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Water Management REPORT

PROJECTED FUTURE SNOW STORAGE IN LAKE OPUHA

PREPARED FOR
Environment Canterbury

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PREPARED BY
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EXECUTIVE SUMMARY

Snow storage in the Lake Opuha catchment during September is projected to decline over the next 100 years at an average rate of 6 % / decade, similar to the estimated decline of September Snow Storage over the last 40 years[1]. Different global climate model and future scenario combinations provide a range of decreasing trends from 0 - 13 % / decade. The lowest trends are estimated for conditions where greenhouse gas emissions reduce over the next century. The highest trends are estimated for conditions where greenhouse gas emissions continue to increase.

The projected change in snow storage is a result of the projected increase in temperature. An increasing trend in temperature of 0.2 °C / decade is projected, less than the observed trend (0.38 °C / decade) in temperature over the last 40 years[1]. If greenhouse gas emissions continue to increase, the temperature is projected to increase at an average rate of 0.3 - 0.6 °C / decade.

There is no clear consensus in the direction or magnitude of change in rainfall across the projections. Only for winter rain under a continued rise in greenhouse gas emissions was the uncertainty less than the trend. For that case the rainfall is projected to increase from 0.5 – 4.5 % / decade.

The result of reduced snow storage but unchanged rainfall will be increased winter inflows to Lake Opuha, and decreased spring inflows. This will result in a declining volume of water able to be supplied from Lake Opuha to irrigators and to assist river flows during the irrigation season.

[1] Kerr, T., 2017. Climate Cycles and Trends: Upper Opihi, Opuha and Orari. Client report for Environment Canterbury. Aqualinc Research Limited.

1 BACKGROUND

Projections of the long term future of the seasonal snow storage within the Lake Opuha catchment is of value for the management of the water resources in the region.

Global efforts at projecting the future climate out to 2100 under a variety of possible futures has been undertaken by many organisations around the world. These efforts use computer models that attempt to incorporate the important aspects of atmospheric, oceanic and land interactions. The global models used in this report, with some of their attributes, are listed in Table 1. For computational efficiency, the spatial resolution of these global models is large providing little detail for regions like New Zealand where the climate can have considerable differences over short distances. To provide the detail needed in New Zealand, downscaling of many of the global model outputs has been carried out for the Ministry for the Environment[2]. This downscaling was carried out using weather models (similar to those used for weather forecasts). The output of this downscaling is the basis for the snow storage assessment of the Lake Opuha Catchment. The data available from the downscaling is at a resolution of 5 km.

Table 1. Global climate change model characteristics[3]

Global Model	Vintage	Agency	Country	Horizontal Resolution (km)
BCC-CSM1.1	2011	BCC-CMA	China	310 x 240
CESM1-CAM5	2010	NSF-DOE-NCAR	USA	100 x 107
GFDL-CM3	2011	NOAA	USA	200 x 200
GISS-E2-R	2011	NASA	USA	222 x 213
HadGEM2-ES	2009	UK Met Office	UK	140 x 160
NorESM1-M	2012	NCC	Norway	210 x 213

Each climate model includes output for the 1971 to 2100 period. The 1971 to 2005 output may be compared to observations to enable assessment of the quality of the model and correction of any biases. From 2006, the models include four different “forcings” of time-varying amounts of greenhouse gasses commonly referred to as Representative Concentration Pathways (RCP). The intention is that the four different forcing scenarios cover a range of possible futures, with what actually happens falling within their range.

Characteristics of the Representative Concentration Pathways[4] are described in Table 2 with plots of the changes in the global concentration of greenhouse gases (expressed as carbon dioxide equivalents) for each Pathway shown in Figure 1. The Representative Concentration Pathways have designated numbers with the lowest number (RCP 2.6) having the lowest greenhouse gas forcing, and the highest number (RCP 8.5) having the highest.

[2] Ministry for the Environment, 2016. Climate change projections for New Zealand: Atmosphere Projections based on simulations from the IPCC fifth assessment. Ministry for the Environment, Wellington.

[3] IPCC, 2013. Climate change 2013: The physical science basis. Contribution of working group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, England and New York, NY, USA.

