Floods and Flood Warning in New Zealand

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ABSTRACT: New Zealand suffers from regular floods, these being the most common source of insurance claims for damage from natural hazard events in the country. This paper describes the origin and distribution of the largest floods in New Zealand, and describes the systems used to monitor and predict floods.

In New Zealand, broad-scale heavy rainfall (and flooding), is the result of warm moist air flowing out from the tropics into the mid-latitudes. There is no monsoon in New Zealand. The terrain has a substantial influence on the distribution of rainfall, with the largest annual totals occurring near the South Island's Southern Alps, the highest mountains in the country. The orographic effect here is extreme, with 3km of elevation gained over a 20km distance from the coast. Across New Zealand, short duration high intensity rainfall from thunderstorms also causes flooding in urban areas and small catchments.

Forecasts of severe weather are provided by the New Zealand MetService, a Government owned company. MetService uses global weather models and a number of limited-area weather models to provide warnings and data streams of predicted rainfall to local Councils. Flood monitoring, prediction and warning are carried out by 16 local Councils. All Councils collect their own rainfall and river flow data, and a variety of prediction methods are utilized. These range from experienced staff making intuitive decisions based on previous effects of heavy rain, to hydrological models linked to outputs from MetService weather prediction models. No operational hydrological models are linked to weather radar in New Zealand.

Councils provide warnings to Civil Defence Emergency Management, and also directly to farmers and other occupiers of flood prone areas. Warnings are distributed by email, text message and automated voice systems. A nation-wide hydrological model is also operated by NIWA, a Government-owned research institute. It is linked to a single high resolution weather model which runs on a super computer. The NIWA model does not provide public forecasts.

The rivers with the greatest flood flows are shown, and these are ranked in terms of peak specific discharge. It can be seen that of the largest floods occur on the West Coast of the South Island, and the greatest flows per unit area are also found in this location.

1 INTRODUCTION

This paper describes typical weather and flooding patterns in New Zealand and provides an overview of flood warning procedures. New Zealand is prone to flooding. It is surrounded by ocean, and moisture laden winds cross high mountain ranges reaching 2,400m in the North Island, and 3,700m in the South Island, which generate large quantities of orographic rainfall. Most communities live on active floodplains, hence flooding is New Zealand's most frequent natural hazard (Smart, 2010).

No national flood warning service exists in New Zealand. Flood warning is carried out by 16 separate organizations in New Zealand. Each is a local council representing a defined land area, each area being divided by a major river system. Each Council carries out its flood warning duties independently, with a different budget and using different prediction and notification techniques.

2 WEATHER PATTERNS

The weather of New Zealand is influenced by three main factors: its location in latitudes where the prevailing airflow is westerly; an oceanic environment; and the mountain ranges which modify the weather systems as they pass eastward, causing high rainfalls on the western windward slopes and sheltering effects to the eastern lee side of the mountains.

Weather is determined mostly by a series of anticyclones and troughs of low pressure that produce alternating periods of settled and variable conditions. Westerly air masses are occasionally replaced by southerly airstreams, which bring cold conditions with snow in winter and spring to areas south of 39°S, and northerly tropical maritime air, which brings warm humid weather to the north and east coasts, and occasionally the west coast.

When mountains that obstruct global circulation are compared, it can be seen that the Southern Alps of New Zealand have a particular high ratio of height versus distance from the coast. The Southern Alps ratio of 150m rise per km from the coast compares to 50m rise per km for the Andes of South America, and 30m per km for the Drackenbergs in South Africa (Ibbit, 2005).

