APPENDIX A

Definitions

Actual evaporation — The actual amount of evaporation that if moisture limited will be lower than the potential rate.

Annual — January to December, unless otherwise stated.

Average — That value of a dataset that is most typical or likely to occur, referring to the mean or median of a dataset.

Cumulative distribution function — F(Q) the theoretical cumulative distribution that is approximated by the observed probability of extreme flow occurrence P(Q).

Dry spell — A period of fifteen days or longer with less than 1 mm of rain on any day (Moir *et al.* 1986).

Effective rainfall — Rainfall minus potential evaporation for a particular time increment.

Evaporation — The combined loss of water from water surfaces, the soil and plants to the atmosphere.

Expected — The value which occurs most frequently or that which is equally likely to have observations above this value or below it.

Mean — Refers to the arithmetic mean.

Normal — The value which occurs most frequently or that which is equally likely to have observations above this value or below it.

Persistence — Tendency for anomalies to remain of the same sign and similar magnitude for many months (Wright 1985).

Potential evaporation — The evaporation rate from a well watered, short green crop.

Probability density function — f(Q) describes the theoretical continuous frequency distribution curve.

Rain days — A day with 0.1 mm of rainfall or greater (Moir *et al.* 1986).

Recurrence interval or return period — the average length of time between two events of a given size or larger.

Seasons	Summer	December, January, February
	Autumn	March, April May
	Winter	June, July, August
	Spring	September, October, November

Teleconnections — Climate anomalies that occur at great distances to each other but appear to be related.

Typical — The value which occurs most frequently or that which is equally likely to have observations above this value or below it.

APPENDIX B

RAINFALL AND DISCHARGE DATABASE

Table B1 Rainfall Stations

Station Location	Station No.	Start Date	Grid Reference NZMS 260	Alt. (m)	Operating Authority
Cape Reinga +	A42462	1941	M02:817-525	191	NIWA
Parengarenga	A42582	1970	N02:011-369	55	NIWA
Cape View	A43701	1967	N03:137-222	37	NIWA
Waiharara	A43921	1956	M02:816-525	30	NIWA
Rangiputa	A43931	1970	O03:428-006	8	NIWA
Mangonui	A43951	1864	O04:596-890	11	NIWA
Aupouri ++	530204	1967	N04:289-879	69	NRC
Kaingaroa	A53031	1962	O04:414-844	30	NIWA
Matauri ++	A53081	1964	P04:922-846	183	NIWA
Ahipara	A53111	1961	N04:252-708	5	NIWA
Kaitaia	A53121	1893	O04:345-766	8	NIWA
Rangitihi	A53132	1961	O04:414-755	37	NIWA
Victoria Valley	531411	1966	O04:482-729	91	NIWA
Kerikeri MAF	A53191	1981	P05:955-687	79	NIWA
Laurensons	531910	1977	P05:972-669	61	NRC
Herekino	A53222	1941	O04:309-597	34	NIWA
Takahue	532311	1976	O05:440-653	122	NIWA
Omahuta	A53253	1977	O05:645-641	30	NIWA
Taus Falls*	A53281	1951	P05:851-614	308	NIWA
Tyrees	532810	1966	P05:910-622	168	NIWA
Waikimihia	532910	1977	P05:996-643	40	NRC
Waihou	533610	1976	P05:708-544	61	NIWA
Omapere	533812	1965	P05:856-486	274	NIWA
Oheawai	533813	1967	P05:901-490	122	NIWA
Puhata	A53321	1979	O05:623-562	9	NIWA
Opononi	A53442	1964	O06:488-350	12	NIWA
Rawene	A53453	1977	O05:566-441	15	NIWA
Kaikohe B.	534724	1985	P05:831-406	282	NRC
Kaikohe +	A53471	1922	P05:855-418	162	NIWA
Kaikohe DSIR ++	A53482	1973	P05:834-418	204	NIWA

Station Location	Station No.	Start Date	Grid Reference NZMS 260	Alt. (m)	Operating Authority
Kaikohe DSIR	A53487	1985	P05:834-418	204	NIWA
Waiotemarama	A53541	1977	O06:494-302	229	NIWA
Waiora	535510	1976	O06:651-255	335	NIWA
Waipoua*	A53651	1928	O06:612-666	88	NIWA
Ty Ranch	536611	1966	O06:689-186	433	NIWA
Waimatenui	A53672	1914	P06:768-191	213	NIWA
Pipiwai +	A53672	1948	P06:012-161	76	NIWA
Kaihu	537611	1968	P07:700-087	244	NRC
Parakao	A53791	1948	P07:969-093	55	NIWA
Mamranui	A53881	1956	P07:829-930	49	NIWA
Awakino	538810	1962	P07:866-962	47	NRC
Baylies Beach	539710	1976	P07:781-831	60	NRC
Dargaville +	A53981	1930	P07:879-950	20	NIWA
Dargaville	A53982	1930	P07:879-950	20	NIWA
Waitangi	542010	1975	P05:065-578	30	NIWA
Russell*	A54201	1919	P07:879-950	20	NIWA
Kawakawa	A54301	1918	P05:072-462	8	NIWA
Waiotu	545111	1978	Q06:150-328	120	NRC
Puhipuhi*	545201	1905	Q06:267-323	215	NIWA/NRC
Hukerenui	545213	1974	Q06:197-303	122	NRC
Whakapara	545310	1968	Q06:335-313	107	NRC
Matapouri	A54551	1964	Q07:469-251	3	NIWA
Jordan Valley	546212	1967	Q06:217-214	107	NRC
Hikurangi	A54622	1970	Q06:272-212	107	NIWA
Ruatangata	A54623	1963	Q06:206-141	152	NIWA
Glenbervie	546301	1947	Q06:325-152	107	NRC
Ngunguru	546412	1968	Q06:419-197	137	NIWA
Riponui	546510	1969	Q06:118-202	107	NRC
Wairua Falls	A54701	1916	P07:072-043	15	NIWA
Maungatapere ++	A54721	1954	Q07:198-044	122	NIWA
Otaika	547219	1979	Q07:235-042	120	NRC
Whau Valley	A54735	1970	Q07:278-099	152	NIWA
Onerahi +	A54733	1949	Q07:340-028	37	NIWA
Onerahi Aero	A54737	1990	Q07:340-028	37	NIWA
Tangihua	A54811	1958	Q07:115-952	84	NIWA
Mangapai	A54821	1970	Q07:277-945	64	NIWA
Tauraroa	548310	1964	Q07:295-914	137	NRC
Monymusk	549010	1976	P08:049-780	20	NRC

Station Location	Station No.	Start Date	Grid Reference NZMS 260	Alt. (m)	Operating Authority
Manganui*	549310	1963	Q08:279-779	60	NRC
Arapohue	A63091	1955	P09:954-780	61	NIWA
Waihoihoi	640411	1968	Q08:397-724	61	NRC
Waipu	A64051	1949	Q08:464-732	61	NIWA
Ruawai +	A64101	1949	P08:027-651	5	NIWA
Ruawai	A64112	1967	Q08:115-632	70	NIWA
Paparoa	A64123	1970	Q08:216-659	30	NIWA
Maungataroto	A64132	1949	Q08:342-589	17	NIWA
Hakaru	641413	1979	Q08:444-613	100	NRC
Mangawhai	A64151	1917	R08:528-628	4	NIWA
Tara	641511	1946	Q08:477-646	90	NRC
Pukehau	A64221	1955	Q08:234-543	61	NIWA
Topuni	A64241	1948	Q08:417-530	63	NIWA

The asterisk (*) beside the rainfall station number signifies those stations with missing monthly rainfall totals in their time series that have been estimated. The rainfall stations with a plus (+) sign beside their station number are those that have been closed and have had their records extended, by the author, up to December 1992. Rainfall stations with two plus signs beside their station number (++) signify those stations that have closed but have not had their rainfall records extended.

Missing values were estimated or records extended for those time series from stations signalled above by deploying single or multiple regression methodology, using monthly rainfall totals from other close rainfall stations as the independent variables. Gordon *et al.* (1992) states that the problem of estimates for sites which have missing records or the extension of short-term records can be addressed with regression methods. The dependent variable (Y) represents records from the short term or intermittent site, and the independent variables (X_1, X_2....X_n), represent record lengths from the long term, surrounding stations in a homogenous climatic zone. The resulting multiple regression equation can be used to generate data for missing periods or to extend the short term record to the length of the long term one (Gordon *et al.* 1992).

