent by mid-century, with most emerging by late-century.
13. The magnitudes of the changes tend to increase with increasing RCP, a pattern which is used to discern the influence of climate change.

When interpreting these results it is important to consider several caveats:

1. The results apply only to the coastal outlets of the studied rivers, not to individual upstream sub-catchments or nearby rivers.
2. The Mean Annual Flood metric reflects an event that is expected to occur once every two to three years, and cannot be interpreted as robustly describing the effect climate change will have on rare flood events.
3. Identification of a climate change effect is made difficult by inter-annual variability, variations among GCMs, and non-linearity of RCP effects.
4. Not all hydrological differences are statistically or practically significant, even when averaged over 20-year periods. It is recommended that future assessments of climate change effects employ repeatable and objective tests of significance.

It is further recommended that this report be read in tandem with Collins and Zammit (2016), which used the same hydrological simulations but examined slightly different hydrological variables over New Zealand's potential agricultural lands.

Table 1. Summary of the projected hydrological changes (direction indicated by the arrow/colour) for 20 rivers around New Zealand.

River	Mean flow					Flow extremes			Flow exceedance percentiles				
	Summer	Autumn	Winter	Spring	Annual	MALF	MAF	FRE3	5%	25%	50%	75%	95%
Wairoa			↓	↓	↓	↓		↓		↓	↓	↓	↓
Hoteo			↓	↓	↓	↓		↓		↓	↓	↓	↓
Waihou						↓							↓
Waikato				↓		↓				↓	↓	↓	↓
Rangitaiki						↓							↓
Waipaoa					↓	↓		↓		↓	↓	↓	↓
Waiapu		↓	↓	↓	↓	↓		↓		↓	↓	↓	↓
Waiongana			↑			↓							
Manawatu						↓				↓	↓	↓	↓
Tukituki		↓	↓	↓	↓	↓		↓		↓	↓	↓	↓
Ruamāhanga						↓				↓	↓	↓	↓
Motueka			↑		↑		↑	↑	↑	↑			↓
Maitai			↑		↑		↑		↑	↑			↓
Awatere			↑										
Buller			↑		↑	↓	↑	↑	↑	↑	↑		
Haast	↑	↑	↑	↑	↑		↑	↑	↑	↑	↑	↑	
Rakaia			↑				↑	↑	↑	↑	↑	↑	
Clutha			↑		↑		↑	↑	↑	↑	↑	↑	
Waiau			↑		↑		↑	↑	↑	↑	↑	↑	
Mataura			↑		↑		↑	↑	↑	↑	↑		

1 Introduction

Rivers are fundamental to New Zealand's society, culture, economy and environment. Ecosystem services they provide include, among others, water provision for drinking, industry and irrigation, hydropower generation, gravel supply, recreation, spiritual values, aesthetic values, recreation, and broad support for ecosystem maintenance and habitats. Rivers also pose a major threat to human population and assets when in flood. As the climate changes, the hydrology of rivers, and hence the ecosystem services provided and hazards posed by rivers, are liable to change as well.

Global and regional water cycles are changing as a consequence of climate change resulting from increasing greenhouse gas concentrations in the atmosphere. The Fifth and most recent Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013, 2014) has reviewed the published research at the time and has concluded that:

- Warming of the climate system is unequivocal and unprecedented over decades to millennia. It is also uneven across the globe.
- It is "extremely likely[1]" that human influences have been the dominant cause of warming since the mid-20th century, and that this is primarily due to fossil fuel emissions.
- Some amount of warming over the 21st century is unavoidable, but that further warming is dependent on future trajectories of greenhouse gas emissions.
- Impacts on the water cycle have included changes in precipitation, drought, and river flow amounts and timing. Globally, renewable water resources are projected to decrease. No compelling links between past flood magnitudes and warming have been made, although flood hazards are projected to increase in the future.

New Zealand air temperatures, as represented by the 7-station series, have increased by about 1°C over the last century or so (Mullan, Stuart et al. 2010). This is approximately 80% of the global warming trend (Ministry for the Environment 2016). Part of the New Zealand warming trend is probably due to natural variability (Salinger and Mullan 1999, Mullan, Stuart et al. 2010), but a significant contribution to the warming can be attributed to greenhouse gas increases (Dean and Stott 2009). Trends in precipitation are harder to detect but declines are seen in Northland and increases on the west coast of the South Island (Griffiths 2006). Due to the roles of air temperature and precipitation on the water cycle, it is valuable to examine how river flows may change under climate change, although no study has yet tested for the presence of such trends in the historical record.

Looking ahead to 2100, changes in air temperature will continue due to greenhouse gas emissions that have already occurred, and potentially accelerate, depending on trajectories of future global emissions (Ministry for the Environment 2016). Hydrological studies based on previous climate change projections suggest that such warming would alter snow cover (Hendrikx, Hreinsson et al. 2012), glacial extent (Anderson, Mackintosh et al. 2010), river flows (Zammit and Woods 2011; Collins 2016), floods (McMillan, Jackson et al. 2010), droughts (Clark, Mullan et al. 2011), and groundwater (Aqualinc Research 2008; Zemansky, Hong et al. 2012); see Collins and Tait (2016) for an extensive review. More recently, Collins and Zammit (2016) used the latest available climate

[1] Following IPCC convention (IPCC, 2013); see Glossary.

projections, detailed in Ministry for the Environment (2016), to assess the potential impacts of climate change for river flows and soil moisture conditions in and around agricultural areas across New Zealand. The main findings of that report that relate to rivers are:

- Mean annual flows are expected to decrease in the north and east of the North Island and the east and north-east of the South Island, while projections are more mixed for the rest of the North Island, and for the South Island increases in mean annual flows are generally projected.
- Mean annual low flows (MALF) are generally expected to decrease for the North Island where low flow conditions are also expected to be reached earlier in the water year, but both increases and decreases in MALF are projected across the South Island, with the West Coast experiencing delays in arrival of low flow conditions.
- The mean annual flood (MAF) is generally projected to increase, more so in the South Island, particularly the south of the South Island.
- The magnitudes of these changes tend to become larger towards the end of the century and under scenarios of higher greenhouse gas emissions.

The focus of this report is on potential future changes in New Zealand river hydrology at 20 locations across the country out to 2099. It draws on the climate change projections detailed in Ministry for the Environment (2016), which are based heavily on the IPCC Fifth Assessment Report (AR5) climate model simulations (also referred to as the CMPI5 simulations; see Glossary). The hydrological projections described in this report are based on the same simulations as used by Collins and Zammit (2016), which focussed on potential impacts of climate change on water resources and hazards related to agricultural areas. As the two reports complement one another in terms of scope it is recommended that they be read in tandem. This report specifically addresses mid- and late-century differences in annual and seasonal average river flows, extreme flow (flood and drought) occurrence, and more generally the occurrence of flows across the range of flow conditions at 20 river mouths across the country. Supplemental information would be required to extend the conclusions upstream within the same river catchment or to other rivers.

2 Data and Models

- This report considers the potential impacts on hydrological characteristics of selected rivers from climate change described by four concentration pathways from the IPCC Fifth Assessment. The pathways are known as Representative Concentration Pathways (RCPs), and abbreviated as RCP2.6, RCP4.5, RP6.0, and RCP8.5, in order of increasing radiative forcing by greenhouse gases.
- From the 41 Global Climate Model (GCM) simulations available to the IPCC, six have been selected for local climate and hydrological modelling across New Zealand. The six GCMs are chosen to validate well on the present climate, and to be as different as possible in the parent global model so as to span the likely range of model sensitivity. The hydrological model used is the national hydrological model TopNet.
- Two future time periods are chosen (mid-century, 2031-2050, and late-century, 2080-2100) to be compared with a baseline time period (1986-2005).
- The hydrological modelling examines 20 rivers across New Zealand, focussing on the outlets at the coast, with at least one river in each region. Variables of interest are:
  - Mean annual and seasonal discharge.
  - Mean annual flood.
  - Mean annual 7-day low flow.
  - The frequency of flows that exceed three times the historical median flow.
  - Flow exceedance percentiles corresponding to 5%, 25%, 50%, 75% and 95%.

2.1 Climate data

The primary input for the hydrological simulations is climate data generated from a suite of Global and Regional Climate Model (RCM) simulations undertaken at NIWA (Ministry for the Environment 2016). In each case the sea surface temperatures used are derived from simulations of Global Climate Models (GCMs) available from the Coupled Model Inter-comparison Project 5 archive (CMIP5), a part of the IPCC's Fifth Assessment Report (AR5). All models used are driven by natural climate forcing such as solar irradiance and historical and modelled anthropogenic forcing driven by emissions of greenhouse gases and aerosols based on four Representative Concentration Pathways (RCPs). They are otherwise "free-running" in that they are not constrained by historical climate observations applying data assimilation.

All available CMIP5 models were assessed for their ability to simulate New Zealand climate. Validation of 41 GCMs was carried out through comparison with large scale climatic and circulation characteristics across 62 metrics (Ministry for the Environment 2016). This analysis provided performance based ranking based on New Zealand's historical climate. The six best performing independent models, where projections across all 4 RCPs were available up to 2099 (van Vuuren, Edmonds et al. 2011), were selected for dynamical downscaling. The output data fields were then bias-corrected relative to a 1980-1999 climatology and subsequently further downscaled to an approximate 5 km grid (Sood 2014). The RCM output (bias-corrected and downscaled to 5km) was then provided as input to a hydrological model which produced soil moisture and river flow.

The downscaled climate data used in this report run from 1971 to 2099. From 2005 onward, as per IPCC recommendations, each GCM is in turn driven by four RCPs that encapsulate alternative scenarios of radiative forcing and reflect alternative trajectories of global societal behaviour with regard to greenhouse gas emissions and other activities. The range of RCPs used can help shed light on the utility of climate change mitigation. Descriptions and trajectories of the four RCPs are provided in Table 2-1 and Figure 2-1. By mid-century, the temperature trajectory of RCP2.6 is the coolest and RCP8.5 the warmest, with RCP4.5 and RCP6.0 producing intermediate warming. While RCP6.0 ends the century with more forcing than RCP4.5, early and mid-century it is RCP4.5 that has higher greenhouse gas emissions and a stronger radiative forcing. This is somewhat reflected by the mid-century temperature change ranges for the New Zealand seven-station network (Table 2-1) for which RCP6.0 overtakes RCP4.5 after the middle of century. As a result, the climatic and subsequent hydrological effects of the RCPs are not simply a linear or monotonic progression from the lowest to highest RCP.

Table 2-1: Descriptions of the Representative Concentration Pathways (RCPs). Temperature changes are the GCM mean (°C) and, in brackets, the likely ranges.

Representative Concentration Pathway	Description	Seven-station temperature change (Ministry for the Environment 2016)		Global surface temperature change for 2081-2100 (IPCC 2014, Table 2.1)
		2031-2050	2081-2100	
RCP2.6	The least change in radiative forcing considered, by the end of the century, with +2.6 W/m^2 by 2100 relative to pre-industrial levels	0.7 (0.2, 1.3)	0.7 (0.1, 1.4)	1.0 (0.3, 1.7)
RCP4.5	Low-to-moderate change in radiative forcing by the end of the century, with +4.5 W/m^2 by 2100 relative to pre-industrial levels	0.8 (0.4, 1.3)	1.4 (0.7, 2.2)	1.8 (1.1, 2.6)
RCP6.0	Moderate-to-high change in radiative forcing by the end of the century, with +6.0 W/m^2 by 2100 relative to pre-industrial levels	0.8 (0.3, 1.1)	1.8 (1.0, 2.8)	2.2 (1.4, 3.1)
RCP8.5	The largest change in radiative forcing considered, by the end of the century, with +8.5 W/m^2 by 2100 relative to pre-industrial levels	1.0 (0.5, 1.7)	3.0 (2.0, 4.6)	3.7 (2.6, 4.8)

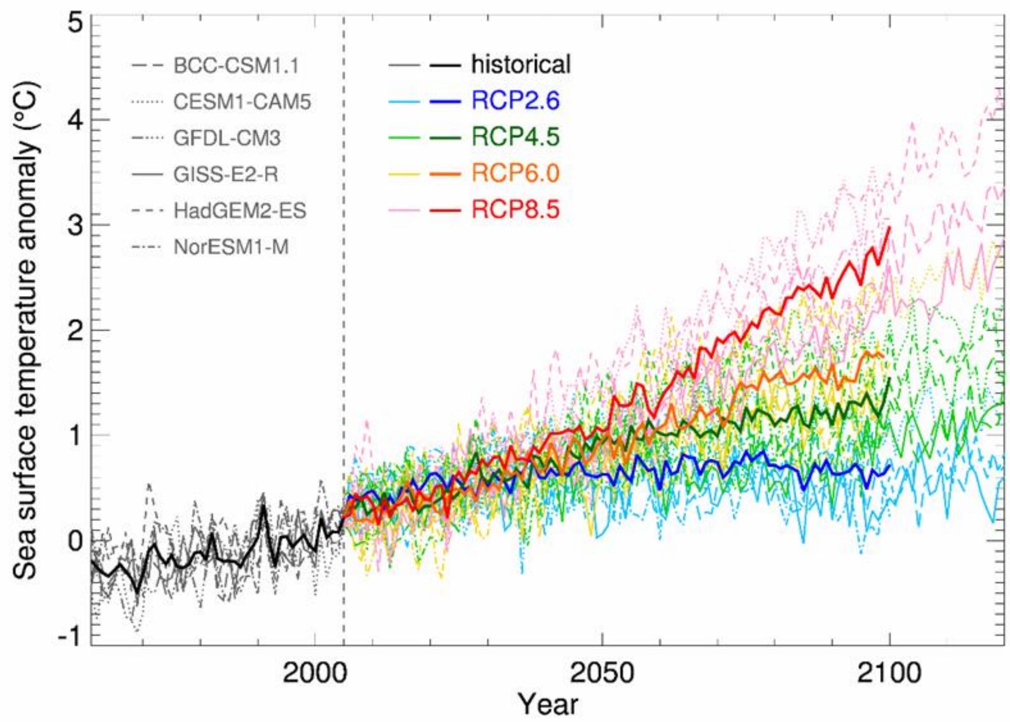


Figure 2-1: Bias-adjusted SSTs, averaged over the RCM domain, for 6 CMIP5 global climate models (2006-2120), the historical simulations (1960-2005), and four future simulations (RCPs 2.6, 4.5, 6.0 and 8.5), relative to 1986-2005 (Sood 2015). Individual models are shown by thin dotted or dashed or solid lines (as described in the inset legend), and the 6-model ensemble-average by thicker solid lines, all of which are coloured according to the RCP pathway.

2.2 Hydrological modelling

To assess the potential impacts of climate change on river flow a hydrological model is required that can simulate hydrological conditions continuously and under a range of different climatic conditions, both historical and future. Ideally the model would also simulate complex groundwater fluxes but there is no national hydrological model capable of this at present. Because climate change implies that environmental conditions are shifting from what has been observed historically, it is advantageous to use a physically based hydrological model over one that is more empirical, with the assumption that a better representation of the biophysical processes will allow the model to perform better outside the range of conditions under which it is calibrated.

The hydrological model used in this study is TopNet (Clark, Rupp et al. 2008), which is routinely used for surface water hydrological modelling applications in New Zealand. It is a spatially semi-distributed, time-stepping model of water balance. It is driven by time-series of precipitation and temperature, and of additional weather elements where available. TopNet simulates water storage in the snowpack, plant canopy, rooting zone, shallow subsurface, lakes and rivers. It produces time-series of modelled river flow (without consideration of water abstraction, impoundments or discharges) throughout the modelled river network, as well as evapotranspiration, and does not consider irrigation. TopNet has two major components, namely a basin module and a flow routing module.

The model combines TOPMODEL hydrological model concepts (Beven, Lamb et al. 1995) with a kinematic wave channel routing algorithm (Goring 1994) and a simple temperature based empirical snow model (Clark et al. 2008). As a result, TopNet can be applied across a range of temporal and spatial scales over large watersheds using smaller sub-basins as model elements (Ibbitt and Woods 2002; Bandaragoda, Tarboton et al. 2004). Considerable effort has been made during the development of TopNet to ensure that the model has a strong physical basis and that the dominant rainfall-runoff dynamics are adequately represented in the model (McMillan, Freer et al. 2010). TopNet model equations and information requirements are provided by Clark, Rupp et al. (2008) and McMillan, Hreinsson et al. (2013).

For the development of the National TopNet used in this application, spatial information in TopNet is provided by national datasets as follows:

- Catchment topography based on a nationally available 30 m Digital Elevation Model (DEM);
- Physiographical dataset based on the Land Cover Database version 2 (LCDB2) and Land Resource Inventory (Newsome, Wilde et al. 2000);
- Soil dataset based on the Fundamental Soil Layer information (Newsome et al. 2000); and
- Hydrological properties based on the concept of River Environment Classification version 1- REC1 (Snelder and Biggs 2002).

The method for deriving TopNet's parameters based on GIS data sources in New Zealand is given in Table 1 of Clark, Rupp et al. (2008). Due to the paucity of some spatial information at national/regional scales, some soil parameters are set uniformly across New Zealand.

To carry out the simulations required here, TopNet is run continuously from 1971 to 2099, with the spin-up period of the first year, 1971, excluded from the analysis. The climate inputs (e.g., temperature, rainfall) are stochastically disaggregated from daily to hourly time steps. For the current application, hydrological simulations are based on the REC version 1 digital river network aggregated up to Strahler[2] catchment order 3 (approximate average catchment area of 7 km^2) to reduce simulation times and data sizes to manageable levels while still providing useful information; residual coastal catchments of smaller stream orders remain included. As a result simulations are carried out across 43,847 catchments at hourly time steps generating over 270 TB of model results. The simulation results comprise hourly time-series of various hydrological variables for each computational sub-catchment, and for each of the six GCMs and four RCPs considered. To manage output data only river flows and soil moisture information were preserved; all the other state variables and fluxes can be regenerated on demand.

Because of TopNet assumptions, soil and land use characteristics within each computational sub-catchment are homogenised and constant within the period of simulation. Essentially this means that the soil characteristics and physical properties of different land uses, such as pasture and forest, will be spatially averaged, and the hydrological model outputs will be an approximation of conditions across agricultural land uses.

[2] Strahler order describes river size based on tributary hierarchy. Headwater streams with no tributaries are order 1; 2nd order streams develop at the confluence of two 1st order tributaries; stream order increases by 1 where two tributaries of the same order converge.

2.3 Study sites and hydrological analysis

Twenty rivers were selected for the study (Figure 2-2:), each defined as the river network and catchment area upstream of the river reach nearest to the coast:

- Northland: Wairoa;
- Auckland: Hoteo;
- Waikato: Waihou and Waikato;
- Bay of Plenty: Rangitaiki;
- Gisborne: Waiapu and Waipaoa;
- Taranaki: Waiongana;
- Wanganui-Manawatu: Manawatu;
- Hawke's Bay: Tukituki;
- Wellington: Ruamāhanga;
- Tasman: Motueka;
- Nelson: Maitai;
- Marlborough: Awatere;
- West Coast: Buller and Haast;
- Canterbury: Rakaia;
- Otago: Clutha;
- Southland: Waiau and Mataura.

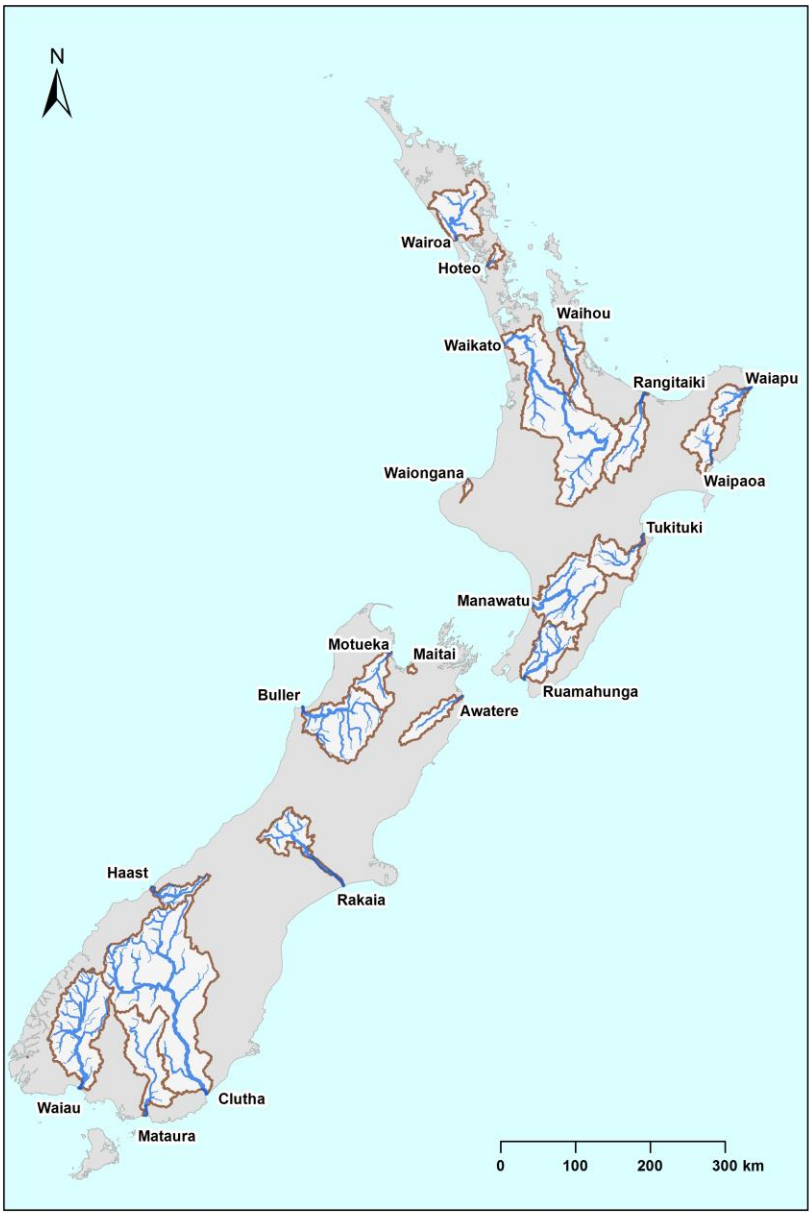


Figure 2-2: Locations of the 20 rivers analysed at their outlet.

In consultation with Ministry for the Environment and in light of preliminary results, 13 hydrological statistics were selected for reporting at the outlet of each catchment, covering a range of flows as well as annual and seasonal periods:

- Mean flow: The mean discharge over the analysis period.
- Mean seasonal flow: The mean discharge for each season over the analysis period.
- Mean annual 7-day low flow (MALF): The mean of the series of each year's lowest 7-day discharge.
- Mean annual flood (MAF): The mean of the series of each year's highest daily flow. Such a flow can be expected to have a recurrence interval of once every two to three years.

- Frequency of ecologically important floods (FRE3): The mean number of floods per year above a given threshold. The threshold is defined as three times the median discharge during the baseline period, and floods become distinct when separated by at least five days. This statistic is a general indicator of several in-stream ecological values, most importantly periphyton accrual. As such, changes in FRE3 under climate change must be assessed with respect to the same threshold flow.
- Flow percentiles: The flows equalled or exceeded 5%, 25%, 50%, 75%, and 95% of the time. 5% exceedance probability corresponds to a high flow, 50% to the median flow, and 95% to a low flow.

The statistics are calculated from hourly model results, comparing the 'baseline' period of 1986-2005 to two future periods: 'mid-century' (2031-2050) and 'late-century' (2080-2099). The late-century period differs slightly from that used by Ministry for the Environment (2016) as the hydrological simulations only ran to the end of 2099, and a full 20-year period is desirable for the analysis. Comparisons are made in one of two ways, depending on the statistic in question: for the mean flows, MALF, MAF, and FRE3, percentage differences are used; for the flow percentiles, we report the new exceedance probabilities for the same flow thresholds identified for the baseline period.

Each statistic for each simulation (six GCMs across four RCPs) and river are reported in tabular and graphical forms. The tabular summaries include the range of results across the six GCMs as well as the multi-model median. The median is chosen as the indicator of the central tendency of the results, rather than the mean, as it is more useful when making decisions based on likelihood across alternative scenarios. Whether a change in any variable is discernible under climate change is interpreted from the medians across the RCPs in the context of the spread of values across the GCMs. Potential trends in the median values are less compelling if the GCM range is large. However, it must be noted that these interpretations are made visually, and are not tested statistically.

2.4 A note on interpreting the results

Presented below are results of numerous hydrological simulations across the country. They are presented to serve as a guide of what kind of hydrological changes may manifest under climate change and how these changes could vary across the country and across different levels of global emissions reductions. Due to coincidental natural variability and the difficulty in projecting both climate change drivers and effects, it is important to look for robust patterns across the results and not rely on any one of these simulations. The rivers have been selected for their importance in each region, but their behaviour under climate change cannot necessarily be extrapolated to other rivers in the region (Collins and Zammit 2016).

Results are presented as differences between a baseline period and two future periods (mid- and late-century). These differences are discussed in qualitative terms and have not been assessed for either statistical significance or practical significance, whether related to social, cultural, economic, or environmental importance. These differences will also reflect a combination of both climate change and natural (simulated) climate variability, so the differences are not directly representative of climate change effects.

Lastly, the 20 locations are specific river mouths. The results cannot be applied to sub-catchments of these river catchments, nor to nearby rivers. A regional or national approach to this analysis would be required to support more extensive and detailed interpretation.

3 Projected Hydrological Changes in Selected Rivers

- Projected changes are presented for mid-century (2031-2050) and late-century (2080-2099), both relative to the IPCC current-climate 'baseline' of 1986-2005.
- The scales of the changes for all hydrological variables tend to increase towards the end of the century and under more extreme warming scenarios (higher RCPs).
- Changes to mean seasonal and annual flows are consistent with projections for rainfall changes using dynamical downscaling presented in Ministry for the Environment (2016).

Mean seasonal and annual discharge:

i) Several rivers show no discernible effect of climate change.
ii) For those rivers that do show an effect, North Island rivers tend to decline in flow and South Island rivers tend to increase in flow, but only for selected seasons.
iii) The most visible effects of climate change are in the South Island during winter.
iv) The scale of the effects tends to increase later in the century and under high RCPs.

Flow extremes:

i) MALF tends to decline for most of the studies rivers, except those in the south and west of the South Island, where MALF increases.
ii) MAF remains about steady or increases, with the larger and more tangible increases in the south and west of the South Island.
iii) FRE3 increases for most of the rivers studied, and for the remainder shows no tangible change.

Flow exceedance percentiles

i) Changes in the flow percentiles reflect changes for the annual discharge and extreme flows.
ii) The 5% exceedance flows tend to be exceeded more often, echoing the changes in MAF and FRE3.
iii) The mid-range exceedance flows (25%, 50%, and 75%) increase, decrease or remain roughly constant depending on the location, with more increases in the south, echoing the changes in the annual discharge.

3.1 Mean seasonal and annual flows

Projected changes in the mean seasonal and annual flows are summarised in Table 3-1 and Table 3-2 and are depicted in Figure 3-1 to Figure 3-20.

Results of the simulations are as follows:

- Changes in mean flows for Waihou, Rangitaiki, Manawatu, and Ruamāhanga in the North Island show no discernable pattern with RCP.
- For Wairoa and Hoteo Rivers there are apparent late-century declines in mean winter, spring and annual flow as RCPs become more severe.
- For the Waikato, mean spring flow shows signs of declining by late-century.
- For the Waipaoa, there are signs of declining mean summer, spring, and annual flows by late-century.

- The Waiapu and Tukituki show the most discernable patterns, with late-century declines in mean flows during autumn, winter, spring, and annually.
- The Waiongana in the west contrasts with the rest of the North Island with a slight late-century increase in mean winter flows.
- For all of the South Island rivers, mean winter flows show increases by late-century; in the case of the Buller, Haast, Clutha, Waiau and Rakaia, possibly by mid-century.
- In the South Island, summer and autumn increases in mean flow is only discernable in the Haast.
- Increases in mean spring flows are apparent for the Haast, Clutha, Waiau, and Mataura rivers by late-century.
- The cumulative changes in mean annual flows for the South Island show late-century increases for all rivers except the Awatere.

In summary, most of the North Island is projected to experience declines in flows by late-century, mostly during spring, fewer during winter, fewer still during autumn, but none during summer. Four North Island rivers show no changes at all. Conversely, for the North Island's Waiongana and all the South Island rivers, mean winter flows are projected to increase by late-century. Southern and western South Island rivers also show increases during spring, and the sole river on the mid-west, the Haast, shows increases during summer and autumn as well. In light of differences in projection uncertainty, the late-century patterns of increasing winter flows in the South Island are more robust than any patterns noted for the North Island, although no statistical tests have been carried out.

Table 3-1: Projected changes in seasonal and annual mean discharge (in %) between 1986-2005 and 2031-2050. The changes are given for four RCPs (8.5, 6.0, 4.5 and 2.6), where the ensemble median is taken over six models. The values in each column represent the ensemble median, and in brackets the range over all six models within that ensemble.

River	Summer	Autumn	Winter	Spring	Annual
Wairoa					
RCP 8.5	-13 (-16, 40)	4 (-22, 27)	-1 (-15, 3)	-6 (-19, 4)	-2 (-16, 12)
RCP 6.0	-9 (-21, 33)	6 (-20, 39)	-3 (-13, 6)	-3 (-13, 14)	-5 (-11, 14)
RCP 4.5	-12 (-33, 2)	5 (-16, 27)	1 (-10, 5)	-1 (-13, 20)	1 (-15, 9)
RCP 2.6	-6 (-18, 44)	11 (-11, 30)	1 (-6, 5)	-2 (-13, 9)	-1 (-7, 15)
Hoteo					
RCP 8.5	-10 (-26, 43)	0 (-12, 21)	-1 (-9, 6)	-10 (-22, 1)	-1 (-12, 7)
RCP 8.5	-12 (-28, 27)	6 (-20, 57)	-1 (-7, 3)	-6 (-19, 21)	0 (-9, 14)
RCP 6.0	-11 (-29, 5)	10 (-13, 29)	-2 (-10, 5)	-8 (-16, 21)	-3 (-12, 11)
RCP 4.5	-1 (-27, 32)	4 (-7, 31)	-2 (-5, 5)	-1 (-18, 6)	0 (-6, 8)
Waihou					
RCP 8.5	-2 (-6, 12)	6 (-10, 10)	5 (-4, 13)	1 (-7, 10)	4 (-4, 10)
RCP 6.0	4 (-8, 20)	7 (-7, 25)	1 (-3, 14)	6 (-11, 18)	2 (-2, 14)
RCP 4.5	-4 (-7, 11)	3 (-14, 8)	3 (-4, 10)	4 (-2, 8)	3 (-5, 9)
RCP 2.6	0 (-6, 18)	4 (-4, 7)	3 (-5, 8)	3 (-1, 14)	3 (-3, 10)

Waikato					
RCP 8.5	-11 (-20, 29)	4 (-3, 17)	3 (-2, 9)	-4 (-19, 3)	1 (-7, 8)
RCP 6.0	-6 (-16, 29)	12 (-16, 47)	-2 (-6, 7)	1 (-22, 16)	1 (-7, 12)
RCP 4.5	-9 (-15, 0)	6 (-19, 23)	1 (-5, 14)	5 (-9, 17)	0 (-6, 10)
RCP 2.6	2 (-21, 16)	4 (-3, 16)	1 (-3, 7)	3 (-10, 11)	2 (-6, 8)
Rangitaiki					
RCP 8.5	-4 (-9, 9)	2 (-11, 14)	2 (-11, 14)	1 (-6, 9)	1 (-8, 11)
RCP 6.0	6 (-11, 24)	4 (-7, 30)	-2 (-10, 23)	2 (-15, 23)	-1 (-5, 21)
RCP 4.5	-4 (-11, 12)	-1 (-17, 11)	5 (-12, 20)	5 (-6, 10)	1 (-10, 13)
RCP 2.6	-2 (-8, 22)	4 (-3, 8)	3 (-11, 13)	-2 (-3, 13)	1 (-6, 14)
Waipaoa					
RCP 8.5	-5 (-33, 27)	-3 (-17, 22)	-6 (-8, 4)	-12 (-19, 3)	-9 (-10, 7)
RCP 6.0	-7 (-20, 53)	-4 (-13, 15)	-2 (-14, 5)	5 (-27, 34)	-6 (-8, 17)
RCP 4.5	-9 (-32, -1)	-1 (-16, 19)	0 (-16, 20)	-3 (-28, 19)	-6 (-12, 16)
RCP 2.6	-7 (-16, 52)	2 (-12, 15)	-1 (-9, 9)	0 (-15, 15)	-1 (-8, 15)
Waiapu					
RCP 8.5	-2 (-33, 9)	3 (-25, 23)	2 (-5, 7)	-10 (-22, -2)	-4 (-9, 7)
RCP 6.0	-4 (-26, 38)	-3 (-19, 18)	-2 (-6, 14)	4 (-27, 24)	-4 (-9, 18)
RCP 4.5	-18 (-25, -4)	6 (-19, 28)	4 (-10, 26)	-2 (-23, 15)	-3 (-12, 10)
RCP 2.6	-5 (-27, 38)	0 (-13, 16)	3 (-10, 8)	0 (-11, 14)	-2 (-13, 15)
Waiongana					
RCP 8.5	1 (-18, 26)	7 (-7, 17)	4 (-2, 11)	1 (-6, 14)	6 (-6, 10)
RCP 6.0	2 (-9, 28)	8 (-12, 16)	4 (-2, 13)	5 (-11, 20)	5 (-2, 16)
RCP 4.5	-1 (-16, 19)	4 (-28, 18)	3 (-2, 6)	2 (-6, 11)	4 (-11, 7)
RCP 2.6	9 (-15, 18)	4 (-9, 9)	1 (-2, 10)	3 (-7, 24)	4 (-4, 11)
Manawatu					
RCP 8.5	-1 (-23, 13)	4 (-12, 6)	0 (-5, 13)	-2 (-11, 7)	1 (-9, 6)
RCP 6.0	0 (-14, 25)	4 (-11, 9)	2 (-10, 8)	2 (-8, 15)	3 (-6, 10)
RCP 4.5	-9 (-13, 32)	1 (-22, 12)	1 (-7, 5)	3 (-4, 12)	0 (-10, 10)
RCP 2.6	-1 (-9, 29)	-1 (-6, 19)	3 (-7, 14)	1 (-4, 25)	2 (-2, 14)
Tukituki					
RCP 8.5	5 (-24, 25)	-1 (-17, 23)	-8 (-13, 10)	-12 (-19, 4)	-7 (-14, 10)
RCP 6.0	9 (-8, 46)	2 (-10, 18)	-5 (-14, 13)	3 (-28, 17)	0 (-10, 18)
RCP 4.5	-11 (-21, 30)	-5 (-20, 14)	-1 (-17, 19)	-3 (-28, 14)	-6 (-15, 18)
RCP 2.6	7 (-6, 69)	2 (-13, 16)	2 (-12, 15)	0 (-21, 16)	2 (-11, 22)
Ruamāhanga					
RCP 8.5	2 (-15, 16)	2 (-6, 15)	1 (-6, 13)	1 (-7, 6)	1 (-7, 9)
RCP 6.0	0 (-6, 22)	-1 (-4, 4)	0 (-5, 12)	3 (-10, 13)	1 (-4, 9)
RCP 4.5	-9 (-15, 31)	3 (-15, 12)	5 (-5, 8)	4 (-5, 8)	0 (-6, 12)
RCP 2.6	-2 (-10, 22)	4 (-7, 15)	1 (-13, 14)	-1 (-9, 15)	1 (-6, 12)
Motueka					
RCP 8.5	-7 (-24, 24)	-2 (-18, 18)	9 (-5, 24)	5 (-12, 20)	2 (-3, 10)
RCP 6.0	-11 (-17, 37)	0 (-7, 18)	9 (4, 25)	3 (-9, 15)	4 (-6, 14)
RCP 4.5	-6 (-36, 29)	7 (-18, 21)	10 (-3, 17)	1 (-4, 26)	7 (-7, 12)
RCP 2.6	6 (-25, 30)	-2 (-11, 14)	9 (-4, 24)	2 (-12, 18)	2 (-3, 12)

Maitai					
RCP 8.5	0 (-28, 59)	0 (-17, 67)	22 (-9, 42)	-3 (-16, 31)	9 (-7, 28)
RCP 6.0	-5 (-12, 85)	9 (-11, 68)	15 (5, 34)	6 (-13, 47)	13 (0, 26)
RCP 4.5	-4 (-37, 82)	13 (-32, 51)	24 (-5, 33)	8 (-15, 43)	16 (-9, 28)
RCP 2.6	9 (-27, 46)	1 (-28, 26)	14 (1, 31)	1 (-13, 20)	7 (-9, 18)
Awatere					
RCP 8.5	-6 (-28, 11)	-2 (-12, 12)	7 (0, 16)	-4 (-12, 17)	0 (-9, 6)
RCP 6.0	1 (-9, 22)	6 (-6, 21)	9 (0, 29)	6 (-3, 13)	4 (3, 19)
RCP 4.5	-9 (-30, 29)	6 (-15, 13)	19 (-7, 27)	4 (-7, 14)	8 (-8, 14)
RCP 2.6	7 (-14, 19)	2 (-8, 22)	5 (-2, 35)	2 (-9, 10)	6 (-6, 14)
Buller					
RCP 8.5	-7 (-24, 15)	-3 (-6, 11)	15 (1, 28)	5 (-10, 24)	3 (-1, 11)
RCP 6.0	-7 (-22, 23)	2 (-4, 17)	13 (1, 27)	2 (-5, 14)	5 (-2, 11)
RCP 4.5	-3 (-33, 17)	6 (-15, 14)	10 (5, 18)	3 (-4, 19)	3 (-3, 14)
RCP 2.6	0 (-18, 17)	-2 (-7, 14)	9 (2, 25)	0 (-12, 17)	2 (-1, 9)
Haast					
RCP 8.5	2 (-11, 12)	3 (-3, 13)	21 (13, 32)	9 (-6, 21)	7 (3, 16)
RCP 6.0	1 (-10, 16)	8 (-5, 19)	19 (7, 34)	4 (-2, 13)	7 (3, 11)
RCP 4.5	5 (-14, 11)	3 (-5, 22)	12 (6, 24)	6 (0, 20)	5 (2, 17)
RCP 2.6	3 (-10, 13)	3 (-5, 19)	15 (6, 24)	7 (-8, 10)	6 (1, 11)
Rakaia					
RCP 8.5	-4 (-13, 11)	2 (-7, 11)	14 (5, 17)	6 (-5, 18)	3 (1, 12)
RCP 6.0	-4 (-15, 18)	5 (1, 20)	11 (1, 22)	3 (-4, 11)	5 (1, 8)
RCP 4.5	-3 (-22, 13)	3 (-10, 22)	9 (3, 16)	2 (-2, 20)	2 (-2, 14)
RCP 2.6	1 (-16, 11)	1 (-6, 19)	9 (1, 17)	3 (-7, 13)	3 (0, 7)
Clutha					
RCP 8.5	1 (-19, 9)	4 (-5, 10)	13 (5, 22)	12 (-1, 20)	5 (2, 14)
RCP 6.0	-4 (-9, 18)	11 (-9, 14)	15 (6, 21)	4 (1, 19)	7 (2, 13)
RCP 4.5	6 (-17, 12)	4 (-2, 14)	10 (1, 18)	8 (-1, 23)	5 (3, 17)
RCP 2.6	3 (-11, 17)	8 (-4, 12)	12 (2, 14)	8 (-6, 15)	7 (2, 10)
Waiau					
RCP 8.5	0 (-22, 4)	2 (-7, 11)	12 (3, 27)	10 (-2, 15)	2 (-1, 13)
RCP 6.0	-3 (-8, 10)	5 (-8, 15)	13 (1, 33)	4 (-2, 12)	3 (-1, 13)
RCP 4.5	2 (-16, 12)	4 (-7, 13)	6 (0, 22)	5 (-3, 17)	3 (0, 13)
RCP 2.6	-1 (-16, 17)	7 (-8, 16)	12 (-3, 17)	6 (-5, 15)	5 (3, 8)
Mataura					
RCP 8.5	3 (-30, 22)	4 (0, 14)	8 (-2, 25)	9 (-3, 28)	4 (0, 22)
RCP 6.0	-1 (-21, 22)	10 (-5, 16)	4 (-1, 21)	7 (3, 19)	9 (-2, 13)
RCP 4.5	6 (-22, 20)	6 (-6, 14)	4 (-4, 20)	12 (2, 28)	5 (-1, 20)
RCP 2.6	4 (-21, 35)	12 (-4, 17)	6 (-5, 11)	10 (-3, 20)	8 (2, 12)

Table 3-2: Projected changes in seasonal and annual mean discharge (in %) between 1986-2005 and 2080-2099. The changes are given for four RCPs (8.5, 6.0, 4.5 and 2.6), where the ensemble median is taken over six models. The values in each column represent the ensemble median, and in brackets the range over all six models within that ensemble.