Average annual rainfall on land ranges from 400 to over 12,000 mm per year, with the highest rainfall being on the western windward slopes of the Southern Alps, and the lowest on the eastern basins in the lee of the Southern Alps in Central Otago and South Canterbury. Annual rain days are at least 130 for most of North Island, but on South Island the totals are far more variable, with over 200 occurring in Fiordland, 180 on the west coast, and fewer than 80 in Central Otago. Summer droughts are relatively common in Northland, and in eastern regions of both islands

3 STORMS THAT CREATE FLOODS

There are two broad categories of flood creating weather in New Zealand. One type results from prolonged rainfall after humid air masses have travelled south from tropical regions picking up moisture from the sea en-route. When these air masses cool they drop rain, and the cooling mechanism is usually a cold front combined with orographic lift. The rise of air is sometimes enhanced by a low pressure system, and further rising and cooling of air can result from instabilities in the atmosphere.

Because the highest mountains of New Zealand are so close to the coast, the humid air that arrives from the tropics in a north westerly airstream is still ripe with moisture when it reached the main mountain ranges. The orographic rainfall is therefore extreme and it is no surprise that the greatest annual rainfall totals recorded in New Zealand occur in the Southern Alps, with the highest 12 month total being 18,442mm in the Cropp Catchment near Hokitika. These north-westerly and westerly storms can also generate large flood in eastern rivers, as up to 15 m of rain can fall on the eastern (lee) side of the Southern Alps (Kerr, 2011)

Often the warm airflow from the tropics approaches New Zealand from a northerly or north-easterly direction, and in these situations the northern extremities and the eastern parts of both islands receive heavy rainfall. Because the orographic effect is not so large in this case the rainfall is generally less, but floods are no less damaging. When a particularly warm and moist easterly airflow reaches the South Canterbury or Otago areas in the south east of the country, large floods can result in areas which are relatively unused to flooding. It can be seen that wind direction is often a critical element for flood prediction in New Zealand, both to determine in which region flooding will occur, and on which slopes the greatest falls will occur.

The second general type of storm to create flooding in New Zealand results from short duration convectional systems. Thunderstorm cells can drop considerable amounts of rain over periods of up to 2 hours or so, and these events affect small catchments and are particularly dangerous for urban areas. Unlike the longer duration totals discussed above, the short duration rainfall totals seen in New Zealand are not notable by global standards.

Table 1 shows some New Zealand rainfall records, all of these occurring on the West Coast of the South Island. The data were sourced from a NIWA calendar, with the 1 hour total being updated since that time from a subsequent storm.

Table 1. Record high intensity rainfalls in New Zealand (NIWA)

Interval	**Rainfall**
1 Hour	134 mm
24 hours	682 mm
48 hours	1,049 mm
1 month	2,927 mm
12 months	18,442 mm

One useful means of showing the distribution of storm producing rainfall for larger catchments is a map of 24 hour rainfall maximums. A plot showing the median of annual maximum 24 hr rainfall, with location of recording sites (Thomson, 2011) is shown as figure 1.

