The value of MetService's public weather forecasts and weather warnings

NZIER final report to MetService and the Ministry of Transport

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About NZIER

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NZIER was established in 1958.

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The assistance of Peter Kreft from MetService has been extremely valuable, while the oversight and guidance from Norm Henry (MetService) and Michael Moore (Ministry of Transport) are gratefully acknowledged.

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Key points

We were asked to undertake secondary research on the value of the weather information currently provided under the Crown contract in New Zealand

MetService and the Ministry of Transport (MoT) commissioned NZIER to undertake secondary research on the value of the public weather information provided under the Crown contract. This report summarises what was identified from the literature scan of comparable overseas jurisdictions and our estimates for the value of the weather information currently provided under the Crown contract for New Zealand. The contract includes publicly available forecasts and warnings for the New Zealand landmass, the surrounding coastal areas, and some of the high seas, along with the infrastructure required to support those services. As the focus is public forecasting and warning services covered by the contract, we have not included some sectors covered by commercial contracts (e.g., commercial aviation, energy) that could be quite important in terms of economic impact of all weather information.

Our literature scan identified a range of studies on the value of meteorological services in other jurisdictions but almost no New Zealand studies

The findings from our literature were mainly overseas studies that compared the costs and benefits of meteorological forecasting services. For studies of developed countries, the benefit to cost ratios (BCRs) mainly fell in the range 4:1 to 14:1. New Zealand based studies of weather events were rare (we identified ten studies in our literature scan).

We found the benefits from the public weather information provided under the Crown contract significantly outweighed the costs

We used a benefit transfer approach based on studies of the Australian Bureau of Meteorology, but including New Zealand values and data on weather events. Taken at face value, the potential benefits to any one of the main user groups on their own could justify the continuation of the provision of public weather services under the Crown contract. In line with comparable studies, this study focuses on the benefits to land-based groups of users. It does not directly address the benefits of the weather forecast and warning services provided to maritime users under the Crown contract.

We found a benefit to cost ratio of over 10:1

The total quantified benefits in this study range between NZ $235 million and NZ $1.13 billion. MetService attributes NZ $23.4 million of its total operating cost (NZ $51 million) to public weather forecasting and warnings. This gives a BCR range for weather forecasting services in the public domain between 10.0:1 and 48.1:1.

We also attempted to distinguish the gross value from the unique value added of weather information

Virtually all the studies we have reviewed make the stringent conservative assumption that in the absence of the taxpayer-funded national meteorological service, no weather forecasts or warnings would be available. This unrealistic assumption generates estimates of gross value added with the high BCRs discussed above.

We attempted to do something not undertaken in the studies we have surveyed – unpack the unique value added from having a national meteorological service using multi-criteria analysis. The resulting heatmap compares the current arrangements with a 'no National Meteorological Service' option and with a more realistic 'alternative suppliers' option, and two 'adjusted capability' options. We found that the 'no National Met. Service' option was dominated by all the other options on all dimensions except for economy (due to savings in the Crown contract). The augmented contract option explored the value of adding additional capability along the value chain. Under this option the technical quality of the publicly available forecast information improved and this in turn improved the credibility of the forecasts with users. The 'no contract, competing suppliers' option was dominated by the two contract options (apart from on economy grounds). This is because the Crown contract meets the overhead and fixed costs of the observing, modelling, forecasting and communications systems which must be met to provide the infrastructure and capability to support the meteorological system.

Further primary research could drill down into the unique value added of public weather information

The high benefit cost ratio overall does not necessarily suggest anything about the value of additional weather information at the margin relative to the extra cost. One way of avoiding this problem in any future research would be to build some recent studies that took a more sophisticated approach and moved away from the unrealistic weather / no weather forecast assumption to consider a richer set of possibilities. We would be happy to discuss how additional primary research could be used to explore the potential for additional value added from public weather forecasts and warnings In New Zealand.

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1. Introduction

We were commissioned by MetService and the Ministry of Transport (MoT) jointly to undertake independent analysis of the economic value of existing public weather forecasting and warning services supplied by MetService under a contract with the Crown. For the purposes of this study, the term "public weather information" and "public weather services" and "public weather forecasts and warnings" mean those weather services delivered by MetService as specified in its contract with the Crown. These services include publicly available forecasts and warnings for the New Zealand landmass, the surrounding coastal areas, and that area of the high seas defined as METAREA XIV. This analysis will be used to inform the development of the contract for public safety weather warnings and forecasts.

The central research question for this study is the value of the services provided under the Crown contract. Specifically, the prime focus is on:

- the gross value of the information contained in public weather forecasts and warnings

with a secondary focus on:

- the unique value added provided by the information contained in public weather forecasts and warnings.

While it is not the main focus, we also looked for opportunities to explore other questions such as:

- where are the avoided costs/ losses mitigated most concentrated; and
- where are the opportunities for potential gains from additional avoided costs/ loss mitigation.

There is an extensive international literature on evaluating the social and economic benefits (SEB) of National Meteorological and Hydrological Services (NMHSs). However, to date these studies have not been undertaken for New Zealand. This is the gap that this study aims to fill.

Table 1 In and out of scope

Dimension	In scope	Out of scope
Focus	Current weather warnings and forecasts *(up to one week)*.	Augmented weather forecasting capabilities or trends in climate.
Locus	Secondary research adapting existing international valuations for New Zealand conditions.	Primary research.
Temporal	Historical weather records.	Modelling future trends.

Source: NZIER

This report sets out what we have done and what we have found about the value of public weather forecasts and warnings in New Zealand.

Section 2 discusses the key findings from the literature scan, which were included in the Interim report provided in October 2017. This section highlights the limits of the standard approach in the valuation literature based on a with/without the meteorological services comparison.

Section 3 discusses the value of public weather forecasts and warnings to major groups of users – the public, agriculture, road transport and disaster management – using a benefit transfer approach. This was based on a study of the Australian Bureau of Meteorology (London Economics 2016), but we included New Zealand values and data on weather events. It highlights the total quantified benefits relative to the costs of public weather forecasts and warnings and the likely range that the full net benefits would fall within.

Section 4 discusses how we explored augmenting the standard approach to try and unpack the unique value added from having a national meteorological service to provide public weather forecasts and warnings.

Section 5 highlights the opportunities to mitigate economic losses or disruptions to economic activity through the use of forecasts and warnings of severe weather events and its effects.

Section 6 discusses potential research approaches based on primary research that could be applied to assess the economic value of public forecasts and warnings.

Appendix A summarises the approach used in the literature search and Appendix B provides an overview of the research more generally, while Appendix C discusses the international obligations that New Zealand faces and how this defines the counterfactual used in this study.

2. Key findings from the literature scan and other analysis

There is a large and growing international literature that focuses on the economic value of weather forecasts. This literature has grown to the point where the World Meteorological Organization produced a manual in 2015 on how to undertake economic valuations (World Meteorological Organization 2015). There is also an authoritative survey of the techniques available (Clements, Ray, and Anderson 2013, published by USAID). In our literature scan we focused mainly on overseas studies comparing costs and benefits of meteorological forecasting services in part because the initial search looking for New Zealand material yielded relatively little material.

2.1. Value of a national meteorological service to an economy

This section summarises studies that looked at the economy-wide impact of a national meteorological service, where this impact is normally expressed as the ratio of the benefits of the service in relation to the costs of providing the service (benefit to cost ratio or BCR).

The studies summarised in Table 2 below have used a number of different approaches. The studies differ in the research technique(s) used, the range of the weather sensitive sectors included, the time period covered (whether forecasts or historical period) and the scope of weather, climate and hydrological services that are included in the study. Most studies used a range of valuation techniques including willingness to pay (WTP) estimates for the general public, avoided insurance costs, value chain analysis, value of human life saved and the weather sensitivity of economic value added.

London Economics suggest that their recent study of the economic impact of the services provided by the Australian Bureau of Meteorology is the "most comprehensive economic assessment of a national meteorological service available to date" (London Economics 2016). They provide estimates of the value to the agriculture sector, general public, other business sectors, value of natural disaster damage avoidance (e.g. bushfires, floods, tropical cyclones), and the value to the aviation sector. Even so, London Economics (2016) states:

> *There are a range of benefits that have not been quantified due to a lack of supporting data or research. This includes benefits to defence, science and research, and international partnerships. For some sectors only a portion of benefits have been quantified, for example only the benefits flowing from improvements in seasonal forecasting have been included for the construction sector, not the total value of seasonal forecasting or the benefits from short-term forecasts. For aviation, only a small subset of benefits has been quantified which relate to reduced contingency fuel load achieved*

from aerodrome forecasts and better flight planning as a result of improved seasonal forecasts.

BCRs for developed countries shown in Table 2, mainly fall in the range 4:1 to 14:1. Moreover, these BCRs are consistently understated, as unquantified benefits are omitted while the full costs of providing meteorological services are included.

One offsetting factor is that very few of the studies focus just on public weather forecasts and warnings alone. The benefit streams often include value added by climate forecasts and hydrological services as well as public weather forecasts and warnings. However, studies that limit their focus on public weather forecast services still report high BCRs. For example, Gray (2015) reports a BCR of 10:1 for the United Kingdom. In part, this reflects the high values reported from surveys of willingness to pay shown in Table 4.

Table 2 BCRs for selected industrialised economies

Study	Geographic location	Sectors	Benefits methods / measures	BCR	Other values
Estimation of the net benefits of the Bureau's services to the Australian economy over a ten year period (London Economics 2016)	Australia	General public and range of sectors	Modelling of benefits	11.6:1	
Public Weather Service value for money review (Gray 2015)	UK	Public, aviation, land transport, flood and storm damage avoidance, added value to economy	Estimating benefits (based on existing studies, with updated info) vs costs. E.g.: Public: used survey info to cal. WTP. Aviation: updated value chain analysis plus cost-loss model. Other sectors applied a percentage to sector value in national accounts (e.g. agric.)	10:1 (at least)	

Study	Geographic location	Sectors	Benefits methods / measures	BCR	Other values
Estimation of the overall net economic value over the next ten years (2015-2025) to the UK of having the planned weather and climate services delivered by the Met Office (London Economics 2015)	UK	General public and range of sectors	Uses market-based approaches wherever possible, followed by perception of value estimations. Avoided cost approaches are only used when alternatives are not feasible	13.4:1 (weather services only - not incl. climate services; 12.7:1 is the min. of the various scenarios)	NPV £26.28b
Success of the United States National Weather Service (NWS) Heat Watch/Warning System in Philadelphia (Ebi et al., 2004, cited in WMO (2015))	Philadelphia, Pennsylvania, US	Households / elderly	Regression analysis to determine lives saved; application of the United States Environmental Protection Agency's (EPA) value of a statistical life (VSL) estimate	2,000:1 +	
Economic efficiency of NMHS modernization in Europe and Central Asia (World Bank, 2008, cited in WMO (2015))	Eleven European and Central Asian countries	Weather-dependent sectors	Sector-specific and benchmarking approaches to evaluate avoided losses	2:1 to 14:1	
Hydro-meteorological information and early-warning systems (Hallegatte 2012)	Europe	Public plus sectors	Estimated value of saved lives and reduced asset losses	-	Floods - €1,500m; storms €260m-€1,200m; saved lives €200m-€800m (per year)
Economic assessment of meteorological services' case studies in Denmark (Ministry of Transport and Energy (Denmark) 2006, cited in Perrels et al. (2013))	Denmark	All sectors, 3 case studies	Product-specific approaches (22 products)	-	"Many detailed examples with good net benefits; aggregate picture lacking"

