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NOTE

South Island storms and floods of December 2010

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Abstract

An unusually severe and spatially extensive storm over the northern and central South Island of New Zealand on 26-28 December 2010 caused severe flooding. Synoptic charts show that markedly warm moist maritime air from subtropical regions adjacent to northern Queensland moved into New Zealand, where it met a series of frontal systems. Much of the rain occurred in an interval of about 24 hours.

Daily rainfall totals exceeded 25 mm over most of the South Island, although totals were below 25 mm for the east coast from about Timaru north, and, surprisingly, in an apparent rain-shadow between Nelson City and Motueka. Exceptional daily totals, with greater than 1/10 annual exceedance probability (AEP), occurred patchily from the most northern extremity of the South Island to Central Otago, but rainfalls exceeding 1/50 AEP quantiles occurred at only a few gauges, mainly located in the northwest Nelson Ranges.

Flood flows in the Aorere and Anatoki Rivers in northwest Nelson were at, or above 1/100 AEP levels, and record high flows occurred in a number of rivers draining the central portion of the Southern Alps, notably the Hokitika and Rakaia. Earlier rainfall between 21-25 December recharged soil moisture levels over much of the island, with the result that losses to soil infiltration were lower and runoff rates higher than average for the 26-28 December storm. This contributed to the severity of floods experienced in a number of rivers.

A comparison between the December 2010 storm and seven historic storms, as measured in 31 different catchments, shows that this storm caused the most widespread flooding in the past 30 years.

The storm and the earlier events were nationally significant because they filled hydroelectric storage lakes in what was expected to be a summer with unusually low inflows because of the prevailing La Niña conditions.

Keywords

Storm: rainfall: flood frequency: flooding: flood peaks: tropical cyclone

Introduction

Large storms and consequent flooding are natural and frequently occurring events in New Zealand but are rarely reported upon by hydrologists unless there is some feature of enduring interest, usually affecting a single catchment. For example, Riddell (1984) describes the Southland flood of 1984, which had a long return period and caused severe damage in Invercargill; Jowett (1979) studied the 1978 Clutha flood because of implications

for estimation of probable maximum flood and the quantity of sediment deposited in Lake Roxburgh, and Hendrikx (2007) analysed the 2006 Canterbury snowstorm with a focus on comparison with earlier major snowfalls.

Here we report on an unusually vigorous weather system involving a warm, moist air mass from Queensland, Australia and a number of fronts, which developed over New Zealand from 26-28 December 2010 and generated severe flooding across much of the western and northern South Island. Particular points of interest include the origin of the system, the spatial extent of flooding and the number of record high flows recorded in rivers ranging from the Rakaia in the central Southern Alps to the Anatoki in north -west Nelson.

The purpose of this paper is to provide a composite record of the December 2010 event and to rate its severity in comparison with some historic large floods that have occurred in the South Island in the past 30 years. In what follows we describe the meteorological conditions, rainfall, floods, historic context and effects on hydroelectric storages.

Meteorological conditions

The meteorological situation is illustrated by a sequence of six synoptic (mean sea level pressure) analysis charts (Figures 1 to 6) at 12-hour intervals from noon on 26 December 2010 to midnight on 28 December 2010.

The first notable feature of this weather system is the warm, moist air mass which affected the South Island. Ex-Tropical Cyclone Tasha dragged in tropical air as it crossed the northern Queensland coast early on 25 December, and produced heavy rainfall and flooding in Queensland on 26 and 27 December. The moist, subtropical air mass then moved towards New Zealand.

The leading edge of the humid air mass is marked as a warm front (red semi-circles), located over the central Tasman Sea at noon on 26 December (Fig. 1) and approaching the West Coast at midnight 26 December (Fig. 2). This air mass was key to the extreme rainfall rates observed. Due to the La Niña climate pattern, sea surface temperatures at the time between New Caledonia and Queensland, and in the Tasman Sea were much warmer than normal. Air masses sitting over oceans are influenced by the characteristics of that ocean surface; consequently this particular air mass was exceedingly warm and moist.

The second notable feature was the gale- to storm-force northwesterly winds that blew across the Tasman Sea towards the Southern Alps during the 27th, ahead of a rapidly deepening complex low system. The intensifying low, which had developed near Fiordland (central pressure 992 hPa) by late on the 27th and had intensified further on the morning of the 28th, crossed the South Island to lie to the southeast by noon on the 28th (central pressure 984 hPa). The humid airmass was forced to ascend the Southern Alps in the northwesterly flow, producing extremely heavy orographic rainfall.

The final notable point is that, with the rapidly deepening low mentioned above, additional lifting of the airmass would have occurred in the central low pressure area, as well as along each front. This additional lifting would have served to exacerbate rainfall rates.

The frontal systems associated with the rapidly intensifying low caused extremely high rainfalls in northern and western regions of the South Island on 27-28 December. Figures 3, 4 and 5, in particular, show a sequence of fronts and troughs advancing rapidly across the country.

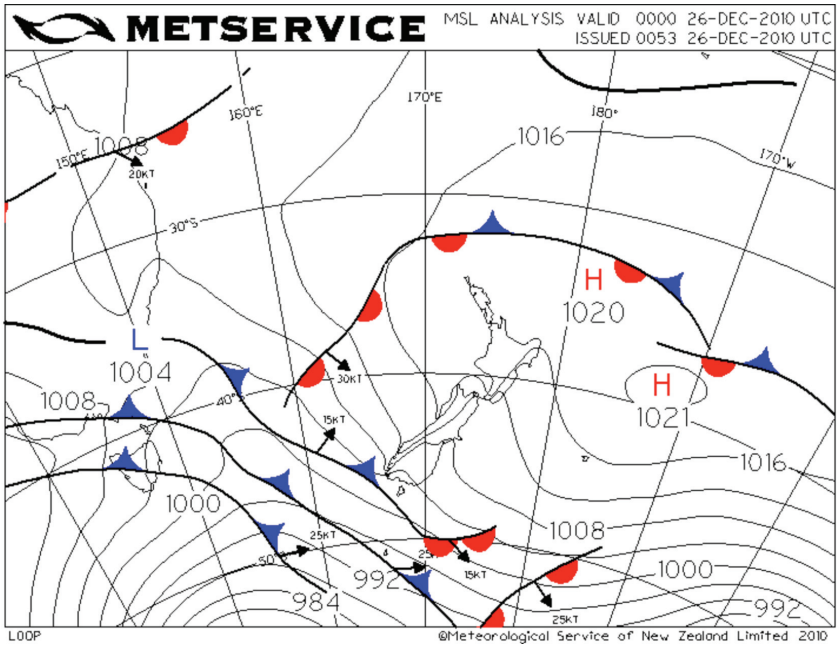

Figure 1 – Synoptic chart for noon (0 h UTC) on 26 December.

(Source: NZ MetService)

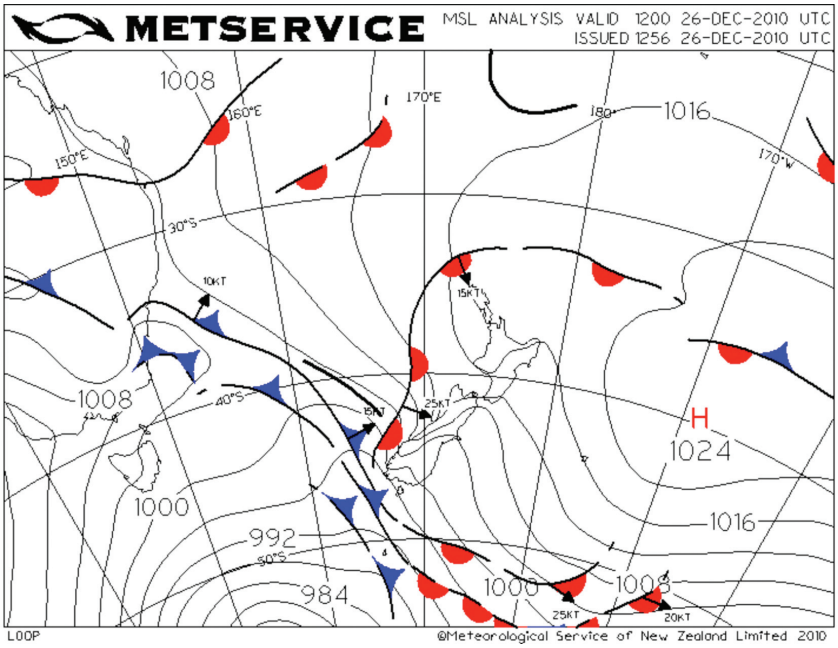

Figure 2 – Synoptic chart for midnight (1200 h UTC) on 26 December.

