New Zealand Climate Change Research Institute, and NIWA

Estimating financial costs of climate change in New Zealand

An estimate of climate change-related weather event costs

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Adapted from https://www.unisdr.org/we/inform/terminology
This terminology is based on the work of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction that was established by the United Nations General Assembly in its resolution 69/284. Their report was adopted by the General Assembly on February 2nd, 2017.

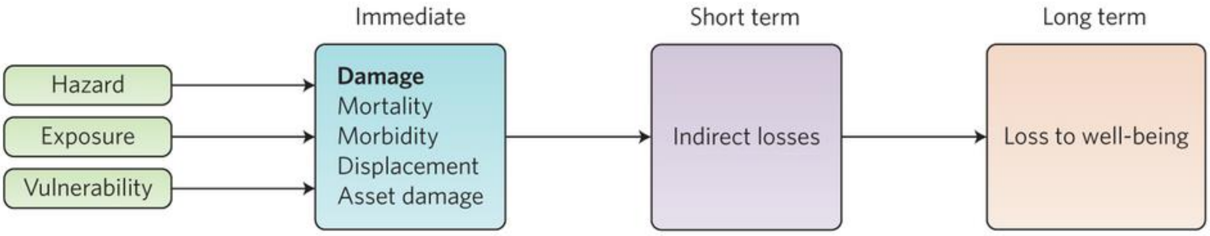
Disaster
A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

Disaster Damage
Disaster damage occurs during and immediately after the disaster. This is usually measured in physical units (e.g., square meters of housing, kilometres of roads, etc.), and describes the total or partial destruction of physical assets, the disruption of basic services and damages to sources of livelihood in the affected area.

Disaster damage is “nearly equivalent” to the concept of *direct economic loss*. *Direct economic loss* is the monetary value of total or partial destruction of physical assets existing in the affected area. Examples of physical assets that are the basis for calculating direct economic loss include homes, schools, hospitals, commercial and governmental buildings, transport, energy, telecommunications infrastructures and other infrastructure; business assets and industrial plants; and production such as crops, livestock and production infrastructure. They may also encompass environmental assets and cultural heritage. Direct economic losses usually happen during the event or within the first few hours after the event and are often assessed soon after the event to estimate recovery cost and claim insurance payments. These are tangible and relatively easy to measure.

Indirect economic loss
A decline in economic value-added as a consequence of direct economic loss and/or human and environmental damage. Indirect economic loss includes microeconomic impacts (e.g., revenue declines owing to business interruption), meso-economic impacts (e.g., revenue declines owing to impacts on natural assets, interruptions to supply chains or temporary unemployment) and macroeconomic impacts (e.g., price increases, increases in government debt, negative impact on stock market prices and decline in GDP). Indirect losses can occur inside or outside of the hazard area and often have a time lag. As a result, they may be intangible or difficult to measure.

Total Impact
Disaster impact is the total effect, including negative effects (e.g., direct and indirect economic losses and damages) and positive effects (e.g., economic gains), of a hazardous event or a disaster. The term includes economic, human and environmental impacts, and may include death, injuries, disease and other negative effects on human physical, mental and social well-being.



Source: Noy, Ilan, 2016. Tropical Storms: The Socio-Economics of Cyclones. *Nature Climate Change* 6: 343-345.

Estimating insured costs of climate change in New Zealand.

A report by Victoria University and NIWA commissioned by The Treasury, which draws on international scientific peer reviewed evidence, has found that climate change related floods and droughts has cost the New Zealand economy at least $120M for privately-insured damages from floods and $720M for economic losses from droughts over the last 10 years. This is expected to be a conservative estimate due to the inclusion of only two weather-related hazards, the choices made regarding the attribution of droughts, the neglect of nonfinancial losses, and the use of insured damages rather than full economic losses for some events. Climate change attributable costs are expected to increase in future years due to enhanced development in areas vulnerable to climate change, and to the on-going emergence of stronger climate change signals. This report does not include other weather events such as wildfires or hail, as there is currently insufficient climate change attribution research conducted for these impacts on New Zealand, and the report does not include the wider impact on ecosystems.

Summary

This report is an initial exploration of the scale of the economic impact of climate change-related floods and droughts in New Zealand over the ten years from mid-2007 to mid-2017. It uses two sets of inputs: estimates of economic impacts associated with floods and droughts, and estimates of the fraction of attributable risk (FAR) of weather events that are due to climate change.

The costs in this report are not a full assessment of the costs of climate change and, because the inputs are financial costs, do not include a discussion of potential benefits associated with climate change. The cost estimates for the two droughts represent economic losses; the costs associated with extreme rainfall events are insured damages, which represent a significant underestimate of the full financial and economic impact costs of these events.

The intention of the report is to provide an indicative assessment of some of the more readily-addressed costs associated with climate change, with a view towards creating a forward liability for climate that could for example be used in cost-benefit analysis of infrastructure resilience investments and other climate change-related policies. Note that the FARs in this report are not static: FARs in the next few decades are expected to change (usually to increase) because the climate continues to change in response to on-going emissions of greenhouse gases (and other factors). The economic inputs are diverse: estimates of the economic losses of droughts, and estimates of insurance damages due to floods. There is significant uncertainty around both types of cost estimates, and insured damages, in particular, very probably underestimate the full economic costs as they ignore any loss in economic activity in the aftermath of these events .

Introduction and context

New Zealand researchers and policymakers have thought about climate change for a few decades now, but there are still some large gaps in our understanding of climate change impacts. Policymakers' attention has focused heavily on price signals associated with climate change mitigation, rather than on how communities might adapt to climate change. Ten years ago in the Intergovernmental Panel on Climate Change (IPCC)'s Fourth Assessment Report (AR4), it was noted that: "Australia and New Zealand have few integrated regional and sectoral assessments of impacts, adaptation and socio-economic risk." Similar points were made again six years later in the IPCC's Fifth Assessment Report (AR5): "Understanding of ecological and physiological thresholds that, once exceeded, would result in rapid changes in species, ecosystems, and their services is still very limited. The literature is noticeably sparse in New Zealand." And "the literature supporting this assessment of key risks is uneven among sectors and between Australia and New Zealand; for the latter, conclusions in many sectors are based on limited studies that often use a narrow set of assumptions, models, and data and that, accordingly, have not explored the full range of potential outcomes."