Study	Geographic location	Sectors	Benefits methods / measures	BCR	Other values
Estimation of the value of free meteorological information in Denmark, by Deloitte in 2016 (Deloitte 2016) (translated); news release (Danish Meteorological Institute 2017)	Denmark	Sectors: electricity, heating, agricultural	Estimate benefits from new access to free data	-	Between 49.8 and 134.6m Kr. annually in selected sectors. Electricity sector 5.8-11.6m Kr; District heating sector 18m Kr; Agricultural sector 26-105m Kr.
Avoided costs of the FMI met/hydro services across economic sectors (Leviäkangas and Hautala, 2009, cited in WMO (2015))	Finland	Key economic sectors	Quantification of avoided costs and productivity gains; also used impact models and expert elicitation	5:1 to 10:1	
Costs and benefits of weather and climate information to the Netherlands (study by Rebel Group 2012, cited elsewhere (Royal Netherlands Meteorological Institute 2013) (Roozekrans 2013)	Netherlands	Economy	[Not available]	5:1 to 42:1	Costs €70m Benefits (range) €338m to almost €3,000m
Economic and social benefits of meteorology and climatology (Frei 2009 (cited in WMO (2015))	Switzerland	Transport, energy, aviation, agriculture, households	Benefit transfer, expert elicitation, decision modelling	5:1 to 10:1	

Source: NZIER, including selected results from WMO (2015) and (Perrels et al. 2013)

For the sake of completeness in Table 3 we have included a range of studies from developing countries. In none of the studies in these other jurisdictions did we find a BCR lower than 2:1 and the BCRs in developing countries are often much larger than in developed countries. We specifically looked for but failed to find a study where the BCR was less than one.

Table 3 BCRs for other jurisdictions

Study	Geographic location	Sectors	Benefits methods / measures	BCR	Other values
Benefits of Ethiopia's Livelihoods, Early Assessment and Protection (LEAP) drought early warning and response system (Law, 2012, cited in WMO (2015))	Ethiopia	Households	Quantification of avoided livelihood losses and decreased assistance costs	3:1 to 6:1	
The benefits to Mexican agriculture of an El Nino/ Southern Oscillation (ENSO) early warning system (Adams et al., 2003, cited in WMO (2015))	Five-state region in Mexico	Agriculture	Change in social welfare based on increased crop production with use of improved information	2:1 to 9:1	
The value of hurricane forecasts to oil and gas producers in the Gulf of Mexico (Considine et al., 2004, cited in WMO (2015))	Gulf of Mexico	Oil drilling	Value of avoided evacuation costs and reduced foregone drilling time	2:1 to 3:1	
Benefits and costs of improving met/hydro services in developing countries (Hallegatte, 2012, cited in WMO (2015))	Developing countries	National level and weather sensitive sectors	Benefits-transfer approach to quantify avoided asset losses, lives saved, and total value added in weather-sensitive sectors	4:1 to 35:1	
Social economic benefits of enhanced weather services in Nepal – part of the Finnish–Nepalese project (Perrels, 2011, cited in WMO (2015))	Nepal	Agriculture, transport and hydropower	Statistical inference and expert judgement	10:1	
Socioeconomic evaluation of improved met/hydro services in Bhutan (Pilli- Sihvola et al., 2014, cited in WMO (2015))	Bhutan	National level	Benefit transfer, expert elicitation, cardinal rating method	3:1	
Benefits of hydrological and meteorological information services in Croatia (Leviakangas et al. 2008, cited in Perrels et al. (2013))	Croatia	Overview of all sectors	Multiple methods: literature reviews and statistics, expert interviews and workshops, and analytical, conceptual and qualitative model building and modelling of expected impacts	3:1 (at least)	

Study	Geographic location	Sectors	Benefits methods / measures	BCR	Other values
Economic benefits of hydro meteorological services (Bedritsky and Khandozko 2001, cited in Perrels et al. (2013))	Russia	Overview of all sectors	Estimation of savings realized due to the use of all types of hydro-meteorological information	3:1 – 4:1	

Source: NZIER, including selected results from WMO (2015) and (Perrels et al. 2013)

In summary, looking across the studies summarised in Table 2 and Table 3:

1. All studies reported a BCR higher than 2:1, with developing countries generally higher than developed economies
2. Studies that included a wider range of weather sensitive sectors had higher BCRs
3. Studies that included a wider range of services (climate forecasts and hydrology) generally reported higher BCRs.

The results from the willingness to pay studies (shown in Table 4) suggest that the benefits for households outweigh the full costs of public weather services by at least 4:1, before the benefits to any other users are considered.

Table 4 Willingness to pay studies

Developed and developing countries

Study	Geographic location	Sectors	Benefits methods / measures	BCR	Other values
Contingent valuation study of the public weather service in a metropolitan area (Anaman et al. 1998)	Sydney, Australia	Households	Willingness to pay survey of household	4:1	
Economic value of weather forecasts (Rollins and Shaykewich 2003)	Toronto, Canada	Commercial sectors	Willingness to pay	-	WTP average $C1.20; Agric. $C2.17; institutional users $.60. Estimates $C16.5m p.a. benefits to commercial users

Study	Geographic location	Sectors	Benefits methods / measures	BCR	Other values
Economic and social benefits associated with the Public Weather Service (PA Consulting (for the Met Office) 2007, cited in Perrels et al. (2013))	UK	General public	Willingness to pay analysis	7:1	
Economic value of current and improved weather forecasts in the United States household sector ((Lazo and Chestnut 2002), cited in WMO (2015))	US	Households	Willingness to pay survey of households	4.4:1	
Value of public weather forecasts (Lazo et al. 2009, cited in Perrels et al. (2013))	US	General public	Willingness to pay analysis	6:1	
Other jurisdictions:					
Assessment of the benefits of the Chinese Public Weather Service (Yuan, Sun, and Wang 2016)	China	Households	Willingness to pay surveys	National 26:1 Regional 2:1 to 81:1	

Source: : NZIER, including selected results from WMO (2015) and (Perrels et al. 2013)

We discuss the application of these estimated values from the WTP studies to New Zealand in Section 3. The key caveat when interpreting these studies is the problem of the counterfactual. All the developed country studies (in Table 2) make the extremely conservative assumption that in the absence of a national meteorological service, no weather forecasts or warnings would be available to the public.

While this is the standard approach, this is clearly an unrealistic comparator partly because of international obligations. For example, International Civil Aviation Organisation (ICAO) requires Contracting States to observe a set of Standards and Recommended Practices in their provision of meteorological services to aviation. Without such meteorological services, commercial aviation could cease. Taken to the logical extreme all of the value added from civil aviation (NZ $4.8 billion per annum in 2011 dollars) could be counted as an economic benefit enabled by Meteorological Services providing ICAO regulated meteorological services for aviation (as discussed by London Economics (2016 p. ii)).

However not all these benefits are unique to National Meteorological Services. In practice in the real world, with a short lag, alternative meteorological services would be forthcoming to ensure that aviation could continue. We return to the problem of the counterfactual and estimating unique value added in Section 4 when we discuss our experimentation with the use of multi-criteria analysis.

2.2. Sectoral shares of net benefits

While the previous section discussed the economy wide net benefits from meteorological services, in this section we explore the share of value added contributed by particular weather sensitive sectors. We looked for economy wide studies from comparable jurisdictions that clearly identified and quantified net benefits for particular sectors.

Table 5 Proportion of value of benefits by sector

Percentages

Country (study)	Agriculture	Construction	Damage prevention (flood, storm)	Energy	Other	Public / households	Transport - aviation	Transport - land	TOTAL
Australia (London Economics 2016)	40	6	15	1	11	27	1		100
Croatia (Leviakangas et al. 2007)	23	2		6	19		37	14	100
Finland (Leviakangas and Hautala 2009)	12	5		4	11		20	47	100
Switzerland ((Frei 2009), (Frei, von Grünigen, and Willemse 2014), (von Gruenigen, Willemse, and Frei 2014))	16			39		21	4	21	100
UK (PA Consulting 2007)		5	8		11	56	20		100
UK (Gray 2015)	2	14	9	5	5	31	26	7	100
UK (London Economics 2015)	2	18	5	7	14	18	32	4	100
Mean	16	9	9	10	12	31	20	19	
Range	2-40	5-18	5-15	1-39	5-19	18-56	1-37	4-47	

Notes:

Croatia (Leviakangas et al. 2007) – *benefits for some sectors provided as a range; took the midpoint.*

Switzerland – combined the results of three studies ((Frei 2009), (Frei, von Grünigen, and Willemse 2014), (von Gruenigen, Willemse, and Frei 2014)) to get a sense of sectoral comparison – is a mix therefore of 2009 and 2011 information.

UK (PA Consulting 2007) – *notes that in addition to the general public, "benefits are also provided to SMEs, particularly those in the construction, agriculture, retail and manufacturing, and leisure and tourism industries", but does not provide estimates for these sectors.*

UK (Gray 2015) - identified Agriculture, Construction, Utilities (electricity, gas and water supply), and Mining and Quarrying as sectors which are very weather-dependent. The value of the Public Weather Service to these sectors was calculated by applying a percentage (0.25%) to their combined value in the

National Accounts. We have reallocated that here to the individual sectors. Mining and Quarrying is included in "Other".

UK (London Economics 2015) – for comparison purposes have allocated the percentage for "other industries" to agriculture etc., based on proportions in Gray 2015.

Source: NZIER. Note that totals do not add to 100 percent due to rounding and missing observations.

Table 5 uses studies from seven developed countries to show the average value and the range of the shares from weather sensitive industries. As with the previous tables, some caveats are required:

- we have focused on quantified net benefits so have not included the significant non-quantifiable benefits
- the studies in the table vary in the research technique(s) used, the time period covered and the scope of weather, climate and hydrological services included
- a number of industries that may be covered by single sector studies (such as agriculture, fisheries, search and rescue, or tourism) are not necessarily included in the economy wide studies.

Despite these shortcomings, Table 5 is useful for illustrative purposes as it brings out the range of the sectoral contributions across the different national studies. As Frei (2009, p. 1) states:

> *benefit analysis should therefore concentrate on those subsectors where weather services are particularly relevant, i.e. agriculture, construction, energy, insurance, telecommunication, tourism, transport, logistics and water availability.*

Two points are worth noting from Table 5:

- the 80/20 rule – the bulk of the benefits on average come from just three sectors – general public, agriculture and transport (aviation and other combined)
- the variability of shares – agriculture ranges from 40% in one study down to 2% of value added in another and in one was not even included.

These points are important for the development of the research design (discussed in Section 4). The 80/20 rule suggests that we can develop robust estimates adapted for New Zealand by focusing on a few critical weather sensitive sectors.