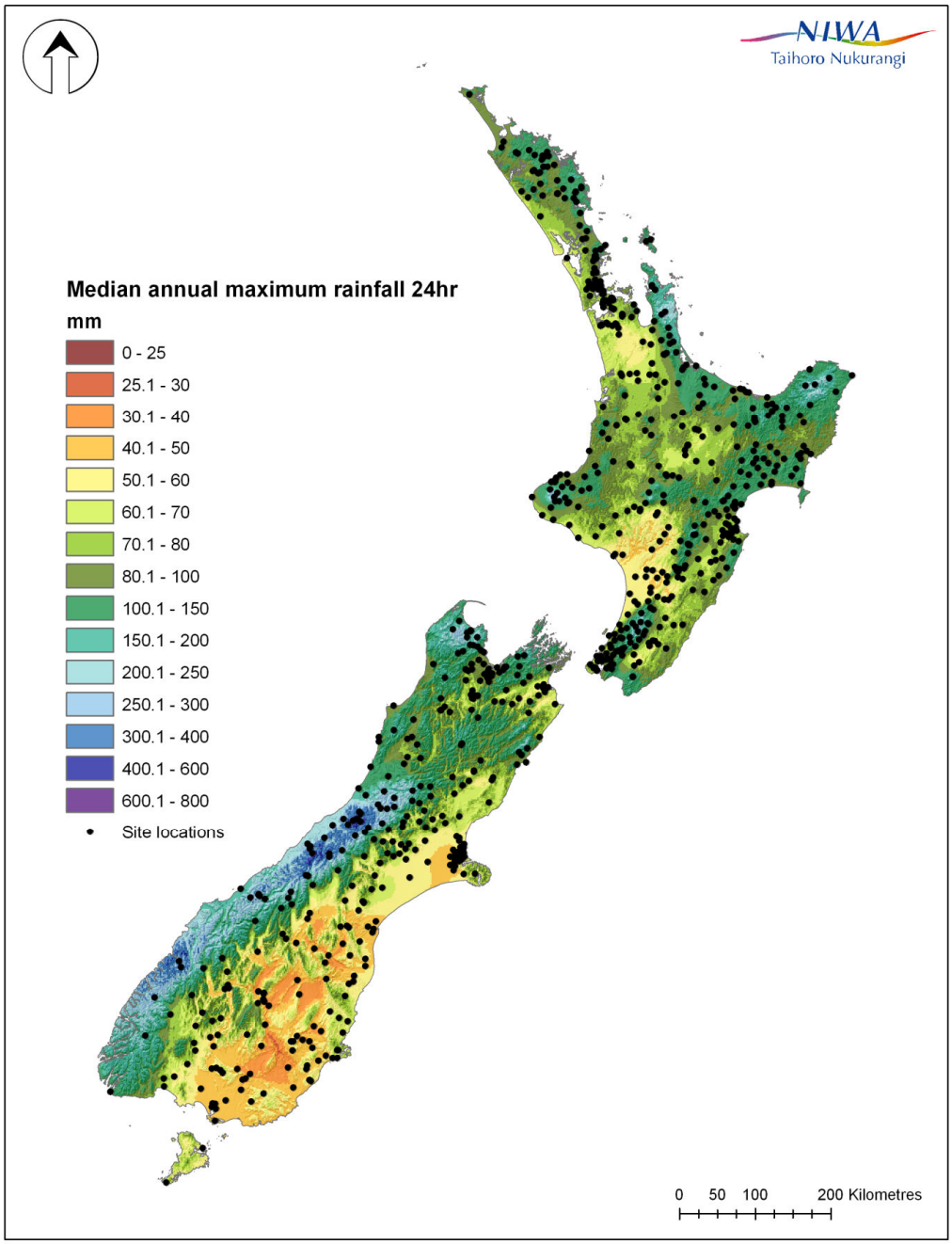

Fig.1. Median annual maximum 24 rainfall for New Zealand

The highest 24 hour values are seen in the areas which have the highest elevation, and are exposed to the prevailing winds. This map closely follows the pattern of annual rainfall totals.

4 ORGANIZATIONS INVOLVED IN FLOOD WARNING IN NEW ZEALAND

There is a cascade of organizations involved in flood warning in New Zealand. Weather forecasting is carried out by the New Zealand MetService (MetService), a company owned by the Central Government. MetService is contracted by the Ministry of Transport to supply a variety of services to the New Zealand public, among them being the provision of severe weather warnings. These warnings are sent free of charge to media outlets and to key organizations involved in Emergency Management. MetService maintains a particularly close relationship with Councils who provide flood warnings.

There are 16 local Councils who have responsibility to provide flood warnings. Staff in each Council liaise with Metservice, manage a network of raingauges, flow recorders and other sensors, make predictions of flooding effects, and provide warnings to Civil Defence Emergency Management staff. They also provide warnings to residents, farmers and other people potentially affected by flooding.

Civil Defence Emergency Management staff are employed by Local Councils, but operate under the policy direction of the Ministry of Civil Defence and Emergency Management, a part of Central Government. If a civil emergency is declared, the Ministry has special powers to control the situation, direct efforts and requisition materials and staff. Police and Fire Service also play a role in responding to emergencies.