(Source: NZ MetService)

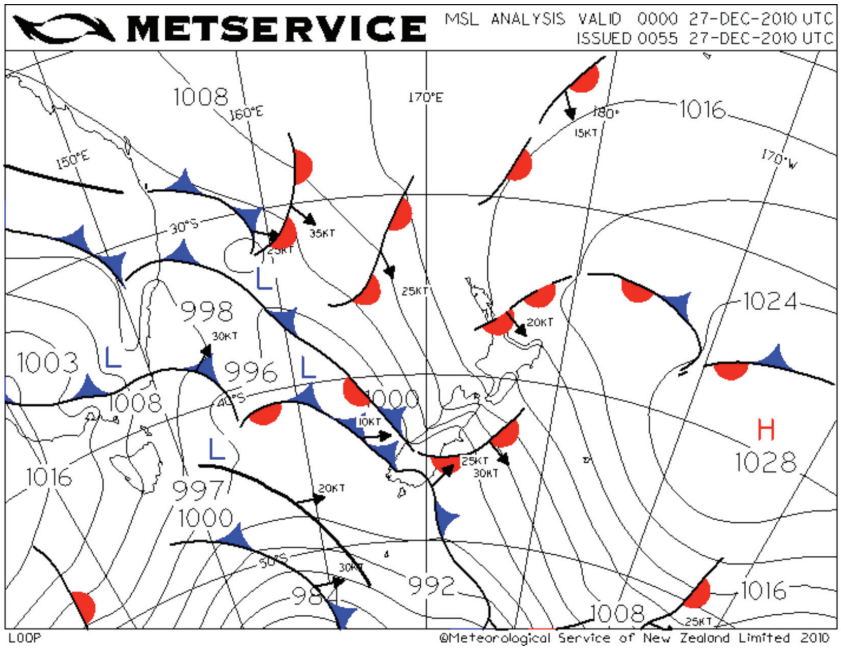

Figure 3 – Synoptic chart for noon (0 h UTC) on 27 December.

(Source: NZ MetService)

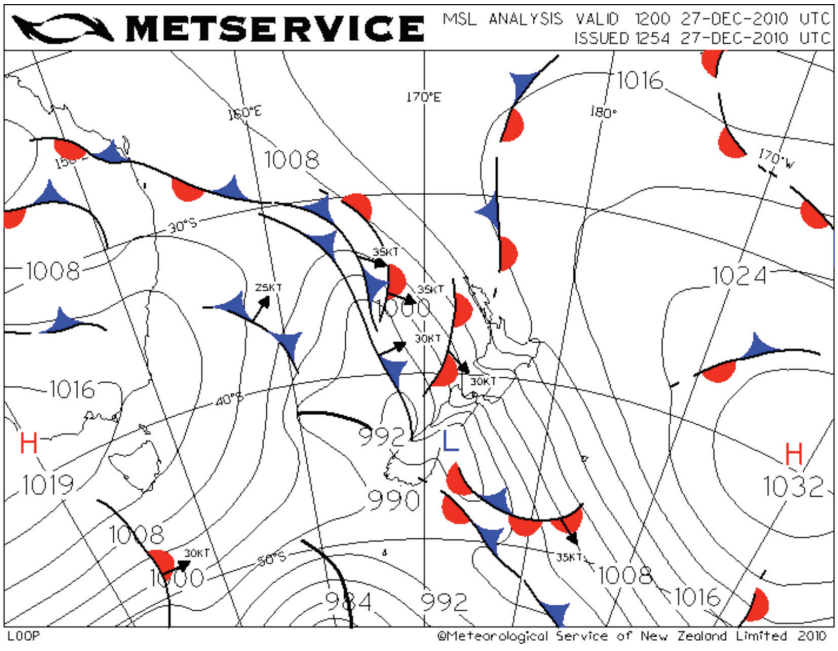

Figure 4 – Synoptic chart for midnight (1200 h UTC) on 27 December.

(Source: NZ MetService)

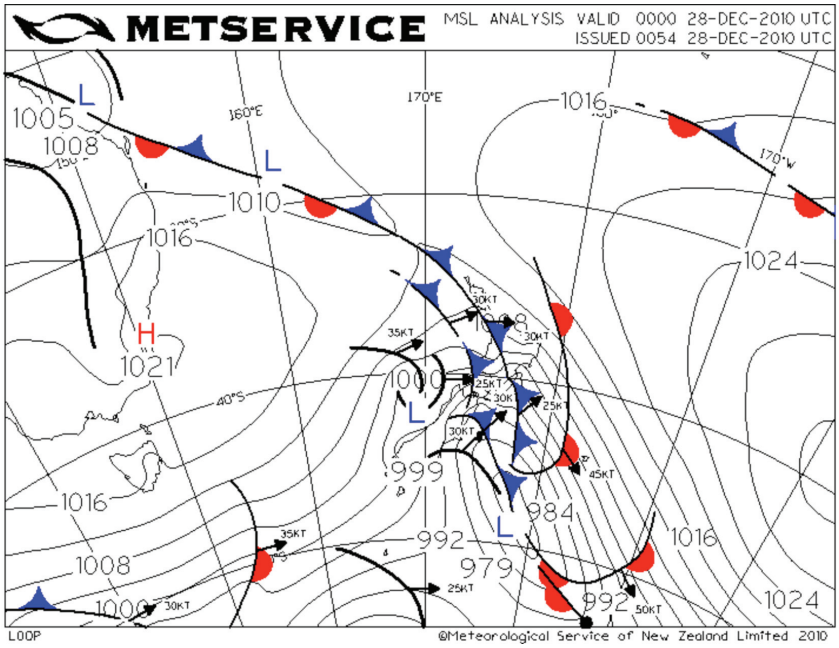

Figure 5 – Synoptic chart for noon (0 h UTC) on 28 December.

(Source: NZ MetService)

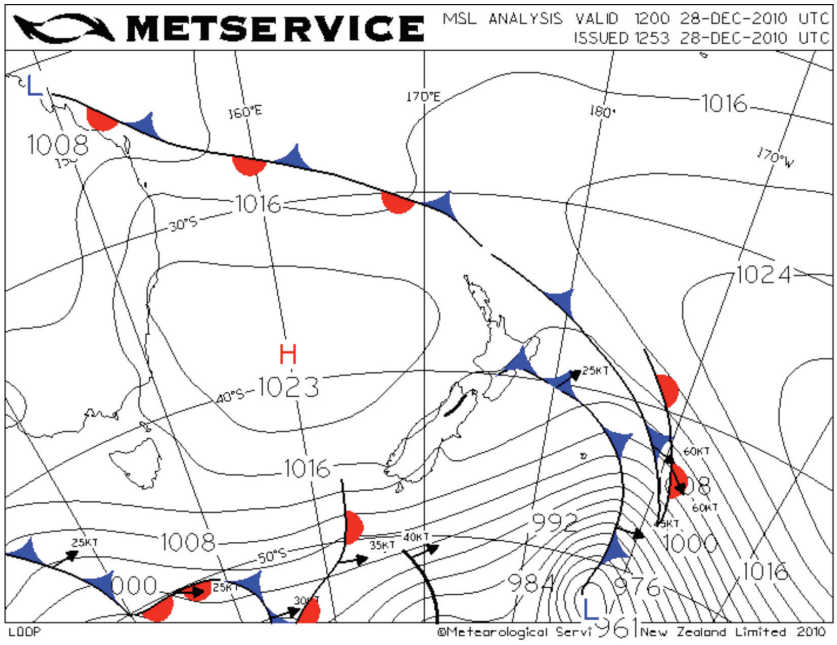

Figure 6 – Synoptic chart for midnight (1200 h UTC) on 28 December.

(Source: NZ MetService)

Rainfall

The 24-hour rainfall totals recorded during 27-28 December for gauges over the South Island are shown in Figure 7. The data used in preparing this map come from 192 automatic and 302 daily-read (manual) raingauges. For consistency, the daily totals (read at 0800 hr NZST) have been multiplied by 1.14, which is an average factor for converting daily-read totals to maxima over any 24-hour interval (Tomlinson, 1980).

