Uncertainty of climate change projections for Waimakariri River flows

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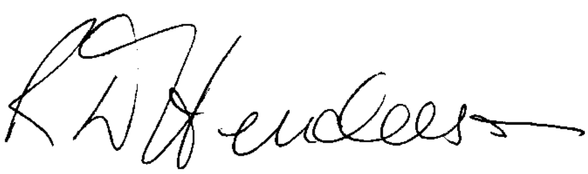

Roddy Henderson

Executive summary

Environment Canterbury wishes to quantify the uncertainty in climate change projections for river flows, so that water allocation decisions can be more robust.

In a previous report for Environment Canterbury (Zammit and Woods, 2011), NIWA made projections for climate change impacts on river flows in the Waimakariri River. These projections were prepared for both the 2040s and 2090s. The results indicated increased Waimakariri River flows in winter (June-July-August) and spring (September-October-November). The projections in that study used an average climate change from 12 global climate models as the input to a hydrological model. The global climate model information in that study used a “middle of the road” greenhouse gas emissions scenario (A1B).

Each combination of global climate model and greenhouse gas emissions scenario leads to a different projected river flow outcome. It is not known which of the global models is most accurate, though all 12 are known to have skill in replicating New Zealand’s current climate. It is not known which of the future greenhouse gas emissions scenarios is closest to what will actually happen in future.

This study quantifies some of the uncertainties in the recent projections for Waimakariri River flows at Otarama. Specifically, it looks at the uncertainties in projections of river flow, due to variation amongst global climate models, and variation amongst the future greenhouse gas emissions scenarios. To assess this, we made multiple hydrological model simulations using climate projections associated with different emissions scenarios and Global Climate Models.

All emissions scenarios, and all GCMs except one, indicate a projected increase in the mean flow of the Waimakariri River at Otarama, which is consistent with the results of Zammit and Woods (2011). The range of percentage changes in mean flow is -7% to +26% by 2040; and -14% to +40% by 2090. All changes are expressed relative to the modelled flows for 1980-99.

All emissions scenarios and all GCMs indicate significant increases in winter mean flows for the Waimakariri River at Otarama, which is consistent with the results of Zammit and Woods (2011). The range of percentage increases in winter mean flows is +2% to +48% by 2040; and +8% to +99% by 2090.

All emissions scenarios and all GCMs indicate an increase in September flows, but not an increase in flows for the whole spring season. In contrast, Zammit and Woods (2011) reported a projected increase in spring flows, and this report supersedes that particular result. We find that there is significant uncertainty in the projections for flows in spring, summer and autumn. The range of projections for 2040 and 2090 includes both decreases and increases in flow in spring, summer and autumn.

The provision of uncertainty bounds on projected changes in river flow enables Environment Canterbury to assess the significance of projected changes in river flows in the context of water allocation and water infrastructure planning.

1 Introduction

Environment Canterbury have projections for climate change impacts on river flows in the Waimakariri River which are based on expected or “middle of the road” future greenhouse gas emissions (Zammit and Woods, 2011). Projections were made for both the 2040s and 2090s. Zammit and Woods (2011) provide detail on the study catchment, model calibration and many other background matters which set the context for this study.

Zammit and Woods (2011) found that the mean flow at Otarama was expected to increase by 7% by 2040, and by 10% by 2090. They also found that August mean flows were expected to increase by 36% by 2040, and by 73% by 2090.

Environment Canterbury now wishes to quantify the uncertainty in climate change projections for river flows, so that water allocation decisions with long timescales can be more robust.

The aim of this project is to estimate the uncertainty in potential climate change effects on mean daily river flows, for one catchment (Waimakariri River in Canterbury). The uncertainty assessment is based on the variation in projected climate among 5 greenhouse gas emissions scenarios and 12 global climate models (GCMs) used in the recent Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report and summarised in Ministry for the Environment (2008).

There are other sources of uncertainty in climate change projections of river flow, which are outside the scope of this report. These include uncertainty in the hydrological model (e.g. whether the TopNet model structure and the calibrated parameter values are appropriate for a future climate), and uncertainty generated by the method for downscaling global climate model output to the catchment.

2 Methods

2.1 Climate

The combinations of emissions scenarios and global climate models (GCMs) used for this study are summarised in Table 2-1. There are 4 extra emissions scenarios and 12 extra global climate models, compared to the work of Zammit and Woods (2011). The emissions scenarios and global climate models are summarised in Appendix 1 and Appendix 2, respectively, of Ministry for the Environment (2008).