[4] Data and characteristics detail are sourced from the RCP Database Version 2.0 https://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=about#descript

Table 2. Characteristics of the four Representative Concentration Pathways

Representative Concentration Pathway	Characteristics
RCP 2.6	The emission pathway is representative of very low greenhouse gas concentration levels. Greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially over time.
RCP 4.5	This is a stabilization scenario where greenhouse gas emissions become steady by 2100.
RCP 6.0	This is a stabilization scenario where greenhouse gas emissions become steady after 2100.
RCP 8.5	This is an increasing scenario with greenhouse gas emissions continuing to rise over time leading to high concentration levels.

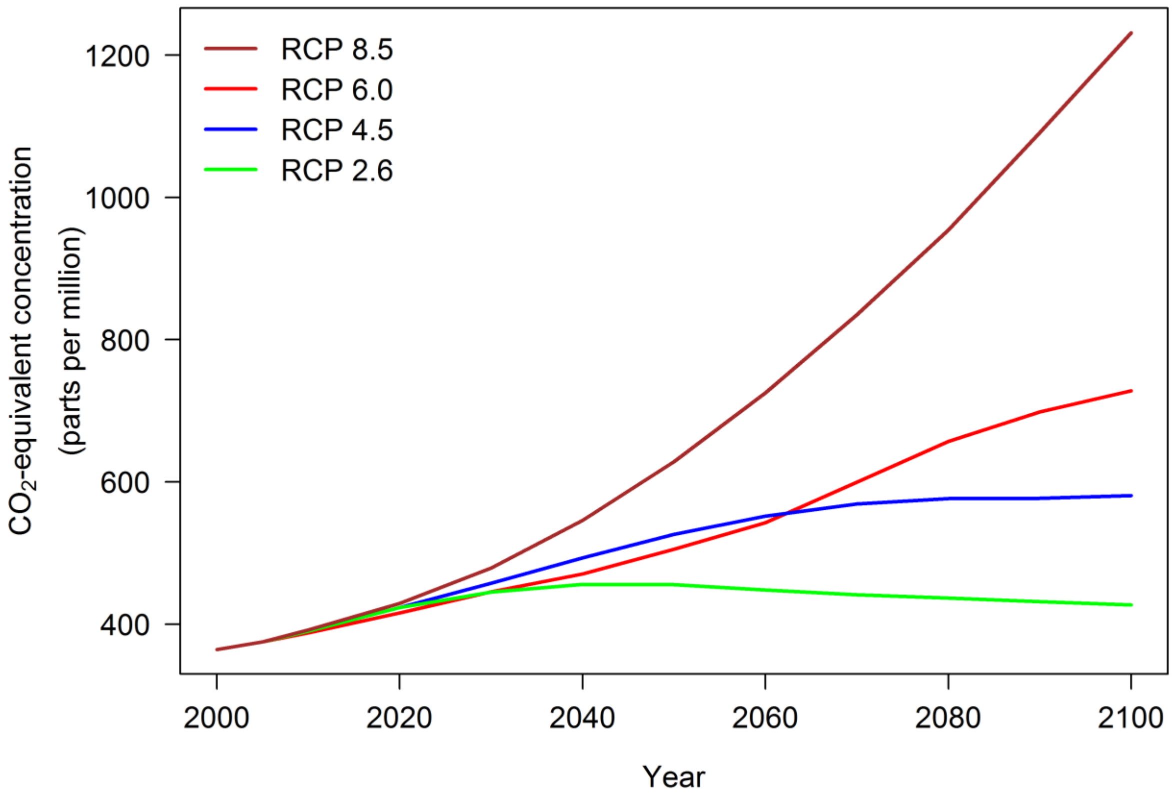

Figure 1. Projected change in greenhouse gas concentrations for each Representative Concentration Pathway.

The snow storage estimation system requires daily rainfall and temperature from the Fairlie Automatic Weather Station site to operate. To undertake projections of snow storage, the downscaled rainfall and temperature model output for the model location closest to the site of the Fairlie Automatic Weather Station has been used to drive the snow storage estimation system.

2 DATA

The downscaled climate change data were provided to ECan by NIWA. This data was bias-corrected by NIWA to ensure the "past" scenario data matched the NIWA Virtual Climate Station Network (VCSN) gridded daily rainfall and temperature products. The data is provided as grid square averages, where each grid square is 0.05^{o} latitude by 0.05^{o} longitude (approximately 5 km by 5 km).

