NIWA
Taihoro Nukurangi

New Zealand Rainfall Intensity Indices

Prepared for Ministry for the Environment

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Executive summary

The Ministry for the Environment (the Ministry) acquired climate data from 30 climate stations from NIWA for the 2015 Environmental Reporting Synthesis Report (Environment Aotearoa 2015). These data were extracted from NIWA's National Climate Database. NIWA subsequently updated these datasets to extend the length of some data time series and infill missing data.

The Ministry requested NIWA to calculate a series of rainfall indices which will contribute to the 2017 Atmosphere and Climate environmental report, using these extended, infilled datasets. Eleven rainfall indices were selected, and these were calculated for 30 New Zealand locations using daily rainfall data for the period 1 January 1960 to 31 December 2016.

In addition, the Ministry requested NIWA to produce a single rainfall index for New Zealand, based on the *r95ptot* (percentage of the annual rainfall total that has come from heavy rainfall events) index data generated for the 30 New Zealand locations.

This report describes the derivation of the updated datasets, and defines the rainfall indices selected. The eleven rainfall indices plus the single New Zealand index were successfully calculated for all locations, and these datasets were provided to the Ministry along with this report.

1 Data quality control

All climate data prepared for the Ministry and described in this report were derived from raw data values extracted from NIWA's National Climate Database (CLIDB). These raw data can be accessed for free from http://cliflo.niwa.co.nz/ and while no guarantee is made regarding the accuracy of the data, all reasonable skill and care has been applied so that the data in the database are as reliable as possible.

The following quality control procedure is ongoing, and undertaken for all data in CLIDB. As observed values are transferred into permanent data tables in the database (e.g. MAX_MIN_TEMP, RAIN etc.) from temporary input tables (e.g. RMS_AWS, RMS_DLYCLI etc.) they are automatically inspected for errors. These are either gross errors when values fall outside very wide universal limits so that an error flag is given the value "E" and the observation is not transferred into CLIDB, or they are potential errors as they lie sufficiently outside of the 1 or 99 percentile for that place/time so that an error flag is given the value "W" and the observation is transferred into CLIDB.

Most data originating from the various data streams entering CLIDB (i.e. of different origins or message types) do so as frequently as possible (e.g. RMS_AWS is hourly but the suite of UPPER_AIR messages are every 6 hours). These frequent transfers do not report errors and warnings but daily collectives are also run and the errors and warnings are reported with these runs. The daily collective runs also log any errors or warnings into the ERRLOG and WARNLOG tables except for AWS data which do not have a daily collective but a daily reporting/logging process runs just after midnight. Time series plots centred on the observation with a "W" warning are generated and the 1 and 99 percentiles are also used to standardise observations and facilitate manual checking of the data.

After manual inspection and depending upon the inspection outcome, the data are either unchanged or corrected (with associated quality flags) or deleted from CLIDB. Data remaining in the database are deemed sufficiently high quality for inclusion in the station data record, and for subsequent data analysis. Should users of the climate data query its validity, then additional user-initiated manual data checks are also made.

2 Virtual Climate Station Network data

Virtual Climate Station Network (VCSN) data were primarily used to infill missing climate data. The VCSN consists of an interpolated grid of 11491 virtual climate stations covering the New Zealand area. Each of these virtual climate stations has daily interpolated values of Rainfall, Wind Speed, Maximum and Minimum Temperature, Relative Humidity, Mean Sea Level Pressure, Vapour Pressure, Potential Evapotranspiration, Soil Moisture, 10cm earth temperature and Global Solar Radiation. The virtual stations start with rain values only in 1960, from 1972 all the above parameters except wind, and from 1997 includes wind. The grid point separation is 0.05 degrees latitude and longitude which is approximately 5km.

VCSN data are calculated using *ANUSplin*: a software tool that takes data values from irregularly-spaced observing sites and provides interpolated values at regularly spaced grid point locations. Specifically, the data are calculated by the ANUSplin trivariate (three independent variables: easting, northing and a third variable, e.g. elevation) thin-plate smoothing spline interpolation methodology, described by Wratt *et al.* (2006).

3 Data infilling procedure

Rainfall data for 30 New Zealand locations were updated by infilling missing data. This was achieved by using daily VCSN data. In addition, time series extensions were performed where older (mostly closed) climate stations were located very near to the currently open station locations. Section 3.2 describes the methods employed to infill missing data for rainfall. Section 3.3 outlines the methods used for time series extension. A list of climate stations used for time series extension and VCSN agent numbers used for infilling missing data at each location is provided in Appendix A. Regression equations and associated R^2 values for the analyses pertaining to daily rainfall are provided in Appendix B. Appendix C lists the period of daily rainfall records available at each site as a result of the procedures described in Sections 3.1, 3.2 and 3.3.

3.1 Selection of regionally-representative sites

As described in Tait et al. (2014), the following criteria were used to select regionally-representative climate stations:

1. The station must currently be open (as at December 2016);
2. The station is likely to remain open for the foreseeable future;
3. The station has a long record of reliable good-quality data;
4. The station is located near a large city (e.g. at an airport site) so is representative of the climate where many people in the region live;

One station per region is to be selected. However, if deemed necessary, two or three stations may be selected to represent a large region.

3.2 Rainfall

For each of the 30 New Zealand locations selected, the following infilling process was used:

1. Select a climate station and obtain daily rainfall for the period 1 January 1960 to 31 December 2016. Identify missing daily values;

2. Extract daily VCSN data from the nearest gridpoint to this station for the period 1 January 1960 to 31 December 2016;

3. Produce a regression plot between the station and VCSN data, then estimate the climate station values based on the VCSN data, according to the regression equation. If the original VCSN daily rainfall is 0 mm then the adjusted daily rainfall is also set to 0 mm;

4. Substitute missing daily station data with adjusted VCSN data. VCSN data was only substituted for the period of time that the original station was operating.

Calculate annual rainfall indices using original and infilled daily rainfall data. No minimum number of days of 'real' station data per month was required for indices to be calculated.

3.3 Time series extension

In some cases older (mostly closed) climate stations were located very near to the currently open station locations (i.e. often located within 500m of each other). Where possible, the data records from these older stations were used to extend the data series back in time. The following steps were used to extend time series for rainfall:

1. Obtain all available daily climate data for both the open and closed climate stations;

2. Produce regression plots using the overlapping data of the open and closed climate stations, then estimate the open station values based on the closed station data, according to the regression equation;

3. Merge the two time series to create an extended time series, using open station data where available;

4. Calculate annual rainfall indices.

In some cases, there was no overlap between rainfall data of the open and closed stations at a given location. VCSN data was utilised if this was the case:

1. Obtain all available daily rainfall data for both the open and closed climate stations, and extract all VCSN data from the nearest gridpoint;

2. Produce a regression plot between the open station data and the VCSN data, then estimate the open station rainfall values based on the VCSN data, according to the regression equation;

3. Produce a regression plot between the adjusted VCSN data and the closed station data, then adjust the closed station data according to the regression equation;

4. Merge the open station data and the adjusted closed station data to create an extended time series, using open station data where available. Infill missing daily values with the adjusted VCSN data;

Calculate the annual rainfall indices.

