DROUGHT AND CLIMATE CHANGE ADAPTATION: IMPACTS AND PROJECTIONS

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SUMMARY HAIKU

Climate change driven
drought will affect New Zealand.
Focus on people.

FOREWORD

This discussion document was developed in draft form as background information for two workshops (making up a "Deep South Dialogue") hosted by Motu in May and June 2018 as part of the Deep South National Science Challenge. This final document incorporates material from expert presentations made at the dialogue, research recommended by participants and other experts, and direct feedback from dialogue attendees.

The seven critical research questions at the end of the document emerged from the second Dialogue meeting and formed the basis of a Request for Proposals for research under the Deep South National Science Challenge. Successful projects will be undertaken over 2018-2020.

Experts in the dialogue are listed on page 8. Experts did not attend as representatives of their organisations. Opinions expressed are those of the authors and not necessarily those of all dialogue participants or of their employers, or the Deep South National Science Challenge.

INTRODUCTION

Since 1909, the average annual temperature in New Zealand has risen by one degree Celsius. As result of greenhouse gas emissions, temperature will continue to rise this century with 0.8 degrees of warming expected by 2040. By 2090, average annual temperatures are expected to be 1.6 degrees warmer than they are today relative to the period of 1986-2005 (MFE, 2016). However, those projected numbers are medians, and models show that there is a large range of possibilities. By 2040, temperature increases could be as low as 0.2 degrees or as high as 1.7 degrees. By 2090, they could range between 0.3 and 4.6 degrees. This range in the projections depends largely on how quickly the world reduces greenhouse gas emissions (MFE, 2016).

As the atmosphere warms, the natural global water cycle intensifies. This intensification could drive increases in the frequency of intense rainfall events, because a warmer atmosphere can hold more water (MFE & Stats NZ, 2017). However, the Intergovernmental Panel on Climate Change found regional and global-scale projections of soil moisture and drought are relatively uncertain compared with other aspects of the water cycle (IPCC, 2013).

We do know, however, that under shifting rainfall patterns, the nature of drought is likely to change. A number of studies predict increases in the intensity, duration and spatial extent of droughts associated with higher temperatures, decreased precipitation, and/or increased evaporation (Dai, 2013; Morrison, Morikawa, Murphy, & Schulte, 2009; Mullan, Porteous, Wratt, & Hollis, 2005). These predictions worsen if the models use futures with higher carbon emissions.

Future drought may very well be the climate change impact with the most significant effect on our economy (see Westpac, 2018). A recent report by Frame et al. (2018) estimated that the economic losses from droughts between mid-2007 and mid-2017 was $720 million. This exceeds the cost of privately-insured damages from floods over the same period, which are estimated at $120 million. This number is, however likely to under-represent the full economic impact of extreme rainfall as uninsured damages and economics losses are not included. Drought already impacts a wide range of activities in Aotearoa including urban water, primary production, and electricity generation. It also has significant impacts culturally and in our communities. Will climate change simply exacerbate these existing pressures, or might it change the nature of impacts?

In 2018, the Deep South National Science Challenge held a dialogue with practitioners and researchers. These participants were from a variety of New Zealand organisations involved in areas where climate-driven changes to drought risk are pertinent for long-term planning. The group's goal was to better understand drought adaptation issues by mapping current knowledge of drought impacts and identifying knowledge gaps. The aim of this paper is to provide a background to the issues and current research, while capturing the understanding developed by the group regarding the impacts of drought in a changing climate.

The group focussed on future drought exacerbated or altered due to climate change and took an people-focussed (anthropocentric) view of the impacts of droughts starting with inspiration from Maslow's Hierarchy of Needs (Maslow 1943). Existing issues not unique to climate change were deemed outside the scope of this dialogue. These included the debate around allocation (and pricing) of water and emergency responses to drought.

WHAT IS DROUGHT?

Put simply, drought can be thought of as a severe decrease in water availability below what is expected (Clark, Mullan, & Porteous, 2011; OECD, 2016). Droughts differ from other natural disasters because of their extended, rather than short sharp, effect. Droughts have a gradual onset without clear start and end points and can occur over a single season or last several years, compared with a storm which generally occurs over a number of days (Clark et al., 2011).

There are different dimensions to drought, including:

- Meteorological drought – (atmospheric and weather) conditions that result in less water available than required (OECD, 2016).
- Soil moisture drought – conditions that lead to soil moisture being below normal levels (Van Loon et al., 2016).
- Hydrological drought – water deficits at different points in the hydrological system, particularly as it relates to flow and soil moisture variables (Van Loon et al., 2016).
- Socioeconomic & environmental drought – when an extreme event resulting in a water deficit has an impact on people, the economy and the environment (OECD, 2016).

These dimensions are interlinked. Extreme meteorological conditions, such as less rainfall, can affect both surface and groundwater, as well as leading to soil moisture deficits. However, the relationship between meteorological drought and hydrological drought is non-linear (Zammit, 2018). Factors such as land cover, soil and geology will also have an influence (Van Loon et al., 2016). Glaciers, snowpack, aquifers and wetlands are also part of the hydrological system and respond to droughts in different ways (PMCSA, 2017).

Often, when people discuss drought, they mean meteorological drought – a primarily natural phenomenon. However, human activities can heavily modify the water cycle. Hydrology and soil moisture are affected by how much water we extract or divert, how we use that water, and how we use the land. Management of dams, changing land cover, and the choice of drainage type all have an effect.