River	Summer	Autumn	Winter	Spring	Annual
Wairoa					
RCP 8.5	-12 (-29, 14)	1 (-30, 32)	-10 (-36, 1)	-19 (-27, -6)	-10 (-26, 5)
RCP 6.0	-6 (-21, 37)	-1 (-20, 25)	-6 (-21, 9)	-14 (-23, -5)	-5 (-18, 5)
RCP 4.5	-10 (-15, 24)	2 (-19, 30)	-7 (-18, 5)	-9 (-26, -1)	-3 (-15, 4)
RCP 2.6	-11 (-29, 17)	10 (-22, 25)	1 (-6, 5)	-1 (-10, 8)	0 (-7, 5)
Hoteo					
RCP 8.5	-3 (-20, 30)	6 (-23, 47)	-8 (-28, 8)	-15 (-29, -7)	-5 (-18, 4)
RCP 8.5	-2 (-27, 16)	0 (-10, 19)	-3 (-20, 13)	-19 (-23, 0)	-5 (-14, 5)
RCP 6.0	-12 (-25, 29)	12 (-16, 21)	-8 (-12, 9)	-12 (-28, 0)	-5 (-11, 4)
RCP 4.5	-16 (-29, 16)	9 (-13, 22)	2 (-6, 6)	-4 (-16, 6)	-2 (-5, 6)
Waihou					
RCP 8.5	-5 (-14, 2)	0 (-15, 9)	5 (-9, 12)	3 (-12, 9)	0 (-8, 8)
RCP 6.0	-4 (-14, 10)	1 (-8, 8)	4 (-1, 10)	3 (-8, 7)	0 (-3, 7)
RCP 4.5	-4 (-15, 6)	0 (-14, 11)	3 (-7, 6)	-2 (-4, 9)	-1 (-8, 8)
RCP 2.6	0 (-10, 7)	2 (-5, 6)	3 (1, 7)	4 (-3, 8)	2 (-2, 4)
Waikato					
RCP 8.5	-18 (-25, 15)	1 (-12, 36)	2 (-20, 13)	-11 (-21, 5)	-1 (-13, 5)
RCP 6.0	-3 (-26, 20)	6 (-12, 9)	2 (-12, 16)	-5 (-15, 2)	-1 (-9, 9)
RCP 4.5	-3 (-24, 2)	7 (-26, 12)	-1 (-5, 5)	-3 (-20, 4)	-3 (-8, 3)
RCP 2.6	-11 (-19, 7)	9 (-10, 17)	3 (1, 5)	2 (-10, 6)	1 (-5, 7)
Rangitaiki					
RCP 8.5	-8 (-16, 1)	-3 (-15, 9)	-2 (-18, 17)	0 (-11, 11)	-3 (-13, 9)
RCP 6.0	-5 (-18, 10)	-1 (-14, 9)	0 (-5, 6)	-3 (-12, 6)	-3 (-7, 4)
RCP 4.5	0 (-16, 7)	1 (-14, 10)	3 (-17, 10)	-3 (-8, 10)	-2 (-14, 9)
RCP 2.6	0 (-11, 5)	1 (-14, 13)	3 (-9, 12)	5 (-2, 10)	3 (-8, 7)
Waipaoa					
RCP 8.5	-18 (-38, 24)	-15 (-38, 5)	-15 (-29, 8)	-13 (-35, 9)	-18 (-25, 3)
RCP 6.0	-2 (-45, 34)	-2 (-17, 7)	-4 (-16, 7)	-12 (-31, -5)	-6 (-17, 0)
RCP 4.5	-1 (-22, 22)	-4 (-18, 6)	-4 (-16, 2)	-13 (-33, 14)	-6 (-15, 5)
RCP 2.6	-12 (-17, 22)	4 (-33, 11)	-3 (-13, 11)	1 (-10, 5)	-4 (-13, 8)
Waiapu					
RCP 8.5	-12 (-38, 10)	-5 (-32, 22)	-8 (-29, 12)	-12 (-29, 8)	-11 (-22, 7)
RCP 6.0	-5 (-31, 15)	-2 (-8, 18)	3 (-24, 15)	-14 (-29, -9)	-5 (-18, 5)
RCP 4.5	-1 (-21, 15)	-7 (-20, 12)	-1 (-12, 8)	-8 (-30, 1)	-3 (-16, 7)
RCP 2.6	-4 (-28, 18)	7 (-32, 24)	0 (-10, 8)	-1 (-9, 3)	-3 (-11, 10)
Waiongana					
RCP 8.5	-10 (-20, 4)	1 (-12, 17)	12 (0, 16)	-3 (-14, 16)	3 (-6, 9)
RCP 6.0	7 (-30, 15)	-2 (-9, 8)	7 (2, 13)	0 (-14, 13)	3 (-6, 10)
RCP 4.5	-3 (-18, 26)	-3 (-15, 29)	2 (-6, 13)	-4 (-9, 19)	-1 (-5, 14)
RCP 2.6	0 (-9, 18)	4 (-2, 15)	6 (-8, 11)	7 (-3, 21)	4 (1, 8)

Manawatu					
RCP 8.5	-16 (-27, 11)	-9 (-23, 3)	5 (-8, 9)	-9 (-13, 9)	-3 (-15, 4)
RCP 6.0	2 (-37, 11)	-5 (-16, 10)	3 (-3, 9)	-1 (-14, 7)	0 (-9, 6)
RCP 4.5	3 (-15, 17)	-8 (-15, 12)	-2 (-4, 10)	-6 (-10, 10)	-5 (-6, 10)
RCP 2.6	-6 (-21, 23)	0 (-15, 11)	3 (0, 5)	3 (-4, 11)	2 (-2, 5)
Tukituki					
RCP 8.5	-11 (-27, -1)	-9 (-26, -3)	-10 (-25, 10)	-14 (-32, 3)	-12 (-24, 3)
RCP 6.0	-6 (-38, 17)	-6 (-15, 19)	-4 (-18, 12)	-9 (-32, -6)	-4 (-19, 5)
RCP 4.5	-7 (-17, 23)	-11 (-19, 23)	-8 (-22, 10)	-7 (-33, 2)	-10 (-21, 12)
RCP 2.6	-10 (-23, 43)	1 (-24, 18)	-3 (-10, 18)	2 (-9, 13)	-2 (-12, 14)
Ruamāhanga					
RCP 8.5	-10 (-18, 15)	-5 (-20, 3)	4 (-7, 13)	-5 (-11, 4)	-4 (-12, 5)
RCP 6.0	0 (-25, 8)	-2 (-13, 7)	3 (-6, 12)	1 (-17, 4)	0 (-10, 7)
RCP 4.5	1 (-14, 21)	-6 (-15, 10)	2 (-12, 14)	-2 (-8, 10)	-2 (-8, 11)
RCP 2.6	-1 (-14, 13)	-2 (-9, 14)	4 (-6, 8)	4 (-3, 10)	2 (-3, 6)
Motueka					
RCP 8.5	-10 (-35, 25)	3 (-14, 24)	29 (21, 36)	3 (-16, 32)	11 (-1, 19)
RCP 6.0	0 (-40, 26)	0 (-19, 14)	21 (10, 29)	-3 (-12, 13)	6 (-3, 13)
RCP 4.5	0 (-38, 39)	-6 (-24, 26)	12 (-3, 26)	2 (-16, 13)	1 (-4, 11)
RCP 2.6	0 (-24, 24)	-1 (-14, 10)	6 (-1, 12)	5 (-8, 12)	0 (-4, 8)
Maitai					
RCP 8.5	7 (-31, 74)	14 (-17, 78)	32 (22, 47)	1 (-13, 42)	18 (4, 36)
RCP 6.0	16 (-46, 47)	5 (-19, 36)	19 (12, 41)	-3 (-25, 30)	11 (-2, 22)
RCP 4.5	6 (-43, 65)	-15 (-31, 66)	17 (3, 51)	2 (-9, 35)	5 (0, 21)
RCP 2.6	-4 (-23, 23)	-1 (-17, 35)	10 (0, 22)	7 (-8, 28)	5 (2, 9)
Awatere					
RCP 8.5	-15 (-30, 4)	-4 (-17, 14)	23 (8, 41)	-6 (-10, 10)	5 (-9, 11)
RCP 6.0	-2 (-35, 16)	-2 (-18, 20)	11 (7, 24)	-7 (-15, 1)	-1 (-9, 10)
RCP 4.5	-5 (-39, 18)	-7 (-21, 7)	6 (-3, 22)	-1 (-14, 5)	-2 (-9, 6)
RCP 2.6	0 (-27, 15)	-4 (-13, 8)	12 (-6, 18)	5 (-10, 11)	3 (-7, 10)
Buller					
RCP 8.5	-18 (-40, 22)	5 (-8, 15)	36 (31, 50)	4 (-12, 29)	10 (1, 22)
RCP 6.0	-3 (-32, 19)	1 (-15, 11)	30 (16, 39)	2 (-8, 16)	7 (1, 15)
RCP 4.5	-2 (-35, 23)	-4 (-19, 10)	15 (2, 37)	1 (-13, 12)	3 (-3, 9)
RCP 2.6	-1 (-21, 11)	-2 (-7, 6)	9 (-10, 26)	1 (-9, 12)	2 (-3, 7)
Haast					
RCP 8.5	11 (-13, 34)	13 (2, 27)	71 (40, 106)	18 (-2, 39)	23 (13, 34)
RCP 6.0	5 (-1, 17)	13 (-10, 26)	53 (24, 65)	10 (6, 22)	15 (7, 24)
RCP 4.5	2 (-15, 20)	8 (-12, 19)	22 (8, 44)	10 (-9, 15)	7 (2, 20)
RCP 2.6	1 (-6, 18)	6 (-10, 19)	14 (-11, 26)	-1 (-11, 8)	2 (-3, 10)
Rakaia					
RCP 8.5	-9 (-25, 12)	3 (-3, 22)	37 (34, 51)	5 (-11, 23)	11 (1, 20)
RCP 6.0	-1 (-21, 15)	6 (-9, 21)	28 (16, 37)	3 (-6, 12)	7 (0, 16)
RCP 4.5	-8 (-24, 17)	5 (-10, 11)	18 (3, 27)	3 (-12, 9)	4 (-2, 9)
RCP 2.6	-6 (-14, 5)	0 (-5, 7)	11 (-11, 18)	1 (-8, 8)	1 (-4, 5)

Clutha					
RCP 8.5	2 (-19, 29)	11 (1, 27)	54 (28, 76)	14 (4, 46)	20 (12, 35)
RCP 6.0	2 (-10, 17)	16 (-10, 22)	34 (11, 47)	10 (7, 23)	15 (5, 22)
RCP 4.5	1 (-22, 21)	8 (-16, 30)	18 (4, 26)	9 (-8, 17)	5 (0, 22)
RCP 2.6	2 (-7, 21)	8 (-8, 16)	15 (-8, 19)	-1 (-8, 9)	4 (-3, 14)
Waiau					
RCP 8.5	2 (-23, 20)	6 (-4, 24)	52 (21, 89)	9 (-4, 36)	13 (7, 32)
RCP 6.0	2 (-15, 17)	10 (-4, 14)	37 (11, 48)	11 (3, 18)	12 (7, 17)
RCP 4.5	-2 (-20, 26)	3 (-8, 24)	15 (0, 31)	7 (-10, 11)	2 (0, 19)
RCP 2.6	-3 (-6, 21)	10 (-8, 15)	15 (-10, 21)	3 (-11, 5)	3 (-1, 12)
Mataura					
RCP 8.5	-3 (-29, 15)	14 (2, 28)	36 (20, 56)	21 (3, 67)	18 (8, 42)
RCP 6.0	3 (-21, 30)	18 (5, 22)	21 (7, 39)	13 (10, 39)	15 (7, 28)
RCP 4.5	3 (-29, 32)	12 (-12, 25)	9 (-3, 21)	8 (-4, 27)	5 (-5, 24)
RCP 2.6	0 (-7, 38)	11 (-7, 17)	6 (-4, 19)	2 (-10, 18)	3 (0, 18)

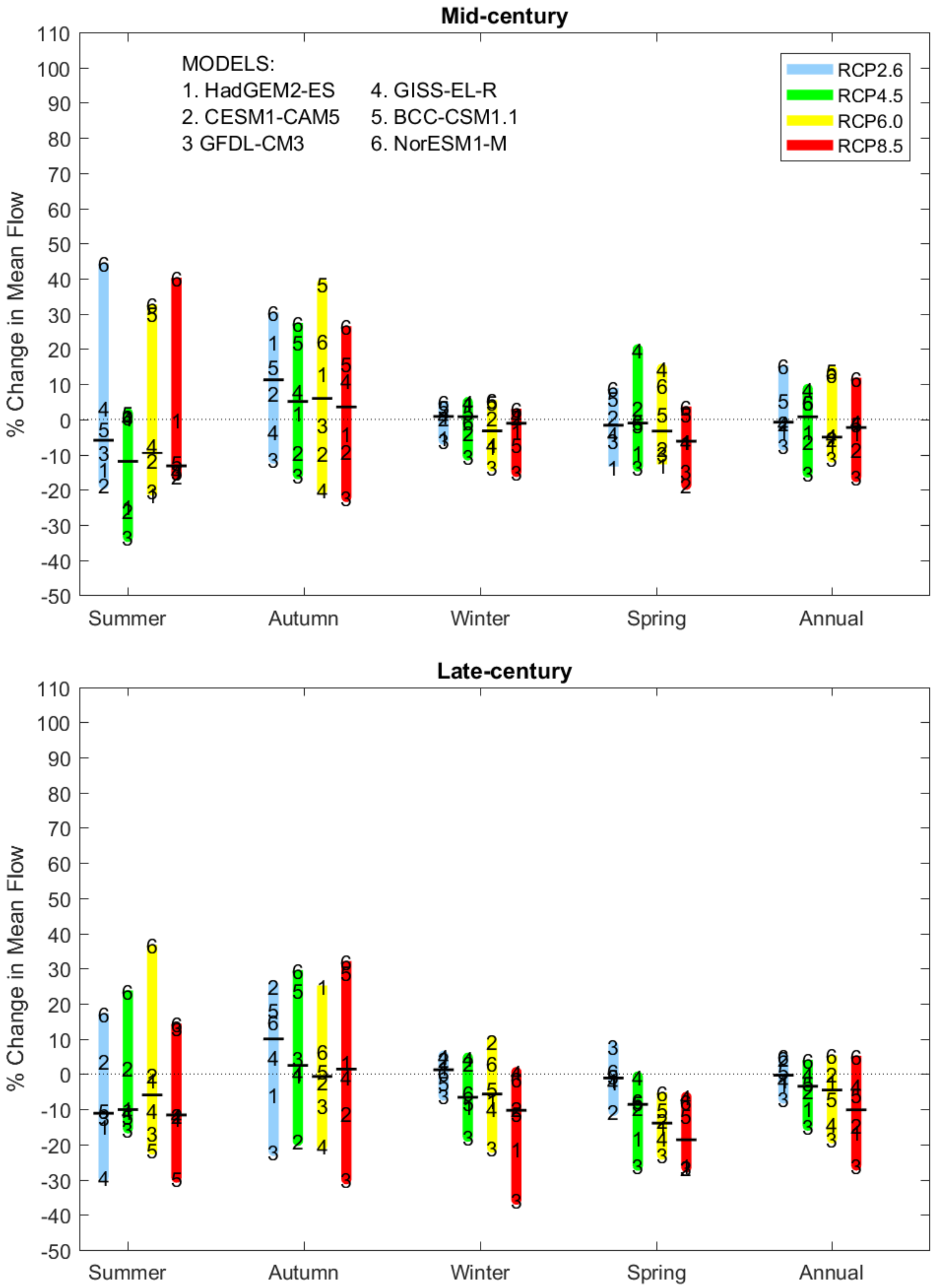


Figure 3-1: Projected mean flow changes for the Wairoa River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

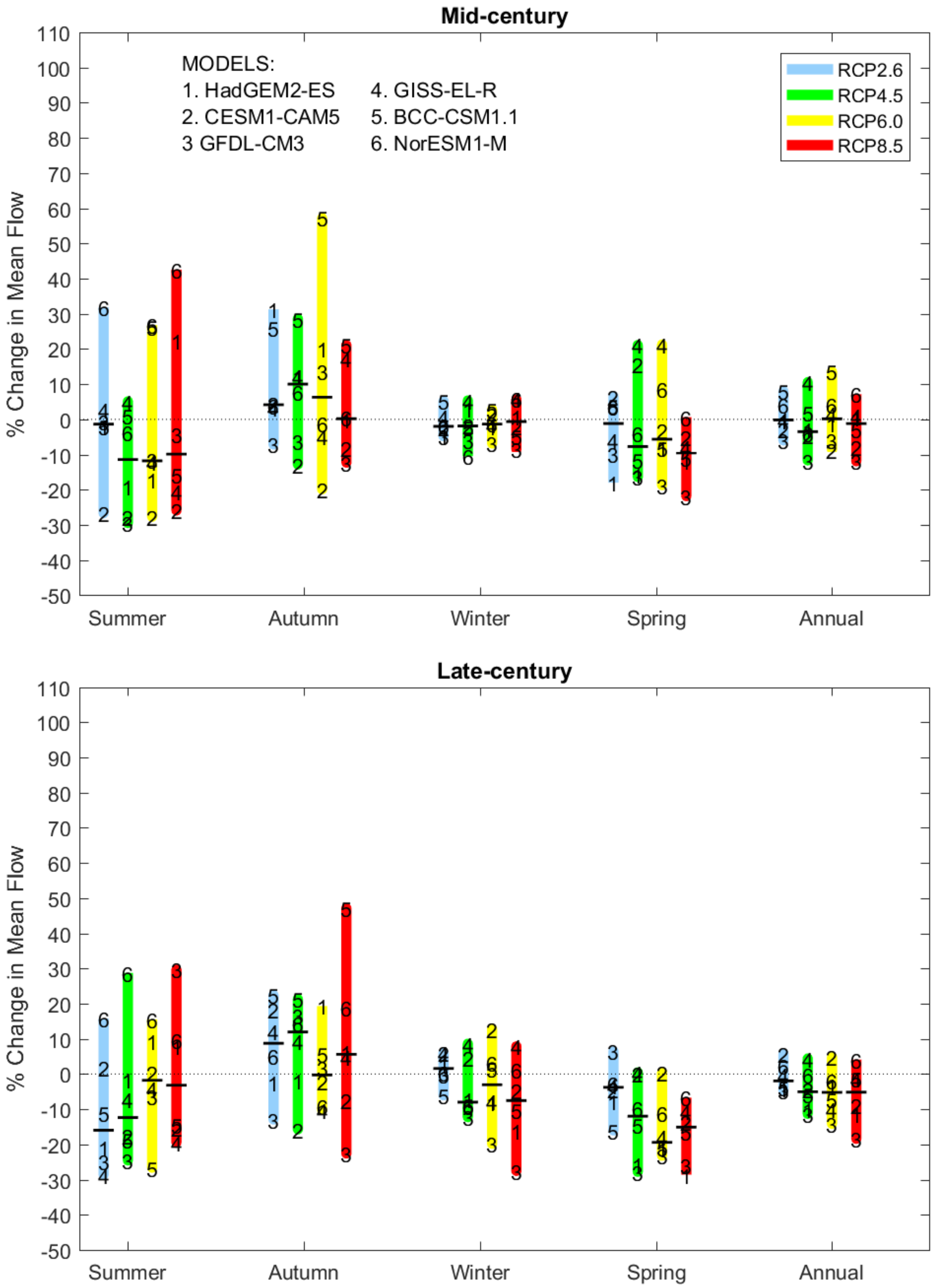


Figure 3-2: Projected mean flow changes for the Hoteo River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

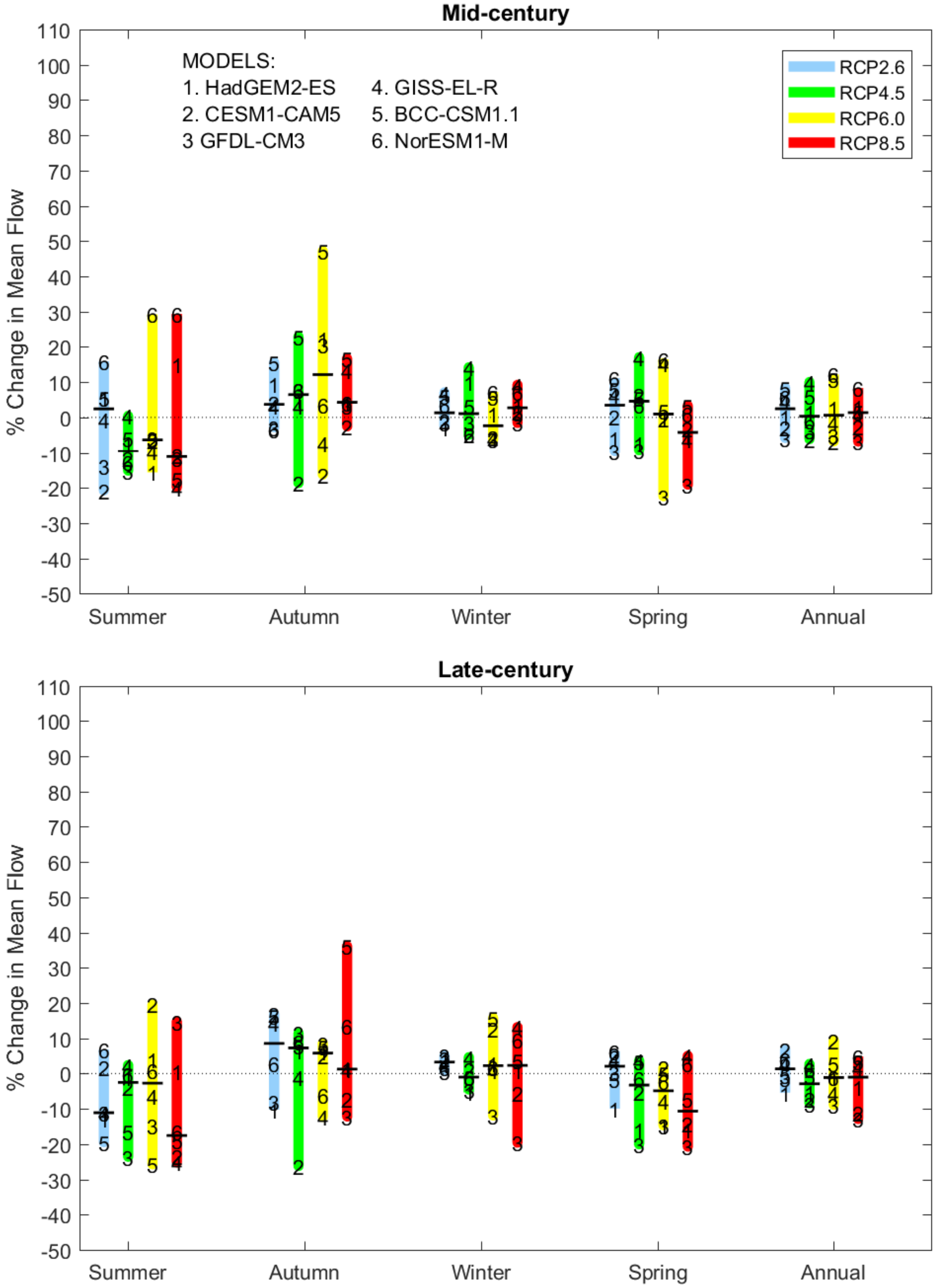


Figure 3-3: Projected mean flow changes for the Waihou River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

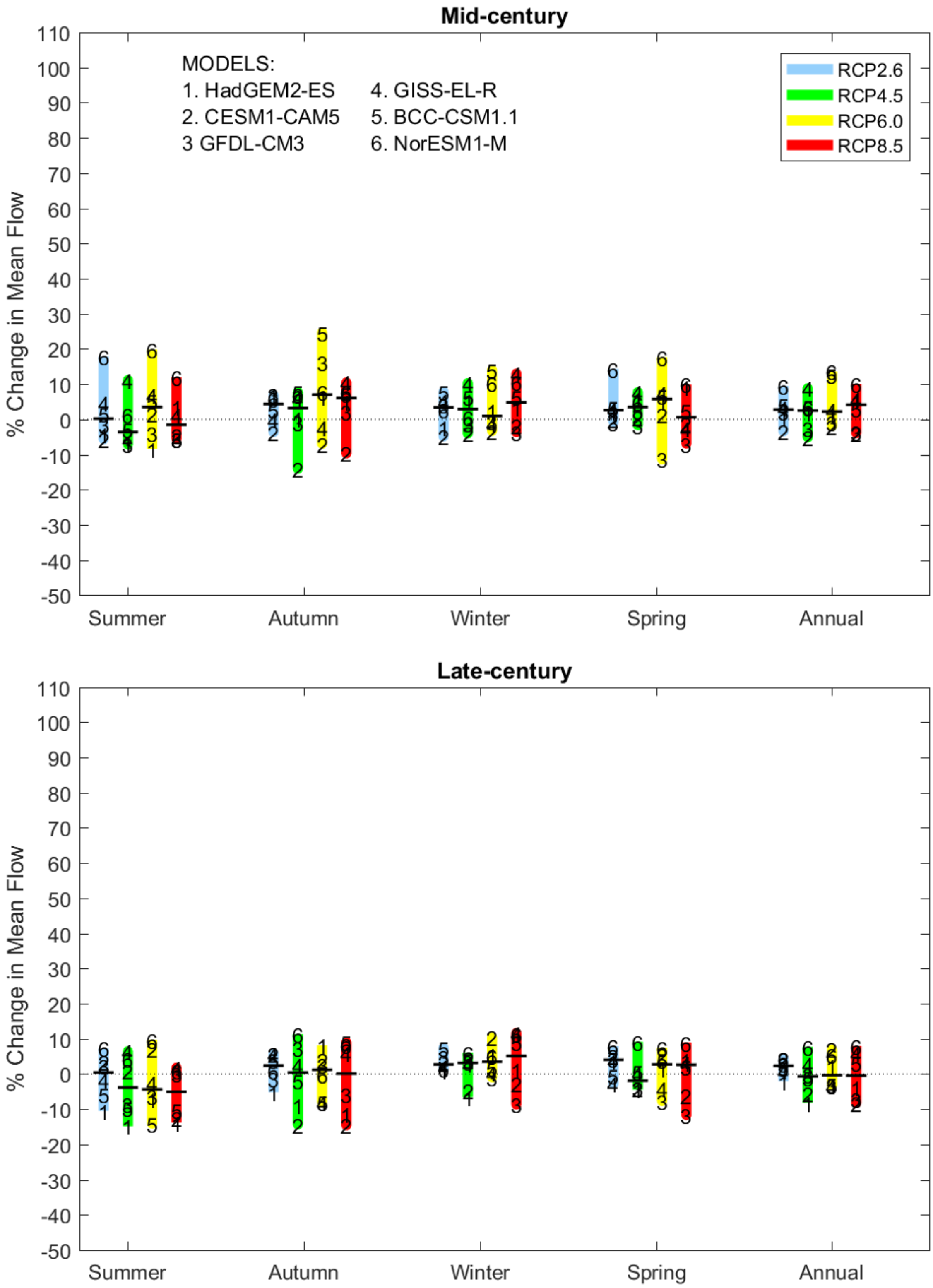


Figure 3-4: Projected mean flow changes for the Waikato River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

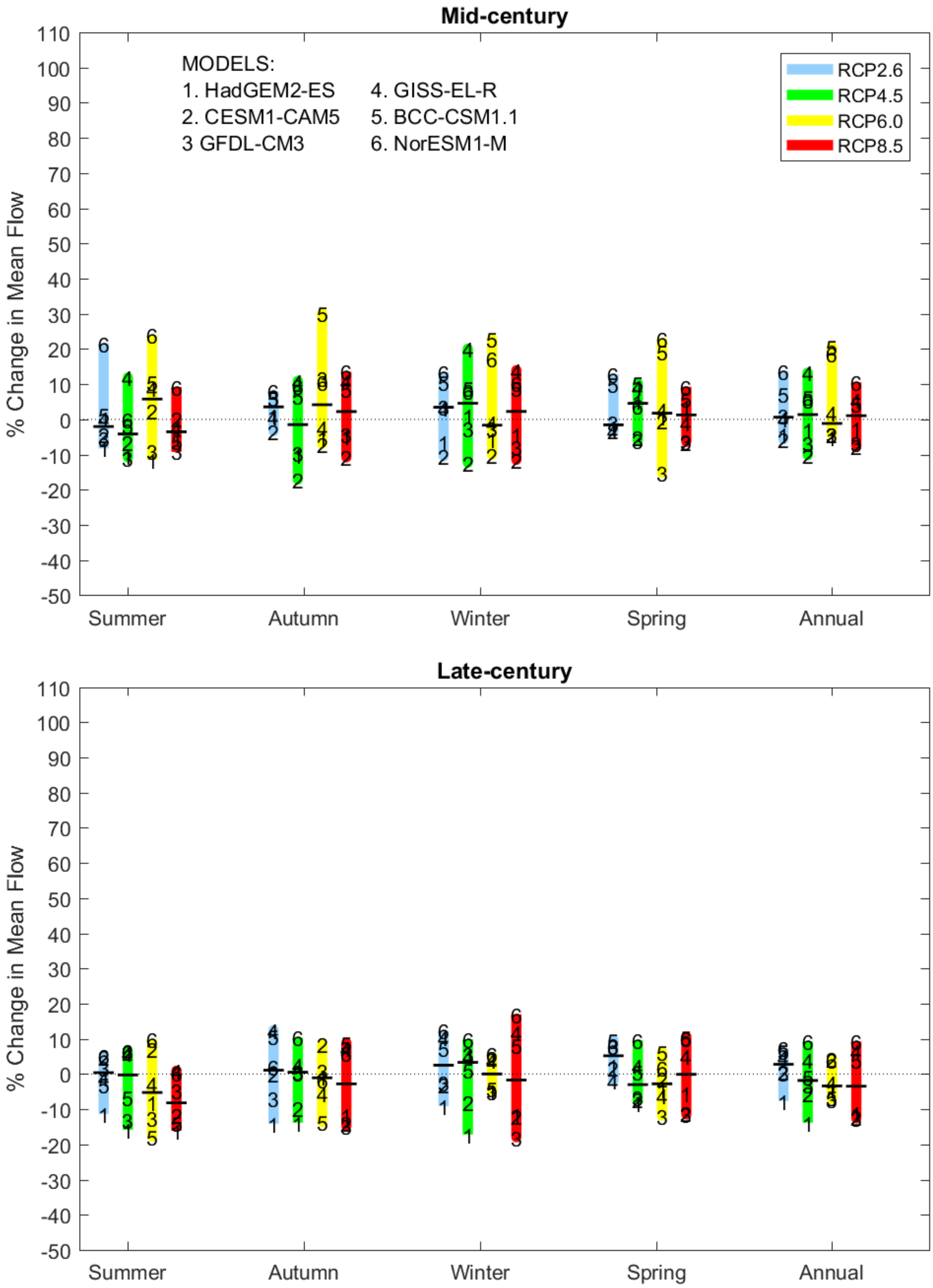


Figure 3-5: Projected mean flow changes for the Rangitaiki River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

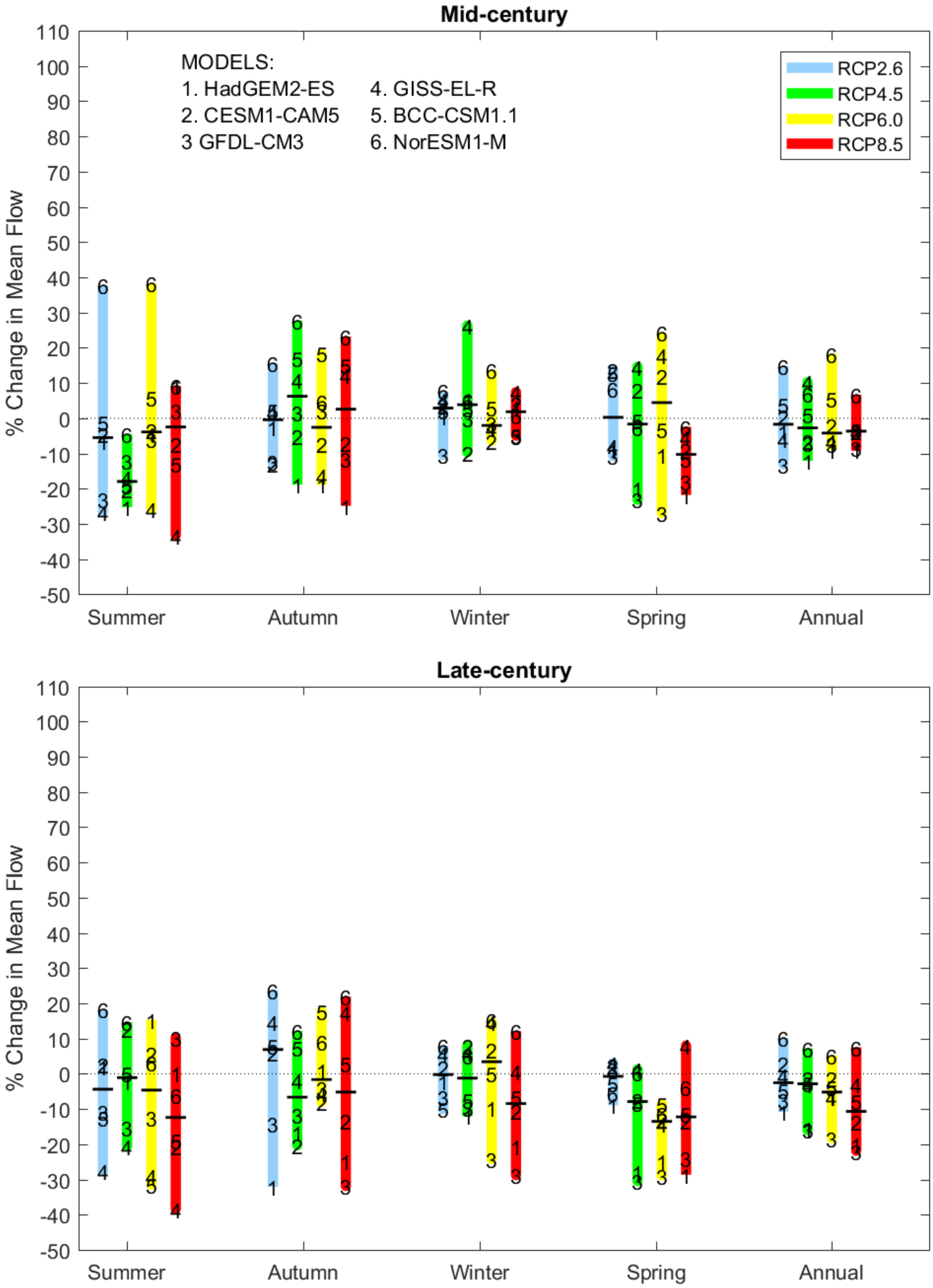


Figure 3-6: Projected mean flow changes for the Waiapu River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

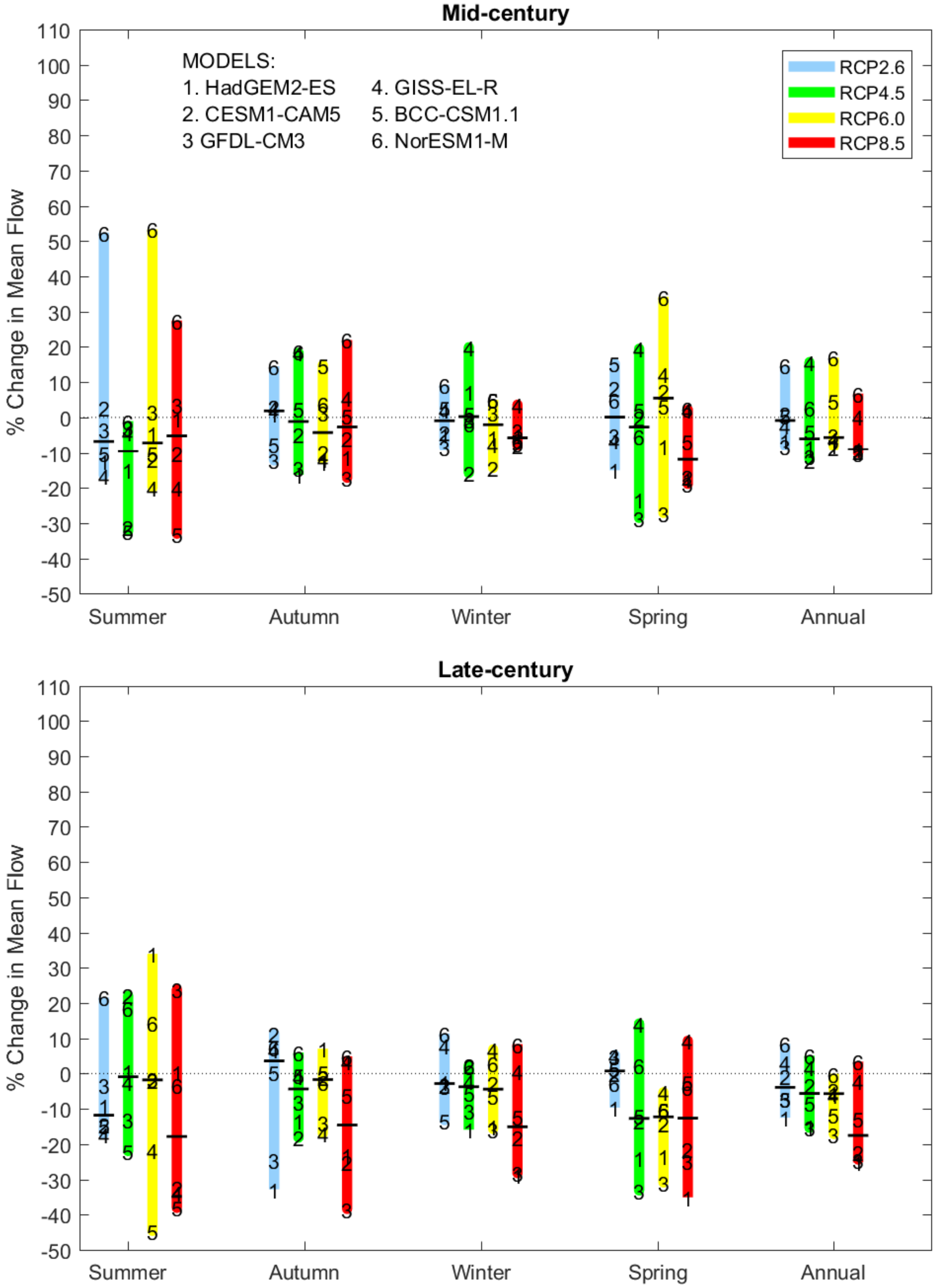


Figure 3-7: Projected mean flow changes for the Waipaoa River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

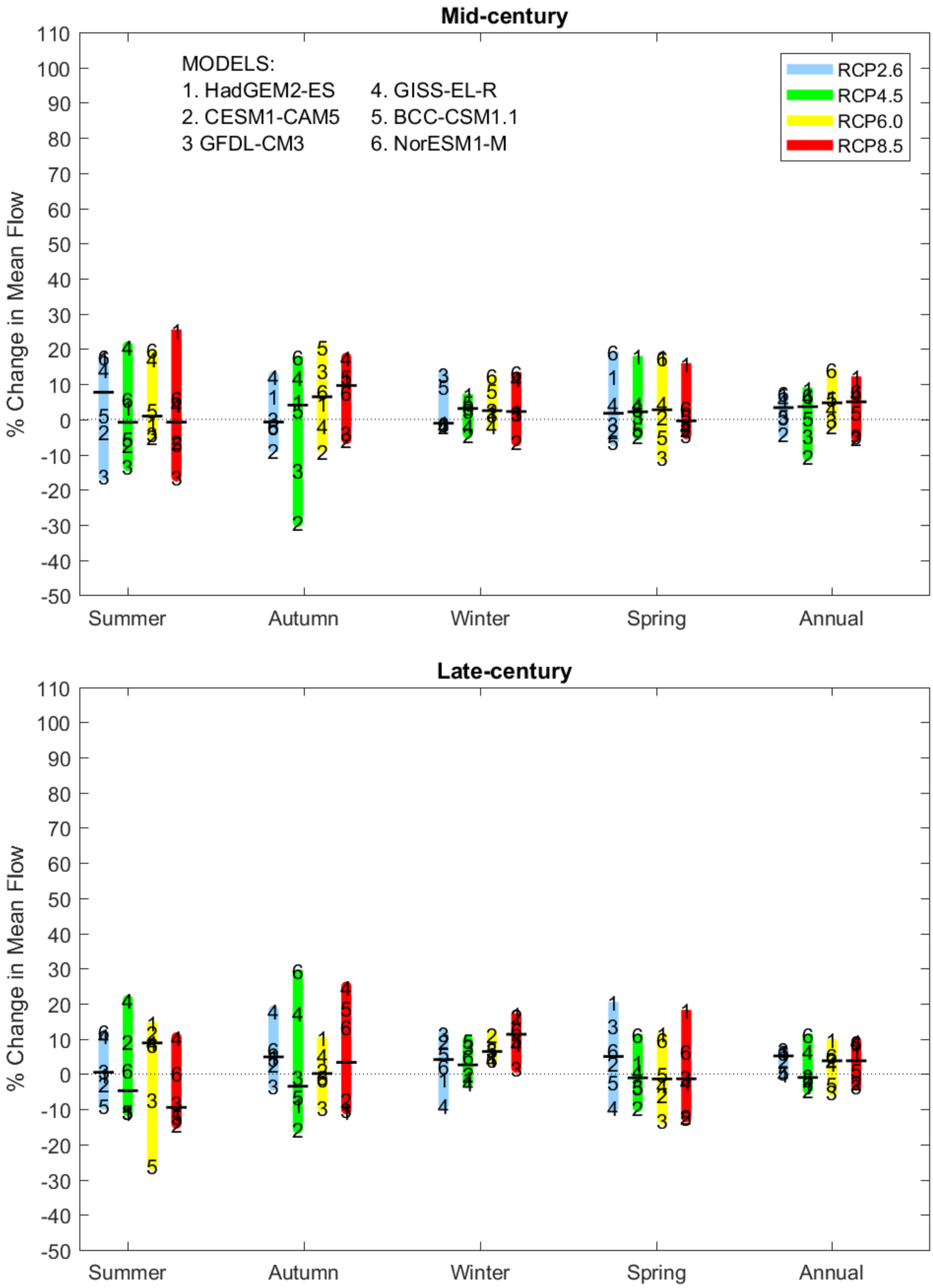


Figure 3-8: Projected mean flow changes for the Waiongana River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