Since then, two major additional research programmes, *Climate Change Impacts and Implications (*CCII*)*, and the *Deep South National Science Challenge*, have attempted to address gaps in our understanding. In general, research into how New Zealand may fare in a changing climate has focused on scenarios, and how systems might change under different levels of *future* climate change. The missions and visions of these two programmes both involved working to enable decision makers to make better decisions in the face of climate change, and also involved strong contributions from the natural sciences, including developing a more complete understanding of some of the drivers of climate change (Deep South[1]) and an improved understanding of natural environment impacts of climate change (CCII[2]). Details of these programmes can be found on websites for the Deep South Challenge[3] and the Climate Change Impacts and Implications programme[4] websites. In addition, a report by the Parliamentary Commissioner for the Environment entitled "Preparing New Zealand for rising seas: Certainty and Uncertainty" included an analysis by NIWA that identified that $19 billion worth of infrastructure[5] was exposed nationwide if a future sea level rise of 1.5 m were to occur. The analysis was limited by available coverage of high resolution data and restricted only to replacement costs, and further development of coastal areas will inevitably see increasing value-at-risk. Uncertainty about the deployment of future assets and their

[1] "The mission of the [Deep South] Challenge is to enable New Zealanders to adapt, manage risk, and thrive in a changing climate. Working with communities and industry we will bring together new research approaches to determine the impacts of a changing climate on our climate-sensitive economic sectors, infrastructure and natural resources to guide planning and policy. This will be underpinned by improved knowledge and observations of climate processes in the Southern Ocean and Antarctica - our Deep South - and will include development of a world-class earth systems model to predict Aotearoa/New Zealand's climate."

[2] The Vision statement of CCII was to: "improve our knowledge of climate change impacts combined with other critical threats on natural environments (land, freshwater, marine and their components). Knowledge of feedbacks among ecosystem services and impacts of climate change and other drivers (e.g., land-use change) is also much improved, leading to enhanced understanding of cumulative impacts on natural resources and environmental limits. As a result, policy makers, planners, resources managers, business and iwi have the capacity to better anticipate future trends and uncertainties in ecosystem services. They will act adaptively to manage services with minimal risk, thereby maintaining current services and safeguarding future options. Lastly, New Zealand's businesses that depend on the environment (e.g., primary industries, tourism and energy) accelerate their transition to a "green growth" pathway, thus New Zealand's economy continues to grow while reducing impacts on the environment."

[3] http://www.deepsouthchallenge.co.nz/

[4] http://ccii.org.nz/

[5] This is the estimate of at risk assets/infrastructure, and does not include the loss that would result from actual damages to these assets through loss of production, dislocation, etc.

vulnerability to climate change events adds an additional layer of uncertainty to the future economic dimensions of climate change: we cannot simply project these costs forward based on emerging climate change signals, because the pattern of assets and value-at-risk is changing over time. This socioeconomic uncertainty places limits on using the techniques in this paper to discuss forward liabilities for climate change. In future reports, this could be addressed through the use of scenarios of future economic development.

This report aims to begin to address the question, especially relevant to the infrastructure and finance sectors: "what are the ***current*** economic costs of climate change in New Zealand, and how might we learn more in the future?" Financial dimensions of climate change in New Zealand are an under-studied area. A recent background paper for the CCII programme showed that while there were 18 publications each looking at the coastal, biological/conservation and primary production dimensions of climate change in New Zealand, there were only two looking at how climate change might be affecting New Zealand's finance and banking sectors.[6] A background paper prepared for CCII identified its first two "Key knowledge gaps and areas that merit further investigation […]: Potential climate change impacts and implications for NZ infrastructure assets including utilities; Potential climate change impacts and implications for the NZ finance sector, including banking and insurance."

The idea of using economic imapcts of extreme events in combination with their changing frequency has been around for over a decade (Allen 2003; Stott, Stone & Allen 2004) but this is believed to be the first time a Government has commissioned a report to explore the concept in any depth. Here we present a preliminary estimate of the costs of floods and droughts that are attributable to climate change, over the period mid-2007 to mid-2017, and discuss gaps and areas of future development. The report's scientific basis is the peer-reviewed research into climate change probabilistic event attribution that has linked New Zealand events such as the 2012/2013 drought (Harrington et al. 2016) and the Northland flood of 2014 (Rosier et al. 2015) to climate change.

The next section outlines a simple methodology for developing a highly approximate and indicative estimate of economic impacts due to climate change-related weather events – specifically droughts and floods – in New Zealand. Each event considered here has an impact associated with it, and some estimate of the fraction of attributable risk (FAR; Rosier et al. 2015), being the fraction of the risk of the event that is attributable to the human influence on climate. The report does not assess the climate change-related imacts and costs of events where we do not yet have in New Zealand peer-reviewed precedents for forming FAR estimates. This is why we do not address storm damage, coastal inundation, or the effects of frost, fire or hail. For the same reasons, we also do not assess the effects of climate change on ecosystems, rivers, urban areas or agricultural productivity. The report also sketches out how similar events in other countries may affect commodity prices for New Zealand exporters.

[6] http://ccii.org.nz/wp-content/uploads/2017/01/RA4-Review-of-recent-research.pdf, page 8.

