



Water availability under climate change

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Executive Summary

The effect of drought on water availability is receiving an increased amount of attention as we head into a future where the impacts of climate change are already being felt. The level of risk to New Zealand from restricted drinking water availability under "as yet unexperienced droughts" emerged as one of the priority questions and knowledge gaps from the *Climate Change and Drought Dialogues* held at Motu in May and June 2018.

This gap in knowledge forms the basis of this project, which responds to the questions:

- 1. What is the likely incidence of future multi-regional drought? What is the likely nationwide spatial pattern of expected change in drought incidence?
- 2. What level of risk are we likely to face in relation to drinking water availability in times of drought?

A report focusing on the "Projected Changes in New Zealand Drought Risk" was completed by the National Institute of Water and Atmospheric Research (NIWA) to address Question 1.

This report addresses Question 2.

This study uses projected climate change information derived from simulations by six global climate models, driven by four IPCC Fifth Assessment emission scenarios (known as RCPs). The global models are dynamically downscaled to a 5-km grid covering the whole country, with the outputs used to generate stream flows using NIWA's TopNet model. These inflows together with other physical characteristics of the water supply schemes were used as inputs to a spreadsheet-based model to calculate water yields at 99.5%, 99%, 98% and 95% assurance of supply.

The projected risk of shortfalls in surface water supply are assessed for 10 case study water supplies - seven in the North Island and three in the South Island. Surface water inflows for each case study are used to calculate water yield (availability) for a baseline period from 1986 to 2005 and is then compared to water yield for 2040, 2060, and 2080 time horizons. In each of the 10 locations, we calculated the water availability at each of the future time horizons using outputs from the six Global Climate Models (GCMs) using four Representative Concentration Pathways (RCPs).

Some key findings of this report are:

- This method represents a first substantial step towards the development of a practical, transparent procedure for assessing the potential impact of climate change on reservoir and catchment yield for water supply.
- In conjunction with the new drought index (Climate-NZDI) developed by NIWA (in response to Question 1 above), this approach provides a tool for rapid assessment of water availability trends under various climate change conditions, where the outputs from these assessments can be used to prioritize water resources planning efforts.
- The projected impact of climate change on long-term reservoir yield and stream flows varies across the RCPs and levels of assurance of water supply that are modelled. The relative changes in yield pose challenges to water managers in making decisions about

water supply resilience, and potentially calls for an adaptive approach to water supply management.

- Our approach however can be used as a long-term planning tool. Decisions about when new water resources or supplementary schemes are needed can then be based on the best available information and with sufficient lead time to allow for implementation. Water availability from alternative surface water resources under climate change conditions can now also be considered as part of an adaptive integrated system planning approach to the provision of water supply.
- Our approach would also benefit from a more detailed understanding of water demand (for example to recognize increased demand brought about by population growth, or to consider changing demand patterns), and including changes to demand that may be required in response to regulatory changes to water resource management. This approach would be significantly strengthened if it were to incorporate a Te Ao Maori perspective on water.

1 Introduction

1.1 Background and context

Most people would have at some point in their lives experienced drought, whether it is living through a season with lower than normal rainfall (meteorological drought), having to water a vegetable garden because of insufficient moisture in the soil (soil moisture drought), having less drinking water available due to reduced streamflow (hydrological drought) or having to make drastic changes to their lifestyles or businesses because there is insufficient water available to sustain the economy, people or the environment (socioeconomic and environmental drought). The various types of droughts are interlinked, therefore a meteorological drought can lead to soil moisture and hydrological droughts with varying, and potentially serious, impacts.

Climate change is likely to continue to affect rainfall patterns. Those effects will not be uniform, either in New Zealand or globally. How communities in New Zealand will adapt to potential prolonged hydrological droughts - and how the availability of water could change - are at this stage unknown.

Recognising the natural variability in streamflow has prompted communities to protect against hydrological drought by building reservoirs to provide water storage. In general, water supply systems that incorporate storage provide greater resilience to drought than those without.

New Zealand has a relatively moist climate, with most areas receiving between 600 mm to 1600 mm of rainfall on average every year. As a result of this, drinking water supplies that are reliant on surface water are sized accordingly. Clarke et al. (2011) showed that by the middle of this century, New Zealand will spend about 10 per cent more time in drought and that droughts will likely be more prolonged. Therefore, to reduce the likelihood of restricted water supplies or even a "Day Zero" scenario such as that which threatened South Africa's Cape Town in 2018, our water supply schemes will need to cater for extended periods of drought. This will most likely need to be through both the reduction in demand (such as through water efficiency measures), as well as an increase in supply (either through new water supplies or increased storage in existing systems).

The level of risk in relation to drinking water that communities (urban and rural) in New Zealand would be exposed to under "as yet unexperienced droughts" in the face of climate change has yet to be quantified, and forms the basis for the work presented in this report.

1.2 Filling in the knowledge gap

This research topic emerged as one of the priority questions from the Climate Change and Drought Dialogues held at Motu in May and June 2018. One of the gaps identified in the dialogues was the level of risk posed for New Zealand by restricted drinking water availability under conditions of "as yet unexperienced droughts". This gap in knowledge forms the basis of this research, which focuses on the impacts of drought on drinking water availability.