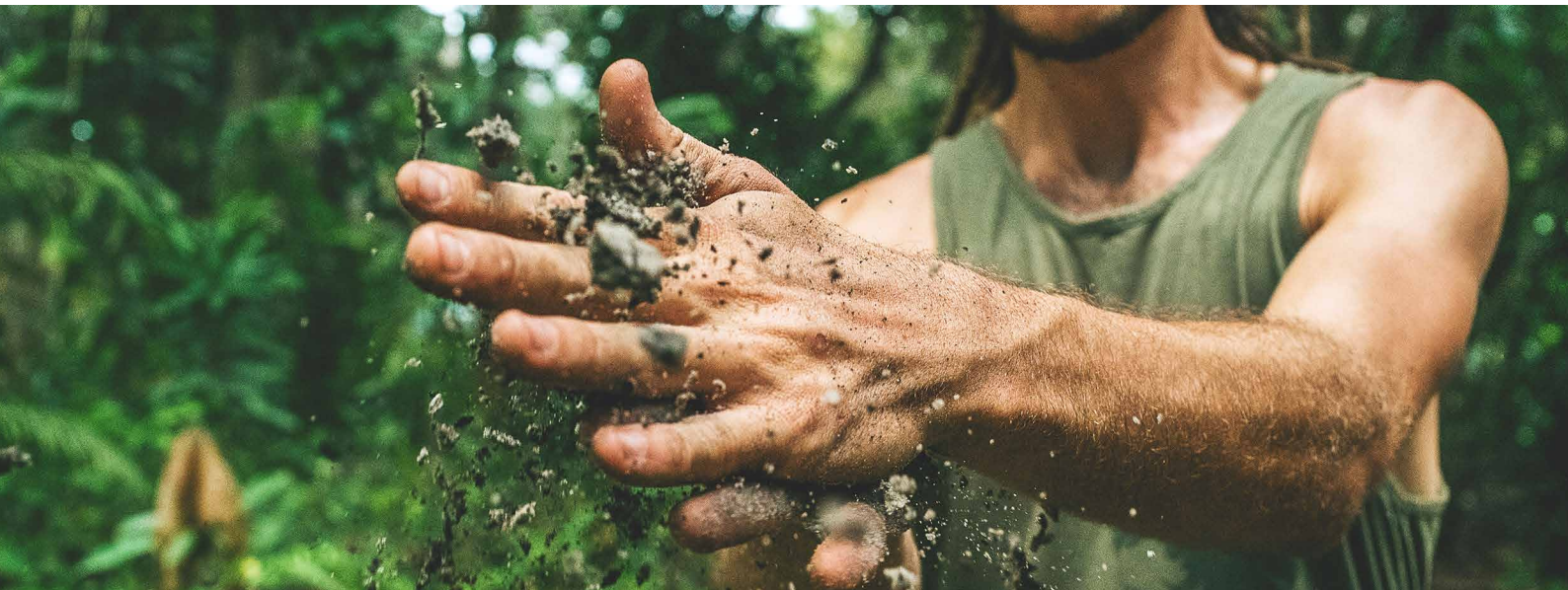
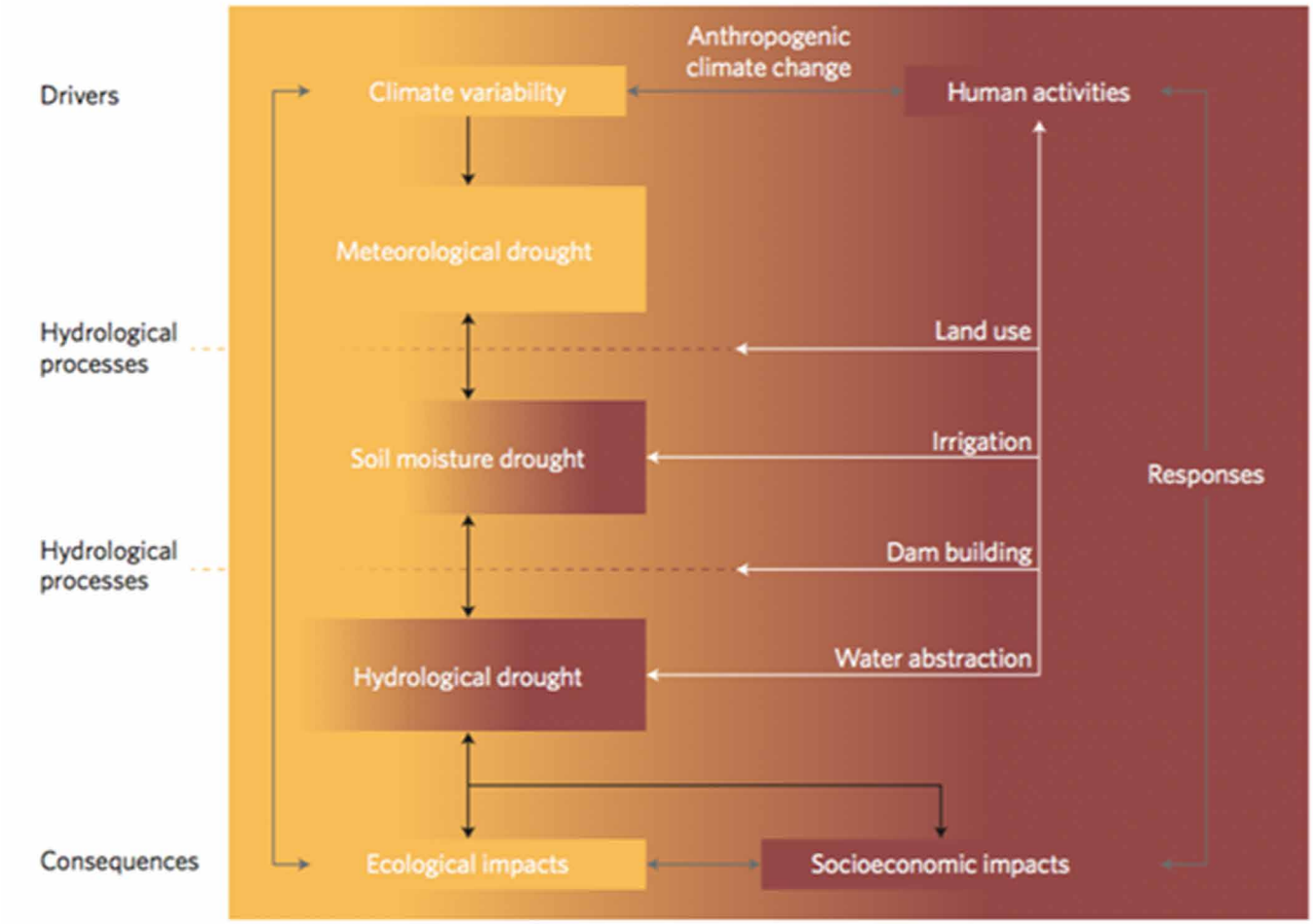


Figure 1: Drought system (Van Loon et al., 2016)



INTERNATIONAL RESEARCH

The causes of the onset of droughts are complex. This complexity makes simulating the chain of events that lead to a drought difficult, and attribution is an exceptionally challenging research question (Angélil et al., 2018; Bony et al., 2015; Harrington et al., 2016). Internationally, the evidence emerging over recent years shows that a large number of heat-related extremes, heatwaves for instance, became more likely because of climate change (Harrington et al., 2016; Perkins, 2015). However, how climate change does and will affect precipitation related-extremes, particularly drought, is not entirely clear, though there is evidence of generally higher atmospheric pressure, and more dry days, in a human influenced world (Harrington et al., 2016).

DROUGHT RISK IN NEW ZEALAND

Over the last fifty years, some regional changes in rainfall patterns have been observed in New Zealand. For example, increases in winter rainfall have been observed in Whangarei, Wellington and New Plymouth, while Dunedin and Kerikeri have seen decreases in summer rain (MFE & Stats NZ, 2017). Twenty percent of the 30 sites reported across Aotearoa have soils that have become progressively drier since the early 1970s (MFE & Stats NZ, 2017). The volume of ice in New Zealand's glaciers has decreased by 25% in the last 20 years (MFE & Stats NZ, 2017). This has significant consequences for summer flows in some South Island glacier-fed rivers, which feed aquifers, hydro-electric power generation and irrigation.

Projections show rainfall in spring and winter increasing in the west of the country and decreasing in the east and north. However, summer will likely follow a different pattern, with wetter conditions in the east and drier conditions in the west and central North Island (MFE, 2016). River flows on the west coast of the South Island are likely to increase, as are those on the eastern flank of the Southern Alps. In contrast, decreased river flows are likely in Waikato, Northland and on the east

We would like to thank all participants involved in the Deep South Drought Dialogue, especially our presenters. Thank you also to Professor Arthur Grimes, Professor Iain White and Dr Adolf Stroombergen for early conversations in preparation for this Dialogue, and to Professor Ilan Noy for useful conversations.

coast of both the North and South Islands (PMCSA, 2017). As a result of temperature and rainfall changes, the snowpack in the Southern Alps is likely to reduce (Renwick et al, 2010).

Successive projections from NIWA of how climate change will affect drought in New Zealand paint a consistent picture. Those projections show that the severity of drought is projected to increase in most areas, with both the frequency and intensity of meteorological drought in already drought-prone regions expected to increase (Clark et al., 2011; MFE & Stats NZ, 2017; MFE, 2016; Mullan et al., 2005). The 2013 drought led to Wellington being very close to running out of drinking water. Season- and area-averaged metrics show that we are more likely to experience a '2013-like' summer in future (Harrington et al., 2016).