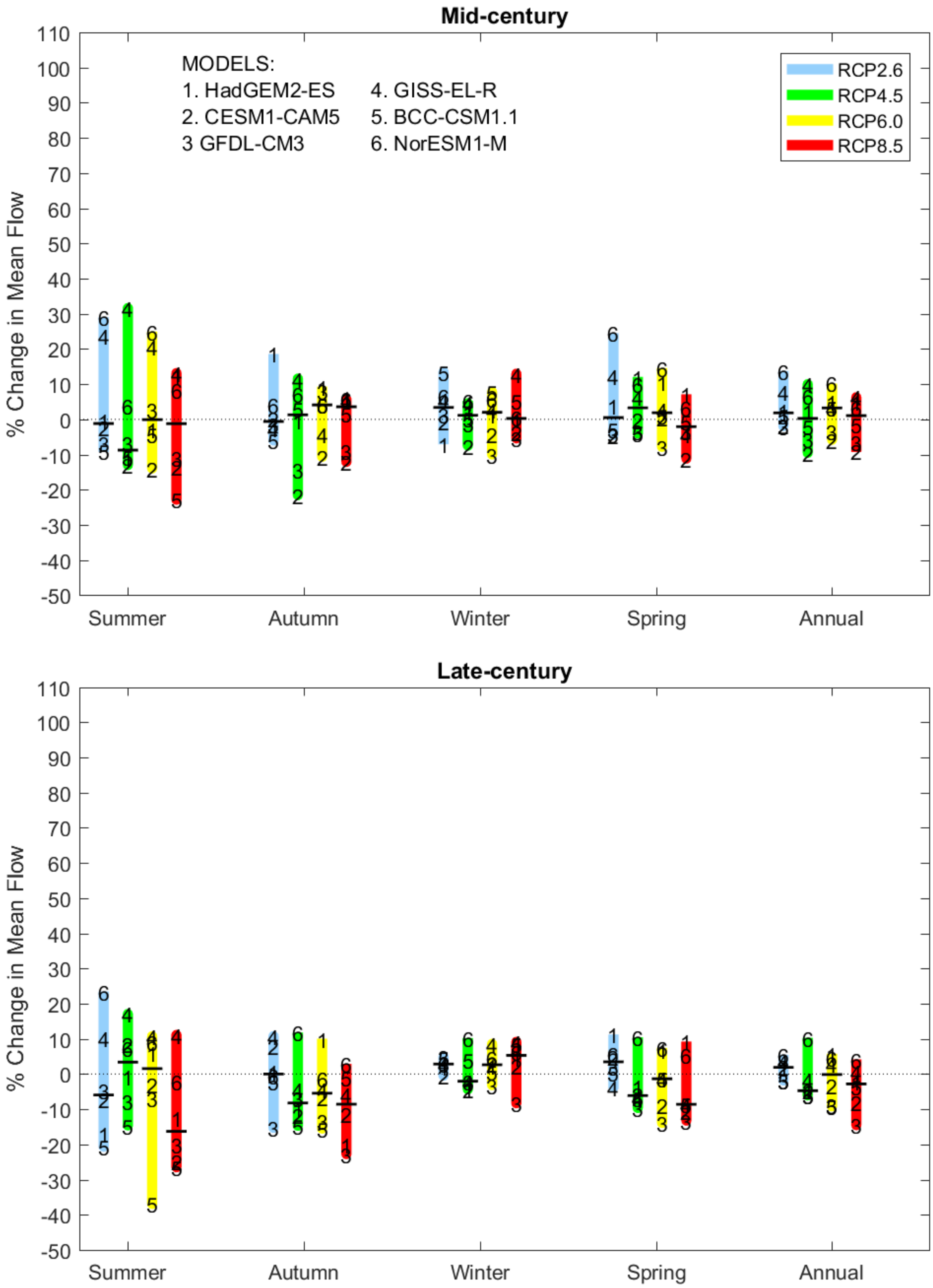


Figure 3-9: Projected mean flow changes for the Manawatu River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

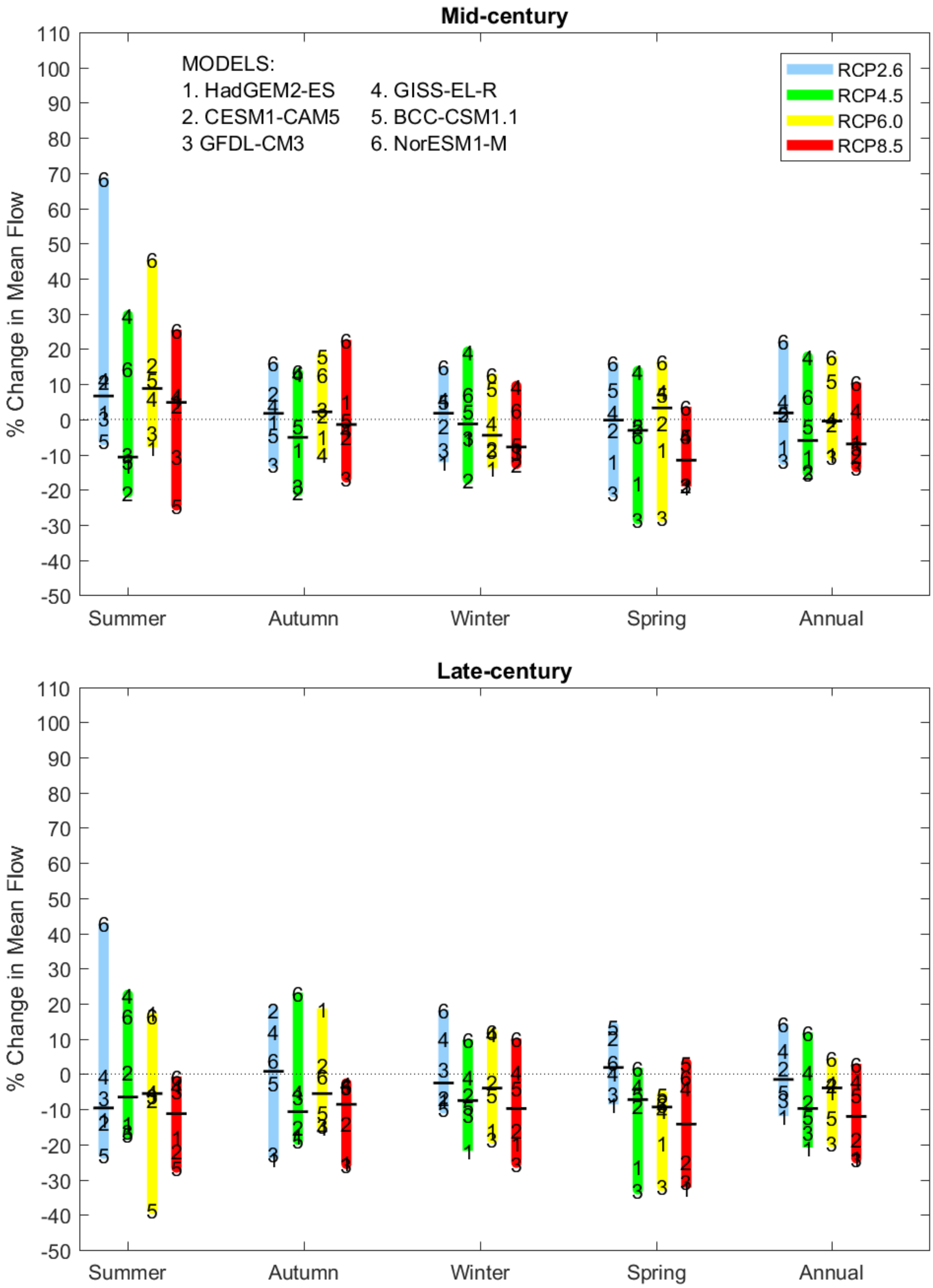


Figure 3-10: Projected mean flow changes for the Tukituki River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

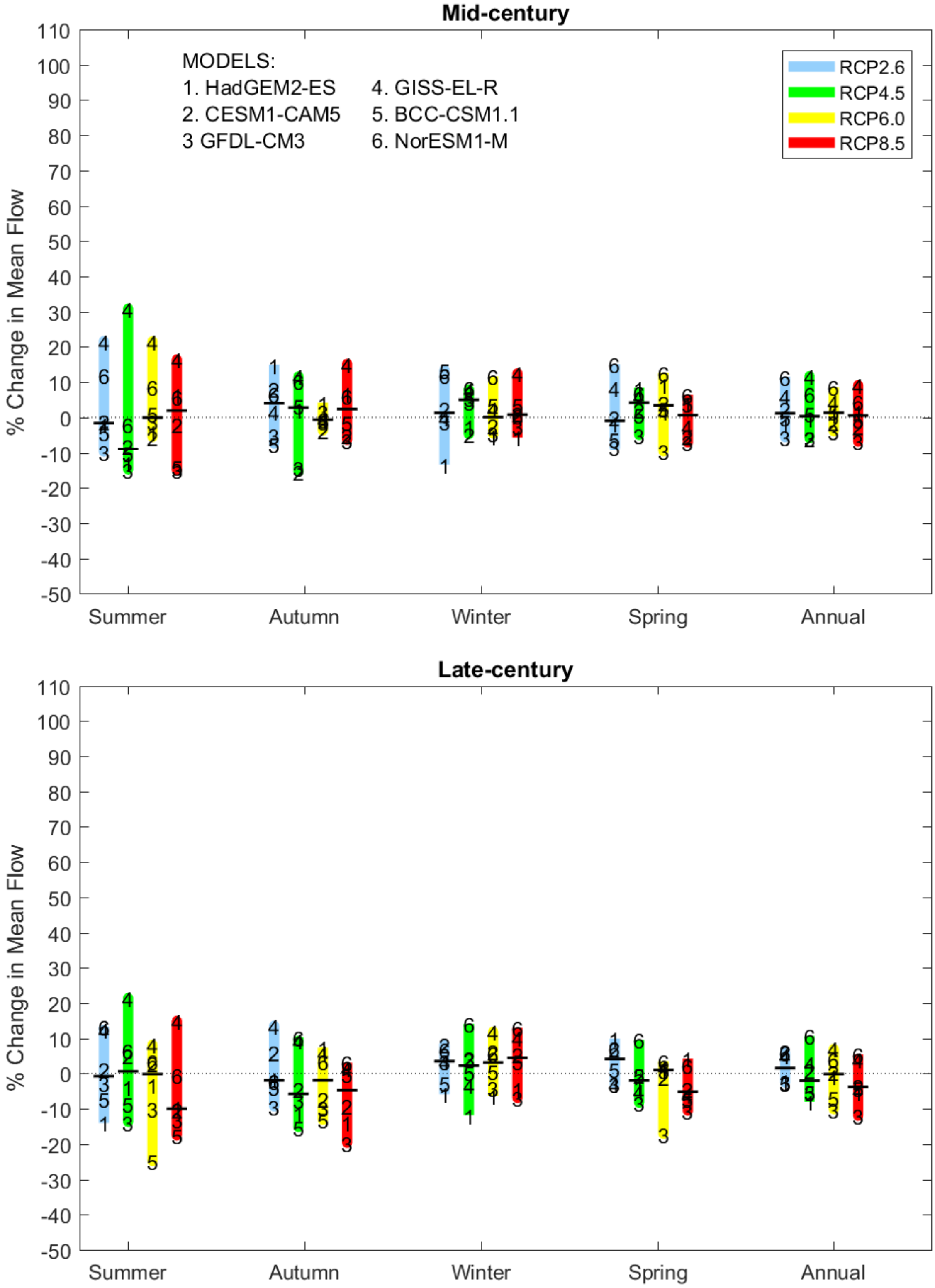


Figure 3-11: Projected mean flow changes for the Ruamāhanga River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

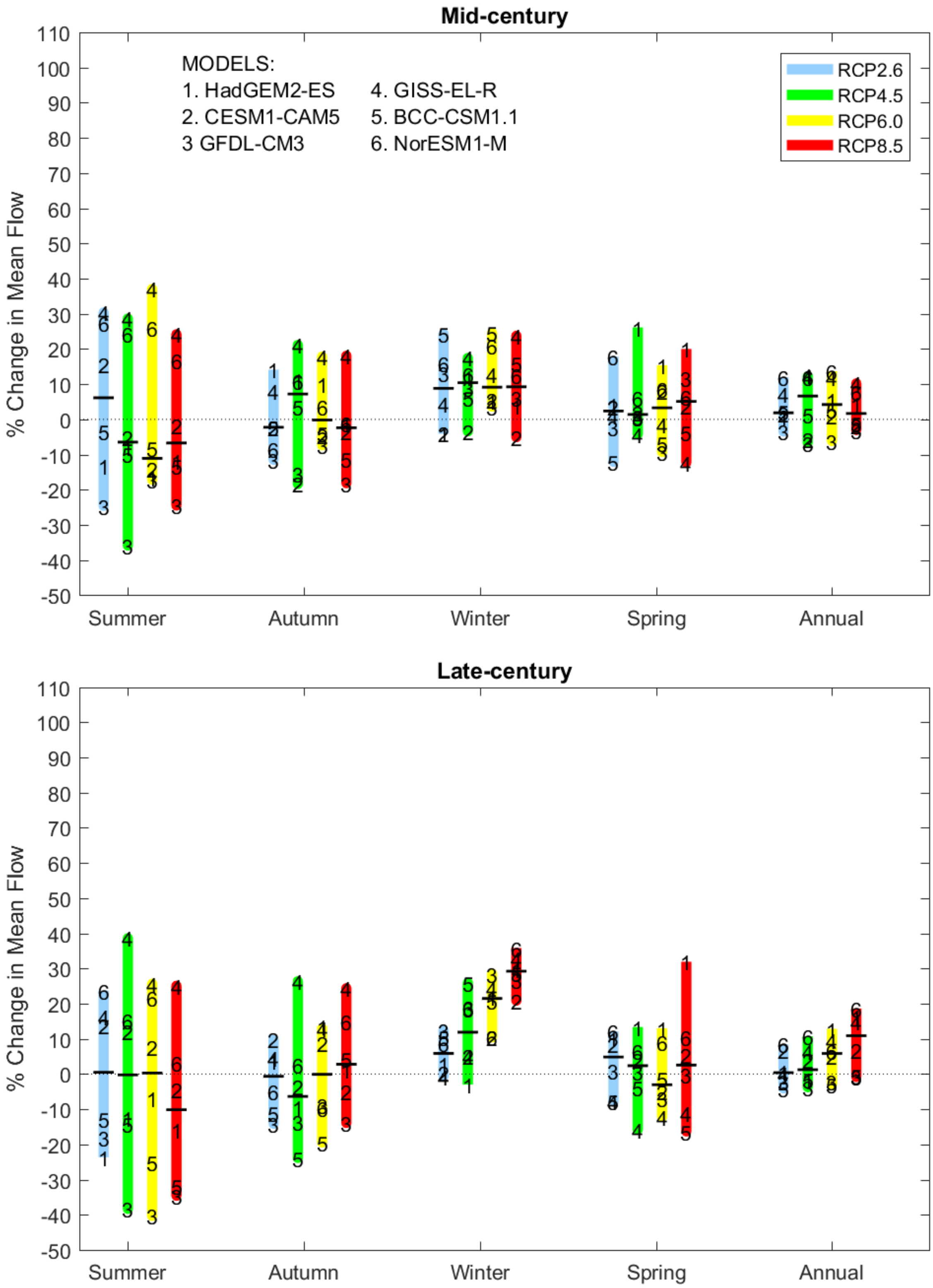


Figure 3-12: Projected mean flow changes for the Motueka River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

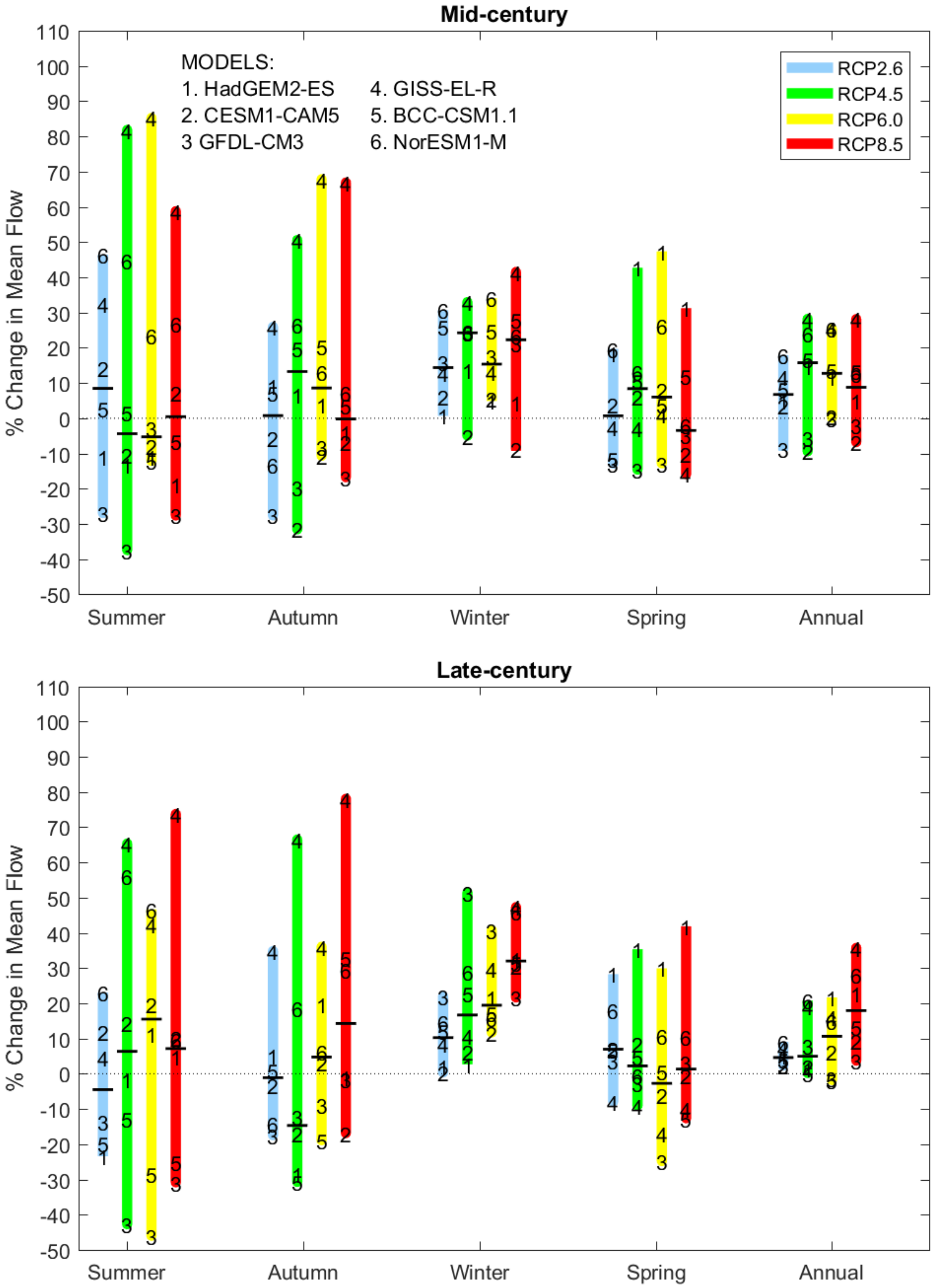


Figure 3-13: Projected mean flow changes for the Maitai River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

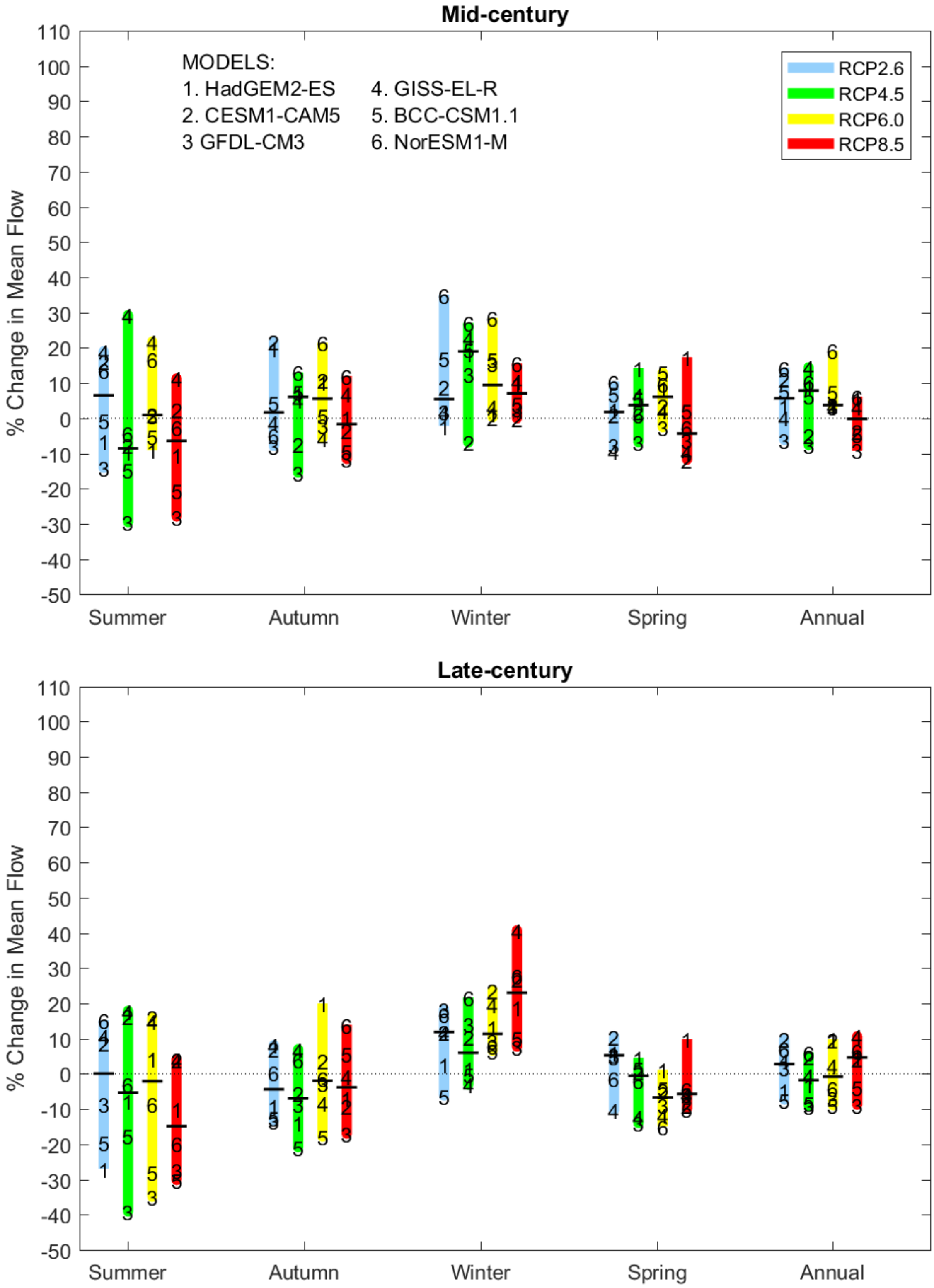


Figure 3-14: Projected mean flow changes for the Awatere River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

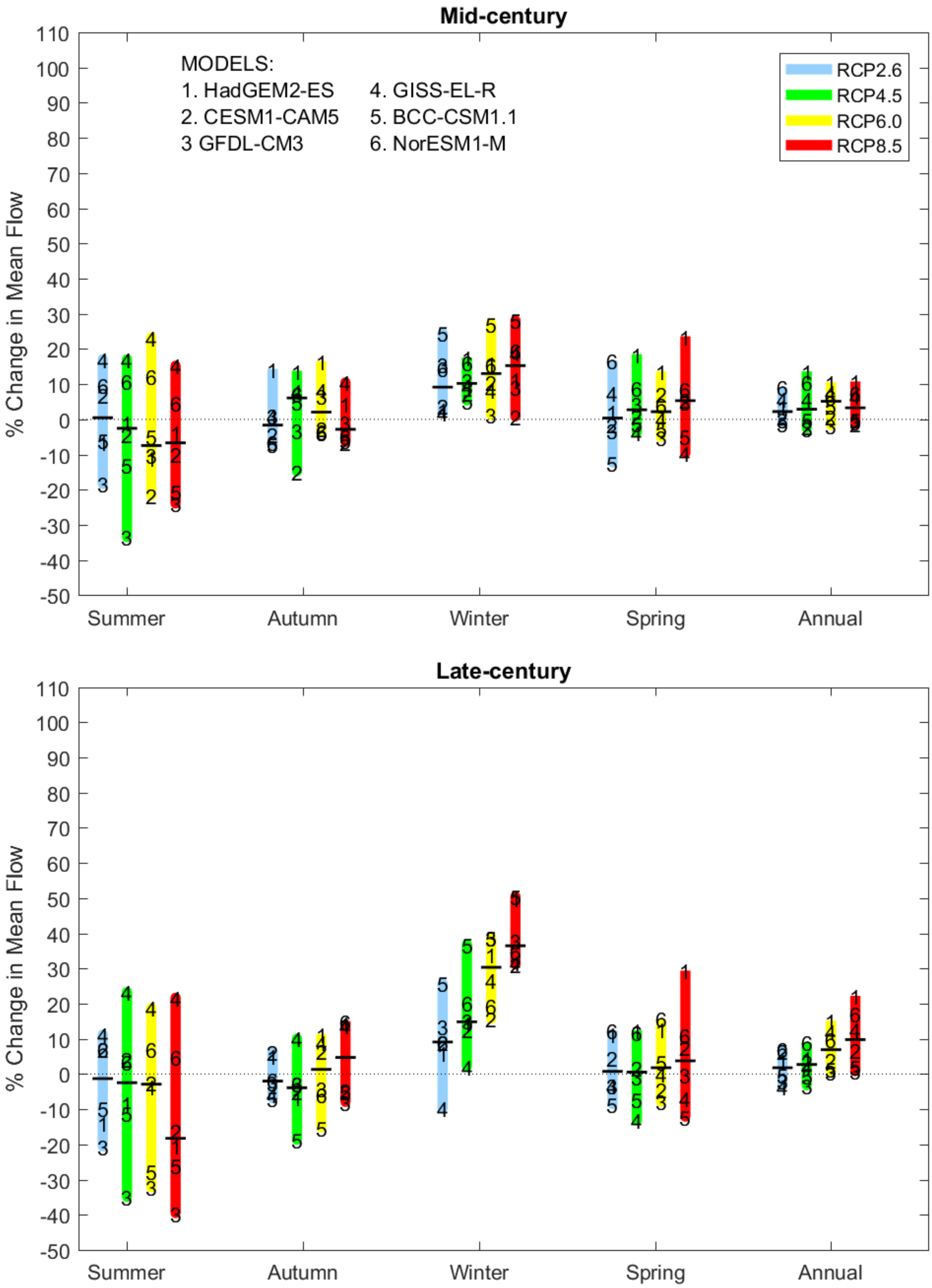


Figure 3-15: Projected mean flow changes for the Buller River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

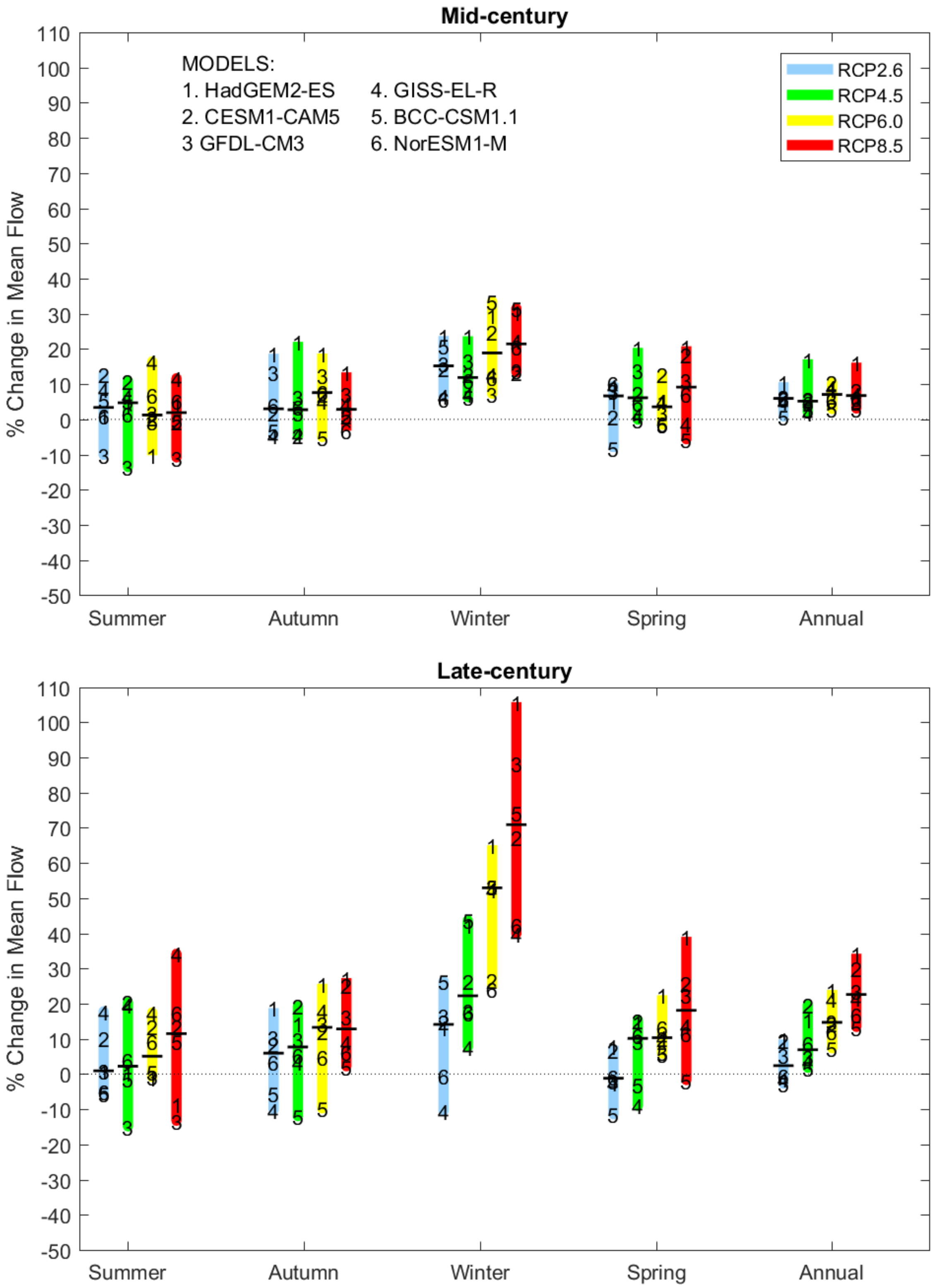


Figure 3-16: Projected mean flow changes for the Haast River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

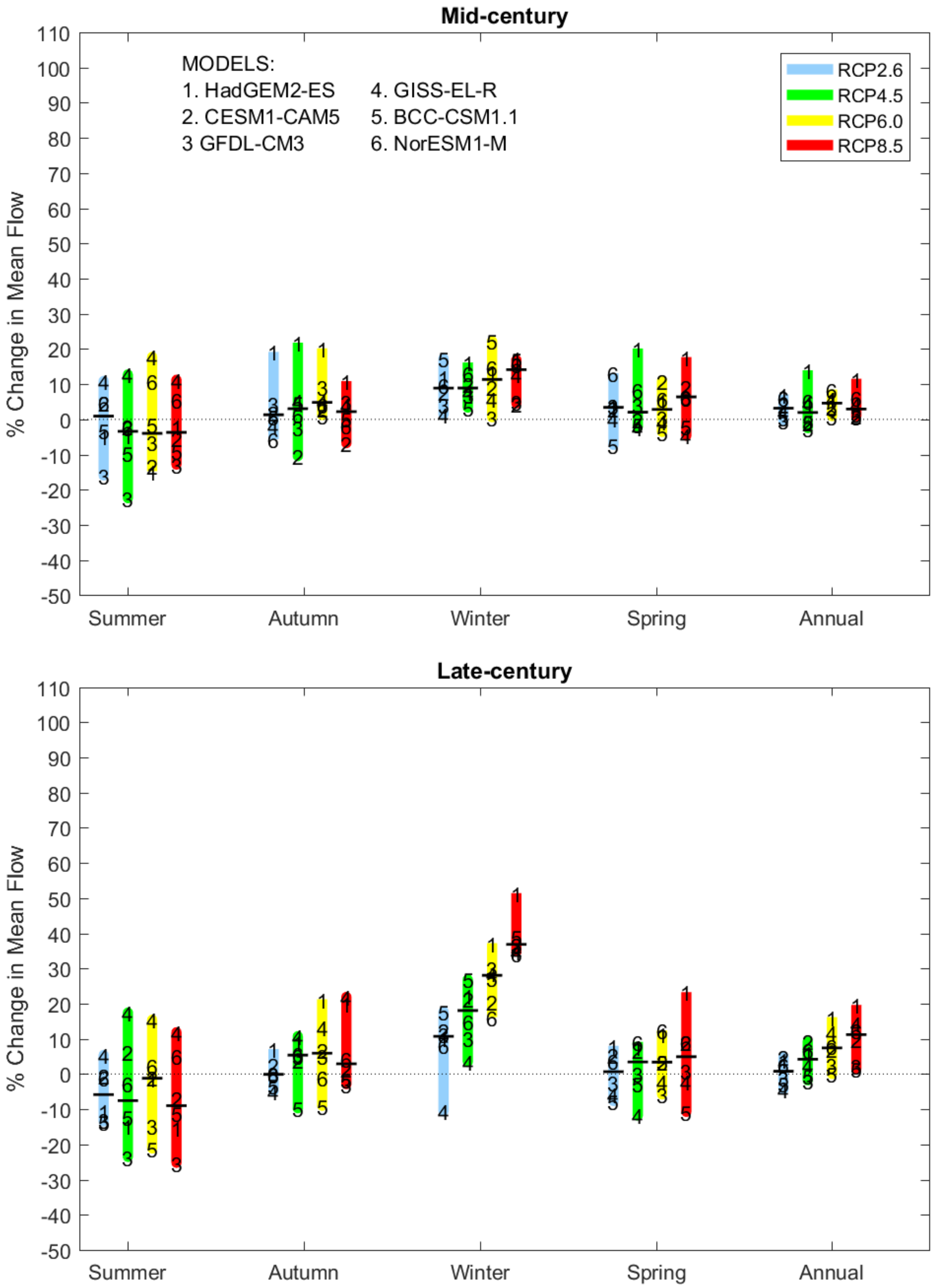


Figure 3-17: Projected mean flow changes for the Rakaia River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

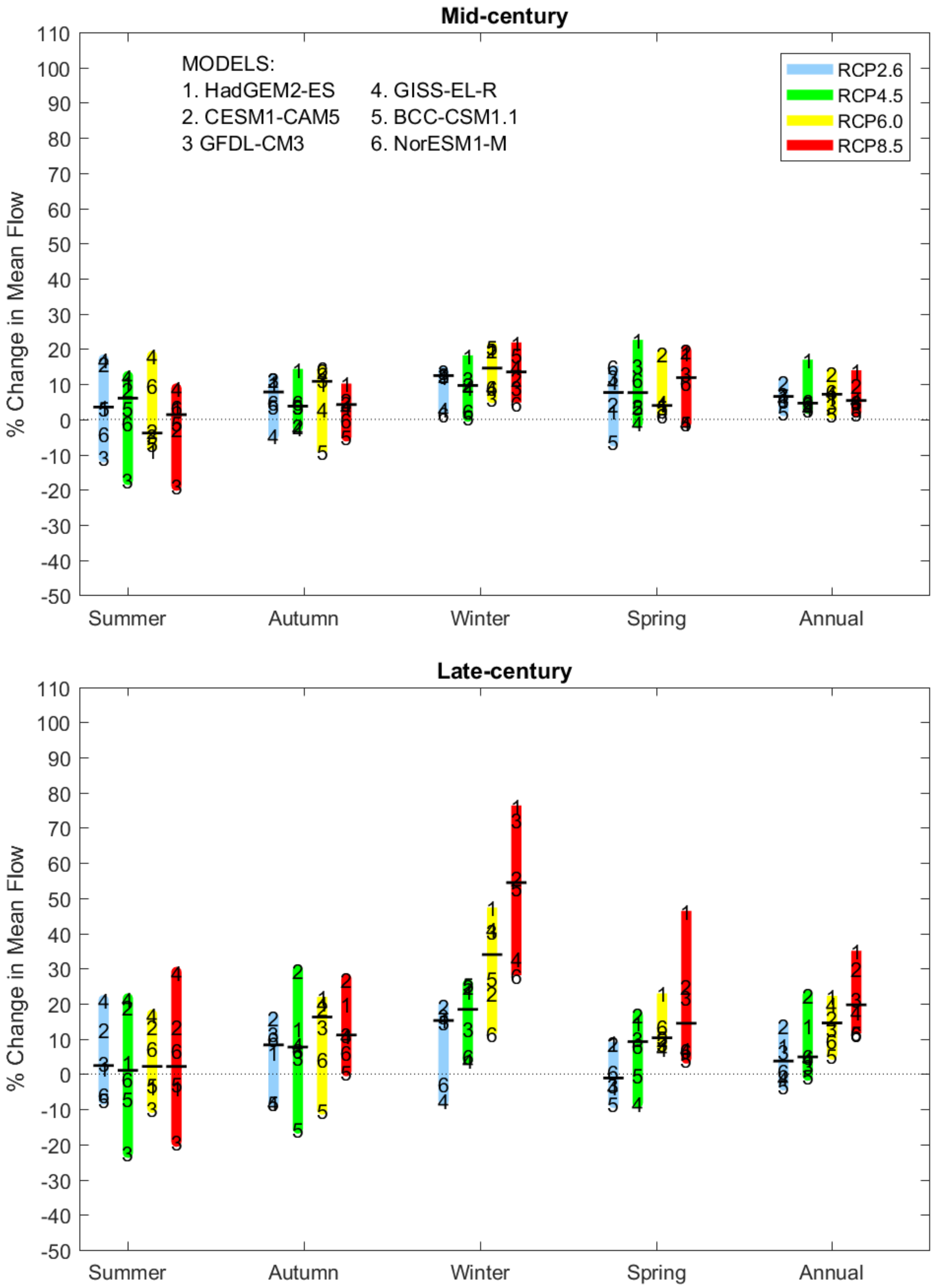


Figure 3-18: Projected mean flow changes for the Clutha River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

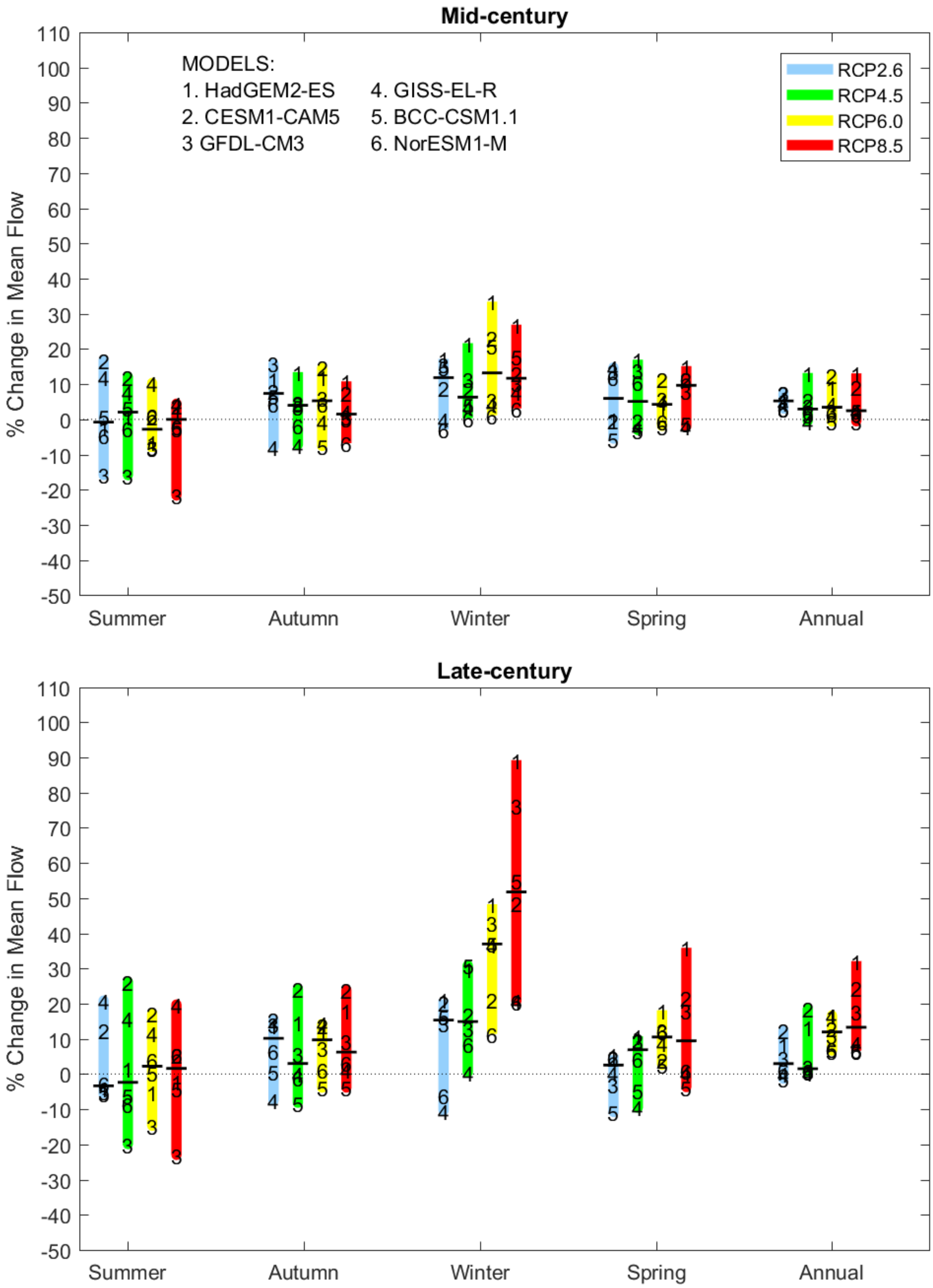


Figure 3-19: Projected mean flow changes for the Waiau River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

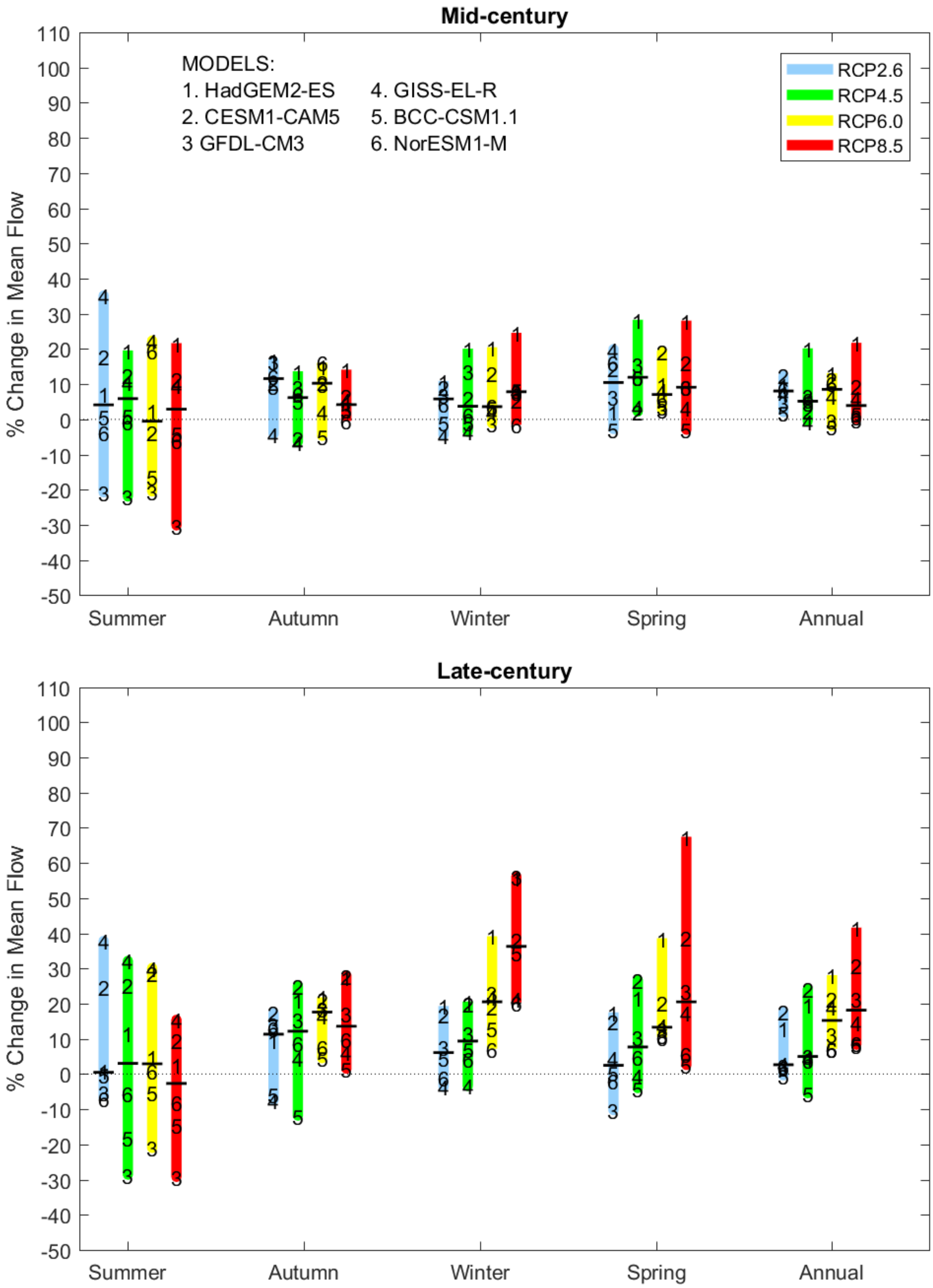


Figure 3-20: Projected mean flow changes for the Mataura River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

3.2 Flow extremes: MALF, MAF, and FRE3

Projected changes in the mean annual 7-day low flow (MALF), the mean annual flood (MAF), and the frequency of floods three times the median flow (FRE3) are summarised in Table 3-3 and Table 3-4 and are depicted in Figure 3-21: to Figure 3-40: .