Specifically, this project responds to the questions:

- 1. What is the likely incidence of future multi-regional drought? What is the likely nationwide spatial pattern of expected change in drought incidence?
- 2. What level of risk are we likely to face in relation to drinking water availability in times of drought?

The first question is addressed in a report prepared by NIWA entitled "Projected Changes in New Zealand Drought Risk" (Sood and Mullan, 2020). This report provides an assessment of existing drought indices used to monitor drought in New Zealand and develops an improved method for analysing future drought risk under climate change.

The second question is addressed in this report. Here projected risk of shortfalls in surface water supply are assessed for 10 case study water supplies - seven in the North Island and three in the South Island. Surface water inflows for each case study are used to calculate water yields for a baseline period from 1986 to 2005 and these are then compared to yields for 2040, 2060 and 2080. In each of the 10 locations, we calculated the water availability at each of the future time horizons using outputs from six Global Climate Models (GCMs) using four Representative Concentration Pathways (RCPs).

Full details of our assessment methodology are presented in Section 2, with the results provided in Section 3.

As a part of this work, the Deep South National Science Climate Challenge asked us to provide a high-level review of the issues identified in Iwi Water Management Plans associated with climate change and water supply. This review is provided in Section 4.

2 Methodology

2.1 Selection of case study areas and SRG members

The identification and selection of the case studies were based on three criteria:

- Likely drought conditions.
- Physical setting and sufficient data that made it amenable to analysis.
- The availability of a Stakeholder Reference Group (SRG) member to provide information on the current or possible future water supply schemes.

2.1.1 Drought conditions

Analyses of drought change under regional warming have been quantified in terms of an index known as Potential Evapotranspiration Deficit (PED). PED can be thought of as the additional amount of water needed for irrigation in order to keep pastures growing at optimum levels. Annual accumulated PED is useful for mapping the spatial coverage of droughts and for comparing drought intensity variations between years.



Figure 2.1: Regional Climate Model (RCM)-projected changes in Potential Evapotranspiration Deficit (PED) (in millimetres accumulation over the July-June 'water year') for the 2081-2100 period with respect to the baseline 1986-2005 period, under RCP4.5 (from Figure 54 of MfE, 2016). Data are mapped on to NIWA's 5kmx5km VCSN grid (Tait, 2008)

Figure 2.1 is an example of a drought scenario showing the increase in PED between a presentday baseline climate (1986-2005) and an end-of-century period (2081-2100) under the Representative Concentration Pathway (RCP) 4.5. According to this figure, all of New Zealand would be to some extent drier in the future. So case study areas were initially selected based on those areas where PED is expected to be greatest (darkest areas in Figure 2.1).

2.1.2 Physical setting and supporting data

To perform a yield analysis in a region, a stream order of greater than 3, an understanding of the characteristics of the reservoir and its operating rules for diverting flows are needed. Often, it was found that the initial options identified by the stakeholder group were unsuitable for analysis because the stream order was too low, and streamflow time series were not readily available from the TopNet model. Therefore, to meet the requirements of national spatial coverage and realistic case studies, a more pragmatic approach was adopted, resulting in the selection of case studies in areas that did not necessarily show a significant increase in PED under future climate change projections.

2.1.2 Stakeholder Reference Group

A Stakeholder Reference Group (SRG) was constituted to assist in formulating answers to operational questions that the project team may encounter.

Each member was selected based on their knowledge of the study area's climate, and of the water supply schemes. Specifically, SRG members were required to provide inputs to the project team on the issues below.

• What constitutes a "region"? Is it an administrative region or a climate region?

- How much of a "region" needs to be affected by drought to classify the event as a "regional drought" a precursor to identifying multi-regional droughts?
- How long should a "region" be in drought for there to be significant stress on urban water supplies?
- Which Representative Concentration Pathways (RCPs) are considered important?
- How does water allocation work under a drought scenario?
- What is the operating policy for the water supply scheme?
- Directing project team members to the appropriate people to answer water supply related questions or to supply water infrastructure related data.

The Stakeholder Reference Group members who guided this project are listed in Appendix B.

2.2 Selected case studies

The selected sites for yield analyses are shown in Figure 2.2 and listed in Table 2.1.



Figure 2.2: Location of sites used in yield analyses

Region	Description		
Northland	Storage in Punakitere River		
Auckland	Cosseys Dam & Reservoir, Cosseys Creek, Hunua		
Waikato	Reservoir in Topehaehae Stream, Matamata Piako District		
Gisborne	Gisborne (A run-of-river option from the Te Arai River)		
Taranaki	New Plymouth (An option selected from a study carried out for New Plymouth District Council (CH2M Beca, 2018)		
Manawatu- Whanganui	Turitea Dams and reservoir, Palmerston North		
Greater Wellington	Masterton - A variation on the Black Creek scheme selected including the proposed Wakamoekau and Black Creek Dams and Waingawa run-of-river transfer		
Tasman	Lee River downstream of Johnstones Road		
Canterbury	Lake Pukaki		
Southland	Mataura River run-of-river diversion		

 Table 2.1:
 Selected water supplies for yield analyses

2.3 Hydrological analysis

2.3.1 Simulated historical and projected future streamflow time series

Daily streamflow time series from 1973 to 2100 were generated by NIWA's TopNet model, using simulated daily rainfall from the six Global Climate Models (GCMs), which were dynamically downscaled. The six GCMs used in this study together with their countries of origin are as follows:

- BCC-CSM1.1 (China)
- CESM1-CAM5 (USA)
- GISS-E2-R (USA)
- GFDL-CM3 (USA)
- HadGEM2-ES (UK)
- NorESM1-M (Norway)

Simulated historic streamflow time series were generated at selected locations for each of the six GCMs, from 1973 to 2005 and simulated streamflow time series were generated from 2006 to 2100, for the six GCMs under four representative greenhouse gas concentration Pathways (RCPs).