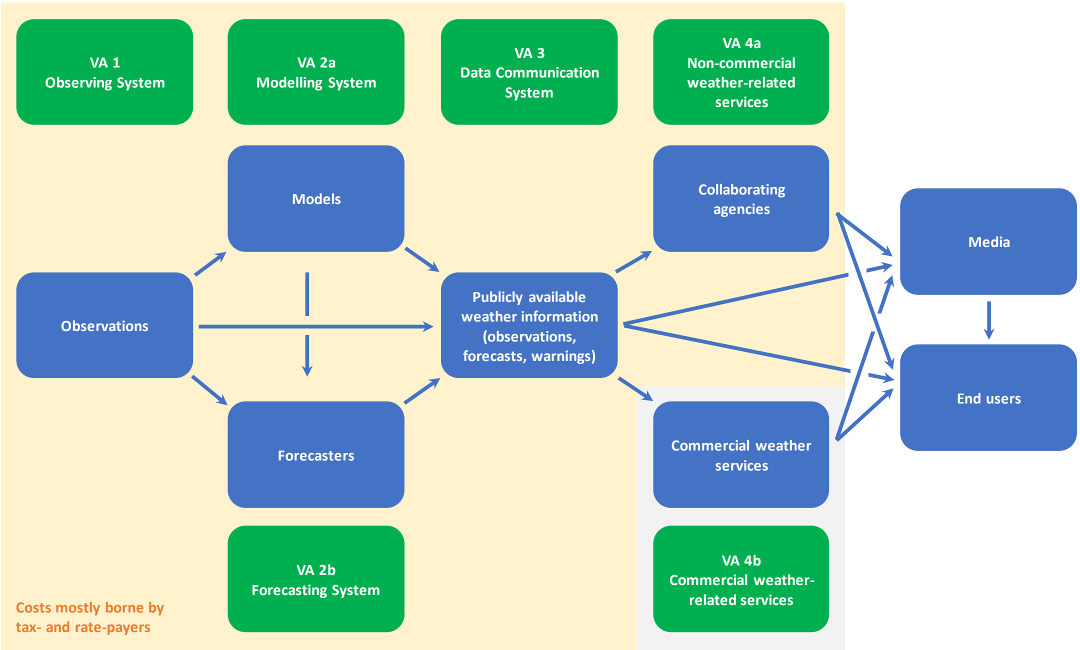
2.3. The value chain for weather information

A key technique used in the literature to understand the value added from public weather forecast and warnings is the weather value chain. Our understanding of the value of publicly funded weather forecasting and warnings has benefited greatly from our discussions with Peter Kreft from MetService. A stylised exposition drawing from Peter's work is set out below in Figure 1.

Several features deserve comment:

- the schema is simplified because the weather value chain is a system within a system – it draws from and feeds into a wider international meteorological system
- weather information feeds into other value chains. For example, the recent independent review into April's Edgecumbe flood[1] includes a flood log, which highlights that MetService information was available for decision-makers to use in the flood warning process
- feedback loops from user feedback or research inform modelling and forecasting and communication practices
- value gets attenuated as one moves from left to right. This is because decision-makers often struggle to incorporate the information in weather forecasts and then to translate that into action (Potter et al. 2017).

Figure 1 Weather value chain



Source: Adapted from Peter Kreft, MetService

The key insight from Figure 1 is that the value added from the weather forecasting system is not limited to final outputs – commercial and public weather forecasts and warnings. The Crown contract covers the lion's share of the cost of an entire weather infrastructure – a curated dataset based on weather observations, modelling and forecasting capability, data exchange with international partners and systems for communicating weather information and warnings to end users. Value is created at each stage as a range of users access the data and forecasts and use them for a range of purposes.

1 See p. 147-154 https://www.boprc.govt.nz/media/681909/2017-10-03-rrsr-final-report-public.pdf).

The discussion to date has focused on the value of weather information. The next section will focus on the cost of weather events rather than weather information per se. Data on severe weather events in New Zealand was needed to adjust frequency and exposure estimates from other jurisdictions to New Zealand conditions.

2.4. New Zealand data on severe weather events

2.4.1. The direct and indirect costs of severe weather events

Severe weather events have both direct and indirect costs. The direct costs relate to property damage and harm to human health including loss of life.

The indirect costs associated with a natural hazard event relate to the flow-on effects of the direct impact. These range from losses due to business disruption to the additional cost faced by others. In the case of severe weather events these flow-on effects take two main forms:

- business disruption losses arising from flooding and/or property damage
- the second- and subsequent-round effects of the disruption on other businesses and households.

Costs arise from the interaction between the natural risk and exposure to vulnerability. US research (Kunkel, Pielke, and Changnon 1999) suggests that the increased cost of weather events over time is mainly due to increased vulnerability (due to societal changes) rather than increased risk. However, climate change is expected to lead to an increase in frequency and intensity of severe weather events, which would lead to a further increase in these costs due to increased underlying risk.

2.4.2. Availability of data

Direct property costs, which are typically the easiest to estimate, are those that arise as immediate consequences of the event itself. These include property costs associated with damage to houses, business premises, stock. Insured property loss data, while underestimating total loss due to underinsurance and excesses and deductibles, provides a useful ballpark estimate for the direct property loss.

Data on loss of human life is collected but data on health costs is more difficult to obtain. However, the main data gap is the lack of information on the indirect impacts.

There are three main sources of data on New Zealand, the Insurance Council of New Zealand (ICNZ), the NIWA historic weather event catalogue along with the MetService log of severe weather events back to 1996.[2]

The ICNZ[3] has a list of documented New Zealand severe weather events and insured losses back to 1968. This provides a list of natural disasters, loosely classified by type (including storms, cyclones, floods, tornadoes and snowstorms) along with each

2 https://hwe.niwa.co.nz/

3 Insurance Council NZ (ICNZ) Cost of Natural Disasters in NZ: https://www.icnz.org.nz/media-and-resources/natural-disasters/

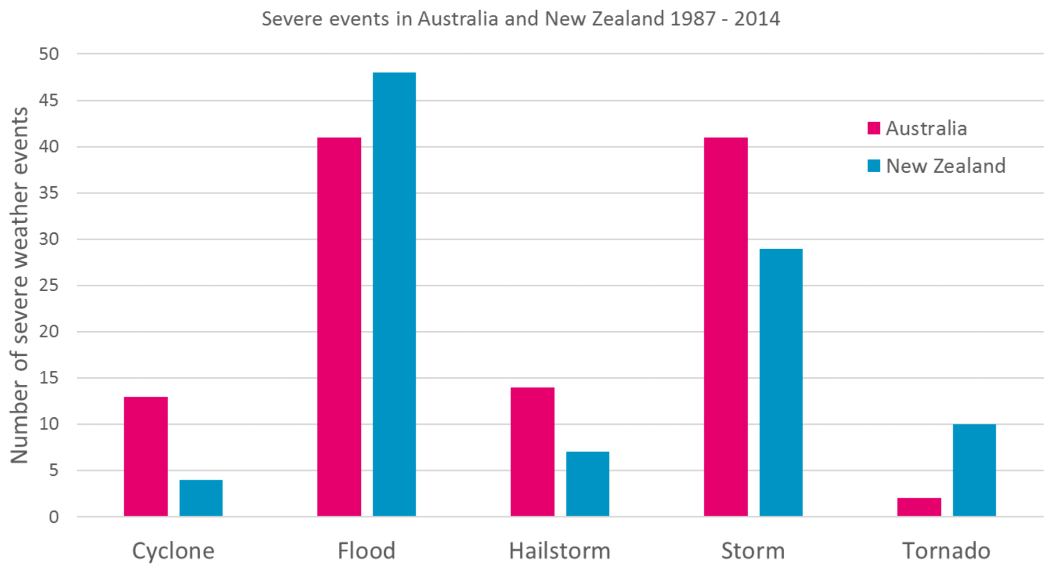
event's associated cost to the insurance industry (ICNZ 2017). These costs represent insurance losses (i.e. claims accepted, which will be determined by insurance coverage less excess amounts), rather than property loss.

The NIWA catalogue provides an incomplete list of events with some additional information on loss of human life and other economic loss. We merged the NIWA catalogue, with the ICNZ list to prepare a more complete dataset.

Comparable data is available from Australia as their insurance data includes a list of severe weather events since 1967 with casualty losses as well as costs to the insurance industry. From the analysis of New Zealand weather events data, we find that on average events classified by ICNZ as cyclones cause the highest insured losses (NZ $27.5 million per event). Of the listed natural disasters over the past 30 years, 48.5% of those have been floods.

Figure 2 provides an initial comparison between ICNZ and Australian insurance data, looking at the frequency of severe weather events.

Figure 2 Severe weather in New Zealand and Australia

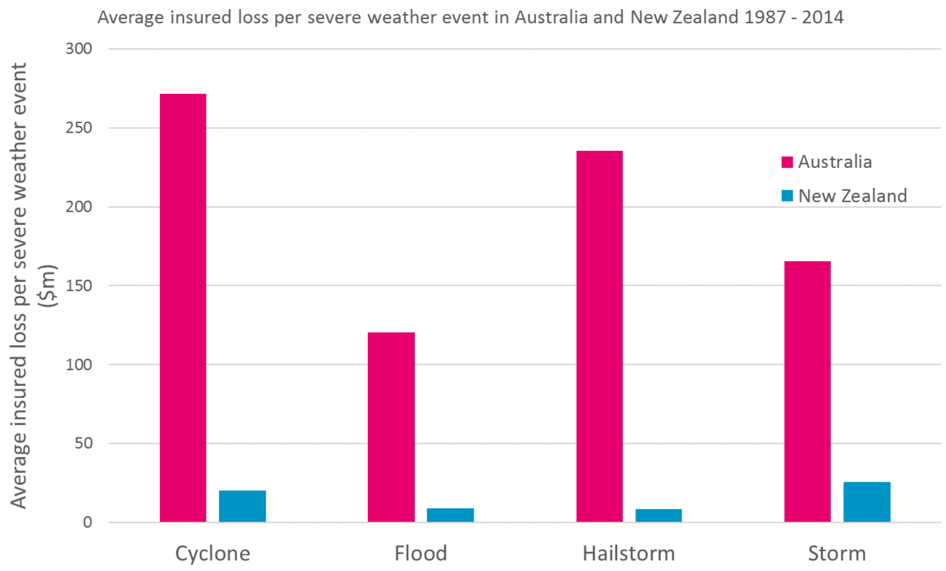


Source: NZIER based on New Zealand and Australian insurance data

Figure 2 suggests that while individual country risk profiles are different, they follow a similar overall pattern of risk. This suggests it should be possible to adjust Australian estimates to allow for weather risk in New Zealand. Separate adjustments were made to allow for differences in weather vulnerability.

Figure 3 compares the average insured losses per event in the two countries. Australia appears to have significantly greater exposure to severe cyclones as well as higher losses per severe weather event (presumably reflecting greater country and population size as well as data differences).

Figure 3 Average insured losses of severe events in New Zealand and Australia[4]



Source: NZIER based on New Zealand and Australian insurance data

2.5. Studies of New Zealand weather events

In this section, we summarise the results from a rapid scan to locate any studies providing a high-level overview of the costs of severe weather events to New Zealand.

We could not find a systematic economy wide study for New Zealand along the lines of two studies that looked at economic and other impacts of weather extremes for the United States ((Kunkel, Pielke, and Changnon 1999), (Changnon 2003)).

Instead what we found were a handful of specific event studies which are summarised in Table 6 below. We did however find a New Zealand event study that attempted to calculate the cost total of a severe weather event.