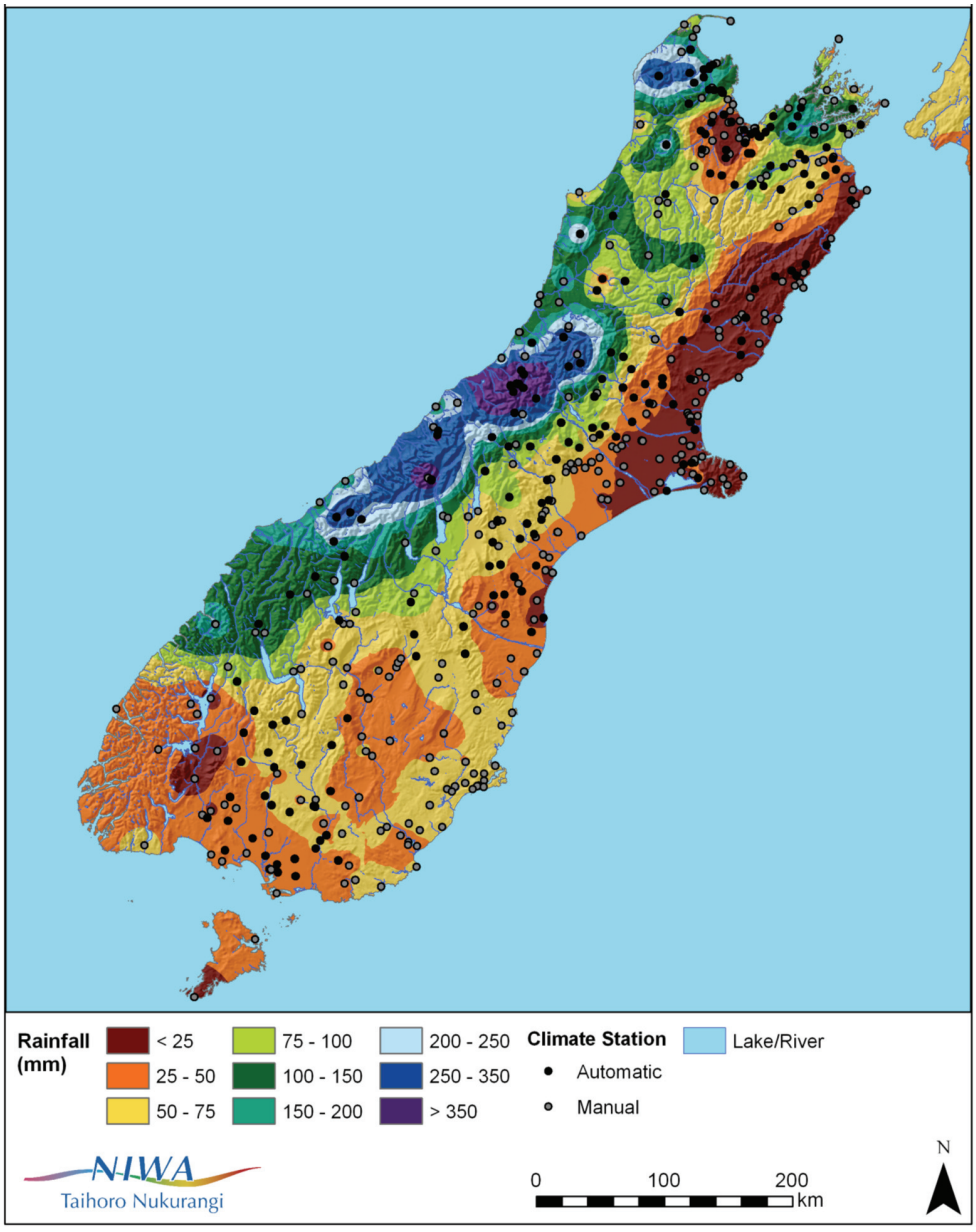

Figure 7 – Distribution of estimated 24-hour rainfalls for 27 December 2011 storm.

In mountainous areas, sparseness of gauges introduces uncertainties into the patterns shown: this is especially notable in Figure 7 for the northern Buller and inland Kaikoura regions, and south Westland and Fiordland. In addition, the very pronounced changes in rainfall over short distances creates problems in displaying the data. Despite these limitations, the chart shows the storm distribution in considerable detail. The most severe rainfalls, exceeding 350 mm, occurred in the central portion of the Southern Alps in the headwaters of the Hokitika River. Here a number of gauges recorded 24-hour totals in the range 450 to 670 mm. Regions with totals exceeding 250 mm occurred in the Southern Alps from the Taramakau River in the north to the Arawata River in the south (at least) and also in northwest Nelson, where one gauge recorded 400 mm. Gauges in the Marlborough Sounds and the Pelorus River catchment received totals exceeding 150 mm.

The main rain shadow area, denoted by gauge totals of less than 25 mm, covered the east coast from Marlborough to mid Canterbury. Another area of rain shadow extended inland from Motueka to Nelson. Also, rainfalls in the Grey River catchment inland from Greymouth were relatively low. The distribution of the heavy rainfalls and rain shadows is consistent with the locations of mountain ranges intercepting the moisture-laden winds. The noteworthy feature of the storm is that it was very extensive and produced substantial rainfalls over most of the island. Much of Otago and northern and eastern Southland received totals exceeding 50 mm. Not surprisingly, significant floods occurred in many rivers.

The severity and return periods of recorded rainfalls is summarised on a spatial basis by comparing the peak intensities with quantiles and return periods predicted by the HIRDS(V3) computer programme (Thompson, 2002) (available on the Internet at http://hirds.niwa.co.nz), which estimates intensity-frequency-duration relations on a national scale. A selection of these results are presented in Figure 8 for a number of automatic raingauges where the totals exceeded the 1/5 AEP estimates from HIRDS(V3). Figure 9 summarises the Island-wide results as a map showing areas where the 1/10 AEP and 1/50 AEP rainfalls were exceeded.

With this type of map, there are inevitable problems in interpolating between sparse gauges, as is evident for several locations on the west coast. Nevertheless, the map does show the very extensive and, as is commonly found, patchy coverage of severe (greater than 1/10 AEP) 24-hour rainfalls experienced during the storm. Areas with rainfalls greater than 1/50 AEP are isolated. Note that the most extensive area, at the central part of the west coast, appears to be an artefact of interpolation.

Finally, as a matter of interest, the rainfall delivered to Queensland in December, which included Ex-Tropical Cyclone Tasha, set a state record for the month of an average of 209 mm. In comparison, the South Island average rainfall for December was 270 mm, and gauge totals ranged from 9 mm to 2453 mm. In contrast to Queensland, New Zealand rainfall deciles for December 2010 (Fig.10), based on key sites used by NIWA for computing deciles, shows that it was the wettest December (since 1972) only for the northern end and an area around The Hermitage, Mt Cook in the South Island, and for coastal north Taranaki in the North Island.

Flood flows

Figures 11–14 present a selection of hydrographs recorded for regional groups of rivers and Table 1 compares the peak flows recorded over the South Island with the mean annual flood and 1/100 AEP flood flow estimates. The plots present the flows

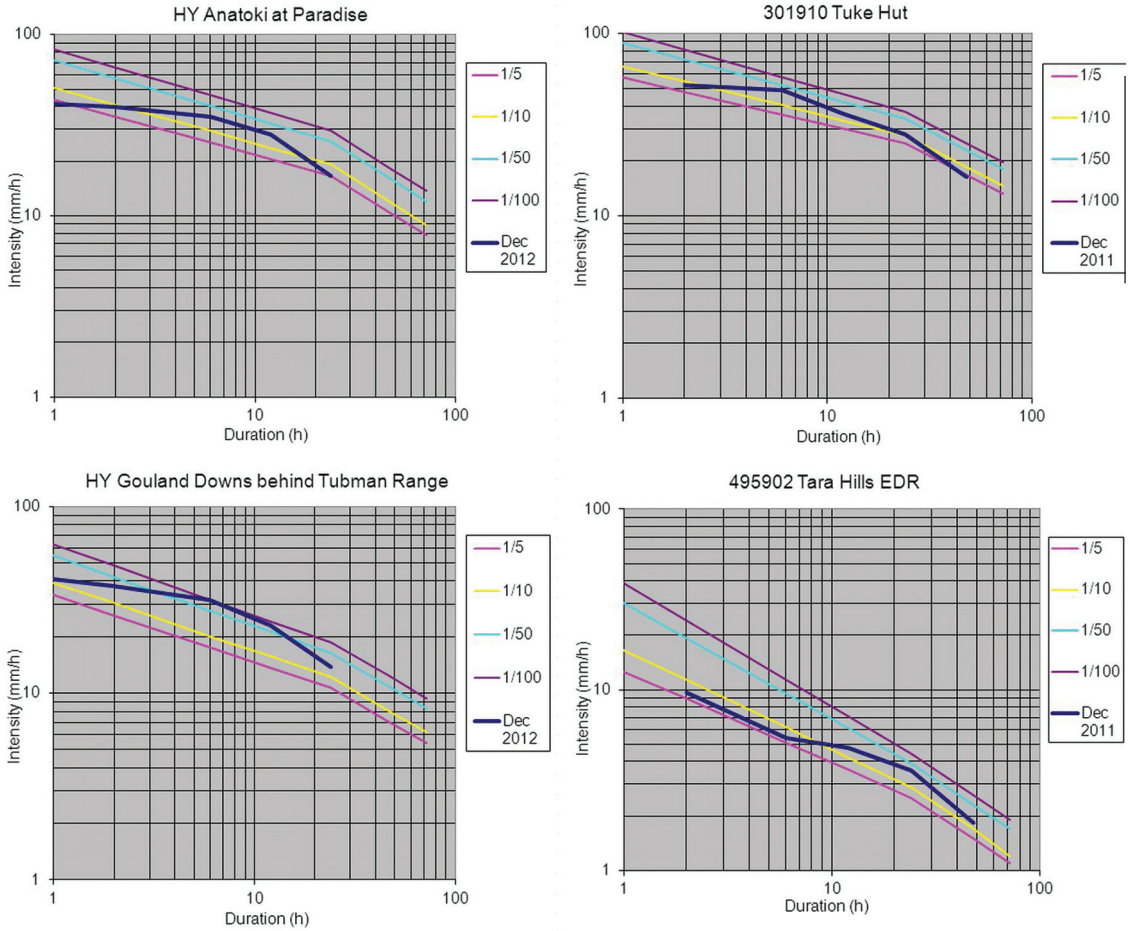

Figure 8 – Comparison of maximum recorded intensities by automatic raingauges for durations from 1 to 24 hours with intensity-frequency-duration plots derived using HIRDS(V3).

recorded from 20-31 December. The data for several days before the peaks of 27 or 28 December is included to demonstrate that there was a sequence of several storms over 20–24 December. These precursor storms almost certainly recharged soil moisture storage, (although we have not analysed relevant measurements in detail), with the result that increasing rates of runoff occurred from the 27 December storm. In fact, for a number of the more southerly rivers, flows were higher on 21 December than in the later event (see Arawata and Haast in Figure 12 and Dart, Shotover and Spey in Figure 14). This is consistent with the relatively less intense rainfalls observed in the region of these catchments (Fig. 9).