3 METHOD

For each model and scenario combination, the temperature and precipitation climate projection data from the model grid square nearest to the Fairlie Automatic Weather Station site was selected.
The modelled data were bias-corrected to match the observed Fairlie Automatic Weather Station data using quantile mapping (see Appendix A).
The bias-adjusted climate model data was used as input to the Opuha Snow Storage estimation system[5].

For each model and each scenario for the following Summary Variables were calculated:

- Average September snow storage
- Average October snow storage
- Date of snow storage being less than the 2006 average November snow storage
- Winter rainfall
- Summer rainfall
- Winter temperature
- Summer temperature

For each scenario and each Summary Variable the average linear trend from the different models was found. In addition the range of trends from the six constituent models was found. The uncertainty of the average trend for each Summary Variable / Scenario combination was taken as the maximum absolute difference between their range limits and their average trend.

4 FUTURE PROJECTIONS

Summary

Snow storage in the Lake Opuha catchment is projected to decrease between 10 and 80 % over the next 100 years. The melt out will occur between 1 and 6 weeks earlier. The change is a result of warming temperatures, with increases of between 0.05 and 0.5 ^{o}C / decade projected, slightly more in summer, slightly less in winter. Projections of rainfall show no clear trend except for slightly increased rain in winter under the more severe climate change scenario, but this is relatively small compared to the inter-annual variability.

Detail

The trend and uncertainty in average September and October snow storage to 2110 for each of the Representative Concentration Pathways is given in Table 3. Figure 2 and Figure 3 show the graph of the average trends (solid lines) together with the range of the trends (dotted lines) from the six different source models.

[5] Kerr R, 2015. Opuha snow storage estimation: Preparation of historic estimates, Client Report for Opuha Water Limited. C15114-01/3. Aqualinc Research Limited.

Table 3. Projected rate of change in Summary Variables

	Representative Concentration Pathway			
Variable	2.6	4.5	6.0	8.5
September snow storage (%/decade)	-1 +/- 1	-2 +/- 2	-4 +/- 4	-8 +/- 5
October snow storage (%/decade)	-2 +/- 2	-4 +/- 2	-8 +/- 3	-13 +/- 12
Melt-out date (days/decade)	-0.7 +/- 0.7	-1.9 +/- 2.0	-3.9 +/- 1.3	-5.2 +/- 1.8
Winter rain (%/decade)	-0.4 +/- 1	0.3 +/- 2	1.1 +/- 2	2.5 +/- 2
Summer rain (%/decade)	-0.67 +/- 1	-0.04 +/- 1	-0.63 +/- 3	0.86 +/- 1
Winter temperature (ºC/decade)	0.02 +/- 0.04	0.14 +/- 0.07	0.21 +/- 0.06	0.39 +/- 0.09
Summer temperature (ºC/decade)	0.02 +/- 0.04	0.17 +/- 0.06	0.28 +/- 0.09	0.48 +/- 0.11

The trends indicate that for all except the very-low greenhouse gas emission pathways, the snow storage is projected to have reduced snow storage in spring. The dotted lines on the graphs indicate the range of trends that the various models returned for each Representative Concentration Pathway. For the worst Representative Concentration Pathway (RCP 8.5), the September snow storage is projected to reduce to a fifth of the pre 2006 September average by the end of the century. The estimated trend in the September snow storage over the last 40 years of -6 % / decade[6] falls halfway between the projected changes for the 6.0 and 8.5 Representative Concentration Pathways. The October snow storage is projected to decrease at a faster rate than the September snow storage.