Table 2-1: The combinations of emissions scenarios and global climate models used in this study. The terms "2040s" and "2090s" refer to 20-year periods from 2030-2049 and 2080-2099, respectively.

Emissions	Climate Model	Years	Reason for run	Notes
Current	Current climate (VCSN)	1980-99	Establish baseline	As for Zammit and Woods (2011)
A1B	Average of 12 GCMs	2040s and 2090s	Effect of emissions scenarios	As for Zammit and Woods (2011)
A1FI	Average of 12 GCMs	2040s and 2090s	Effect of emissions scenarios	Greater warming than A1B
B1	Average of 12 GCMs	2040s and 2090s	Effect of emissions scenarios	Less warming than A1B
B2	Average of 12 GCMs	2040s and 2090s	Effect of emissions scenarios	Less warming than A1B
A2	Average of 12 GCMs	2040s and 2090s	Effect of emissions scenarios	Greater warming than A1B
A1B	cnrm_cm3	2040s and 2090s	Effect of GCM	
A1B	cccma_cgcm3_1_t63	2040s and 2090s	Effect of GCM	
A1B	csiro_mk3_0	2040s and 2090s	Effect of GCM	
A1B	gfdl_cm2_0	2040s and 2090s	Effect of GCM	
A1B	gfdl_cm2_1	2040s and 2090s	Effect of GCM	
A1B	miroc3_2_hires	2040s and 2090s	Effect of GCM	
A1B	miub_echo_g	2040s and 2090s	Effect of GCM	
A1B	mpi_echam5	2040s and 2090s	Effect of GCM	
A1B	mri_cgcm2_3_2a	2040s and 2090s	Effect of GCM	
A1B	ncar_ccsm3_0	2040s and 2090s	Effect of GCM	
A1B	ukmo_hadcm3	2040s and 2090s	Effect of GCM	
A1B	ukmo_hadgem1	2040s and 2090s	Effect of GCM	
A1FI	miroc3_2_hires	2090s	Combined effect of GCM and emissions	miroc3_2_hires produces largest mean flow increase
A2	miroc3_2_hires	2090s	Combined effect of GCM and emissions	
B2	miroc3_2_hires	2090s	Combined effect of GCM and emissions	
B1	miroc3_2_hires	2090s	Combined effect of GCM and emissions	
A1FI	miub_echo_g	2090s	Combined effect of GCM and emissions	miub_echo_g produces smallest mean flow increase
A2	miub_echo_g	2090s	Combined effect of GCM and emissions	
B2	miub_echo_g	2090s	Combined effect of GCM and emissions	
B1	miub_echo_g	2090s	Combined effect of GCM and emissions	

To evaluate the combined uncertainty of GCM and emissions scenario, we ran TopNet with two selected GCMs (miroc3_2_hires and miub_echo_g), for all emissions scenarios. These two GCMs were selected because they produce the most extreme changes in mean flow, under the A1B emissions scenario (see Figure B2). We did not carry out simulation runs for all possible combinations of GCMs and emissions scenarios, because of the very high computational costs.

Each climate data set in this study is 20 years long: either the “current” climate (1980-99 data from the Virtual Climate Station Network), or a projected future climate. The terms “2040s” and “2090s” are used to refer to 20-year periods from 2030-2049 and 2080-2099, respectively. The modified climate information is generated by altering the current climate data in a way that reflects the projected climate changes. This approach is known as the “delta change method”. Climate data and climate change projections are described in more detail in Zammit and Woods (2011).

2.2 TopNet Model

This study used the same TopNet hydrological model of the Waimakariri that is described in Zammit and Woods (2011), to convert the future climate projections listed in Table 2-1 into river flow scenarios. To provide context for the projected changes in this report, the modelled monthly mean flows for 1980-99 for Waimakariri River at Otarama are listed in Table 2-2.

Table 2-2: Modelled monthly mean flow for Waimakariri at Otarama, 1980-99.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean flow (m^3/s)	102	70	66	74	80	90	81	105	152	194	158	123

3 Results

A total of 43 model simulations were analysed: two simulations (2040s and 2090s) for each of 5 emissions scenarios (using the average of 12 global climate models) and 12 global climate models (GCMs) (using only the A1B emissions scenario), plus one simulation for the current climate. Finally, for the 2090s two selected GCMs were run for four emissions scenarios. Each TopNet model simulation produces 20 years of hourly data.