4 Climate indices

Climate indices are used to describe different aspects of climatic extremes, including frequency, intensity and duration. The World Meteorological Organisation (WMO) Commission for Climatology (CCl) Open Panel of CCl Experts on Climate Information for Adaptation and Risk Management (OPACE 4) have managed the development of a standardised set of approximately 50 climate indices. Initially, the Joint CCl/Climate and Ocean – Variability, Predictability and Change (CLIVAR)/Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) Expert Team on Climate Change Detection and Indices (ET-CCDI) developed a core set of 27 climate indices to be used by national meteorological and hydrological organisations (Klein Tank *et al.*, 2009). Additional climate indices were developed by the Expert Team on Sector-specific Climate Indices (ET-SCI): the successor of ET-CCDI.

4.1 Rainfall indices selected

After consultation with the Ministry, the following rainfall indices were selected for analyses of daily rainfall data:

- **rx1day**: Annual maximum 1-day precipitation total.
- **r10mm**: Annual number of days when precipitation ≥ 10 mm.
- **r20mm**: Annual number of days when precipitation ≥ 20 mm.
- **sdii**: Annual total precipitation divided by the number of wet days (a wet day is when total daily precipitation ≥ 1 mm).
- **r95p**: Annual sum of daily precipitation > 95th percentile.
- **r95ptot**: Percentage of the annual rainfall total that has come from heavy rainfall events (as defined by the 95th percentile daily rainfall total).
- **r99p**: Annual sum of daily precipitation > 99th percentile.
- **rnnmm**: Annual number of days when precipitation ≥ 50 mm.

NIWA selected an additional three rainfall indices for analyses to supplement those requested by the Ministry:

- **prcptot**: Annual total precipitation.
- **rx5day**: Annual maximum 5-day precipitation total.
- **cwd**: Annual maximum number of consecutive wet days (a wet day is when total daily precipitation ≥ 1 mm).

The climate normal period used for calculating these indices was 1981-2010. Where daily rainfall data began later than 1981, the normals were generated from all available rainfall data up to and including 2010. Indices were calculated using *ClimPACT v2* software which operates using *R* via a graphical user interface (GUI). The software was developed by the ET-SCI. It is free and available at https://github.com/ARCCSS-extremes/climpact2/archive/master.zip

5 Example rainfall plots

A selection of rainfall plots are provided here to illustrate the rainfall indices data generated at the 30 New Zealand locations. All rainfall indices data for each of the 30 locations were provided to the Ministry.

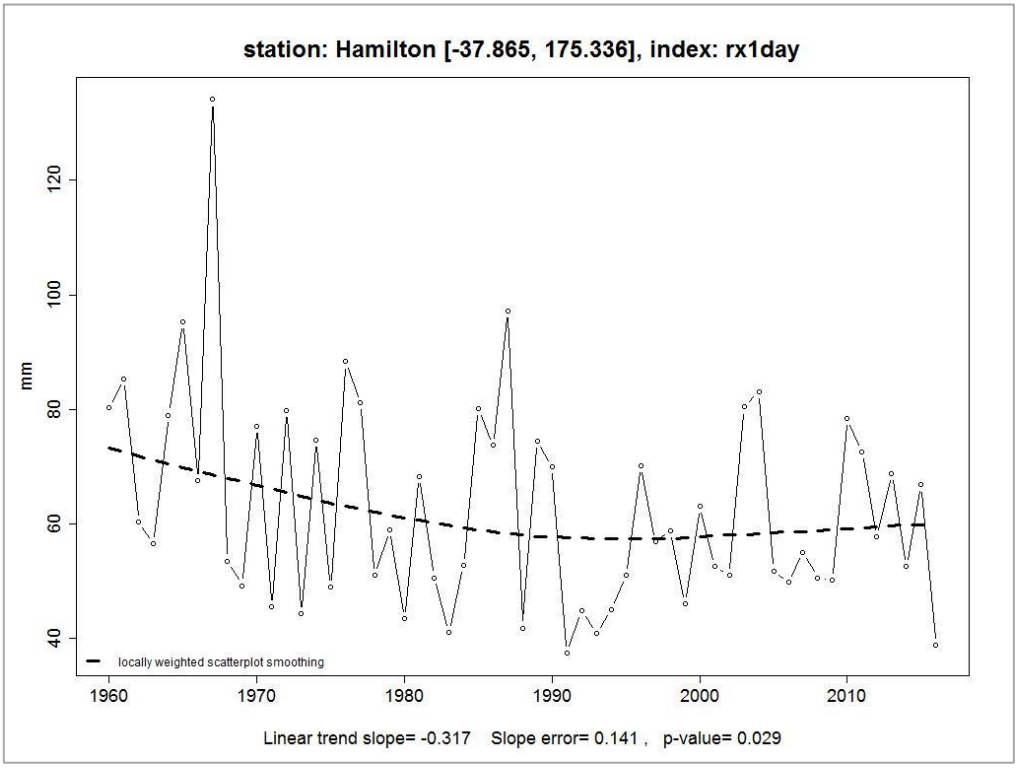

Figure 1: Hamilton *rx1day* (annual maximum 1-day precipitation total).