Results of the simulations are as follows:

- For all North Island rivers MALF tends to decline by late century.
- For the Wairoa, Hoteo, Waipaoa, Waiapu, and Tukituki rivers, FRE3 declines by late-century.
- The only North Island river where MAF appears to change is the Waikato, showing a possible increase, along with an increase in FRE3 as well, both by late-century.
- For all South Island rivers except for the Awatere, MAF tends to increase by late-century; FRE3 also tends to increase with the additional exception of the Maitai.
- Mid-century increases in MAF are apparent for the Buller and possibly also the Mataura; mid-century increases in FRE are possible for the Waiau and Mataura.
- In the South Island, the only rivers with discernable changes in MALF are the Buller (late-century decrease) and the Haast (late-century increase).

In summary, for most of the North Island there is a tendency for late-century MALF to decline with increasing RCP, and for fewer rivers, also FRE3. For the southern North Island and north-eastern South Island no effects are discernable. For most of the South Island, MAF and FRE3 show increases. There are also changes in MALF on the west coast of the South Island, with the Buller decreasing and the Haast increasing.

The increase in MAF in the South Island, but not the North Island, is a change that is largely consistent with the changes to rainfall presented in Ministry for the Environment (2016), especially with regard to the 99th percentile of daily rainfall. Analysis of flow records indicates that MAF has a strong correspondence with observed mean annual rainfall (Henderson, Collins et al. 2018). It is noteworthy that flood design standards for significant infrastructure are usually made on the basis of events with annual exceedance probabilities much smaller than that represented by MAF. Analysis of RCM rainfall projections undertaken for the High Intensity Rainfall Design project (Carey-Smith, 2018), has shown that events with small annual exceedance probability are projected to increase ubiquitously across the country in a way that scales with increasing temperatures. As such, MAF should not be considered a comprehensive metric for the possible impact of climate change on New Zealand flooding.

Table 3-3: Projected changes in mean annual 7-day low flow (MALF), mean annual flood (MAF), and the frequency of floods three times the median flow (FRE3) (in %) by mid-century. Changes are given for four RCPs (8.5, 6.0, 4.5 and 2.6). The values in each column represent the GCM ensemble median, and in brackets the range over all six GCMs.

River	MALF	MAF	FRE3
Wairoa			
RCP 8.5	-8 (-12, 4)	-2 (-24, 29)	-5 (-28, 28)
RCP 6.0	-11 (-20, 18)	-3 (-21, 28)	-5 (-18, 31)
RCP 4.5	-4 (-27, 7)	1 (-12, 31)	-3 (-24, 23)
RCP 2.6	-5 (-10, 18)	8 (-4, 31)	-7 (-10, 28)
Hoteo			
RCP 8.5	-11 (-18, -1)	12 (-40, 63)	-1 (-23, 6)
RCP 8.5	-9 (-23, 18)	-1 (-32, 74)	2 (-13, 4)
RCP 6.0	-7 (-29, 9)	-2 (-36, 50)	-2 (-17, 18)
RCP 4.5	-4 (-6, 13)	15 (-32, 50)	-1 (-6, 1)
Waihou			
RCP 8.5	0 (-6, 6)	10 (-1, 43)	1 (-17, 12)
RCP 6.0	0 (-3, 12)	31 (-8, 58)	-10 (-19, 27)
RCP 4.5	1 (-7, 4)	16 (-28, 56)	-2 (-11, 23)
RCP 2.6	1 (-6, 13)	-5 (-11, 66)	5 (-8, 16)
Waikato			
RCP 8.5	-3 (-11, 6)	16 (-15, 40)	29 (21, 82)
RCP 6.0	-5 (-10, 15)	34 (-31, 69)	18 (-21, 81)
RCP 4.5	1 (-17, 6)	0 (-30, 85)	0 (-21, 38)
RCP 2.6	3 (-17, 13)	7 (-44, 46)	4 (-14, 19)
Rangitaiki			
RCP 8.5	-1 (-9, 6)	6 (-18, 50)	64 (-58, 100)
RCP 6.0	-2 (-9, 18)	24 (-9, 82)	95 (-17, 220)
RCP 4.5	-1 (-12, 4)	10 (-30, 82)	38 (-83, 214)
RCP 2.6	-2 (-7, 12)	10 (-25, 83)	37 (-42, 167)
Waipaoa			
RCP 8.5	-7 (-18, -2)	-1 (-27, 44)	-3 (-8, 5)
RCP 6.0	-8 (-15, 8)	11 (-35, 33)	0 (-7, 3)
RCP 4.5	-4 (-18, 1)	1 (-26, 52)	-4 (-8, 6)
RCP 2.6	-5 (-23, 6)	4 (-18, 38)	0 (-5, 2)
Waiapu			
RCP 8.5	-5 (-16, -4)	10 (-12, 40)	-4 (-16, 5)
RCP 6.0	0 (-15, 17)	8 (-28, 57)	-2 (-15, 22)
RCP 4.5	-15 (-19, 5)	9 (-16, 24)	-1 (-18, 18)
RCP 2.6	-1 (-8, 14)	-1 (-20, 39)	-3 (-10, 18)
Waiongana			
RCP 8.5	-7 (-20, 15)	25 (-14, 51)	19 (-18, 27)
RCP 6.0	0 (-5, 17)	13 (-26, 58)	19 (-10, 37)
RCP 4.5	-5 (-13, 8)	23 (-16, 55)	7 (-27, 19)
RCP 2.6	4 (-11, 18)	31 (-11, 79)	8 (-23, 12)

Manawatu			
RCP 8.5	-8 (-20, 11)	21 (0, 29)	-3 (-26, 35)
RCP 6.0	-3 (-20, 4)	13 (3, 21)	4 (-27, 10)
RCP 4.5	-13 (-16, 0)	14 (-1, 44)	-8 (-24, 26)
RCP 2.6	7 (-12, 9)	28 (-18, 75)	-6 (-10, 33)
Tukituki			
RCP 8.5	-4 (-20, 4)	7 (-22, 40)	-11 (-25, 19)
RCP 6.0	-8 (-18, 13)	23 (-21, 40)	5 (-40, 33)
RCP 4.5	-7 (-17, 3)	9 (-32, 51)	-13 (-35, 30)
RCP 2.6	-5 (-10, 18)	7 (-2, 101)	-1 (-17, 32)
Ruamāhanga			
RCP 8.5	-3 (-17, 5)	8 (-1, 32)	4 (-9, 24)
RCP 6.0	-5 (-14, 3)	0 (-15, 29)	8 (-7, 34)
RCP 4.5	-12 (-18, 8)	0 (-15, 8)	3 (-10, 28)
RCP 2.6	-3 (-17, 2)	12 (-21, 23)	3 (-5, 36)
Motueka			
RCP 8.5	-3 (-21, 14)	6 (-25, 32)	7 (-5, 30)
RCP 6.0	-4 (-14, 14)	1 (-11, 23)	9 (-22, 41)
RCP 4.5	-6 (-23, 4)	26 (-23, 31)	17 (-10, 44)
RCP 2.6	3 (-17, 11)	4 (-27, 22)	6 (-7, 32)
Maitai			
RCP 8.5	-1 (-23, 8)	6 (-18, 43)	-3 (-12, 15)
RCP 6.0	-5 (-18, 28)	23 (9, 52)	-1 (-10, 26)
RCP 4.5	-9 (-25, 12)	7 (-3, 40)	-8 (-14, 15)
RCP 2.6	-2 (-18, 13)	4 (-5, 31)	-3 (-13, 20)
Awatere			
RCP 8.5	-10 (-15, 3)	-3 (-46, 38)	-5 (-25, 20)
RCP 6.0	-3 (-14, 6)	37 (-5, 74)	16 (-4, 54)
RCP 4.5	-9 (-19, 9)	28 (-8, 94)	22 (-20, 38)
RCP 2.6	-6 (-13, -1)	27 (-25, 174)	14 (-9, 62)
Buller			
RCP 8.5	-5 (-29, 2)	6 (-1, 38)	9 (-6, 23)
RCP 6.0	-6 (-15, 4)	11 (0, 57)	11 (-7, 17)
RCP 4.5	-10 (-24, 1)	15 (-15, 42)	14 (-3, 18)
RCP 2.6	-1 (-14, 4)	-5 (-22, 16)	12 (-5, 15)
Haast			
RCP 8.5	8 (3, 27)	5 (-5, 27)	16 (2, 21)
RCP 6.0	13 (4, 29)	1 (-7, 36)	11 (6, 19)
RCP 4.5	5 (-7, 31)	7 (-7, 31)	13 (0, 27)
RCP 2.6	4 (1, 22)	11 (-12, 31)	9 (0, 25)
Rakaia			
RCP 8.5	-4 (-14, 5)	18 (-9, 40)	14 (6, 43)
RCP 6.0	-3 (-11, 6)	13 (-7, 62)	17 (4, 30)
RCP 4.5	-7 (-16, 3)	10 (-17, 40)	13 (4, 44)
RCP 2.6	-2 (-6, 6)	1 (-9, 32)	11 (-1, 29)

Clutha			
RCP 8.5	1 (-5, 13)	8 (-20, 25)	23 (3, 49)
RCP 6.0	2 (-2, 13)	22 (-21, 63)	18 (-2, 45)
RCP 4.5	-4 (-8, 16)	29 (-2, 73)	31 (0, 48)
RCP 2.6	5 (-1, 9)	26 (-12, 63)	17 (6, 42)
Waiau			
RCP 8.5	3 (-1, 21)	0 (-27, 30)	17 (0, 41)
RCP 6.0	7 (2, 10)	1 (-2, 38)	9 (-6, 37)
RCP 4.5	2 (-9, 22)	1 (-23, 23)	21 (-3, 32)
RCP 2.6	4 (-5, 12)	10 (-2, 28)	15 (2, 30)
Mataura			
RCP 8.5	-3 (-22, 19)	21 (-17, 87)	23 (-4, 73)
RCP 6.0	-2 (-14, 15)	30 (2, 66)	25 (5, 75)
RCP 4.5	-4 (-13, 11)	47 (-10, 168)	25 (-2, 54)
RCP 2.6	3 (-15, 12)	33 (28, 45)	23 (21, 55)

Table 3-4: Projected changes in mean annual 7-day low flow (MALF), mean annual flood (MAF), and the frequency of floods three times the median flow (FRE3) (in %) by late-century. Changes are given for four RCPs (8.5, 6.0, 4.5 and 2.6). The values in each column represent the GCM ensemble median, and in brackets the range over all six GCMs.

River	MALF	MAF	FRE3
Wairoa			
RCP 8.5	-22 (-27, -1)	25 (-22, 54)	-18 (-48, 14)
RCP 6.0	-5 (-15, 11)	-5 (-25, 59)	-15 (-30, -2)
RCP 4.5	-7 (-7, 16)	5 (-16, 12)	-17 (-28, 4)
RCP 2.6	-5 (-23, 16)	1 (-17, 81)	-2 (-19, 10)
Hoteo			
RCP 8.5	-28 (-35, -14)	36 (7, 79)	-12 (-29, -2)
RCP 8.5	-7 (-24, 35)	4 (-19, 40)	-17 (-25, -2)
RCP 6.0	-2 (-20, 21)	4 (-31, 74)	-5 (-22, 1)
RCP 4.5	-8 (-24, 22)	15 (-36, 31)	-3 (-16, 2)
Waihou			
RCP 8.5	-5 (-13, 3)	25 (-21, 72)	-16 (-29, 9)
RCP 6.0	-4 (-10, 7)	23 (-7, 109)	-3 (-25, 3)
RCP 4.5	-2 (-8, 4)	-4 (-37, 80)	-11 (-19, 8)
RCP 2.6	2 (-4, 5)	10 (-17, 58)	-9 (-18, 13)
Waikato			
RCP 8.5	-14 (-20, -6)	49 (-25, 78)	27 (-7, 100)
RCP 6.0	-9 (-14, 13)	44 (-30, 126)	23 (-38, 73)
RCP 4.5	-8 (-17, 6)	9 (-14, 61)	-7 (-44, 64)
RCP 2.6	3 (-10, 10)	8 (-29, 29)	4 (-29, 45)

Rangitaiki			
RCP 8.5	-7 (-15, 0)	14 (-23, 28)	42 (-58, 133)
RCP 6.0	-6 (-10, 9)	14 (1, 49)	15 (-42, 157)
RCP 4.5	-3 (-14, 5)	8 (-20, 15)	29 (-42, 200)
RCP 2.6	1 (-10, 9)	-1 (-17, 80)	24 (-50, 117)
Waipaoa			
RCP 8.5	-28 (-32, -16)	1 (-37, 42)	-10 (-23, -4)
RCP 6.0	-10 (-29, -5)	3 (-15, 119)	-12 (-19, -8)
RCP 4.5	-9 (-19, 3)	-2 (-19, 81)	-12 (-18, -4)
RCP 2.6	-3 (-29, 14)	4 (-13, 24)	-7 (-12, 4)
Waiapu			
RCP 8.5	-24 (-32, -21)	14 (-24, 53)	-17 (-31, -3)
RCP 6.0	-15 (-24, 2)	19 (-6, 62)	-14 (-28, -4)
RCP 4.5	-9 (-24, 14)	-3 (-18, 59)	-10 (-21, 1)
RCP 2.6	-1 (-16, 27)	-2 (-8, 21)	-3 (-19, 9)
Waiongana			
RCP 8.5	-11 (-19, 16)	16 (-22, 109)	10 (-25, 25)
RCP 6.0	-8 (-23, 11)	24 (-10, 44)	2 (-12, 23)
RCP 4.5	-5 (-13, 22)	22 (-24, 112)	-5 (-18, 24)
RCP 2.6	2 (-3, 10)	22 (-23, 67)	9 (-5, 19)
Manawatu			
RCP 8.5	-19 (-31, -9)	18 (-8, 45)	-15 (-31, 22)
RCP 6.0	-11 (-28, 1)	8 (-18, 75)	-9 (-20, 14)
RCP 4.5	-6 (-19, 12)	7 (-28, 58)	-15 (-25, 14)
RCP 2.6	-12 (-14, 14)	7 (-15, 26)	-7 (-22, 3)
Tukituki			
RCP 8.5	-24 (-29, -11)	16 (-17, 35)	-22 (-47, 10)
RCP 6.0	-9 (-26, -6)	37 (-23, 103)	-9 (-27, 7)
RCP 4.5	-11 (-28, 5)	-2 (-39, 54)	-12 (-46, 13)
RCP 2.6	-7 (-13, 12)	-10 (-32, 108)	-4 (-26, 21)
Ruamāhanga			
RCP 8.5	-17 (-24, 3)	14 (-17, 41)	3 (-16, 26)
RCP 6.0	-9 (-28, 4)	15 (0, 20)	1 (-19, 19)
RCP 4.5	-5 (-17, 17)	4 (-15, 21)	-4 (-13, 18)
RCP 2.6	-9 (-16, 12)	2 (-22, 45)	3 (-11, 8)
Motueka			
RCP 8.5	-13 (-28, 7)	34 (-8, 48)	28 (-3, 55)
RCP 6.0	-3 (-27, 5)	16 (-12, 20)	12 (-13, 35)
RCP 4.5	-6 (-21, 12)	12 (-20, 25)	3 (-9, 28)
RCP 2.6	-2 (-9, 9)	-6 (-29, 31)	2 (-14, 27)
Maitai			
RCP 8.5	-13 (-40, 9)	38 (6, 66)	-13 (-18, 11)
RCP 6.0	-2 (-29, 21)	18 (3, 38)	1 (-22, 8)
RCP 4.5	-8 (-29, 25)	13 (-1, 25)	-4 (-21, 10)
RCP 2.6	-4 (-20, 12)	-10 (-18, 8)	-2 (-16, 8)

Awatere			
RCP 8.5	-18 (-25, 0)	37 (-24, 100)	14 (-30, 41)
RCP 6.0	-10 (-19, 4)	19 (-12, 77)	-11 (-14, 37)
RCP 4.5	-14 (-17, 18)	29 (-20, 105)	-15 (-31, 26)
RCP 2.6	-7 (-20, 5)	-4 (-19, 58)	0 (-7, 43)
Buller			
RCP 8.5	-17 (-31, 1)	27 (-5, 92)	29 (19, 40)
RCP 6.0	-5 (-30, 2)	13 (-20, 38)	22 (2, 34)
RCP 4.5	-7 (-26, 3)	15 (-16, 41)	9 (7, 18)
RCP 2.6	-5 (-9, 10)	7 (-24, 19)	-1 (-7, 14)
Haast			
RCP 8.5	27 (9, 49)	21 (7, 48)	29 (19, 40)
RCP 6.0	18 (16, 24)	7 (-6, 38)	22 (2, 34)
RCP 4.5	19 (4, 21)	4 (-8, 12)	9 (7, 18)
RCP 2.6	14 (-7, 20)	5 (-16, 24)	-1 (-7, 14)
Rakaia			
RCP 8.5	-10 (-20, 11)	38 (0, 95)	51 (23, 95)
RCP 6.0	-2 (-15, 10)	26 (-19, 54)	28 (9, 61)
RCP 4.5	-4 (-13, 11)	18 (-18, 44)	11 (-7, 45)
RCP 2.6	-5 (-12, 1)	-1 (-15, 21)	-5 (-10, 16)
Clutha			
RCP 8.5	7 (-15, 19)	51 (-10, 101)	77 (45, 111)
RCP 6.0	8 (-4, 13)	25 (-11, 56)	38 (18, 80)
RCP 4.5	2 (-6, 16)	1 (-3, 48)	13 (-7, 66)
RCP 2.6	1 (-6, 11)	22 (-2, 52)	4 (-27, 38)
Waiau			
RCP 8.5	9 (-6, 21)	36 (2, 62)	36 (14, 74)
RCP 6.0	12 (4, 16)	21 (0, 39)	28 (3, 48)
RCP 4.5	3 (0, 14)	10 (-6, 47)	8 (-4, 43)
RCP 2.6	5 (-2, 12)	13 (-15, 20)	3 (-12, 36)
Mataura			
RCP 8.5	-5 (-27, 10)	75 (37, 187)	89 (39, 148)
RCP 6.0	3 (-16, 27)	45 (26, 75)	63 (10, 80)
RCP 4.5	-5 (-20, 11)	38 (-3, 154)	28 (-20, 120)
RCP 2.6	-3 (-8, 19)	40 (15, 76)	5 (-9, 65)

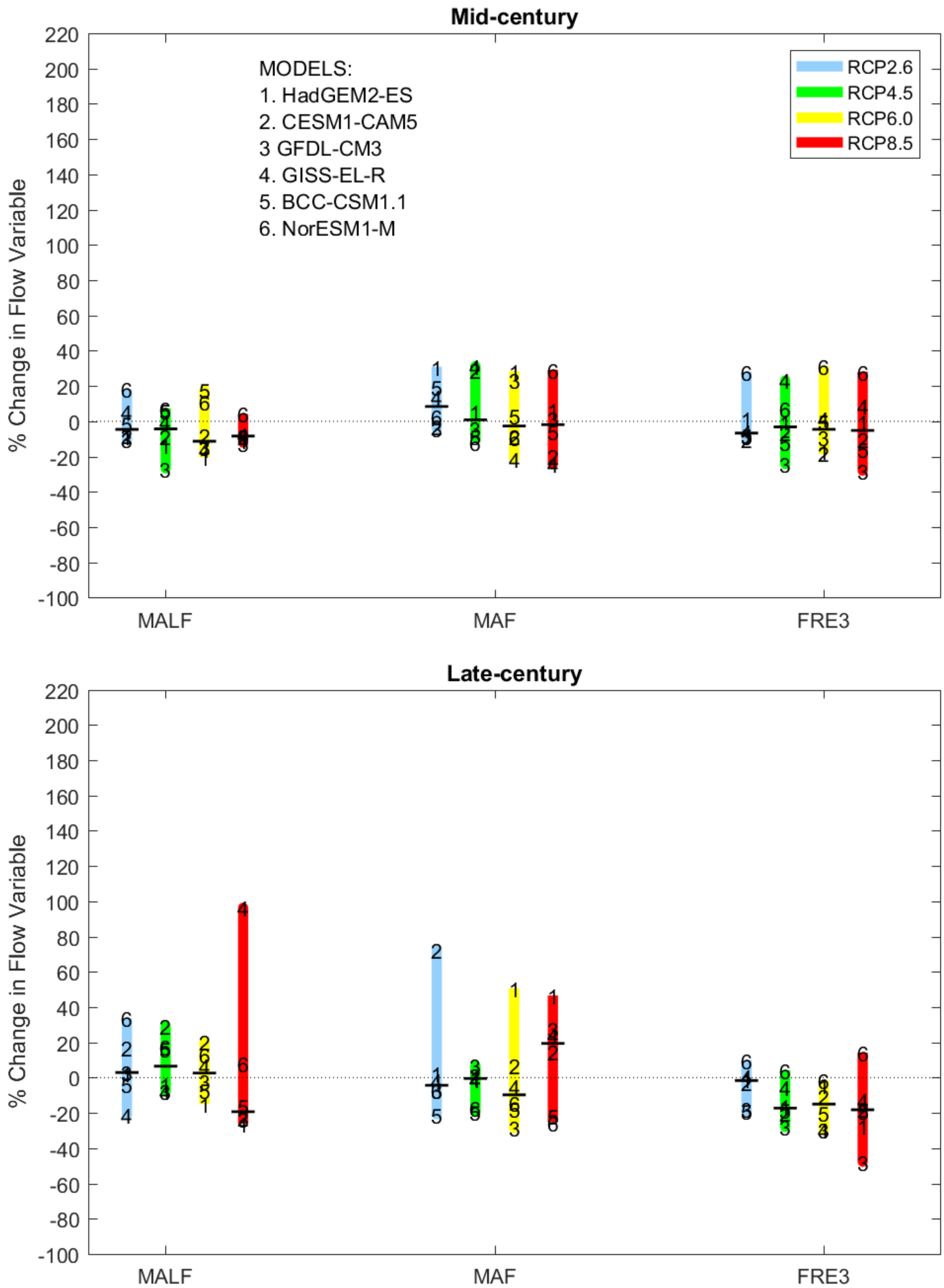


Figure 3-21: Projected changes in MALF, MAF, and FRE3 for the Wairoa River. Mid-century (top panel) and late-century (bottom panel), for all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars the GCM medians.

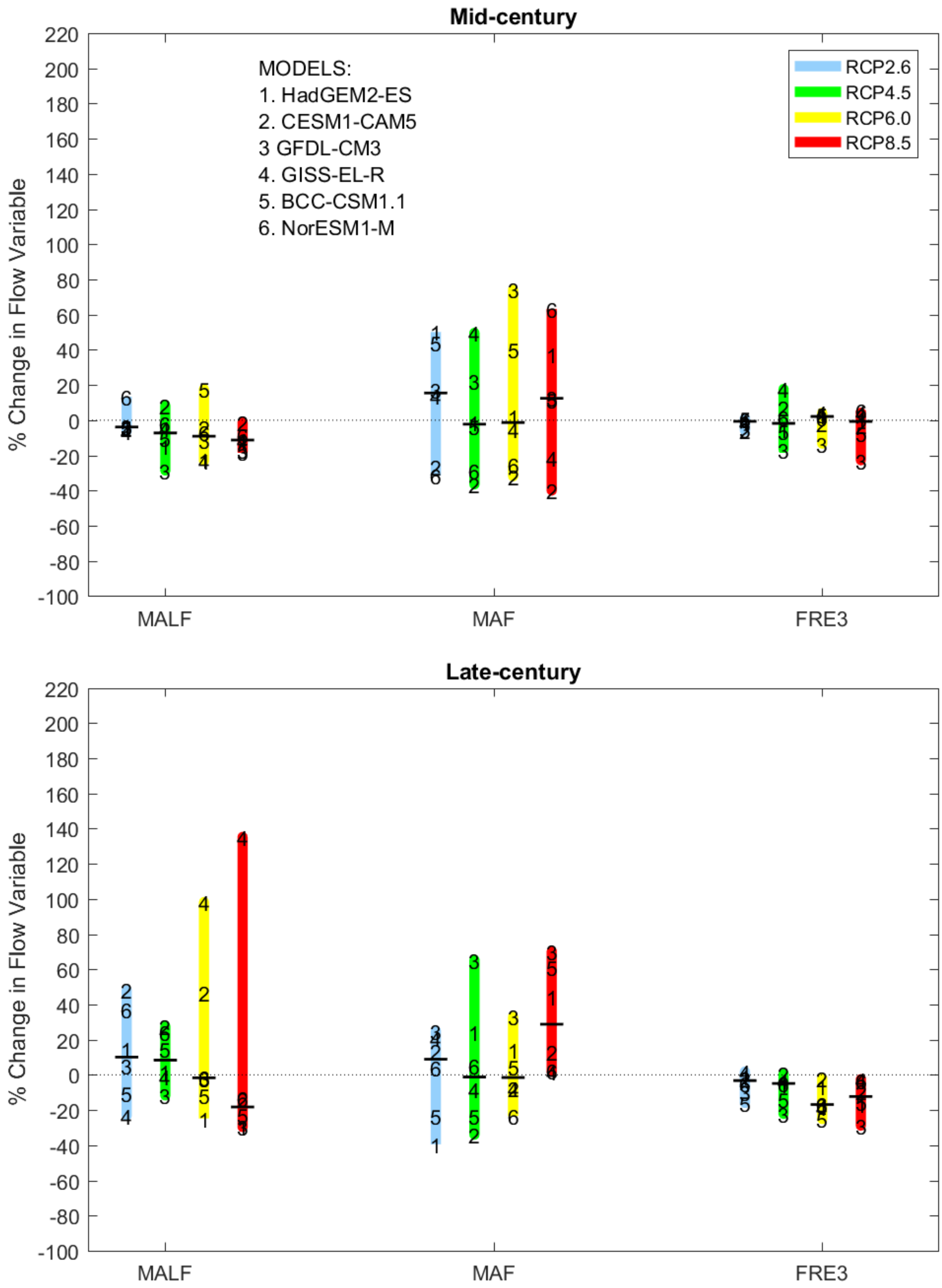


Figure 3-22: Projected changes in MALF, MAF, and FRE3 for the Hoteo River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

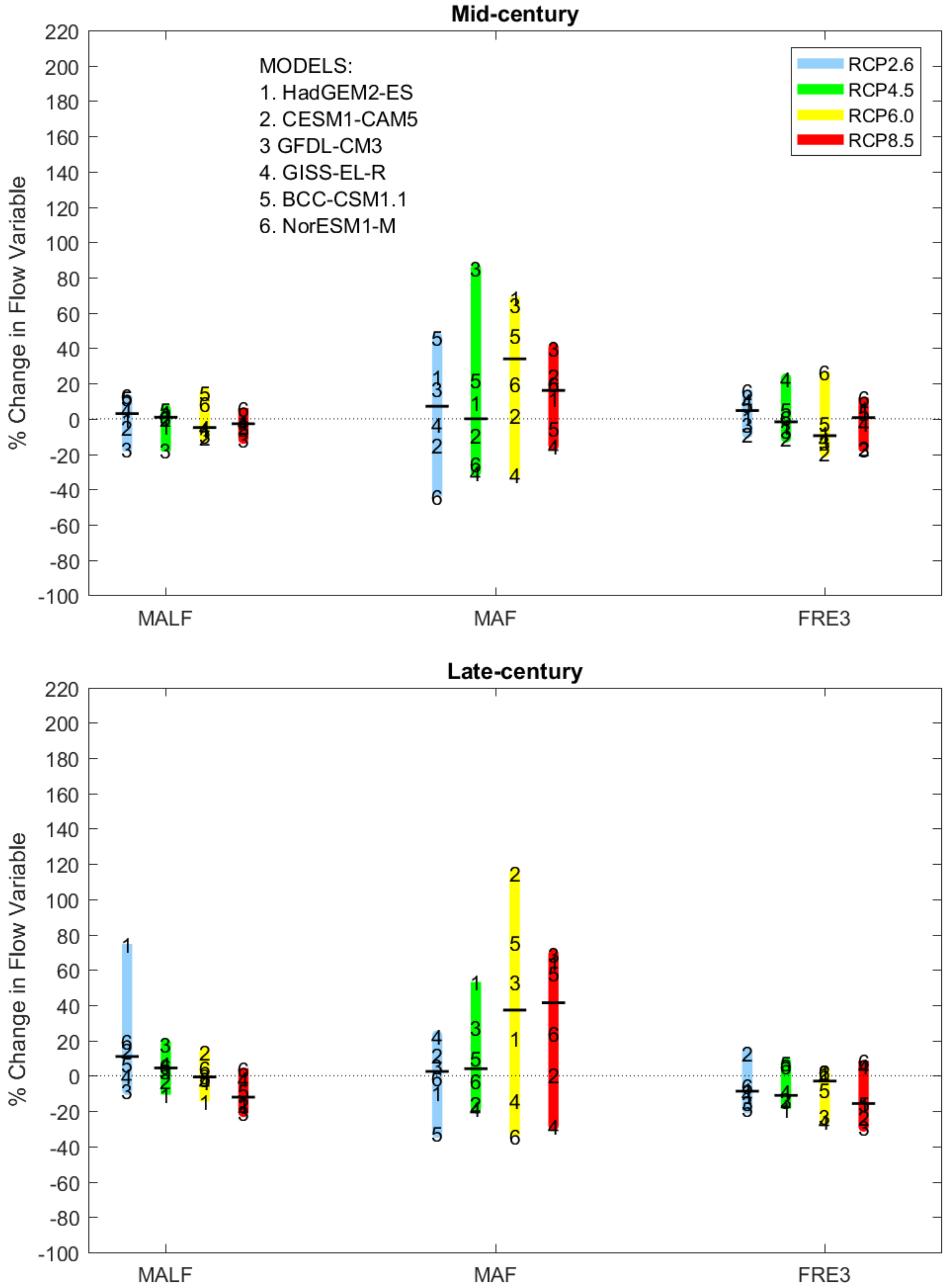


Figure 3-23: Projected changes in MALF, MAF, and FRE3 for the Waihou River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

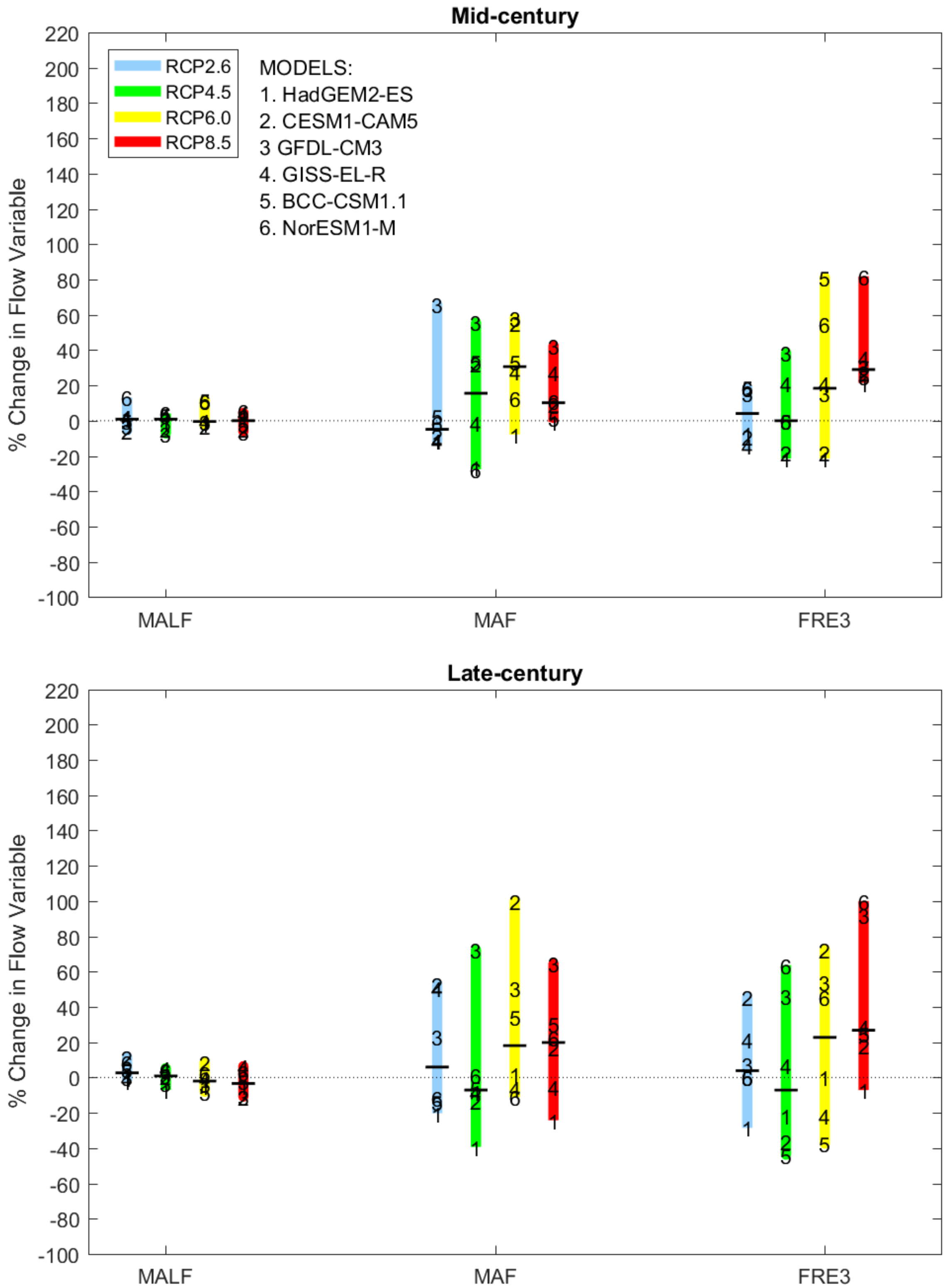


Figure 3-24: Projected changes in MALF, MAF, and FRE3 for the Waikato River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

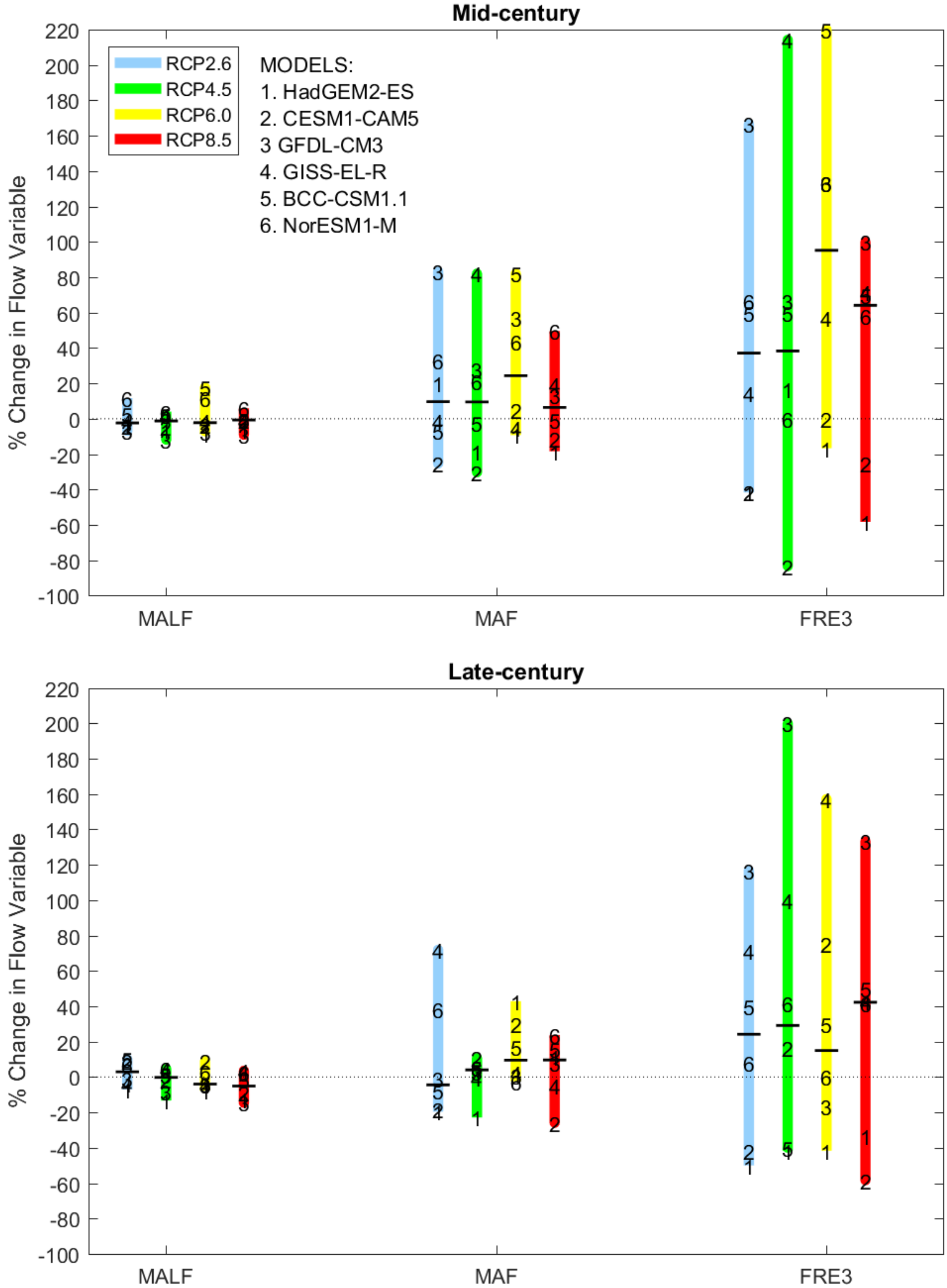


Figure 3-25: Projected changes in MALF, MAF, and FRE3 for the Rangitaiki River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