Estimate of insurance losses associated with climate change

Direct costs of climate-related weather events

In this report we restrict our attention to two types of events, floods and droughts. This is for simplicity and tractability. The estimates of losses for the two droughts are from the Treasury.[7] The estimates of insured damages associated with floods are from the Insurance Council of New Zealand.[8] In this report, all the cost inputs are positive, i.e. the impacts of the events are costly. Future analyses could also consider the FAR associated with various benefits from climate change (subject to such costs and benefit estimates being available). As discussed above, the costs associated with droughts are estimates of the economic loss of drought, while those associated with extreme rainfall are insured damages. Insured damages under-represent the full economic impact of extreme rainfall, since they do not include un-insured damages (e.g., transportation networks), and do not include economic losses, such as lost production because of infrastructure failures, the costs associated with medical and pastoral care of affected communities, disaster relief, clean-up costs and so on. The absence of full assessments of economic impact costs associated with the extreme events is probably the largest uncertainty in this report and the two types of events should be considered separately. In the absence of full economic losses associated with extreme rainfall events, we have drawn on insured losses as the most readily-available proxy for the scale of the event, but fuller analysis of the economic impact of weather-related disasters that will tally the range of damages and losses is required for a better understanding of the total impact of extreme weather on New Zealand.

Fraction of Attributable Risk

In estimating the risk of events attributable to anthropogenic climate change we follow IPCC Working Group I definitions: "Fraction Attributable Risk, defined as FAR = 1 – P0/P1, P0 being the probability of an event occurring in the absence of human influence on climate, and P1 the corresponding probability in a world in which human influence is included. FAR is thus the fraction of the risk that is attributable to human influence (or, potentially, any other external driver of climate change) and does not require knowledge of absolute values of P0 and P1, only their ratio."

This technique is familiar in an everyday context through its long-standing use in modern medicine to search for cause and effect in human disease. An analytic epidemiology study uses the same statistical technique as is used here, with analysis of at least two groups of people, one of which serves as a comparison (or control) group. Differences in exposure prevalence between the case and control groups allow investigators to conclude by how much exposure changes the risk of a disease. It is usually considered in medicine that epidemiology by itself can never prove that a particular exposure caused a particular outcome. Often, however, epidemiology provides sufficient evidence to take appropriate control and prevention measures. In the 1950s, epidemiologists reported the increased risk of lung cancer among smokers. In the 1970s, epidemiologists documented the role of exercise and proper diet in reducing the risk of heart disease. In the mid-1980s, epidemiologists identified the increased risk of HIV infection associated with certain sexual and drug-related behaviours.

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[7] The Treasury (2013), Budget Economic and Fiscal Update, pages 17-18, and MAF (2009) Regional and national impacts of the 2007–2008 Drought.

[8] http://www.icnz.org.nz/statistics-data/cost-of-disaster-events-in-new-zealand/

When applied to the problem of climate change groups of people are replaced with computer simulations of weather and climate. Here the case group is a very large number of computer simulations of a particular year, with all conditions the same as in the real world. In the corresponding control group, the impact of human emissions of greenhouse gases are not included in an equally large number of simulations, creating realisations of a 'world that might have been'.

To calculate extreme rainfall FARs we follow the practices established in (Pall et al. 2011), and, in Australasian contexts, (Black et al. 2016; Black, Karoly, and King 2015) and (Rosier et al. 2015). It should be emphasised that event attribution in New Zealand is very much a work in progress. The estimates of FAR in this report are, for the most part, indicative estimates based on the current state of knowledge aimed at providing an approximate order of magnitude of the costs of current climate change. While in general extreme precipitation at New Zealand latitudes increases with the thermodynamic contribution from the Clausius-Clapeyron relationship (Pall et al. 2011), recent research [Rosier et al., 2017, in prep] has demonstrated that changes in weather patterns associated with extremes can compete with this effect. In some instances, at some locations, the net effect can be a reduction in extreme precipitation (Pfahl, Ogorman, and Fischer 2017). This means we do consider cases where FAR<0, i.e. where the risk of extreme events in some places has reduced because of climate change.

In some of the cases considered we have higher confidence in the estimates because we have direct simulations for the year in question. Resourcing constraints mean that at present we only have three full years of simulations on which to draw – the years 2013 to 2015. As a result we have restricted the analysis to considering only the impact of climate change on events within the last 10 years. It is entirely possible to run simulations for each year for which there are reliable observations of the past, and this would substantially improve our ability to quantify historical and current climate risks.

The FAR for the 2012/13 drought is estimated from (Harrington et al. 2016). The model ensemble used to assess drought risk was the Coupled Model Intercomparison Project Phase 5 (CMIP5) ensemble.[9]

We emphasise that the FARs we obtain for this period will be different from – usually less than – FARs in the future, because the effects of climate change on the coupled atmosphere-ocean system are intensifying.

Treatment of uncertainties

The economic impact cost estimates and FAR estimates in this report are both subject to considerable uncertainties, with cost uncertainties perhaps being the larger of the two. Because this is a pathfinder report, and because we lack a measure for the uncertainties associated with the costs of floods and droughts, we have not presented a systematic assessment of the uncertainties associated with the costs or the FARs in the table. Further work would usefully include uncertainty estimates that try to take consistent account of uncertainties in both costs and FARs. In general subjective estimates of uncertainties associated with the FARs would include a likely (central 2/3rd of the distribution[10]) numerical range of around 0.2. In some cases – notably the Dunedin event, which

[9] CMIP5: http://cmip-pcmdi.llnl.gov/cmip5/
[10] Broadly consistent with practice in IPCC.

is the subject of a paper in preparation – this means that the FARs have some considerable likelihood of being negative, i.e. there is considerable likelihood that the event in question has become less likely because of climate change, even though the balance of evidence suggests certain aspects within the event (namely the intensity of rainfall) were likely made more severe because of climate change. The other significant point to note regarding FAR uncertainties is that the uncertainties associated with FARs estimated for the two droughts are highly asymmetric (see section Droughts below). The uncertainties about economic impact costs arise first and foremost because in both cases (droughts and floods), we only have a quantification of a part of the overall impact costs (economic losses, and insured damages, respectively). In addition, the quantities we do use are estimates of the true quantities, and especially the estimates of economic losses for droughts are subject to substantial uncertainties around them.