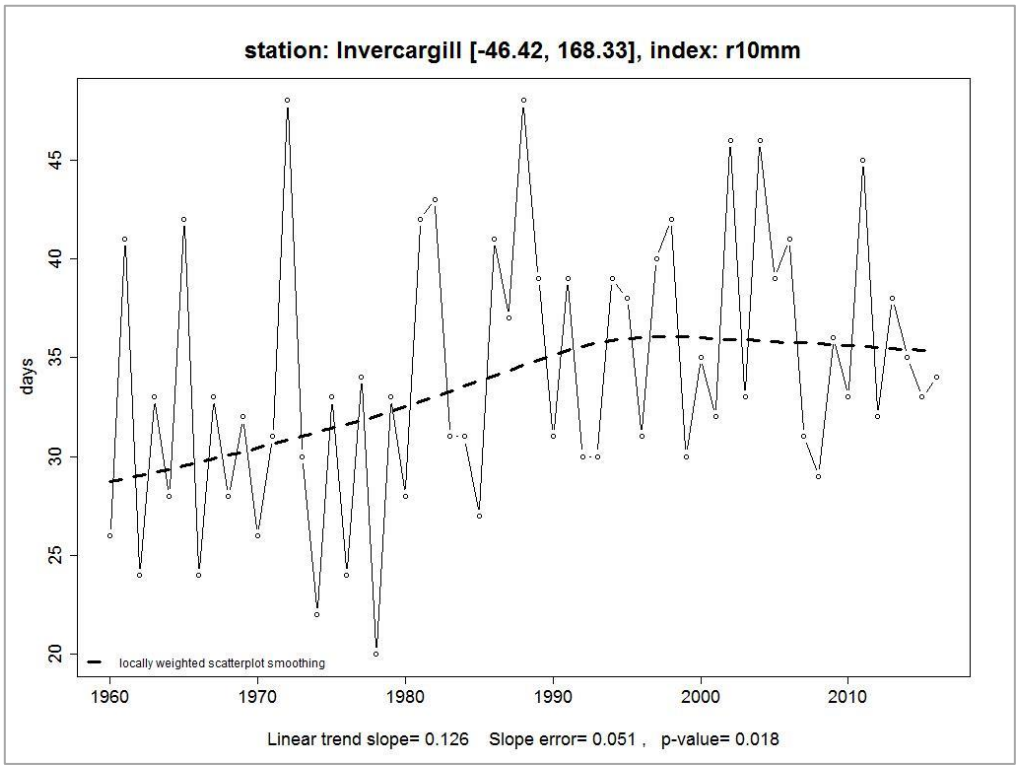

Figure 2: Invercargill *r10mm* (annual number of days when precipitation ≥ 10 mm).

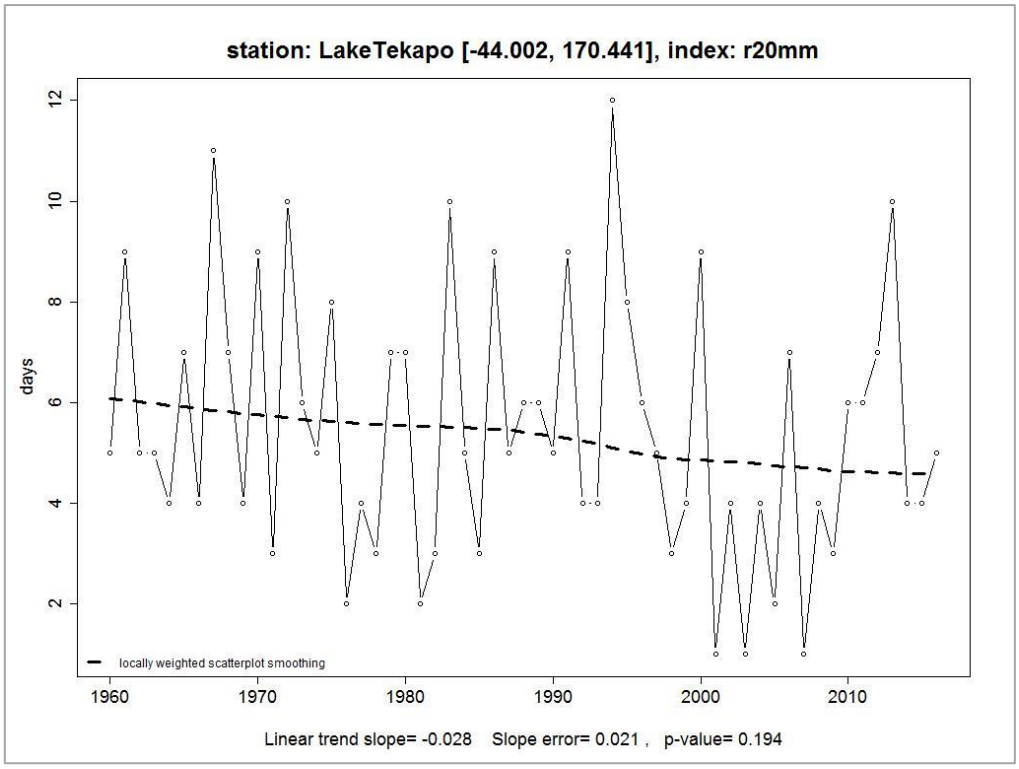

Figure 3: Lake Tekapo *r20mm* (annual number of days when precipitation ≥ 20 mm).

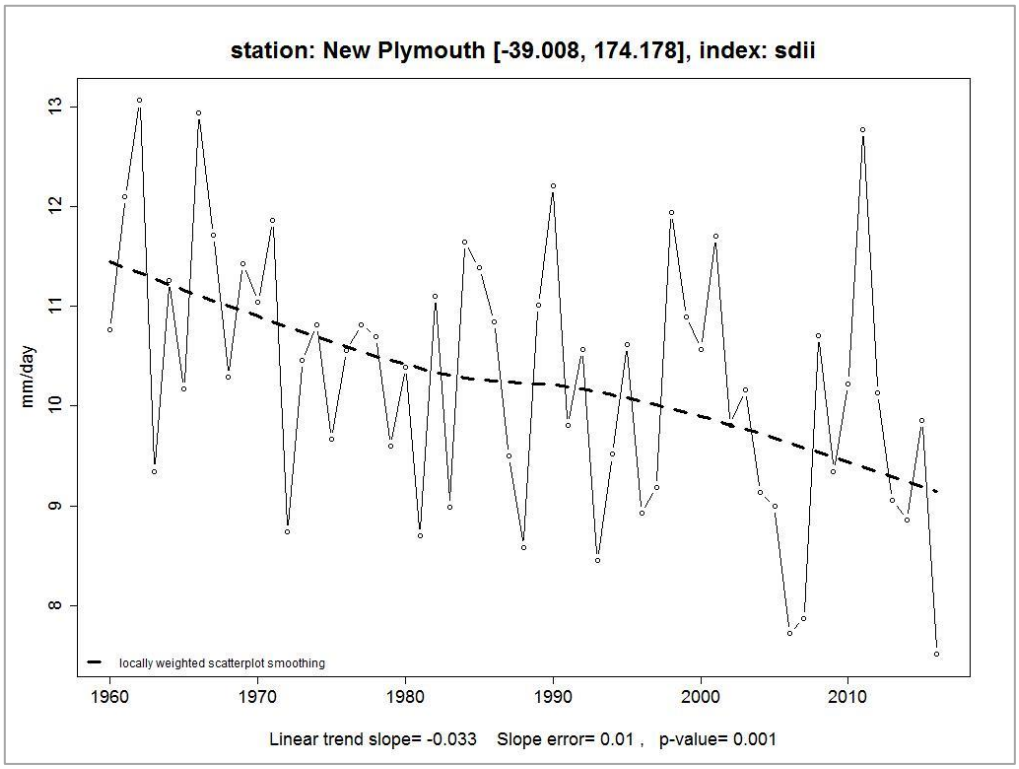

Figure 4: New Plymouth *sdii* (annual total precipitation divided by the number of wet days).