The stations whose missing rainfall records were estimated or whose records were extended and those time series that were used as independent variables in the multiple regression equations are given in Table B2. Regarding the closed rainfall stations with a shortened data record, if there was a rainfall station located close by that had similar statistical parameters to the shortened time series the two time series were simply added together.

Table B2 Description of adjusted rainfall time series

Taus Falls	Missing months: Nov 1966, Dec 1968, Nov 1977, May 1974, Sep 1974, Jan 1975. Rainfall time series used to estimate the missing Taus Falls values was Kerikeri (A53191) and Tyrees (532821).
Waipoua	Missing months: April-May 1987. Rainfall time series used to estimate the missing Waipoua Forest data was Opononi (A53442) and Waitemarama (A53541).
Puhipuhi	Missing months: June-July 1987, Feb 1988 and April 1992. Rainfall time series used to estimate the missing Puhipuhi data was Waiotu (545111) and Hukerenui (545213).
Manganui	Missing month: Sept 1991. Rainfall time series used to estimate the missing Manganui data was Tauraroa (548310).
Russell	Missing months Oct 1975-Dec 1979, Sep 1989. Rainfall time series used to estimate the missing Russell data was Kawakawa (A54301) and Wakelins (542010).
Cape Reinga	Station closed in December 1988. Record extended from Jan 1988 to Dec 1992. Rainfall time series used to estimate the Cape Reinga time series was Parengarenga (A42582) and Cape View (A43701).
Kaikohe (Orr)	Station closed in June 1971. DSIR Freshwater in Whangarei extended this time series using rainfall time series from Kaikohe (A53487), Kaikohe (A53482) and Kaikohe (534724).
Onerahi	Station closed in March 1988. Record extended from April 1988 to Dec 1992. The Whangarei Aeroclub (A54737) time series was added on to the Onerahi time series.
Dargaville	Station closed in Dec 1989. Record extended from Jan 1990 to Dec 1992. The Dargaville (A53982) time series was added on to the Dargaville (53981) time series.
Ruawai	Station closed in Jan 1985. Record extended from Feb 1985 to Dec 1992. Rainfall time series used to estimate the Ruawai time series was Ruawai (A64112), Arapohue (A63091) and Pukehau (A64221).
Mangawhai	Station closed in April 1986. Record extended from May 1986 to Dec 1992. Rainfall time series used to estimate the Mangawhai time series was Waipu (A64051), Hakaru (641413) and Tara (641551).

Table B3 Discharge stations

Station No.	River	Grid Reference NZMS 260:	Area above Flow Station (km^2)	Start Date	Recorder Type	Operating Authority
1316	Awanui	O04:352-761	222	Jan-58	F&P/Fox	NIWA
46618	Mangakahia	P06:878-189	246	Dec-60	F&P	NIWA
3722	Waitangi	P05:061-577	302	Feb-79	F&P	NIWA
48015	Mangamuka	O05:564-668	23.3	Mar-76	F&P	NIWA
4901	Ngunguru	Q06:405-214	12.5	Aug-69	L&S	NIWA
3506	Mangaparerua	P05:913-625	11.1	Nov-67	F&P	NIWA
47527	Opahi	N15:234-344	10.6	1966	L&S	NIWA
46614	Wairua	Q06:149-158	544	Mar-60	L&S	NRC
46651	Manganui	Q07:110-816	411	May-60	L&S	NRC

- All discharge stations have automatic water level records installed.
  F&P = Fischer and Porter
  L&S = Leupold and Stevens

It should be noted that neither the rainfall nor discharge time series were adjusted to compensate for the systematic errors that could exist, particularly inherent in the collection of precipitation data, which tend to result in undercatch (Houghton *et al.* 1992). The methods for correcting precipitation and discharge records are complex and require specific site and climatic data that is not readily available.

APPENDIX C

SUMMARY STATISTICS

This appendix provides the monthly summary statistics for rainfall time series from 20 rainfall stations in Northland.

Table C1 Monthly Means

Rainfall Station	Sample Size (years)	Months											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cape Reinga	50	66	62	72	99	96	119	125	112	90	69	62	59
Waiharara	35	68	83	78	96	106	140	133	133	106	85	76	74
Kaitaia	90	92	89	81	111	136	154	150	145	121	105	93	88
Herekino	38	91	97	100	122	148	183	168	177	138	125	115	100
Waipoua	63	88	103	100	135	161	188	187	176	138	135	112	104
Dargaville	70	84	85	77	99	129	148	136	126	96	96	85	80
Ruawai	38	70	84	93	94	115	141	130	137	99	94	87	87
Kaikohe	71	102	115	107	137	156	178	169	167	135	127	99	104
Pipiwai	38	87	108	130	121	137	174	173	166	131	124	105	118
Wairua Falls	76	92	97	93	114	135	150	150	139	110	101	93	92
Manganui	26	99	93	125	136	126	163	142	162	123	110	109	110
Maungataroto	38	89	100	116	112	136	160	146	160	124	107	101	100
Mangonui	100	87	90	91	120	144	157	154	156	119	102	87	80
Russell	73	89	102	107	122	148	149	162	156	122	101	88	85
Kawakawa	73	99	110	108	125	156	175	167	165	120	99	90	90
Onerahi	39	88	116	140	116	135	164	164	157	132	113	83	98
Mangawhai	76	80	85	88	105	123	154	144	134	105	96	86	78
Waimatenui	79	112	138	119	161	208	240	238	225	172	157	126	124
Taus Falls	38	136	184	197	193	207	256	237	257	202	181	134	148
Puhipuhi	86	125	148	167	168	199	216	228	216	162	140	115	111
Average		97	110	115	131	153	179	174	172	134	119	102	102

Table C2 Monthly Medians

Rainfall Station	Sample Size (years)	Months											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cape Reinga	50	45	41	58	86	87	111	114	105	82	57	53	50
Waiharara	35	40	58	73	84	100	118	130	125	97	75	63	68
Kaitaia	90	63	71	67	109	123	142	151	148	114	97	91	83
Herekino	38	69	81	106	117	136	174	161	173	135	130	113	101
Waipoua	63	71	80	88	133	149	191	187	177	138	118	108	91
Dargaville	70	70	62	59	86	117	144	131	130	98	87	82	71
Ruawai	38	54	60	82	83	112	129	129	141	90	87	79	77
Kaikohe	71	81	75	87	118	149	161	170	167	124	115	97	95
Pipiwai	38	72	90	107	113	131	170	173	180	124	115	101	100
Wairua Falls	76	72	75	83	102	125	147	145	130	109	93	89	89
Manganui	26	67	63	112	119	115	143	135	151	120	95	105	95
Maungataroto	38	51	66	101	89	127	161	136	152	119	99	93	92
Mangonui	100	70	69	81	104	132	146	149	140	115	100	79	67
Russell	73	64	63	87	111	134	148	162	156	114	85	81	69
Kawakawa	73	76	79	89	115	150	166	162	153	120	99	90	69
Onerahi	39	71	91	107	87	108	151	158	143	109	93	78	87
Mangawhai	76	60	66	77	94	110	138	132	129	99	92	81	85
Waimatenui	79	77	108	108	141	195	246	225	225	174	157	126	113
Taus Falls	38	86	133	182	148	195	221	249	248	187	181	117	128
Puhipuhi	86	93	113	150	137	179	182	219	205	142	129	98	89
Average		71	81	100	115	141	168	169	167	127	111	96	90

Table C3 Monthly Standard Deviations (Sd)

Rainfall Station	Sample Size (years)	Months											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cape Reinga	50	66	72	63	64	48	60	55	50	48	42	36	33
Waiharara	35	68	76	57	65	62	70	47	60	42	47	48	43
Kaitaia	90	84	69	55	55	75	63	60	63	50	58	45	45
Herekino	38	86	75	59	68	67	76	48	67	45	62	50	48
Waipoua	63	60	75	67	61	66	60	55	57	50	64	46	50
Dargaville	70	64	67	53	51	58	57	52	43	33	53	39	47
Ruawai	38	54	70	54	47	51	58	46	62	38	47	44	53
Kaikohe	71	82	91	74	95	85	82	67	70	58	69	48	80
Pipiwai	38	80	75	90	67	72	78	61	61	46	61	46	61
Wairua Falls	76	78	77	65	68	64	61	63	55	38	48	50	53
Manganui	26	96	73	81	111	69	78	50	75	47	64	54	65
Maungataroto	38	85	80	66	71	68	79	57	76	55	60	50	60
Mangonui	100	71	74	75	80	79	75	63	72	51	48	45	55
Russell	73	93	89	83	74	87	94	83	78	60	59	59	61
Kawakawa	73	85	87	77	83	86	88	71	72	60	58	52	59
Onerahi	39	83	92	105	84	92	93	73	81	72	76	44	58
Mangawhai	76	66	72	64	59	69	75	63	69	43	47	44	42
Waimatenui	79	91	112	77	92	102	87	87	83	57	82	59	72
Taus Falls	38	137	144	121	160	128	128	86	115	93	115	70	84
Puhipuhi	86	117	131	119	118	125	117	110	107	92	80	72	76
Average		87	90	79	83	82	83	68	75	57	65	53	60