The results from each simulation are summarised into monthly mean flows, and then each simulation of the future is compared to the monthly mean flows from the simulation of the current climate. The difference between the modelled outputs is interpreted as being the potential impact of climate change on flow.

Figure 3-1 shows the effect of emissions scenario on change in monthly mean river flows at Otarama. More detailed results are shown in Appendix B. All five of the emissions scenarios lead to broadly similar results regarding the direction and seasonality of the change, but with some differences in magnitude of change in winter (June-July-August) and spring (September-October-November). The A1FI and A2 scenarios lead to the largest projected increases in flow.

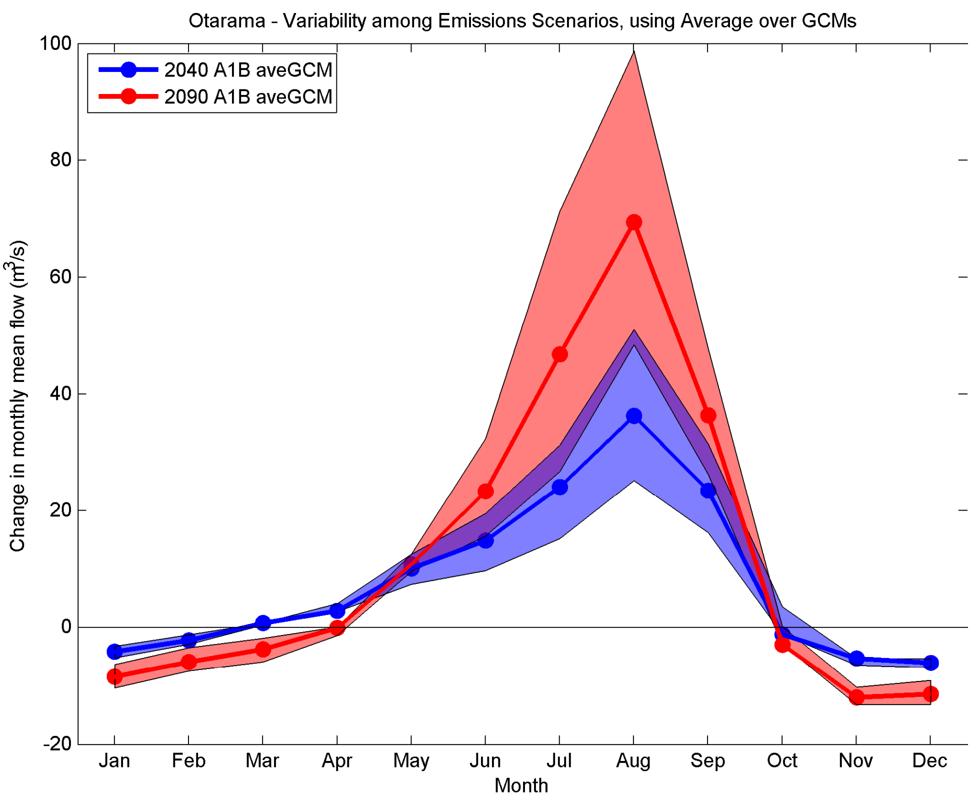

Figure 3-1: Effect of emissions scenario on changes in monthly mean flow at Otarama. Blue and red shading indicates the full range of results for 2040s and 2090s, respectively. Solid lines are for A1B emissions, which is the same case as used in Zammit and Woods (2011).[1]

[1] There is an unresolved discrepancy of 7 m3/s between this A1B simulation using the GCM-average model, and that shown in Zammit and Woods (2011). We consider this small enough that resolving it would not affect the conclusions of this report.

Figure 3-2 shows the effect of GCM on change in monthly mean river flows at Otarama. More detailed results are shown in Appendix B. The GCMs all lead to broadly similar results regarding a projected increase in flow in the months July to September. Some GCMs result in a projected increase in flow for summer (Dec-Jan-Feb) and autumn (Mar-Apr-May), and some result in a decrease for summer and autumn.