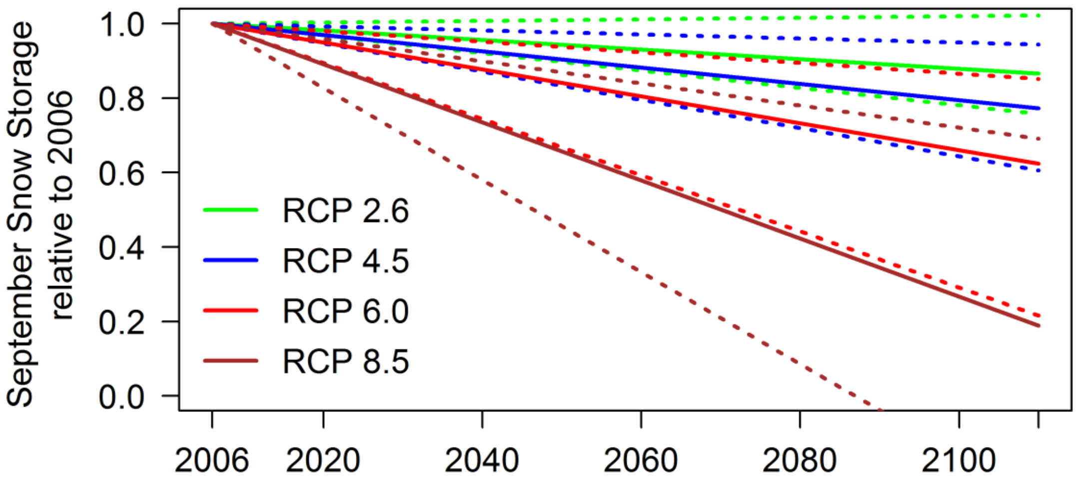

Figure 2. Projections of the change in average September snow storage. The change is with respect to the modelled estimate of average September snow storage in 2006. Solid lines represent the average trend for all models for each Representative Concentration Pathway. The dotted lines represent the range of trends across all models for each Representative Concentration Pathway.

[6] Kerr, T., 2017. Climate Cycles and Trends: Upper Opihi, Opuha and Orari. Client report for Environment Canterbury. Aqualinc Research Limited.

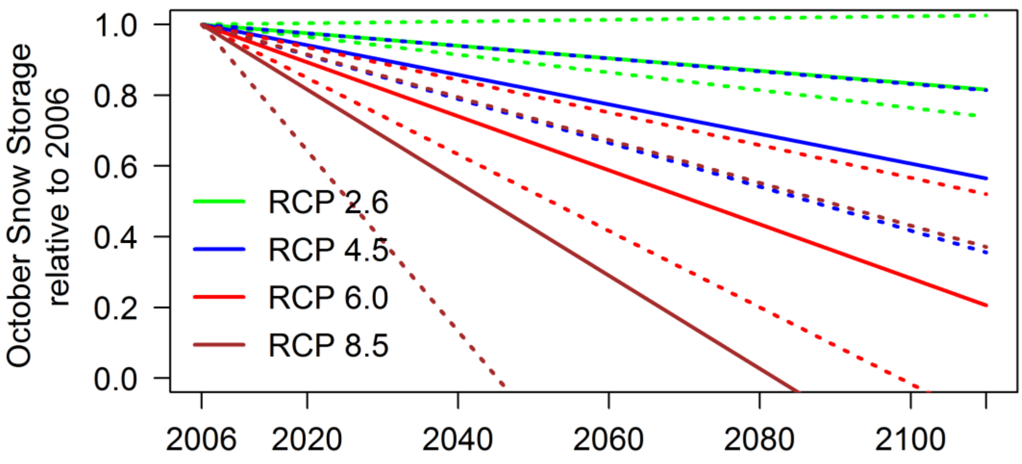

Figure 3. Projections of the change in average October snow storage. The change is with respect to the modelled estimate of average October snow storage in 2006. Solid lines represent the average trend for all models for each Representative Concentration Pathway. The dotted lines represent the range of trends across all models for each Representative Concentration Pathway.

In conjunction with a projected reduced snow storage, the date each year that the snow storage reduces below a set threshold is projected to get earlier. An arbitrary threshold was selected, set to the 2006 average November snow storage. The trend in the first date in the melt season when the snow storage drops below this threshold is presented in Figure 4 and Table 3. By 2100, the snow storage that currently remains in early November, will be reached earlier. For the severe Representative Concentration Pathway (RCP 8.5), the snow melt-out below the 2006 November threshold will occur seven weeks earlier.