Other sources of variability will also have an impact – at times amplifying and at other times dampening the underlying effect of climate change. One such source is the El Niño–Southern Oscillation (ENSO) cycle. The El Niño part of this cycle occurs every two to seven years and lasts about a year. It tends to lead to stronger westerlies and to more rain in the west and drought in the east (MFE & Stats NZ, 2017). La Niña (the positive phase of the ENSO) can also lead to drought for certain regions of NZ (e.g. central Otago, South Canterbury), as the predominant westerly wind flows weaken from El Niño (MFE & Stats NZ, 2017).

Different New Zealand studies have historically classified the severity, extent and duration of droughts in different ways. NIWA last year launched a Drought Monitor for keeping track of drought conditions across New Zealand. This is based on a standardised climate index based on four indicators:

1. Standardised Precipitation Index,
2. Soil Moisture Deficit,
3. Soil Moisture Deficit Anomaly, and
4. Potential Evapotranspiration Deficit.

The index has five categories: Dry, Very Dry, Extremely Dry, Drought, and Severe Drought (NIWA, 2017).

Before the Drought Monitor was launched, widespread rainfall deficits lasting over a month were considered to be agricultural droughts, as pasture and crop production become vulnerable in these conditions (Clark et al., 2011). On average, every year or two somewhere in New Zealand has experienced a drought (NIWA, 2018).

WHICH INSTITUTIONS HAVE A ROLE?

Many New Zealand institutions have either a direct or an indirect role in adapting to climate change as it relates to drought.

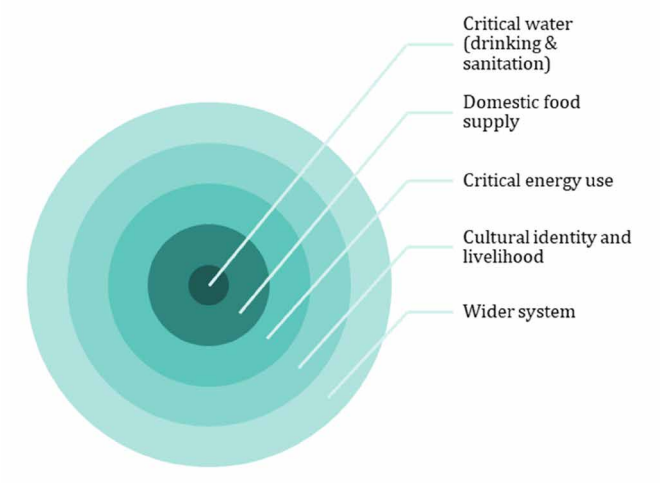
Local government has responsibility for helping communities adapt to climate change (CCATWG, 2017). Among other things, they are responsible for resource management processes and planning, freshwater management/allocation, emergency management, and the operation and maintenance of some aspects of New Zealand's infrastructure. In addition, Iwi management plans (IMP) could provide useful options for effective climate adaptation. Within the institutional landscape, corporations, advocacy groups, and other stakeholders could all help play a part in effective adaptation.

Central government agencies have roles in terms of climate change adaptation and drought and funding, including:

Ministry of Primary Industries (risks to primary industries); Ministry for the Environment (environmental risks, and frameworks for planning); Fire and Emergency New Zealand (fire risk); Ministry of Health (health risks and frameworks for managing these); Department of Internal Affairs (advises on requirements for local government infrastructure planning); Department of Conservation (threats to conservation land, native species and natural ecosystems); and the Ministry of Business, Innovation & Employment (major infrastructure investment). In addition, many non-government organisations have a role, including: Environmental Defence Society; Fish & Game New Zealand; Rural Support Trust; Irrigation NZ and various other industry groups and community groups.

DIALOGUE FOCUS

Figure 2: Ordering possible channels for drought to impact human health and wellbeing



Drought has an impact on people's lives in a multitude of ways, through water supply, health, ecosystems, primary production and more.

In order to structure our thinking and understanding about these, the group prioritised fundamental human needs first and foremost, followed by other impacts on our lives and wellbeing. This provided a structure that could recognize that impact channels are complex and multi-sectoral.

In the Dialogue's second meeting, initially inspired by Maslow's theory of needs and related frameworks, we arranged impact channels by importance to people (thinking pictured in Figure 2).

IMPACTS OF DROUGHT IN A CHANGING CLIMATE

Having been historically 'water-rich', New Zealand is not well-prepared to cope with a future that will involve more drought in some areas. For example, much of our irrigation in drier areas is on a run-of-river basis, a model extremely vulnerable to drought given environmental obligations. New Zealand's dependence on agricultural exports and urban reservoirs may yet be a recipe for drought vulnerability.

Changing drought risk will have an impact on our society in many ways (OECD, 2016), including through:

- the three waters (water supply, wastewater and stormwater),
- primary production (including agriculture, horticulture, forestry and freshwater fisheries),
- electricity production, and
- industrial water use in processing and manufacturing.

It will also have significant cultural, community, and ecological effects. Households may face diseases due to water-born pathogens or as a result of water-shortage induced lack of hygiene. They may also experience more frequent watering bans and higher prices (or the imposition of water prices) in some areas. In some scenarios, wide-scale drinking water shortages may eventuate. There will also be an impact on in-situ water uses (water within the landscape, i.e. rivers, lakes, and streams), including the use of waterways for safe contaminant assimilation, as migratory pathways for wild species, commerce (e.g. tourism), and for recreation.

Potentially, the largest impact will not be the effect of drought in isolation, but the cumulative impacts of back-to-back extreme climatic events (Clark et al., 2011). Some argue these cumulative impacts are the least-understood, and the most difficult to identify and anticipate (e.g. Clark et al., 2011). Most recently, in the summer of 2017–2018, drought conditions were brought to a dramatic end with extreme rainfall (Mitchell, 2018). Another major concern is understanding the impact of concurrent events, such as high winds in combination with drought, or the effect of flooding on drought-stricken soil.

IDENTIFYING RESEARCH PRIORITIES

Not only is drought an issue for the future, but it is clearly a significant issue now, even without the exacerbation by climate change.

New Zealand's current drought response is limited firstly by an unavailability of information (though this has improved immensely since the introduction of the Drought Monitor). Further, available information (be it data or knowledge) is not always accessible to decision-makers and their advisors. Both limitations are of particular concern given the exacerbation of drought issues predicted for the future, and are especially problematic given the long lead time for infrastructure investments that might counter future drought issues.

In addition, New Zealand is yet to understand how to achieve optimal water allocation in the face of conflicting regional, sectoral, and cultural needs. Our allocation framework is relevant to this discussion document, but unfortunately it is not something that can be solved in the small research projects following our Dialogue. The discussion of drought impacts and future drought resilience is currently under way through implementation of the recommendations of the Land and Water Forum, current Three Waters Sector review, and in various regional councils updated freshwater strategies (e.g. Waikato Regional Council (2017)).

Unfortunately, as Deep South is strictly limited to climate change adaptation, issues regarding current drought response and national water frameworks are out of scope for research following this dialogue.

RESEARCH INTO CLIMATE CHANGE AND DROUGHT

An overarching concern of the group was that New Zealand doesn't know what resilience to future climate change related droughts means or what it looks like. We therefore don't know how to evaluate whether it has been achieved. A major question from the dialogue was, 'what is the objective; what are we trying to achieve?'