Data and methods

To estimate the probability of each observed event occurring, climate station rainfall observations from NIWA's National Climate Database[11] were used, provided there were at least 40 years of observations available. At each observing location impacted by the event, extreme value theory was used to estimate an annual exceedance probability. The event duration was chosen to be the longest period over which the event was extreme, since the damages accrue across the period over which the rain falls. It is not usually just the most extreme peak that does the damage, but the full event.

The basis for our inferences about FARs comes from extremely large ensembles of simulations of a regional climate model from the "climate*prediction*.net" project (Allen 1999) running the "weather@home" experiment for the Australia/New Zealand (ANZ) region. This is an ANZ version of the modelling capability described by Massey et al. (2015). In this setup, the Met Office HadAM3P model (Pope et al. 2000) is run globally, providing lateral boundary conditions to the regional model HadRM3P (Jones et al. 2004), which covers a domain spanning Australia, New Zealand, and much of Indonesia at approximately 50-km resolution. The model has been shown to reproduce many large- and medium-scale features of weather and climate with a good degree of accuracy (Black et al. 2016).

For this study, experiments were conducted creating very large initial condition ensembles to represent many different realizations of possible weather under varying climate conditions. One set of ensembles had all forcings included (ALL)—sea surface temperatures (SST) for 2013, 2014 and 2015 from the "Operational Sea Surface Temperature and Sea Ice Analysis"(Donlon et al. 2012), greenhouse gases, aerosol, ozone, solar, and volcanic. A second "natural forcings only" (NAT) ensemble was produced, where the anthropogenic contribution to the forcings was removed. This produces many realisations of the weather possible in a hypothetical world without anthropogenic influence on climate. For the NAT ensemble SSTs, patterns of changes are estimated using around 10 different Coupled Model Intercomparison Project Phase 5 (CMIP5) models and a multimodel mean. Other forcings such as greenhouse gas concentrations, ozone and aerosols are set to pre-industrial levels. This is the same configuration as described in (Schaller et al. 2016) and (Black et al. 2016).

The basic experimental setup has been used in many pieces of recent climate research, and is a recognised part of the climate change detection and attribution literature; interested readers should

[11] CliDB: https://cliflo-niwa.niwa.co.nz/

see IPCC Chapter 10.6.2, which is largely based on this architecture, or the recent review article by (Stott et al. 2016).

For five of the 12 observed events we have model ensembles available which reflect both the greenhouse gas concentrations and the SST fields at that time. For the remaining seven flooding events we do not have model ensembles reflecting the SSTs of the months in question, so we have instead used the FARs calculated for the appropriate season with data from the available years (2013-2015) pooled. This adds uncertainty, but should not contribute largely to bias.

Floods

The approach here is to use the best estimates we have of FAR values at each location, and combine these with the insured damages associated with these events to estimate a contribution from anthropogenic climate change.

We ordered the events by the magnitude of insured damage costs, and then analysed the observed rainfall at stations within the catchment of a flooding event. We then chose only those cases in which there was significant extreme rainfall near or beyond the 97th percentile at more than one station. We analysed events on three time horizons: 1-day, 3-day and 5-day. We did not apply the analysis to longer than five day events because most flooding in New Zealand occurs on short timescales, and because the anthropogenic signal associated with the thermodynamic effects are usually synoptic in scale. The result is that all the flooding events we consider in this study involved heavy precipitation immediately before the flooding. Finally, we focused the analysis on the most costly flooding events over the period July 2007-June 2017.

In assessing the FARs of each event we first ensured that the modelled FARs were giving a consistent message towards the tail of the distribution, to reflect the uncertainty in estimating the rarity of the actual event. We examined FAR maps for extreme precipitation events at each integer threshold across 1-4% annual exceedance probabilities inclusive, for each season. Results are presented in table 1.

Droughts

Our assessment of the FAR associated with drought is based primarily on Harrington et al 2016, in which the CMIP5 ensemble of models (Taylor, Stouffer, and Meehl 2012) was investigated using self-organising maps (Hewitson and Crane 2002) (Gibson et al. 2017). In the case of the NZ drought of 2012/13 estimates of the FAR depend on exactly the variable chosen to characterise the drought, and this yields a range of plausible FARs, from 40% (if we use monthly pressure anomalies or the frequency of blocking high pressure systems) to 20% (if we use precipitation deficits or daily circulation properties). Lower and higher values are possible to the extent that the models only imperfectly capture the relationships between climate change and drought (even the definition of drought is not simple). Since the overall FAR of the drought will be some (currently uncertain) linear combination of the individual FAR (or risk ratio) components, the choice of a low but plausible FAR represents a conservative choice. On this basis, the FAR we provide for the 2012/13 drought is 20%.

Economic losses associated with the 2012/2013 drought have been estimated at NZ$1.5 billion by the New Zealand Treasury based on a reduced growth in Gross Domestic Product, compared to a hypothetical year without drought. With a FAR of 20% this yields excess costs of the drought due to anthropogenic climate change of NZ$300M. Using the same sets of inferences would quantify the anthropogenic component of the 2007/8 drought at 20% of NZ$2.5billion. This is certainly plausible, but this earlier drought occurred on the back of a significant El Nino (ENSO). Contributions from ENSO may not add linearly with contributions from anthropogenic climate change. Without a full study of 2007/8 conditions we cannot be sure that the anthropogenic contribution is similar in the earlier and later cases, since the relative frequency of different synoptic patterns contributing to the drought may be different in El Nino years compared to neutral years and compared to La Nina years. At present these influences have not been decomposed for New Zealand. However, even if the FAR of the earlier drought was only 15%, i.e. less than the value of the later drought, that would still add $420,000,000 to the numbers in the table. There is about as much reason to think that the joint effects would be superlinear as sublinear, since there are strong reasons to believe that the frequency of ENSO conditions is increasing as a result of climate change (Wang et al. 2017). In this report we have chosen what we believe is an reasonably conservative value of 15%, but higher values are plausible.