Figure 11 shows a cluster of six rivers in the northern South Island: the peak flow for the Aorere (3560 m^3/s) is estimated to be approximately 12% more than the 1/100 AEP estimate for that river and is 15% more than the previous maximum of 3086 m^3/s, recorded in January 1985. In terms of comparisons with 1/100 AEP flood quantiles, this is the most severe of all the floods for this event (Table 1). It is consistent with the intense rainfall measured at Gouland

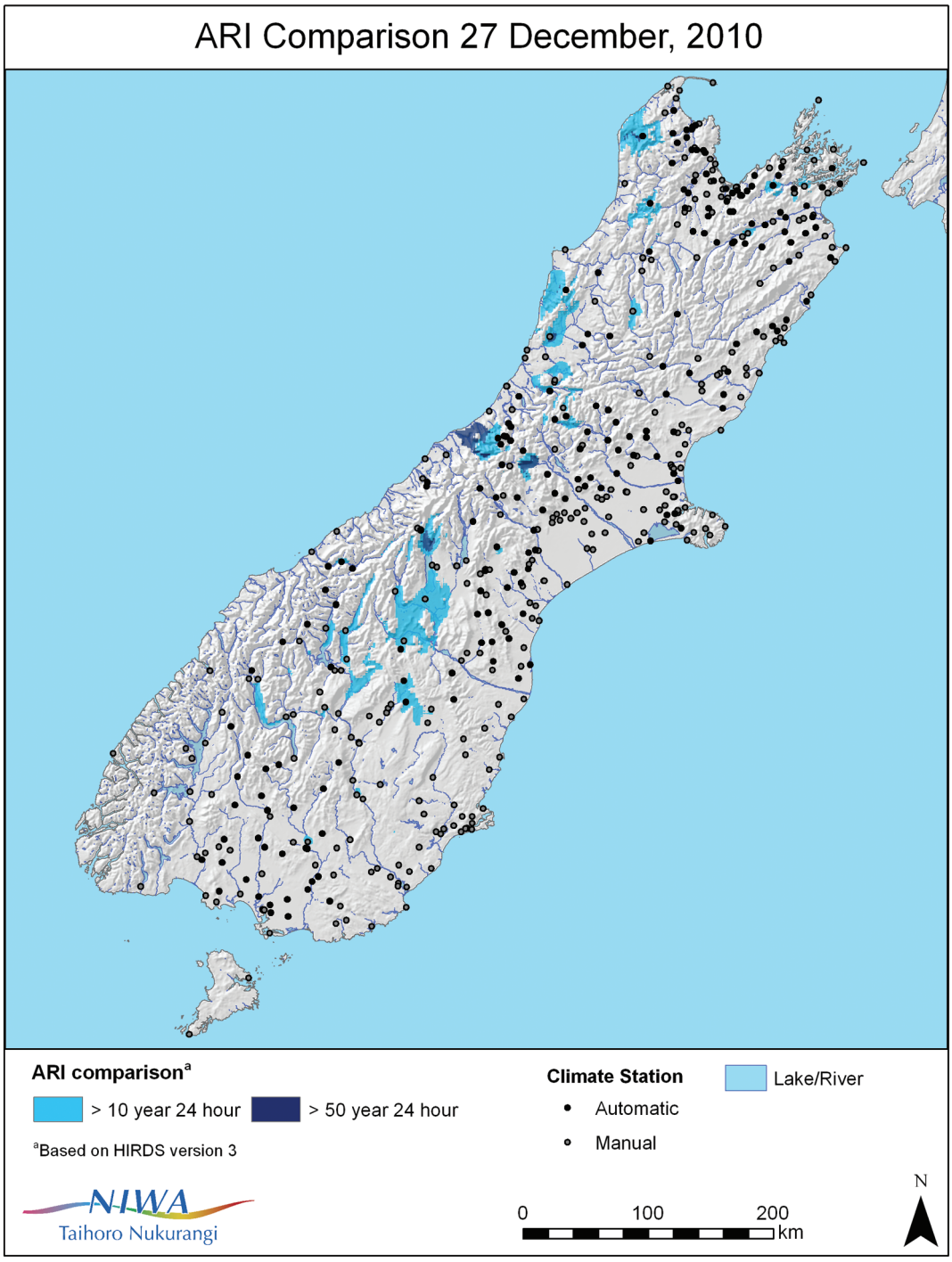

Figure 9 – Map showing areas where the 24-hour 1/10 AEP and 1/50 AEP rainfalls were exceeded.

Table 1 – 26-28 December 2010 flood statistics

River	Site	Mean annual flood (Q_m) m^3/s	1/100 AEP (Q_{100}) m^3/s	28-Dec Peak m^3/s	Peak/ Q_m	Peak/ Q_{100}	Specific discharge $m^3/s/km^2$
Aorere	Devils Boots	1990	3168	3560	1.79	1.12	6.2
Anatoki	Happy Sams	351	630	629	1.79	1.00	6.2
Waingaro	Hanging Rock	523	1018	610	1.17	0.60	2.9
Cobb	Trilobite	95.37	167	148	1.55	0.89	3. 2
Riwaka Sth Br	Moss Bush	49.0	108	32.6	0.67	0.30	0.71
Baton	Baton Flats	206	494	102	0.50	0.21	0.61
Motueka	Gorge	293.4	855	175	0.60	0.20	1.1
Motueka	Woodstock	978	2120	1015	1.04	0.48	0.58
Hunters Gully	Weir	2.33	4.76	1.09	0.47	0.23	0.22
Tadmor	Mudstone	60.5	134	76	1.26	0.57	0.864
Wangapeka	Walter Peak	500	1192	932	1.86	0.78	1.946
Wairoa	Irvines/Gorge	707	1560	495	0.70	0.32	1.071
Wakapuaka	hira	61.3	202	49	0.80	0.24	1.169
Collins	Drop Structure	29.6	79.6	55	1.86	0.69	3.125
Pelorus	Bryants	919.9	2117	1930	2.10	0.91	5.147
Rai	Falls	343.7	851	719	2.09	0.84	3.408
Taylor	Borough Weir	54	260	5.5	0.10	0.02	0.086
Wairau	Barnetts Bank/Tuamarina	1906	5103	2739	1.44	0.54	0.799
Wairau	Dip Flat	351	747	549	1.56	0.73	1.087
Omaka	Gorge	56.6	253	13.5	0.24	0.05	0.150
Waihopai	Olive Grove/Craiglochart	395	1031	471	1.19	0.46	0.616
Awatere	Awapiri	170.5	379	151	0.89	0.40	0.153
Acheron	Clarence	327.6	824	502	1.53	0.61	0.516
Clarence	Jollies	193.3	489	137	0.71	0.28	0.311
Rosy Morn	Weir	2.27	12	3.20	1.41	0.27	1.893
Waiau	Marble Pt/Leslie Hills	986	1828	1335	1.35	0.73	0.674
Waiau	Malings Pass	87.7	171	166	1.89	0.97	2.225
Hope	Glynn Wye	573	982	789	1.38	0.80	1.134
Stanton	Cheddar Valley	35.0	117	0.602	0.02	0.01	0.014
Hurunui	SH1 Br.	769	2055	561	0.73	0.27	0.223
Hurunui	Mandamus	523	1224	622	1.19	0.51	0.587
Hurunui Sth Br	Esk Head	218	535	373	1.71	0.70	1.223
Waipara	White Gorge	118	429	0.830	0.01	0.002	0.002
Waipara	Teviotdale	209	859	1.09	0.01	0.001	0.002
Ashley	Gorge	311	987	47	0.15	0.05	0.100
Okuku	Fox Ck	159	446	6.42	0.04	0.01	0.029
Ashley	Rangiora Traffic Br	718	2505	20	0.03	0.01	0.017
Waimakariri	Old Highway Bge	1481	4155	2472	1.67	0.59	0.770
Camp Stm	Craigieburn	0.577	2.39	0.190	0.33	0.08	0.211
Avon	Gloucester St Br	17.8	29.3	7.00	0.39	0.24	0.184
Heathcote	Buxton	16.3	34.0	5.05	0.31	0.15	0.079
Opara (Okains)	Friesian Stud Farm	21	67.0	0.175	0.01	0.003	0.008
Kaituna	Kaituna Valley Rd	34.9	113	0.929	0.03	0.01	0.024
Selwyn	Whitecliffs	76.9	367	16.8	0.22	0.05	0.102
Selwyn	Coes Ford	141	956	1.05	0.01	0.001	0.001
Rakaia	Fighting Hill/Gorge	2517	5768	5636	2.24	0.98	2.202
Ashburton	SHBr	293	1087	238	0.81	0.22	0.151
Sth Ashburton	Mt Somers	100	290	58.4	0.58	0.20	0.108
North Ashburton	Old Weir	148	408	42.0	0.28	0.10	0.152
Rangitata	Klondyke	1156	4228	2146	1.86	0.51	1.469
Orari	Gorge/Silverton	195	1148	142	0.73	0.12	0.272
Temuka	Manse Br	241	1440	20.7	0.09	0.01	0.036
Opihi	Rockwood	154	944	119	0.77	0.13	0.293
Rocky Gully	Rockburn	14.6	103	5.61	0.38	0.05	0.244
Kakahu	Mitchell's Weir No 9	2.19	6.65	0.650	0.30	0.10	0.236
Kakahu	Turnbulls Weir No 10	4.75	20.1	1.82	0.38	0.09	0.400
Tengawai	Picnic Grounds	199	1548	51.6	0.26	0.03	0.106
Waihi	DOC Reserve	45.5	150	41.3	0.91	0.28	1.033