NZIER with GNS, NIWA and the University of Tasmania produced a comprehensive economic analysis of the impact of the Waikato "weather bomb" of June 2002 (Walton et al. 2004), using survey and insured loss data.[5] The event lasted four days with heavy rain, flooding and high winds and high seas to much of the upper North Island. The report summary concluded:

> *Analyses of the economic impacts of New Zealand natural hazard events have been relatively sparse compared to analyses undertaken overseas. Impacts have been assessed here under the categories of direct and indirect impacts……. The most notable outcome of this analysis is that the economic impacts, although enormous for some individuals, were relatively minor for the Waikato community as a whole, and much less than might have been anticipated, given the severity of the weather event.*

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4 Australian insurance council records losses for events with damage greater than AUD 1.5 million, hence the Australian average insured loss is an underestimate and no Tornado events had damages greater than AUD 1.5 million.

5 Available at http://www.mfe.govt.nz/publications/climate-change/waikato-weather-bomb-understanding-impact.

Direct costs were limited almost entirely to property damage. The estimated insurance claims made as a result of the event were $21.5 million, with around $8 million related to the Thames-Coromandel area. Data from the survey suggests that this was split 0.84/0.16 between households and businesses ($6.7 and $1.3 million respectively). Total uninsured losses are estimated at $2.1 million, based on the survey data. In addition, TCDC estimated that agency response costs were $3.1 million, with much of that attributed to labour costs. The total direct costs are thus estimated to have been $13.2 million for the TCDC area. The true loss to the area likely sits somewhere between 0.1 - 0.6 % of the area's asset base (estimated to be around $1750 million). This relatively crude estimate provides an indication of the relative size of the event.

In terms of indirect losses the business survey results suggest that the net impact of the weather bomb on business sales was positive (around 30 % more revenue from increased business than the value of lost business). Note that this does not represent a true positive net impact to businesses in the Thames-Coromandel area, because many negative impacts, particularly damage to property (a direct loss, quantified above), are missing. The cost borne by insured TCDC households and businesses via insurance excess payments is estimated to total around $0.45 million. Additional losses as a result of losses of no-claims bonuses, premium increases and, in some cases, cancellation of policies, also occurred but are extremely difficult to quantify. These losses are also only partly related to the Weather Bomb event alone. Adopting a longitudinal framework involving assessment of the incremental impact of successive hazard events is likely to provide a fairer picture of the longer-term cost of repeated events.

Table 6 summarises the other items identified from the literature. These impact studies were used as a cross check on the benefit transfer estimates generated as part a cost benefit analysis.

Table 6 Other literature items on costs of New Zealand weather events

By domain then date of event

General	Agriculture	Transport
Technical report for Environment Waikato which describes the extent of the damage caused by the Weather Bomb of 21 June 2002, and provides a summary of costs e.g. for repair work (Munro 2002). Study which used a 114-sector Input/Output model to estimate the economic impacts of the Manawatu-Wanganui flooding in February 2004 (Vision Manawatu 2004). Report which described damage caused by a West Coast regional weather event ex Tropical Cyclone Ita 17 April 2014 (West Coast Regional Council 2014).	Early estimates of the damage to agriculture, cropping, forestry, and horticulture, from the storms of 15-18 February 2004 (Sutton 2004). Costs of floods and storms, agricultural focus – short literature review included (EcoClimate 2008). The economic costs on the farm of a major rain storm in the Hawke's Bay, April 2011 (Barham, Ross, and McIvor 2012). Effects of storms on farms in the Hawke's Bay, April 2011 (McIvor 2012). June 2015 Taranaki and Horizons Regions Storm: primary sector impact assessment (Ministry for Primary Industries 2015).	Road closures due to natural hazards case study (Kaikoura) (Clydesdale 2000). Effects of closing railway due to storm (Ministry of Transport et al. 2013).

Source: NZIER

3. Benefit transfer

The literature scan highlighted that there was very little readily available New Zealand-specific research on the economic impact of severe weather events or the value of weather forecasting. The primary constraint on the project was that within the time and resources available we were restricted to secondary research. Benefit transfer is the main technique which lends itself to secondary research and this approach is discussed in more detail in Appendix B.

In brief, benefit transfer involves utilising the approach used in cost benefit analyses of overseas meteorology services and adapting these studies for New Zealand specific information where it is available. In the case of National Meteorological Services we adapted the London Economics study of the Australian Bureau of Meteorology (London Economics 2016) to New Zealand. This was augmented as required by other studies such as the Copenhagen Consensus perspective paper on Natural Disasters (Hallegatte 2012) and the Royal Meteorological Society study of weather forecasting in Finland (Nurmi et al. 2012).

Using a benefit transfer approach enabled us to address the primary research question – the gross value of the information in public weather forecast and warnings. An 80/20 estimate of the total gross value of weather information is the sum of the gross values of the following sectors:

- general public
- agriculture
- disaster management
- road transport.

This is an 80/20 solution as we have focused on the four sectors that the literature survey identified as generating the largest net benefits. We have taken a conservative approach to estimating the benefits and only including sectors whose benefits can be quantified using the studies mentioned above. As not all benefits can be estimated, this leads to underestimating the overall benefits. As the costs of public weather forecasting are reasonably robust, this means that net benefits are systematically understated.

In the next section, we detail for each use the expected benefit stream and whether the evidence suggests that the reported benefit is expected to be under- or overestimated. For each benefit stream, we also conducted sensitivity analysis based on parameters from past studies and those specific to New Zealand.

3.1. General public

To determine the value of weather forecasts to the general public, we followed the methodology used in the London Economics study of the Australian Bureau of Meteorology (London Economics 2016). This looked at international estimates of willingness to pay for weather services, (which were also discussed in Table 4 above). London Economics (2016) reviewed studies from Australia, the United Kingdom and the United States, which conducted telephone and online surveys of between 500 and 2,800 adults and asked respondents to state the maximum amount they would be willing to pay for a weather service.

London Economics reported a willingness to pay range from AU $20.79 to AU $219.31 (2017 prices) per adult. For our base-case, we used the conservative estimate of AU $20.79 (NZ $22.87). Additionally, for sensitivity analysis, we also considered the upper limit of AU $219.31 (NZ $241.25). The formula used for modelling these values per year is the following:

Benefit = Willingness to pay × Adult (18+) population in New Zealand

London Economics discusses potential reasons for differences in willingness to pay:

- differences in the points in time at which the studies were implemented
- differences in the respondents' perception or understanding of the question
- whether the question was framed as an open-ended question or bounded by price ranges.

In summary, value of public weather forecasts and warnings to the general public is **between NZ $84.0 million and NZ $886 million *per annum***. The method highlighted above is limited by the quality of the surveys citied by London Economics, so the real value to New Zealanders may be higher or lower than the estimates we have calculated.

3.2. Agriculture

The methodology used by London Economics to estimate the benefits of weather forecasting to the agriculture sector was based on a study that looked at the benefits to cropping land by reducing herbicide re-spraying in Australia. In New Zealand, cropping land makes up roughly 5% of total farm area[6] so using cropping values would materially underestimate the value of weather information in New Zealand.

We discussed with Beef and Lamb New Zealand the role of weather forecasting information for a range of agricultural products in New Zealand including beef, lamb and wool, fruits and crops, as these are significant contributors to New Zealand's agricultural sector.

Our approach focused around managerial decisions/actions that need to be taken due to adverse weather conditions to avoid stock losses and minimise crop damage. For stock, these decisions include whether to delay sheep shearing and/or whether to move stock to higher/safer ground. For crops and fruits, these the decisions are about whether to protect/cover and harvest under adverse weather conditions. These managerial decisions are then influenced by numbers on exposure and vulnerability of the stock and land in adverse weather conditions. A summary of the managerial decisions and questions to answer on exposure and vulnerability are given in Table 7 below.

6 Statistics NZ Infoshare: http://archive.stats.govt.nz/infoshare/Default.aspx

Table 7 Weather related agricultural managerial decisions

Domain	Weather event	Managerial decision / action	Consequence	Exposure question	Vulnerability question 1	Vulnerability question 2
Livestock	Flood / Storm / Rain / Frost/ Hail / Dry	Delay shearing	Minimise stock loss	What % of sheep / lamb are exposed?	What % of stock will be lost without forecasts?	What % of stock will be lost with forecasts?
Livestock	Flood / Storm / Rain / Frost/ Hail / Dry	Move sheep / lamb to higher ground	Minimise stock loss	What % of sheep / lamb are exposed?	What % of stock will be lost without forecasts?	What % of stock will be lost with forecasts?
Livestock	Flood / Storm / Rain / Frost/ Hail / Dry	Move cows to higher ground	Minimise stock loss	What % of cows are exposed?	What % of stock will be lost without forecasts?	What % of stock will be lost with forecasts?
Crops	Frost / Hail / Rain	Protect / cover/ helicopter scatter	Minimise crop damage / avoid drying costs	What % of farms / land is exposed?	What % of farms / land affected without forecasts?	What % of farms / land affected with forecasts?
Peas	Frost / Hail / Rain	Harvest or not	Minimise damage / avoid drying costs	What % of farms / land is exposed?	What % of farms / land affected without forecasts?	What % of farms / land affected with forecasts?

Source: NZIER, based on email correspondence from Beef and Lamb New Zealand.

The exposure question (column 5 in Table 7 above) for all livestock was addressed using two resources – Ministry for Primary Industries (MPI) paper on Primary Sector Impact Assessment (2015), and Beef and Lamb New Zealand's professional judgement. The MPI paper looked at the number of sheep and beef farms in Taranaki, Wanganui, Rangitikei and Manawatu that were impacted due to adverse weather conditions. On average, 34% of sheep and beef farms in these regions were impacted (ranging from 5% in Manawatu to 92% in Wanganui). Arguably the "weather impact" is at least as big in other regions such as Canterbury, Otago and Southland, where snowfalls have a big influence on stock and on farmer's stock management decisions.

We explored with Beef and Lamb New Zealand the impact of weather impact across New Zealand. Their professional judgement was that 100% of farms would be impacted due to adverse weather conditions. We used the range (34% and 100%) of livestock exposure to adverse weather conditions.

Vulnerability questions 1 and 2 (columns 6 & 7 in Table 7 above) are answered using Beef and Lamb New Zealand's professional judgement. They estimate that 4% of exposed livestock is lost in adverse conditions with *no* weather forecast (question 1), whereas 2% of exposed livestock is lost in adverse conditions with a live forecast (question 2). To estimate the benefits of weather forecast to the beef, lamb and wool industry, we use the following formula:

Benefit = % exposed livestock × (% stock lost with no forecasts - % stock lost with forecasts) × stock count × unit cost

The MPI paper estimates NZ $100 per sheep head and NZ $1,000 per beef cattle head. Stock counts from Statistics NZ are 3.5 million beef cattle and 26.1 million sheep. Our conservative benefits estimate using 34% livestock exposure is NZ $41.7 million and our optimistic estimate using 100% livestock exposure is NZ $123 million.[7]

Quantifying the value of weather for the cropping sub-sector was difficult due to a lack of readily available New Zealand data. We approached Farmers' Mutual Group (FMG) Insurance who informed us that a customised data request would be required to determine this benefit stream, and while the data was available it couldn't be supplied within the timeline of this project.