Results

The results of our analysis are shown in Table 1. Based on the FARs presented, we estimate that flood and drought costs attributable to anthropogenic influence on climate are currently somewhere in the vicinity of $120M per decade for insured damages from floods, and $720M for economic losses associated with droughts. These costs will almost certainly increase over time, because the climate continues to change. Further investigation into additional flooding events, a more thorough analysis of the 2007/08 drought, and extension of the weather@home analysis framework to include storm damage would almost certainly increase, rather than decrease, these numbers.

We reiterate the point that the procedures to estimate the costs associated with floods (in which case these are insured damages) and droughts (in which case the economic losses represent an assessment of impact on economic activity) are different. The former will underestimate more the full economic costs of these events; as it neither includes un-insured damages nor economic loss. A full and comprehensive approach to the costs and benefits of climate change would require like-for-like inputs which capture both the costs and the benefits of climate change. In this pathfinder report we simply use the available cost estimates to illustrate the approach.

Year	Date	Event	FAR	Cost ($M)	Attributable Cost ($M)
2007	10 -12-Jul	North North Island	0.30	68.65	20.595
2017	3-7 April	North Island	0.35	66.4	23.24
2013	19-22 April	Nelson, BoP	0.30	46.2	13.86
2017	7-12 March	Upper North Island	0.40	41.7	16.68
2015	18-21 June	Lower North Island	0.10	41.5	4.15
2016	23-24 March	West Coast-Nelson	0.40	30.2	12.08
2015	2-4 June	Otago	0.05	21.5	1.075
2015	13-15 May	Lower North Island	0.30	21.9	6.57

2011	29-Jan	Northland to BoP	0.30	19.8	5.94
2014	8-10 July	Northland	0.30	18.8	5.64
2017	13-16 April	Mostly North Island	0.35	18.	6.3
2007	29-Mar	Far North	0.30	12.	3.6
	Total attributable extreme rainfall insurance costs				**$119.73**

Table 1: Financial damages associated with extreme weather and flooding events in New Zealand over the period 2007-2017 where it has been possible to form estimates regarding the FAR of the event. The last column refers to the insured losses attributable to climate change, i.e. the (inflation-adjusted) insurance loss estimate times the FAR of the event.

Year	Date	Event	FAR	Cost ($M)	Attributable Cost ($M)
2007/08	Summer	Drought	0.15	2,800.	420.
2012/13	Summer	Drought	0.20	1,500.	300.
		Total attributable drought costs			**720.**

Table 2: Financial damages associated with droughts in New Zealand over the period 2007-2017 along with estimated FAR of the event. The last column refers to the damage attributable to climate change, i.e. the (inflation-adjusted) loss estimate times the FAR of the event. Note that the procedures to estimate the costs associated with floods (in which case these are insured losses) and droughts (in which case the losses represent a more comprehensive assessment of impact on the economy) are different.

Although there is no universally-agreed single methodological approach to the calculation of FAR, each of the methods that underlie the data-driven assessments of specific FAR that have gone into this report have formed part of the peer-reviewed literature. Ideally, New Zealand would possess the capability to deploy multiple lines of evidence, based on mixtures of experimental designs, model suites, and statistical techniques, to arrive at best estimate ranges for possible FARs.

Because no NZ-based peer-reviewed papers yet exist investigating the FAR associated with storm damage, hailstorms, wildfire, frosts or tornadoes, we have left these out from the analysis. Our neglect of such events means we ignore at least NZ$279M in weather-related losses between July 2007 and June 2017. As an indicative comparison, if the FARs associated with these events were similar to those in the table – around 0.3 – then the extra attributable losses would add another $84M.

In at least one case (the "Flockton Basin" event in 2014), geological changes provide an important contributor to the change in risk. We can still assess the anthropogenic contribution to the rainfall event that contributed to the flood, irrespective of the new hydrology of the environment; however, work incorporating the changed hydrology is a priority for future research in this area of the impacts of climate change.

The current year, 2017, has seen a large number of damaging weather events, including several floods and considerable storm damage. Interest is naturally high from New Zealanders keen to understand more about what the future holds in terms of possible increased frequency of such rainfall events in a warmer world. In this report we have used the existing ensembles to make estimates of the FARs of events. We hope to be able to investigate 2016 and 2017 more comprehensively in future weather@home ensembles, though this depends on sequencing experiments with our overseas partners, and scientific capacity within New Zealand to set up, manage, and analyse experiments.

Other weather events

This report has developed a simple and transparent estimate of the insured damages from floods and economic losses from droughts which are associated with climate change. The report is not comprehensive, and certainly represents a significant underestimate of the full range of even economic impacts of climate change.

A brief outline for the development of a more comprehensive costing of the direct weather-related effects of climate change is outlined in table 2. Some elements of this could be incorporated into the framework used in this report relatively straightforwardly, provided the phenomena being assessed are handled reasonably well by the attribution frameworks we have available (and researcher time permitting). Incorporation of other important elements of hydrometeorological change are further away, because models cannot yet simulate adequately the appropriate scales or processes, as is the case for instance with tropical cyclones and tornadoes.