The representative concentration pathways are:

- RCP 2.6 (low emissions)
- RCP 4.5 (low-mid emissions)
- RCP 6.0 (mid –high emissions)
- RCP 8.5 (high emissions)

2.3.2 Yield analysis

Quantifying the level of risk that water supply schemes are likely to face under climate change means that the risk of shortfall in water supply for these schemes has to be determined.

The risk of a shortfall is the inability of the system to supply a base yield for a specified draft or water take (DWAF, 1986 also refer to Appendix A for yield and draft definitions). In this case the yield depends on the inflow and storage in the system.

For this project, streamflow inflow time series were generated in TopNet using the rainfall time series from the six GCMs. These streamflow time series were divided into subsets (see Table 2.2) to represent inflows for a range of time horizons. The period used for each time horizon was approximately 35 years for each GCM. Combining the time series for the six GCMs resulted in 210 years that were simulated for each time horizon. The time horizons, together with the subset of streamflow used in the yield analyses, are listed in Table 2.2. It is noteworthy that all subsets of the streamflow series, including the historical series, are simulated.

Time horizon	Subset of streamflow series used
2005 (historical)	1973 to 2005
2040	2020 to 2055
2060	2040 to 2075
2080	2065 to 2100

Table 2.2:	Time horizons	used i	in this	study
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A spreadsheet-based model was developed to estimate the draft that could be supplied without shortfall for 99.5%, 99%, 98% and 95% of the time for the time horizon simulated. Due to the limited number of streamflow sequences (six) for each time horizon, the assurances of supply are approximate only. More streamflow sequences would be required to increase confidence in the yields.

The yield model implements a simple water balance where:

 $Storage_{(N)} = Storage_{(N-1)} + Inflow_{(N)} - Draft \ (0 \le Storage \le Full storage)$

The draft includes all water supplied to users and includes the minimum requirements for the downstream river usually referred to as compensation flows. This is usually a constant and can be subtracted from the yield to determine the quantity available for supply.

In the simulations carried out here only the streamflow and releases are considered in the mass balance. However, in New Zealand the potential evaporation is usually less than rainfall, resulting in a conservative (slightly underestimated) yield estimate from the approach.

The purpose of the study is to assess the likely effect that climate change will have on water supply by showing the trend and relative changes in yield with time. Simplifying assumptions, such as not varying the draft through the year, or not applying variable releases to meet compensation flow requirements will have little, if any, effect on relative yields.

Simulations were carried out separately using the inflow time series from each of the six GCMs with the reservoir at full supply capacity at the start of the simulations. Years with simulated shortfalls in supplying the draft were combined for all six GCMs and divided by the total number of years in the simulation period to estimate the assurance of supplying the target

draft. Analyses were based on hydrological years, so that periods with shortfall did not cross calendar year boundaries and remained independent.

Since the only change in the yield analyses at each time horizon is the projected streamflow, the effect of climate change is implicitly accounted for in this approach.

The Te Arai and Mataura water supply case studies are run of river schemes and don't have storage. For these supplies flow duration curves were prepared showing the percentage of time that flow is exceeded. The flow duration curves were prepared for the same time horizons and historical record periods used in the yield analyses for those schemes with storage. The median, and three times median, flow are included on the flow duration curve plots to add perspective. The median flows were determined from the combined daily flows for the period 1973 to 2005 for all six GCMs and for all time horizons. Using the exceedance curves, it now becomes possible to estimate the amount of time that pumping from the river would be possible under each projected time horizon relative to the historic period.

2.4 Limitations

The following limitations are noted for this study:

- Only ten water supply options/schemes were analysed because of time and budget constraints.
- Streamflow time series supplied by NIWA were generated using an uncalibrated TopNet model. While this might affect absolute yields, when expressed as a percentage of the 2005 yield, the relative difference between this and each time horizon and between each RCP should be the same. This limitation is discussed in more detail in Section 3.12.
- Simulations were carried out using between 33 and 35 years of daily streamflow from each of the six RCMs, (210 years in total) for each time horizon. This limits confidence in the yield results.
- In order to provide national coverage, not all water supply schemes analysed were for drinking water.
- Static draft and compensation flows were assumed. We know, however, that water demand is variable and that many schemes have residual or compensation flow that vary depending on the environmental values, minimum flow requirements, etc.
- A simplified analysis where only a single reservoir could be accommodated was used.
- Water supply schemes using groundwater were not considered.