London Economics (2016) state that satellite and cell phone coverage is an important component in determining the benefit of weather forecasts to agriculture. Relatively to Europe, New Zealand has poorer cell phone coverage, which translates to higher transaction costs. To account for this and to ensure a degree of robustness to our analysis, we discounted the benefits from this stream by 25%. We estimate the value of weather forecasting to the agriculture sector (based on sheep and beef alone) to be **between NZ $31.3 million and NZ $92.0 million *per annum***. This is clearly an underestimate as it does not include the benefits to agricultural output other than sheep and beef farming.[8]

3.3. Disaster management

Disaster management is one of the key uses of public weather forecasts and warnings identified in the literature scan. To quantify the benefits of weather forecasts, we adopted the methodology utilised in the Copenhagen Consensus perspective paper on natural disasters (Hallegatte 2015). This study looked at the reductions in asset losses and loss of human life due to more effective weather forecasts in Europe. Floods and storms are the focus of the study in determining these losses. Forecasting and loss reduction assumptions made in Hallegatte's paper are:

- between 50% and 75% of floods and storms are actually forecast
- forecasts reduce asset losses by 10% to 50%
- forecasts can save between 200 and 800 lives per year.

Adding up asset and human losses leads to an estimate of the annual benefits from forecasts in Europe between €470 million and €2.8 billion per year (between NZ $839 million and NZ $5.0 billion in 2017 prices).

To provide corresponding estimates for New Zealand, we reviewed insurance losses provided by the Insurance Council New Zealand (ICNZ) and the NIWA catalogue. The

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7 We limited ourselves to Sheep and Beef rather than other primary industries as our focus is on the public weather forecasts and we understand MetService has contracts with selected primary production companies for the provision of bespoke weather services.

8 The omission of other agricultural output materially underestimates the value of weather information to agriculture. To illustrate this, we found a Canadian study that estimates that the value of precipitation forecast for hay production as $C21.74 per acre and the value of improved forecast at $C4.75 per acre. If, and it is a big if, these values were to apply to cropping in New Zealand, they would generate values of weather information between NZ $29 million and NZ $35 million.

ICNZ has a list of documented New Zealand severe weather events and insured losses back to 1968. This provides a list of natural disasters including storms, floods, tornadoes and snowstorms, along with each event's associated cost to the insurance industry (ICNZ 2017). These costs represent insurance losses (i.e. claims accepted, which will be determined by insurance coverage less excess amounts), rather than property loss.

The NIWA catalogue provides an incomplete list of events with some additional information on loss of human life and other economic loss. We merged the NIWA catalogue, with the ICNZ list to prepare a more complete dataset.

For our analysis, we considered insured losses going back to 1988 (30 years). We chose a 30-year time frame as this is sufficient time series to provide a valid average. The average insured losses per year are NZ $64 million and there was an average of six fatalities per year due to adverse weather events. Hallegatte (2015) estimates that between 200 and 800 lives per year can be saved in Europe due to weather forecasts. Assuming similar variability in weather in Europe and New Zealand this translates to between two and six lives saved in New Zealand per year. We apply the following formula to determine benefits:

Benefit = Average insured losses × % events that can be forecasted × % reduction in asset losses due to forecasting + number of lives saved × value of statistical life

Using the forecasting and loss reduction assumptions mentioned above, our conservative estimate of damage avoidance assumes (following Hallegatte) 50% of floods and storms [9] can be forecast, a 10% reduction in asset losses (average insured losses) and two lives saved per year due to weather forecasts. We also use the MoT recommended Value of Statistical Life (VOSL) at NZ $4.26 million (2017 prices).[10] These values give our conservative benefits estimate to be NZ $11.7 million per year. The more optimistic estimate assumes 75% of adverse weather events can be forecasted,[11] a 50% reduction in asset losses and six lives saved per year. Using the same VOSL as above, the optimistic benefits estimate is NZ $49.6 million per year.

Compared to Europe, New Zealand has relatively poor cell phone coverage. As before, we estimate discounting the benefits from this stream by 25%. This means the value of weather forecasts for disaster management lies **between NZ $8.8 million and NZ $37.2 million *per annum***.

We have used insurance losses, which do not consider property and stock losses as a proxy for total losses. This means our benefit estimates are a significant underestimate. The London Economics study found insured losses represent 20-50% of total economic losses. NZIER's Waikato "weather bomb" study found insured losses to represent 60% of total economic losses (Walton et al. 2004). This suggests that the total value of economic loss of disaster management could be between 2 and 5 times higher than the number reported above. Given insured losses (NZ $64 million per year)

9 The perspective paper assumes forecasting probability for floods and storms only. We assume these probabilities for all types of adverse weather events.

10 Social cost of road crashes and injuries 2016 update: http://www.transport.govt.nz/assets/Uploads/Research/Documents/Social-cost-of-road-crashes-and-injuries-2016-update-final.pdf

11 In MetService's SCI (http://about.metservice.com/assets/SCI/MetService-SCI-2017-19.pdf) – see page 9 – are business plan targets for the accuracy of broad-scale severe weather warnings. For the current FY, the KPI targets for heavy rain Probability of Detection and False Alarm Ratio are >90% and <25% respectively. Given MetService's record of performance in forecasting broad-scale severe weather, the minimum annual financial benefit to disaster management is likely to be rather greater than $11.7m.

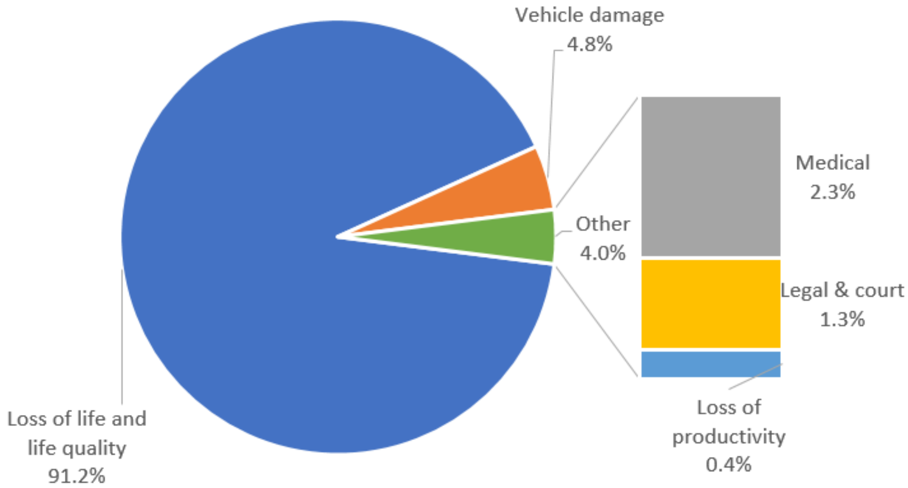
represent 20-60% of total economic losses, this translates to economic losses between NZ $107 million and NZ $320m per year. Offsetting that undercounting is the risk of double counting as it is likely that some of the benefits to disaster management are being captured under benefits to the general public (discussed in Section 3.1 above).

3.4. Road transport

We adopted the methodology in the Royal Meteorological Society study (Nurmi et al. 2012) of the value of weather forecasts to road transport in Finland. This methodology has also been used by Gray (2015), London Economics (2015) and other studies. The study estimates the value of weather forecasts to reducing road accidents caused by adverse weather conditions in Finland. They estimate that on average, 10% of accidents are due to adverse weather conditions. Using unit-costs of material damage of accidents with and without casualties, the accident costs amounted to €226 million per annum. Then, using a value chain analysis, the study found that the weather information had a value of 14% at the final stage, and weather forecasts had a value of €37 million per annum (NZD 64.8 million per year in 2017 prices).

To map this to New Zealand data, we requested a customised data set from MoT showing the number of accidents annually (2000 to 2017) broken down by different adverse weather conditions (heavy rain, light rain, mist and snow) and whether the accident had fatalities, serious injuries and minor injuries. Attached to the number of accidents are the 'social cost of road crashes'. Social cost measures the total cost of road crashes to the nation, including loss of life and life quality, loss of productivity, medical, legal, court and vehicle damage costs. A breakdown of the total cost of injury crashes by cost component is given in Figure 4 below.

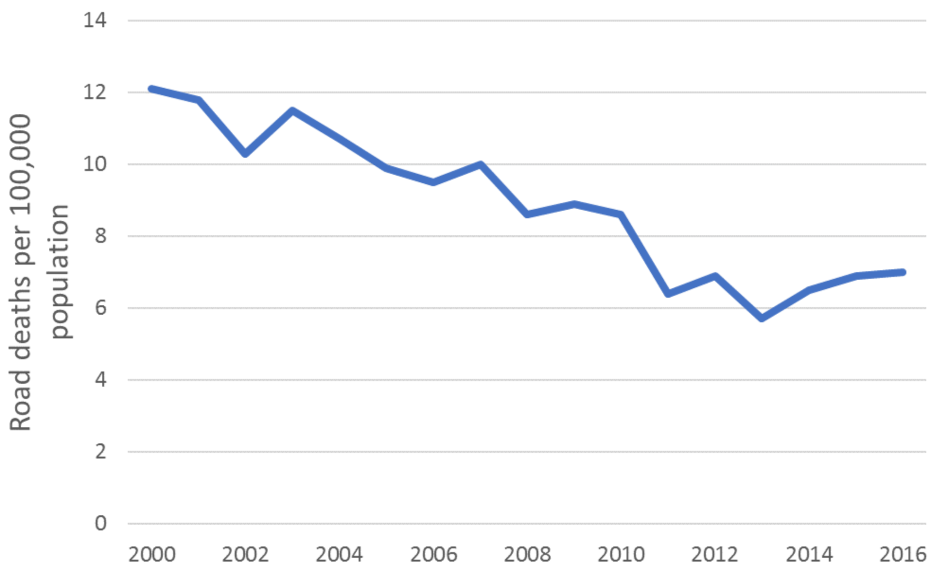
Figure 4 Total cost of injury crashes by cost component



Source: NZIER, MoT

To estimate the total cost *per annum* of accidents due to adverse weather conditions, we first summed the social cost for all adverse weather conditions for each injury type (fatal, serious, minor) annually. Then we took an average of the total social cost for each injury type over the period 2013 to 2017. An average over the full 20-year period was not considered to firstly, avoid any impacts of newly introduced technology in vehicles and secondly, to keep up with contemporaneous trends. An example of such a trend is road deaths in New Zealand over the past 20 years as shown in Figure 5.

Figure 5 Road deaths in New Zealand per 100,000 population



Source: NZIER, MoT

Figure 5 above clearly shows a downwards trend in the number of road deaths until a levelling off in 2013. This means by averaging costs over a longer period we would be overestimating the total social costs from accidents in adverse weather conditions.

We apply the following formula to determine benefits:

> *Benefit = information value at final stage of Value Chain × (social cost of accidents + benefit)*

The bracketed term in the above formula represents the social cost of accidents if National Meteorological Services *did not exist,* including the contract between NZTA and MetService for tailored weather forecasts directed at road safety. The social cost of accidents we determined from the MoT data is using real time data in a state where National Met. Service *does* exist. The total social cost of accidents *per annum* from MoT data in New Zealand is NZ $680 million (2017 prices). Using the 14% value of information at the final stage of the value chain analysis in the Finnish study, we find the value of weather forecasts to the road transport sector in New Zealand to be **NZ $111 million *per annum***.

3.5. Benefit to cost ratios

MetService's operational cost of providing weather forecasting services to the country is NZ $51 million[12] of which NZ $23.4 million is attributable to services provided in the public domain.

The total quantified benefits in this study range between NZ $235 million and NZ $1.13 billion. This means the BCR for weather forecasting services in the public domain is **between 10.0:1 and 48.1:1**.