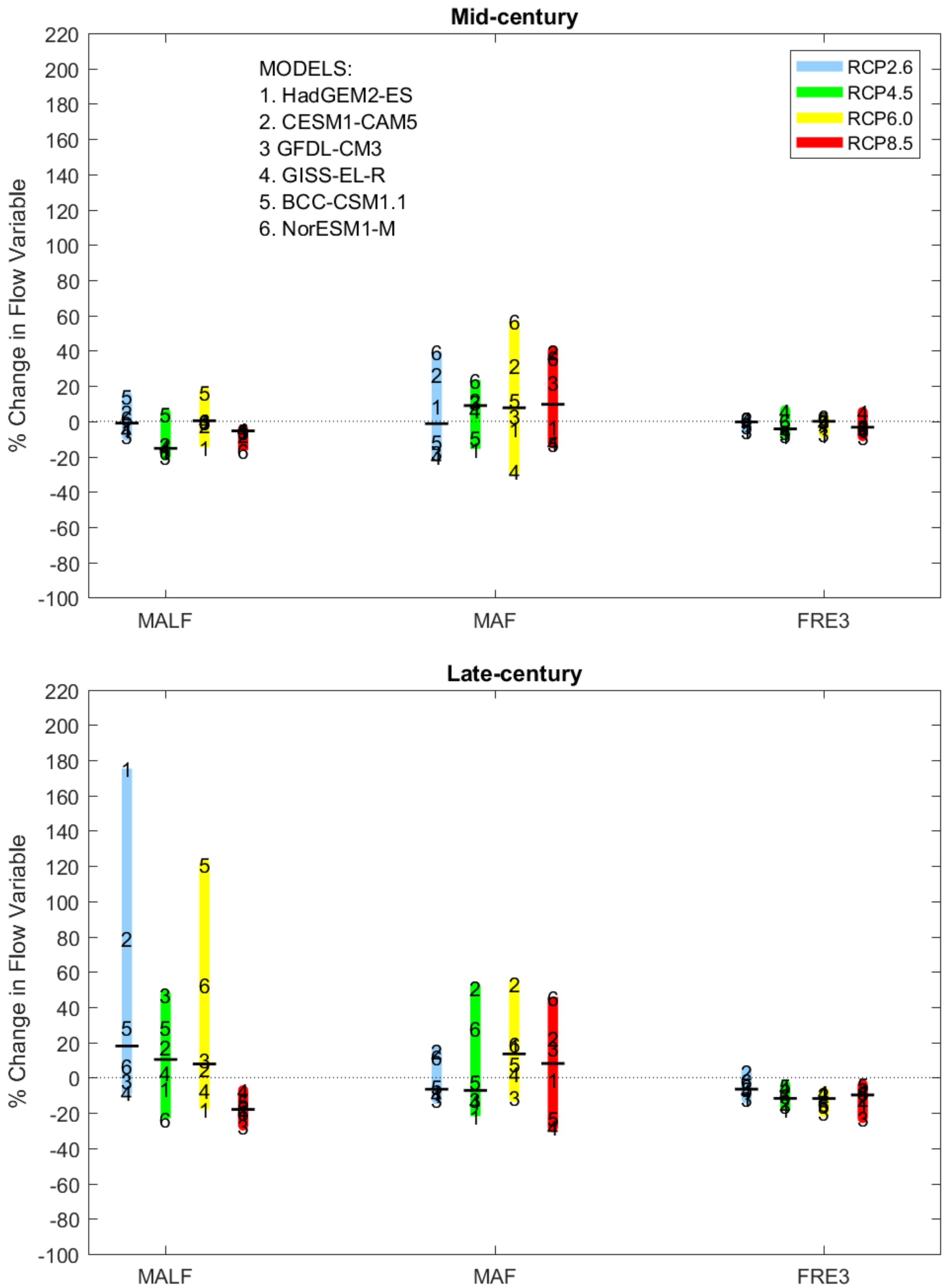


Figure 3-26: Projected changes in MALF, MAF, and FRE3 for the Waiapu River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

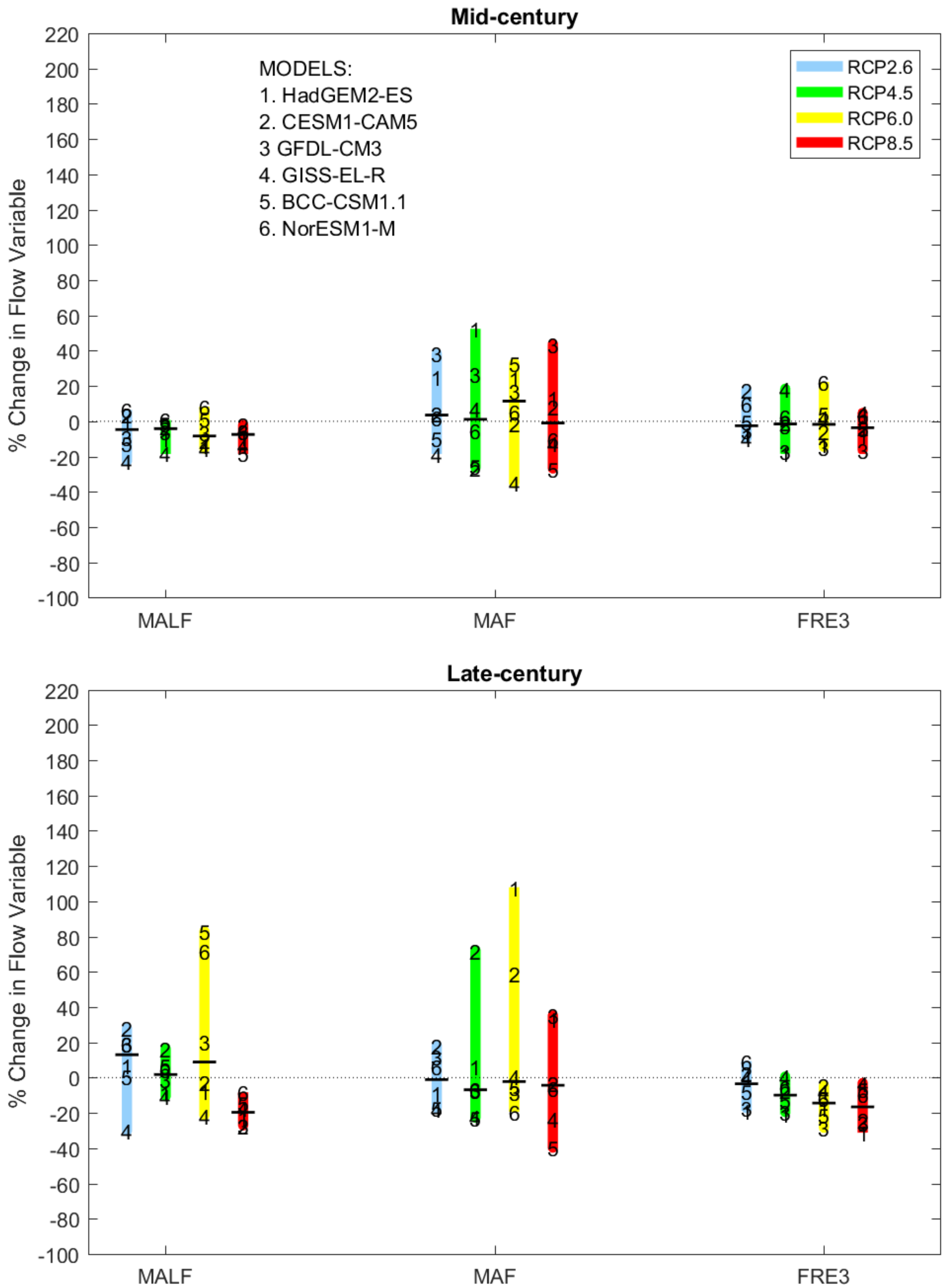


Figure 3-27: Projected changes in MALF, MAF, and FRE3 for the Waipaoa River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

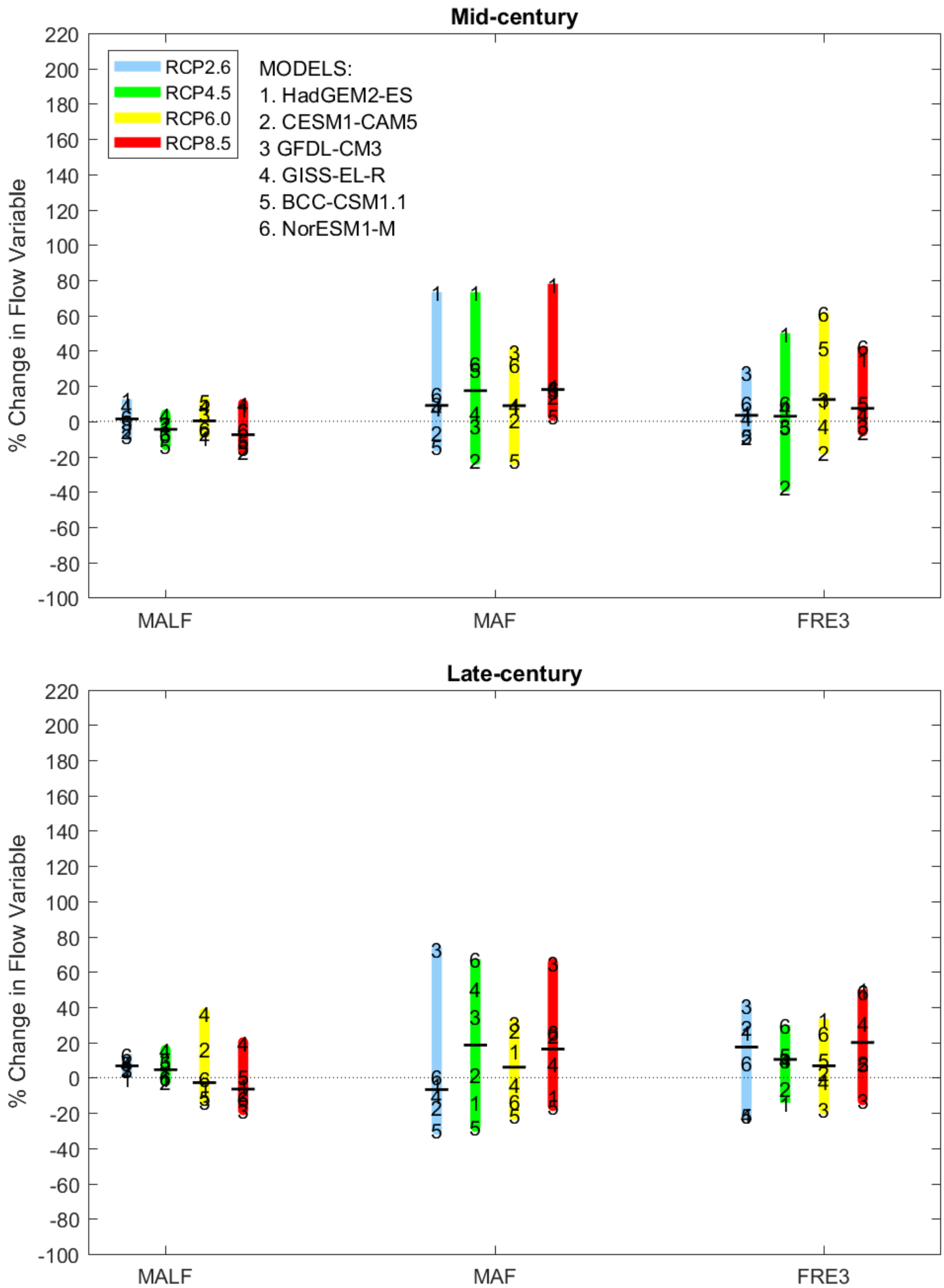


Figure 3-28: Projected changes in MALF, MAF, and FRE3 for the Waiongana River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

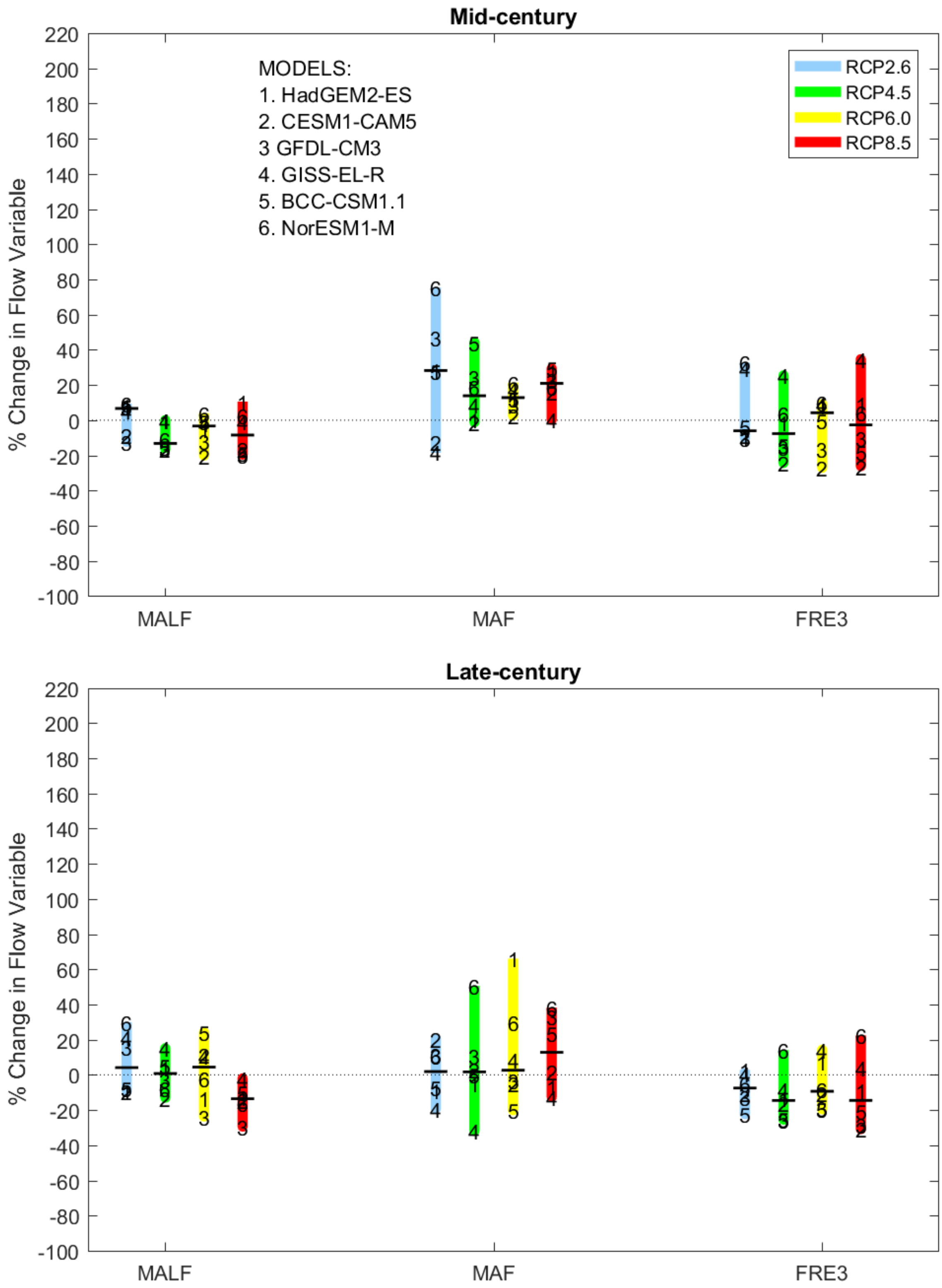


Figure 3-29: Projected changes in MALF, MAF, and FRE3 for the Manawatu River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

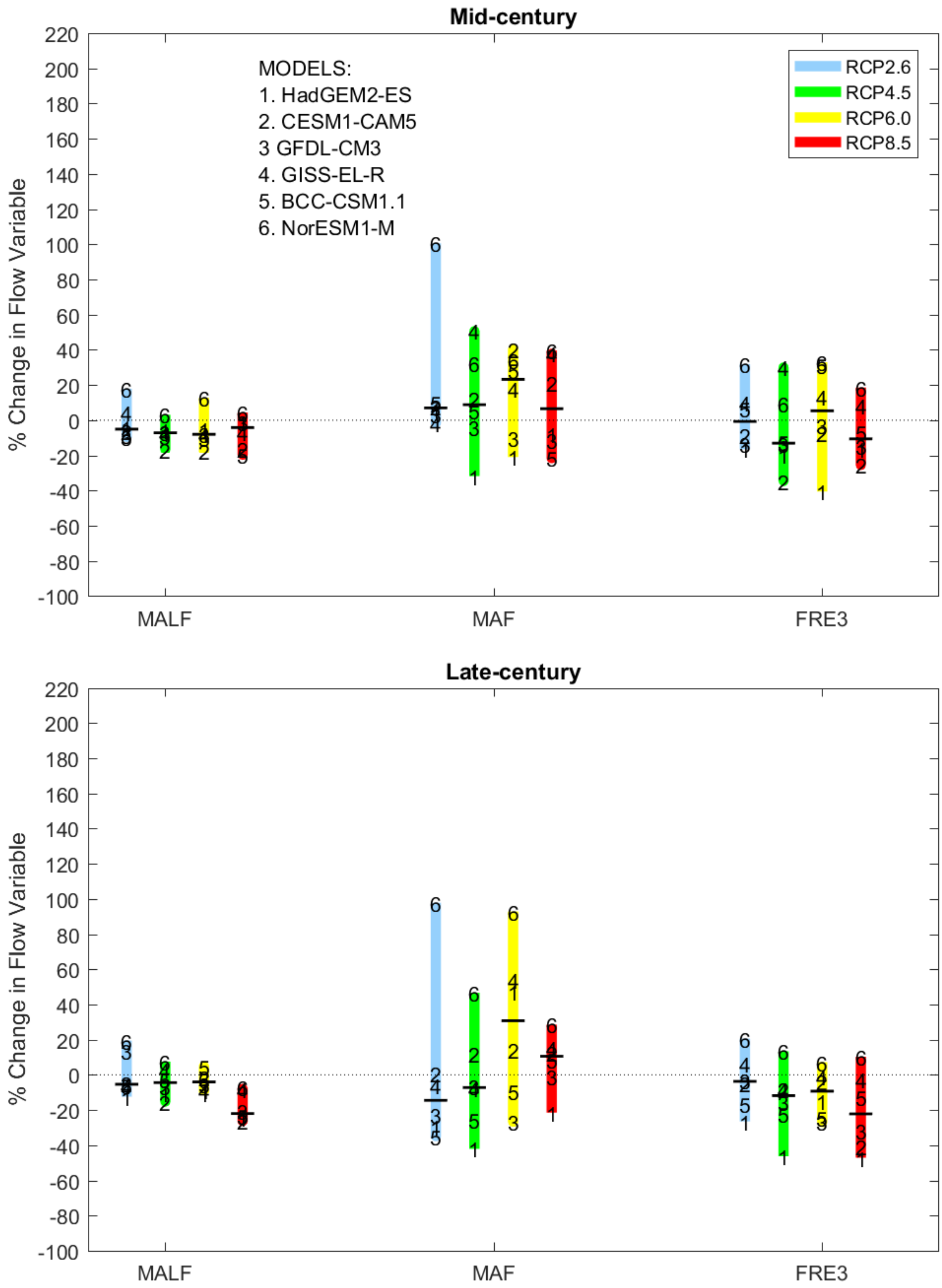


Figure 3-30: Projected changes in MALF, MAF, and FRE3 for the Tukituki River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

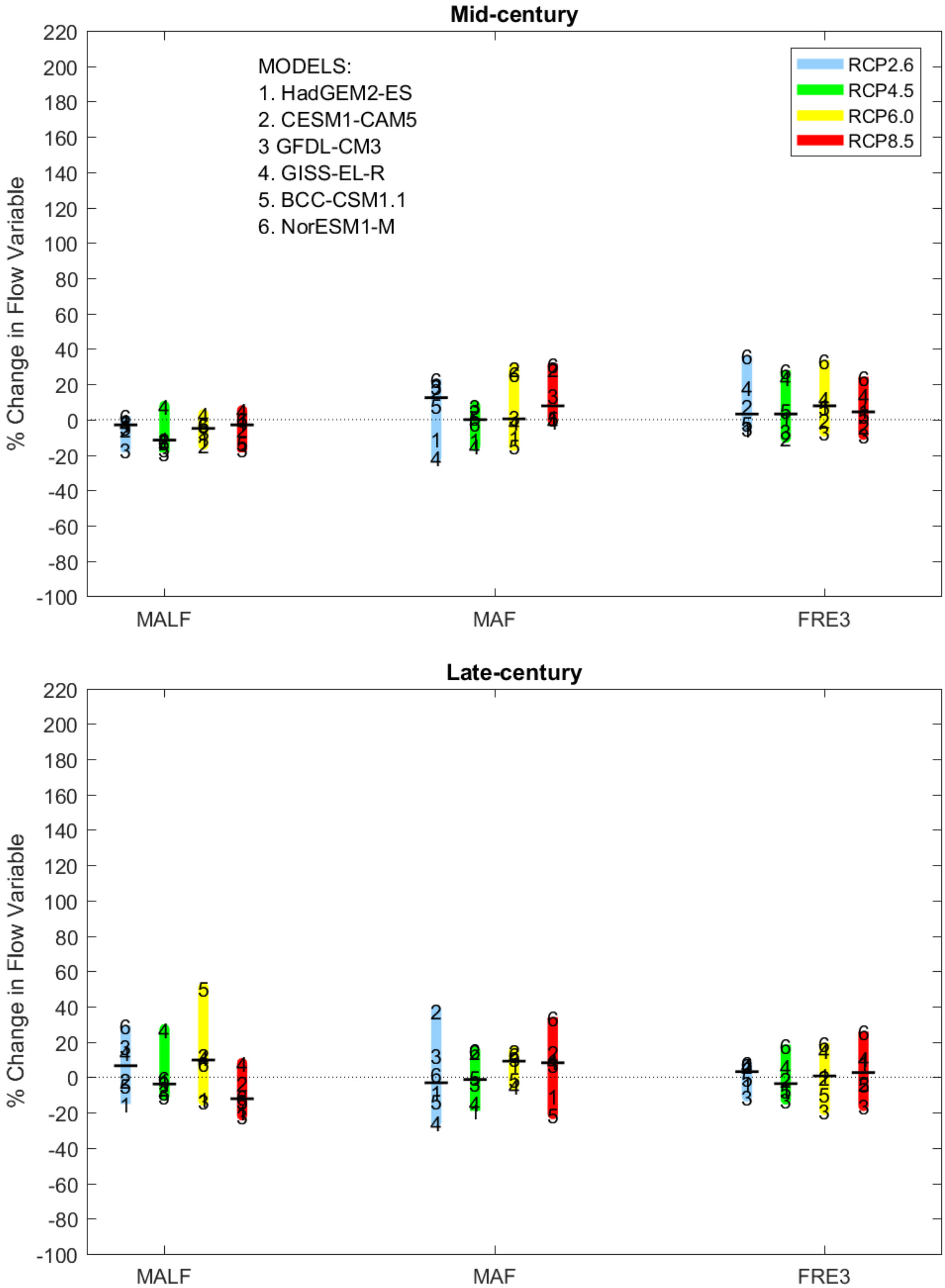


Figure 3-31: Projected changes in MALF, MAF, and FRE3 for the Ruamāhanga River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

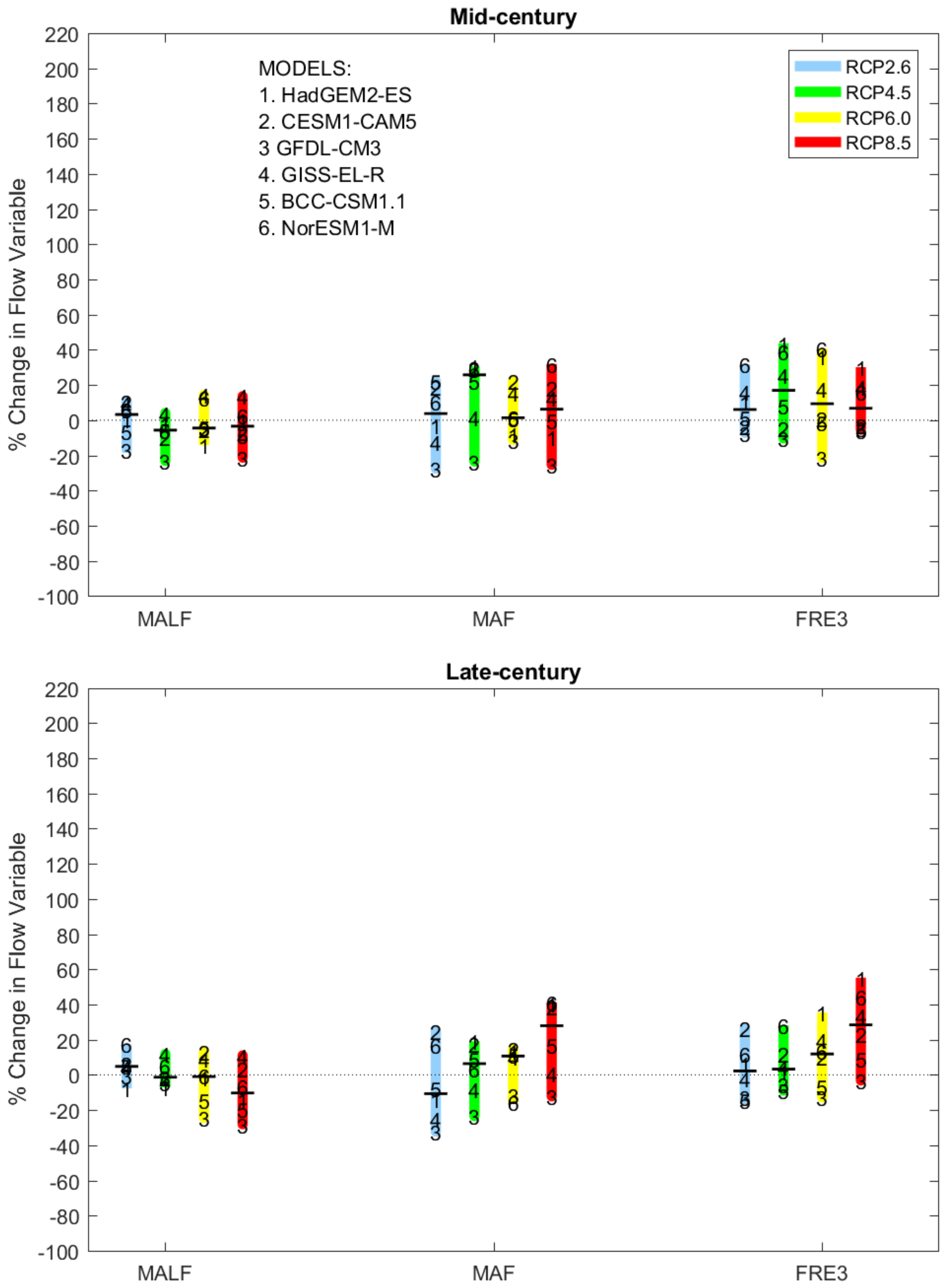


Figure 3-32: Projected changes in MALF, MAF, and FRE3 for the Motueka River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

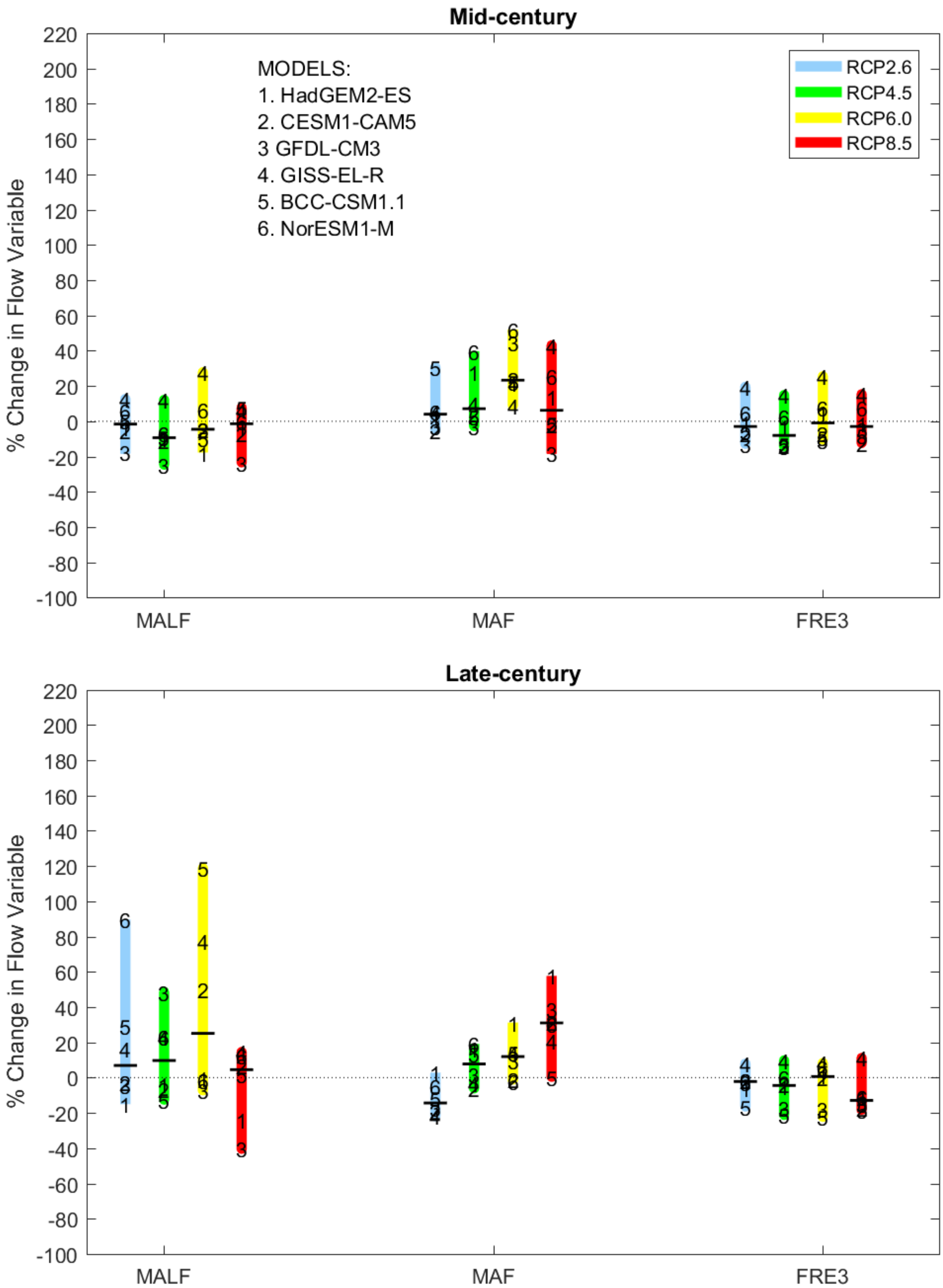


Figure 3-33: Projected changes in MALF, MAF, and FRE3 for the Maitai River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

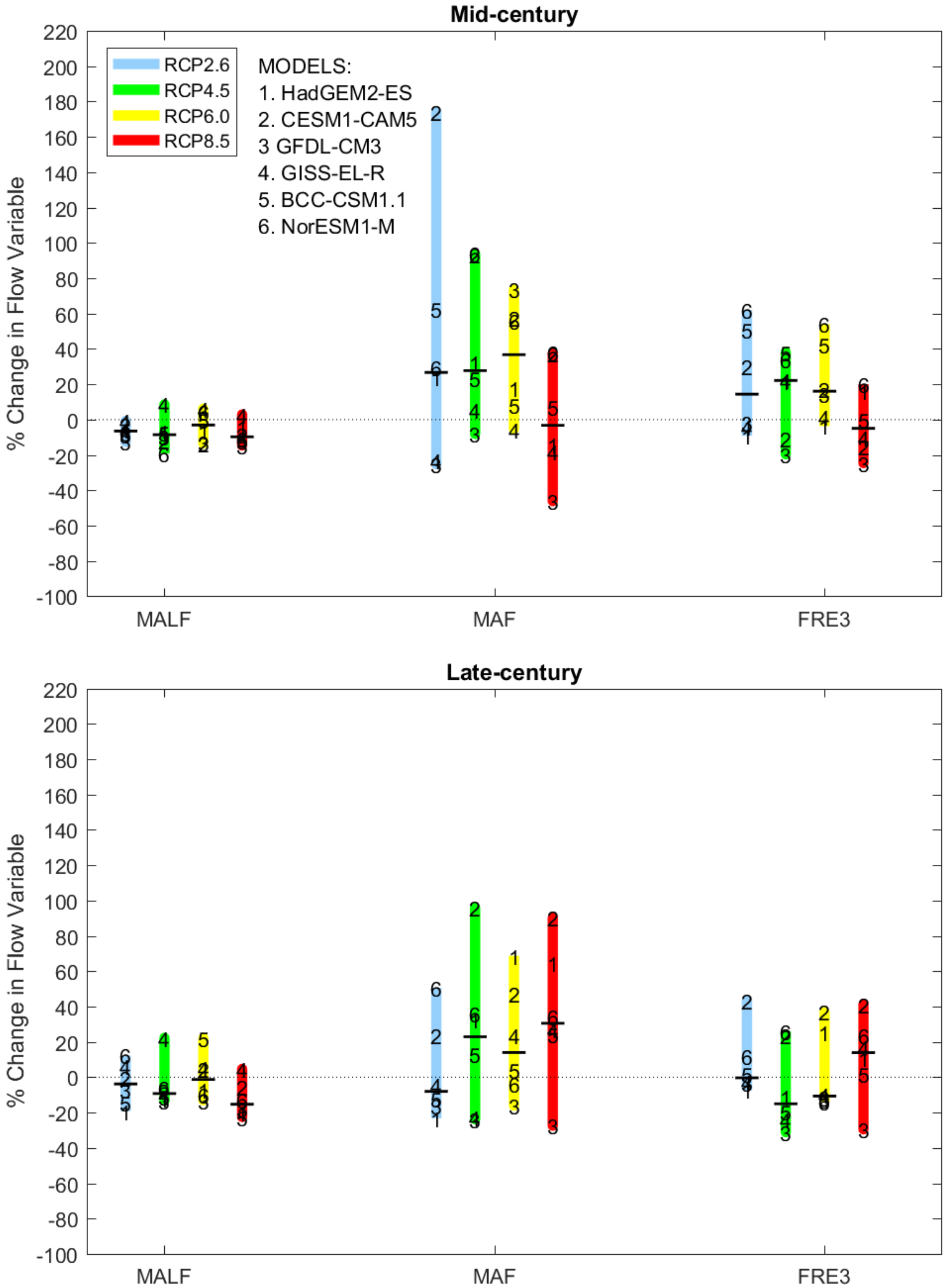


Figure 3-34: Projected changes in MALF, MAF, and FRE3 for the Awatere River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

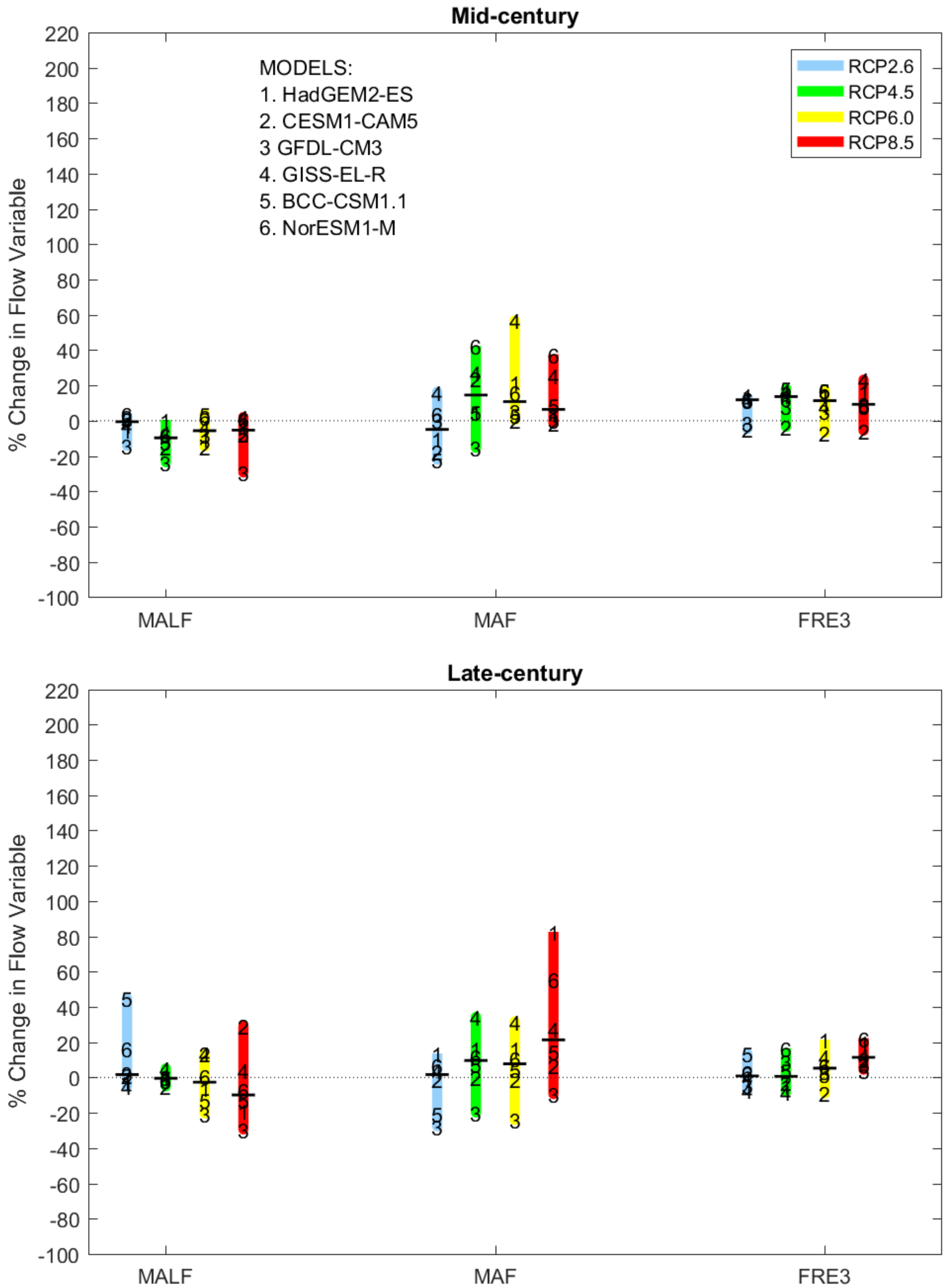


Figure 3-35: Projected changes in MALF, MAF, and FRE3 for the Buller River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

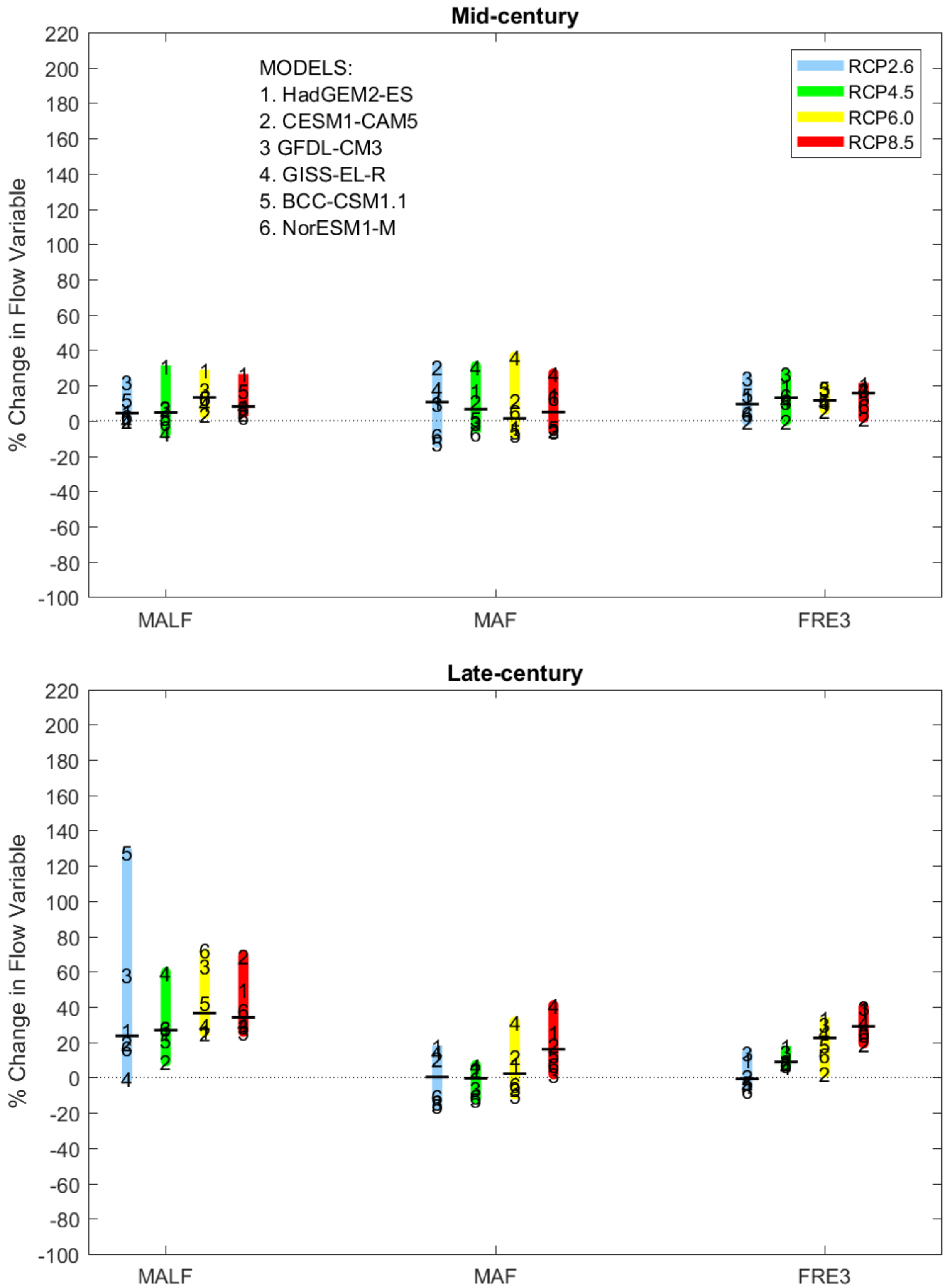


Figure 3-36: Projected changes in MALF, MAF, and FRE3 for the Haast River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