Table C4 Monthly Skewness Coefficients (Sk)

Rainfall Station	Sample Size (years)	Months											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cape Reinga	50	2.1	2.9	2.2	1.9	1.0	1.0	0.2	1.3	1.0	1.6	0.6	0.9
Waiharara	35	1.7	1.3	0.9	1.9	1.4	1.2	0.7	0.6	1.1	0.4	1.7	1.3
Kaitaia	90	1.6	1.2	0.8	0.6	1.8	0.8	0.4	0.4	1.0	1.0	0.8	0.8
Herekino	38	2.3	1.7	0.5	1.2	1.0	0.9	0.6	0.2	1.3	0.3	0.6	0.4
Waipoua	63	1.2	0.9	2.0	1.1	0.9	0.3	0.4	0.4	0.4	1.6	0.6	1.1
Dargaville	70	1.4	1.0	1.2	1.5	0.7	0.3	1.1	0.4	0.0	1.9	0.4	1.1
Ruawai	38	1.3	1.3	-0.3	-0.5	-0.2	0.0	0.0	5.7	0.5	-0.5	-0.3	1.3
Kaikohe	71	1.4	1.1	0.8	1.9	0.6	0.6	0.5	0.2	0.8	1.3	0.8	3.7
Pipiwai	38	1.4	1.0	1.6	1.7	1.0	0.3	0.1	-0.2	0.5	0.3	0.3	0.6
Wairua Falls	76	2.0	1.2	1.6	1.7	0.5	0.4	0.9	0.6	1.0	0.9	0.7	0.9
Manganui	26	2.2	0.9	0.6	1.7	1.3	0.8	0.0	0.9	0.6	0.7	0.2	0.4
Maungataroto	38	1.7	1.1	0.5	1.3	0.9	0.3	0.5	0.8	0.9	0.3	0.8	0.7
Mangonui	100	1.3	1.1	2.0	2.0	1.1	1.0	1.1	0.6	0.7	0.4	0.6	1.1
Russell	73	2.2	1.4	1.1	1.5	0.7	1.4	1.0	1.0	1.4	1.4	1.0	1.6
Kawakawa	73	1.5	1.1	0.9	1.5	0.7	0.9	0.6	1.0	1.5	1.2	0.6	1.2
Onerahi	39	1.8	1.0	1.1	1.4	1.2	0.7	0.5	0.9	1.4	1.0	0.6	0.8
Mangawhai	76	1.4	1.6	1.4	1.8	0.8	1.1	0.5	1.2	0.6	0.7	0.5	0.4
Waimatenui	79	1.1	1.5	1.5	1.5	1.0	0.2	0.6	0.3	0.0	1.1	0.6	0.9
Taus Falls	38	2.3	1.1	0.5	2.1	1.2	0.5	0.3	0.5	1.3	0.7	0.9	1.0
Puhipuhi	86	2.2	1.6	1.1	1.3	1.0	1.0	0.6	0.6	1.6	0.9	0.7	1.0
Average		1.8	1.4	1.2	1.5	1.0	0.7	0.6	0.9	0.9	0.9	0.7	1.1

Table C4 Monthly Skewness Coefficients (Sk)

Rainfall Station	Sample Size (years)	Months											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cape Reinga	50	2.1	2.9	2.2	1.9	1.0	1.0	0.2	1.3	1.0	1.6	0.6	0.9
Waiharara	35	1.7	1.3	0.9	1.9	1.4	1.2	0.7	0.6	1.1	0.4	1.7	1.3
Kaitaia	90	1.6	1.2	0.8	0.6	1.8	0.8	0.4	0.4	1.0	1.0	0.8	0.8
Herekino	38	2.3	1.7	0.5	1.2	1.0	0.9	0.6	0.2	1.3	0.3	0.6	0.4
Waipoua	63	1.2	0.9	2.0	1.1	0.9	0.3	0.4	0.4	0.4	1.6	0.6	1.1
Dargaville	70	1.4	1.0	1.2	1.5	0.7	0.3	1.1	0.4	0.0	1.9	0.4	1.1
Ruawai	38	1.3	1.3	-0.3	-0.5	-0.2	0.0	0.0	5.7	0.5	-0.5	-0.3	1.3
Kaikohe	71	1.4	1.1	0.8	1.9	0.6	0.6	0.5	0.2	0.8	1.3	0.8	3.7
Pipiwai	38	1.4	1.0	1.6	1.7	1.0	0.3	0.1	-0.2	0.5	0.3	0.3	0.6
Wairua Falls	76	2.0	1.2	1.6	1.7	0.5	0.4	0.9	0.6	1.0	0.9	0.7	0.9
Manganui	26	2.2	0.9	0.6	1.7	1.3	0.8	0.0	0.9	0.6	0.7	0.2	0.4
Maungataroto	38	1.7	1.1	0.5	1.3	0.9	0.3	0.5	0.8	0.9	0.3	0.8	0.7
Mangonui	100	1.3	1.1	2.0	2.0	1.1	1.0	1.1	0.6	0.7	0.4	0.6	1.1
Russell	73	2.2	1.4	1.1	1.5	0.7	1.4	1.0	1.0	1.4	1.4	1.0	1.6
Kawakawa	73	1.5	1.1	0.9	1.5	0.7	0.9	0.6	1.0	1.5	1.2	0.6	1.2
Onerahi	39	1.8	1.0	1.1	1.4	1.2	0.7	0.5	0.9	1.4	1.0	0.6	0.8
Mangawhai	76	1.4	1.6	1.4	1.8	0.8	1.1	0.5	1.2	0.6	0.7	0.5	0.4
Waimatenui	79	1.1	1.5	1.5	1.5	1.0	0.2	0.6	0.3	0.0	1.1	0.6	0.9
Taus Falls	38	2.3	1.1	0.5	2.1	1.2	0.5	0.3	0.5	1.3	0.7	0.9	1.0
Puhipuhi	86	2.2	1.6	1.1	1.3	1.0	1.0	0.6	0.6	1.6	0.9	0.7	1.0
Average		1.8	1.4	1.2	1.5	1.0	0.7	0.6	0.9	0.9	0.9	0.7	1.1

Table C5 Monthly Kurtosis Coefficients (Kd)