River	Site	Mean annual flood (Q_m) m^3/s	1/100 AEP (Q_{100}) m^3/s	28-Dec Peak m^3/s	Peak/ Q_m	Peak/ Q_{100}	Specific discharge $m^3/s/km^2$
Pareora	Huts	245	1510	4.60	0.02	0.00	0.011
Waihao	McCulloughs Br	161	1682	3.09	0.02	0.00	0.006
Hakataramea	Above MHBr	165	1231	26.6	0.16	0.02	0.030
Maerewhenua	Kellys Gully	133	428	50	0.38	0.12	0.268
Ahuriri	Sth Diadem	240	615	357	1.49	0.58	0.641
Forks	Balmoral	22.6	74.5	35.3	1.56	0.47	0.360
Jollie	Mt Cook Stn	74.1	243	110	1.48	0.45	0.791
Kakanui	Clifton Falls Br	145	500	21	0.14	0.04	0.073
Taieri	Tiroiti	135	470	44	0.33	0.09	0.018
Taieri	Canadian Flat	107	250	65	0.61	0.26	0.413
Shotover	Peats Hut	253	712	193	0.76	0.27	0.327
Dart	The Hillocks	1237		831	0.67		1.476
Sutton	SH87	64	321	9	0.15	0.03	0.062
Lindis	Lindis Peak	96	342	69	0.72	0.20	0.127
Pomahaka	Burkes Ford	402	1416	121	0.30	0.09	0.063
Manuherikia	Ophir	177	735	108	0.61	0.15	0.053
Shotover	Bowens Peak	430	980	291	0.68	0.30	0.267
Matukituki	West Wanaka	1028	1750	588	0.57	0.34	0.736
Mataura	Gore HBr	634	2726	291	0.46	0.11	0.084
Mataura	Parawa	215	585	119	0.55	0.20	0.155
Mataura	Tuturau	661	2729	300	0.45	0.11	0.069
Mataura	Seaward Downs	843	3246	311	0.37	0.10	0.061
Waimea	Mandeville Br	85.8	316	7.15	0.08	0.02	0.018
Mokoreta	McKays/Glenham Br	136	316	41.7	0.31	0.13	0.154
Waikaka	Willowbank	122	340	16.5	0.14	0.05	0.052
Waikaia	Mahers Beach Rd	371	1090	193	0.52	0.18	0.166
Waikaia	Piano Flat	271	721	171	0.63	0.24	0.350
Waihopai	above Scour/Kennington	44	99	2.14	0.05	0.02	0.014
Oreti	Wallacetown	624	1699	184	0.29	0.11	0.084
Oreti	Three Kings	138	359	62	0.45	0.17	0.229
Otapiri	Otapiri Gorge	70.9	183	10.2	0.14	0.06	0.094
Makarewa	Counsell Rd/Freezing Works Br.	228	640	38.6	0.17	0.06	0.039
Oreti	Lumsden Cableway	566	1245	252	0.45	0.20	0.231
Irthing Stm	Ellis Rd Br	225	390	117	0.52	0.30	0.268
Aparima	Thornbury	507	1313	66	0.13	0.05	0.052
Aparima	Dunrobin	149	400	29.9	0.20	0.07	0.139
Hamilton Burn	Waterloo Br/Matuku Rd	131	303	27.6	0.21	0.09	0.208
Mararoa	Cliffs	425	1173	88.6	0.21	0.08	0.073
Spey	West Arm	267	370	98.4	0.37	0.27	1.030
Arawata	County Bridge	2967	5400	2688	0.91	0.50	2.768
Haast	Roaring Billy	3762	7462	4569	1.21	0.61	4.479
Moeraki	Lake Moeraki	374	720	452	1.21	0.63	4.593
Makawhio	Rocks	855	1140	950	1.11	0.83	7.037
Lake Wahapo	Lake	522	991	755	1.45	0.76	14.804
Whataroa	SHBr	2655	5228	3594	1.35	0.69	8.076
Hokitika	Gorge/Colliers Creek	1911	3166	3071	1.61	0.97	8.724
Taipo	SHBr	676	1287	664	0.98	0.52	3.669
Taramakau	Greenstone	2377	4715	3046	1.28	0.65	3.530
Grey	Dobson	3752	6811	4614	1.23	0.68	1.205
Grey	Waipuna	926	1777	1115	1.20	0.63	1.737
Ahaura	Gorge	1414	3157	2320	1.64	0.73	2.937
Pattinson	Weir Site 2	0.778	1.93	0.537	0.69	0.28	0.814
Tiropahi	SHB	181	361	233	1.29	0.65	6.384
Buller	Te Kuha	4765	9410	6714	1.41	0.71	1.057
Inangahua	Landing	1524	3109	2250	1.48	0.72	2.250
Inangahua	Blacks Point	445	833	494	1.11	0.59	2.111
Karamea	Gorge/Arapito	2043	3952	3080	1.51	0.78	2.655