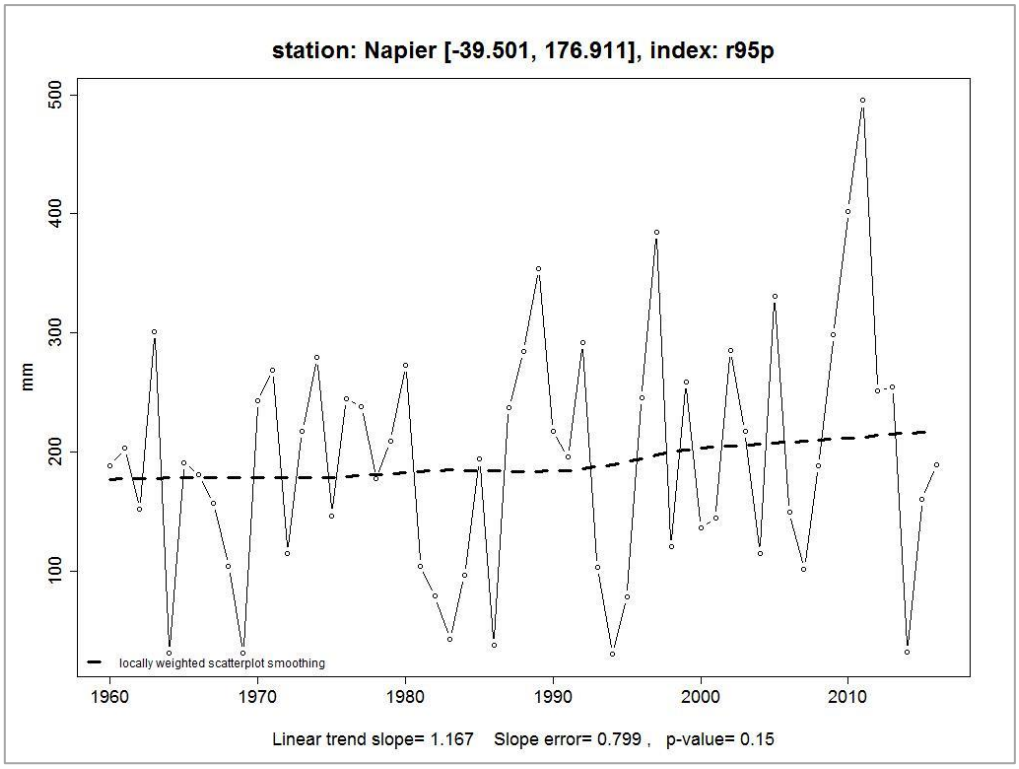

Figure 5: Napier *r95p* (annual sum of daily precipitation > 95th percentile).

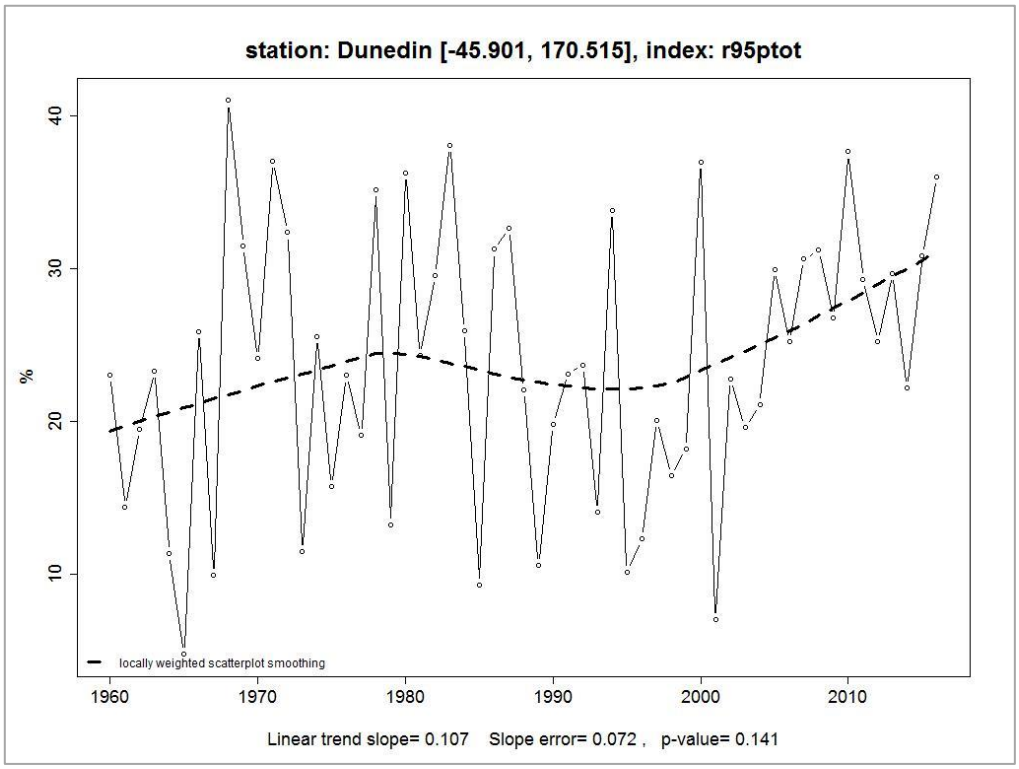

Figure 6: Dunedin *r95ptot* (percentage of the annual rainfall total that has come from heavy rainfall events).