Rainfall Station	Sample Size (years)	Months											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cape Reinga	50	4.5	10.4	6.1	5.7	0.8	0.9	-1.0	1.3	0.3	1.6	-0.3	0.2
Waiharara	35	2.0	0.8	0.6	4.6	1.8	0.9	0.6	-0.2	1.1	-0.3	3.9	2.5
Kaitaia	90	1.9	1.7	-0.1	0.7	6.5	0.2	-0.2	-0.4	1.5	1.8	0.8	0.8
Herekino	38	6.4	3.4	-0.3	1.5	0.5	0.4	0.3	-0.8	3.3	-0.6	-0.3	0.3
Waipoua	63	1.9	0.9	0.0	6.9	1.8	0.9	0.9	0.3	-0.4	-0.3	3.8	-0.3
Dargaville	70	2.4	0.3	1.2	3.1	0.0	-0.5	2.0	-0.1	-0.7	6.8	-0.5	1.1
Ruawai	38	1.3	1.3	-0.3	-0.5	-0.2	0.0	0.0	5.7	0.5	-0.5	-0.3	1.3
Kaikohe	71	1.7	0.1	-0.2	4.9	0.2	0.3	0.0	0.2	0.4	3.4	0.8	2.0
Pipiwai	38	1.6	0.3	3.6	3.7	1.2	-1.0	-1.1	-0.9	0.1	-0.8	-0.8	0.0
Wairua Falls	76	5.6	1.4	4.0	4.9	-0.2	-0.2	2.2	-0.1	2.2	1.0	0.0	0.9
Manganui	26	4.0	-0.6	-0.6	2.7	2.2	-0.2	-0.8	0.5	0.0	-0.4	-0.9	-0.9
Maungataroto	38	2.1	0.5	-0.5	1.2	0.0	-0.7	0.0	0.5	1.4	-1.2	0.6	-0.2
Mangonui	100	1.5	0.4	6.8	7.8	1.6	1.5	2.3	-0.1	0.5	-0.1	-0.3	1.4
Russell	73	5.0	1.3	0.5	3.6	0.0	2.7	1.7	0.7	2.7	2.7	0.9	3.0
Kawakawa	73	2.0	0.4	0.6	3.5	2.0	1.7	0.8	1.1	3.4	2.4	-0.3	1.2
Onerahi	39	3.7	0.1	0.9	1.3	0.8	-0.3	-0.5	0.8	1.3	0.2	0.0	0.5
Mangawhai	76	1.9	3.0	2.7	5.2	0.1	1.8	-0.6	2.3	0.4	0.4	-0.3	0.0
Waimatenui	79	0.5	2.3	5.3	3.3	1.1	-0.4	0.1	-0.5	0.0	3.5	0.5	1.3
Taus Falls	38	6.2	0.2	-0.5	4.6	1.7	-0.6	0.5	0.1	1.7	-0.2	0.8	0.8
Puhipuhi	86	6.5	2.7	1.1	1.6	1.6	1.0	0.1	0.2	3.1	1.1	-0.6	0.3
Average		3.3	1.6	1.6	3.7	1.2	0.4	0.4	0.6	1.2	1.1	0.4	0.9

APPENDIX D

DROUGHT INDEX RESULTS

Table D1 Drought index severity results calculated over the entire time series record length for 20 selected rainfall stations.

Rainfall Station	1874-75	1877-78	1897-98	1902-03	1907-08	1911-12	1912-13	1913-14	1914-15	1917-18	1918-19	1919-20
Cape Reinga												
Waiharara												
Kaitaia			3.60	1.95	1.90	2.31		1.38		0	2.87	2.59
Mangonui	2.09	5.02		1.91	1.77	1.18	2.19	1.45	6.65	0	3.26	1.89
Russell												2.44
Kawakawa											3.52	1.55
Onerahi												
Mangwhai										0	3.05	5.81
Kaikohe												
Waimatenui									4.92	1.32	0	0
Taus												
Wairua										1.07	3.97	5.53
Pipiwai												
Puhipuhi					1.39	0	5.24	3.18	7.66	0	3.71	0
Manganui												
Herekino												
Waipoua												
Dargaville												
Ruawai												
Mangataroto												

Key

Blank space = missing rainfall data

0 No drought detected

Table D1 -cont-

Rainfall Station	1922-23	1923-24	1924-25	1925-26	1927-28	1928-29	1930-31	1931-32	1932-33	1933-34	1938-39	1941-42	1942-43	1944-45	1945-46
Cape Reinga												1.21	0	0	2.99
Waiharara															
Kaitaia	0	0	1.26	1.57	2.18	1.26	3.55	2.32	3.84	0	1.61	1.18	1.85	0	2.17
Mangonui	3.08	1.36	4.52	2.65	2.77	1.72	2.08	1.58	2.87	1.54	0	2.21	2.44	0	3.10
Russell	0	0	0	0	1.99	2.52	4.27	0	2.99	0	0	2.03	1.96	2.08	3.59
Kawakawa	0	0	2.36	1.87	2.14	1.47	3.06	0	2.76	0	0	4.06	1.34	1.25	3.93
Onerahi															
Mangwhai	0	2.38	1.65	1.56	2.06	1.65	2.07	0	1.52	0	1.68	3.58	1.89	0	4.84
Kaikohe	0	0	3.38	1.82	2.59	1.33	3.20	0	2.87	1.25	1.22	0	2.25	0	3.19
Waimatenui	0	0	2.18	1.51	2.70	1.51	2.91	0	0	1.52	1.54	1.61	1.72	0	3.32
Taus															
Wairua	1.24	0	2.04	1.49	2.38	1.31	2.61	0	3.93	0	1.47	1.06	1.44	0	3.47
Pipiwai															
Puhipuhi	0	1.62	1.75	1.60	1.58	1.66	3.47	0	0	0	1.11	1.58	1.43	0	3.25
Manganui															
Herekino												1.84	1.80	0	3.74
Waipoua						1.21	0	0	2.42	1.21	1.64	1.12	1.00	0	2.63
Dargaville	3.17	0	3.21	1.55	2.61	2.04	0	1.95	3.27	0	1.60	1.29	2.10	0	2.34
Ruawai															
Mangataroto															

Key

Blank space = missing rainfall data

0 No drought detected

Table D1 -cont-

Rainfall Station	1946-47	1947-48	1949-50	1953-54	1954-55	1957-58	1960-61	1961-62	1962-63	1963-64	1967-68	1969-70	1970-71	1971-72
Cape Reinga	0	0	3.85	1.15	0	1.50	1.23	3.07	0	0	1.30	2.31	1.80	0
Waiharara						1.42	1.83	2.16	1.61	2.42	1.53	1.02	0	0
Kaitaia	1.66	0	3.35	1.91	0	1.61	0	1.54	1.21	2.91	3.66	0	0	0
Mangonui	2.16	0	2.99	1.15	0	1.38	0	1.86	2.47	2.40	1.53	1.38	1.53	0
Russell	1.67	1.62	5.00	1.30	1.96	1.13	0	1.71	1.73	1.81	1.39	0	1.24	0
Kawakawa	1.39	0	4.05	0	0	1.74	0	1.25	3.53	1.45	0	1.06	0	0
Onerahi			3.83	0	0	3.20	0	0	0	2.24	1.32	2.17	0	0
Mangwhai	1.71	0	4.10	1.44	1.70	0	0	2.01	0	0	1.18	0	0	0
Kaikohe	1.56	0	3.10	1.12	0.00	0	1.41	0	0	2.57	1.72	1.95	0	0
Waimatenui	1.75	0	2.45	2.04	1.78	0	0.00	2.14	0	0	2.35	2.29	0	0
Taus				0	0	1.47	1.24	0	0	2.15	2.09	2.73	1.14	0
Wairua	1.17	0	2.28	1.45	1.89	0	1.27	1.44	0	2.00	1.32	1.28	0	0
Pipiwai		0	3.48	1.37	1.61	0	1.30	0	0	2.85	1.35	1.47	0	0
Puhipuhi	0	0	3.68	0	0	0	1.29	0	0	1.33	1.29	3.13	1.70	0
Manganui											1.03	2.95	0	0
Herekino	1.99	1.17	3.59	1.30	0	0	0	2.38	0	2.67	1.36	0	0	1.43
Waipoua	0	0	1.95	2.09	0	0	0	2.13	0	2.46	1.84	0	1.86	0
Dargaville	0	0	2.31	2.98	0	0	0	1.57	0	1.98	1.11	0	0	0
Ruawai			3.36	1.42	1.18	0	1.63	1.04	0	3.19	0	0	0	1.41
Mangataroto			2.83	1.30	2.12	1.19	1.00	1.58	0	1.56	0	0	0	0