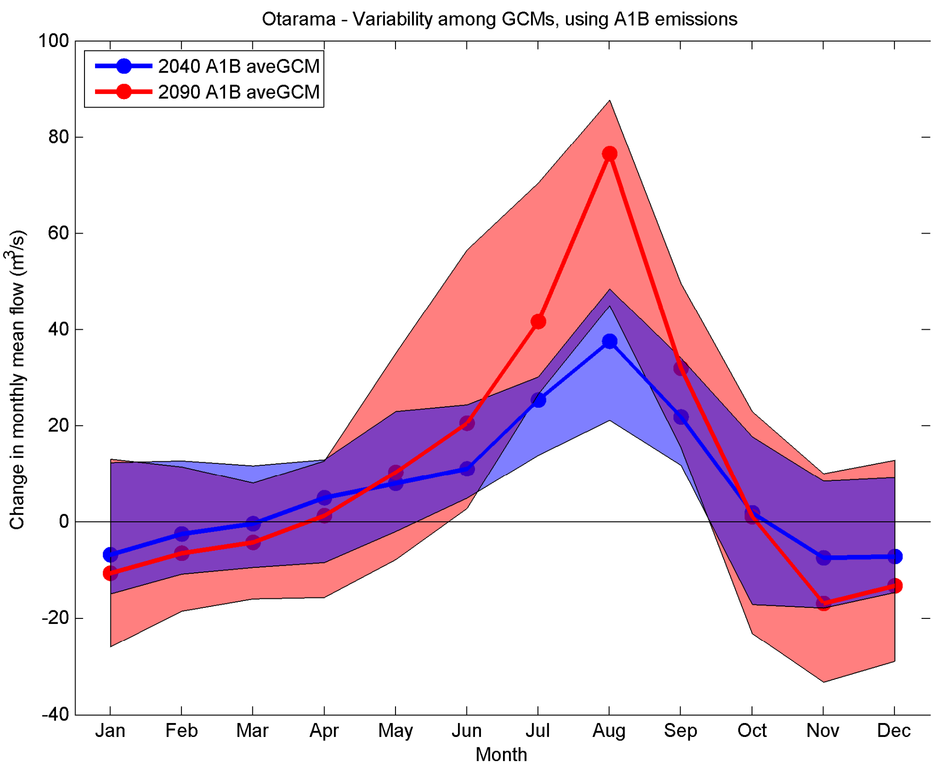

Figure 3-2: Effect of GCM on changes in monthly mean flow at Otarama. Blue and red shading indicates the 10th and 90th percentile of results for 2040s and 2090s, respectively. Solid lines are for the average GCM climate used in Zammit and Woods (2011).

In Figure 3-3 we see the impact of emissions scenario for two selected GCMs, for the 2090s. This figure indicates that for an individual GCM, the uncertainty associated with the emissions scenario is between +/-8 m^3/s in autumn and +/-18 m^3/s in winter. From the results in Figure 3-1, it is reasonable to expect that the uncertainty in 2040 would be about half this.

The emissions scenario A1FI is associated with the greatest global warming, and it leads to increased winter flows in both GCMs. However, the A1FI emissions scenario leads to greater summer flows in one GCM (miroc3_2_hires) and smaller summer flows in the other GCM (miub_echo_g).

This explains why the emissions scenarios in Figure 3-1 have such a small range in summer. Under extreme warming emissions like A1FI, Figure 3-3 shows that some GCMs produce more summer rain (compared to A1B), while others produce less summer rain (compared to A1B). So if under A1FI we take the average summer GCM rain across all models, it will be close to the average that the GCMs give under A1B. Thus there will only be a small difference in summer rain between the A1FI and A1B scenarios, when we take the average across all GCMs.