5 HYDROMETRIC DATA COLLECTION FOR FLOOD WARNING

During the weather forecasting phase of flood warning, the MetService accesses data from global systems providing model predictions and other data. It also operates its own network of weather stations, and utilizes rainfall information from other sources such as Local Councils and the National Institute of Water and Atmospheric Research Ltd (NIWA), a Government owned research organization.

Councils make predictions of flood flows, and to do this they collectively operate a large network of raingauges and weather stations, and also utilize data provided by Metservice and NIWA. In addition, they operate a wide network of river flow stations, again utilizing flow data from other organizations.

Across NZ around 1,650 raingauges are operated in total, and around 1,300 stations exist to measure open surface water level, many of these also measuring flow (Keane, 2011). The average density of raingauges is 1 per 162 km^2, but most gauges exist in populated areas, so for many locations there is little information about rainfall. Rainfall data collection began in the mid-1800s, and water level recording began in 1905, but only several hundred water level sites existed prior to the International Hydrological Decade beginning in 1964 (Keane, 2011). Raingauges invariably use a tipping bucket mechanism, and water level sensors are usually either float and weight systems in stilling wells, or bubbling gas sensors. Pressure transducers and radar systems also exist but are less common.

Data are transmitted to base by a variety of means, with radio telemetry being a preferred option in rural areas. Where cell coverage exists this is also a popular choice, but satellite data systems are only used occasionally. Data are usually retrieved from sites at intervals of one hour or less, and more often during a flood. Each Council operates its own database of hydrological information from which models are run and predictions made. There are three main types of hydrological database used in New Zealand, and efforts are made to ensure compatibility.

6 PREDICTION OF FLOOD FLOWS

A wide variety of methods are used by the various Councils to predict flood flows in NZ, ranging from intuitive estimates made by experienced staff, to complex models using multiple inputs. In some locations a lengthy time of travel from upstream flow stations allows predictions to be made by simply routing the river flows downstream. Sometimes this is done by simple rule of thumb methods, or otherwise by hydraulic modelling.

In some circumstances flows are forecast by experienced staff making intuitive judgments about the magnitude and timing of flooding based on how much rainfall is falling in upstream catchments. This requires staff with considerable knowledge of local conditions.

A number of Councils utilize rainfall-runoff models which use actual rainfall as inputs. Common models are Kisters Hydro Modeling, the Mike NAM model, and Topnet. More commonly now, rainfall-runoff models use inputs based on both actual rainfall and predicted rainfall. The predicted rainfall is supplied by the MetService as an automatic data feed. One Council is trialing the use of radar imagery which has been corrected using raingauge information to provide the inputs to a rainfall-runoff model, but this is not in operational use yet.

NIWA has developed a “Topnet” rainfall-runoff model which is linked to a high resolution weather model which runs on a super computer. Except for catchments where detailed calibration work has been carried out, for much of New Zealand the Topnet model uses default parameters sourced from data layers such as topography, geology and landuse. The output from the NIWA model is not publically available.

A survey across all of New Zealand Councils was carried out for this paper to see which flood prediction methods are being used. In total, flow forecasts are carried out for 305 rivers. Of these, 130 rivers have predictions times exceeding 6 hours, and 97 rivers have forecast systems that use both actual and predicted rainfall as inputs. A total of 94 rivers have a forecast system that relies on experienced staff make intuitive estimates. The information is summarised in Table 2.