Table D1 -cont-

Rainfall Station	1972-73	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79	1980-81	1981-82	1982-83	1986-87	1988-89	1989-90	1990-91	1991-92
Cape Reinga	3.33	1.99	0	0	2.09	2.16	0	1.02	0	2.12	0	0	0	2.83	1.36
Waiharara	1.28	3.97	0	0	2.17	2.47	0	0	0	3.29	2.37	0	0	1.67	1.23
Kaitaia	2.43	2.91	0	1.35	1.69	0	0	0	0	3.13	1.91	0	0	1.61	2.58
Mangonui	2.34	2.46	0	1.25	0	0	0	0	0	4.20	3.48	0	0	4.02	2.34
Russell	4.19	1.15	0	0	0	0	0	1.33	0	3.43	4.43	0	0	1.82	1.60
Kawakawa	3.08	1.96	0	0	0	0	0	0	0	2.88	4.60	1.77	0	1.78	1.42
Onerahi	3.31	0	0	1.18	0	2.82	2.04	0	0	2.94	5.10	2.10	0	3.11	2.87
Mangwhai	1.75	2.29	0	1.30	0	1.79	1.82	0	1.63	3.93	2.30	0	1.42	1.22	2.39
Kaikohe	3.12	1.96	0	0	0	2.95	0	0	1.15	2.57	2.38	0	0	2.06	2.72
Waimatenui	0.00	3.73	0	0	0	2.15	0	0	1.03	5.32	0	0	0	2.46	0
Taus	1.33	1.38	0	0	0	4.01	0	0	0	4.50	2.82	0	0	2.72	2.54
Wairua	1.60	1.26	0	0	0	1.76	0	0	0	3.63	4.92	1.63	0	2.93	2.78
Pipiwai	2.53	1.66	0	0	1.19	3.20	0	0	0	4.28	1.31	0	0	1.44	2.21
Puhipuhi	6.46	2.66	0	0	0	3.20	0	0	0	3.95	0	0	0	0	2.89
Manganui	2.23	1.71	0	0	0	2.97	0	0	0	3.23	2.25	2.02	1.81	1.35	2.32
Herekino	1.41	2.62	1.52	0	0	2.47	0	0	1.04	4.02	0	0	0	2.18	1.53
Waipoua	1.94	2.03	0	1.96	0	0	0	0	1.09	4.12	0	1.29	0	1.45	1.55
Dargaville	2.13	2.14	0	1.27	0	0	0	0	1.35	4.86	0	1.45	0	1.39	0
Ruawai	1.94	1.77	0	1.48	0	2.16	0	0	1.86	4.48	0	0	0	2.13	0
Mangataroto	2.92	2.71	0	0	0	2.95	0	0	1.33	3.62	4.60	0	0	2.91	3.46

Table D2 Drought index severity results for the 1982-83, 1986-87, 1990-91, 1991-92 droughts for the 51 rainfall stations used in the construction of the drought severity maps.

Station Location	Station No.	1982-83	1986-87	1990-91	1991-92
Parengarenga	A42582	1.95	1.81	1.83	1.68
Cape View	A43701	2.13	3.70	2.13	0
Rangiputa	A43931	3.61	3.94	1.94	1.39
Aupouri	530204	3.88	0	2.79	0.00
Kaingaroa	A53031	4.37	1.06	1.71	1.91
Matauri	A53081	3.41	4.11		
Ahipara	A53111	3.30	1.18	3.41	0.95
Rangitihi	A53132	4.60	1.41	1.54	
Victoria Vlly	531411	3.51	0	2.55	
Laurensons	531910	3.10	0	0	1.24
Takahue	532311	2.81	0	0	
Omahuta	A53253	3.21	0	0	1.21
Tyrees	532810	4.30	0	0	1.71
Waikimihia	532910	3.86	0	0	2.12
Waihou	533610	3.70	0	0	1.65
Omapere	533812	3.70	0	1.22	
Oheawai	533813	3.52	0	3.93	0
Puhata	A53321	3.18	0	1.68	0
Opononi	A53442	4.38	0	2.00	3.09
Rawene	A53453	6.70	0	1.71	0
Waiora	535510	0	0	1.66	0
Ty Ranch	536611	0	0	0	0
Kaihu	537611	3.98	0	1.52	1.92
Parakao	A53791	4.47	4.22	1.95	2.26
Mamranui	A53881	3.68	0	2.34	1.61
Awakino	538810	3.06	1.19	2.87	1.38
Baylies Bch	539710	3.54	0	2.06	1.47
Waitangi	542010	3.25	1.26	0	
Waiotu	545111	2.85	0	0	2.87
Hukerenui	545213	3.35	2.40	0	2.75
Whakapara	545310	3.24	3.67	1.26	3.10
Matapouri	A54551	2.39	4.84	1.56	1.75
Jordan Vlly	546212	3.73	3.29	0	3.30
Hikurangi	A54622	2.41	5.62		
Ruatangata	A54623	2.13	2.20	0	2.24
Glenbervie	546301	2.72	3.68	3.41	3.58

Key

Blank space = missing rainfall data
0 = no drought detected

Table D2 -cont-

Station Location	Station No.	1982-83	1986-87	1990-91	1991-92
Ngunguru	546412	3.00	4.94	0	
Riponui	546510	2.76	1.55	0	3.23
Maungatapere	A54721	4.06			
Otaika	547219	2.02	2.50	2.26	2.28
Whau Valley	A54735	0	3.09	0	2.86
Tangihua	A54811	2.71	3.33	1.52	2.15
Mangapai	A54821		2.98	4.41	4.42
Tauraroa	548310	2.42	1.40	1.87	2.92
Monymusk	549010	2.73	0	1.21	1.46
Arapohue	A63091	5.51	1.45	2.00	1.27
Waihoihoi	640411	0	2.84	1.53	1.33
Waipu	A64051	3.63	2.15	1.29	2.21
Paparoa	A64123	3.48	1.78		
Pukehau	A64221	4.19	2.92	1.24	0
Topuni	A64241	2.68	0	0	0

Key

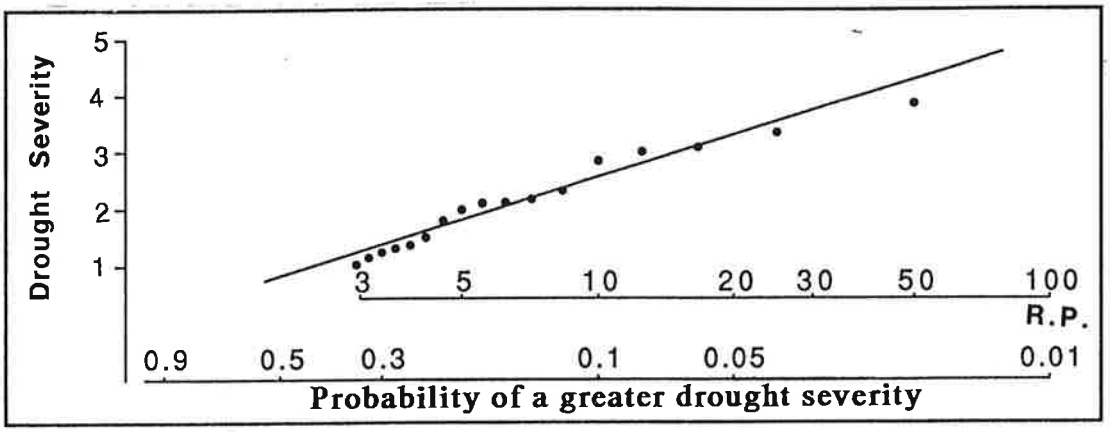
Blank space = missing rainfall data
0 = no drought detected