3 Case study yield analyses and results

3.1 Northland

No suitable drinking water supplies were identified for yield analysis in Northland so an irrigation option with storage of 6 million m³ in the Punakitere River south of Kaikohe was assessed. This is Option 8 from "Scoping of irrigation scheme options in Northland" prepared for Northland Regional Council (NRC, 2020). The location of the proposed storage is shown in Figure 3.1.



Figure 3.1: Location of Northland yield analysis (Option 8 from "Scoping of irrigation scheme options in Northland")

Trends in simulated yield as a percentage of the 2005 yield are shown in Figure 3.2.

A decreasing water availability trend is shown for the RCP 8.5 scenario for all levels of assurance of supply. Under the RCP 6.0 scenario, however, an initial increase in water availability is observed for all levels of assurance of supply, which is not present for the other RCP scenarios. Considering the droughts currently being experienced in this region, water availability is most likely tracking along the RCP paths (RCPs 2.6, 4.5 and 8.5) that show a decreasing trend in water availability and not the one that shows an increasing trend in water availability.





Figure 3.2: Yield results: Northland (Storage 6 million m³) expressed as percentage of 2005 yield

3.2 Auckland

Cosseys Reservoir in the Cosseys Creek is part of Watercare's water supply infrastructure for supplying water in the Auckland area. The location of the reservoir is shown in Figure 3.3. This dam was selected because the inflow reach NZREACH 2042441 is Strahler 4 and inflows were available from NIWA. The reservoir has a working storage of approximately 14 million m³, which is approximately 50% of the mean annual runoff from the catchment. Yields were determined for a July to June hydrological year.



Figure 3.3: Location of Auckland yield analysis

Yields from the reservoir were calculated for assurances of 99.5%, 99%, 98% and 95% and time horizons of 2005 (historic), 2040, 2060 and 2080 to assess trends due to climate change. Figure 3.4 shows plots of the trends in yield with time as a percentage of the 2005 yield.

At the highest assurance level of supply there is an initial decrease for all RCPs except RCP 8.5. For RCP 8.5, however, there is an increase in water yield for the 2040 time horizon before showing a decreasing trend thereafter. At the highest level of assurance of supply, the other RCP scenarios show an upward trend after the 2040 time horizon.



Figure 3.4: Yield results: Auckland – Cosseys Reservoir (Storage 14 million m³) expressed as percentage of 2005 yield

3.3 Waikato

The Waikato Regional Council identified an existing water supply scheme that utilises storage of approximately 0.32 million m³ in the Topehaehae Stream, east of Hamilton. The location of the scheme is shown in Figure 3.5 (nzsegment 3063858).

Current consents permit a maximum of $12,000 \text{ m}^3/\text{day}$ to be taken from storage and specify a minimum downstream release of 0.03 m³/s, except for up to 100 days per year when the minimum downstream release can be reduced to 0.007 m³/s. Yield analyses for this study assume that downstream releases are constant and included in the yield that is taken as a constant draft. Yields were determined for a January to December hydrological year.



Figure 3.5: Location of Waikato yield analysis

Figure 3.6 shows plots of trends in yield with time, as a percentage of the 2005 yield. The results show that, except for RCP 8.5 the water yield remains fairly constant (±5% of the 2005 yield) into the future. For RCP 8.5 the water yield shows a significant decrease from the 2040 time horizon onwards with the decrease being more pronounced for the higher assurance level of supply.



Figure 3.6: Yield results: Topehaehae (Storage 0.32 million m³) expressed as percentage of 2005 yield

3.4 Gisborne

The main water supply to Gisborne is from the Mangapoike Dams. A potential source to augment water supply to Gisborne is from a run-of-river source in the Te Arai River at the location shown in Figure 3.7. This case study was specifically selected to show how the projected streamflow information can be applied to run-of-river schemes.

Abstractions from the Te Arai River will depend on discharge in the river at the time, and on downstream water requirements, will have to be agreed. These rules will likely stipulate minimum discharge (e.g. maintaining a median historical discharge) in the river before abstractions can commence as well as maximum allowable abstraction (e.g. 3 x median historical discharge). The scheme will not be able to deliver a constant draft because the discharge in the river will be variable.

The Te Arai option would supply water when available so that water stored in the dams can be used during low flow periods. Accordingly, analyses for this option were limited to preparing flow duration curves that can be used to assess the percentage of time and how much water can be abstracted from a run-of-river type scheme. Flow duration curves were generated for the pseudo stationary periods 35 years long associated with each of the time horizons 2040, 2060 and 2080. These curves, together with the median and three times median flow from the historic streamflow time series, (1973 to 2005) are shown in Figure 3.8, the projected change in flow with time for selected percentage exceedances in Figure 3.9, and as a percentage of the 2005 flows in Figure 3.10.

Figure 3.10 shows a general trend in reduced flows in the Te Arai River. By 2080 median flows (50% exceedance) are projected to decrease by approximately 3% for RCP 2.6, 7% for RCP 4.5 and RCP 6.0 and 14% for RCP 8.5.