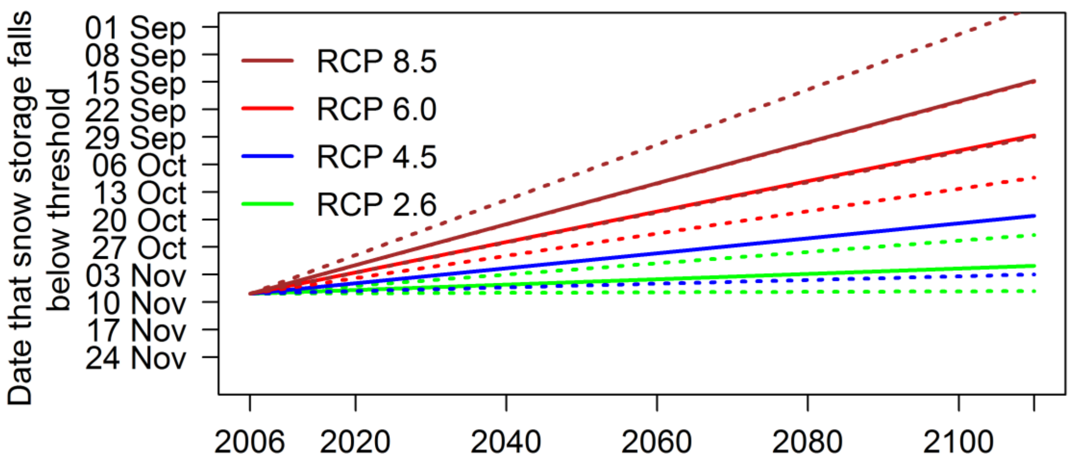

Figure 4. Trend in the onset date each year of when the snow storage falls below a threshold. The threshold was arbitrarily set to the 2006 average November snow storage.

The snow storage estimation is based on just two variables, daily rainfall totals, and daily average temperature. For the snow storage to reduce, either the rainfall must reduce or the temperature must increase. To investigate the cause of the projected change in snow storage, the projected linear trend in rainfall and temperature have been plotted for the summer (October to March) and winter (April to September) periods. These trends are shown in Figure 5 to Figure 8 and listed in Table 3.

The projections indicate that trends in rainfall are highly uncertain, with a slight positive bias for winter rainfall for the two harshest Representative Concentration Pathways. Summer rain average trends are very small, especially with respect to inter-annual variation, and the ranges of all Representative Concentration Pathways encompass 0, so there is no consensus in the direction of the trend between all models.

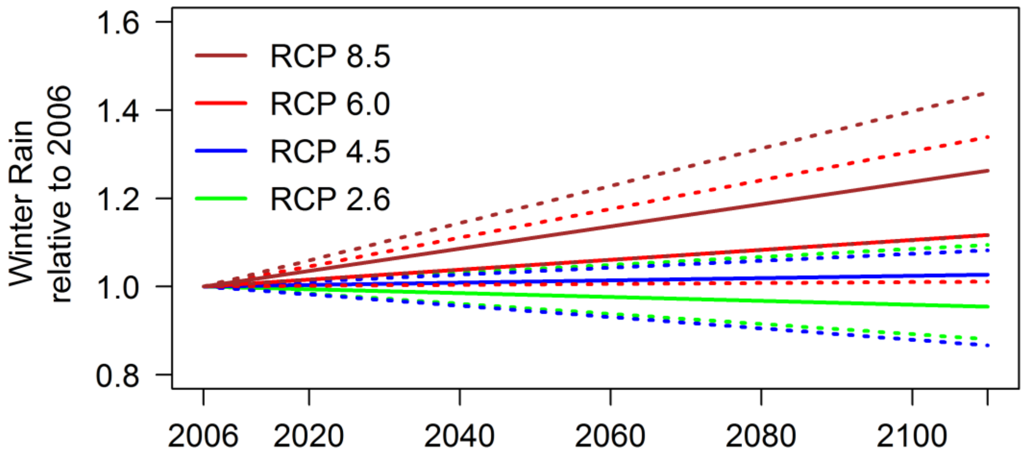

Figure 5. Average model linear trends in total winter (April to September) rain for different Representative Concentration Pathways. The dotted lines represent the range of the trends from the different models.