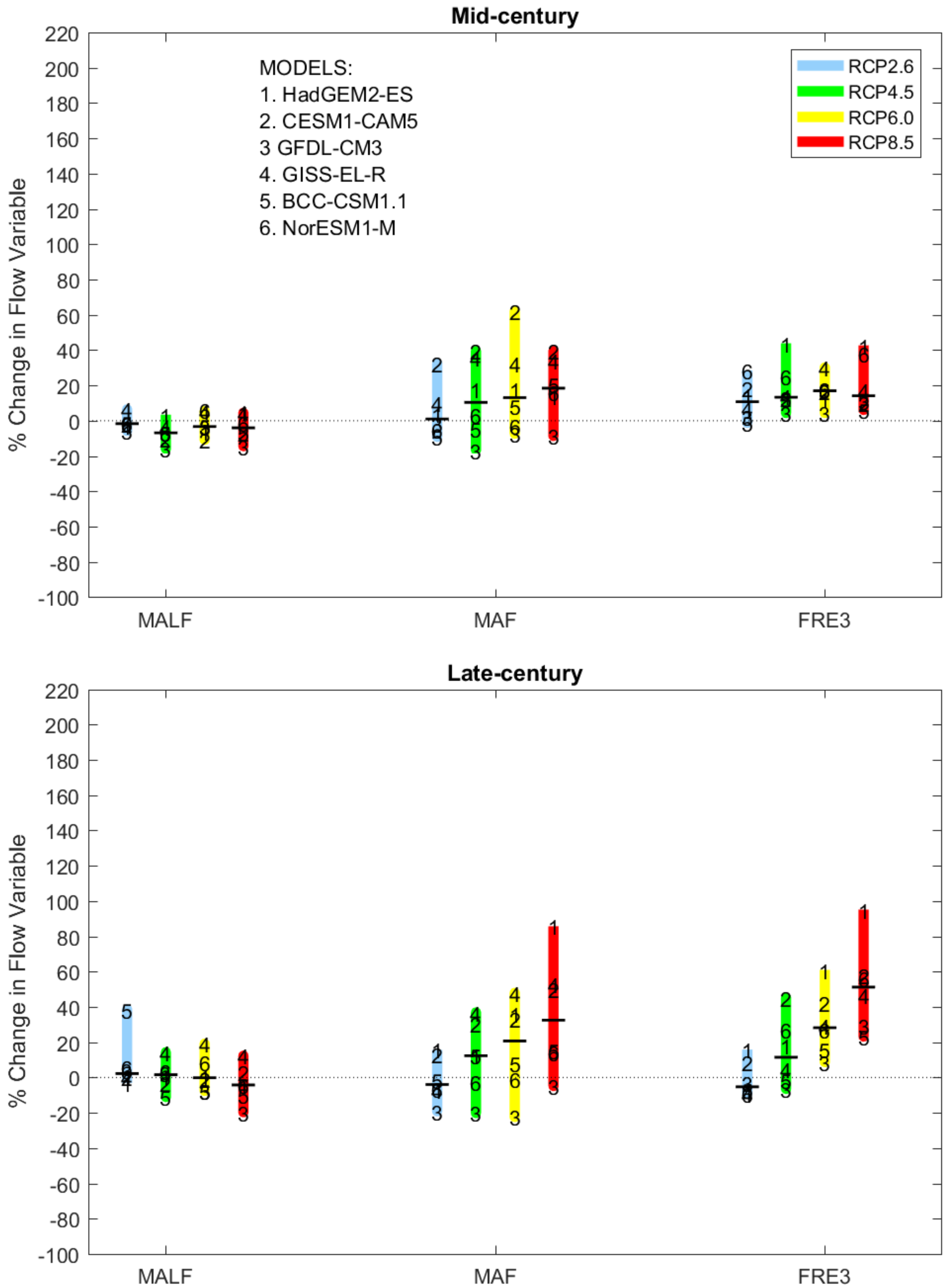


Figure 3-37: Projected changes in MALF, MAF, and FRE3 for the Rakaia River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

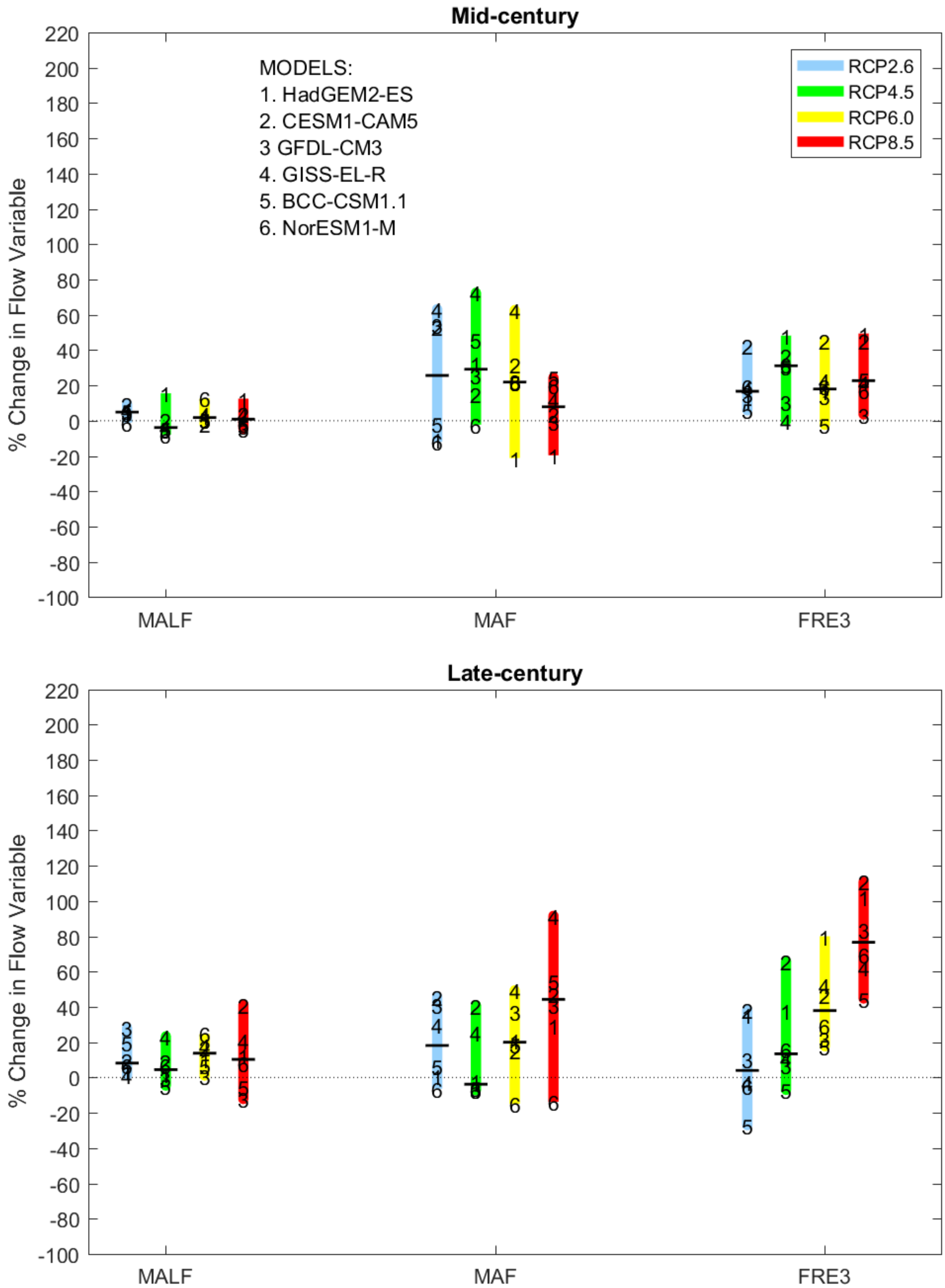


Figure 3-38: Projected changes in MALF, MAF, and FRE3 for the Clutha River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

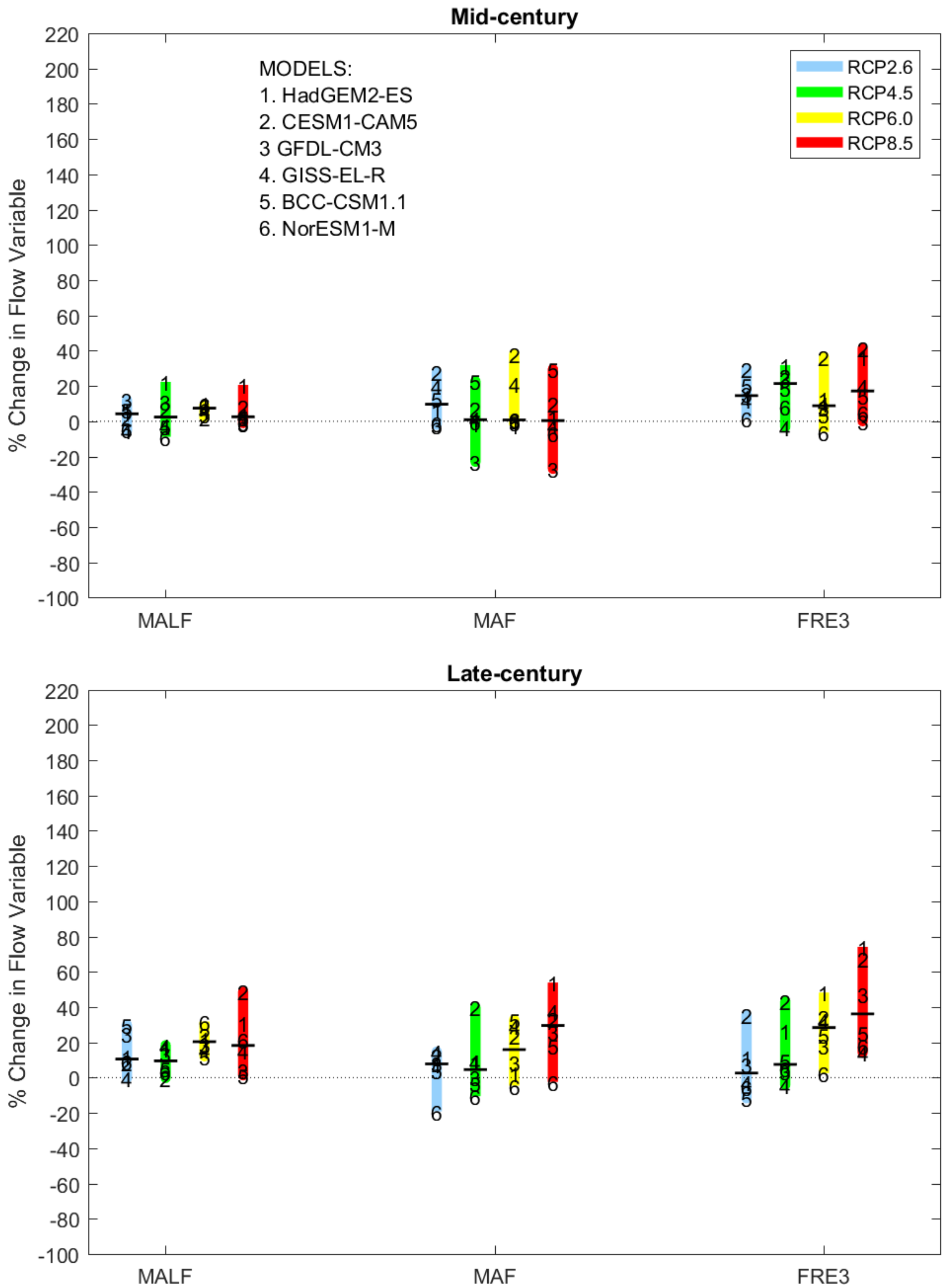


Figure 3-39: Projected changes in MALF, MAF, and FRE3 for the Waiau River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

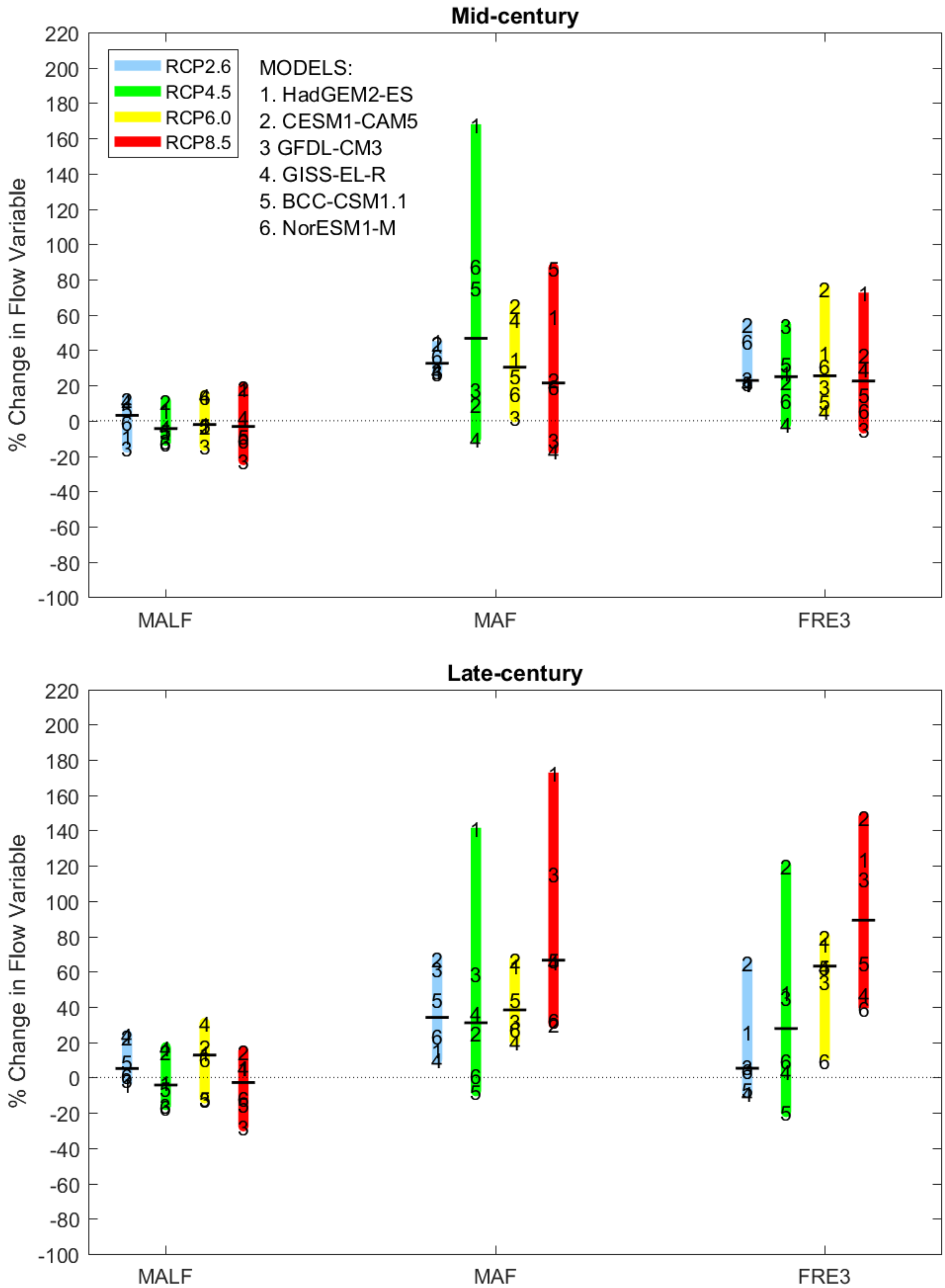


Figure 3-40: Projected changes in MALF, MAF, and FRE3 for the Mataura River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

3.3 Flow percentiles

Projected differences in the exceedance probabilities of baseline flows are summarised in Table 3-5 and Table 3-6 and are depicted in Figure 3-41 to Figure 3-60. They show whether historical flow thresholds calculated over the baseline period (1986-2005) for each GCM, chosen to correspond to the 5%, 25%, 50%, 75%, and 95% exceedance probabilities, are exceeded more or less frequently in the future.

To illustrate how to interpret these results, consider the Wairoa River and a baseline flow percentile of 25%. This flow is a mid-to-high range flow exceeded 25% of the time during the simulated baseline period. During the mid-century period, the flow is also exceeded 25% of the time for RCPs 2.6 and 4.5, but for RCP 6.0 the exceedance is 23% and for RCP 8.5 is 24%. That means that for RCPs 6.0 and 8.5 the flow threshold is exceeded slightly less often; i.e., the range of flows above this threshold become rarer.

Results of the simulations are as follows:

- For the Wairoa, Hoteo, Waikato, Waiapu, Waipaoa, Manawatu, and Tukituki all exceedance flows except for the very highest (5% exceedance), are exceeded less often by late-century.
- For the Ruamāhanga, the 25%, 50%, and 75% exceedance flows are exceeded less often by late-century.
- For the Waihou and Rangitaiki, only the 95% exceedance flow is exceeded more often by late-century.
- Of the North Island rivers, the Waiongana is the only one to show no discernable changes in flow exceedances, and for the South Island this only occurs for the Awatere.
- In the north of the South Island, the Motueka and Maitai are projected to experience more frequent flows above both the 25% and 5% exceedance flows, while the 95% exceedance flow is exceeded less often.
- The Buller resembles the Motueka and Maitai, with the addition of the 50% exceedance flow being exceeded more often late-century.
- The remaining South Island rivers of the Haast, Rakaia, Clutha, Waiau, and Mataura have the baseline exceedance flows of 5%, 25%, and 50% exceeded more often, while the Haast, Rakaia, Clutha, and Waiau also have more frequent exceedances of the 75% baseline exceedance flow.
- The Haast River is the only river studied to show changes with RCPs across all flow percentiles, with all baseline flow ranges being exceeded more often in the future.

In summary, baseline exceedance flows for most North Island rivers are exceeded less often, with the notable exception of the 5% exceedance flow (the high flow). Central-north and western rivers show little or no change. For the South Island, the Awatere shows no change in flow exceedances. For the north-west rivers, the low 95% exceedance flow is exceeded less often. For all South Island rivers except the Awatere, the high range flows (5% and 25% exceedance) and to a lesser extent the 50% and 75%, are exceeded more often.

These changes in flow percentile exceedances are closely aligned to changes in the extreme and mean statistics reported in Sections 3.1 and 3.2.

Table 3-5: Projected mid-century flow percentiles for baseline flow exceedance percentiles of equivalent discharge. The new percentiles are given for four RCPs (8.5, 6.0, 4.5 and 2.6), where the ensemble median is taken over six models. The values in each column represent the ensemble median, and in brackets the range over all six models within that ensemble.

River	Baseline flow exceedance percentile				
	5%	25%	50%	75%	95%
Wairoa					
RCP 8.5	5 (3, 7)	24 (19, 29)	48 (40, 55)	74 (69, 78)	94 (90, 97)
RCP 6.0	5 (3, 7)	23 (20, 30)	48 (45, 57)	74 (71, 84)	94 (89, 98)
RCP 4.5	5 (3, 7)	25 (20, 29)	49 (42, 54)	73 (65, 79)	94 (90, 97)
RCP 2.6	5 (4, 7)	25 (21, 31)	49 (47, 56)	74 (71, 83)	95 (91, 98)
Hoteo					
RCP 8.5	5 (4, 6)	25 (20, 28)	49 (43, 53)	73 (70, 76)	93 (90, 95)
RCP 6.0	5 (4, 6)	25 (21, 28)	50 (47, 54)	75 (71, 81)	94 (88, 98)
RCP 4.5	5 (4, 6)	25 (21, 29)	49 (43, 53)	74 (68, 77)	93 (90, 95)
RCP 2.6	5 (5, 6)	27 (21, 28)	50 (48, 55)	74 (73, 79)	95 (92, 97)
Waihou					
RCP 8.5	5 (4, 7)	26 (20, 28)	50 (45, 53)	74 (69, 76)	94 (92, 97)
RCP 6.0	5 (4, 7)	26 (20, 31)	50 (45, 56)	74 (70, 81)	94 (92, 97)
RCP 4.5	5 (4, 7)	26 (22, 31)	50 (45, 56)	73 (69, 78)	94 (90, 97)
RCP 2.6	5 (4, 7)	27 (22, 29)	50 (47, 53)	73 (68, 79)	95 (90, 97)
Waikato					
RCP 8.5	7 (4, 11)	29 (21, 33)	54 (45, 57)	77 (68, 81)	95 (94, 98)
RCP 6.0	6 (4, 12)	26 (22, 38)	52 (47, 64)	77 (72, 87)	97 (94, 98)
RCP 4.5	7 (4, 8)	27 (21, 32)	52 (43, 61)	76 (68, 82)	96 (91, 98)
RCP 2.6	6 (4, 9)	27 (22, 34)	51 (46, 60)	75 (71, 86)	97 (93, 99)
Rangitaiki					
RCP 8.5	5 (3, 10)	28 (17, 35)	51 (39, 60)	74 (64, 80)	95 (91, 98)
RCP 6.0	5 (4, 14)	24 (20, 46)	48 (42, 72)	75 (65, 88)	95 (92, 99)
RCP 4.5	6 (3, 10)	27 (16, 39)	51 (36, 64)	74 (61, 83)	94 (88, 98)
RCP 2.6	5 (3, 11)	26 (19, 39)	50 (44, 65)	74 (68, 86)	96 (91, 98)
Waiapu					
RCP 8.5	5 (4, 6)	24 (22, 25)	46 (43, 50)	72 (69, 75)	95 (93, 96)
RCP 6.0	5 (4, 7)	24 (22, 28)	48 (45, 53)	73 (71, 77)	95 (93, 97)
RCP 4.5	5 (4, 6)	24 (22, 28)	47 (43, 52)	72 (66, 76)	93 (91, 96)
RCP 2.6	5 (4, 7)	25 (21, 28)	49 (44, 52)	73 (69, 77)	95 (94, 97)
Waipaoa					
RCP 8.5	5 (4, 7)	22 (20, 27)	45 (41, 51)	71 (69, 76)	95 (93, 96)
RCP 6.0	5 (4, 7)	23 (21, 31)	47 (44, 57)	74 (71, 80)	96 (93, 97)
RCP 4.5	5 (4, 7)	23 (19, 31)	48 (40, 55)	73 (67, 75)	94 (93, 96)
RCP 2.6	5 (4, 7)	25 (21, 29)	48 (43, 54)	74 (70, 80)	95 (93, 97)

Waiongana					
RCP 8.5	6 (4, 7)	28 (22, 31)	53 (46, 56)	75 (69, 81)	95 (91, 98)
RCP 6.0	6 (4, 9)	27 (23, 35)	53 (48, 58)	77 (71, 78)	96 (94, 98)
RCP 4.5	6 (3, 7)	27 (19, 30)	51 (42, 55)	75 (67, 80)	95 (93, 97)
RCP 2.6	5 (4, 6)	27 (22, 33)	53 (47, 56)	74 (72, 81)	97 (93, 98)
Manawatu					
RCP 8.5	5 (4, 7)	26 (21, 28)	51 (44, 53)	74 (68, 77)	94 (93, 96)
RCP 6.0	5 (4, 7)	27 (22, 30)	51 (48, 56)	76 (71, 77)	95 (93, 97)
RCP 4.5	5 (4, 7)	26 (21, 30)	50 (44, 56)	74 (69, 80)	94 (92, 96)
RCP 2.6	5 (5, 7)	26 (23, 32)	50 (48, 58)	75 (71, 79)	96 (94, 97)
Tukituki					
RCP 8.5	4 (4, 7)	22 (18, 28)	46 (42, 53)	72 (70, 77)	95 (92, 96)
RCP 6.0	5 (3, 9)	23 (20, 32)	51 (44, 55)	76 (73, 79)	96 (93, 96)
RCP 4.5	5 (3, 8)	22 (17, 32)	46 (40, 57)	71 (67, 79)	94 (93, 96)
RCP 2.6	5 (4, 9)	26 (19, 32)	50 (44, 57)	74 (71, 81)	95 (93, 97)
Ruamāhanga					
RCP 8.5	6 (4, 6)	26 (22, 31)	49 (44, 55)	74 (68, 78)	94 (92, 97)
RCP 6.0	5 (5, 7)	26 (23, 31)	50 (46, 54)	74 (70, 78)	94 (92, 97)
RCP 4.5	5 (5, 7)	26 (22, 32)	50 (44, 59)	73 (68, 82)	93 (92, 97)
RCP 2.6	5 (4, 7)	26 (22, 32)	49 (45, 56)	75 (69, 79)	95 (93, 97)
Motueka					
RCP 8.5	6 (5, 6)	27 (25, 31)	52 (46, 56)	75 (70, 79)	94 (91, 96)
RCP 6.0	6 (4, 7)	29 (23, 32)	52 (44, 59)	75 (70, 81)	95 (92, 97)
RCP 4.5	6 (4, 7)	29 (23, 33)	53 (44, 57)	75 (67, 82)	94 (88, 96)
RCP 2.6	5 (5, 7)	26 (25, 31)	51 (48, 56)	76 (70, 82)	96 (91, 97)
Maitai					
RCP 8.5	6 (5, 7)	28 (23, 31)	51 (45, 57)	75 (71, 78)	95 (92, 96)
RCP 6.0	6 (5, 7)	28 (23, 32)	52 (47, 59)	74 (72, 81)	94 (93, 97)
RCP 4.5	7 (5, 7)	29 (22, 34)	53 (44, 59)	75 (66, 79)	94 (89, 97)
RCP 2.6	6 (4, 6)	27 (23, 32)	51 (46, 58)	76 (70, 79)	95 (93, 97)
Awatere					
RCP 8.5	5 (4, 7)	26 (23, 29)	48 (43, 56)	71 (65, 81)	93 (91, 97)
RCP 6.0	7 (5, 9)	28 (27, 36)	54 (49, 58)	76 (69, 83)	95 (90, 99)
RCP 4.5	7 (5, 8)	29 (21, 33)	52 (44, 61)	72 (63, 82)	93 (90, 96)
RCP 2.6	6 (4, 9)	26 (24, 32)	52 (46, 56)	76 (68, 80)	94 (90, 96)
Buller					
RCP 8.5	5 (5, 7)	27 (24, 29)	52 (49, 55)	76 (72, 78)	94 (91, 96)
RCP 6.0	5 (5, 7)	28 (24, 30)	53 (49, 55)	76 (73, 78)	95 (93, 96)
RCP 4.5	6 (5, 7)	26 (24, 31)	51 (47, 56)	76 (71, 78)	93 (91, 95)
RCP 2.6	5 (5, 7)	26 (25, 30)	51 (50, 54)	76 (74, 77)	96 (93, 97)
Haast					
RCP 8.5	6 (5, 7)	28 (26, 32)	54 (53, 59)	79 (76, 83)	97 (95, 98)
RCP 6.0	6 (5, 7)	28 (26, 29)	54 (52, 57)	80 (77, 82)	97 (96, 98)
RCP 4.5	5 (5, 7)	27 (26, 32)	53 (50, 58)	77 (75, 81)	96 (94, 98)
RCP 2.6	6 (5, 6)	27 (26, 30)	53 (52, 57)	78 (76, 81)	96 (95, 98)

Rakaia					
RCP 8.5	6 (5, 9)	27 (26, 32)	53 (49, 56)	77 (74, 79)	94 (94, 96)
RCP 6.0	6 (5, 7)	27 (25, 32)	54 (50, 58)	76 (75, 82)	96 (95, 97)
RCP 4.5	6 (4, 10)	27 (24, 34)	52 (48, 58)	76 (70, 80)	94 (92, 96)
RCP 2.6	6 (4, 7)	26 (25, 30)	52 (50, 56)	77 (72, 79)	96 (95, 98)
Clutha					
RCP 8.5	6 (5, 9)	29 (27, 33)	54 (52, 60)	77 (76, 84)	96 (93, 97)
RCP 6.0	6 (4, 9)	29 (27, 34)	55 (53, 58)	79 (77, 82)	96 (95, 97)
RCP 4.5	6 (6, 9)	28 (26, 35)	53 (51, 61)	76 (74, 83)	95 (94, 98)
RCP 2.6	6 (5, 8)	29 (27, 32)	54 (51, 57)	79 (76, 81)	96 (95, 97)
Waiau					
RCP 8.5	5 (4, 8)	26 (25, 31)	53 (50, 59)	77 (76, 85)	96 (94, 98)
RCP 6.0	5 (4, 8)	27 (25, 31)	54 (51, 58)	78 (77, 84)	96 (96, 97)
RCP 4.5	5 (5, 8)	27 (25, 31)	52 (50, 58)	76 (74, 82)	96 (94, 98)
RCP 2.6	6 (6, 6)	27 (25, 29)	53 (51, 56)	79 (75, 80)	96 (94, 97)
Mataura					
RCP 8.5	6 (5, 9)	28 (27, 35)	53 (50, 65)	76 (72, 85)	95 (92, 98)
RCP 6.0	6 (5, 8)	30 (24, 33)	55 (49, 60)	76 (72, 81)	95 (93, 97)
RCP 4.5	6 (4, 9)	28 (25, 34)	53 (46, 62)	76 (74, 83)	95 (93, 97)
RCP 2.6	7 (6, 8)	29 (25, 32)	54 (50, 56)	77 (75, 80)	95 (93, 98)

Table 3-6: Projected late-century flow percentiles for baseline flow exceedance percentiles of equivalent discharge. The new percentiles are given for four RCPs (8.5, 6.0, 4.5 and 2.6), where the ensemble median is taken over six models. The values in each column represent the ensemble median, and in brackets the range over all six models within that ensemble.

	Baseline flow exceedance percentile				
River	**5%**	**25%**	**50%**	**75%**	**95%**
Wairoa					
RCP 8.5	4 (2, 7)	20 (13, 28)	44 (33, 52)	69 (62, 78)	91 (90, 95)
RCP 6.0	5 (3, 6)	23 (17, 26)	47 (41, 52)	73 (69, 79)	94 (92, 98)
RCP 4.5	5 (3, 6)	23 (18, 26)	47 (42, 53)	73 (69, 80)	94 (92, 97)
RCP 2.6	5 (4, 6)	25 (23, 27)	49 (46, 51)	74 (69, 81)	94 (91, 97)
Hoteo					
RCP 8.5	5 (3, 6)	23 (16, 27)	46 (38, 52)	68 (65, 76)	92 (88, 93)
RCP 6.0	5 (4, 6)	23 (19, 27)	48 (43, 51)	73 (69, 76)	94 (90, 98)
RCP 4.5	5 (3, 6)	24 (19, 28)	47 (43, 52)	73 (68, 78)	95 (90, 97)
RCP 2.6	5 (4, 5)	25 (22, 27)	49 (47, 53)	73 (70, 79)	94 (90, 97)
Waihou					
RCP 8.5	5 (4, 8)	24 (17, 28)	46 (38, 50)	69 (63, 73)	92 (86, 94)
RCP 6.0	5 (4, 6)	25 (18, 26)	47 (42, 50)	72 (69, 76)	93 (90, 98)
RCP 4.5	5 (4, 6)	24 (20, 28)	46 (43, 52)	71 (66, 76)	94 (89, 97)
RCP 2.6	5 (4, 6)	25 (23, 28)	49 (47, 53)	75 (70, 78)	95 (92, 98)

Waikato					
RCP 8.5	6 (4, 12)	25 (18, 33)	46 (38, 56)	70 (63, 80)	94 (88, 96)
RCP 6.0	6 (4, 9)	26 (19, 31)	49 (42, 55)	73 (64, 80)	96 (88, 99)
RCP 4.5	6 (4, 9)	25 (19, 32)	47 (39, 58)	70 (63, 80)	96 (91, 97)
RCP 2.6	6 (5, 8)	27 (24, 29)	52 (46, 54)	77 (69, 79)	96 (93, 97)
Rangitaiki					
RCP 8.5	5 (2, 14)	23 (15, 37)	45 (32, 58)	67 (56, 80)	92 (80, 98)
RCP 6.0	5 (3, 7)	22 (18, 30)	45 (37, 54)	71 (61, 81)	96 (89, 99)
RCP 4.5	5 (2, 9)	25 (14, 34)	46 (33, 58)	68 (56, 80)	94 (87, 100)
RCP 2.6	6 (3, 9)	27 (20, 31)	52 (43, 60)	76 (65, 82)	96 (93, 98)
Waiapu					
RCP 8.5	5 (3, 6)	22 (17, 25)	43 (35, 49)	68 (60, 74)	92 (88, 93)
RCP 6.0	5 (4, 6)	23 (19, 24)	45 (38, 47)	69 (64, 73)	93 (92, 95)
RCP 4.5	5 (4, 6)	23 (20, 25)	45 (40, 48)	70 (66, 73)	93 (91, 97)
RCP 2.6	5 (4, 6)	24 (22, 26)	48 (44, 51)	74 (68, 77)	95 (92, 97)
Waipaoa					
RCP 8.5	4 (2, 7)	19 (13, 25)	40 (34, 49)	67 (63, 73)	92 (89, 94)
RCP 6.0	4 (4, 6)	22 (17, 23)	44 (38, 48)	70 (67, 73)	94 (90, 96)
RCP 4.5	5 (3, 6)	23 (19, 26)	45 (41, 49)	72 (67, 74)	95 (94, 96)
RCP 2.6	5 (4, 6)	23 (20, 27)	47 (43, 51)	74 (67, 79)	95 (94, 98)
Waiongana					
RCP 8.5	6 (5, 8)	29 (23, 33)	52 (47, 56)	74 (70, 80)	95 (91, 96)
RCP 6.0	5 (4, 7)	27 (23, 32)	52 (45, 58)	75 (68, 80)	95 (92, 97)
RCP 4.5	6 (4, 7)	25 (23, 32)	48 (45, 57)	72 (69, 80)	96 (93, 98)
RCP 2.6	6 (4, 7)	28 (25, 30)	53 (51, 55)	76 (75, 77)	96 (94, 97)
Manawatu					
RCP 8.5	5 (4, 7)	25 (17, 27)	47 (38, 52)	71 (67, 74)	93 (90, 95)
RCP 6.0	5 (4, 6)	25 (21, 27)	48 (42, 52)	73 (65, 75)	93 (91, 96)
RCP 4.5	5 (4, 7)	23 (22, 30)	47 (45, 54)	72 (70, 76)	95 (93, 97)
RCP 2.6	5 (4, 6)	26 (23, 27)	50 (47, 54)	75 (71, 77)	95 (92, 97)
Tukituki					
RCP 8.5	4 (3, 7)	19 (13, 28)	40 (32, 48)	67 (59, 72)	90 (89, 92)
RCP 6.0	4 (3, 6)	23 (15, 25)	46 (38, 47)	71 (64, 72)	94 (90, 95)
RCP 4.5	4 (2, 7)	21 (17, 28)	44 (39, 53)	69 (65, 76)	93 (89, 95)
RCP 2.6	5 (3, 8)	24 (21, 29)	49 (44, 52)	75 (67, 76)	95 (92, 98)
Ruamāhanga					
RCP 8.5	5 (4, 6)	24 (19, 28)	45 (38, 52)	70 (63, 76)	93 (91, 97)
RCP 6.0	6 (4, 6)	25 (20, 28)	48 (41, 52)	73 (65, 78)	94 (91, 97)
RCP 4.5	5 (4, 7)	24 (22, 30)	47 (43, 55)	71 (68, 80)	94 (92, 98)
RCP 2.6	5 (5, 7)	26 (24, 29)	50 (47, 55)	73 (71, 79)	95 (92, 97)
Motueka					
RCP 8.5	7 (6, 9)	31 (27, 34)	52 (47, 57)	72 (66, 78)	93 (85, 95)
RCP 6.0	6 (5, 8)	28 (24, 33)	52 (46, 56)	77 (65, 78)	95 (87, 97)
RCP 4.5	6 (5, 7)	27 (24, 32)	48 (47, 57)	74 (66, 79)	94 (88, 97)
RCP 2.6	5 (4, 7)	26 (24, 29)	50 (48, 55)	75 (70, 79)	95 (93, 98)

Maitai					
RCP 8.5	7 (5, 8)	29 (24, 34)	50 (45, 59)	71 (67, 78)	94 (87, 96)
RCP 6.0	6 (5, 8)	28 (24, 32)	53 (45, 55)	76 (66, 80)	95 (90, 98)
RCP 4.5	6 (5, 7)	27 (24, 31)	49 (47, 58)	74 (69, 80)	95 (92, 97)
RCP 2.6	6 (5, 6)	27 (26, 28)	51 (49, 54)	74 (72, 77)	95 (93, 97)
Awatere					
RCP 8.5	7 (4, 8)	27 (22, 32)	49 (43, 56)	69 (62, 78)	90 (87, 96)
RCP 6.0	5 (4, 9)	25 (22, 31)	49 (41, 54)	72 (63, 77)	94 (88, 96)
RCP 4.5	5 (4, 7)	24 (21, 30)	48 (43, 55)	70 (63, 82)	92 (90, 98)
RCP 2.6	6 (5, 8)	27 (22, 31)	50 (41, 55)	73 (68, 78)	93 (89, 98)
Buller					
RCP 8.5	7 (6, 9)	28 (26, 34)	53 (49, 59)	74 (69, 79)	93 (88, 95)
RCP 6.0	7 (6, 8)	28 (26, 31)	53 (48, 57)	76 (69, 79)	94 (89, 96)
RCP 4.5	6 (5, 6)	26 (25, 30)	50 (48, 56)	75 (70, 76)	94 (90, 96)
RCP 2.6	5 (5, 6)	26 (24, 29)	50 (47, 55)	75 (71, 78)	95 (93, 96)
Haast					
RCP 8.5	8 (7, 10)	34 (30, 39)	60 (56, 67)	83 (81, 88)	98 (97, 99)
RCP 6.0	7 (6, 8)	31 (27, 35)	59 (55, 62)	83 (80, 85)	98 (96, 98)
RCP 4.5	6 (5, 8)	28 (26, 32)	56 (52, 58)	79 (78, 82)	97 (96, 98)
RCP 2.6	5 (4, 6)	27 (24, 29)	52 (49, 57)	78 (74, 82)	96 (93, 98)
Rakaia					
RCP 8.5	8 (5, 12)	32 (26, 37)	58 (51, 60)	77 (71, 82)	94 (90, 97)
RCP 6.0	7 (5, 10)	30 (25, 37)	55 (49, 62)	78 (72, 82)	95 (92, 97)
RCP 4.5	6 (5, 8)	27 (25, 30)	54 (50, 56)	77 (71, 80)	95 (93, 97)
RCP 2.6	5 (4, 7)	26 (22, 29)	51 (46, 53)	75 (71, 79)	95 (94, 96)
Clutha					
RCP 8.5	9 (7, 15)	37 (33, 46)	63 (57, 70)	84 (76, 86)	96 (93, 97)
RCP 6.0	8 (6, 10)	34 (29, 40)	59 (54, 66)	81 (75, 85)	97 (93, 98)
RCP 4.5	6 (4, 12)	29 (25, 36)	55 (52, 61)	79 (74, 83)	96 (94, 97)
RCP 2.6	5 (4, 8)	27 (23, 34)	54 (48, 58)	78 (73, 83)	95 (94, 98)
Waiau					
RCP 8.5	7 (5, 12)	32 (28, 42)	59 (54, 68)	82 (77, 88)	97 (94, 98)
RCP 6.0	7 (5, 8)	31 (27, 35)	58 (54, 62)	82 (79, 85)	97 (96, 98)
RCP 4.5	5 (4, 9)	27 (24, 33)	53 (51, 58)	79 (77, 82)	96 (95, 97)
RCP 2.6	5 (4, 8)	27 (23, 31)	53 (49, 57)	80 (73, 81)	96 (94, 97)
Mataura					
RCP 8.5	10 (7, 16)	36 (30, 46)	59 (53, 70)	77 (72, 84)	93 (91, 97)
RCP 6.0	8 (6, 12)	34 (30, 40)	57 (54, 66)	78 (74, 84)	95 (92, 99)
RCP 4.5	7 (3, 12)	29 (23, 37)	55 (48, 61)	76 (71, 81)	94 (92, 96)
RCP 2.6	6 (5, 9)	27 (23, 34)	52 (50, 59)	76 (74, 82)	95 (92, 98)

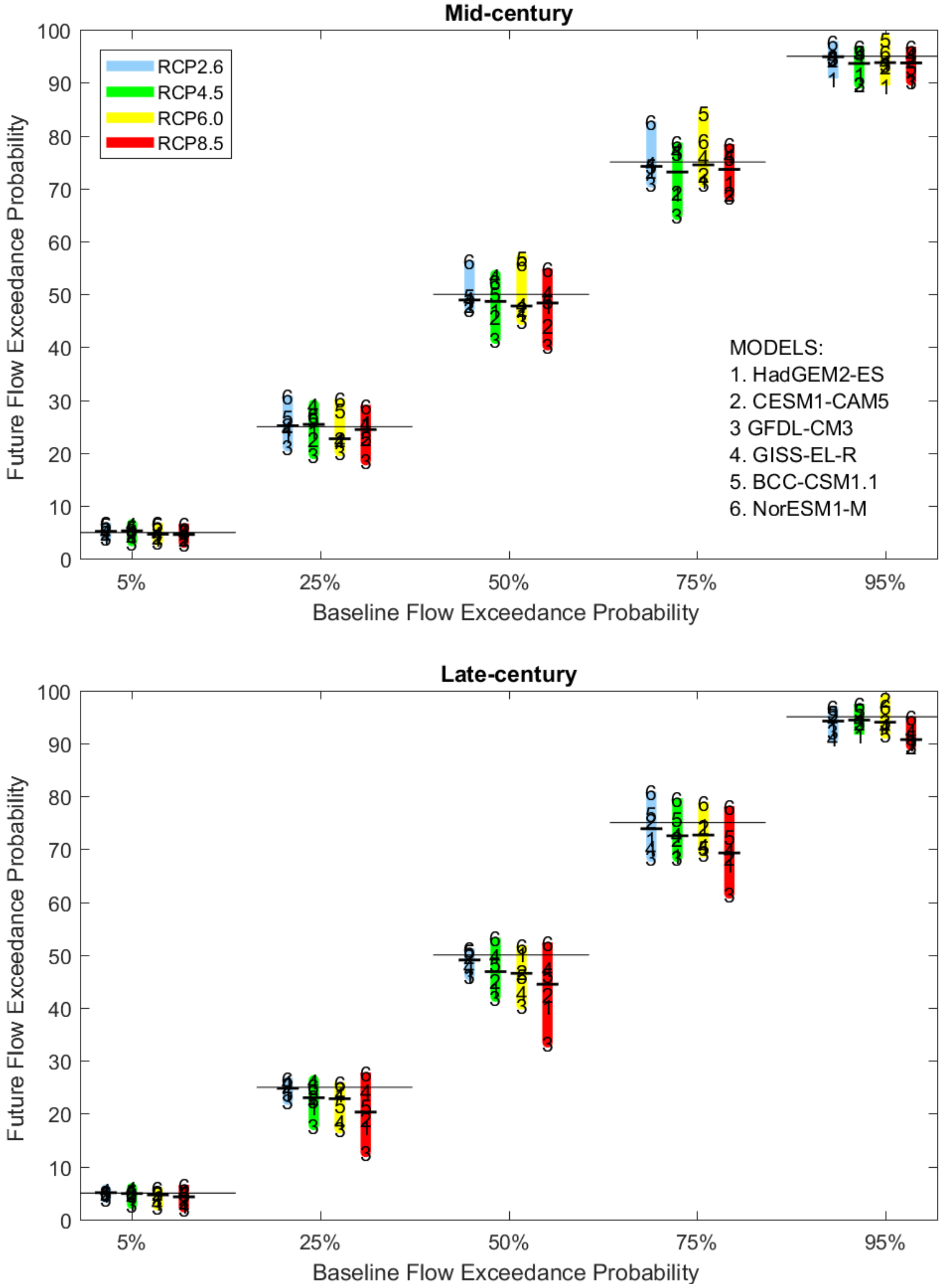


Figure 3-41: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Wairoa River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median**.**