Figure 3.7: Location of Gisborne yield analysis



Figure 3.8: Flow duration curves for Te Arai River at proposed take for time horizons 2040, 2060 and 2080



Figure 3.9: Simulated flows in Te Arai River for a range of exceedances for RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 and time horizons from 2005 to 2080



Figure 3.10: Simulated flows in Te Arai River for a range of exceedances for RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 and time horizons from 2005 to 2080 expressed as percentage of 2005 flows

3.5 Taranaki

New Plymouth District Council has identified potential options to augment its water supply. Option S1, shown in Figure 3.11, was selected for yield analysis. It is an online water storage dam near the confluence of the Korito and Mangorei Streams. Maximum storage is approximately 6.5 million m³, which is about 3.5% of the mean annual runoff (MAR) from the catchment. No other storage sizes were analysed for this option.

Daily streamflow time series for the period 1973 to 2100 were obtained from NIWA for NZREACH 6172523 for input to the yield model.



Figure 3.11: Location of Taranaki yield analysis

Figure 3.12 shows plots of the future trend in yield as a percentage of the 2005 yield. Except for the RCP 6.0 scenario, the other RCP scenarios show a decreasing trend in water availability at the 99.5% and 99% assurance of supply. The RCP 6.0 scenario shows an initial increase at water availability at the 2040 time horizon before decreasing. For the lower levels of assurance supply the RCP 8.5 scenario shows the most marked downward trend in water availability.



Figure 3.12: Yield results: New Plymouth Option S1 (Storage 6.5 million m3) expressed as percentage of 2005 yield

3.6 Manawatu – Whanganui

Surface water is supplied to Palmerston North from the Turitea Dams located to the south of the city (Figure 3.13). For the purposes of assessing how yield could change due to climate change, storage in the two reservoirs was combined to give a total storage of 1.8 million m³. Inflow time series for total inflow to the two dams (NZREACH 7240764 - Strahler 3) were used.



Figure 3.12: Location of Manawatu - Whanganui yield analysis

Figure 3.14 shows plots of the future trend in yield as a percentage of the 2005 yield. The plots indicate a general decreasing trend in yield at the highest level of assurance of supply from the 2060 time horizon. With a lower assurance level of supply the water yield remains stable across the future time horizons.



Figure 3.13: Yield results: Palmerston North Turitea Dams (Storage 1.8 million m3) expressed as percentage of 2005 yield

3.7 Greater Wellington Regional Council

The proposed Black Creek Scheme in the Masterton area was identified as a potential option for supplying water to Masterton. The proposed scheme comprises dams in the Black Creek and Wakamoekau Creek with transfer into the reservoir from the Waingawa River downstream of the Atiwhakatu Stream confluence. The approximate location of the dams and transfer from the Waingawa River are shown in Figure 3.15. The Black Creek and Wakamoekau Creek reservoirs are connected by an open channel and operate as a single reservoir with live storage of 46.2 million m³.

Daily streamflow time series for the period 1973 to 2100 were obtained for NZREACH 9254606 (Black Creek), NZREACH 9253545 (Wakamoekau Creek), and NZREACH 9254601 (Waingawa River) for input to the yield model. The flows for NZREACH 9254271 were requested for Black Creek inflows but the more readily available NZREACH 9254606 was accepted because the incremental runoff is minimal.

Water is pumped from the Waingawa River into Black Creek Reservoir. The transfer of water from the Waingawa River is based on the following: when flow in the river is between the median $(7.4 \text{ m}^3/\text{s})$ and three times the median flow (22.3 m³/s), then half the flow in the

Waingawa River is transferred to the reservoir. The maximum transfer to storage was set at 5.6 m³/s.

The daily flows into Black Creek and Wakamoekau Creek reservoirs were combined with transfers from the Waingawa River to generate the inflow time series for the combined storage used in the yield analysis.

The yield model was used to determine yields for of 99.5%, 99%, 98% and 95% assurances for 2005, 2040, 2060 and 2080 time horizons with live storage of 46.2 million m³.



Figure 3.14: Location of the Greater Wellington Regional Council yield analysis

Figure 3.16 shows plots of trends in yield with time, as a percentage of the 2005 yield. The plots indicate that yields could decrease by 2080 for all be the RCP 2.6 scenario. The largest decrease in yield being observed under the RCP 8.5 scenario. Yields under the other RCPs also show a decreasing trend but is not as marked as the decreasing trend of the RCP 8.5 scenario.





Figure 3.15: Yield results: Masterton Black Creek option (Storage 46.2 million m3) expressed as a percentage of 2005 yield

3.8 Tasman

Streamflow data was provided for the reach downstream of Johnstones Road and this streamflow was used to analyse the water availability at the storage site as shown in Figure 3.17. Daily streamflow was obtained from NIWA for NZREACH 10021002 (Strahler 4) and working storage in the reservoir was nominally set at 25% of the mean annual runoff from the catchment.



Figure 3.16: Location of Tasman yield analysis

Figure 3.18 shows plots of trends in yield with time, as a percentage of the 2005 yield. The results indicate an initial projected upward trend in water availability at high assurance yields (99.5% and 99% assurance) under the RCP 8.5 scenario and a decreasing trend thereafter. For the other RCPs no initial increasing trend is observed with yield showing a general decreasing trend towards the 2080 time horizon.



Figure 3.17: Yield results: Tasman (Storage 6 million m³) expressed as percentage of 2005 yield

3.9 Canterbury

Most of the drinking water supply in Canterbury is obtained from groundwater sources and not amenable to analysis using the methodology in the study. In order to provide national coverage, Lake Pukaki was therefore selected as a case study and as a surrogate for other water supplies in the region. Operating storage in Lake Pukaki was obtained from Meridian Energy and daily inflow time series to the lake for NZREACH 13165194 (Strahler 6) were obtained from NIWA. The operating storage used in the yield analyses is 2,395 million m³.