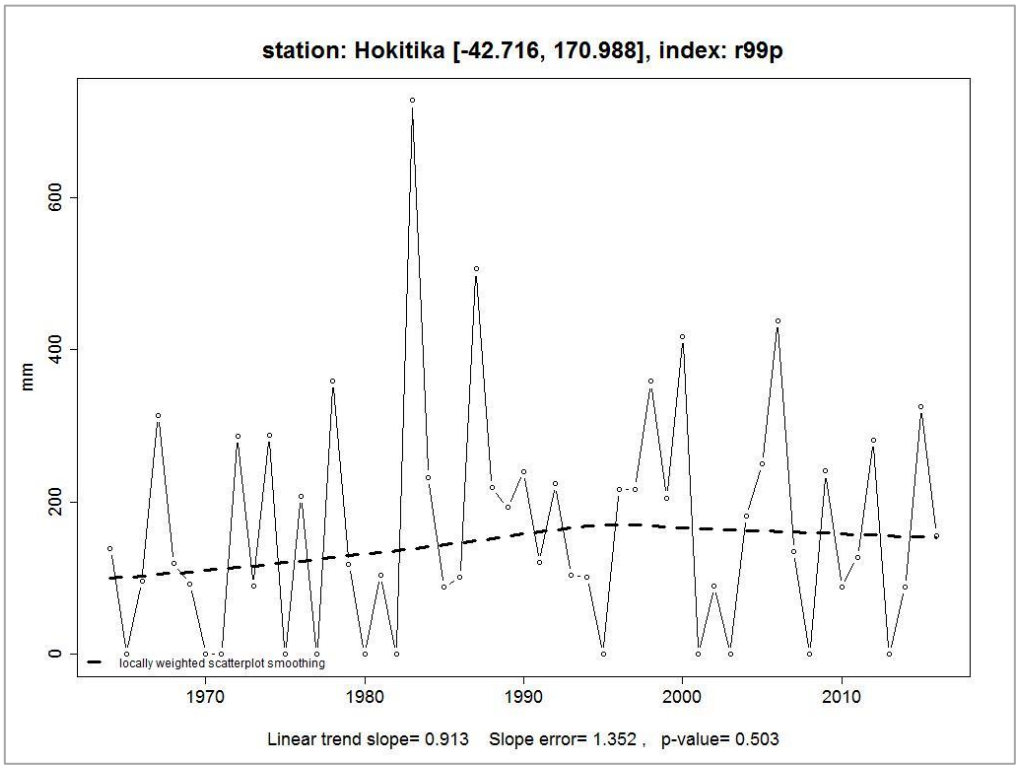

Figure 7: Hokitika *r99p* (annual sum of daily precipitation > 99th percentile).

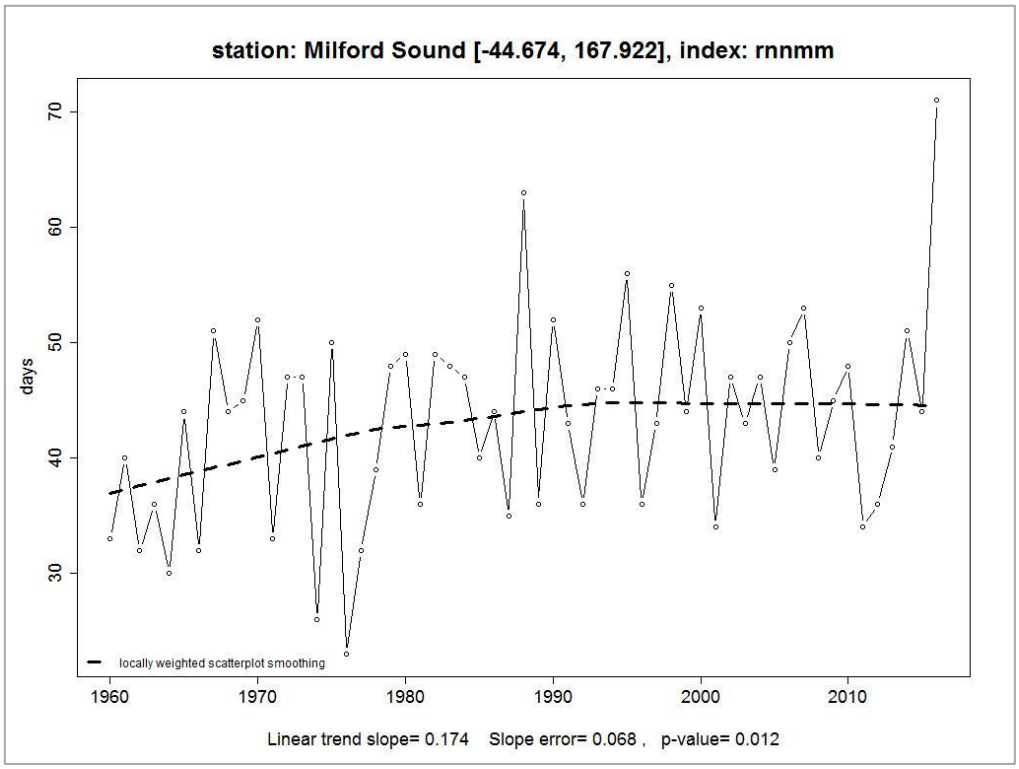

Figure 8: Milford Sound *rnnmm* (annual number of days when precipitation ≥ 50 mm).

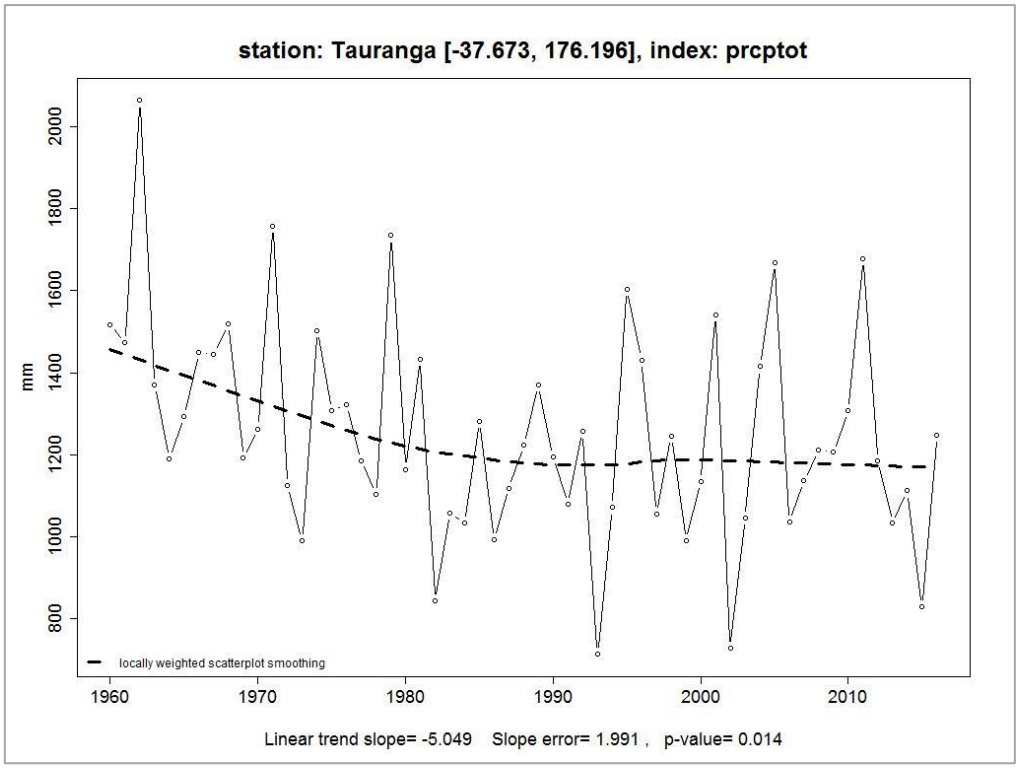

Figure 9: Tauranga *prcptot* (annual total precipitation).