New Zealand does have an integrated hydrology and climate modelling system, but this has not yet been applied to the complex problem of estimating FARs for given events. This restricts scientists' ability to incorporate underlying catchment conditions into the estimates regarding flooding presented here. Floods come in several different types, including coastal flooding (in which storm surge is a factor, as well as tides and rainfall), fluvial flooding (in which rivers overflow, and can be associated with ice melt and excessive rainfall over a period of time, as well as with heavy precipitation events), and pluvial flooding, in which a heavy rainfall event causes surface flooding. Utilising an integrated hydrological and climate infrastructure to calculate FARs would allow better quantification of flood risk, as well as improvements in our understanding of current and future climate risks.[12]

Event	Barrier	Prospects for including	Time-scale
Storms	Should be reasonably straightforward as long as the W@H climate model framework is capturing extra-tropical storms adequately.	Optimistic	1-2 years
Fires	Depends upon coupling between land surface and forest models with climate model inputs.	Optimistic	A few years
Hail	Depends upon model's ability to simulate processes governing hail, and on downscaling to relevant spatial scales. Higher resolution may be necessary.	Reasonable	A few years
Frosts	Depends upon model's ability to simulate processes governing frost, and on downscaling	Reasonable	A few years

[12] By way of comparison, in the UK, the MaRIUS project aims to integrate climate model data with hydrological modelling frameworks: details are available at http://www.mariusdroughtproject.org/. The project budget is around $5M over 5 years.

	to relevant spatial scales. Higher resolution may be necessary		
Cyclones	State-of-the-art models are beginning to capture the scales and processes required to simulate cyclones. Some issues still remain. Attribution probably a little way off.	Model development making rapid progress in some of the main modelling centres.	Several years at least
Tornadoes	Tornadogenesis not well captured by current generation of climate models.	A long way off.	Uncertain

Table 2: Weather-related climate impacts that are relevant to New Zealand, along with details about the barriers to incorporating them, future prospects for inclusion, and very approximate timescales for incorporating them into future costs of climate change analysis.

Wider climate impacts

Climate change impacts are most directly experienced through changes in weather, particularly extreme weather, and the effects – the benefits and opportunities as well as costs - are felt across a large range of sectors and systems. A full account of the impacts of climate change would include consideration of damages from storms, welfare and productivity losses associated with weather-related traffic congestion, changes in pastoral, agricultural and forestry productivity due to shifts in growing seasons, ecosystem impacts, enhanced vulnerability to biosecurity threats, health-related impacts and so on. The current state of the science is such that "almost two-thirds of the impacts related to atmospheric and ocean temperature can be confidently attributed to anthropogenic forcing" but our ability formally to attribute wider climate impacts is weaker (Hansen and Stone 2016). Over time we expect models and observations of climate impacts to improve, and this in turn will broaden the range of impacts across which attribution questions can be posed. Integrating detection and attribution science with climate impacts science (and social science) requires a multi-pronged approach, and investments in modern observational networks across managed and unmanaged ecosystems, and hydrological, marine and cryospheric systems, as well as investments in Earth System Models and attribution skillsets.

Recent research initiatives such as the Deep South National Science Challenge, the MBIE-funded Climate Change Impacts and Implications programme, and work undertaken by NIWA to assess the scale of coastal risks have begun to sketch out an understanding of climate change impacts, and in some cases also the adaptation issues facing New Zealand, but at this stage we lack a formal, national-level, operational understanding of the economic, social and environmental costs and benefits of climate change.

Figures 1 and 2 are attempts from the CCII project to represent impacts cascading from higher mean temperatures and droughts (figure 1) and more intense rain events and storm events (figure 2) as they are understood by partners and stakeholders in New Zealand.

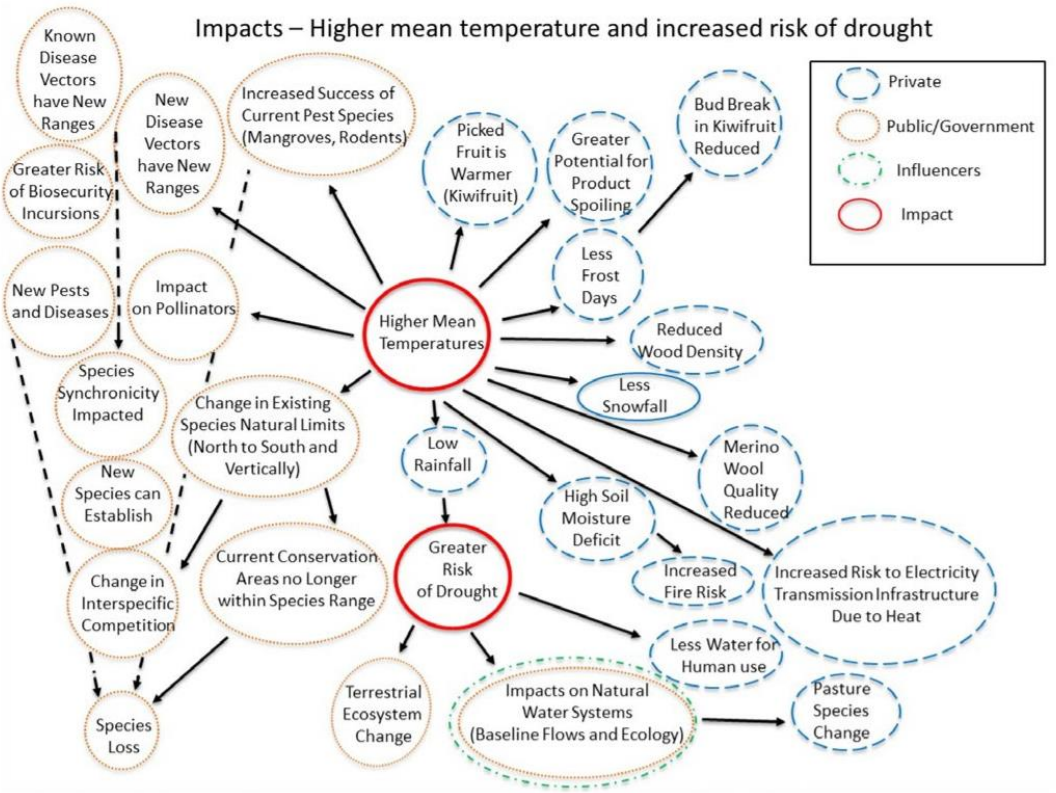

Figure 1: Perceived impacts arising from higher mean temperature and increased drought risk. After CCII Synthesis Report. Perspectives elicited from a range of stakeholders and partners.