The location of the lake is shown in Figure 3.19. Figure 3.20 shows plots of trends in yield with time, as a percentage of the 2005 yield.

Because high inflows to the lake - due to snow melt - occur late in late winter and spring, calendar years were used in the yield assessment rather than a July to June hydro-year so that shortfall years are independent.



Figure 3.18: Canterbury: Lake Pukaki

Figure 3.20 shows plots of trends in yield with time, as a percentage of the 2005 yield. The simulation results show a general increase in yield by 2080 with the RCP 8.5 scenario displaying the largest increase in yield.



Figure 3.19: Yield results: Canterbury Lake Pukaki (Storage 2,395 million m³) expressed as percentage of 2005 yield

3.10 Southland

The Mataura River flows through Gore. An option to augment water supply to the town is shown in Figure 3.21. It comprises storage on a tributary to the east of the town with transfers from the Mataura River to fill the reservoir. Daily stream flows were obtained from NIWA for the Mataura River (NZREACH 15300394 - Strahler 7) and the tributary (NZREACH 15300360 - Strahler 3). Yield analyses were carried out for an option with storage in the tributary and transfers of half the flow in the Mataura River when flow is between the median, and three times the median flow, to assess possible trend in yield due to climate change.



Figure 3.20: Location of Southland yield analysis

Figure 3.22 shows plots of trends in yield with time, as a percentage of the 2005 yield. Trends at the higher level of assurance of supply (99.5% and 99%) are not easily discernible and remains relatively stable. At the lowest level of assurance of supply an increasing yield is noted for RCPs 6.0 and 8.5.





Figure 3.21: Yield results: Southland (Storage 0.32 million m³) expressed as percentage of 2005 yield

3.11 Discussion

Northland, Taranaki, Manawatu-Whanganui, Greater Wellington Regional Council and Tasman storage-based case studies all show a decrease in yield under climate change. This possibly indicates that there will be longer low flow periods in the streamflow sequences as a result in climate change for these case study areas. These case studies are not located in the areas showing the largest increase in PED, but do seem to occur in areas of notable increases in PED shown Figure 2.1.

For the Auckland and Waikato case studies an overall trend is not that clear, but for RCP 8.5 there is a clear decreasing yield from 2040 onwards.

The Gisborne case study considers a run-of-river scheme and shows a general decrease in the projected flows.

The Canterbury case study showed an increase in yield into the future with this increase being largest under RCP 8.5. The Southland case studies showed a decrease in yield for all but the RCPs 2.6 scenario at the 2040 horizon at the higher levels of assurance of supply (99.5% and 99%). This, however, can be incidental if the water availability far exceeds the demands on the system.

It is worth noting that where long term decreased yields have been predicted, they may still be adequate when compared with future demands on the system, as we have assumed that demand remains constant. The fact that some of these schemes are proposed suggests that there is increasing demand experienced in these regions, and it would be expected that population growth and increased economic activity would result in increased water demand.

Although we acknowledged that increased storage in a water supply system will increase its resilience to drought, storage cannot be increased without bounds. Other factors, such as the need to meet the outcomes of the National Policy Statement on Freshwater Management and Te Mana O Te Wai, cost and loss of value from land inundated by storage schemes, also need to be taken into account.

3.12 Limitations of analyses

The analyses in this project were undertaken within the context of long-term yield analysis under climate change conditions. This implies that the performance of the reservoir was assessed based on a full supply starting level, subjected to various target draft levels and fed by a reasonably long inflow sequence. It is also important that the demand pattern and operating policies do not vary from one sequence to another. Whether one is determining historical or future reservoir yields, these will still be determined by the severest critical subsequence in the sequence of inflows.

Using streamflow from an uncalibrated hydrological model (as was done in this study) means that absolute values of flows and yields are not representative of reality. Relative differences will however be useful, since errors will be conserved between simulations at the different time horizons.

Overall, the stochastic determination of reservoir yield and many other hydrological computational procedures also rely on the assumption that the streamflow (historical or projected future) annual totals and extremes vary about a constant mean value, with constant variance and constant serial correlation (stationarity/constancy) (Clarke, 2007). By virtue of the short streamflow record used in this study, these criteria have been adhered to.

Previous applications of historical reservoir yield determination have used a 64-year record length (Basson et al., 1994) where the probability of observing a drought with a 100-year average recurrence interval (ARI) is 47%, while the probability of observing a 200-year (ARI) drought would be 27%. The probability of encountering a 100-year ARI (or worse) drought in a 36-year streamflow record length is therefore significantly reduced in this study.

When determining yields, stochastically generated flow sequences provide alternative pasts or futures that are required to assess the probabilistic behaviour of reservoir/river yields. Earlier applications of this methodology showed that more than 40 stochastically generated flow sequences are typically required for quantifying reliability of supply. In this study, however, stochastic stream flow sequences were produced based on inputs from the six Regional Climate Models (RCMs).