3.6. Unquantified benefits

There are several sectors, which are important in New Zealand that are difficult to quantify, or for which existing research and data was not available. These are:

- search and rescue
- general aviation
- biosecurity
- traffic management.[13]

In line with comparable studies, this study focuses on the benefits to land-based groups of users. The Crown contract services related to both maritime and search and rescue cover large ocean areas, which could potentially have quite a high economic impact if they could be reasonably estimated. For example, services provided to the maritime community constitute a significant portion of the contract deliverables. This includes both commercial shipping and recreational boating. The study does not directly address the benefits of the weather forecast and warning services provided to maritime users under the Crown contract, although some of the value may be indirectly captured by the public's willingness to pay (discussed in section 3.1 above). New Zealanders' extensive involvement in recreational boating, means they have more exposure to weather risk than other comparable jurisdictions and arguably may have more exposure at sea than on land. Estimates suggest that 1.4 million New Zealanders are involved in recreational boating and 52% of those surveyed suggested they checked the weather forecast every time before going out on the water. [14]

In our analysis, we have quantified direct tangible (e.g. insurance claims) and intangible costs (e.g. loss of life). There are indirect tangible and intangible costs which are difficult to quantify (Balbi et al. 2013). These are given in Table 8.

Table 8 Unquantified indirect costs

Tangible	Intangible
Cost of traffic / transport disruption	Trauma
Temporary housing of evacuees	Mental illness

12 MetService Annual Report 2017.

13 NZIER opinion.

14 https://www.maritimenz.govt.nz/recreational/safety-campaigns/documents/Recreational-boating-participation-research-2017.pdf

Loss of tax revenue due to migration of companies in the aftermath of a natural disaster	Bereavement
Disruption of public services outside area affected by natural disaster	Loss of trust in authorities
Induced production losses to companies in the area affected by natural disaster (suppliers of affected companies)	Loss of jobs (societal disruption)

Source: NZIER, Balbi et al. 2013

Additionally, we have also only considered adverse impacts due to natural disasters. However, some adverse impacts may be able to be offset. For example, a flood might devastate a community. But, nearby communities may realise economic benefits due to the flood, since it may trigger business opportunities that cannot be exploited by the flood-affected companies.

3.7. Summary of benefit transfer analysis

Overall using the benefit transfer approach, we found the benefits from the public weather forecasts and warnings provided under the Crown contract significantly outweighed the costs. We estimate that the BCR for public weather forecasts and warnings is between 10.0:1 and 48.1:1. These findings for New Zealand are consistent with the studies for a range of overseas jurisdictions shown Table 2 (see Section 2.1).

The likely benefits are an order of magnitude greater than the costs. The estimated benefits of any of the main users – the public, agriculture, road transport and disaster management could be used to justify the continuation of New Zealand's National Meteorological Service. While the costs are fully captured, the benefits are understated as a number of sectors such as search and rescue that were not included due to data availability problems.

The key caveat to this analysis is the counterfactual problem. In the analysis reported in this section we have followed the convention in the literature which is based on the stringent conservative assumption. That assumption is that in the absence of the national meteorological service, no weather forecasts or warning would be available. This somewhat unrealistic assumption generates estimates of gross value added with the high BCRs discussed above.

If there was no contract between the Ministry of Transport and MetService, all New Zealand users of weather information would have to arrange alternative supplies of meteorological information and supporting advice. New Zealand has international obligations to ensure that certain meteorological functions are undertaken to support aviation and maritime services, although not necessarily by MetService. The next section discusses how we experimented with the use of multi-criteria analysis to try and unpack the unique value added from having a national meteorological service.

4. Multi-criteria analysis

We used multi-criteria analysis to explore how to unpack the unique value added from public weather forecasts and warnings (the secondary research question discussed above). Using this approach was necessarily experimental as it is not something that has been undertaken in the studies we have surveyed. Overall the results from this approach were less intriguing that we had expected. Nonetheless this section sets out how we approached the task and what we found.

The criteria we used was drawn from the literature on the factors affecting the value of climate services (see Clements, Ray, and Anderson 2013 p. 21). Our 'starter for ten' list included both technical supply and user demand criteria as shown in Table 9.

Table 9 Multi-criteria analysis draft criteria

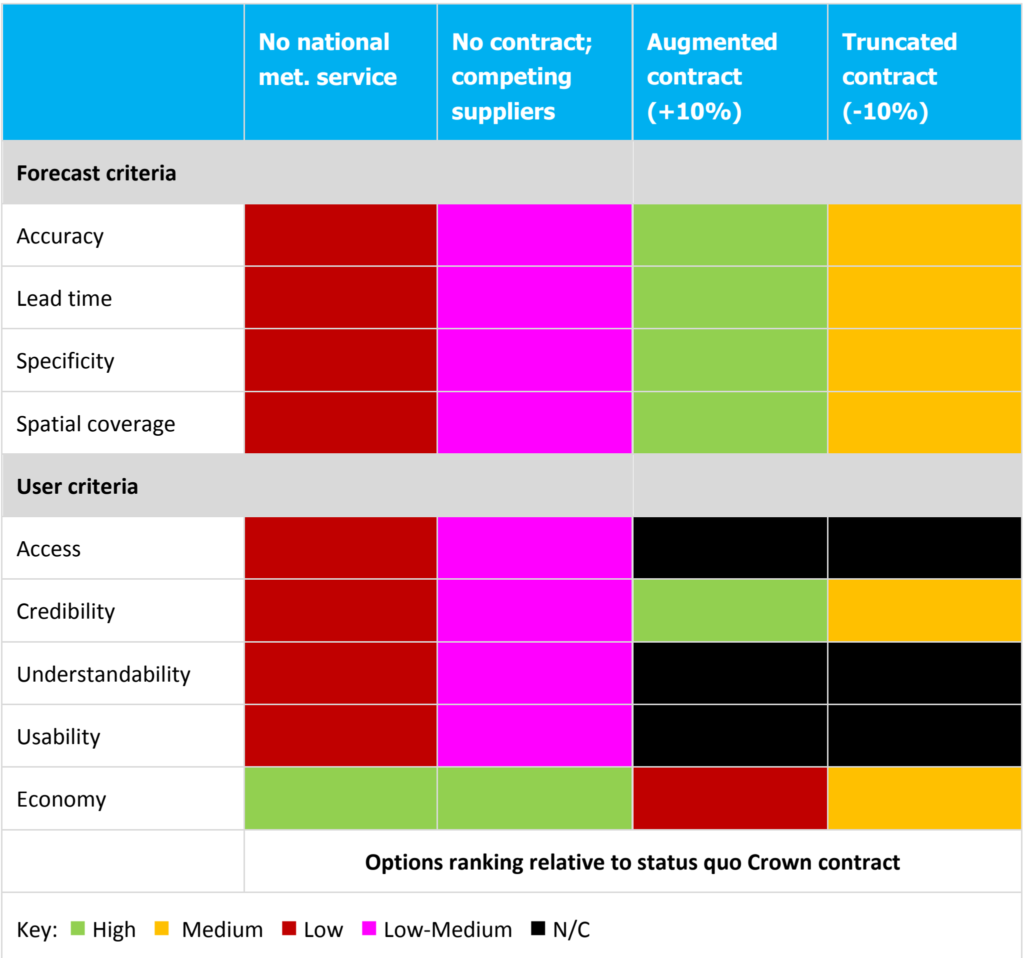
Category	Criteria
Technical forecast criteria (supply)	• Accuracy • Lead time • Specificity • Spatial coverage
User criteria (demand)	• Access • Credibility • Understandability • Usability/tailored to different decision-maker • Economy/least cost

Source: NZIER

We undertook an analysis of a number of the services delivered under the current contract against the criteria in Table 9, focusing on the impact on the observing system (VA1 in Figure 1 above) and non-commercial weather services (VA4 in Figure 1 above). We found little variation in the relative rankings across the service lines (marine, public and regional weather services, general aviation, WMO representation etc.) so the analysis is not repeated here. Similarly, we found relatively limited variation in the relative rankings at different points in the value chain. As the components of the value chain are interrelated, with a variation in one resulting in variations in the others, the rankings were prepared at a system level.

Our approach produced a heatmap that compares the current arrangements with a 'no national Meteorological service' option and with a more realistic 'alternative suppliers' option. We also explored some 'adjusted capability' options to test the generalisability of the rankings from the multi-criteria analysis. Figure 6 provides a summary heat map.

Figure 6 Summary heat map



Source: NZIER

The ‘no national met. service’ option was dominated by all the other options on all dimensions with the exception of economy. (One option dominates another if it is better in some dimensions and worse in none.) This ranking is unsurprising given the high benefit to cost ratio for public weather forecasts and warnings discussed in the previous section. The high ranking for the ‘no national met. service’ option on economy was because of the direct fiscal savings in the absence of the Crown contract. Economy (least fiscal cost) says nothing directly about efficiency and effectiveness however of reducing the availability of an authoritative source of weather information and warnings.

The Crown contract with MetService has some significant efficiency and effectiveness advantages. This is because the provision of meteorological services involves a critical mass of a bundle of overhead and fixed costs which must be met to provide the infrastructure and capability to support the meteorological system. The weather value chain (Figure 1 above) shows the value added from the observing system (VA1), the modelling system (VA2a) the forecasting system (VA2b) and the communication system (VA3).

New Zealand is a Member State of the World Meteorological Organization and, as such, is subject the WMO Technical Regulations. The Crown contract provides the funding for MetService to provide New Zealand's National Meteorological Service – that is, to comply with the WMO Technical Regulations; indeed, Schedule 2 of the Contract defines explicitly how each activity funded under the Contract meets the Technical Regulations. Being a Member State of the WMO means New Zealand has ready access to a rich body of weather expertise and curated information. In effect, the Crown Contract ensures New Zealand membership to a selective club which enables access to a rich body of resources whose cost far exceeds New Zealand's contribution to that club.

The 'no contract, competing suppliers' option provides a low intermediate case as it dominates the 'no met. service' option but is inferior to the two Crown contract options on all dimensions except economy. Under this option the technical quality of public forecasts and warnings suffers without the underpinning of the observing, modelling, forecasting and information systems. The 'no contract, competing suppliers' option implies that New Zealand is no longer a Member State of the World Meteorological Organization with a corresponding loss of access to resources available through WMO. On the users' side, this option suffers from no single authoritative source of official weather information and warnings which undermines the credibility, usability and understandability of the information. The erosion of the single authoritative source of official weather information and warnings is recognised by WMO as a major issue facing Member States (and, hence, National Weather Services).

The truncated contract option provides a medium case. This option explored the accumulated effect of the erosion in the real value of the Crown contract due to inflation and the associated erosion in service quality. It is an intermediate case that reflects the risk of 'the death of a thousand cuts'. The technical quality of the public forecast and warnings are higher than in no Crown contract case but below those available with an augmented capability option. On the demand side, the single official voice improves the credibility of the forecast but has no material impact on access or usability of the forecasts.

The augmented contract option explored the value of adding additional capability along the value chain. Augmenting capability unsurprisingly improved the technical quality of the public forecast information and this in turn improved the credibility of the forecasts with users. However augmented capability did not materially alter the relative ranking of the usability, access to or understandability of the forecasts.

Overall the results shown in the heatmap in Figure 5 show a reasonably predictable pattern. Leaving aside economy, the augmented contract dominates the truncated contract (in the sense that it is better on some dimensions and no worse in the others) which in turns dominates the competing suppliers and no contract options. Economy is a notable exception but addressing the relative value for money of the different options is beyond the scope of this study based as it is on secondary research.