APPENDIX E

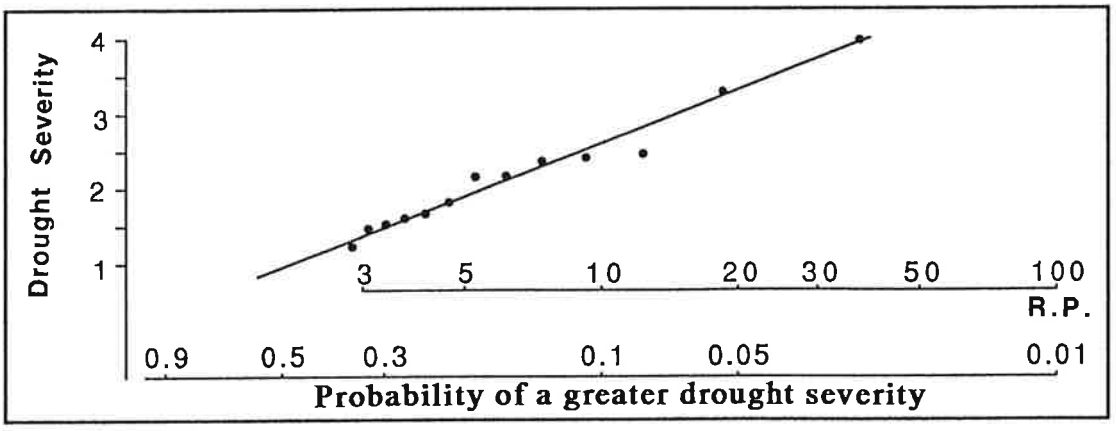
DROUGHT FREQUENCY PLOTS

Drought frequency plots for selected rainfall stations

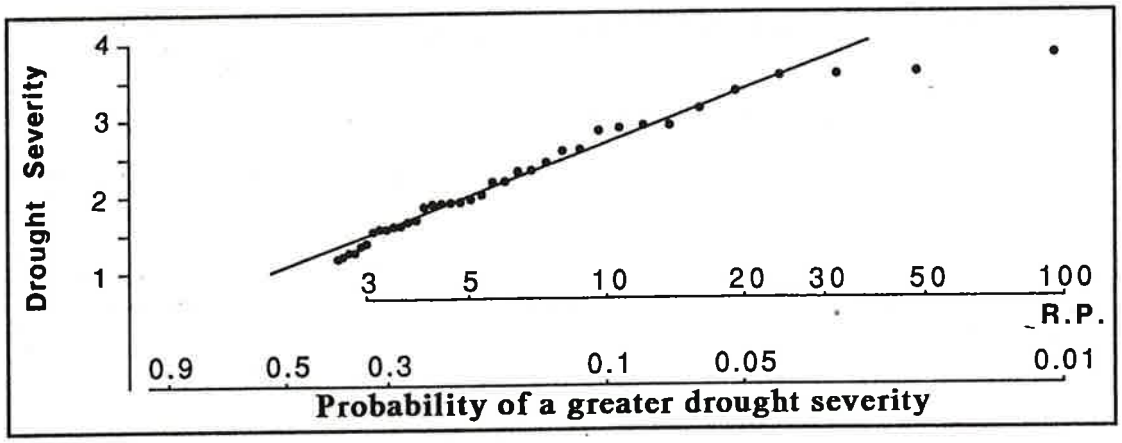
(a) Cape Reinga (NIWA A42461)



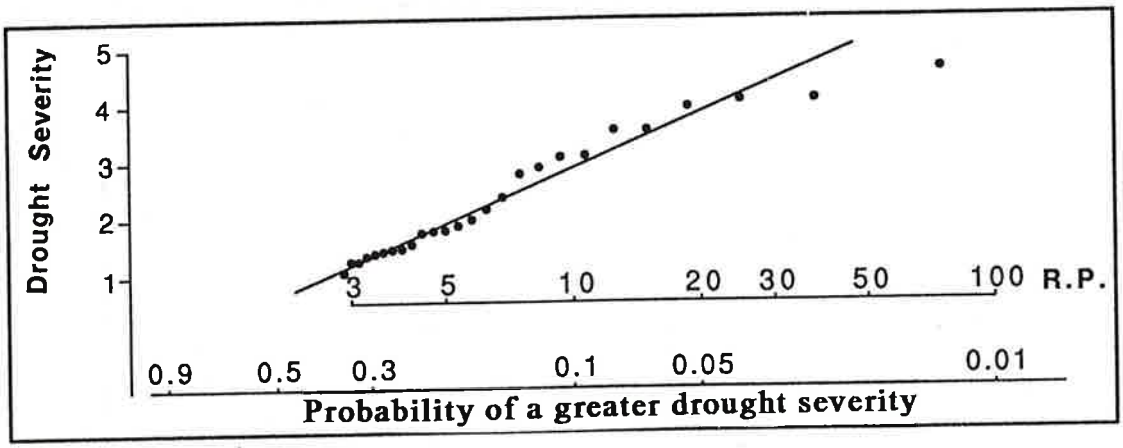
(b) Waiharara (NIWA A43921)



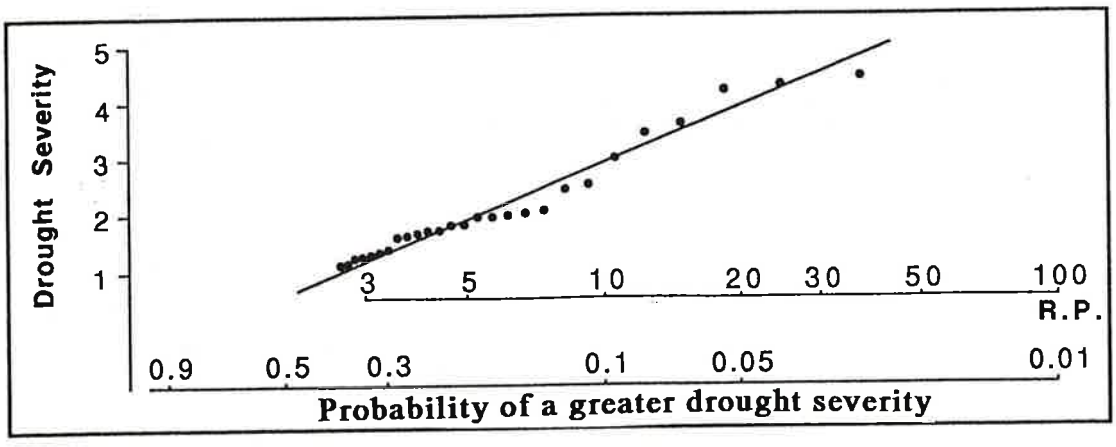
(c) Kaitaia (NIWA A53121)



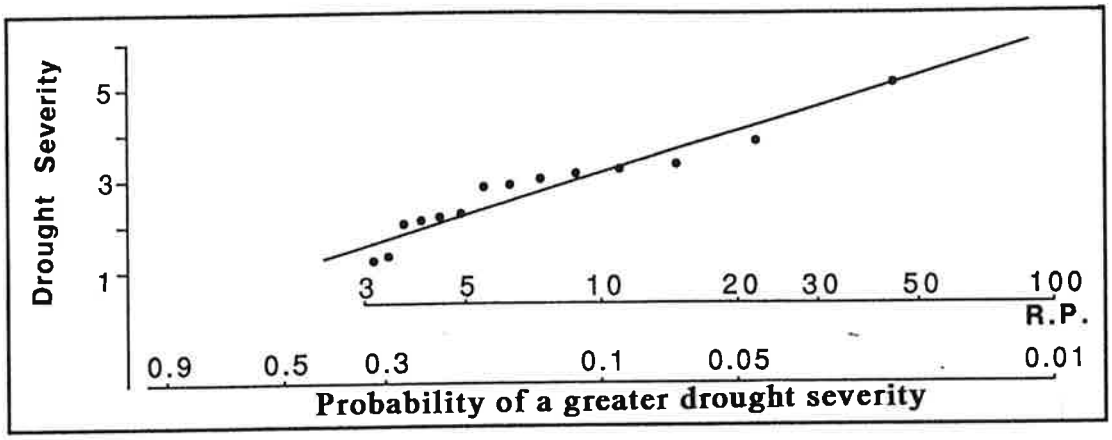
(d) Kawakawa (NIWA A54301)



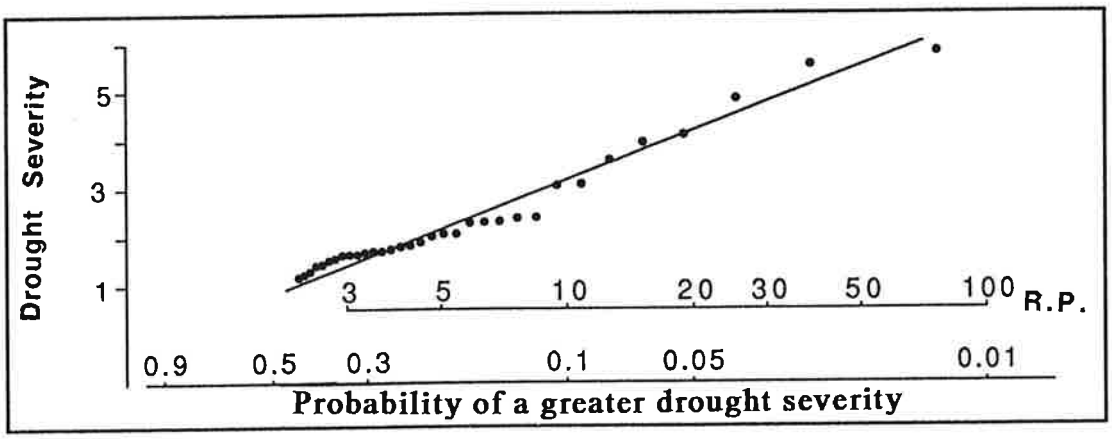
(e) Russell (NIWA A54211)