It can be seen that different communities are focused on different impacts, some of which (pest species, species loss, areal extent of species) interact with each other in complex ways. No attempt was made in CCII, or in this brief study, to assess the relative scale of all these impacts; though obviously some will be relatively localised and others widespread, the scales of impact are likely to be highly variable, and some may be subject to thresholds while others may be more continuous.

Though the purpose of this report is to look at damages due to direct climate change impacts, some of these secondary impacts may be extremely important either economically (disruptions to infrastructure, impacts on agricultural productivity, impacts on water systems), environmentally (threats of new pest habitats or biosecurity risks), or socially (disruptions to infrastructure, threats to iconic species, urban inundation).

Although the CCII programme developed an improved understanding both of the interaction between potential climate impacts, and the importance of these impacts to various partners and stakeholders, a quantified estimate of the aggregate costs of climate change impacts on New Zealand is some years away, and would require a larger investment in considering climate change impacts on New Zealand.

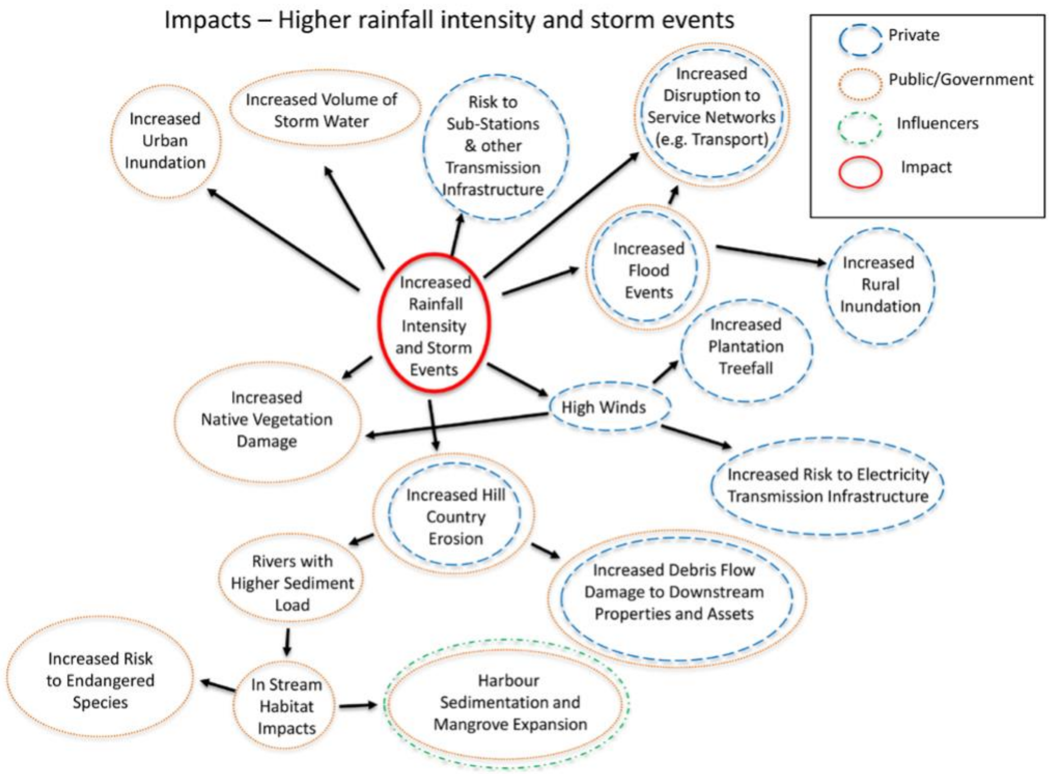

Figure 2: Perceived impacts arising from higher rainfall intensity and storm events. After CCII Synthesis Report. Perspectives elicited from a range of stakeholders and partners.

An assessment of climate change impacts for the Australasian region appeared in Chapter 25 of the IPCC Working Group II report [Reisinger et al., 2014]. Table 3 presents headline impacts results for Australasia from the WGII Summary for Policymakers. For a variety of reasons, most of the information in the table is more pertinent to Australia than it is to New Zealand, but nevertheless the table summarises recent understanding of significant impacts in the region.

Snow & Ice, Rivers & Lakes, Floods & Drought
• Significant decline in late-season snow depth at 3 of 4 alpine sites in Australia (1957– 2002) (medium confidence, major contribution from climate change) • Substantial reduction in ice and glacier ice volume in New Zealand (medium confidence, major contribution from climate change) • Intensification of hydrological drought due to regional warming in southeast Australia (low confidence, minor contribution from climate change) • Reduced inflow in river systems in southwestern Australia (since the mid-1970s) (high confidence, major contribution from climate change)
Terrestrial Ecosystems
• Changes in genetics, growth, distribution, and phenology of many species, in particular birds, butterflies, and plants in Australia, beyond fluctuations due to variable local climates, land use, pollution, and invasive species (high confidence, major contribution from climate change) • Expansion of some wetlands and contraction of adjacent woodlands in southeast Australia (low confidence, major contribution from climate change) • Expansion of monsoon rainforest at expense of savannah and grasslands in northern Australia (medium confidence, major contribution from climate change)

• Migration of glass eels advanced by several weeks in Waikato River, New Zealand (low confidence, major contribution from climate change)
Coastal Erosion & Marine Ecosystems
• Southward shifts in the distribution of marine species near Australia, beyond changes due to short-term environmental fluctuations, fishing, and pollution (medium confidence, major contribution from climate change) • Change in timing of migration of seabirds in Australia (low confidence, major contribution from climate change) • Increased coral bleaching in Great Barrier Reef and western Australian reefs, beyond effects from pollution and physical disturbance (high confidence, major contribution from climate change) • Changed coral disease patterns at Great Barrier Reef, beyond effects from pollution (medium confidence, major contribution from climate change)
Food Production & Livelihoods
• Advanced timing of wine-grape maturation in recent decades, beyond advance due to improved management (medium confidence, major contribution from climate change) • Shift in winter vs. summer human mortality in Australia, beyond changes due to exposure and health care (low confidence, major contribution from climate change) • Relocation or diversification of agricultural activities in Australia, beyond changes due to policy, markets, and short-term climate variability (low confidence, minor contribution from climate change)

Table 3: Observed impacts attributed to climate change reported in the scientific literature since the AR4. These impacts have been attributed to climate change with very low, low, medium, or high confidence, with the relative contribution of climate change to the observed change indicated (major or minor), for natural and human systems across eight major world regions over the past several decades. Absence from the table of additional impacts attributed to climate change does not imply that such impacts have not occurred. After IPCC WGII Summary for Policymakers.