5. Loss mitigation

We also explored what insights emerged from the project about the opportunities to mitigate economic losses or disruption of economic activity through the use of forecasts and warnings of severe weather events. While it was not the main focus, the terms of reference identified two subsidiary questions:

- where are the avoided costs/ losses mitigated most concentrated? and
- where are the opportunities for potential gains from additional avoided costs/ loss mitigation?

Addressing these questions directly proved difficult as disaggregated data on insured losses in New Zealand was not available and our study used secondary research techniques. While we know about the gross value of weather information in New Zealand for the four areas we looked at (agriculture, disaster management, road transport, and the general public) that doesn't tell us anything necessarily about value relative to other sectors we did not explore (marine and general aviation, search and rescue, energy, construction, mining, defence etc.).

There are also conceptual difficulties with unpacking the value of weather information. This is because information contained in weather forecast or any other natural hazard warning has no inherent value in an economic sense. Information acquires value by the way that it influences the behaviour of individuals or actors within organisations. Information is only valuable if it is usable, used and useful.

Weather information can vary in value from negligible to close to infinity. Understanding the economic value of weather forecasts and warnings is not straightforward. It will depend both upon the technical qualities of the information (accuracy, granularity etc.) and the extent to which forecast sensitive users are influenced by the information. Use of information will depend on access, credibility, understandability, and usability. These values will necessarily be specific to sectors and points of time. Therefore, more information is not necessarily as valuable as currently supplied information. Future research needs to understand more about how forecast sensitive users are influenced and what technical qualities are important.

Nonetheless while this was not our primary focus in this study, we did gain some insights through the literature scan about the value of weather information in overseas jurisdictions that are likely to also apply to New Zealand. Turning to the question of where are avoided costs/ losses mitigated most concentrated, the literature highlighted how a range of studies tended to focus on a similar list of weather sensitive sectors. This list typically included Agriculture, Construction, Utilities (electricity, gas and water supply), Tourism, Land Transport and Mining and Quarrying as sectors which are very weather-dependent. Table 5 (Section 2.2) highlighted how the bulk of the benefits from weather from information generally came from three main sources (agriculture, transport and the general public) although the size of the shares varied significantly across countries and studies.

Our overwhelming impression gained from what we have read and the New Zealanders we have talked to is how deeply embedded weather forecast and warning information is in the decision-making across the range of weather sensitive sectors. Weather information generates value by changing people's information structures. The value generated depends upon how decision-makers react to the different way they now see the world as a result of receiving the weather information. From our discussions with Beef and Lamb NZ, it was clear, for example, that the ready availability of rain radar images influences a range of agricultural management decisions shown in Table 7.

Another key insight has been the widespread use of weather warnings (in addition to weather forecasts per se). Warnings were important in each of the sectors we examined in more detail – agriculture (potential stock losses), transport (road closures), general public (recreational decisions) and disaster management. The value of warning depends upon the type of event.

Our analysis of New Zealand weather and hydrological events data, suggests that while total insured loss from what NZIC classified as storms is the highest overall, cyclones have the highest average insured losses (NZ $27.5 million per event). However, since 1987, floods have occurred with the highest frequency (66 times), followed by storms (31 times). The data on New Zealand weather events (shown in Table 10) did not allow the unpacking of the contribution from the weather warnings in mitigating costs and avoiding losses.

Table 10 Weather event analysis

1987-2017

Event	Total loss ($m)	Number of events	Average loss per event ($m)
Storm	746	31	24.1
Flood	647.4	66	9.8
Cyclone	192.7	7	27.5
Hailstorm	59.5	7	8.5
Severe Weather	53.2	3	17.7
Other [15]	110.2	22	5.0

Source: NZIER, Insurance Council NZ

One line of inquiry for future research could be to review the relationship between the severity of a weather event and the resulting economic losses. For some type of weather-related events (such as floods) it seems likely that the economic loss function is convex over certain ranges (such as when the water level tops the height of the stop bank) so that the economic loss increases at an increasing rate as the severity of the weather event increases. This points to the value of having weather warnings for public safety focus on the most serious weather events.

The second question – the opportunities for potential gains from additional avoided costs/ loss mitigation – is not possible to answer empirically for New Zealand for the reasons set out above.

But it may be possible on theoretical grounds to predict where further unexploited opportunities may exist. This is because public weather information is a ‘club good’ i.e. a ‘public good’ with two key characteristics it is non-rival but excludable. Non-rival goods may be consumed by one consumer without preventing simultaneous

[15] Other events include tornadoes, snowstorms, windstorms, wind and hail, high winds, thunderstorms, frost and snow.

consumption by others (while private goods are rivalrous). Excludability refers to the ability to exclude other consumers. Because it is potentially feasible to exclude people from weather information, this creates incentives for MetService to help potential users band together to capture the benefits from weather forecasts and warnings. In some case users enter into commercial arrangements with MetService for forecasts tailored to their needs. A dairy co-operative purchasing weather information for its members would be an example of a kind of club in operation. In other sub-sectors such as sheep and beef farmers, the lack of a dominant buyer may mean that the costs of contracting preclude forming a 'club'.

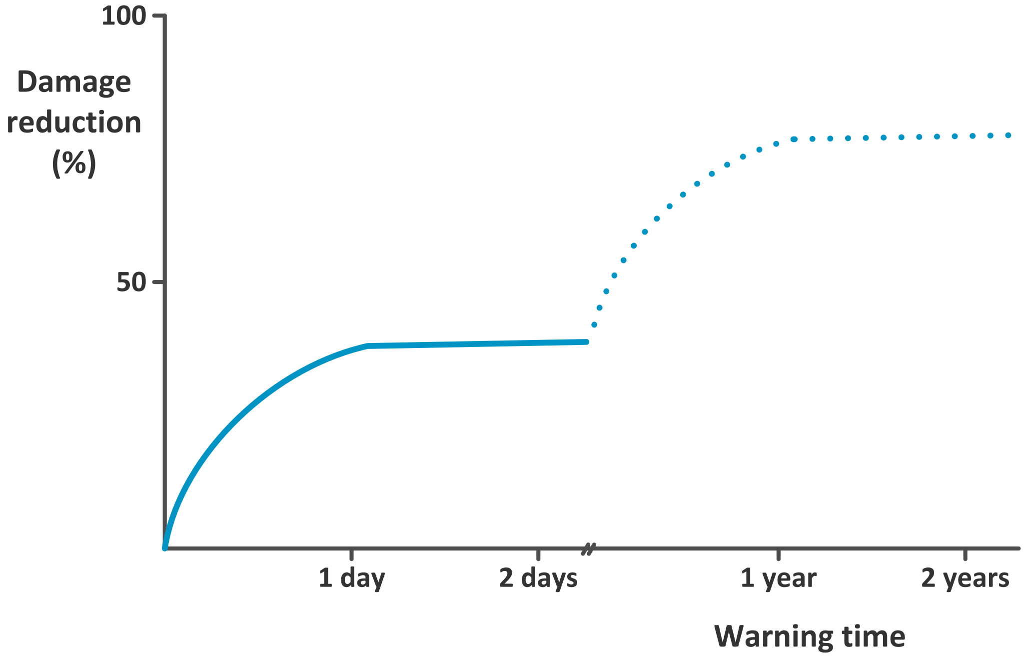
Another means of identifying opportunities for additional avoided costs/ loss mitigation is to explore the value of different characteristics of weather of information.

One theme that emerged from the literature and the exploration of the different benefit streams in this study was the importance of lead time. With enough lead time, public authorities can evacuate or arrange shelter for large numbers of people, farmers to move livestock to safe ground and safeguard their crops, road users to prepare and plan their journey, etc.

The basic relationship between lead time and losses averted is shown in the Figure 6 below. The left-hand side (the Day curve) shows increasing lead time leads to increased loss mitigation but at a diminishing rate over a 1-2 day period. The intuition behind this is that with adequate time businesses can relocate inventory and mobile capital assets (such as vehicles).

The next increment in mitigation comes with a much longer time lag, 1-2 years once buildings are redesigned to make them more resilient to weather events. The right-hand side shows NZIER's extrapolated Day curve. Given enough lead time, capital can be reorganised (e.g. to shelter critical assets and protect human life) and capabilities developed (such as public warning systems) which could significantly reduce the damage exposure.

Figure 7 The enhanced Day curve



Source: NZIER based on Day (1970) cited by Hallegate (2012 p.3)

A key limitation to using the technical forecast criteria and user criteria (access, credibility, understandability and usability) is that the criteria may interact. Technical and user criteria operate simultaneously in a 'scissor-like' fashion. Opportunities for damage mitigation are increased when users are easily able to access the forecast information, have trust in it, can understand it and suitably use it to enforce mitigatory actions. Improving the user criteria directly links with improvements in forecast criteria. For example, credibility of the forecasts can be improved with increased accuracy.

Another approach again to the exploring the opportunities for weather information to add more value is to consider the different uses of weather information over the life cycle of an event. The official New Zealand approach to hazard and risk management is the 'Four Rs', involving two ex-ante phases, one ex-post phase and one during the event:

- Reduction – identifying and analysing long-term risks to human life and property from hazards, and taking steps to eliminate these risks if practicable or, if not, to reduce their likelihood and the magnitude of their consequences
- Readiness – developing operational systems and capabilities before an emergency happens, including self-help and response programmes for the public as well as specific programmes for emergency services, lifeline utilities (infrastructure providers) and other agencies
- Response – taking action immediately before, during or directly after an emergency to save lives and property, and to help communities recover

- Recovery – using coordinated efforts and processes to bring about the immediate, medium-term, and long-term regeneration of a community following an emergency.

The value of weather information will vary over the cycle. The short run Day curve speaks to the response phase, the longer run Day curve speaks more to readiness and the speed of the recovery.

6. Directions for further research

This study used the benefit transfer approach (without undertaking any primary research) to reviewing the value of public weather forecasts and warnings as a whole. Consistent with overseas studies, it has found large positive benefit-to-cost ratios. It would be possible to refine these estimates by undertaking primary research. For example, we identified a valuable unexploited data source on cropping in New Zealand that could be used to quantify the of value of weather forecasts to the cropping sector. While the precise magnitude of the benefits from this additional study are not knowable in advance, the sign is entirely predictable. Refined estimates would merely generate an even higher benefit to cost ratio for public weather forecasts.

Existing research on the value of weather information has struggled to adequately address the problem of realistic counterfactuals. The discussion in Section 4 illustrated that there are a number of potential counterfactuals and which is appropriate depended on what assumptions were made about what was different about the world. Choosing between them was a job that should entail quite a bit of discussion and analysis.

The high benefit cost ratio overall does not necessarily suggest anything about the value of additional weather information at the margin relative to the extra cost. One way of avoiding this problem in any future research would be to take a "shock" approach rather than a "ground zero" approach. In other words, take where we are and look at the potential effect of new weather information. An interesting opportunity for further research could involve quantifying users' willingness to pay in each benefit stream for marginal improvements in both user and forecast criteria. This can help determine the increase in benefits to the different sectors from marginal improvements in those criteria. For example, the 'avoided cost' in agriculture of a marginal increase in forecast accuracy. That would encompass farmers ability to take up information (and MetService's ability to communicate the forecast information), understand it and apply it towards mitigatory actions.