In this project the question of what future flow records are likely to look like at a particular future horizon has been answered by using the outputs from the climate models, which were then propagated through the TopNet hydrological model to produce an inflow sequence. This approach determines whether the considered future time horizons are generally wetter or drier and provides a simplified method for using existing climate change data in water availability studies.

In spite of limitations alluded to in the previous paragraphs, this study clearly highlights the effort required to mobilise existing climate change data to obtain projected streamflow under various RCP scenarios, and confirms that a sufficient amount of climate change data already exists to allow for the quantification of available water yield in the various climatic regions of New Zealand.

However, it is clear that the approach in this study has two clear limitations:

- The length of the projected inflow sequence is short, and this has the potential to miss the critical low flow periods that determine water availability, leading to an optimistic estimate of water availability.
- The number of stochastic sequences for each time horizon is small and this has the potential to also lead to optimistic estimates of water availability.

Despite these limitations, the yield analyses results in this study provide a sufficiently robust method to assess the relative effects of climate change on water supply. However, this approach would need refinement before application within a detailed planning context is attempted.

4 Supporting Te Mana O Te Wai

The analyses presented in this report all consider the effects of climate change with the purpose of understanding whether existing or proposed water supply uses will be able to be met. These water uses are managed via resource consents usually through a water allocation regime set out in a Regional Plan and by requirements to mitigate adverse effects of these uses on water quality and ecology, predominantly during periods of drought or low flow. This has been accounted for in our analysis through the provision of compensation or residual flows, where this information was available.

A selection of Iwi Management Plans were reviewed in order to identify to how these plans consider matters such as water allocation, drought and climate change, and to highlight the potential links between the matters raised in these plans and this research. Key themes emerging from this high-level review were the recognition of the importance of water supply and its resilience to climate change and drought, water availability to papakāinga and marae and sustainability of water flow.

While on face value the sustainability of water flow could appear to be met through the provision of compensation flows, the matters raised in Iwi Management Plans point to the need to more deeply and holistically consider how water is managed.

For many centuries, Iwi have maintained a strong intrinsic relationship with their Awa Tuupuna. Within this relationship exists mana whakahaere – roles and responsibilities to the Awa Tuupuna as well as Mana Whanake - to ensure the health and wellbeing of the Awa. Iwi view rivers and streams holistically so it includes not just the water but also the bed, banks, flood plains, flora and fauna and its metaphysical wellbeing. Iwi view their role as responsible for the river's long-term sustainability and viewed in its entirety. Therefore, the continuous supply of fresh water is seen as fundamental to the sustainable social, environmental, cultural and economic development for Iwi and Mana o Te Wai.

The concept of Te Mana O Te Wai, which is a part of the Government's recently proposed National Policy Statement on Freshwater Management, promotes a framework in which water use and its allocation is considered. In its broadest sense, Te Mana O Te Wai recognises the fundamental value of water and the importance of prioritising the health and wellbeing of the water before providing for human needs and wants.

In the context of climate change, giving effect to Te Mana O Te Wai would require rethinking and resetting of current resource management priorities. First and foremost, it would demand that the needs of the waterbody are provided for, based on both Mātauranga Māori and science. From a science perspective, this would require a much deeper understanding of the effects of climate change on surface water regimes, and its subsequent effects on ecology, water quality and in-stream processes.

5 Conclusions

The development of a methodology that uses existing downscaled results from six Global Climate Models for New Zealand represents a first substantial step towards the development of a practical, transparent procedure for assessing the potential impact of climate change on reservoir and catchment yield for water supply.

This approach provides a tool for rapid assessment of water availability trends under various future climate conditions, where the outputs from these assessments can be used to prioritise water resources planning efforts.

To do this assessment, we have needed to simplify our approach and make assumptions about stationarity. We have also had to accept that because of the relatively short length of streamflow records, that some critical low flow periods (which would have influenced our results) may not have been sampled or picked-up over that particular time horizon. These assumptions and simplifications can however be addressed to provide a potentially more reliable and quantitative "second generation" assessment.

These refined assessments would also benefit from a more detailed understanding of water demand (for example to recognise increased demand brought about by population growth, or to consider changing demand patterns), and to include changes to demand that may be required in response to regulatory changes to water resource management. This analysis would be significantly strengthened if it were to incorporate a Te Ao Maori perspective on water.

The projected impact of climate change on long-term reservoir yield and stream flows varies across the RCPs and assurance of supply levels and water providers would have to refine the estimates for their water supply schemes based on the level of assurance of supply they wish to provide in light of this assessment. Given that we have modelled different outcomes for different RCPs, this could be challenging for them.

Representative estimates of current and future water demands are essential for water allocation and these need to be used in conjunction with the results from the water availability studies when planning future water supply infrastructure.

Our approach allows future water availability under climate change conditions to be reconciled against future demands and can therefore be used as a long-term planning tool. Decisions about when new water resources or supplementary schemes may be required to meet demand can then be based on the best available information and with sufficient lead time to allow for implementation. Water availability from alternative surface water resources under climate change conditions can now also be considered as part of an adaptive integrated system planning approach to the provision of water supply.

Alternative options for intervention (either in demand management or supply) can then be evaluated based on future water availability. Criteria such as cost (unit reference value approach) and contribution to system storage can also be considered.