Climate change elsewhere affects New Zealand's income

Thus far we have considered only climate change impacts within New Zealand. Another way in which New Zealand, as a small, open agricultural producer, can be significantly affected by climate impacts is through international prices. If growing conditions elsewhere are unusually good or unusually bad, this can potentially affect commodity prices.

This report has not quantified the potential range of these effects, but this could be done by developing an understanding of current and future climate events that affect prices (especially and most obviously droughts, but also potentially flooding of major river systems) here and in farming areas in other commodity-producing countries, along with the potential economic consequences of climate change-induced changes in supply.

Climate Change Risk Assessments – putting it all together

A full risk assessment of climate change would take account of the systems and issues in figures 1 and 2 and table 2 and 3, as well as table 1. Current climate change potentially affects all four Capitals Within the Living Standards Framework used by the New Zealand Government, though most obviously Natural Capital and Financial Capital. Current climate change also affects several of the Points, most obviously Managing Risks, Sustainability for the Future and, especially in drought years, Economic Growth. As is the case in other countries, poorer communities often have less adaptive capacity than richer communities, so harmful impacts associated with climate change often act as an amplifier of inequality.

In order to move towards a more comprehensive view of the domestic impacts of climate change, several developed countries such as Australia[13], the USA, Canada, and most thoroughly the UK[14], have begun to conduct national assessments of climate risks. New Zealand does not have anything comparable at this point, though the recently-established Climate Change Adaptation Technical Working Group provides a potential focal point for the commissioning, development or facilitation of a range of specific studies, each of which can form part of an over-arching assessment of current and future risks and opportunities. The Working Group is well placed to broker interests, ensure science funding is well-coordinated and targeted at priority policy challenges, and commission policy-relevant research in a way that aligns well with the public interest.

A New Zealand Climate Change Risk Assessment could draw on several science inputs, including estimates of the scale of coastal hazards under different sea-level rise scenarios, estimates of ecosystem change and others, as well as a more thorough investigation of current and future weather-related climate change costs and benefits.

One concrete next step is the development of the attribution framework in this report. This involves working with climate modellers in New Zealand to understand how best to develop our climate change detection and attribution capability, in view of the climate change priorities articulated through the Deep South National Science Challenge, and in view of the very small current investment in these aspects of climate science in New Zealand. The framework here could be extended to consider benefits and costs of high importance to Treasury and other Departments, i.e. to work out which climate change impacts are of highest priority for future investment in attribution.

One very obvious conclusion from this exercise is that it would be useful for New Zealand to develop a database of economic damage (insured and uninsured) and loss data from these events.

Conclusion

The brief of this report has been to focus on estimating the current costs of recent (2007-2017) weather-related climate change in New Zealand. It is necessarily approximate and a significant underestimate, since we have only a limited number of studies which attempt to quantify the role of climate change on specific weather events. We use only insured damages–and not uninsured damages nor economic losses—associated with flooding events, and only economic losses—and not damages—when examining droughts. In addition, it is incomplete because it restricts its attention to weather-related climate change. The report is limited in the information it can draw upon, in large part because climate change detection and attribution capability is currently at a low level in New Zealand, at a little under 1.0 FTE. In spite of the fact that current climate change is having a clear impact on New Zealand through extreme weather events, and that New Zealand scientists are working closely with world leaders in understanding the links between extreme events and climate change, investment remains low compared to countries such as Australia, the UK and the USA.[15]

[13] Climate Change Risks to Australia's Coast: A First Pass National Assessment, 2009.

[14] UK Climate Change Risk Assessment 2017. http://www.theccc.org.uk/uk-climate-change-risk-assessment-2017

[15] For instance, Australia has recently launched a large investment into understanding its climate extremes; event attribution has a long pedigree in the UK through work at the Met Office and the University of Oxford.

In this report we present the first national scale assessment of the current (2007-2017) costs of floods and droughts that are attributable to climate change. Our first estimate is that climate change attributable extreme rainfall-related floods have cost New Zealand around $120M in climate change-attributable privately insured damages over that ten year period. Our second estimate is that climate change-attributable economic losses associated with droughts have cost New Zealand around $720M over that ten year period. These estimates are necessarily approximate and incomplete. Nevertheless, they provides ball-park estimates of current climate change-attributable costs, and the methodology could be extended to examine a wider range of hydrometeorological and other impacts, potentially forming one important element of a future more comprehensive understanding of climate risks in New Zealand.

To develop a more comprehensive understanding of the effect of climate impacts in New Zealand, we need to both broaden scientific understanding of climate change impacts upon New Zealand (and our EEZ), but also to deepen the skillsets that are most fundamental to understanding the causal connections between climate drivers and climate impacts. This suggests a strengthening of capability in physical climate sciences, especially climate change modelling and the skills relevant to detection and attribution.

Finally we emphasise that the FARs are not static in time. Because concentrations of greenhouse gases – especially carbon dioxide – continue to rise, the odds of damaging events like floods and droughts continue to rise. This implies the costs due to climate change are also expected to rise for many decades to come.

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The USA has a strong community in detection and attribution which plays a role in developing assessments of current climate risks, and so on.

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