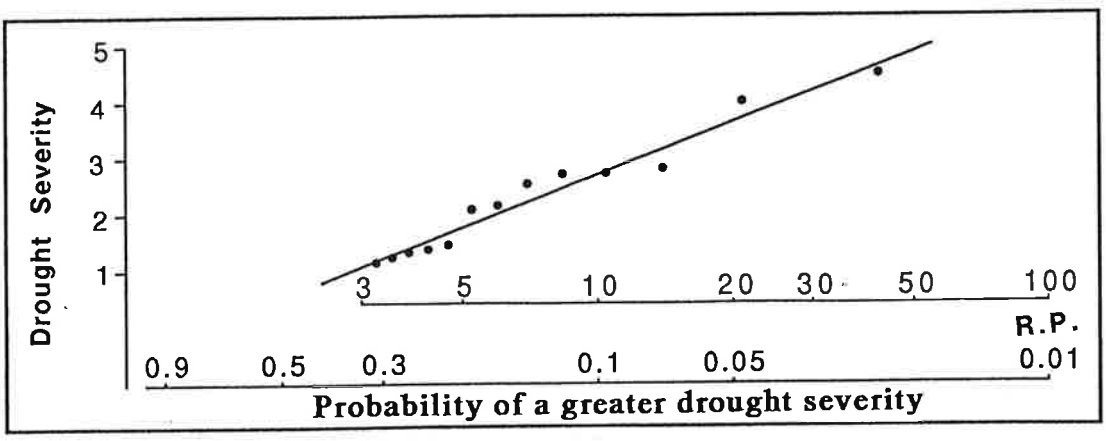
(f) Onerahi (NIWA A54733)



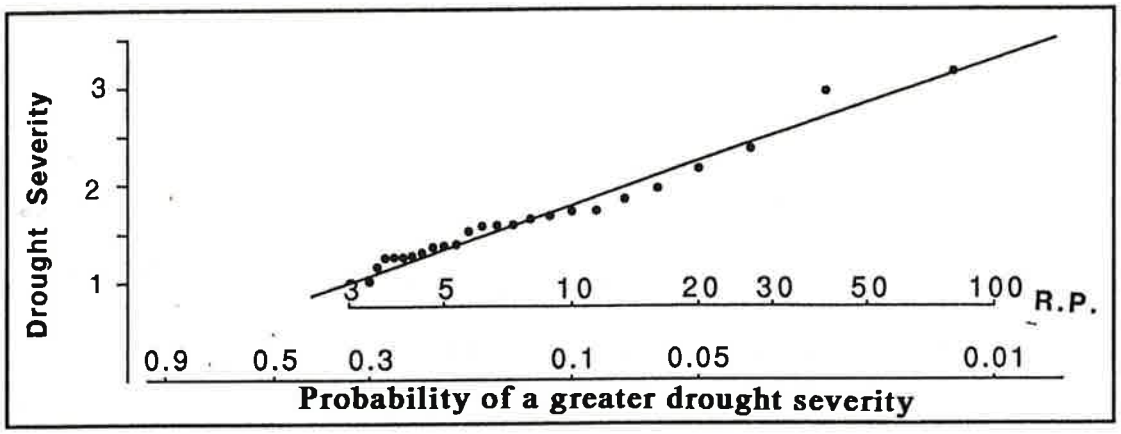
(g) Mangawhai (NIWA A64151)



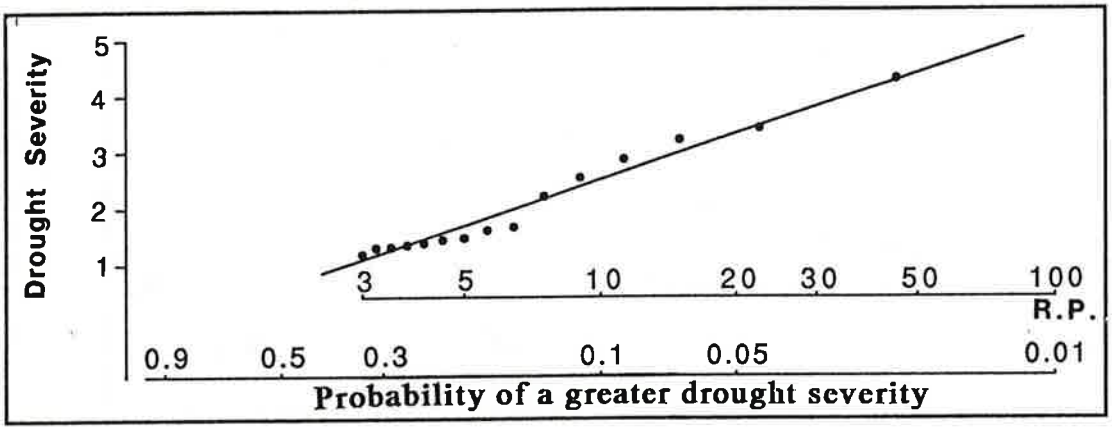
(h) Taus Falls (NIWA A53281)



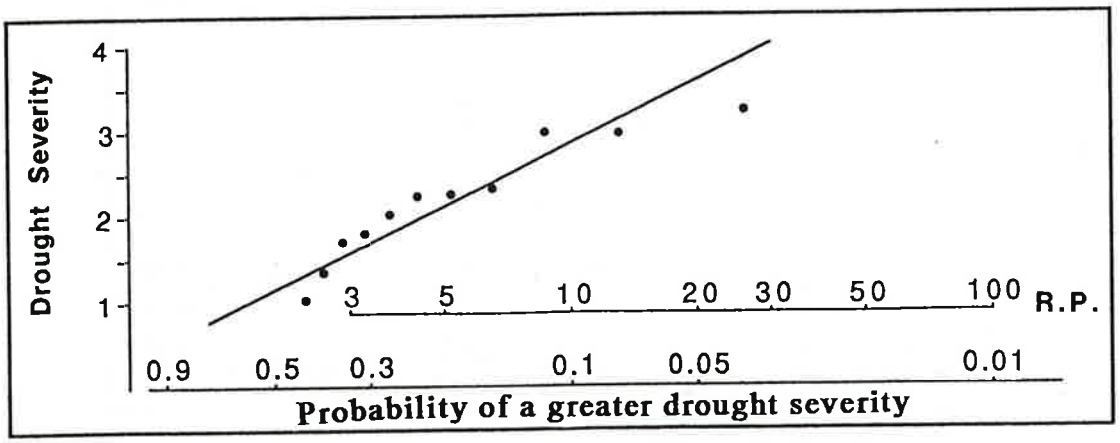
(i) Waimatenui (NIWA A53672)



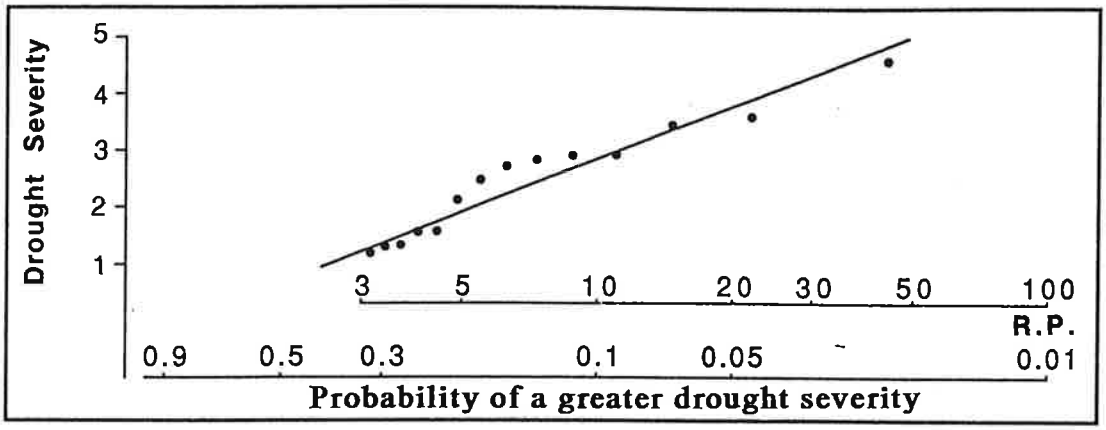
(j) Pipiwai (NIWA A53691)