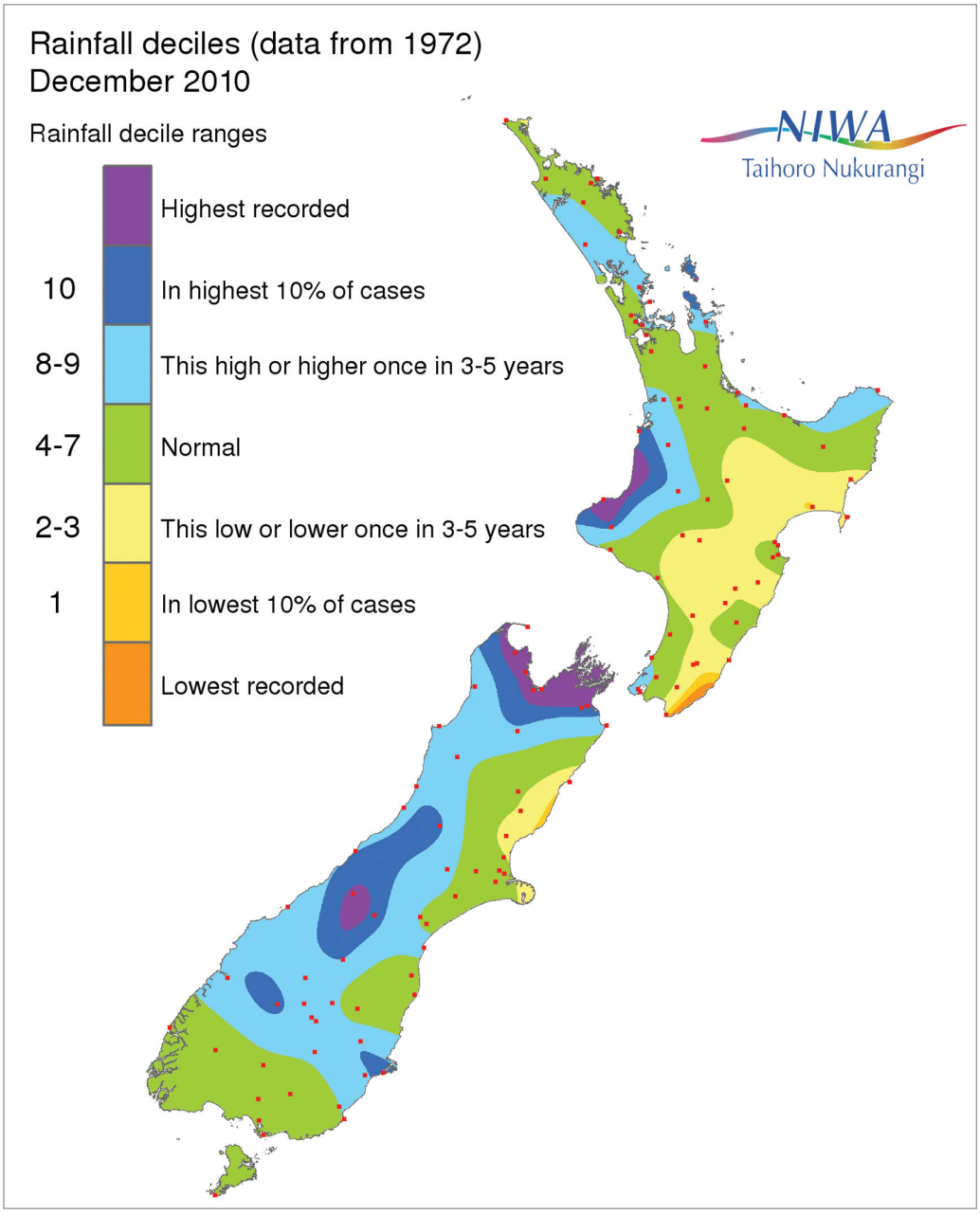

Figure 10 – New Zealand rainfall deciles for December 2010 (data from 1972).

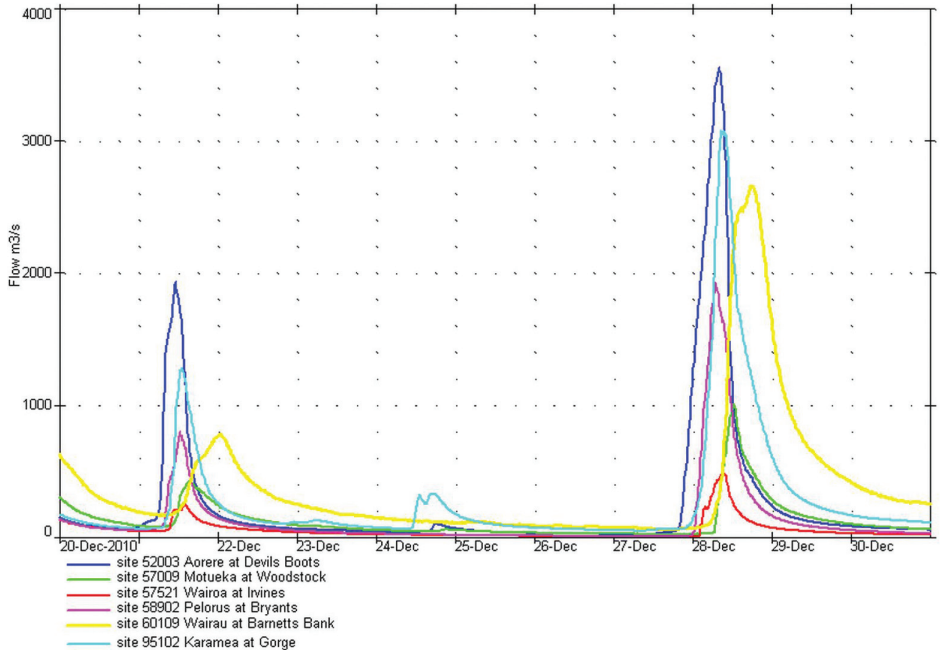

Figure 11 – Hydrographs for northern South Island rivers.

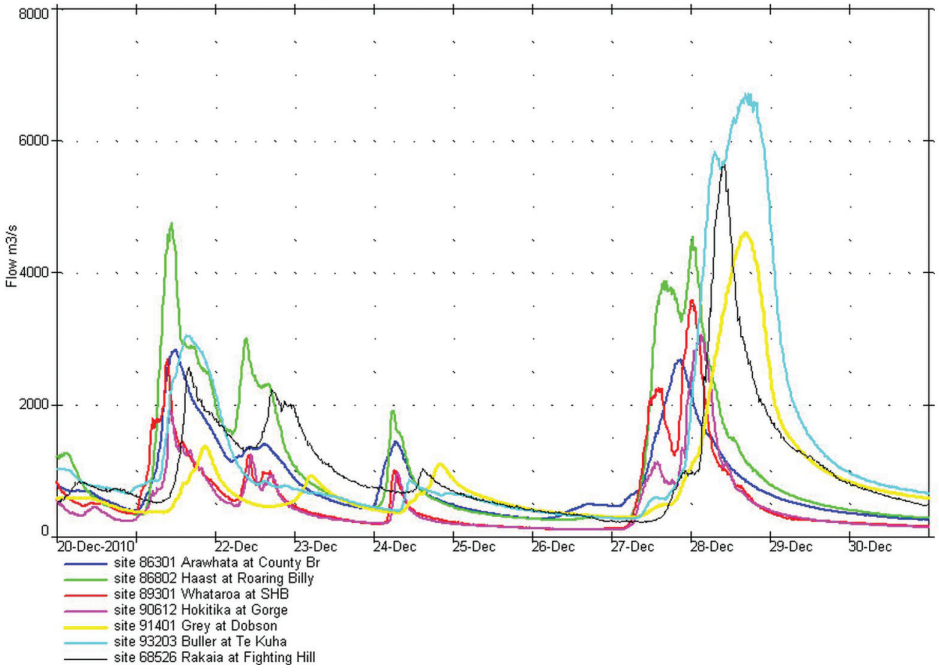

Figure 12 – Hydrographs for West Coast rivers and Rakaia River.

Downs (Fig. 8). Similarly, the Pelorus peak flow was 11% higher than the previous recorded maximum, which occurred in October 1983. The other notable feature in Figure 10 is that the peak flow for the Wairau River occurred many hours after the peaks for the other rivers. This reflects the larger size of the Wairau catchment and thus the travel time to reach the recorder.

Figure 12 presents plots of hydrographs for six west coast rivers and for the Rakaia River, which had its highest recorded flow. As noted above, the peak for the more southerly rivers (Arawata, Haast) was higher on 21 December. Also, their 27-28 December peaks precede those of the other rivers. The latest peaks occur in the Buller and the Grey, which are further north, reflecting, perhaps, the pattern of storm movement. The Rakaia and Hokitika Rivers drain the high rainfall areas shown in Figure 7 and, not surprisingly, their peak flows were the largest recorded since records begin (in 1958 and 1971 respectively).

Figure 13 presents plots of hydrographs for six Canterbury rivers. Again, the most southerly of this group (the Rangitata) peaks first. Its flood was the fourth highest of the annual maxima since 1979, and the peaks for the Acheron, Waiau, and Waimakariri ranked as 6, 5 and 8 amongst the respective annual maxima.

Figure 14 presents plots of hydrographs for a selection of rivers in South Canterbury, Otago and Southland. All these rivers experienced floods, the most notable being for the Ahuriri, which ranked as 10 amongst the annual maxima.

The usual method for comparing the relative magnitude of the flood peaks in various rivers is to non-dimensionalise each peak value by dividing by the relevant and readily calculated value of mean annual flood. Figure 15 displays these non-dimensional values in ranges. The larger the range, the more exceptional the event. Note the large number of catchments (shaded dark green

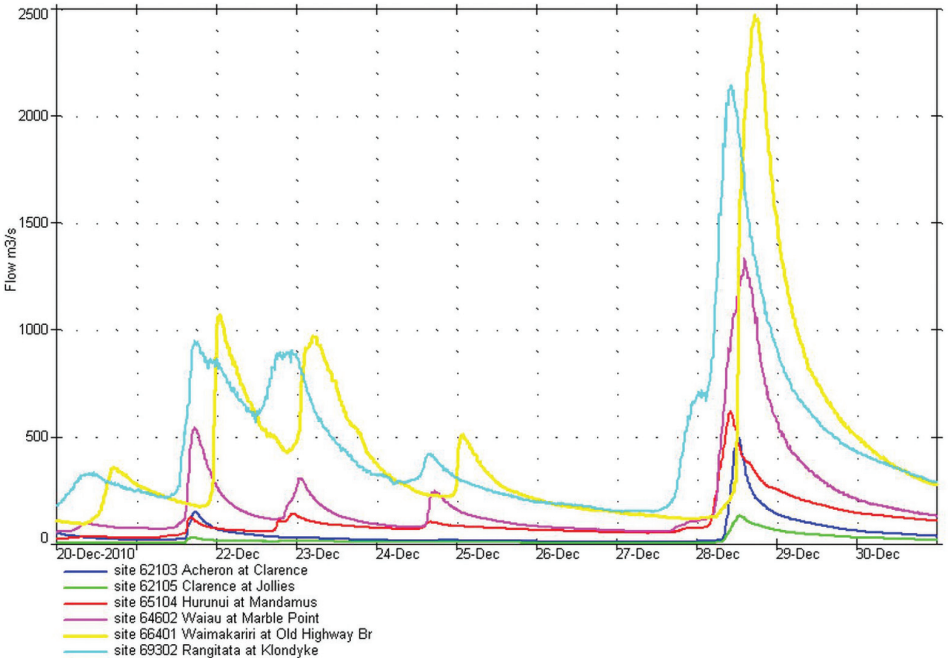

Figure 13 – Hydrographs for north and mid Canterbury rivers.