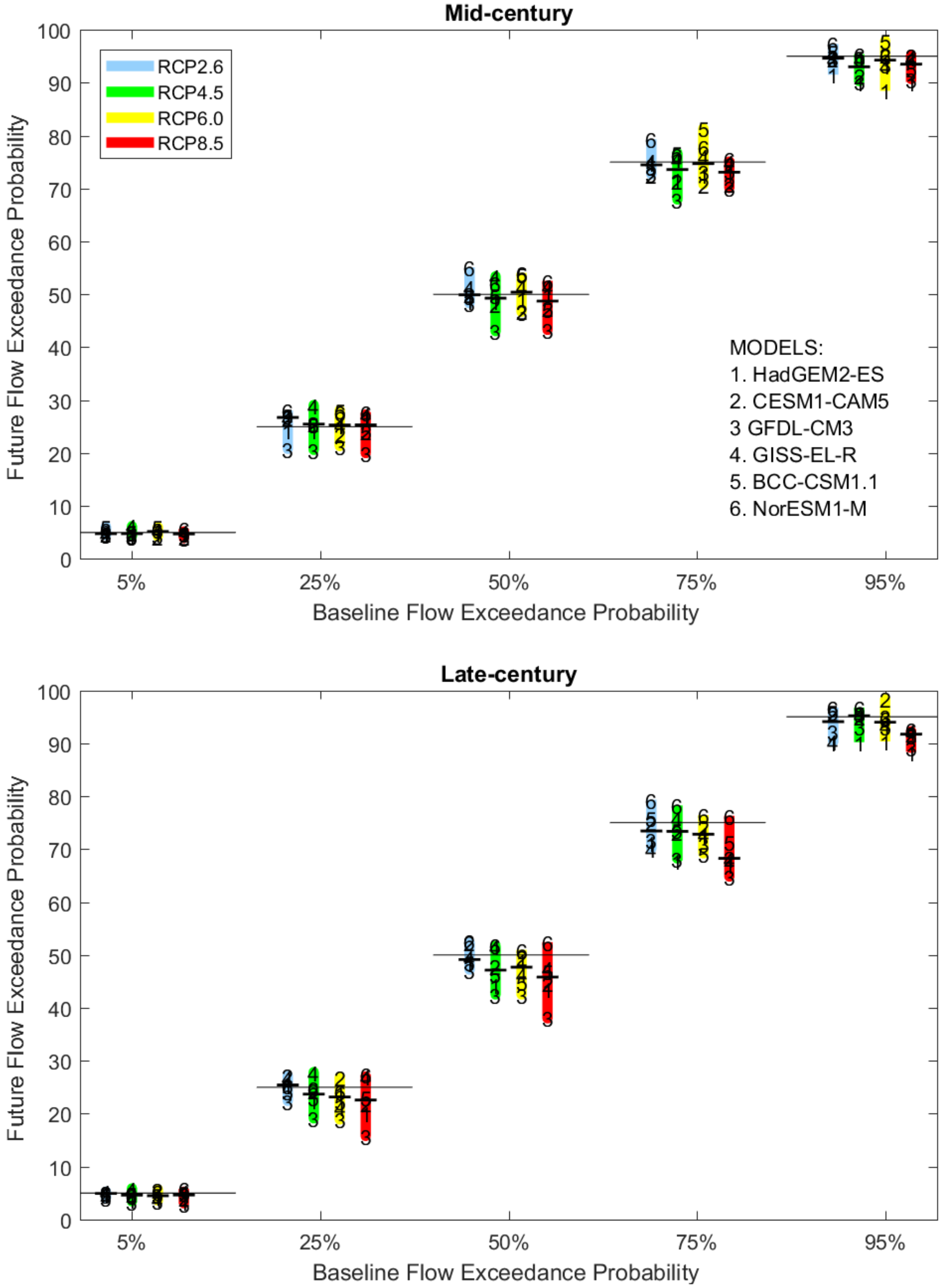


Figure 3-42: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Hoteo River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

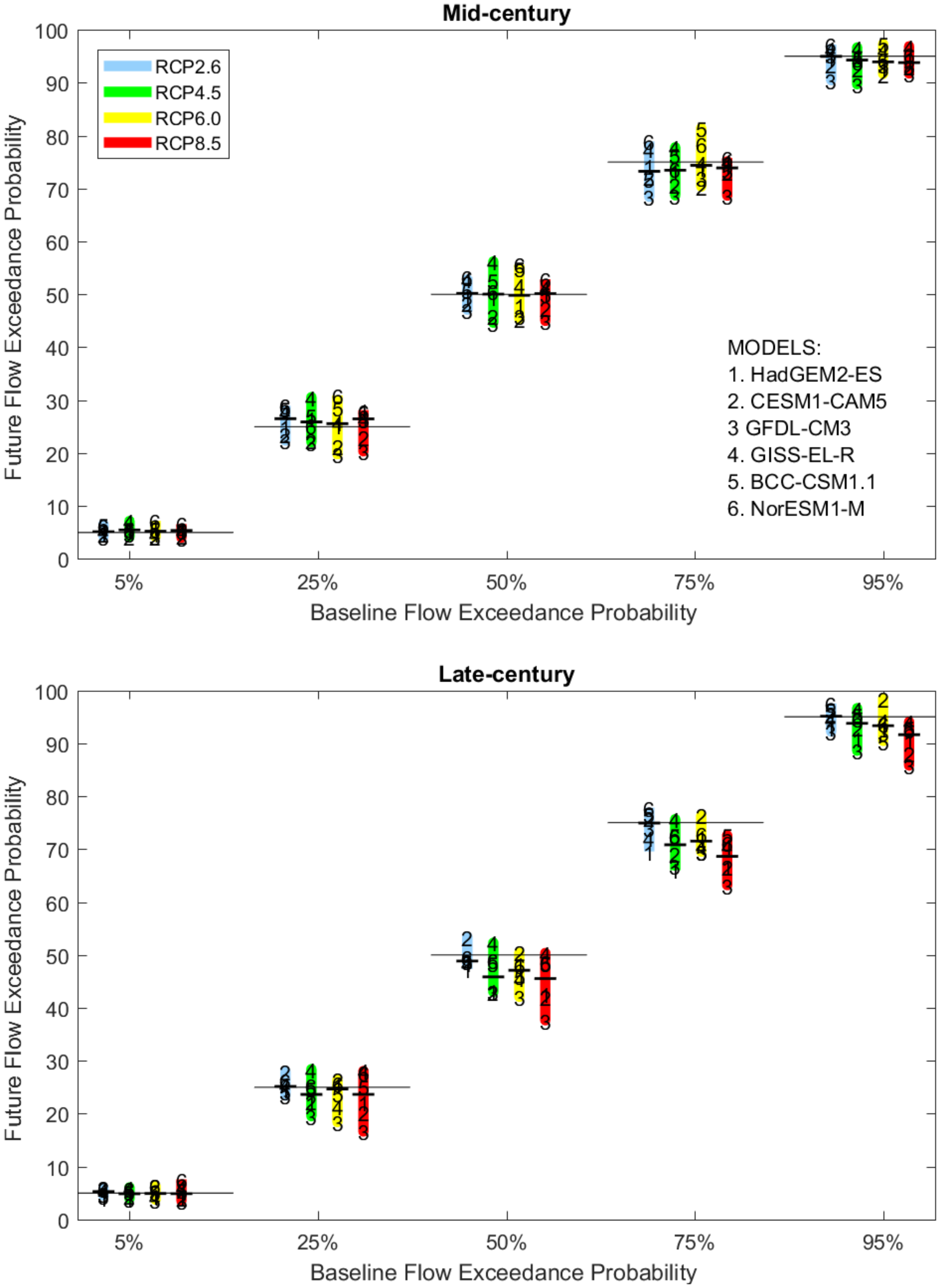


Figure 3-43: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Waihou River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

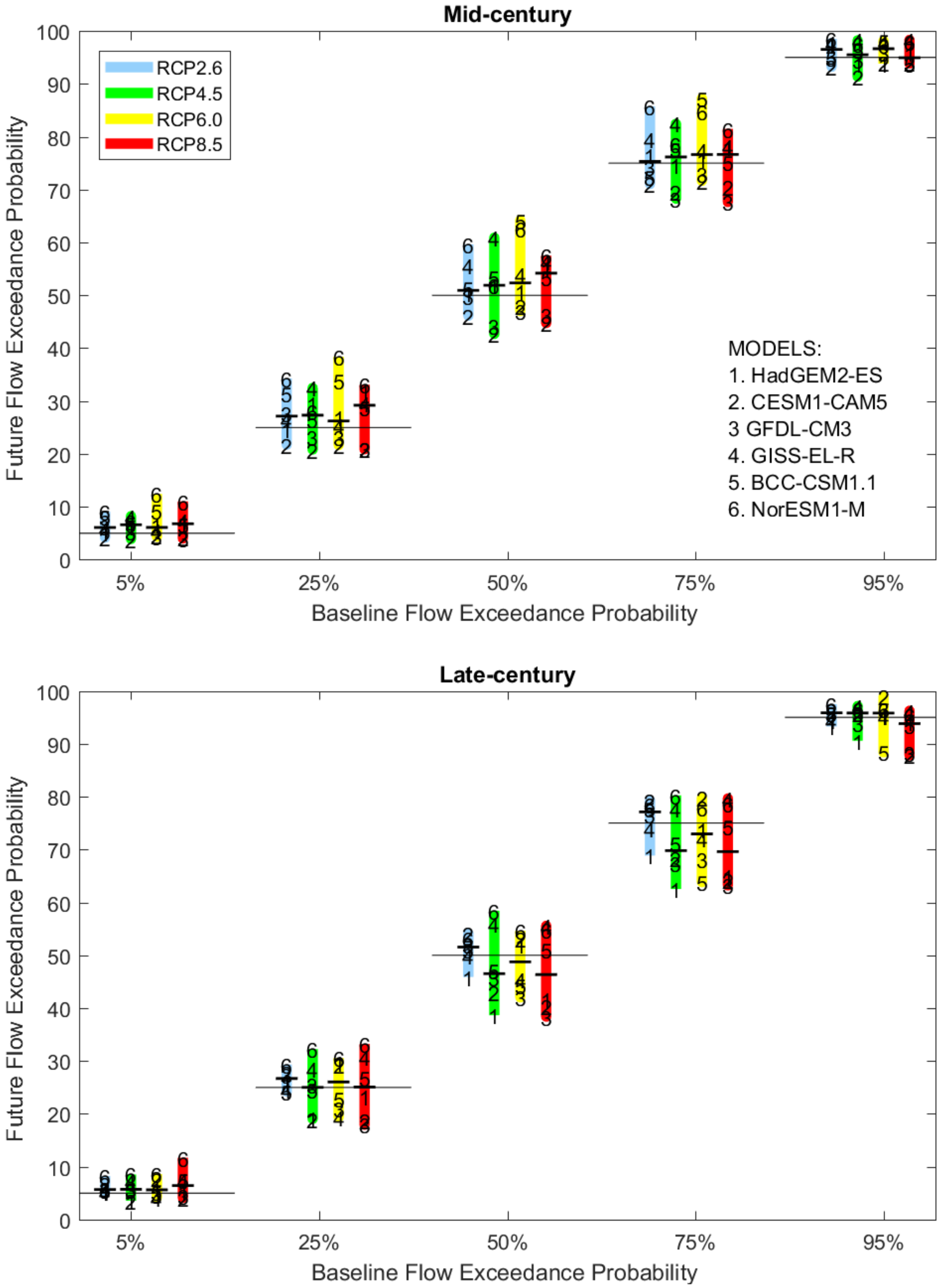


Figure 3-44: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Waikato River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

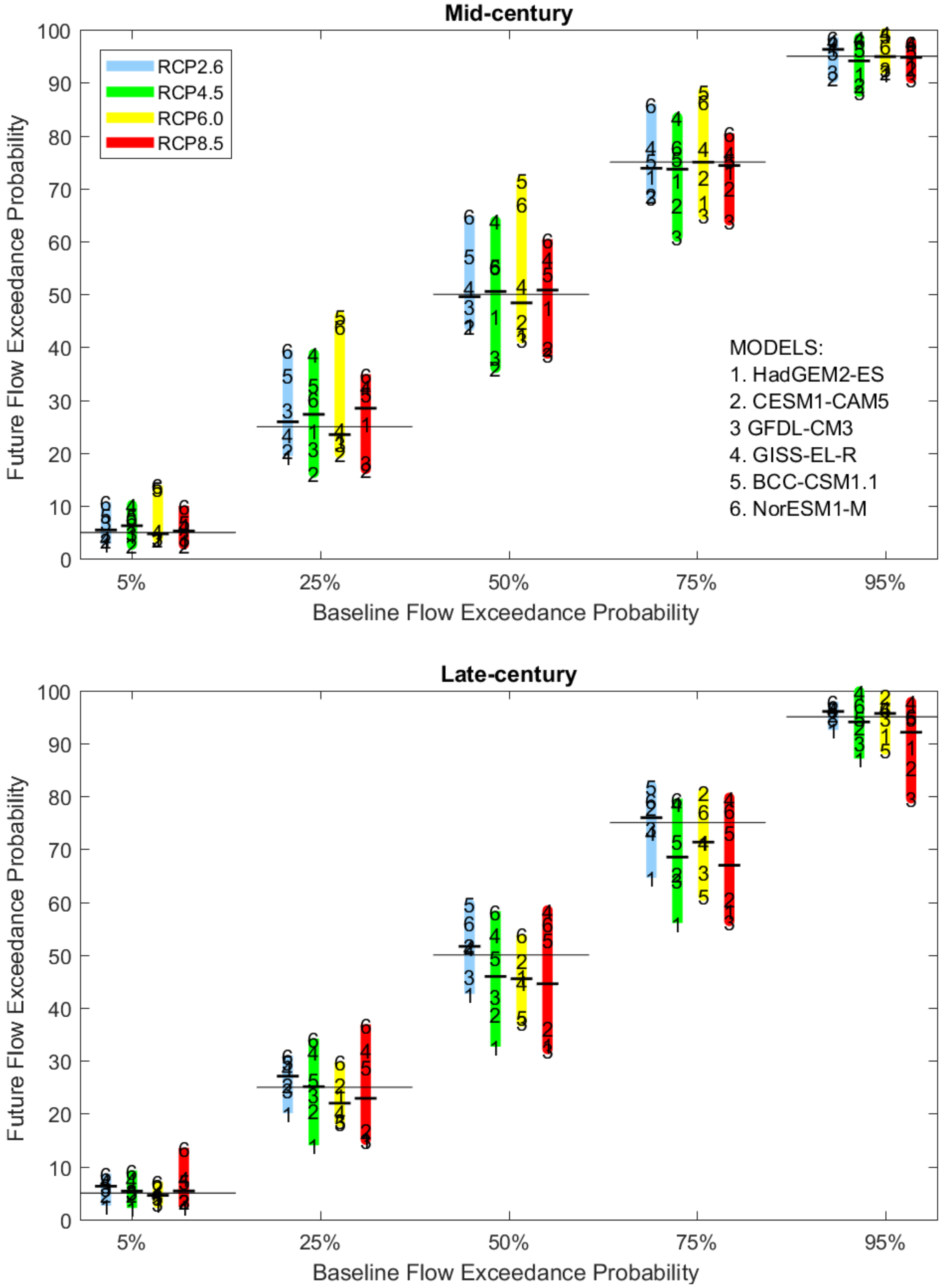


Figure 3-45: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Rangitaiki River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

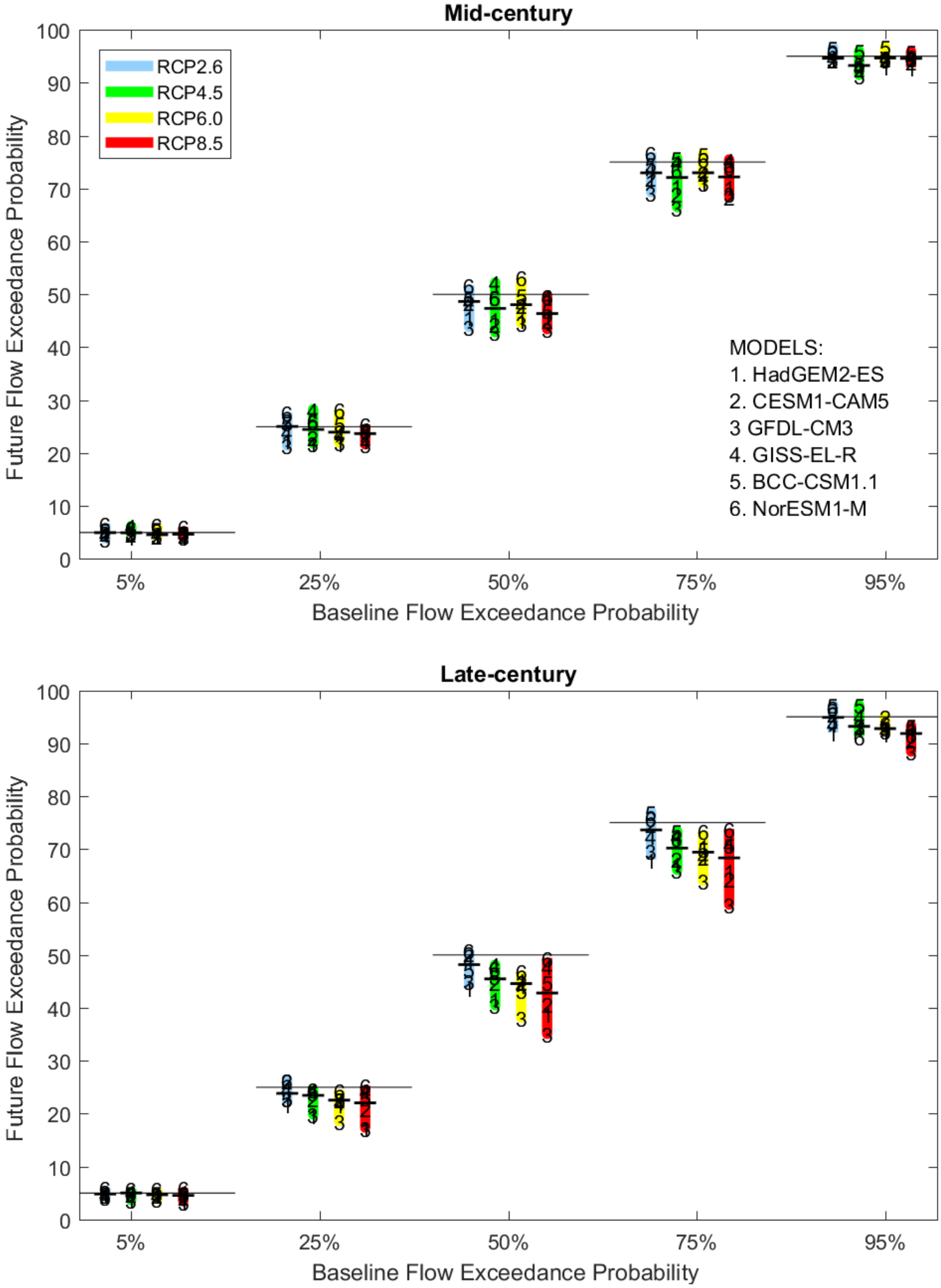
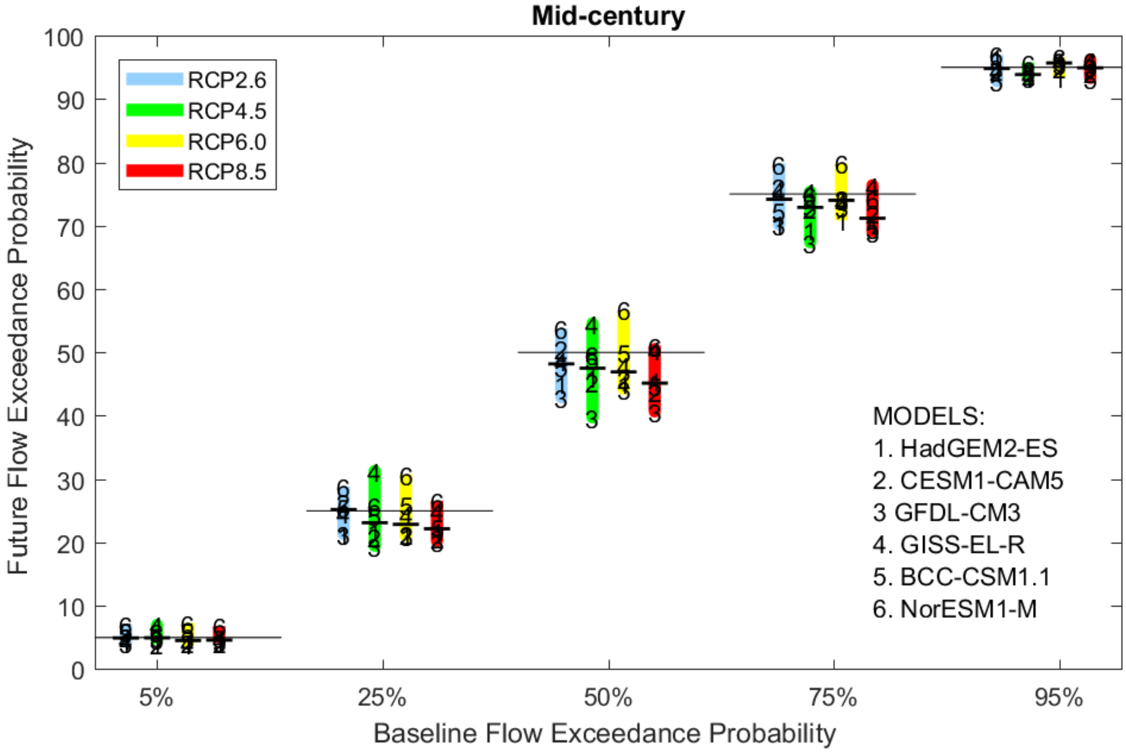


Figure 3-46: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Waiapu River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.



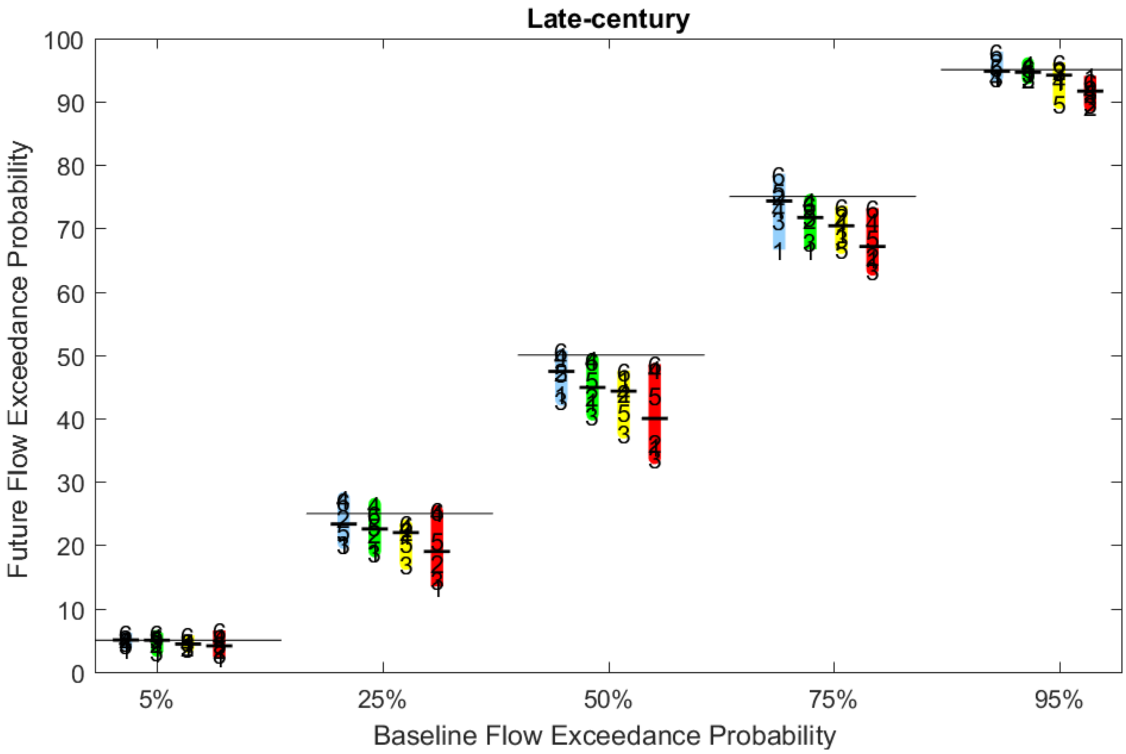


Figure 3-47: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Waipaoa River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

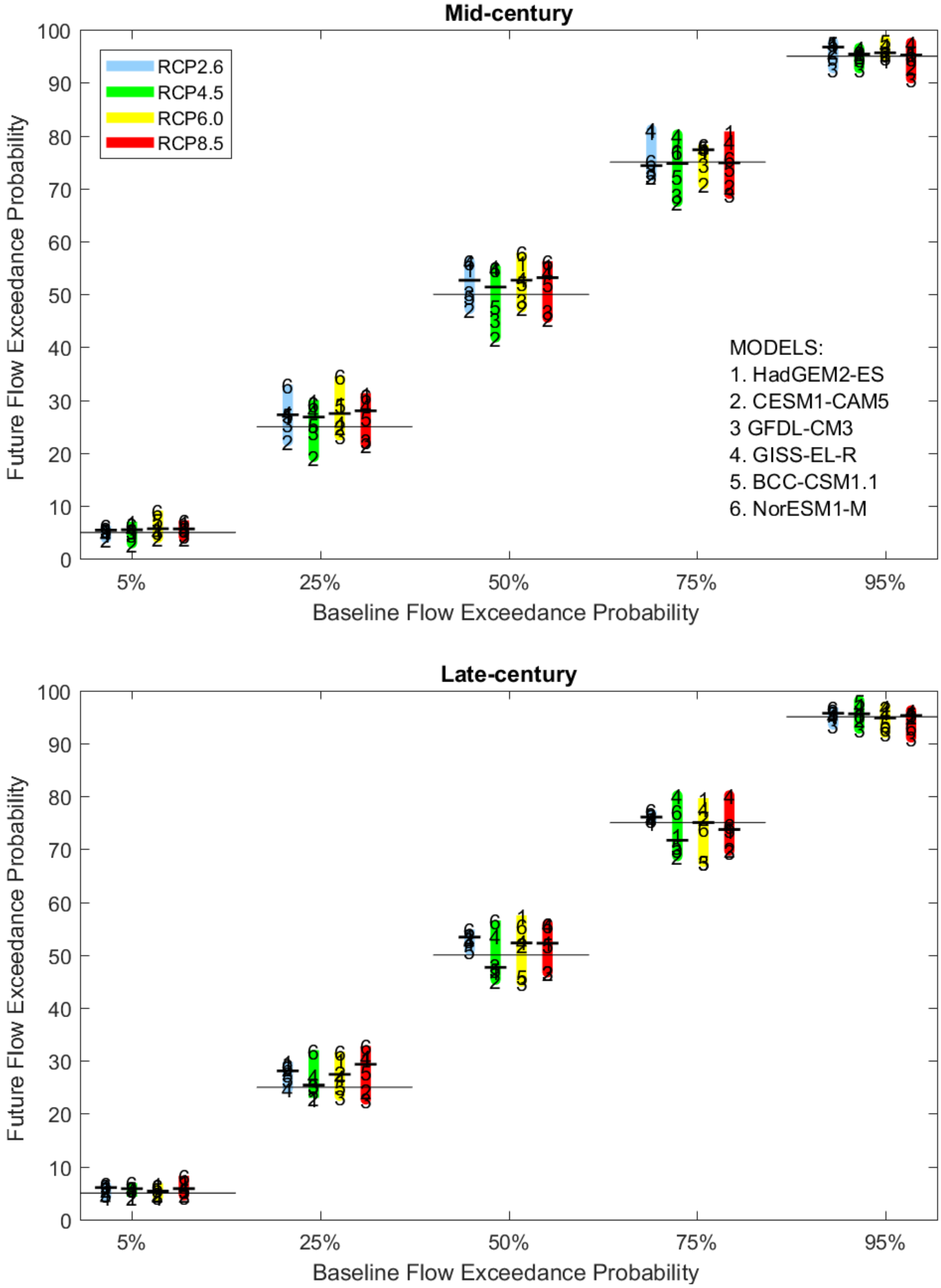


Figure 3-48: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Waiongana River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

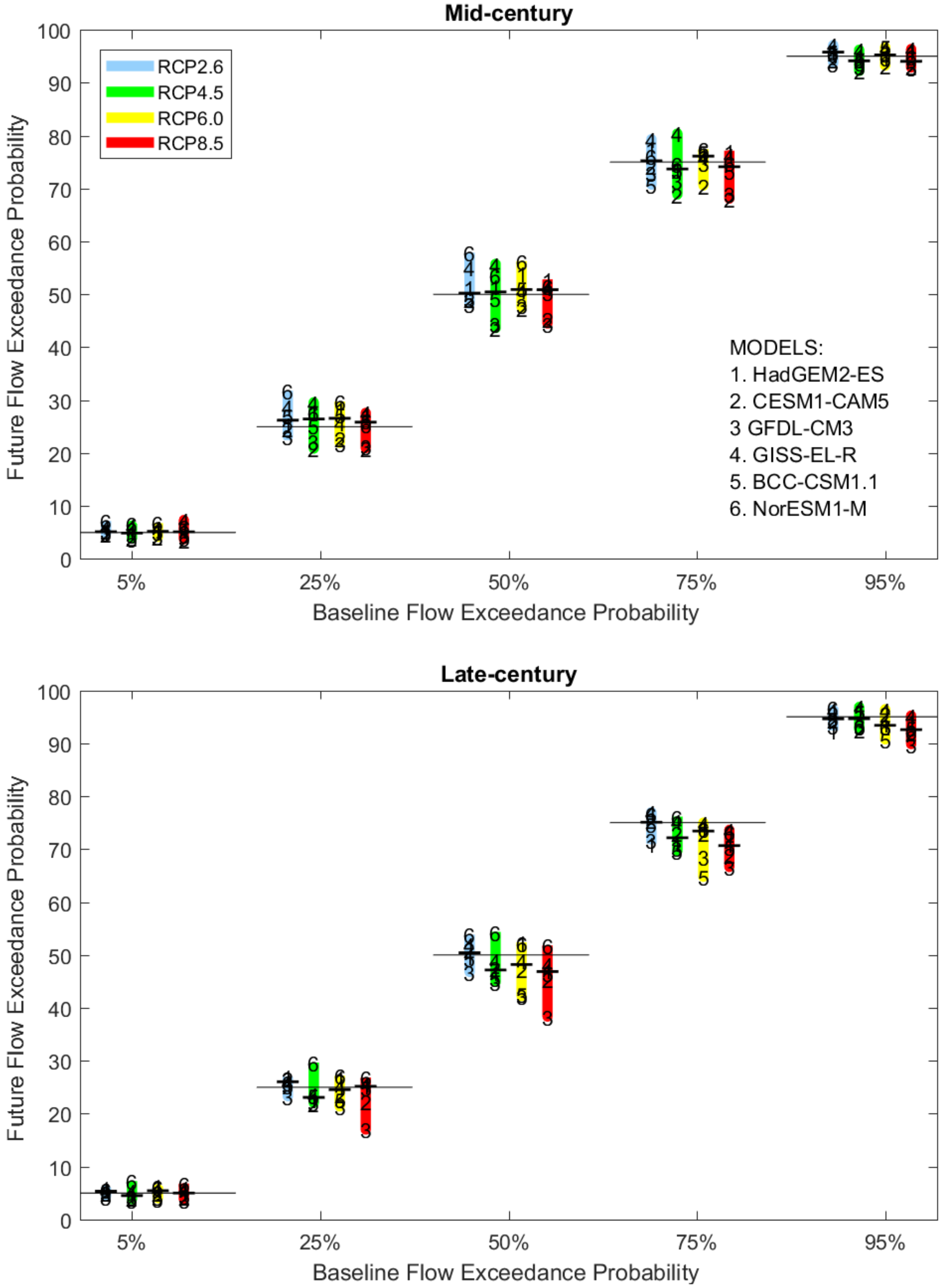


Figure 3-49: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Manawatu River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

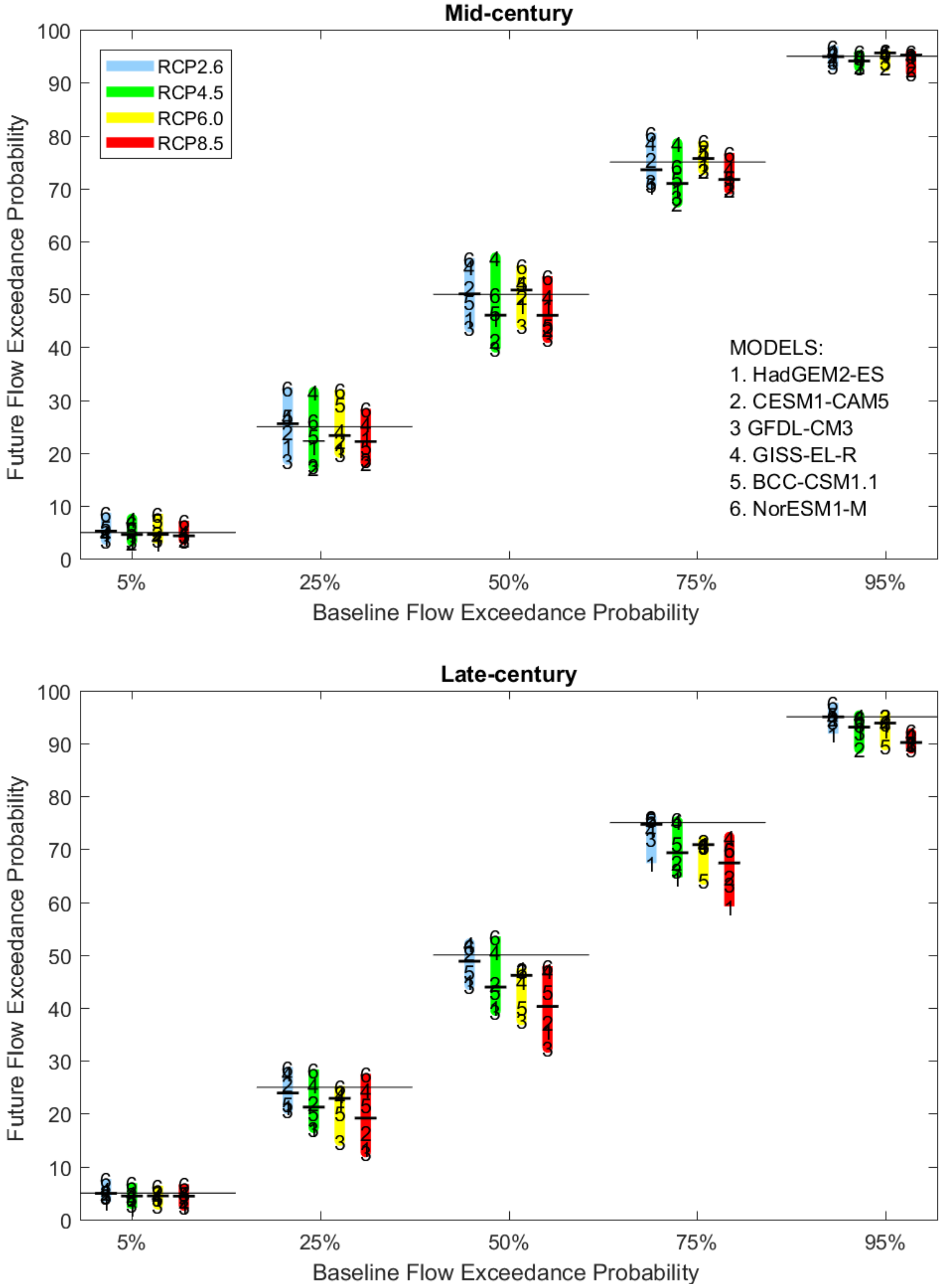


Figure 3-50: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Tukituki River Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

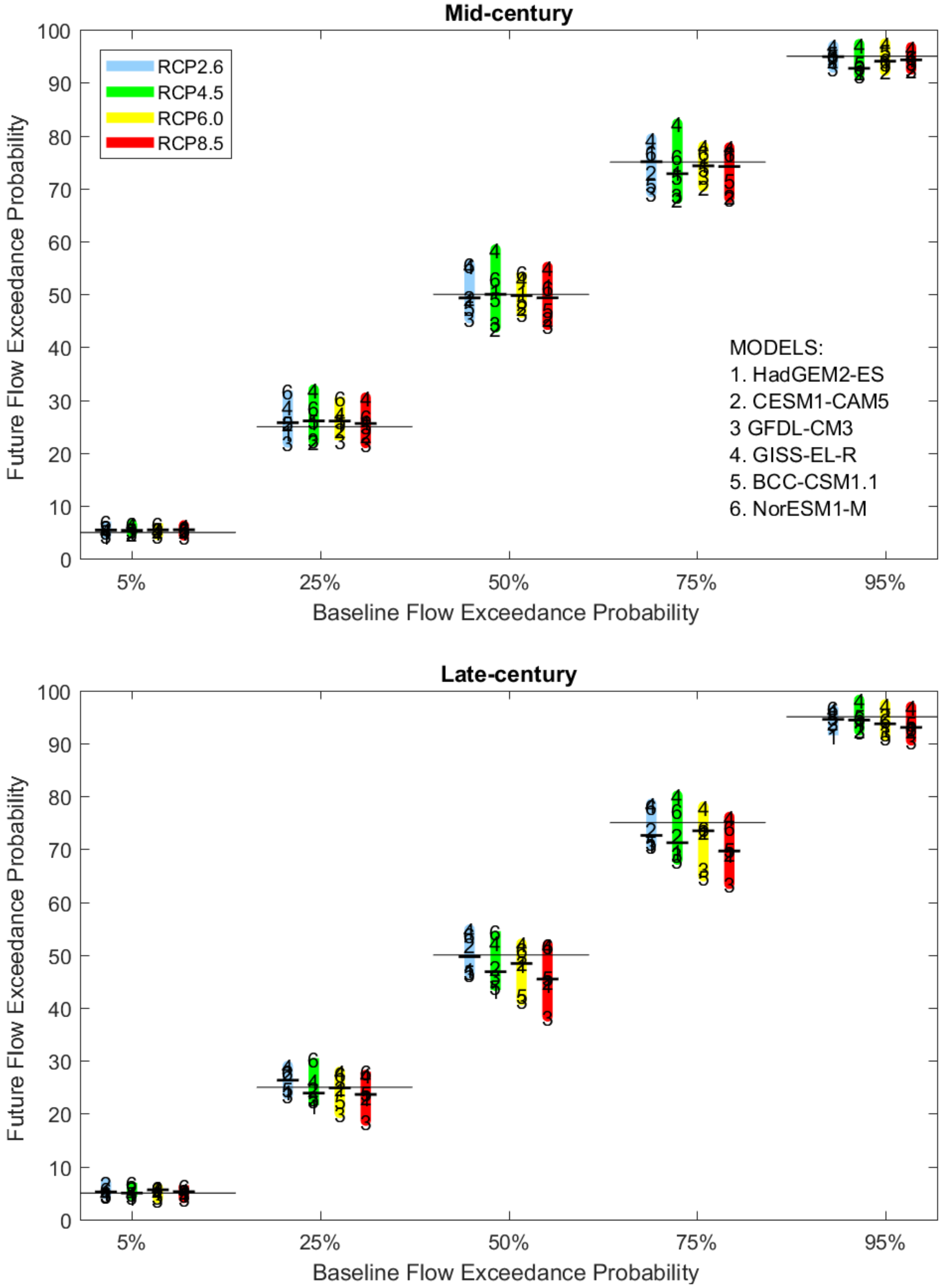


Figure 3-51: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Ruamāhanga River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