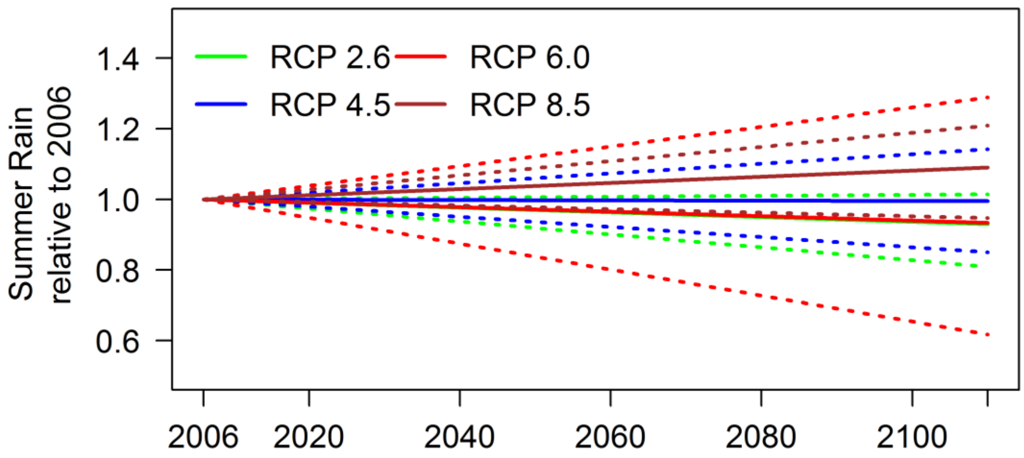

Figure 6. Average model linear trends in total summer (October to March) rain for different Representative Concentration Pathways. The dotted lines represent the range of the trends from the different models.

For temperature, the linear trends are all increasing with the greatest trends occurring in summer.

The projections associated with Representative Concentration Pathways 6.0 and 8.5 are closest to the observed trends from the last 40 years[7].

This change in temperature is the driver to the reduction in the projected snow storage. Increased temperature has other implications, including reduced frost occurrence, longer growing season, and increased evapotranspiration.

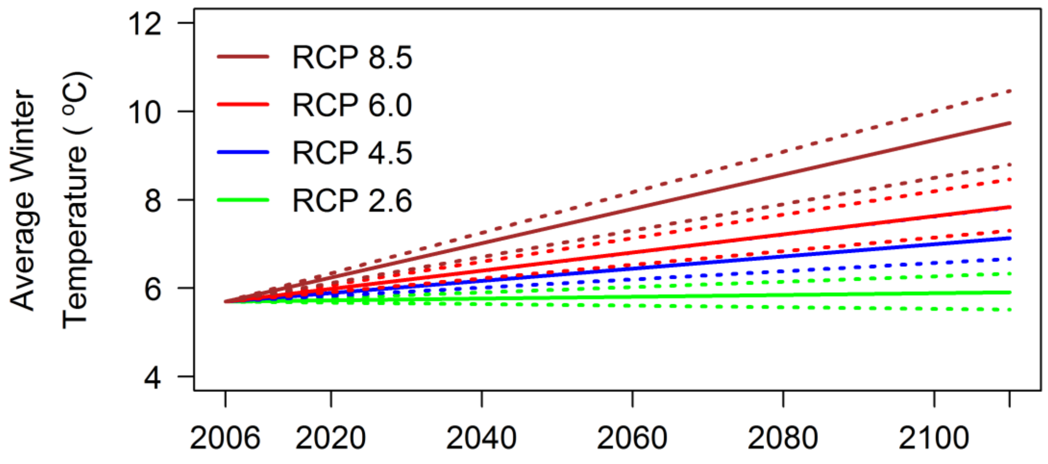

Figure 7. Average model linear trends in average winter (April to September) temperature for different Representative Concentration Pathways. The dotted lines represent the range of the trends from the different models.