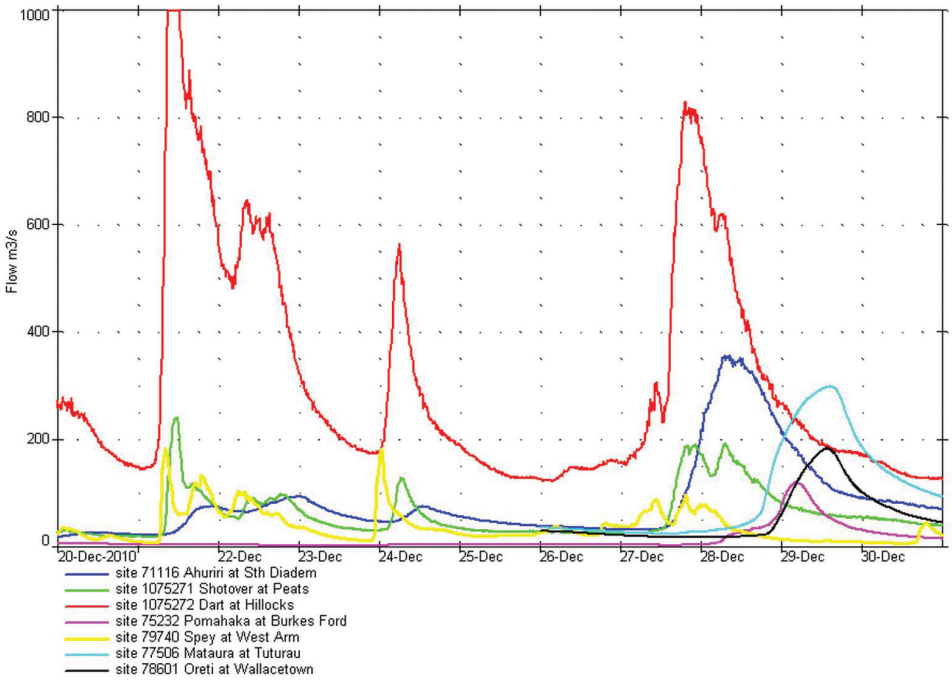

Figure 14 – Hydrographs for South Canterbury, Otago and Southland rivers

and blue) which exceed the mean annual flood.

Specific discharges are displayed in Table 1 and in Figure 16. The highest specific discharges occur in the Aorere River in North West Nelson and in the small catchments in South Westland, in particular Lake Wahapo.

Part of the purpose of this project was to compare the December 2010 event with historic widespread floods in the South Island. An analysis of selected catchments around the South Island was limited to rivers with a considerable length of record. For the 31 selected rivers the peak flows, normalised by the relevant mean annual flood, are displayed in Table 2 for seven historic events and the December 2010 event. These storms were selected owing to the widespread coverage and availability of river flow information for the 31 catchments. It is important to note that prior to 1979, coverage of widespread flood events was patchy and uncertain.

Listed at the bottom of Table 2 is the total number of rivers which exceeded the mean annual flood for each of the historical flood events. The December 2010 tops the list with a value of 13.

Paradoxically, because of the prevailing La Niña conditions, summer inflows,to the South Island hydroelectric storage lakes were expected to be low. Instead the December inflows were exceptionally high: they filled the South Island storages (Lakes Pukaki, Tekapo and Hawea) and secured the country's hydroelectricity supplies for 2011.

Conclusions

The meteorological situation that led to the December 2010 floods was exacerbated by the warmer than usual subtropical water associated with the prevailing La Niña conditions and the after-effects of a tropical cyclone that affected northern Queensland.

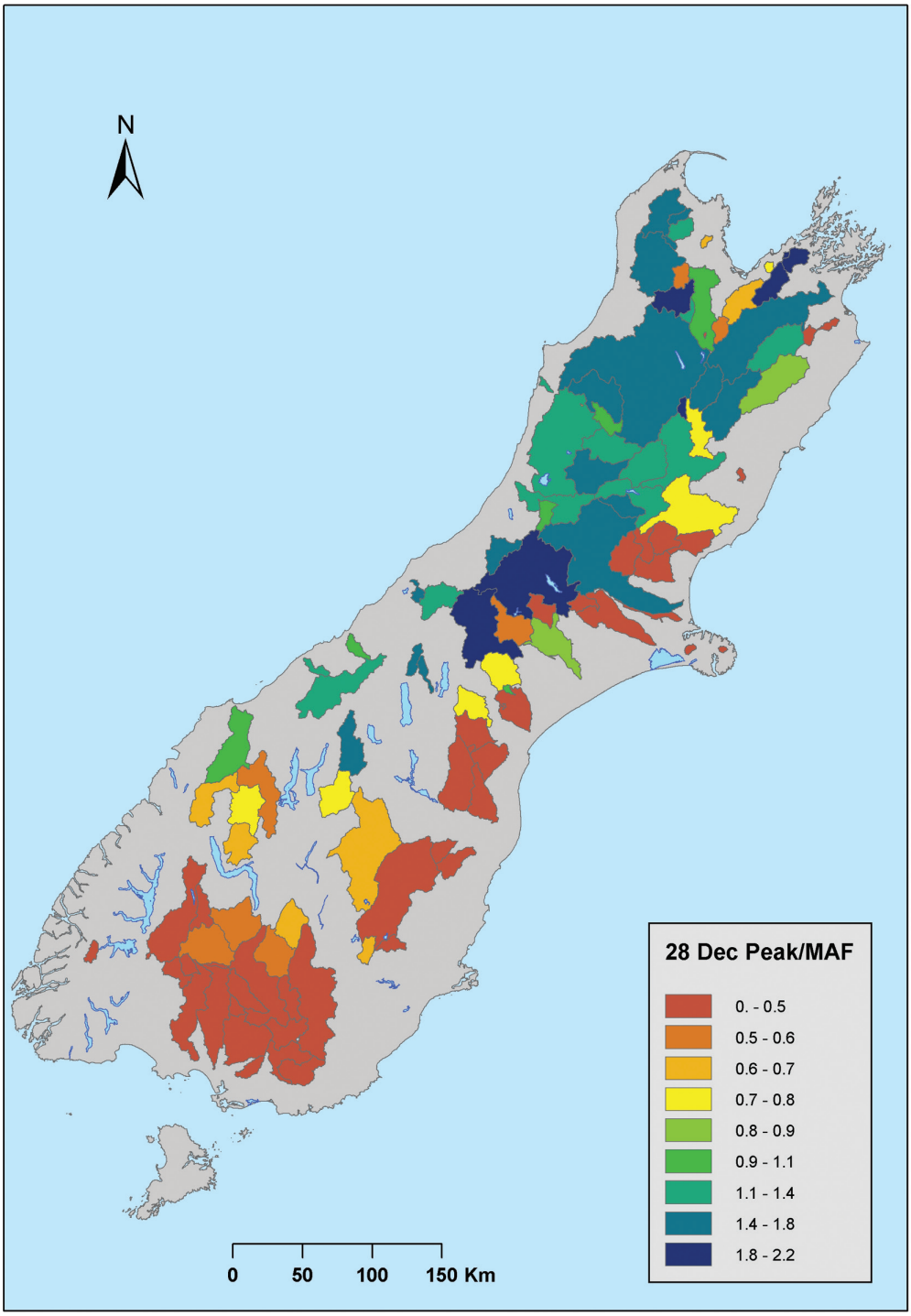

Figure 15 – Map of river flood peaks as a proportion of their mean annual flood.