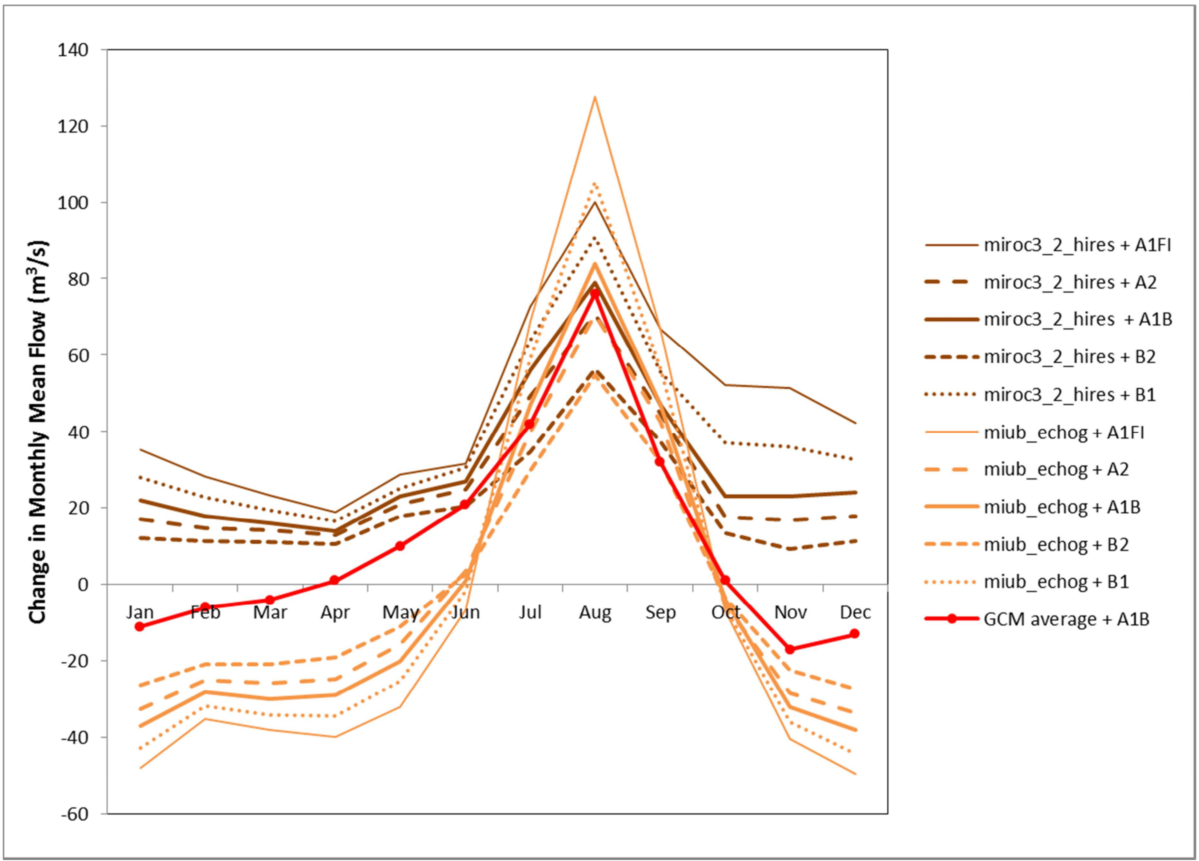

Figure 3-3: Effect of emissions scenario on flow in 2090s at Otarama, for two selected GCMs. Dark brown lines are for the miroc3_2_hires GCM, with various emissions scenarios (miroc3_2_hires was chosen because it produces the largest increase in mean flow). Orange lines are for the miub_echo_g GCM, with various emissions scenarios (miub_echo_g was chosen because it produces the lowest increase in mean flow). The red line for GCM average with A1B emissions is shown for reference.

In winter, under extreme warming emissions like A1FI, all GCMs produce more rain (compared to A1B). So if under A1FI we take the average winter GCM rain across all models, it will be greater than the average winter rain that the GCMs give under A1B. For this reason, the GCM-average results for the various emissions scenarios, in Figure 3-1, are not a reliable representation of the effect of emissions scenario uncertainty in summer.

All the above results are summarised in tabular form in Table 3-1 (where changes are shown as percentages). The same information is presented in m^3/s units in Appendix A.

Table 3-1: Upper and lower estimates of climate change impacts (in % terms) on mean river flows for Waimakariri River at Otarama, by season. All uncertainties expressed in percentages of the mean flows for the corresponding season. (See Appendix A for changes expressed in units of m^3/s.)

	When	Winter (JJA)	Spring (SON)	Summer (DJF)	Autumn (MAM)	Annual
Range across Emissions Scenarios, using GCM average	2040	[+18,+37]	[+2,+6]	[-5,-3]	[+5,+8]	[+5,+10]
	2090	[+33,+73]	[+3,+7]	[-11,-6]	[+2,+4]	[+7,+16]
Range across Emissions scenarios using individual GCMs	2040	+/- 10	+/- 4	+/- 6	+/- 5	+/- 6
	2090	+/- 19	+/- 8	+/- 11	+/- 10	+/- 11
Range across GCMs	2040	[+12,+38]	[-8,+13]	[-16,+14]	[-13,+24]	[-1,+20]
	2090	[+27,+80]	[-13,+18]	[-35,+22]	[-36,+24]	[-3,+29]
Total Range over Emissions Scenarios and GCMs*	2040	**[+2,+48]**	**[-12,+17]**	**[-22,+20]**	**[-18,+29]**	**[-7,+26]**
	2090	**[+8,+99]**	**[-21,+26]**	**[-46,+33]**	**[-46,+34]**	**[-14,+40]**

*Note that we have computed the total range by adding the ranges due to emissions scenarios using individual GCMs to the range across GCMs.