One way to approach this is by considering what systems in other countries look like, and how New Zealand might respond to interventions in order to achieve similar results. In the context of drought issues, these were particularly noted in the context of water conservation in arid countries, or of "good" and "bad" responses to expected and unexpected conditions.

This raised further points, such as the question of who should decide the objective. It also raises the concern that this type of decision might be prone to interference by those with incentives not in the national interest. This led to the question: who gets to decide what the objective is, and how can we avoid manipulation of that group's decision?

Another set of concerns involved understanding how New Zealand society might change in the future, for example, in terms of land-use, population, technological change and attitudes. Some understanding of these will be crucial in understanding how Zealand can best adapt to future drought. However, it was recognised that some level of uncertainty will always have to be dealt with. Concerns centred predominantly around not knowing future land-use or population and thus likely future water demands, and not knowing enough about catchment behaviour or extreme events to accurately predict future water supply.

A final concern involved the likely impact of future drought on social cohesion. The idea of 'Mad Max or Utopia' helps to think about this: where a future of extreme drought could lead, at one extreme, to social cohesion being eroded (possibly leading to extreme inequality – 'Mad Max') and at the other end to social cohesion being improved, possibly leading to extreme cooperation ('Utopia'). This is addressed in greater detail in the section on cultural identity, livelihood, and wider issues.

Knowledge we would like on climate change and drought	Research gaps
What would a future resilient-to-Climate-Change-and-Drought New Zealand society look like? What sorts of "institutions" would lead to "good" and "bad" outcomes? How do others deal with this problem?	Are there drought-stricken societies in equilibrium (and what does that look like)? Are there societies that have effectively managed unexpected meteorological droughts (and what does that look like)? Could these lessons or approaches to be applied in NZ? How might our society respond to those?
How do arid countries' systems work, what lessons or options could be developed from those to apply in New Zealand, how might we expect New Zealand to respond to those?	Case studies of arid areas to possibly investigate include Australia and Iran.
Understanding of flow-on ecosystem effects in times of severe, repeated or persistent drought.	Can we create more understanding of the intensity, frequency and persistence of future severe meteorological or hydrological drought?

IMPACTS ON DRINKING WATER

Drought can clearly affect the fundamental human need of drinking water. In intense drought, both urban and rural water supply networks with inadequate storage capacity or alternate adaptation will be threatened with potential water quality or quantity issues.

The impact on human health of affected drinking water is clear. First and foremost, severe drought-related water supply which leads to water being cut off can lead to dehydration and death. Further, drought can increase the burden of water related diseases, and other diseases influenced by a lowered ability to keep conditions hygienic and sanitary (Bennett et al., 2014).

Domestic water supply in New Zealand is primarily treated town supply piped from rivers, lakes, storage reservoirs and bores. The rest is sourced from private community schemes, private wells, stock water, and rainwater tanks. On intense drought, water supply networks will be threatened. Work has been done to explore sustainability of water supply in isolated Māori communities in Northland (Te Hiku o te Ika). Rainfall is the main source of drinking water in these rural Māori settlements. Drinkable mains water is almost non-existent, household infrastructure is generally poor and whānau struggle to keep up with maintenance. Floods and drought will create more serious issues – projections suggest that water quality could be compromised and that water shortages are likely (Henwood & et al., 2018).

Drought affects domestic water supply systems in many ways, including by reducing filter operating cycles and increasing susceptibility to toxin bypass. There is clear potential for increased costs of water treatment, which in some international cases, such as Cape Town, has led to increased costs of water supply passed on to consumers.

Droughts can also lead to increased runoff from unsaturated land. Combined with higher effluent pathogens, this means when drought is followed by periods of intense rainfall, the flushing out can result in increased disease occurrence (Lal et al., 2013). Together with other factors, such as reduced flushing inputs and increased temperatures, drought can lead to increased algal concentrations and toxins (Royal Society Te Apārangi, 2017; Kamish, 2018). The prevalence of potentially toxic blue-green algal blooms for example, can mean non-conventional water treatments are necessary before water can be drinkable.

Evidence is growing that climate change could increase the burden of water related diseases (e.g. Delpla, Jung, Baures, Clement, & Thomas (2009)) which can also infiltrate our water supplies. Drought reduces water flows and levels, leading to increased concentrations of pathogens from contaminated effluent discharges (Hambling, 2012). Extreme rainfall is a major factor in water-borne outbreaks of diseases – through contamination of piped water supplies or from surface water. Untreated water supplies such as small communities' systems or private wells are especially susceptible (Royal Society Te Apārangi, 2017). Dry conditions could also affect the continuity of household water supplies, leading to effects on diseases influenced by hygiene (Bennett et al., 2014).

Knowledge we would like on drinking water	Research gaps
More information on the natural science of drinking water	What is the frequency of low flow conditions in a given year on Waikato and Clutha/Waitaki lakes/river systems? What is the incidence of multi-regional drought looking forward? What is the nationwide spatial pattern of expected change in drought incidence?
How are water supplies prioritized across New Zealand and regionally?	How might future droughts, in the context of a changing climate, affect future water supply and demand for the local food production sector when this sector competes for water with other uses (e.g. domestic/commercial)?
What is the risk factor in relation to drinking water availability in NZ in times of drought more broadly? *(urban and rural supplies/storage)	What influences water demand behaviour in NZ? How can this be harnessed to reduced demand in times of drought? Is it worth having dynamically responding (?) pricing in NZ? Is there a relationship between drought and drinking water quality in NZ? (bore water, ground water)

DIALOGUE PARTICIPANTS

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IMPACTS ON DOMESTIC FOOD

Drought can have direct impacts on people's food supply. What happens to domestic food supply during times of drought is an emerging concern. In this section, we focus on domestic food production rather than examine the economic impact on our export sector (e.g. dairy, kiwifruit). In taking a New Zealand-based, people-centric view, it is particularly important to understand the impact on:

- domestically consumed horticulture,
- other domestically consumed agricultural products, and
- domestically consumed freshwater fisheries.

For example, in January 2018, Horticulture New Zealand warned of supply shortages of fruit and vegetables due to the hottest month recorded in 150 years (Nichol, 2018). As well as horticultural products, other domestically consumed agricultural products will be affected by future drought.