In the course of this project we came across more recent studies of decision-making that moved away from the simple weather forecast/ no weather forecast approach. One study (Fox et al. 2013) compared the economic value of weather forecasting for Alfalfa production. The study compared the value of production with the available weather forecast to the value with three other cases: an improved forecast, a perfect forecast as well as naïve forecast (today's weather will be like yesterday). This suggests that additional primary research could be used to explore the potential for additional value added from public weather forecasts. This information could be used to inform decisions about how to optimise the operation of public weather forecasting and warnings in New Zealand.

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Appendix A Literature scan method

A.1 Economic value of a national weather service

In-depth literature searches were conducted over July – September 2017.

Primary focus: The economy-wide value of a national meteorological service, specifically presented as a BCR, for specific jurisdictions, summarised in Tables 2 and 3.

Then: Based on studies found above, identify studies that can be used to determine the proportion of benefits per sector, to be summarised in a table.

Resources searched

Databases and other resources searched were Econlit, RePEc, journals of the American Meteorological Society and of the Royal Meteorological Society, Advances in Science and Research open-access proceedings of the European Meteorological Society, CORDIS (for EU-funded research), and extensive internet searches were performed on the general topic and targeted at specific agencies.

Keywords included meteorological, hydrometeorological, weather, economic, socioeconomic, cost benefit etc.

National meteorological agencies

WMO's list was used to identify agency names for the jurisdictions of interest from amongst OECD countries – we selected Australia, Canada, United Kingdom, United States, Denmark, Finland, Netherlands, Norway, Sweden, Switzerland and Chile; checked the agency web sites, and searched online for studies (value to the economy, economic impact, cost benefit studies etc.).

Citations

Checked subsequent citations via Google Scholar of key items (e.g. (World Meteorological Organization 2015), (Perrels et al. 2013) (Leviakangas 2009)), and looked for other work by key authors.

Inclusions and exclusions

In the literature, the focus varies – the value of a service, the value of the information provided by that service (i.e. forecasts in general), the value of an improved service or improved information to an economy or sector, and the value of warnings (avoided costs). Another aspect (looked at separately) is the cost of weather events to a local or national economy, or to sectors within that economy. As noted, the focus here was on finding material covering the economy-wide value of a national meteorological service.

When looking at the value of a service – meteorological services overlaps with hydrological and climatological services because these services are often provided by the same agency.

The value of forecasts overlaps with literature on the value of information generally, and also literature on the open data movement.

The value of weather warnings (aka hazardous weather forecasts) overlaps with literature on mitigation of natural disasters / disaster risk reduction (to the extent that these items are about information/warnings as opposed to physical infrastructure).

The costs of weather events (extreme weather, high impact weather events) overlaps with the literature on the cost of natural disasters generally (sometime this is provided as insurance costs, financial costs, or economic costs).

In scanning the literature kept an open mind regarding these overlaps, checking items if they looked like they might provide leads to relevant material.

Specific exclusions: developing countries (with the exceptions noted in Table 3), quality of weather forecasting, public and others' response to forecasts, costs of weather events, climate services (on its own).

Relevant literature identified: is discussed in Section 2.

Studies providing an indication of the value of a meteorological service to an economy are summarised in Table 2 and Table 3.

Studies used to provide a sector comparison are summarised in Table 5.

A.2 Costs of weather events for New Zealand

A rapid scan was conducted to locate any studies (authoritative, formal reports or other analysis) providing a high-level overview of the costs of severe weather events to New Zealand, along the lines of two useful but dated studies looking at economic and other impacts of weather extremes for the United States (Kunkel, Pielke, and Changnon 1999) (Changnon 2003).

The focus was on the cost of weather events as (opposed to the value of weather information).

Coverage: in-house research support collection database, previous NZIER work, economics databases (RePec, Econlit), New Zealand databases (Index New Zealand, Te Puna, nzresearch.org.nz), and searching across government and consultancy etc. websites.

Keywords included extreme weather, weather extremes, weather bomb, weather event, storm/s, flood/s, flooding, cyclone/s, cost to the economy, economic, costs.

Exclusions:

- climate change material – this was filtered out, unless it addressed specific weather events
- drought
- news items
- local authority records e.g. applications submitted to councils for funding to repair roads etc.

Relevant literature identified: is summarised in Section 2.4.

Appendix B Method selection

A key constraint on the research design is that the scope is limited to secondary research. As a result, almost all the methods surveyed are out of scope as they are based on primary research.

The main technique which lends itself to secondary research is benefit transfer. In brief benefit transfer involves applying cost benefit analyses of overseas meteorology services' information to New Zealand. In this case we used results from the London Economics study of the Australian Bureau of Meteorology (2016), but adjusted these estimates to New Zealand conditions. The London Economic study was augmented by other papers such as the Copenhagen Consensus perspective paper on natural disasters and the Royal Meteorological Society study of weather forecasting in Finland. The main adjustments involved using:

- New Zealand GDP weights
- New Zealand weather event data (NZIC augmented by NIWA) for frequency of weather events
- the weather event studies that are available.

B.1 Sectors of most interest

The main area of focus was on the most material and weather sensitive sectors. The most important sectors are:

- general public
- agriculture
- disaster management
- road transport.

London Economics were unable to quantify the following:

- search and rescue
- energy
- construction
- mining
- defence
- international.

Using a benefit transfer approach enabled us to address the primary research question – the gross value of the information in public weather forecast and warnings.

We followed the standard approach in the literature and created a base case with 'No National Meteorological Service' to generate a with/without MetService contract estimate of the gross value added of the Crown contract in a hypothetical year (2017 + x). The results are discussed in Section 3.

B.2 The counterfactual

We augmented the base case with an additional counterfactual based on '*no Crown contract but with competing providers*'. The intuition behind this is that without the

MetService contract, individual users arrange alternative supplies of meteorological information and supporting advice. Demand for weather information will necessarily call forth supply. New Zealand would be in breach of WMO Technical Regulations and not meet other international obligations such as ICAO. The rationale for the competing suppliers' counterfactual is set out in more detail in Appendix C.

The approach would involve comparing the current MetService contract to two counterfactuals: no contract/public MetService and no contract/competing providers and compared these cases with an augmented contract (current revenue +10%) and a truncated contract (current revenue -10%). The augmented contract option explored the value of adding additional capability along the value chain. The truncated contract option explored the accumulated effect of the erosion in the real value of the Crown contract due to inflation and the associated erosion in service reliability.

Appendix C The counterfactual[16]

Section 2 discussed how all the cost benefit studies we have reviewed make the stringent conservative assumption that in the absence of the public weather service, no weather forecasts or warnings would be available. This somewhat unrealistic assumption generates estimates of gross value added with the high BCRs discussed in Section 2. In reality, New Zealand has international obligations as a member of a range of international bodies such as the World Meteorological Organization (WMO), and ICAO which mean that this 'ground zero' option is not feasible.

If there was no contract between the Ministry of Transport and MetService (or another provider), most of the functions listed below would still have to be undertaken – not necessarily all in New Zealand, not necessarily by MetService, and not necessarily all by one agency – to meet New Zealand obligations and to serve New Zealand customers.

C.1 Legal and contractual background

New Zealand's obligations under the World Meteorological Organization (WMO) Technical Regulations are broadly described in the Meteorological Services Act 1990. These obligations are fulfilled via a contract between the Ministry of Transport and MetService. Schedule 2 of this Contract describes the (minimum) set of weather services required for the safety of life and property on land and sea.

New Zealand has entered other international arrangements which, to be fulfilled, require MetService to collaborate with other agencies. An example is the Safety of Life at Sea (SOLAS) Convention, which requires ships subject to it to carry Global Maritime Distress and Safety System (GMDSS) equipment, e.g., satellite and high frequency (HF) transmitters/receivers. An important component of the GMDSS is forecasts and warnings of the weather on the high seas, which are broadcast by the maritime (HF) radio service for New Zealand, operated by Maritime New Zealand.

Not all international arrangements entered into by New Zealand, and requiring some contribution by MetService, are provided for under the contract between the Ministry of Transport and MetService. For example, as a Contracting State to ICAO New Zealand is required to meet the requirements for meteorological observing, forecasting, and so on. These requirements are fulfilled via a contract – essentially, a collaboration – between the Civil Aviation Authority (CAA) and MetService.

The core functions carried out by MetService under the Crown contract ensure compliance with the WMO Technical Regulations and support the functions required by other New Zealand obligations (e.g., to the CAA) and to generate other revenue. These core functions are:

- gathering of meteorological observations
- maintenance of a weather watch
- communication and exchange of meteorological information

[16] This Appendix draws very heavily on a note that Peter Kreft produced for the project.

- production of forecasts and warnings
- ensuring that meteorological staff are appropriately qualified, trained, certified and experienced
- international representation of New Zealand's interests.

C.2 The counterfactual

If there was no contract between the Ministry of Transport and MetService, users would seek out weather information because it is valuable to them. Collaborating agencies, other major users of weather information, and the public, would use publicly and/or privately available weather information (observations, weather model data, forecasts produced by human forecasters) and supporting advice to make decisions about the safety of life and property, continuity of service, etc.

If there was no contract between the Ministry of Transport and MetService, New Zealand would not observe the WMO Technical Regulations with regard to:

- gathering of meteorological observations:
  - there would be no national source of surface weather (land or sea) observations gathered by methods that meet the WMO Technical Regulations (e.g., calibration)
  - there would be no New Zealand weather radar or upper air observations
  - there would be no curated source of New Zealand-centric satellite data
- communication and exchange of meteorological information:
  - there would be no relay of nationally gathered/produced observations, forecasts, analyses and other messages to and from Australia and the Pacific Island National Meteorological Centres (NMCs) and other specified Pacific States
- forecasting of any type of (severe) weather: there would be no authoritative source ("Single Official Voice") of information about severe weather:
  - on the New Zealand landmass
  - in New Zealand's coastal waters
  - on the high seas in METAREA XIV, including information about tropical cyclones,
  - available to vulnerable countries in the Southwest Pacific,
- training of meteorological staff:
  - weather forecasters would not have undertaken a prescribed post-graduate course of study and would not have been certified
- representation of New Zealand with WMO:
  - New Zealand's interests would not be represented.

C.3 Consequences of no Crown contract

Currently, most but not all major New Zealand users of weather information obtain that information from MetService. These include Civil Aviation Authority, Airways

Corporation, New Zealand Transport Agency, New Zealand Defence Force, Department of Conservation, major airlines, energy companies and media companies. If there was no contract between the Ministry of Transport and MetService, all New Zealand users of weather information would have to arrange alternative supplies of meteorological information and supporting advice. The project explored the consequences of the no Crown contract using Multi-criteria analysis. This included addressing some of the consequences are listed below:

- CAA would have to arrange for another provider of meteorological services to aviation to be certified under Civil Aviation Rule Part 174 to meet New Zealand’s obligations to ICAO
- the absence of upper air observations and the lack of a national source of surface observations of a “reference” standard
- collaborating agencies would lose access to meteorological staff who are have the appropriate qualifications, training and experience
- vulnerable countries in the Southwest Pacific currently supported by New Zealand with observational and weather model data, and guidance on likely severe weather, would have to arrange alternative supplies of such information
- there would be no single authoritative source of weather warnings and advice, so different decision makers could receive inconsistent advice in response to the same weather-related hazard.