4 Discussion

The range of percentage changes in mean flows for the two time periods is: 2040s: -7% to +26%; 2090s: -14% to +40%. The Zammit and Woods (2011) estimates of change in mean flows for these two periods were +7% and +10%, respectively. All changes are expressed relative to the modelled flows for 1980-99.

The projected changes in flows are not uniform through the year, and the largest projected changes are in winter (Jun-Jul-Aug) and early spring (i.e., September). The projected changes for the 2040s are:

- Winter: increase; +2% to +48%
- Spring: decrease or increase; -2% to +17%
- Summer: decrease or increase; -22% to +20%
- Autumn: decrease or increase; -18% to +29%

The projected winter changes for the 2090s are for larger increases: +8% to +99%. The spring, summer and autumn changes for the 2090s are of similar character to those for 2040s, but generally with wider ranges.

The four calendar months with the largest projected changes are June, July, August and September: these months all have increases, for all emissions scenarios, and for all global climate models.

August is the month with the largest projected increase: between +25% and +65% by 2040, and between +50% and +120% for 2090s. Zammit and Woods (2011) found that August flows were expected to increase by 36% by 2040, and by 73% by 2090.

The uncertainty due to GCMs is larger than the uncertainty due to emissions scenarios, in all seasons, and all years. Details of the model outputs are available in Appendix B. The uncertainty due to emissions scenarios is relatively small in spring, summer and autumn.

The following sources of uncertainty are not considered:

- Hydrology model uncertainty – a component of the uncertainty is that the TopNet hydrological model may have wrongly predicted the effect of climate change on flows. For example, TopNet may have wrongly estimated the effect of temperature rise on whether precipitation falls as rain or snow. The validity of the TopNet snow component can be tested once sufficient snow data have been collected in the catchment.
- Climate downscaling uncertainty – another component of the uncertainty is that the statistical downscaling method we used may have incorrectly translated the changes in global climate model output into changes in the climate of the Waimakariri catchment.

5 Conclusion

This study quantifies some of the uncertainties in the recent projections for Waimakariri River flows at Otarama. Specifically, it looks at the uncertainties in projections of river flow, due to variation amongst global climate models, and variation amongst the future greenhouse gas emissions scenarios. To assess this, we made multiple hydrological model simulations using climate associated with five different emissions scenarios (using the average over the 12 GCMs) and 12 different Global Climate Models (using the A1B emissions scenario).

All emissions scenarios, and all GCMs except one, indicate a projected increase in the mean flow of the Waimakariri River at Otarama, which is consistent with the results of Zammit and Woods (2011). The range of percentage changes in mean flow is -7% to +26% by 2040; and -14% to +40% by 2090. All changes are expressed relative to the modelled flows for 1980-99.

All emissions scenarios and all GCMs indicate significant increases in winter mean flows for the Waimakariri River at Otarama, which is consistent with the results of Zammit and Woods (2011). The range of percentage increases in winter mean flows is +2% to +48% by 2040; and +8% to +99% by 2090.

All emissions scenarios and all GCMs indicate an increase in September flows, but not an increase in flows for the whole spring season. In contrast, Zammit and Woods (2011) reported a projected increase in spring flows, and this report supersedes that result. We find that there is significant uncertainty in the projections for flows in spring, summer and autumn. The range of projections for 2040 and 2090 includes both decreases and increases in flow in spring, summer and autumn.

The provision of uncertainty bounds on projected changes in river flow enables Environment Canterbury to assess the significance of projected changes in river flows in the context of water allocation and water infrastructure planning.

6 References

Ministry for the Environment (2008). Climate Change Effects and Impact assessment. A Guidance Manual for Local Government in New Zealand. 2nd edition. Prepared by Mullan, B.; Wratt, D.; Dean, S.; Hollis, M. (NIWA); Allan, S.; Williams, T. (MWH NZ Ltd); Kenny, G. (Earthwise Consulting Ltd), in consultation with Ministry for the Environment. NIWA Client Report No WLG2007/62. 156 p.

Zammit, C.; Woods, R.A. (2011). Projected climate and river flow for the Waimakariri catchment for 2040s and 2090s. NIWA Client Report No. CHC2011-025. 52 p.

Appendix A Changes in flows (m^3/s units)

Table A1: Upper and lower estimates of climate change impacts (in m^3/s) on river flows for Waimakariri River at Otarama. All changes expressed in m^3/s. See main body of report for % changes.