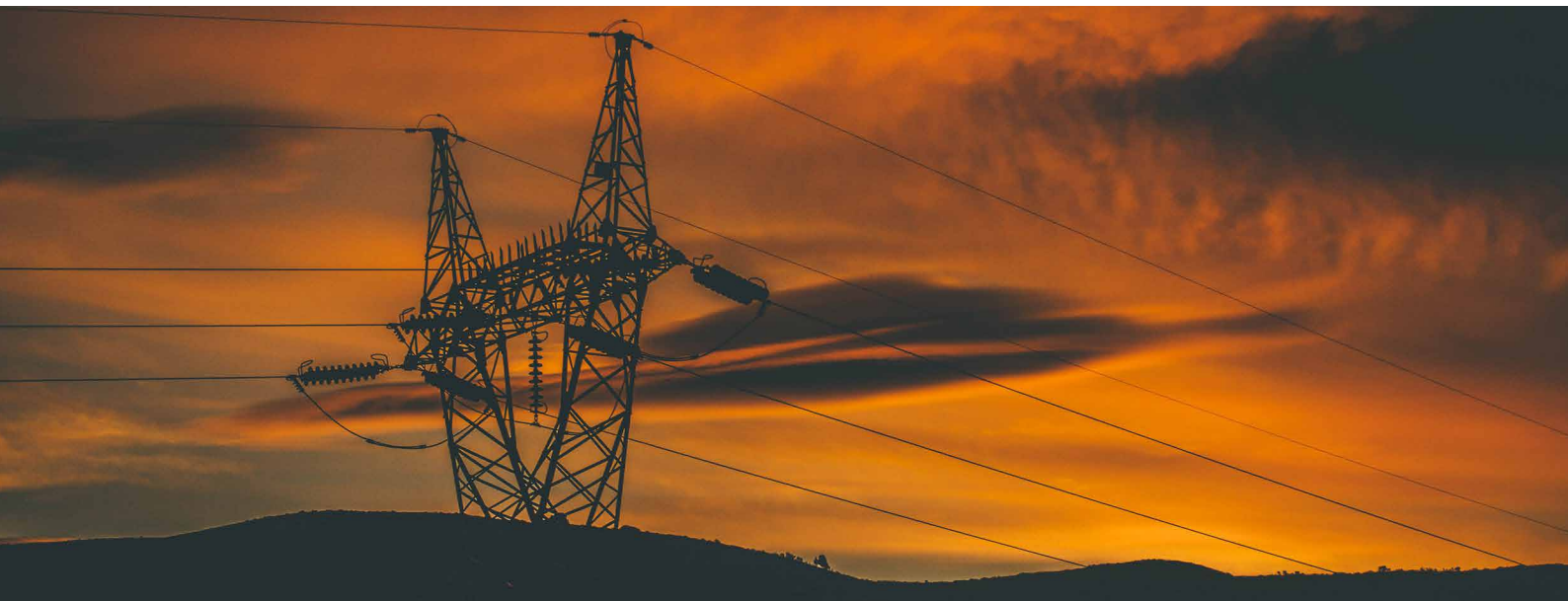
Another affected domestic food product is domestic fisheries. The group was not aware of any analysis of the effects of drought on domestic freshwater fisheries and noted that most commercial freshwater fish are for export, with the exception of aquaculture such as salmon or koura.

Knowledge we would like on domestic food and mahinga kai	Research gaps
How might drought redefine how (when, where, what) we use our land and freshwater for domestic food security/production?	In order to ensure that we respond to drought, how can we improve the resilience and flexibility of our food security/production systems? What farm practices/systems increase adaptive capacity to short-to-long term drought? How might future drought impact on future water supply/demand for food security/production versus other uses (e.g. urban water, domestic/commercial)? What are the specific drought effects on freshwater fish species harvested for traditional or recreational use?

IMPACTS ON ENERGY

A particular priority is how to maintain a basic level of household energy use in future drought. People need to stay warm (or cool) and dry, and to live with light, cook food and communicate. Other critical energy users, such as hospitals, are also of particular importance when using a people-centric view.

More than half of New Zealand's electricity comes from hydro generation (EECA, 2016a). While some large hydro dams – such as Benmore, Manapouri and Clyde – have considerable storage, New Zealand overall has a relatively small water storage capacity (4TWh storage vs annual inflows of 24TWh (Batstone, 2018)). Historically, there has been high variability in water levels for the South Island hydropower lakes. New Zealand also has some run-of-river hydro systems e.g. the Waikato River, which are reliant on instantaneous water flows all year round. Impacts on river flows in times of drought will have



effects for electricity. Interestingly, these effects are usually temporary – electricity systems are able to recover in a matter of weeks, which is another consequence of both New Zealand's relatively low amount/proportion of water storage and the relatively high frequency of rainfall.

Both changes in precipitation and rapidly melting glaciers are likely to increase winter flows to New Zealand's hydropower lakes. However, this may reverse in summer. The net effect would flatten the annual cycles of flows and generation capacity from the major South Island dams (Renwick et al., 2010). In the South Island, snowmelt is also likely to affect power generation (Dunlop, 2018, p. 2018). Work is being done within the Deep South Challenge to better understand this.

Climate change will also affect our electricity industry in other ways. In addition to hydropower, over 17% of New Zealand's electricity is generated by thermal power plants (EECA, 2016a, p. 201). These plants rely on water as a coolant – once used in coolant systems it is then discharged back into waterways. Thermoelectric power plants could be affected in droughts through water restrictions, and possibly due to restrictions on discharge into rivers because of temperature limits in resource consents.

For the electricity market, the timing and location of drought conditions can mean quite different consequences. There can also be situations when system-based effects amplify the consequences. Like other industries, many security risk assessments are based on analysis of historical data – clearly problematic given climate change.

It is hard to predict the impact of the complexity and uncertainty of climate change on reservoir management and security of supply. Reservoir management is a behaviour-driven job: influenced by the manager's risk aversion, anchoring etc, and day-to-day decision making can be particularly difficult for operators. Although there are plenty of optimisation models, the day-to-day human decisions are still necessary and difficult. This may also be affected if there are changes in allocation regimes, meaning electricity generators may choose to utilise stored water for other higher value uses at certain times.

In drought, irrigation places stress on electricity providers. For example, in Nov/Dec 2017 national electricity demand trebled (Batstone, 2018). This elevation in electricity demand due to irrigation demand in dry years will be a major challenge for New Zealand going forward. Another consideration for electricity demand is the drought/wind relationship in years to come. Drought is often exacerbated by wind, therefore the use of wind turbines may be a viable alternative energy source in some areas during drought.

Knowledge we would like on critical energy use	Research gaps
What are the impacts of the incidence and length of drought (and concurrent effects of climate change) on electricity/energy production and consumption (including irrigation)	How will drought affect: • security of supply, • cost to consumers, • water quality, • hydropower lake flow cycles, • minimum flows, • renewable investment (incl. emissions), and • fuel substitution?
Criticality of electricity-fuelled services (including transport)	What is the resilience of the electricity (energy) system to the impacts of climate change (concurrent with drought)?
What are the energy-related social impacts of drought?	How do local and central government prioritise supply during water shortages? How affordable is self-provided resilience e.g. home batteries -> social inequity? What is the network expenditure/reinforcement of urban vs rural?

IMPACTS ON CULTURAL IDENTITY, LIVELIHOOD AND WIDER ISSUES

Impacts that affect our cultural identity

People's relationship with water is complex and ever-changing. Meaning, place attachment, and identity are all wrapped up in this. The social experience of drought varies based on these as well. For example, "drought" means quite different things to a farmer, golfer, or naturalist.

The (visible) impacts on our birdlife, insect life, and other fauna, and concurrently, the impacts of deteriorating flora will have an impact on community identity and wellbeing. Adverse mental health and psychological issues can result from the effect of ongoing drought on valued flora and fauna (Penny et al., 2005), notably among Māori but also the wider New Zealand community. Note that the Durie (1994) model of Māori health categorises effects of environmental health on Māori as:

- Taha hinengaro – mental and emotional wellbeing
- Taha tinana – physical wellbeing
- Taha wairua – spiritual wellbeing
- Taha whānau – social wellbeing

These could all be diminished in a future of more extreme drought.

Increasing storage to harvest water may involve changing the nature of our societal relationship with water (see Hay & Kitson (2013) for a discussion of possible issues due to water harvesting.) Recent controversy over swimmable rivers points to heightened nationwide community concern about consequences of land use changes and water uses on rivers and lakes.

Community cohesion may be eroded as impacts hit different groups in different ways. Socio-cultural/institutional inequities shape how drought is experienced and prepared for. Inequities can be due to a number of structural conditions and relations intersecting around race, gender, sex, class, religion, citizenship, ablism, education, age, etc. Relationships among these constitute society and therefore the social construction and experience of drought. If we are working to mitigate and prepare for the drought, especially in ways that aim for justice and fairness, the root causes and drivers of inequality should also be incorporated (e.g. institutional racism, sexism, classism, etc).