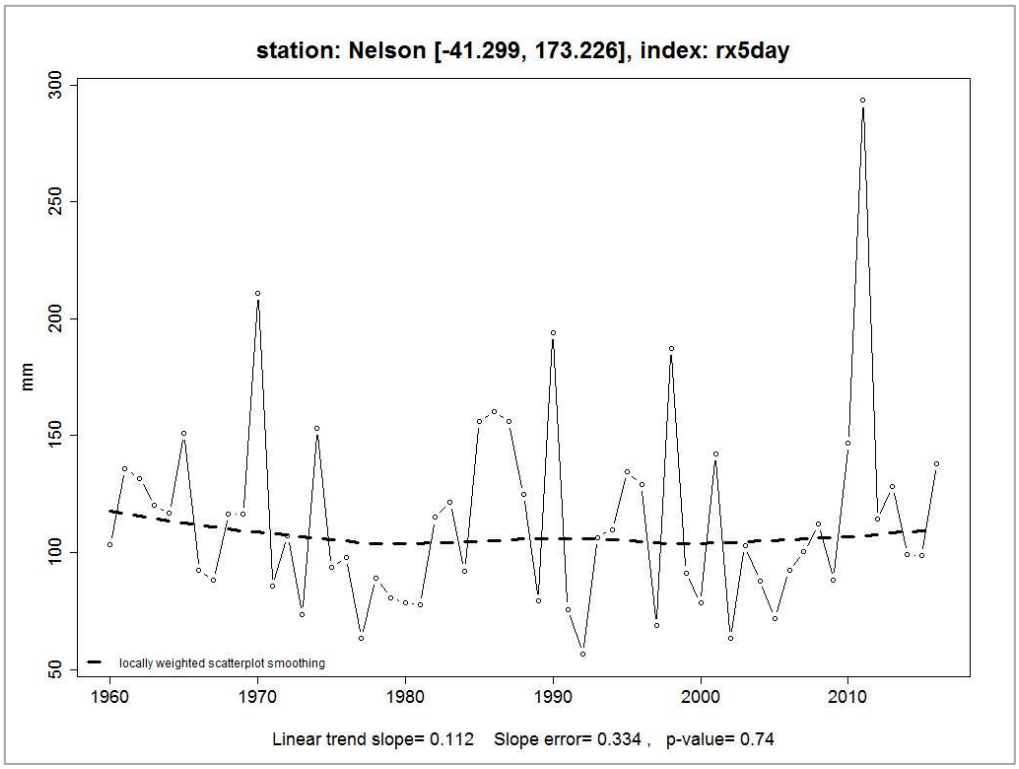

Figure 10: Nelson *rx5day* (annual maximum 5-day precipitation total).

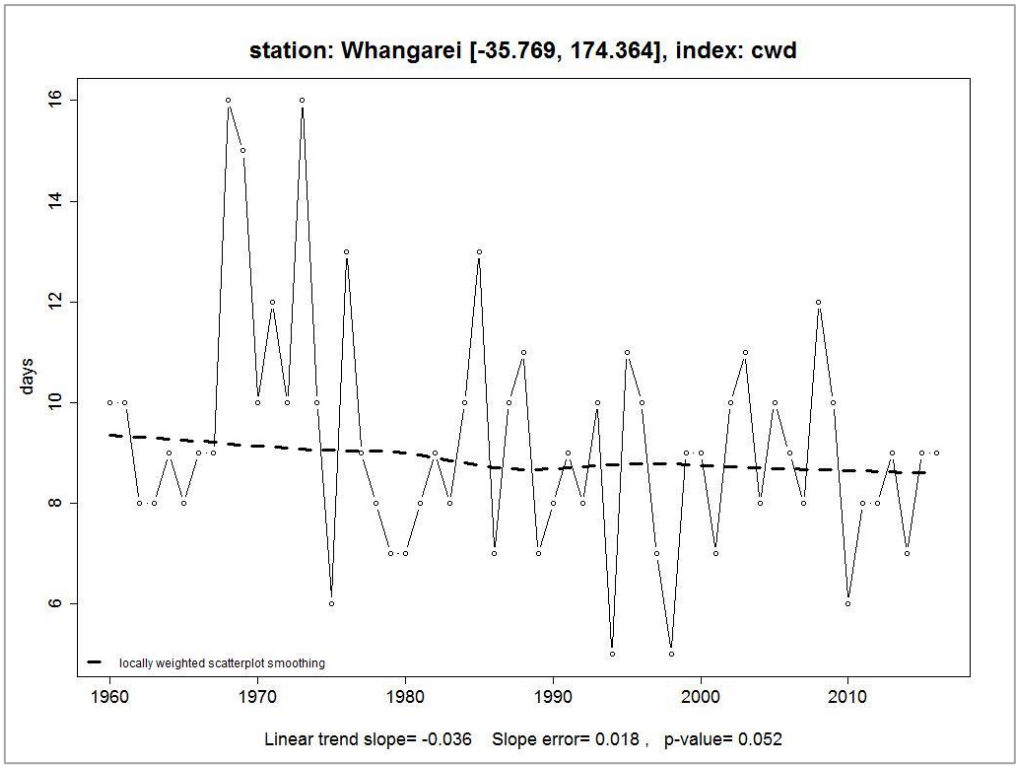

Figure 11: Whangarei *cwd* (annual maximum number of consecutive wet days).

6 New Zealand rainfall index

A single rainfall index was generated for New Zealand for the period 1960-2016. This was based on the *r95ptot* index data generated for the 30 New Zealand locations included in this investigation (Appendix A). Firstly, the 1981-2010 average *r95ptot* was calculated for each location (i.e., the "*normal*" percentage of the annual rainfall coming from heavy rainfall events). Next, for each year, the number of sites where the annual percentage value exceeded their respective 1981-2010 average was tallied. Note:

- When the value of *r95ptot* > *normal*, it may be interpreted that a given location has received a greater proportion than usual of its annual rainfall from heavy rainfall events.
- The annual tally of locations where *r95ptot* > *normal* enables a ratio to be generated; ratio values below 0.5 indicate less than half of the available New Zealand locations observed *r95ptot* > *normal*, whereas ratio values above 0.5 indicate more than half of the New Zealand locations observed *r95ptot* > *normal*.