Table 2. Types of flood forecasts carried out in New Zealand

Flood prediction method	No. of rivers warning time < 3 hrs	No. of rivers warning time 3hr - 6hrs	No. of rivers warning time > 6 hrs
Routing from upstream gauges	24	16	32
Predicted from rainfall using staff intuition	61	24	9
Predicted from rainfall by mathematical means (not modeled)	6	5	3
Rainfall-runoff models using actual rainfall only	18	3	7
Rainfall runoff models using actual AND predicted rainfall	9	9	79

7 FLOOD FREQUENCY ANALYSIS

The last nationwide analysis of flood frequency in New Zealand was carried out 22 years ago (McKerchar, 1989), and since that time considerable further high quality flow information has been collected. The McKerchar publication mapped mean annual flood/(catchment area) $^{0.8}$, and also mapped the ratio of the 1% Annual Excedence Probability (AEP) flood to the mean annual flood. A table then provided ratios between the magnitude of the 1% AEP flood and other AEP floods. Recently many regions have been re-analysed, but a single nationwide study of flood frequency is overdue and would be of great benefit.

A map in the 1989 McKerchar report (not reproduced here) which shows the ratio of the 1% AEP flood to mean annual flood is useful to explain flood behaviour. The ratio on the West Coast is around 1.8, and this is a result of the greater number of floods experienced in these areas – a largish flood occurs most years and hence the mean annual flood value is high. In contrast, the ratios in the South East of the South Island climb above 5.0, resulting from floods generally being of a low magnitude, with the occasional very high flood. From the flood warning perspective, it is assumed that residents living on the West Coast are used to frequent flooding and are better able to contend with the consequences of a large flood than are, say, the resident of Otago and South Canterbury.

8 WHERE ARE THE LARGEST FLOODS IN NEW ZEALAND?

The largest floods occur in rivers draining to both sides of the mountain spine of the South Island. It might be expected that only the West Coast rivers would generate the largest flows, but the Rakaia (East Coast) and the Wairau (northern tip of the South Island) are two exceptions. This is partly due to the large catchment area of both, but also because the Wairau is vulnerable to northerly rain, while the Rakaia gets considerable spill-over from the West Coast.

Regional Council and NIWA staff were surveyed to obtain information about the largest floods in each region. The largest flood flow recorded in New Zealand was 8,500 cumecs in the Buller River. Of the 15 rivers with the largest recorded flood flows, all except two are in the South Island, the two exceptions located on the West Coast of the Central North Island. A table of the 15 rivers with the largest flood flows (ranked by size of flood), is shown below as Table 3.

Table 3. Maximum flood flows recorded in New Zealand

River	District	Peak Flow (cumecs)	Catchment Area (km^2)	Specific Discharge ($m^3s^{-1}km^2$)
Buller	West Coast	8,500	6,350	1.34
Haast	West Coast	6,330	1,020	6.21
Grey	West Coast	5,680	3,830	1.48
Rakaia	Canterbury	5,636	2,520	2.24
Wairau	Marlborough	5,000	3,430	1.46
Arawata	West Coast	4,775	971	4.92
Clutha	Otago	4,580	20,582	0.22
Taramakau	West Coast	4,564	863	5.29
Wanganui	Manawatu	4,100	6,643	0.62
Waimakariri	Canterbury	3,990	3,210	1.24
Whataroa	West Coast	3,952	445	8.88
Aorere	Tasman	3,560	573	6.21
Manawatu	Manawatu	3,515	3,900	0.90
Waiau	Southland	3,330	8,134	0.41
Karamea	West Coast	3,170	1,160	2.73

Also of interest are the peak specific discharges recorded for these same rivers. It can be seen that the Whataroa River has generated the greatest specific flow of 8.9 cumecs per km^2. This is similar to the Hokitika River which is not shown in the table, but is mentioned here in the text as it illustrates the flood behaviour of the Southern Alps, both of these rivers draining the area where the highest topography is found. In contrast, some of the flood flows seen from rivers in the South East have very low specific discharges, and the best example of this is the Clutha River, which in full flood produces only 0.22 cumecs per km^2, albeit from a very large catchment by New Zealand standards.

It should be noted that greater specific discharges have been seen in smaller rivers around New Zealand, and the significance of the values quoted here stems from the larger catchment areas which have generated the peak flows.

9 REFERENCES

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