The most vulnerable communities are those that are exposed to existing climatic variability and hazards in conjunction with other challenges (King et al., 2010). Two communities likely to particularly feel the impacts of future drought are rural and Māori communities. Challenges could include limited access to capital, poor information, remote and substandard infrastructure, unstable or weak institutions, and inequitable empowerment and representation in government planning. Not all in this situation of multiple vulnerability-creating challenges are Māori, but Māori are likely to be over-represented.

For Māori, water is a taonga. In Māori culture, the health of the water reflects the health of the people, and thus is deeply linked with identity. Numerous iwi have whakatauki about the unity of people and water. For example, in the Whanganui rōhe there is a saying 'ko au te awa, ko te awa ko au' (I am the river and the river is me) (Wai Māori, 2008). A large proportion of the Māori economy is also either directly or indirectly related to natural resources. Thus, climate change may well exacerbate disparities for Māori by impacts being felt more deeply (King et al., 2010).

Another tension that future drought may create is in social cohesion between geographic groups. Rural-urban linkages concerning drought appear to be understudied. The studies that exist are often concerned with how development pressures impact farmers. For instance, Kenny (2011) found that farmers view urban growth and urbanisation as a fundamental issue for water use and that this creates a form of tension around usage. Others have examined the institutional politics of drought risk in the southwestern U.S. (Hess et al., 2016), finding that approaches to water-supply are more informed by development logistics than partisan orientation.

Impacts that affect people's work

The psychological stress on rural communities resulting from drought is well known. A number of Australian studies have focussed on this issue. For example, Hanigan et al. (2012) conducted a study into the connection between suicide and drought in Australia and found a 15% increased risk of suicide among rural males aged 30–49 when the Hutchinson Drought Index (which integrates consecutive months of lower-than-median rainfall based on percentiles of rainfall records) rose from the first quartile to the third quartile. Similarly, Ellis & Albrecht (2017) found that the impact on farms of long-term patterns of climate change (largely drought) chronically affected farmer's sense of place, undermined self-identity and ultimately increased the risk of depression and suicide. A recent New Zealand study by Beautrais (2018) also suggested that drought may have contributed to farmer suicide. Declines in physical health are also particularly prevalent amongst the elderly in drought-affected rural communities in Australia (Horton et al., 2010).

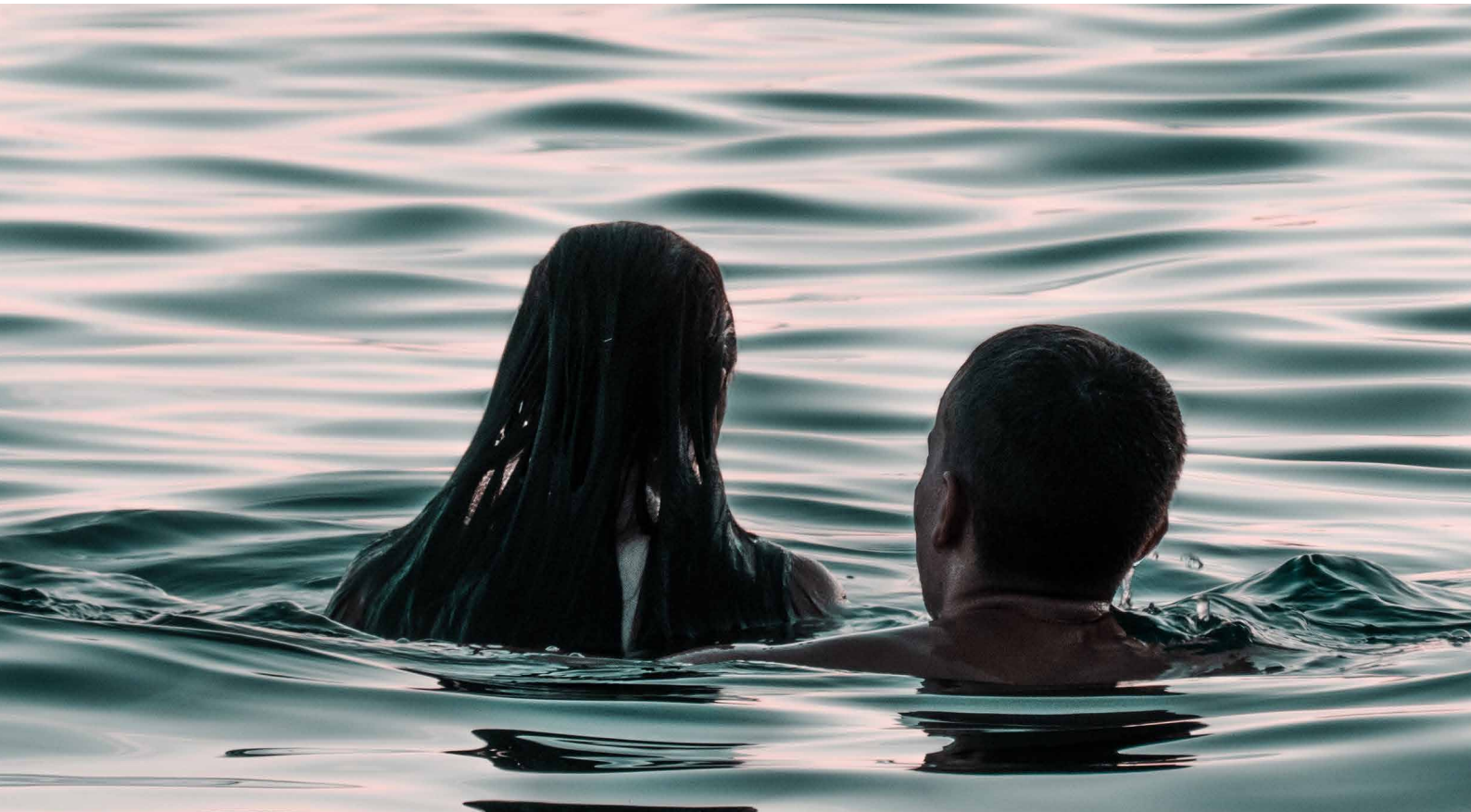
It has long been recognised that communities play a critical role in determining the severity of rural drought experiences. Of particular importance is the role rural communities (both farm communities and local towns) play in providing psychological support (Stain et al., 2011) and promoting general resilience and adaptive capacity (Alston et al., 2018; Stehlik, 2003). As part of a wider study in North Otago, Burton & Peoples (2008) found community support to be very important for farmers' response to drought. Since then, other New Zealand based studies have noted the importance of communities. In particular, Pomeroy & Newell (2011) suggest that the principle of caring in the community was a resilience factor in climate change response, while Smith et al. (2011) observe that the 'hollowing out' of rural New Zealand has "changed the capacity of rural communities to respond to natural hazards and increased their sense of isolation."

In addition to the impacts noted above, future drought will also negatively affect people's primary sources of employment. The effects of increasing drought risk may include reduced work opportunities (MFE & Stats NZ, 2017).

Wider system impacts

Water use is interconnected with socioeconomic, political and cultural systems. The group also recognised that there are additional, less direct, likely channels of future drought impact on people. These include:

- Via the region's economic health
- Via the country's import/export ratio
- Economic and financial stability



With international trade and the ability to substitute between crops, the impact on different nation's markets will depend on the relative impacts between regions. For example, it has been suggested that the impacts of climate change on Australia could lead to a competitive advantage for New Zealand in some areas, including agriculture (Reisinger, Mullan, Manning, Wratt, & Nottage, 2010).