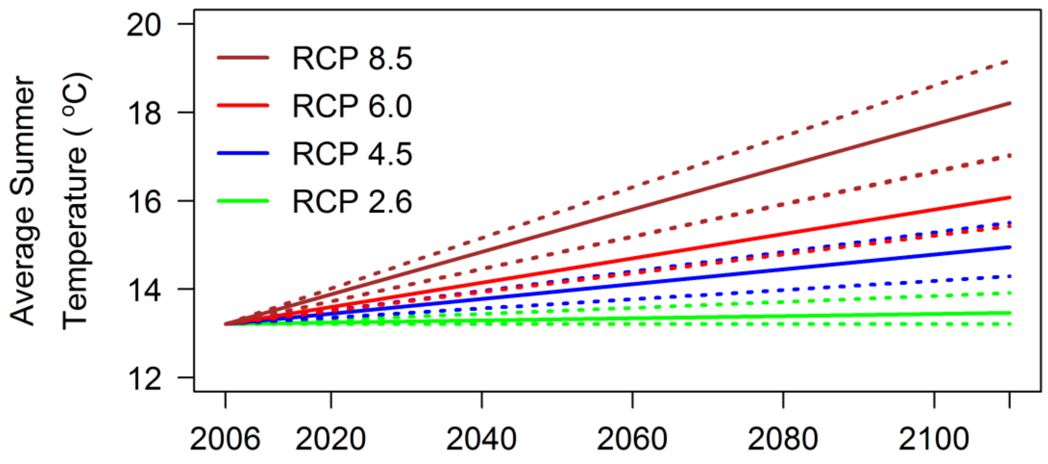

Figure 8. Average model linear trends in average summer (October to March) temperature for different Representative Concentration Pathways. The dotted lines represent the range of the trends from the different models.

[7] Kerr, T., 2017. Climate Cycles and Trends: Upper Opihi, Opuha and Orari. Client report for Environment Canterbury. Aqualinc Research Limited.

5 CONCLUSIONS

Temperature is projected to continue to increase in the Lake Opuha catchment over the next 100 years. The rate of increase varies depending on the greenhouse gas emission scenario. The rainfall is not projected to change significantly. The projected increase in temperature leads to a projection of reduced September snow storage in the catchment of 6 % / decade. This matches the estimated reduction in September snow storage over the last 40 years.

The reduced snow storage also leads to an earlier date of snow melt-out. The snow storage levels currently estimated for early November are projected to be experienced as early as mid-September for the most severe Representative Concentration Pathway.

While snow storage is projected to reduce, rainfall is not, so Lake Opuha will receive greater inflows throughout winter and reduced inflows during spring.

Appendix A: Quantile mapping

The modelled rainfall and temperature are not perfect. For the model outputs for 1971 to 2005 it is possible to compare the estimates to the observed data and to adjust the model data to better match the observed data. These adjustments may then be applied to future projections of the same model. One method to do this is quantile mapping. Quantile mapping adjusts the modelled data's distribution to match that of the observed data.

Quantile mapping was applied using the "qmap" package[8] for the R statistical programming environment[9]. Examples of how quantile mapping re-aligns the model output distribution is shown for rainfall and the average daily temperature in Figure 9 and Figure 10 respectively. Note the correction of the over represented low rainfall events in the model data and the bias correction of the temperature.