	When	Winter (JJA)	Spring (SON)	Summer (DJF)	Autumn (MAM)	Annual
Range across Emissions Scenarios using GCM average	2040	[+17,+34]	[+3,+10]	[-5,-3]	[+3,+6]	[+5,+11]
	2090	[+30,+67]	[+5,+11]	[-10,-6]	[+2,+3]	[+8,+17]
Range across Emissions scenarios using individual GCMs	2040	+/- 9	+/- 7	+/- 6	+/- 4	+/- 6
	2090	+/- 18	+/- 14	+/- 11	+/- 8	+/- 12
Range across GCMs	2040	[+11,+35]	[-13,+22]	[-16,+14]	[-9,+17]	[-1,+21]
	2090	[+25,+74]	[-21,+31]	[-34,+21]	[-26,+18]	[-3,+31]
Total Range over Emissions Scenarios and GCMs	2040	**[+2,+44]**	**[-20,+29]**	**[-22,+20]**	**[-13,+21]**	**[-7,+27]**
	2090	**[+7,+92]**	**[-35,+45]**	**[-45,+32]**	**[-34,+26]**	**[-15,+43]**

Appendix B Simulation results for individual model runs

Rather than using shading to show the range of uncertainty as in the main body of the report, here we show the details of variations amongst the model runs.

Figure B1 shows the effect of emissions scenario on change in monthly mean river flows at Otarama, for all five emissions scenarios. The emissions scenario for each model run is noted on the graph, for the 2090s. From most change in August to least change in August, the emissions scenarios are A1FI, A2, A1B, B2, B1. This is also the order of the results for the 2040s.

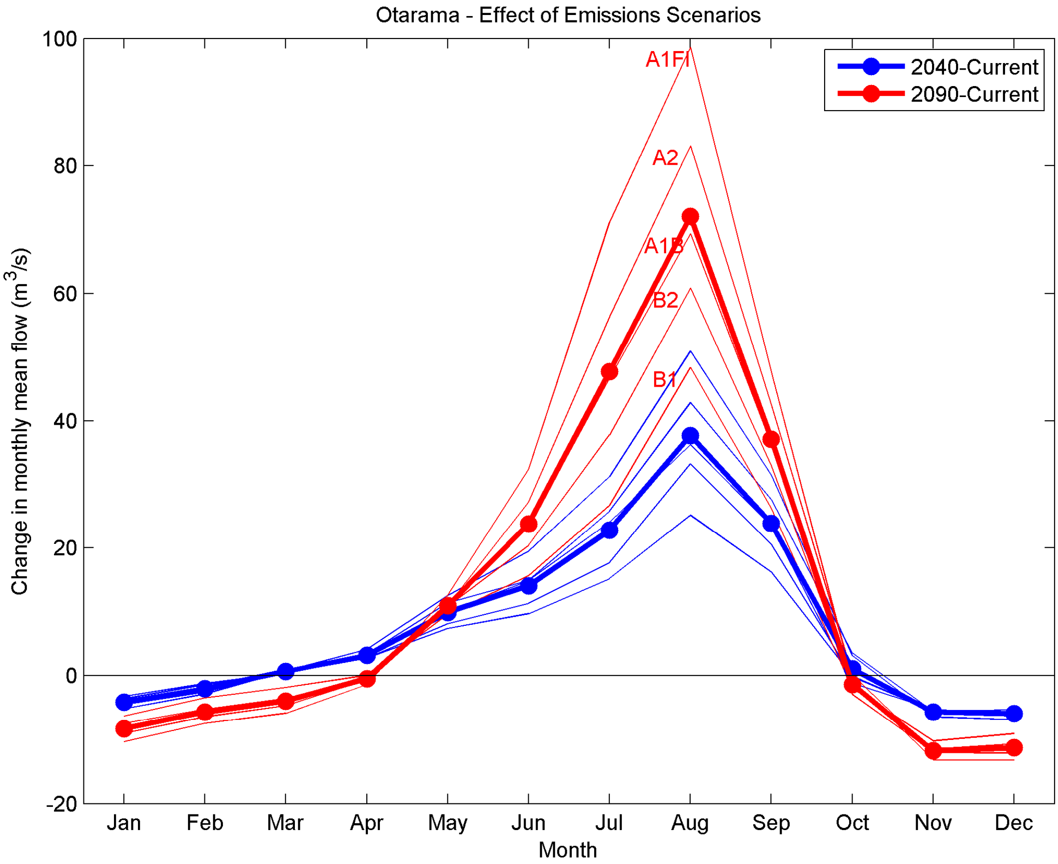

Figure B1: Effect of emissions scenario on changes in monthly mean flow at Otarama. The thin blue and red lines indicate the results for 2040s and 2090s, respectively. The thick lines are for A1B emissions used in Zammit and Woods (2011). The labels indicate the name of the emissions scenario for each model run in the 2090s[2].