Knowledge we would like on livelihood, cultural identity, and wider system impacts	Research gaps
What is the impact of drought on vulnerable communities?	Where does labour go to or return from? What is the impact of drought on your turangawaewae? What happens to local spending, income, wages and employment during droughts, and are there long-lasting effects for example on residential house prices or land values?

What is the impact of drought on agriculture & tourism profits, food production, debt and communities?	What are the impacts of drought on:
	• Primary production
	  • Food that is exported (pastoral/horticulture/fisheries)
	  • Other products that are exported (e.g. commercial forestry, where workers are particularly impacted when we consider increasing fire risk.)
	• The industrial sectors (e.g. processing/manufacturing)
	• Tourism (e.g. increased risk of drought in the east of NZ has been identified as likely to impact on tourism (Becken, 2010)).

RECOMMENDED FUTURE RESEARCH QUESTIONS

After discussing likely impacts, unknowns, possible research methodologies and how to prioritize impacts on people, the group democratically voted on which of the research questions were most important to address and agreed on the below as recommendations.

Top priority research questions as developed by the dialogue group
How might future droughts, in the context of a changing climate, affect future water supply and demand for the local food production sector when this sector competes for water with other uses (e.g. domestic/commercial)?
a) What is the likely incidence of multi-regional drought looking forward? What is the likely nationwide spatial pattern of expected change in drought incidence? b) What level of risk are we likely to face in relation to drinking water availability* in NZ in times of drought? *urban and rural supplies/storage
What is the impact of drought on vulnerable communities? (E.g. Where does labour go? Does it return? What impact on your turangawaewae? What happens to local spending, income, wages and employment during droughts, and are there long-lasting effects for example on residential house prices or land values?)
What is the impact of drought on agriculture and tourism profits, land values, food production, debt and communities?
a) What is the likely frequency of low flow conditions in a given year on Waikato and Clutha lakes/river systems? b) What are the likely impacts of the incidence and length of future drought (and concurrent other effects of climate change) on electricity/energy production and consumption (incl. irrigation) [i.e. on security of supply, cost to consumers, water quality, minimum flows, renewable investment (incl. emissions), fuel substitution]?

National SCIENCE Challenges

THE DEEP SOUTH

Te Kōmata o Te Tonga

CONCLUSION

The Deep South National Science Challenge Drought Dialogue group has tried to better understand drought adaptation issues by mapping current knowledge of drought impacts and identifying knowledge gaps. New Zealand can learn from approaches being developed internationally, but there remain many questions which are unique to New Zealand.

Having been historically 'water-rich', New Zealand is not well-prepared to cope with a future that will involve more drought in some areas. Drought already impacts a wide range of activities in Aotearoa and has significant impacts culturally and in our communities. Future drought may very well be the climate change impact with the most significant effect on the New Zealand economy.

The group took a people-focussed view of the impacts of droughts and focussed on future drought exacerbated or altered due to climate change. An overarching concern of the group was that New Zealand doesn't know what resilience to future climate change related droughts means or what it looks like.

The key research priorities were identified as the impacts on drinking water, domestic food, energy, cultural identity, livelihoods, and wider system impacts. We hope that future research projects will be developed and supported to address these important issues.

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REFERENCES

Alston, M., Clarke, J., & Whittenbury, K. (2018). Limits to adaptation: Reducing irrigation water in the Murray-Darling Basin dairy communities. Journal of Rural Studies, 58, 93–102.

Angélil, O., Stone, D., Perkins-Kirkpatrick, S., Alexander, L. V., Wehner, M., Shiogama, H., … Christidis, N. (2018). On the nonlinearity of spatial scales in extreme weather attribution statements. Climate Dynamics, 50(7–8), 2739–2752. https://doi.org/10.1007/s00382-017-3768-9

Batstone, S. (2018, May). Electricity and drought. Presented at the Deep South Dialogue on Climate Change and Drought - Meeting #1, Motu Research.

Beautrais, A. L. (2018). Farm suicides in New Zealand, 2007–2015: A review of coroners' records. Australian & New Zealand Journal of Psychiatry, 52(1), 78–86.

Becken, S. (2010). The importance of climate and weather for tourism: literature review.

Bennett, H., Jones, R., Keating, G., Woodward, A., Hales, S., & Metcalfe, S. (2014). Health and equity impacts of climate change in Aotearoa-New Zealand, and health gains from climate action. The New Zealand Medical Journal (Online), 127(1406), 16.

Bony, S., Stevens, B., Frierson, D. M. W., Jakob, C., Kageyama, M., Pincus, R., … Webb, M. J. (2015). Clouds, circulation and climate sensitivity. Nature Geoscience, 8(4), 261–268. https://doi.org/10.1038/ngeo2398

Burton, R., & Peoples, S. (2008). Learning from Past Adaptation to Extreme Climatic Events: A Case Study of Drought. Ministry of Agriculture and Forestry.

Caruso, B. S. (2001). Regional river flow, water quality, aquatic ecological impacts and recovery from drought. Hydrological Sciences Journal, 46(5), 677–699.

CCATWG. (2017). Adapting to Climate Change in New Zealand: Stocktake report from the Climate Change Adaptation Technical Working Group.

Clark, A, Mullan, B., & Porteous, A. (2011, June). Scenarios of Regional Drought under Climate Change. NIWA. Retrieved from https://www.niwa.co.nz/sites/niwa.co.nz/files/slmacc_drought_sldr093_june2011.pdf

Collins, D, K. Montgomery, C. Zammit. Hydrological projections for New Zealand rivers under climate change. NIWA Report 2018193CH. Prepared for Ministry for the Environment, June 2018.

Dai, A. (2013). Increasing drought under global warming in observations and models. Nature Climate Change, 3(1), 52.

Delpla, I., Jung, A.-V., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. Environment International, 35(8), 1225–1233.

Dunlop, R. (2018, January 30). South Island snow "melt-off" in heat could affect power and irrigation. New Zealand Herald. Retrieved from www.nzherald.co.nz

Durie, M. (1994). Maori perspectives on health and illness. Social Dimensions of Health and Disease: New Zealand Perspectives, 194–203.

EECA. (2016a, November 3). Energy use in New Zealand: Renewable energy resources - Hydroelectricity. Energy Efficiency and Conservation Authority: Te Tari Tiaki Pūngao. Retrieved from https://www.eeca.govt.nz/energy-use-in-new-zealand/renewable-energy-resources/hydroelectricity/

EECA. (2016b, November 3). Energy use in New Zealand: Renewable energy resources - Geothermal. Energy Efficiency and Conservation Authority: Te Tari Tiaki Pūngao. Retrieved from https://www.eeca.govt.nz/energy-use-in-new-zealand/renewable-energy-resources/geothermal/

Ellis, N. R., & Albrecht, G. A. (2017). Climate change threats to family farmers' sense of place and mental wellbeing: A case study from the Western Australian Wheatbelt. Social Science & Medicine, 175, 161–168.