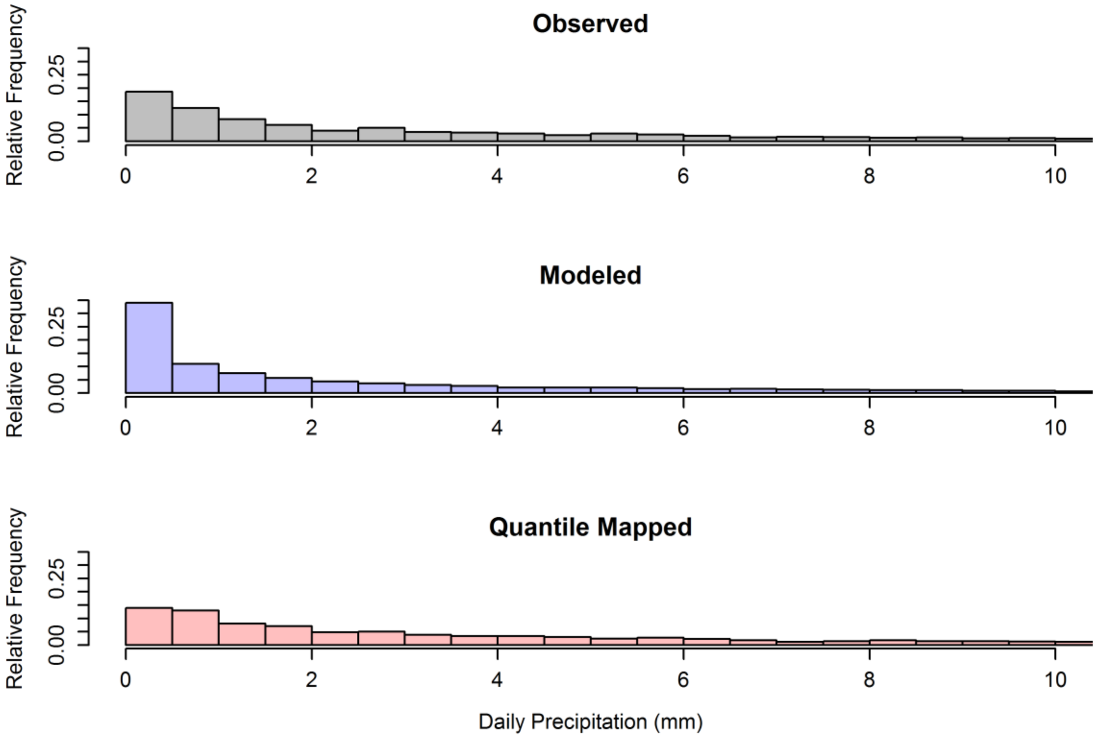

Figure 9. Example of the frequency distribution of rainfall at the Fairlie Automatic Weather Station site for the 1981 to 2005 period based on observed data (top), modelled data from the Ministry for the Environment downscaled NorESM1-M global model (middle) and the quantile mapped model data.

[8] Gudmundsson, L. (2016). qmap: Statistical transformations for post-processing climate model output. R package version 1.0-4.
Gudmundsson, L.; Bremnes, J. B.; Haugen, J. E. & Engen-Skaugen, T. Technical Note: Downscaling RCM precipitation to the station scale using statistical transformations - a comparison of methods. Hydrology and Earth System Sciences, 2012, 16, 3383-3390, doi:10.5194/hess-16-3383-2012.

[9] R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

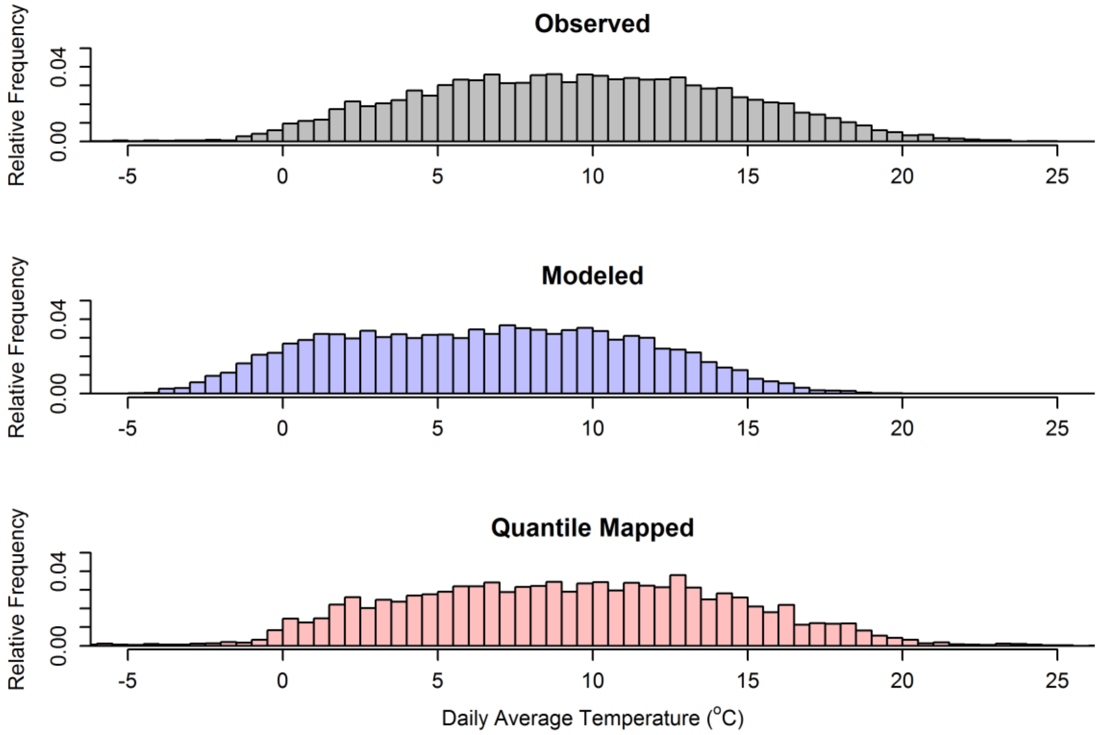

Figure 10. Example of the frequency distribution of temperature at the Fairlie Automatic Weather Station site for the 1981 to 2005 period based on observed data (top), modelled data from the Ministry for the Environment downscaled HadGEM2-ES global model (middle) and the quantile mapped model data.