Figure 12 shows the annual New Zealand rainfall index for the period 1960-2016. The 1981-2010 average New Zealand rainfall index ratio was 0.49. The highest ratio of 0.80 was observed in 2011. Notably, a strong La Niña event in the equatorial Pacific dominated New Zealand's climate for the first half of 2011, with northeasterly winds more frequent than normal over the country for the year overall. A relatively low ratio of 0.20 was observed in 2007. Air pressures were higher than normal over New Zealand during 2007, and many parts of the country observed less than 75% of normal annual rainfall.

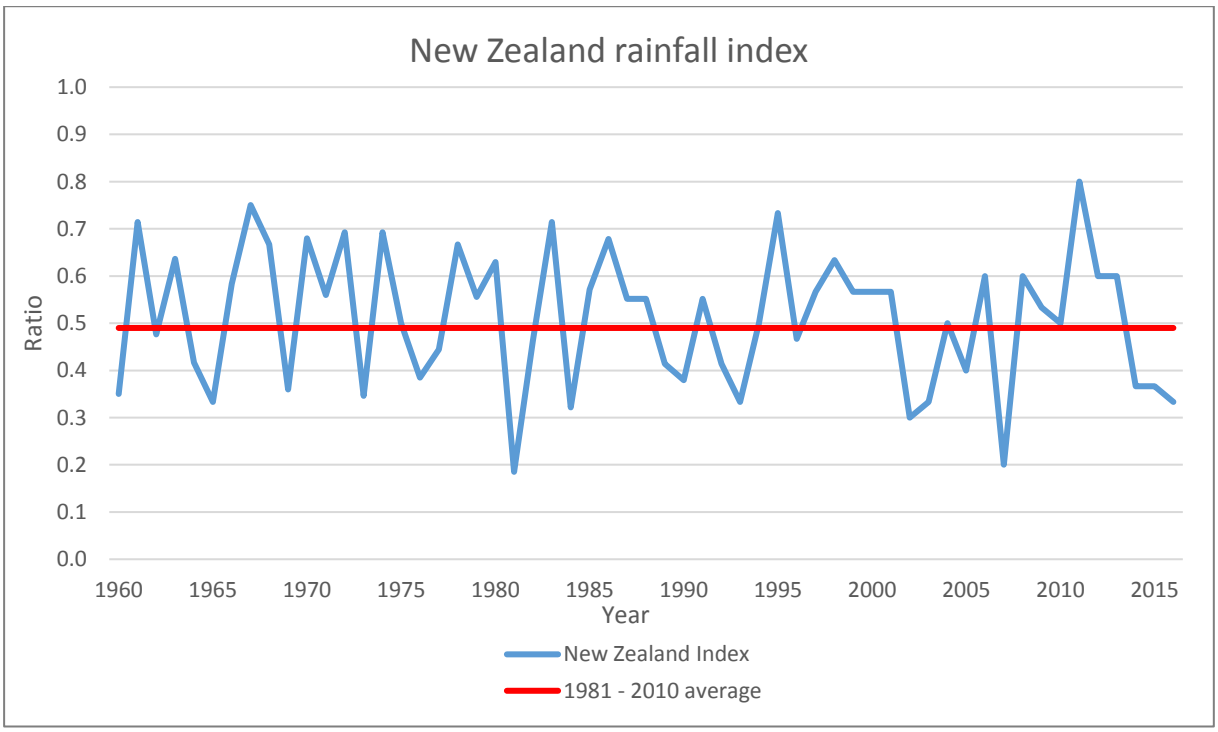

Figure 12: Annual New Zealand rainfall index. Plotted as a ratio, which was calculated as the number of locations where *r95ptot* > *normal* divided by the number of locations available. The 1981-2010 average and linear trend line is also shown.

7 References

Klein Tank, A.; F. Zwiers and X. Zhang (2009) Guidelines on Analysis of extremes in a changing climate in support of informed decisions for adaptation. WCDMP-No. 72, WMO-TD No. 1500, 52p.

Tait, A.; G. Macara and V. Paul (2014) Preparation of climate datasets for the 2015 Environmental Synthesis Report: Temperature, Rainfall, Wind, Sunshine and Soil Moisture. Client Report no. WLG2014-91. Prepared for the Ministry for the Environment, 27p.

Wratt, D.; A. Tait; G. Griffiths; P. Espie; M. Jessen; J. Keys; M. Ladd; D. Lew; W. Lowther; I. Lynn; N. Mitchell; J. Morton; J. Reid; S. Reid; A. Richardson; J. Sansom and U. Shankar (2006) Climate for crops: Integrating climate data with information about soils and crop requirements to reduce risks in agricultural decision-making. *Meteorological Applications*, 13, pp 305–315.

Appendix A Stations selected

Note: If more than one station is listed for a given location, then these data were merged (i.e. the data record was extended back in time) according to the methods outlined in Section 3.

Location	Station (agent #)	VCSN agent #
Auckland	Auckland Aero (1962)	25397
Blenheim	Blenheim Aero Aws (4326) Blenheim Aero (4322)	27539
Christchurch	Christchurch Aero (4843)	21209
Dannevirke	Dannevirke Ews (26958) Dannevirke (2534)	27324
Dunedin	Dunedin, Musselburgh Ews (15752) Dunedin, Musselburgh (5402)	19446
Gisborne	Gisborne Aws (2810) Gisborne Aero (2807)	30645
Gore	Gore Aws (5778) Gore, Grasslands D.S.I.R. (5780)	12819
Hamilton	Hamilton Aws (2112) Hamilton Aero (2110)	27690
Hokitika	Hokitika Aero (3909)	19484
Invercargill	Invercargill Aero (5814)	10735
Kerikeri	Kerikeri Ews (1056)	27019
Lake Tekapo	Lake Tekapo, Air Safaris (4970)	14142
Masterton	Masterton, Te Ore Ore Cws (37662) Masterton, Te Ore Ore (7578)	28818
Milford Sound	Milford Sound (4107)	7697
Napier	Napier Ews (41330) Napier Nelson Pk (2997)	30044
Nelson	Nelson Aero (4241)	20596
New Plymouth	New Plymouth Aws (2283)	27582

	New Plymouth Aero (2282)	
Queenstown	Queenstown Aero Aws (5451) Queenstown Aero (5450)	14551
Reefton	Reefton Ews (3925)	18967
Rotorua	Rotorua Aero Aws (1770) Rotorua Aero 2 (1768)	30493
Tara Hills	Tara Hills Aws (5212) Omarama, Tara Hills (5211)	13473
Taumarunui	Taumarunui Ews (40983) Taumarunui (2250)	28702
Taupo	Taupo Aws (1858) Taupo Aero (1856)	28898
Tauranga	Tauranga Aero Aws (1615) Tauranga Aero (1612)	28397
Timaru	Timaru Aero Aws (5086) Timaru Aero (5084)	19839
Waiouru	Waiouru Treatment Plant (3629)	29323
Wellington	Wellington, Kelburn Aws (25354) Wellington, Kelburn (3385)	28602
Whanganui	Wanganui, Spriggens Park Ews (3715)	28141
Whangaparaoa	Whangaparaoa Aws (1400)	21808
Whangarei	Whangarei Aero Aws (1287) Whangarei Aero (1283)	21619

Appendix B Regression analyses – rainfall

The following table shows the regression equation and associated R^2 value for analyses pertaining to daily rainfall.