Frame, D, Rosier, S.,Carey-Smith, T., Harrington, L., Dean, S., Noy, I. (2018). Estimating financial costs of climate change in New Zealand - An estimate of climate change-related weather event costs. Report for the NZ Treasury. Retrieved from https://treasury.govt.nz/sites/default/files/2018-08/LSF-estimating-financial-cost-of-climate-change-in-nz.pdf

Hambling, T. (2012). Environmental health indicators: development of a tool to assess and monitor the impacts of climate change on human health. Health Analysis & Information for Action (HAIFA). Retrieved from www.esr.cri.nz

Hanigan, I. C., Butler, C. D., Kokic, P. N., & Hutchinson, M. F. (2012). Suicide and drought in New South Wales, Australia, 1970–2007. Proceedings of the National Academy of Sciences, 109(35), 13950–13955.

Harrington, L. J., Gibson, P. B., Dean, S. M., Mitchell, D., Rosier, S. M., & Frame, D. J. (2016). Investigating event-specific drought attribution using self-organizing maps. Journal of Geophysical Research: Atmospheres, 121(21).

Hay, J., & Kitson, J. (2013). Flow harvesting: A review of policy and potential effects. Prepared for Environment Southland.

Henwood, W., & et al. (2018). Website page from the Deep South National Science Challenge project: Drinking water in Te Hiku o Te Ika. Retrieved from http://www.deepsouthchallenge.co.nz/projects/drinking-water-te-hiku-o-te-ika

Hess, D. J., Wold, C. A., Hunter, E., Nay, J., Worland, S., Gilligan, J., & Hornberger, G. M. (2016). Drought, risk, and institutional politics in the American southwest. In Sociological Forum (Vol. 31, pp. 807–827). Wiley Online Library.

Horton, G., Hanna, L., & Kelly, B. (2010). Drought, drying and climate change: emerging health issues for ageing Australians in rural areas. Australasian Journal on Ageing, 29(1), 2–7.

IPCC. (2013). Summary for Policymakers. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, … P. M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom, New York, NY, USA: Cambridge University Press. Retrieved from http://www.climatechange2013.org/

Kamish. (2018). Presentation to Climate Change and Drought Dialogue.

Kenny, G. (2011). Adaptation in agriculture: lessons for resilience from eastern regions of New Zealand. Climatic Change, 106(3), 441–462.

King, D., Penny, G., & Severne, C. (2010). The climate change matrix facing Māori society. In Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. (pp. 100–111). Wellington New Zealand: New Zealand Climate Change Centre. Retrieved from http://www.climatecloud.co.nz/CloudLibrary/Climate%20change%20adaptation%20in%20New%20Zealand%20(NZCCC)%20(A4%20low).pdf

Lal, A., Baker, M. G., Hales, S., & French, N. P. (2013). Potential effects of global environmental changes on cryptosporidiosis and giardiasis transmission. Trends in Parasitology, 29(2), 83–90.

Maslow, A.H. (1943). A Theory of Human Motivation. Psychological Review, 50(4), 370-396.

MFE. (2016). Climate change projections for New Zealand: atmosphere projections based on simulations undertaken for the IPCC 5th assessment. Retrieved from http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/Climate-change-projections-2nd-edition-final.pdf

MFE & Stats NZ. (2017). New Zealand's Environmental Reporting Series: Our atmosphere and climate 2017 (Ministry for the Environment and Statistics New Zealand report).

Mitchell, C. (2018, January 6). From drought scare to deluge despair: The science of the storm. Stuff: National. Retrieved from www.stuff.co.nz

Morrison, J., Morikawa, M., Murphy, M., & Schulte, P. (2009). Water Scarcity & Climate Change. Retrieved from http://www.pacinst.org/

Mullan, B., Porteous, A., Wratt, D., & Hollis, M. (2005). Changes in drought risk with climate change. Prepared for Ministry for the Environment (NZ Climate Change Office) and Ministry of Agriculture and Forestry. NIWA Client Report: WLG2005–23.(National Institute of Water and Atmospheric Research, Wellington).

Nichol, T. (2018, April 1). Food for thought: How to secure New Zealand's food supply in the face of a changing climate. New Zealand Herald. Retrieved from www.nzherald.co.nz

NIWA. (2017). New Zealand Drought Index and Drought Monitor Framework.

NIWA. (2018). NZ Drought indicator products and information. NIWA Taihoro Nukurangi. Retrieved from www.niwa.co.nz

OECD. (2016). Mitigating Droughts and Floods in Agriculture: Policy Lessons and Approaches (OECD Sudies on Water). Paris: OECD Publishing. Retrieved from http://dx.doi.org/10.1787/9789264246744-en

Penny, G., Silvers, K., Williams, E., & Skipper, A. (2005). Māori health and the changing relationship with the coastal marine environment – Ngati Hokopu ki Hokowhitu (NIWA Client Report) (p. 71).

Perkins, S. E. (2015). A review on the scientific understanding of heatwaves—Their measurement, driving mechanisms, and changes at the global scale. Atmospheric Research, 164–165, 242–267. https://doi.org/10.1016/j.atmosres.2015.05.014

PMCSA. (2017). New Zealand's fresh waters: Values, state, trends and human impacts (Office of the Prime Minister's Chief Science Advisor). Retrieved from www.pmcsa.org.nz/wp-content/uploads/PMCSA-Freshwater-Report.pdf

Pomeroy, A., & Newell, J. (2011). Rural community resilience and climate change. Retrieved from https://www.otago.ac.nz/centre-sustainability/otago057742.pdf

Reisinger, A., Mullan, A. B., Manning, M., Wratt, D. W., & Nottage, R. (2010). Global and local climate change scenarios to support adaptation in New Zealand. In Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage, RAC, Wratt, DS, Bornman, JF, Jones, K.(eds). New Zealand Climate Change Centre, Wellington (pp. 26–43).

Renwick, J., Mladenov, P., Purdie, J., McKerchar, A., & Jamieson, D. (2010). The effects of climate variability and change upon renewable electricity in New Zealand. In Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives (pp. 70–81).

Royal Society Te Apārangi. (2017). Human health impacts of climate change for New Zealand.

Smith, W., Davies-Colley, C., Mackay, A., & Bankoff, G. (2011). Social impact of the 2004 Manawatu floods and the 'hollowing out'of rural New Zealand. Disasters, 35(3), 540–553.

Stain, H. J., Kelly, B., Carr, V. J., Lewin, T. J., Fitzgerald, M., & Fragar, L. (2011). The psychological impact of chronic environmental adversity: Responding to prolonged drought. Social Science & Medicine, 73(11), 1593–1599.

Stehlik, D. (2003). Australian drought as lived experience: Social and community impacts. Beyond Drought: People, Policy and Perspectives. Melbourne: CSIRO Publishing, 87–108.

Te Rūnanga o Kaikōura. (2009). Te Poha o Tohu Raumati - Environmental Management Plan 2009.

Van Loon, A. F., Gleeson, T., Clark, J., Van Dijk, A. I., Stahl, K., Hannaford, J., … Uijlenhoet, R. (2016). Drought in the Anthropocene. Nature Geoscience, 9(2), 89.

Wai Māori. (2008). Discussion on Freshwater: A Wai Māori Perspective. Retrieved from http://waimaori.maori.nz/home.htm

Waikato Regional Council. (2017). Waikato Freshwater Strategy - Te Rautaki Waimāori mō Waikato. Retrieved from https://www.waikatoregion.govt.nz/assets/PageFiles/40487-lets-talk-water/Fresh-water-strategy-2017-COMBINED-web.pdf

Westpac. (2018). Westpac NZ: Climate Change Impact Report. Retrieved from https://www.scribd.com/document/375407665/Westpac-NZ-Climate-Change-Impact-Report

Zammit, C. (2018). Presentation to Deep South Dialogue 4: Climate Change and Drought.