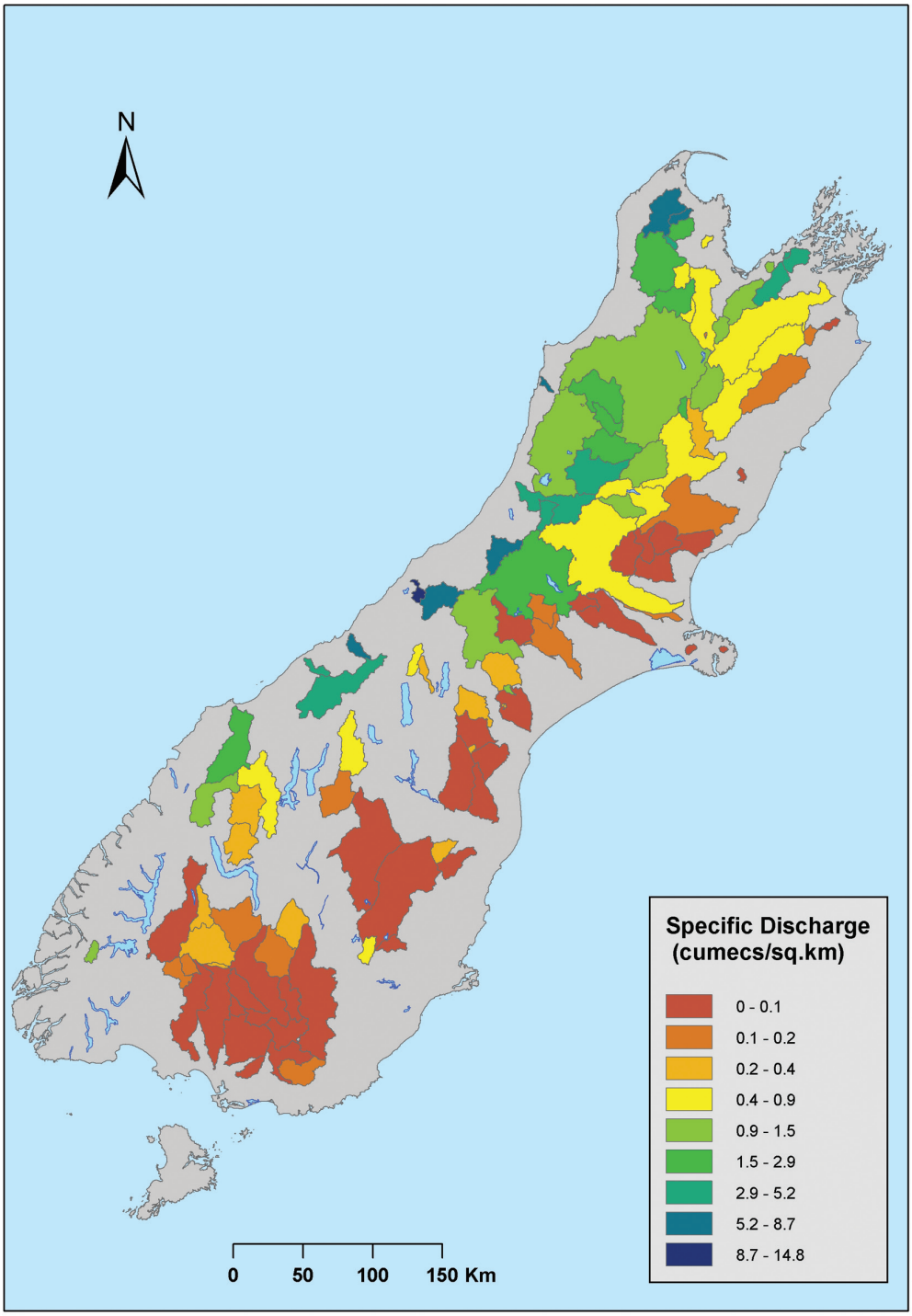

Figure 16 – Map of river flood peak specific discharge.

Table 2 – Flood peak magnitudes normalised by mean annual flood value for eight past storms at 32 South Island recording stations.

River	Site	3-Dec 1979	10-Jul 1983	27-Jan 1984	13-15 Mar 1986	10-12 Aug 1986	5 -10 Jan 1994	19-Aug 2000	28-Dec 2010
Aorere	Devils Boots	0.89	1.14	0.06	0.48	0.16	0.66	0.43	1.79
Cobb	Trilobite	0.81	1.50	0.01	0.21	0.55	0.25	0.61	1.55
Motueka	Woodstock	0.65	2.20	0.02	1.07	0.46	0.33	0.68	1.04
Wairoa	Irvines/Gorge	0.14	1.50	1.50	0.02	0.03	0.10	0.19	0.70
Pelorus	Bryants	0.19	1.55	0.01	0.17	0.07	0.10	0.15	2.10
Taylor	Borough Weir	0.01	0.40	0.00	0.08	0.39	0.00	0.04	0.10
Wairau	Barnetts Bank/Tuamarina	0.36	1.13	0.02	NA	NA	0.28	0.19	1.44
Clarence	Jollies	0.46	1.28	0.04	0.17	0.70	0.79	1.73	0.71
Waiau	Marble Pt/Leslie Hills	1.16	0.92	0.19	0.10	0.79	1.02	0.98	1.35
Stanton	Cheddar Valley	0.00	0.08	0.00	0.11	1.59	0.01	1.66	0.02
Ashley	Gorge	0.15	0.58	0.03	0.52	2.45	0.33	2.51	0.15
Selwyn	Whitecliffs	0.08	0.89	0.04	2.39	2.61	0.17	4.46	0.22
Rakaia	Fighting Hill/Gorge	2.16	0.44	0.60	0.16	0.10	2.22	0.08	2.24
Sth Ashburton	Mt Somers	1.05	1.39	0.16	1.96	3.09	1.27	1.23	0.58
Orari	Gorge/Silverton	0.06	0.69	0.05	4.10	1.98	0.11	0.95	0.73
Opihi	Rockwood	0.06	0.67	NA	6.62	2.62	0.14	1.29	0.77
Pareora	Huts	NA	0.23	0.02	4.36	2.20	0.02	1.54	0.02
Ahuriri	Sth Diadem	2.14	0.22	0.70	0.75	0.10	2.38	0.09	1.49
Kakanui	Clifton Falls Br	NA	0.05	0.15	0.81	0.83	0.34	0.35	0.14
Pomahaka	Burkes Ford	0.22	0.60	1.16	0.04	0.40	0.89	0.29	0.30
Manuherikia	Ophir	0.34	0.25	0.34	1.27	0.33	1.83	0.29	0.61
Shotover	Bowens Peak	1.11	0.18	1.32	0.24	0.09	0.74	0.11	0.68
Matukituki	West Wanaka	0.71	0.10	0.62	0.27	0.03	0.75	0.06	0.57
Mataura	Gore HBr	0.64	0.64	1.21	0.05	0.25	1.16	0.21	0.46
Mokoreta	McKays/Glenham Br	NA	0.24	2.16	0.01	0.22	0.48	0.09	0.31
Oreti	Wallacetown	0.83	0.43	1.71	0.02	0.15	0.90	0.16	0.29
Mararoa	Cliffs	0.99	0.26	1.94	0.03	0.13	0.60	0.14	0.21
Haast	Roaring Billy	NA	0.35	1.39	0.23	0.01	1.53	0.03	1.21
Hokitika	Colliers Creek	1.00	0.32	0.88	0.13	0.03	1.28	0.18	1.61
Grey	Dobson	1.07	1.13	0.31	0.11	0.07	1.29	0.37	1.23
Buller	Te Kuha	0.98	1.37	0.24	0.15	0.08	1.05	0.33	1.41
Karamea	Gorge/Arapito	1.01	0.69	0.08	0.24	0.16	1.07	0.22	1.51
Number of flood peaks greater than mean annual flood		8	10	8	7	7	11	7	13

Rainfalls were widespread across much of northern, western and alpine regions of the South Island. Exceptional daily totals (greater 1/10 AEP) occurred patchily from its most northern extremity to central Otago, but rainfalls exceeding 1/50 AEP quantiles occurred at only a few gauges. Much of Southland also received substantial (more than 25 mm) rainfalls. Minimal rainfalls (less than 25 mm) occurred on the east coast from Timaru northwards and in an area between Nelson and Motueka, reflecting perhaps rain shadow effects.

Inspection of flood hydrographs shows high flows occurred in most rivers draining from the main divide of the Southern Alps, as well as those in northwest Nelson and in vicinity of the Marlborough Sounds. Previous rain during 21-25 December very probably recharged soil moisture levels over much of the island, resulting in lower rates of loss to soil infiltration and higher runoff rates for the storm of 26-28 December. This contributed to the severe floods encountered in a number of rivers.

The December inflows helped fill South Island hydroelectric storage lakes.

In a comparison with historic large floods which have occurred since December 1979, the 2010 event was the largest, as measured by the number of key rivers which exceeded their mean annual flood.

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The efforts of local authority and NIWA field teams and volunteer observers in collecting and organising the data used in this study are appreciated. Kathy Walter and Kevin McGill compiled data files; James Sturman and Julian Sykes prepared the maps; Ross Marsden of MetService New Zealand Ltd kindly provided the synoptic charts; Martin Doyle of the Tasman District Council conceived and promoted the project with funding from EnviroLink.

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