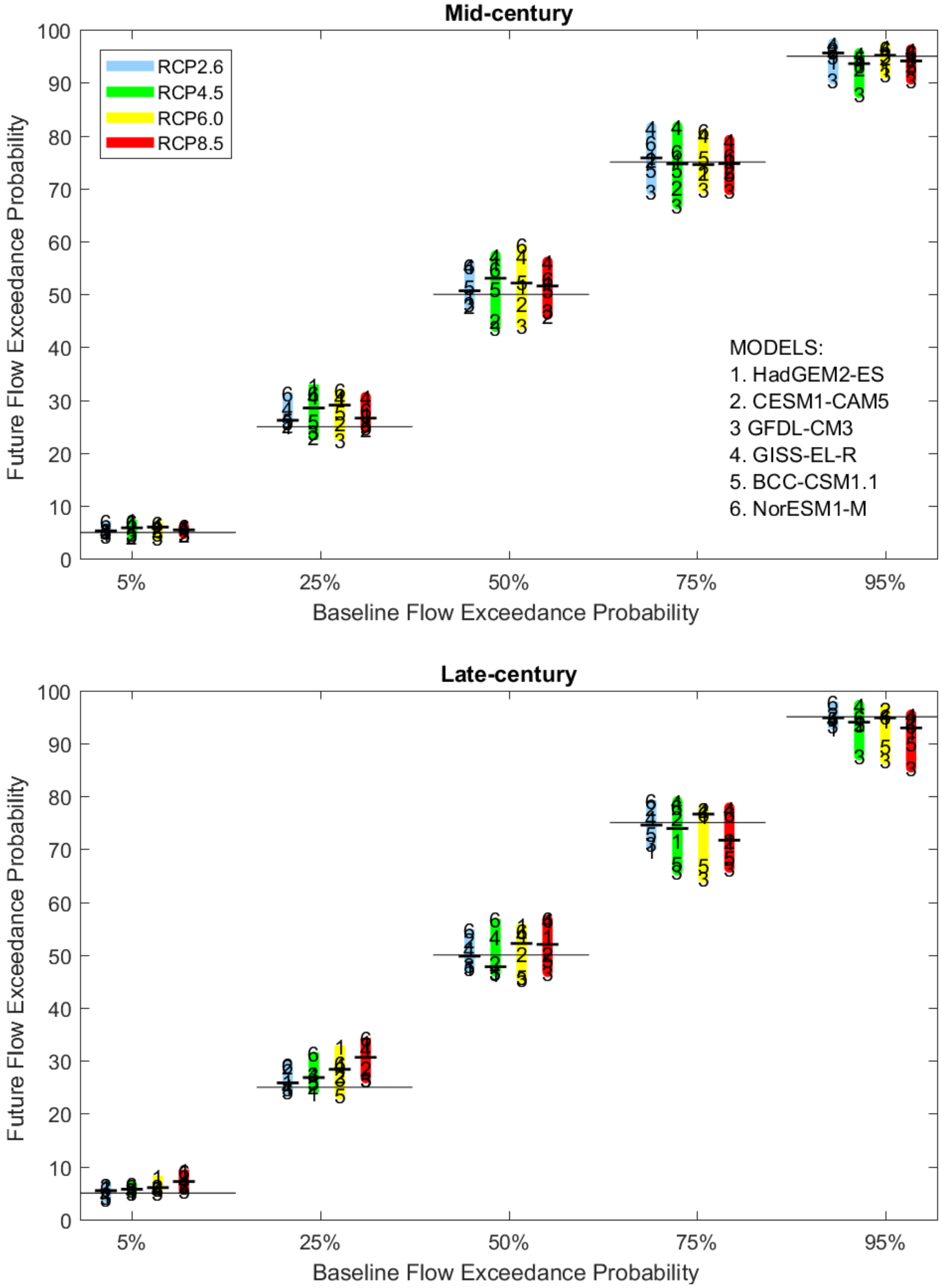


Figure 3-52: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Motueka River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

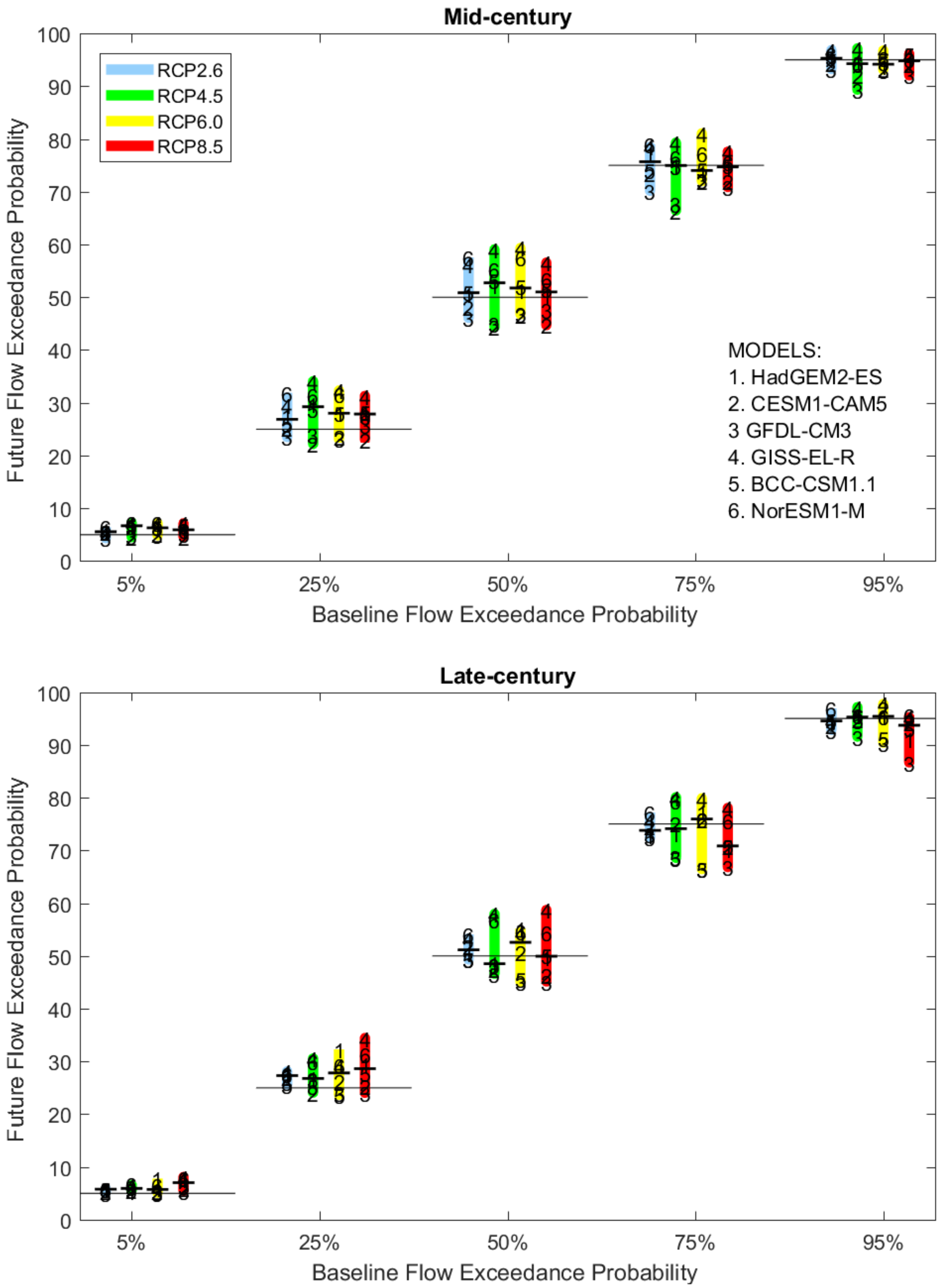


Figure 3-53: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Maitai River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

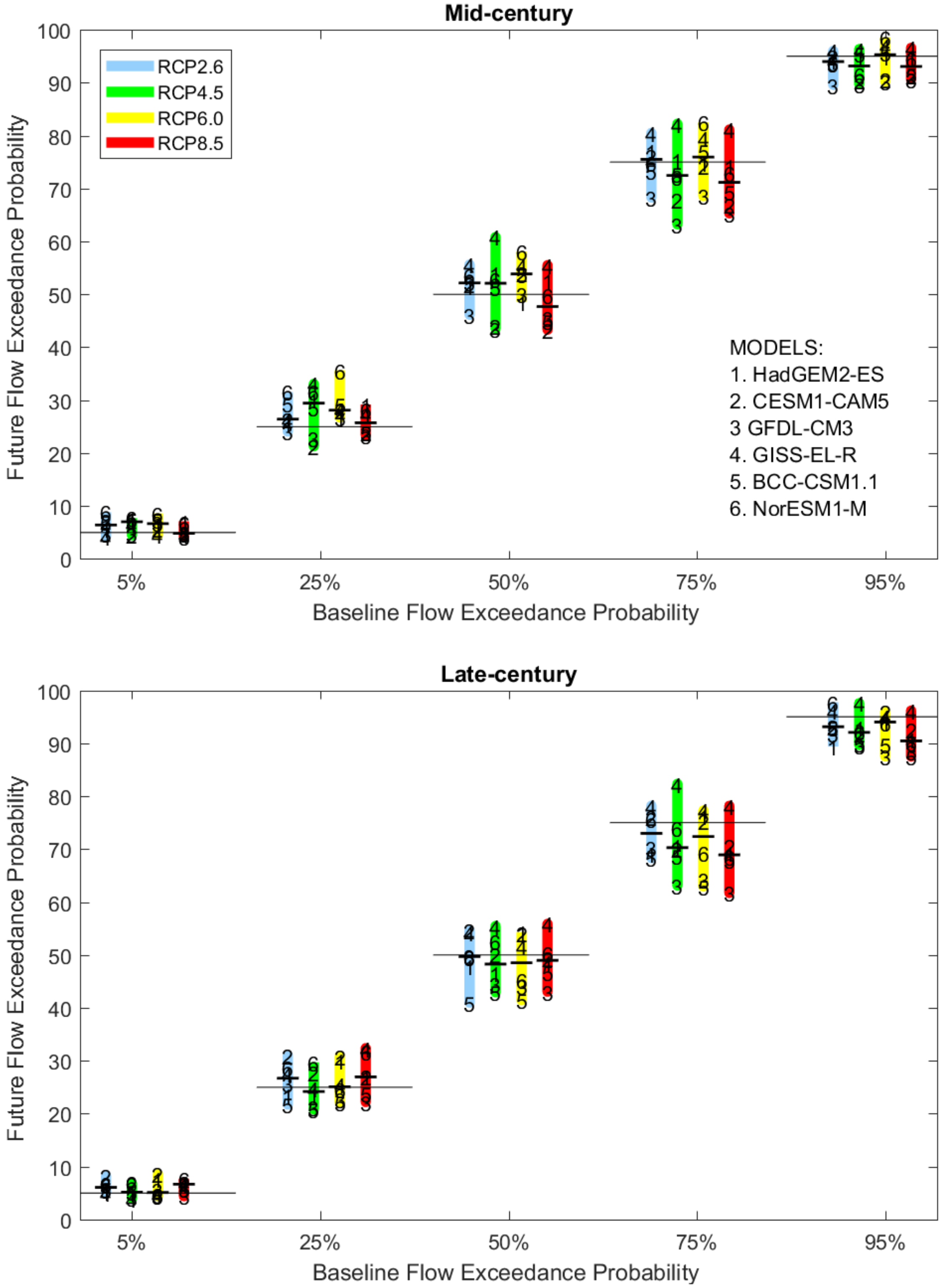


Figure 3-54: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Awatere River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

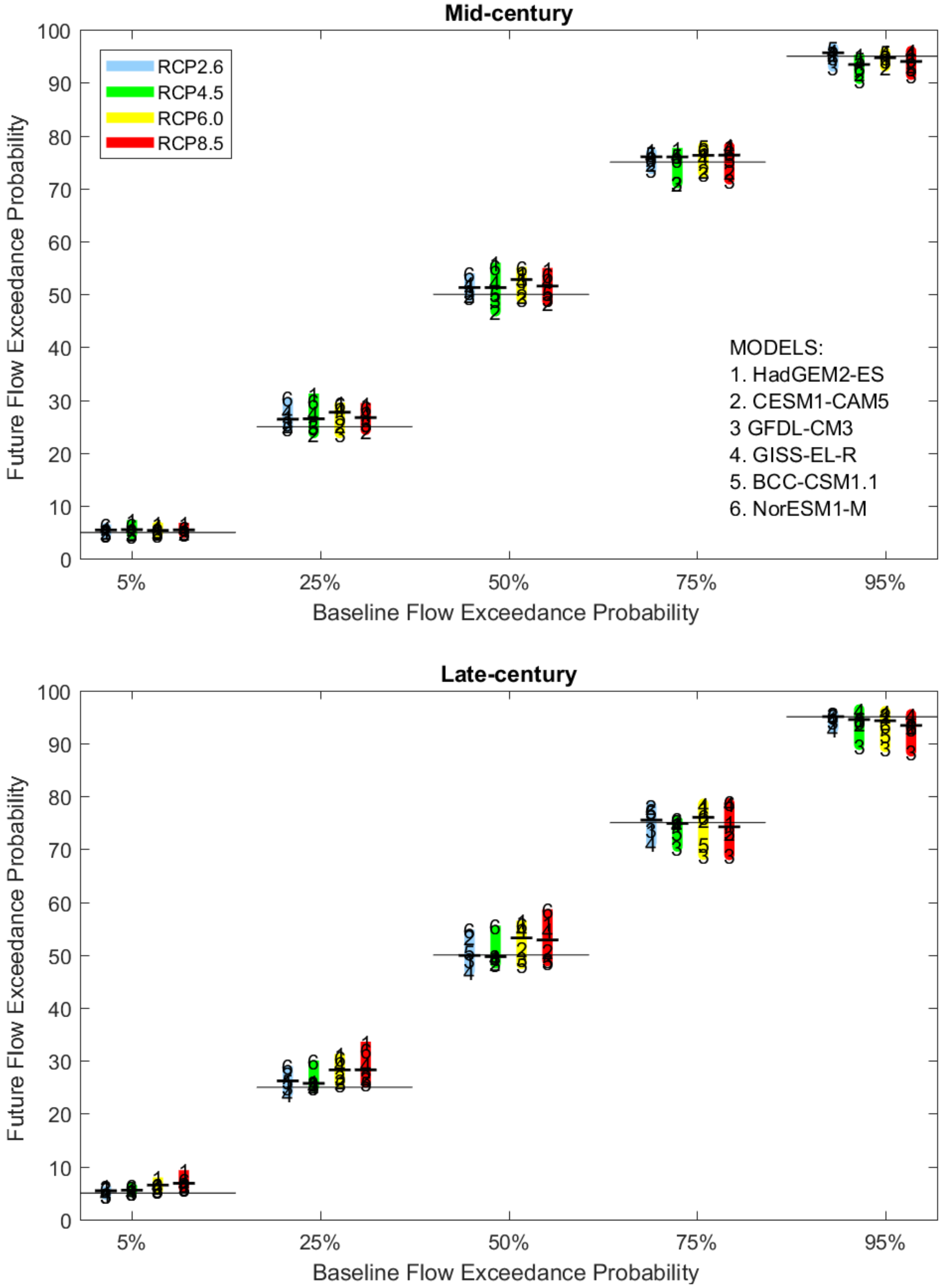


Figure 3-55: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Buller River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

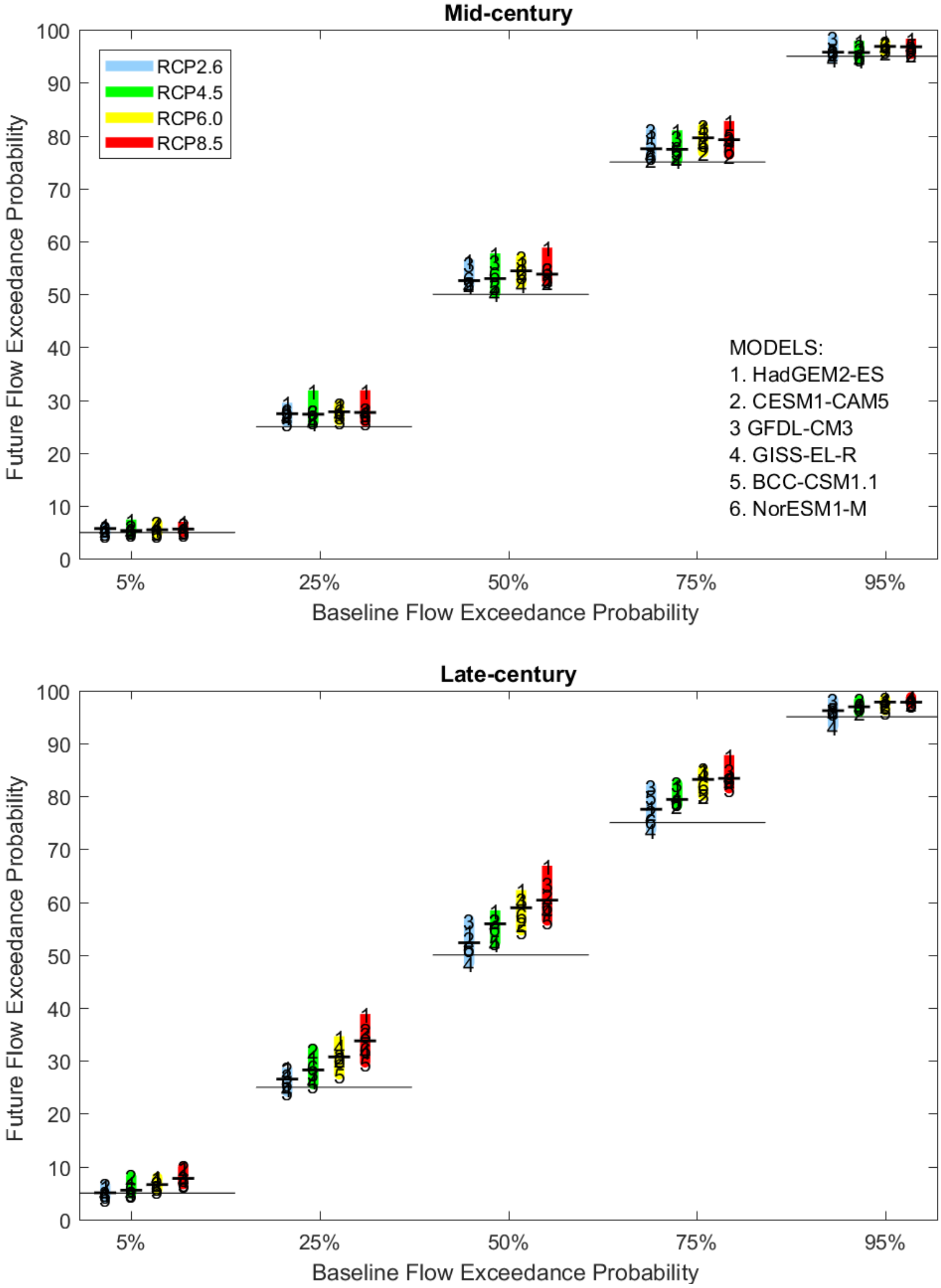


Figure 3-56: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Haast River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

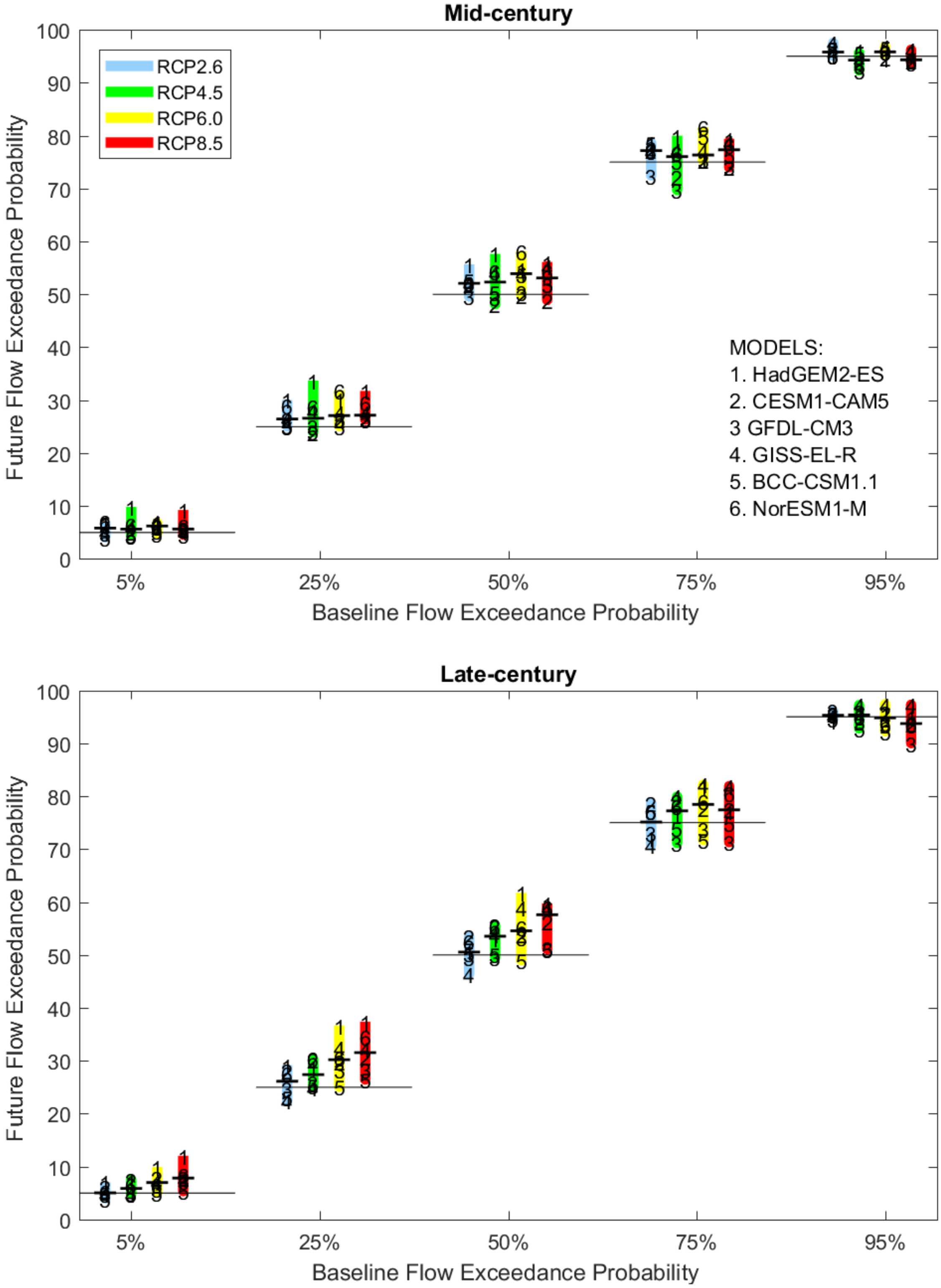


Figure 3-57: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Rakaia River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

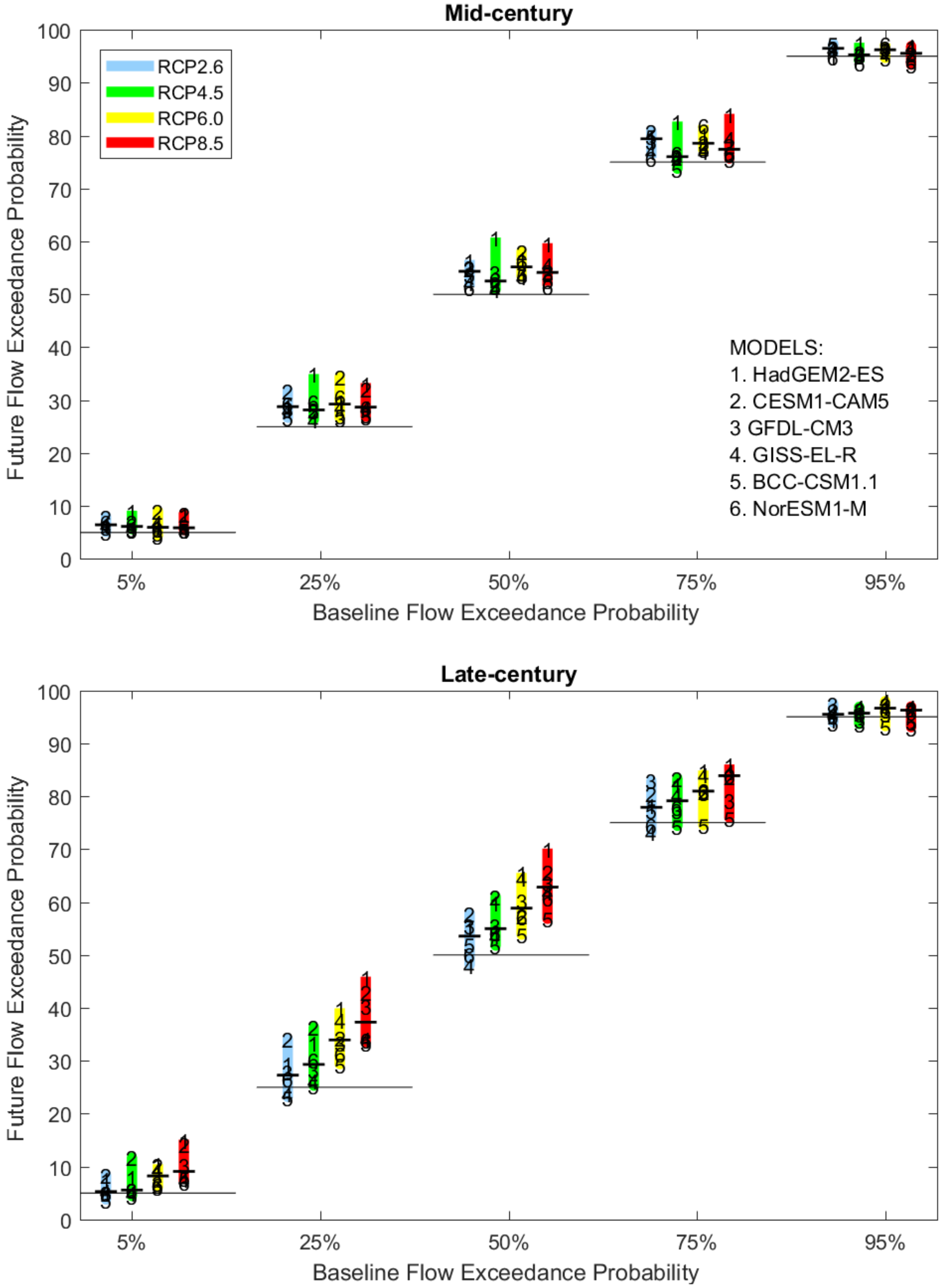


Figure 3-58: Projected flow exceedance probabilities corresponding to flow exceedances for the Clutha River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

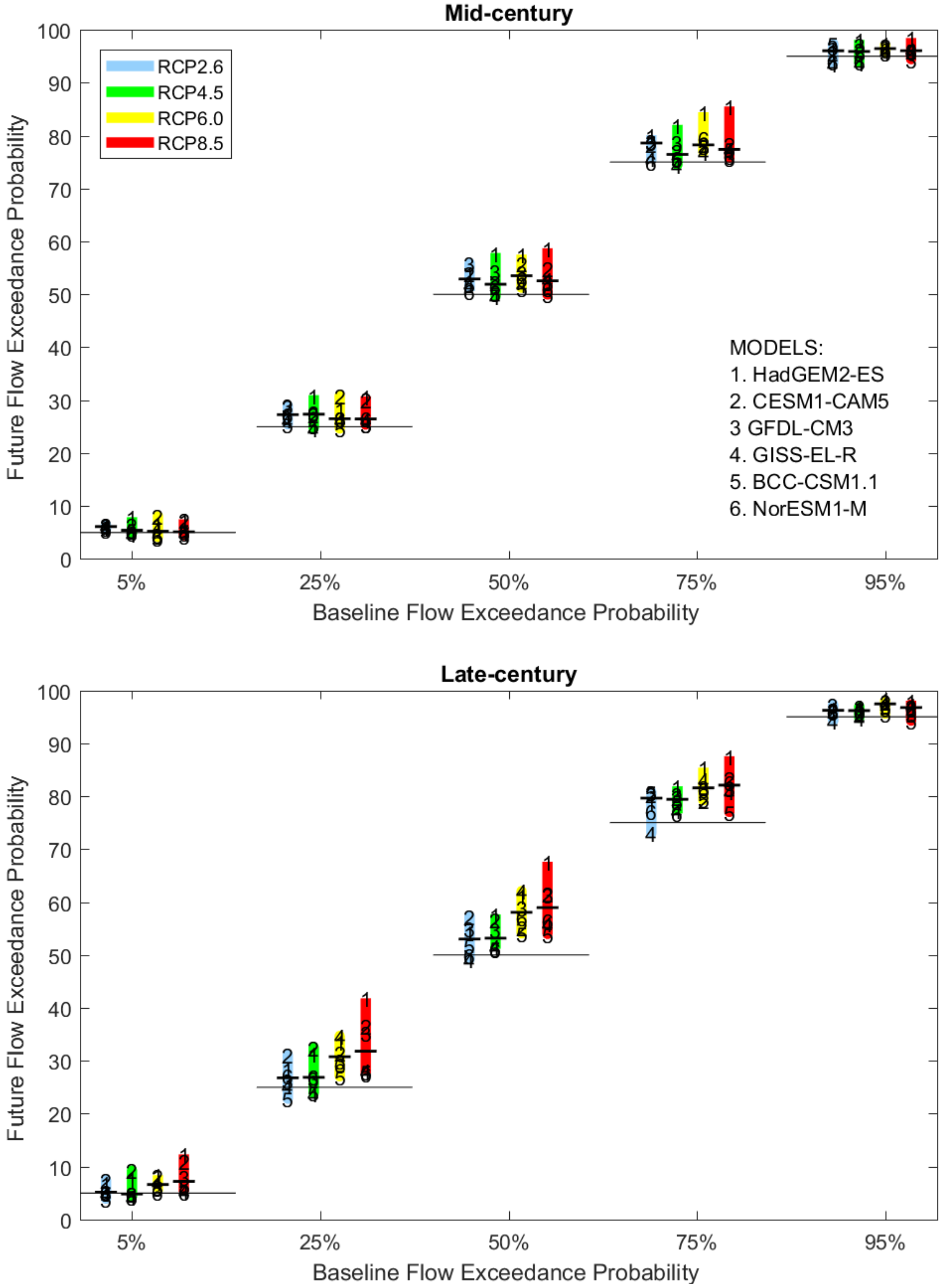


Figure 3-59: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Waiau River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

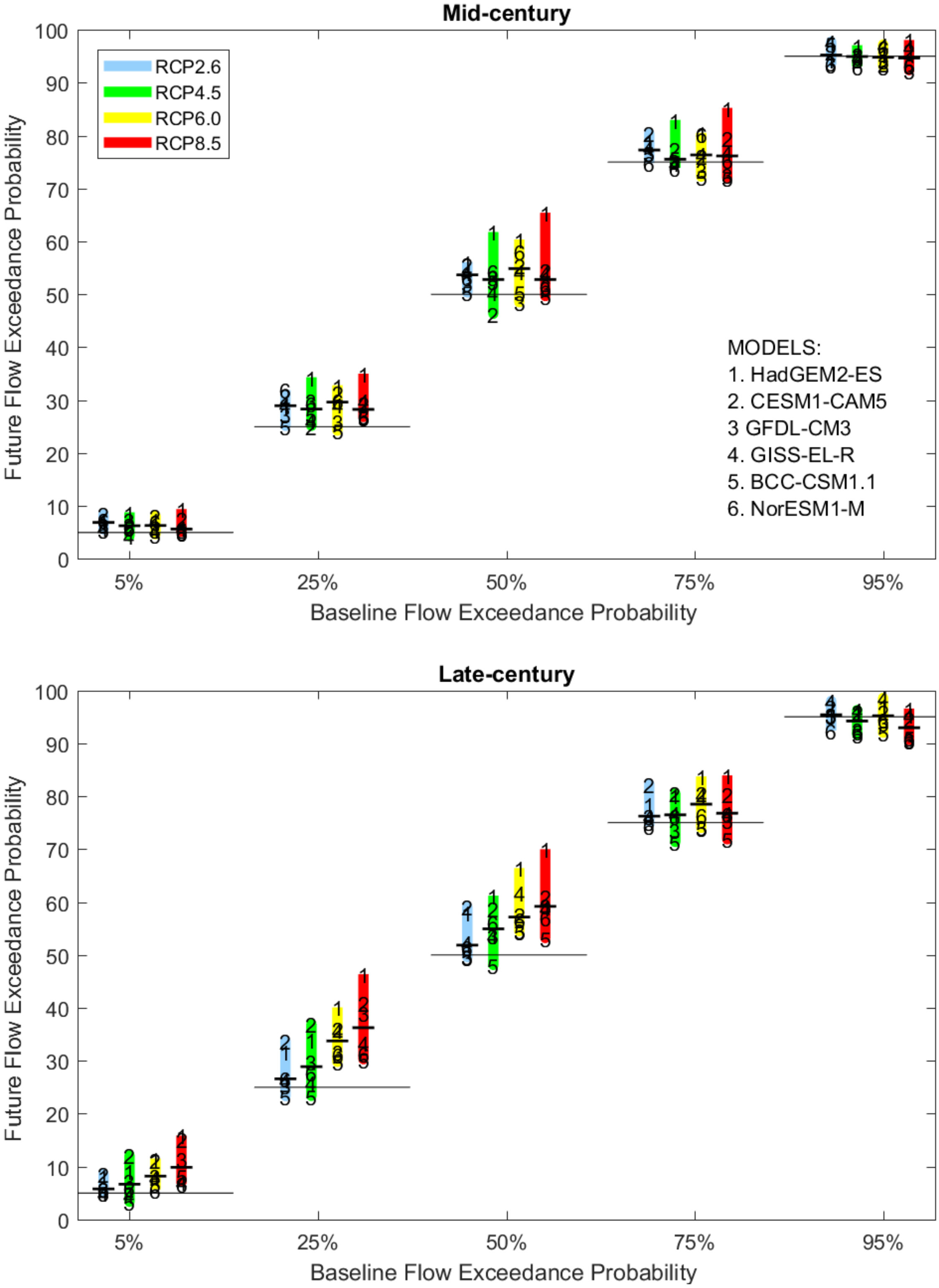


Figure 3-60: Projected flow exceedance probabilities corresponding to baseline flow exceedances for the Mataura River. Mid-century (top panel) and late-century (bottom panel), for all seasons and plus annual, all RCPs (coloured vertical bars) and all GCMs (numbers); horizontal bars are the GCM median.

4 Interpretation and limitations

The results presented above provide an illustration of how climate change may affect New Zealand river hydrology at 20 specific locations. This information will be valuable to decision-makers as they consider whether or how to design mitigation and adapt to climate change. However, it is also important to put these results into perspective, in the context of the modelling and analysis limitations and comparing the results to other studies.

4.1 Model simplifications and assumptions

All stages in the modelling, from the climate to the hydrology, employ simplifications and assumptions to some degree, as is necessary for modelling in general. One issue that effects the skill of the bias corrections is the use of a limited time period from 1980 to 1999. Another is the use of only a single model downscaling. For boundary conditions, six GCMs are used in order to encapsulate a range of plausible interpretations of the climate system. If all GCMs produce similar results, then we are afforded greater confidence in these results – they are more robust. However, for each of the regional climate modelling simulations (including bias correction) and hydrological modelling stages, only a single model is used. This precludes any analysis to explore the sensitivity of the results to simplifications and assumptions being made in the hydrological model. It has been reported previously that TopNet tends to underpredict floods (MAF) and to overpredict low flows (MALF) (McMillan, Booker et al. (2016). Using multiple hydrological models would be a way to compensate for any one model's inaccuracies. The same may be said of the regional climate modelling. In light of these factors, it is likely that the simulated flows are in some way biased. Whether this bias is important for the conclusions and whether it is uniform over the country or over time is unknown.

4.2 Hydrological variables

Two of the variables chosen for the analysis – MAF and MALF – are typical variables used in hydrological analysis and either hazard management or water resource management. They are both indicators of only moderately extreme flow conditions. As such, it would be inaccurate to connect modelled differences in these variables to differences in either flood or drought hazard.

In the first case, the mean annual flood (MAF) is a flood, but not a large flood. This magnitude flood occurs, on average, every two to three years and is of a similar magnitude to the flow necessary to fill a river up to the top of its banks. This size of flood is rarely a nuisance or a hazard, but is used in flood hazard analysis as a reference for the size of floods that could occur. Changes in MAF alone cannot be used to infer changes in flood hazard. For this, research would need to address the more extreme floods, in terms of both size and frequency, and both discharge and inundation extent. Translating the hazard into a risk would require the further consideration of social, cultural, economic, and environmental vulnerability of flood-prone areas.

In the second case, the mean annual low flow (MALF) is an indicator of low flow conditions (e.g., Ministry for the Environment 2008), widely used as a rule-of-thumb for setting minimum flows, but rivers with flows equal to MALF are not typically considered to be in drought. This magnitude of flow occurs, on average, every two to three years. MALF is used as an indicator of how low river flows can drop, but does not describe the most extreme low flows that may occur, nor the implications. For this, research would need to address the more extreme low flow events and examine how these droughts affect social, cultural, economic, and environmental uses of water, whether in-stream or extractive.

4.3 Significance

Throughout this report, comparisons have been made between a baseline period (1986-2005) and two future periods (2031-2050 and 2080-2099). The report has documented the differences in the variables, but when interpreting the results it is important to bear in mind that these differences may be neither statistically significant nor practically significant.

Statistical significance represents our confidence that numerical differences in the variables' values do in fact represent real changes between time periods and are not random consequences of, in this case, natural variability (e.g., El Niño-Southern Oscillation). If variability in hydrological conditions from year to year are large, it would be difficult to be confident that small differences do not occur by chance. The larger the inter-annual variability, the more difficult this assessment becomes. Thus, if differences between time periods are small compared with their inter-annual variability, we cannot make any robust judgements about the potential effects of climate change. This assessment, however, has not been done here. Assessing the statistical significance of these hydrological differences is the subject of other research.

Practical significance represents the importance of numerical differences to stakeholders or affected ecosystems. A difference, whether statistically significant or not, may be too small to be of concern. Alternatively, a difference that is not statistically significant may still be large enough to be of concern. The distinction between statistical significance and practical significance is important as they can both inform decision-making in slightly different ways. Assessing what magnitude of difference is practically significant depends on the exposed community or ecosystem, and is not the subject of this study.

The absence of significance testing, of either statistical or practical significance, means that the results presented here may be interpreted as indicative and preliminary. Should any decisions be made from these results, it would be important to assess the significance of the effects more rigorously.

4.4 Comparisons with other hydrological research

As stated above, the present study draws from the same hydrological simulations as did Collins and Zammit (2016). With different scopes between the two, it is valuable to compare and contrast results from the present study with those of the former.

Many of the patterns observed in the present study were also observed in Collins and Zammit (2016), as would be expected given the common simulation data. Namely:

- Changes in mean, flood, and low flows vary across the country, with some locations registering little effect under climate change.
- Changes tend to become larger towards the end of the century and under more extreme warming scenarios (RCPs).

Where the present study offered particular insight is the analysis of seasonal mean flows. Results presented in Section 3.1 demonstrate that there can be substantial differences in the potential effects of climate change throughout the year, and that simply examining changes in annual flow averages subdues such patterns. This can be important when considering the changing seasonal variability of water supply.

Collins and Zammit (2016) also offered particular insight that the present study does not. They report that climate change is liable to affect seasonal soil moisture as well as river flow, and that the nature of low flow conditions is expected to change in more ways than simply indicated by changes in MALF. This touched specifically on reliability – the ability for abstractors to access water. Also apparent in the results was that single points are not necessarily representative of wider regions or districts, and that large rivers are not necessarily representative of smaller rivers, even if nearby or indeed nested within the larger river.

Comparing the two studies spatially also sheds light on how to conduct hydrological impact assessments under climate change. The maps presented by Collins and Zammit (2016) make it easier to interpret spatial patterns in climate change effects as opposed to using a limited number of study sites. A complete national approach lends itself to more robust spatial conclusions, although location-specific information would still be important for local decision-making.

In light of the above-mentioned contrasts, it is valuable to read both the present report and Collins and Zammit (2016) in tandem.

5 Glossary of abbreviations and terms

7-station series	This refers to 7 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
Anthropogenic	Human-induced; man-made
AR5	Acronym for IPCC Fifth Assessment Report 2013-14
AOGCM	Acronym for Atmosphere-Ocean Global Climate Model – a comprehensive climate model containing equations representing the behaviour of the atmosphere, ocean and sea ice and their interactions
CMIP5	Coupled Model Inter-comparison Project, Phase 5. 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. See website http://cmip-pcmdi.llnl.gov/cmip5/ for more information
Downscaling	Deriving local climate information (at the 5km grid-scale in this report) 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
GCM	Acronym for Global Climate Model. These days almost all GCMs are AOGCMs
IPCC	Acronym for 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. Its latest reports (the Fifth Assessment) were published in 2013-14 (see http://www.ipcc.ch/)

Likelihood estimates	IPCC terminology (see Introduction chapter or Technical Summary) for indicating the assessed likelihood of an outcome or result: ▪ Virtually certain: More than 99% probability of occurrence ▪ Extremely likely: More than 95% probability ▪ Very likely: More than 90% probability ▪ Likely: More than 66% probability ▪ More likely than not: More than 50% probability ▪ Very unlikely: Less than 10% probability ▪ Extremely unlikely: Less than 5% probability
MAF	Mean annual flood (m^3/s). The mean of the series of each year's highest daily mean flow
MALF	Mean annual 7-day low flow (m^3/s). The mean of the series of each year's lowest 7-day discharge
Precipitation	Describes all forms of moisture that falls from clouds (rain, sleet, hail, snow, etc.). "Rainfall" describes just the liquid component of precipitation
Radiative forcing	A measure of the energy absorbed and retained in the lower atmosphere. More technically, radiative forcing is the change in the net (downward minus upward) irradiance (expressed in W m^{-2}, and including both short-wave energy from the sun, and long-wave energy from greenhouse gases) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun
RCM	Acronym for Regional Climate Model. Such models run at higher spatial and time resolution than GCMs but over a limited area of the globe. RCMs take boundary conditions from GCMs, and provide a physically consistent downscaling of the large-scale climate changes simulated by the GCM. They can cater for relatively small-scale features such as New Zealand's Southern Alps
RCP	Representative Concentration Pathway: A concentration scenario identified by its approximate total radiative forcing at 2100 relative to 1750

Scenario	In common English parlance, a "scenario" is simply an imagined sequence of future events. The IPCC Fifth Assessment describes a "climate scenario" as: "A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models" The word "scenario" is often given other qualifications, such as "emission scenario" or "socio-economic scenario". For the purpose of forcing a global climate model, the primary information needed is the time variation of greenhouse gas and aerosol concentrations in the atmosphere. In New Zealand, the climate impacts community prefers to limit the term "scenario" to describing a storyline consistent with a particular combination of greenhouse gas and socio-economic "pathways". Therefore in this report of results from climate model simulations, we endeavour to use the term RCP or pathway, rather than scenario
Surface temperature	Air temperatures measured near or 'at' the surface (usually 1.5 metres above the ground). Soil temperatures at the ground or below can also be measured, but are not presented in this report
SST	Sea Surface Temperature
W m^{-2}	Watts per square meter (a measure of radiation intensity)

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