Finally, information on catchment yield under climate change could also allow for informed decision making about the effects of climate change on freshwater ecosystems, which in turn could inform policy decisions on the protection and management of water resources and on water allocation.

6 Opportunities for further investigation

We have identified several opportunities for further investigation, should the Deep South National Science Challenge wish to further advance this area of research:

- A methodology for extending the streamflow record length and/or producing more ensemble streamflow records under climate change conditions at the various time horizons should be investigated. The development of an improved "second generation" methodology could potentially use downscaled rainfall data for a particular time horizon as a point of departure.
- The methodologies for assessing climate change impact on water availability should be tested with models capable of taking operating rules and changing demand into account. This will, however, require more detailed information on the water supply systems to be available.
- A Te Ao Maori perspective on water and water use and an evaluation of how this would impact on water allocation in New Zealand, to inform either this research and/or a "second generation" method.
- How this research could be used to support an assessment of the response of freshwater ecosystems to climate change induced changes in catchment yield.

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8 Applicability

This report has been prepared for the exclusive use of our client NIWA - Deep South National Science Challenge, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

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Appendix A: Yield definitions (DWAF, 1986)

Yield	The volume of water (per time unit) that is abstracted over a period	
Target draft	Volume that users would like to obtain from a water supply system to supply demands over a specified period	
Base yield	Minimum yield over a specified number of consecutive time intervals that can be abstracted from a river/reservoir system of a unique configuration and fed by a given inflow sequence while attempting to satisfy a given target draft associated with a specified temporal demand pattern for water and specific operating policy	
Firm yield	Maximum base yield that can be abstracted from a river/reservoir system of unique configuration and fed by a given inflow sequence while attempting to satisfy a given target draft associated with a specified temporal demand pattern for water and specific operating policy	
Secondary yield	Yield that can be abstracted from a uniquely defined river/reservoir system in excess of target draft; given a specified inflow sequence, temporal demand pattern, operating policy and abstraction capacity	
Non-firm yield	Yield above base yield that can be abstracted from a uniquely defined river/reservoir system to meet the target draft	
Average yield	Sum of the base yield and the average value of non-firm yield; given a specified inflow sequence, temporal demand pattern for water and operating policy	
Total yield	Sum of the base yield, secondary yield and non- firm yield for a uniquely defined river/reservoir system given a specified inflow sequence, temporal demand pattern, operating policy, installed abstraction capacity and target draft	

Appendix B: Stakeholder reference group members (SRG)

SRG member	Organisation	Role	
Blair Dickie	Waikato Regional Council	Principal Strategic Advisor	
Tutahanga Douglas	Waikato Regional Council	Kaiwhakarite Tai-ranga-whenua, Community and Services	
David Taylor	New Plymouth District Council	Network Planning Lead	
Dennis Jamieson	Environment Canterbury	Project leader – Water Infrastructure	
Lawrence Kees	Environment Southland	Water Resources Scientist	
Mike Thompson	Greater Wellington Regional Council	Senior scientist - Hydrology	
Paul Murphy	Gisborne District Council	Environmental Science Team Leader	
Stephen Rooney	Marlborough District Council	Operations and Maintenance Engineer	

Appendix C: Review of selected Iwi water management plans

Several Iwi water management plans were reviewed for references to "water allocation", "drought" and "climate change" with the intention of highlighting the potential links between concepts highlighted in the management plans and future water availability. The management plans cover wide ranging actions on climate change and in general promotes that:

- Activities that encourage Greenhouse gas emissions' reduction
- Planning takes into consideration the effect of climate change
- Developments need to implement methodologies that reduce pressure on available water resources
- Environmental flows need to be accounted for in water allocation

Only those issues related to water availability were focused on in this study. Some pertinent actions from selected Iwi management plans are listed in the table below.

lwi water management plan	Council	Required actions (Climate change)	Required actions (Water supply)
Hapu/Iwi Management Plan of Nga Ariki Kaiputahi	Gisborne District Council	The need to provide for resilience against the biophysical effects of climate change (such as through infrastructure for supply, storage and distribution of fresh water)	-
Te Rūnanga o Kaikōura Environmental Management Plan	Environment Canterbury	To consider the potential impacts of natural hazards that may be associated with global climate change (e.g. sea level rise; severe weather events) with regards to the use and development of land and water resources, particularly in coastal regions of the Takiwā. (3.1.2 Policy 8)	-
Ngāti Hauā Environmental Management Plan	Waikato Regional Council	Take steps to prepare and adapt to the effects of climate change. This includes ensuring a secure and reliable water supply (10B4)	Work with regional and district councils to ensure a reliable water supply for marae and papakāinga. This may include specific plan policy or rules and/or a rebate on water rates (10A.8)

Selected actions from Iwi management plans

Maniapoto Environmental Management Plan	Waikato Regional Council	Recognise and manage the risk and potential effects of climate change and natural hazards in land use planning (20.3.1.1)	-
Te Ātiawa o te waka- a-māui lwi Management Plan	Marlborough District Council	-	Policy 1 Take steps to ensure that water-takes, both casual and formal, do not compromise the sustainable flow of waterways throughout the rohe. Policy 3 Require legal enforcement where there is a breach of water-take requirements that impacts on sustainable flows (7.7)