Original	Comparison	Regression	R^2
Auckland Aero	VCSN	0.8860*x* + 0.1190	0.9316
Blenheim Aero Aws	VCSN	0.9696*x* + 0.0825	0.9779
Blenheim VCSN adjusted	Blenheim Aero	0.9726*x* - 0.0355	0.9680
Christchurch Aero	VCSN	0.9545*x* + 0.0451	0.9619
Dannevirke Ews	Dannevirke	0.9900*x* - 0.0552	0.9752
Dannevirke merged	VCSN	0.9307*x* + 0.1914	0.8929
Dunedin, Musselburgh Ews	Dunedin, Musselburgh	0.8905*x* - 0.0799	0.9903
Dunedin merged	VCSN	0.7570*x* + 0.1235	0.9274
Gisborne Aws	Gisborne Aero	0.9568*x* + 0.1709	0.9389
Gisborne merged	VCSN	0.9449*x* + 0.0850	0.9677
Gore Aws	Gore, Grasslands D.S.I.R.	0.9635*x* - 0.0555	0.9544
Gore merged	VCSN	0.9164*x* + 0.0237	0.9444
Hamilton Aws	VCSN	0.9832*x* + 0.1165	0.9488
Hamilton VCSN adjusted	Hamilton Aero	0.9859*x* + 0.1377	0.9637
Hokitika Aero	VCSN	1.0041*x* + 0.0620	0.9660
Invercargill Aero	VCSN	0.9777*x* + 0.0683	0.9762
Kerikeri Ews	VCSN	0.9575*x* + 0.0938	0.9757
Lake Tekapo, Air Safaris	VCSN	0.8907*x* + 0.0502	0.9054
Masterton merged	VCSN	0.9491*x* + 0.1753	0.9438
Milford Sound	VCSN	1.0326*x* - 0.0956	0.9937
Napier Ews	VCSN	0.9574*x* + 0.1013	0.9747
Napier VCSN adjusted	Napier Nelson Pk	0.9245*x* + 0.0505	0.9345
Nelson Aero	VCSN	0.9201*x* + 0.0414	0.9631
New Plymouth Aws	New Plymouth Aero	1.0044*x* + 0.1073	0.8841
New Plymouth merged	VCSN	0.9715*x* - 0.0248	0.9587
Queenstown Aero Aws	Queenstown Aero	0.9199*x* + 0.2377	0.6781
Queenstown merged	VCSN	0.8630*x* + 0.1151	0.9059
Reefton Ews	VCSN	0.9800*x* + 0.0797	0.9587
Rotorua Aero Aws	Rotorua Aero 2	0.9701*x* + 0.0681	0.8725
Rotorua merged	VCSN	0.9740*x* - 0.0137	0.9404
Tara Hills Aws	Omarama, Tara Hills	1.0182*x* - 0.0622	0.9849
Tara Hills merged	VCSN	0.9502*x* + 0.0578	0.9543
Taumarunui Ews	Taumarunui	0.8344*x* + 0.3109	0.8146

Taumarunui merged	VCSN	0.8520*x* + 0.2073	0.9594
Taupo Aws	Taupo Aero	0.9825*x* + 0.1083	0.9726
Taupo merged	VCSN	0.9099*x* + 0.1328	0.9452
Tauranga Aero Aws	Tauranga Aero	0.9973*x* + 0.1677	0.8518
Tauranga merged	VCSN	0.9384*x* + 0.0250	0.9623
Timaru Aero Aws	VCSN	0.9374*x* + 0.1018	0.9288
Timaru VCSN adjusted	Timaru Aero	0.9499*x* + 0.0171	0.9633
Waiouru Treatment Plant	VCSN	0.9538*x* + 0.0995	0.8912
Wellington, Kelburn Aws	Wellington, Kelburn	1.0612*x* - 0.0073	0.9947
Wellington merged	VCSN	1.0544*x* + 0.1245	0.9664
Whanganui, Spriggens Park Ews	VCSN	0.9509*x* - 0.0131	0.9631
Whangaparaoa Aws	VCSN	0.7936*x* + 0.1598	0.7339
Whangarei Aero Aws	VCSN	0.9031*x* - 0.0281	0.9156
Whangarei VCSN adjusted	Whangarei Aero	0.9318*x* + 0.5123	0.9033

Appendix C Daily rainfall record availability

The following table lists the availability of daily rainfall data at each location, subsequent to data infilling and time series extension.

Location	Data available
Auckland	1/5/1962 – 31/12/2016
Blenheim	1/1/1960 – 31/12/2016
Christchurch	1/1/1960 – 31/12/2016
Dannevirke	1/1/1960 – 31/12/2016
Dunedin	1/1/1960 – 31/12/2016
Gisborne	1/1/1960 – 31/12/2016
Gore	1/10/1971 – 31/12/2016
Hamilton	1/1/1960 – 31/12/2016
Hokitika	1/12/1963 – 31/12/2016
Invercargill	1/1/1960 – 31/12/2016
Kerikeri	1/10/1981 – 31/12/2016
Lake Tekapo	1/1/1960 – 31/12/2016
Masterton	1/9/1992 – 31/12/2016
Milford Sound	1/1/1960 – 31/12/2016
Napier	1/1/1960 – 31/12/2016
Nelson	1/1/1960 – 31/12/2016
New Plymouth	1/1/1960 – 31/12/2016
Queenstown	1/9/1968 – 31/12/2016
Reefton	1/8/1960 – 31/12/2016
Rotorua	11/11/1963 – 31/12/2016
Tara Hills	1/1/1960 – 31/12/2016
Taumarunui	1/1/1960 – 31/12/2016
Taupo	1/2/1976 – 31/12/2016
Tauranga	1/1/1960 – 31/12/2016
Timaru	1/1/1960 – 31/12/2016
Waiouru	1/1/1960 – 31/12/2016
Wellington	1/1/1960 – 31/12/2016
Whanganui	1/1/1960 – 31/12/2016
Whangaparaoa	1/12/1986 – 31/12/2016
Whangarei	1/1/1960 – 31/12/2016