[2] There is an unresolved discrepancy of 7 m3/s between this A1B simulation using the GCM-average model, and that shown in Zammit and Woods (2011). We consider this small enough that resolving it would not affect the conclusions of this report.

Figure B2 shows the effect of GCM on change in monthly mean river flows at Otarama. Note that one or two models produce results that are more extreme than the majority of the models.

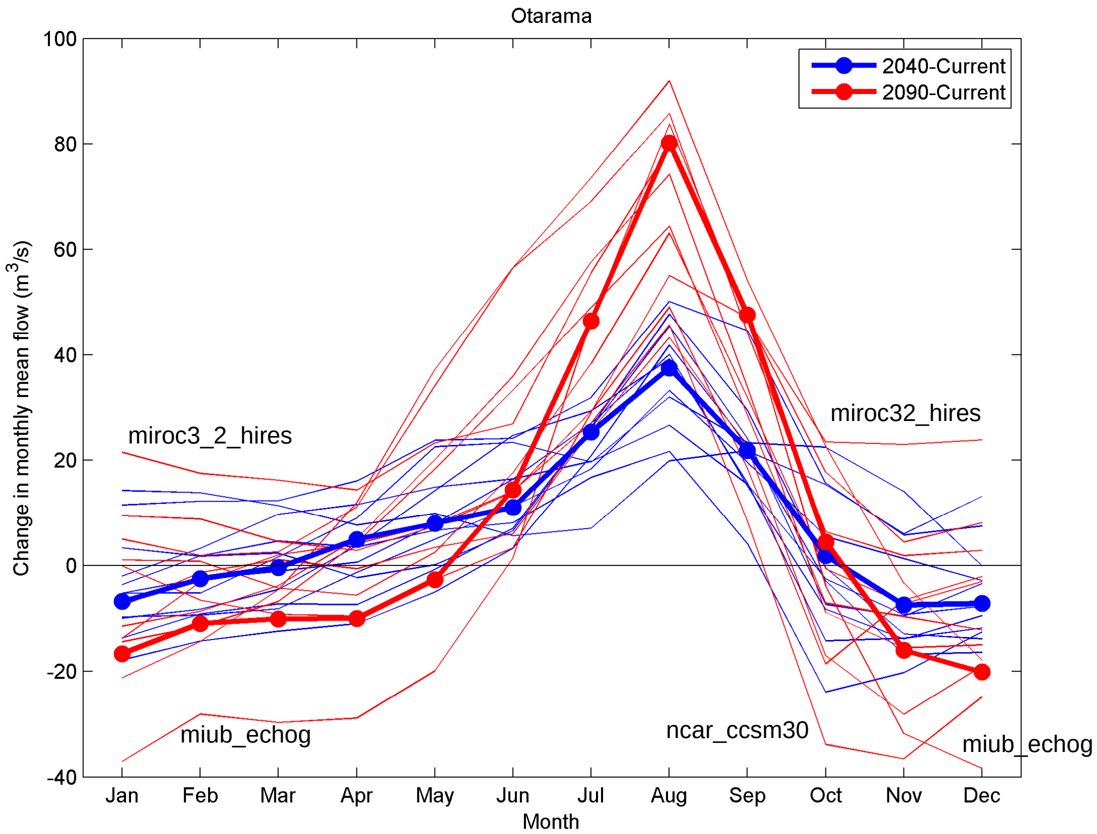

Figure B2: Effect of GCM on changes in monthly mean flow at Otarama. The thin blue and red indicate the results from each GCM for the 2040s and 2090s, respectively. Solid lines are for the average GCM climate used in Zammit and Woods (2011). The names of selected GCMs are attached to the traces for the 2090s

The GCMs which produce the largest increases in mean flow are miroc3_2_hires and mpi_echam5. The GCM which produces the smallest increase in mean flow is ncar_ccsm30 and the model which produces a slight decrease in mean flow is miub_echog. This ranking of the models applies to mean flows for both the 2040s and 2090s. However, the order of the GCM changes during the year, and no GCM produces consistently the smallest or largest change in monthly flow.