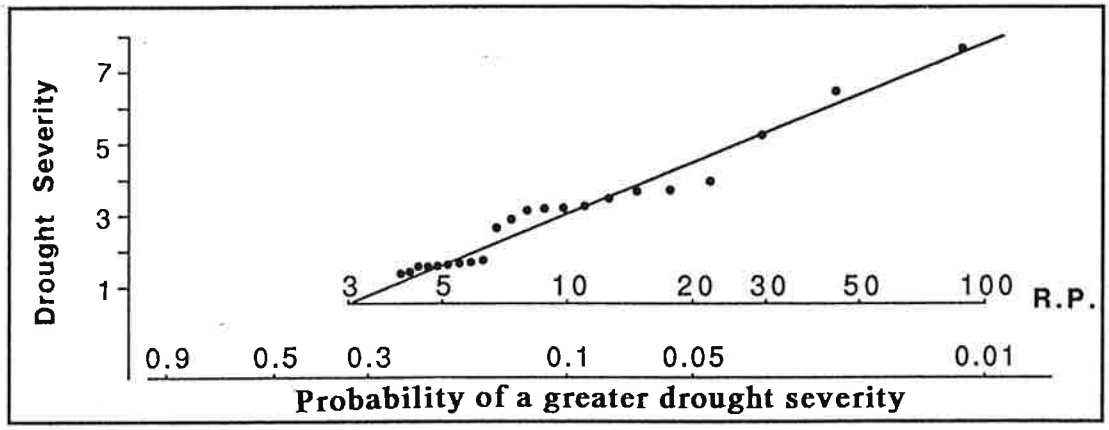
(k) Manganui (NRC 549310)



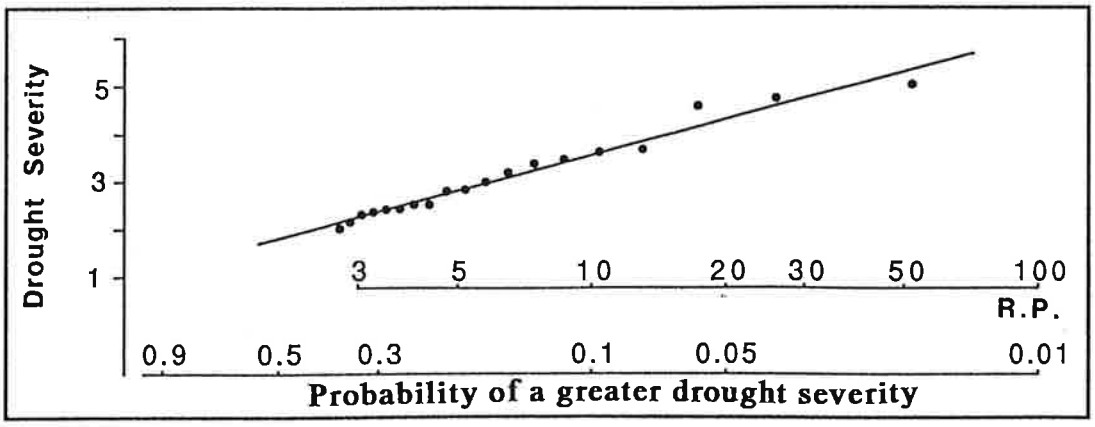
(l) Maungataroto (NIWA A64132)



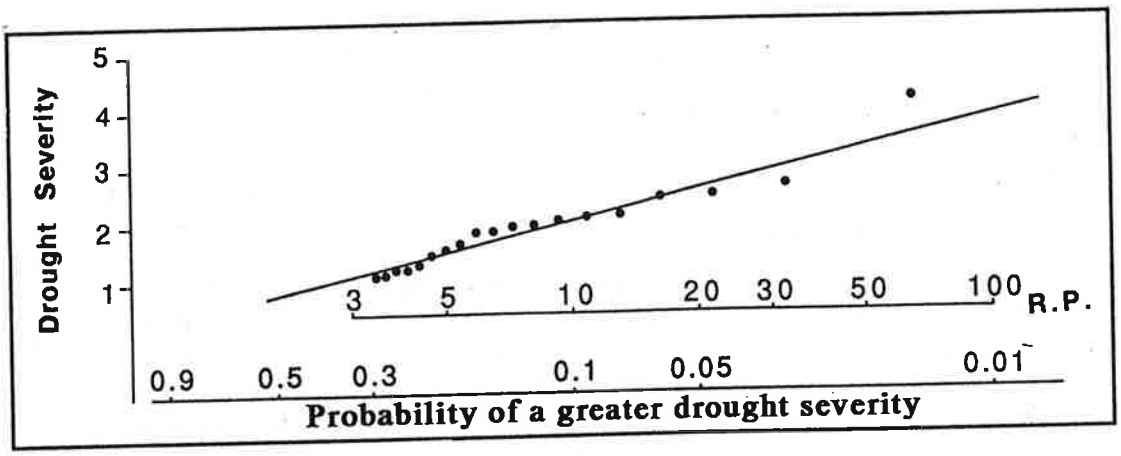
(m) Puhipuhi (NRC 545201)



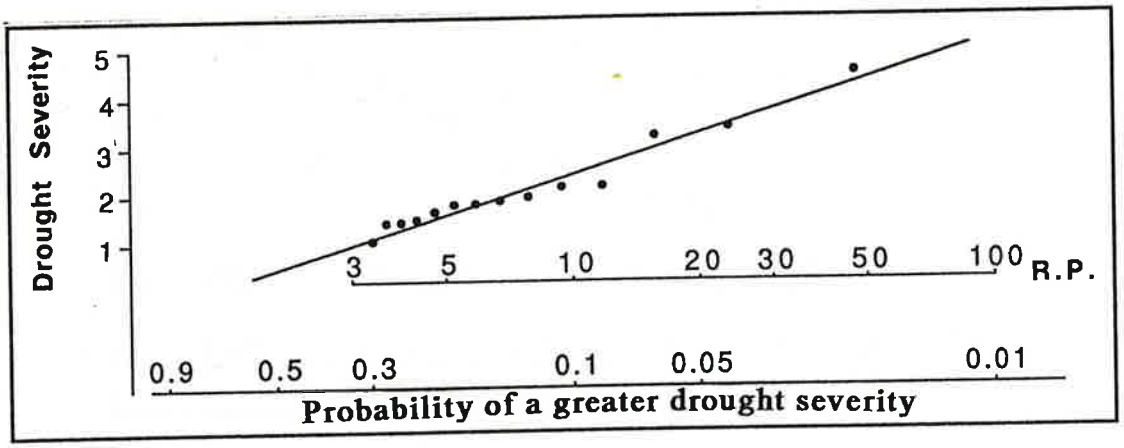
(n) Herekino (NIWA 53222)



(o) Waipoua (NIWA A53651)



(p) Ruawai (NIWA A64101)



APPENDIX F

DOCUMENTATION OF REGIONALLY SEVERE DROUGHTS

The 1914-15, 1982-83, 1986-87, 1990-91 and 1991-92 droughts have been described in relation to their severity patterns in Chapter Four. The severity patterns of regional droughts not described in Chapter Four are briefly documented in this appendix. All drought severities mentioned below refer to the regionally averaged drought index severities. The Southern Oscillation Index (SOI) value given corresponds to the annual average sea level pressure difference between Tahiti and Darwin for the first drought year specified. The annual SOI averages (January to December) were calculated from the monthly sea level pressure differences.

1907-1908 DROUGHT

Only three rainfall stations had records long enough to calculate this drought, Mangonui, Puhipuhi and Kaitaia. However, because these stations are not located close to each other, it is considered that this drought would have been regional in nature. It had a regional severity of 1.7 and a regional return period of around four years, and was not particularly severe in Northland, but was more severe at northern stations. This drought was evidently quite severe throughout most of New Zealand, inducing many bush fires (Bondy 1950). It is associated with the occurrence of a weak ENSO event (SOI = -4.3).

1913-1914 DROUGHT

Only three rainfall stations had record lengths long enough to calculate this drought. It had a regional severity of around 2.0 and a regional return period of around six years. It was most severe at Puhipuhi with a severity of 3.2. This drought is associated with the beginning of one of the worst ENSO events this century (SOI = -8.8).

1918-1919 DROUGHT

Seven rainfall stations had record lengths that were long enough to calculate this drought. It was a relatively severe drought, the third most severe regional drought in 95 years of record, and was detected at six out of the seven stations, with severities between 3.0 and 4.0. It was not detected at Waimatenui which is a high altitude station. This was a high magnitude-short duration event, associated with the occurrence of a medium ENSO event (SOI = -6.6).

1919-1920 DROUGHT

Eight rainfall stations had records long enough to calculate this drought and it was detected at six out of the eight stations, not being detected at the two high altitude stations, Waimatenui and Puhipuhi. It was the fifth most severe regional drought to occur on record and was severe around Whangarei and southern Northland with severities averaging around 5.0. It was less severe on the east coast of northern Northland. Severities ranged from 1.6 at Kawakawa to 5.8 at Mangawhai. It was a low magnitude, long duration event, associated with the end of an ENSO event (SOI = -7.6).

1924-1925 DROUGHT

10 rainfall stations had records long enough to calculate this drought, and a drought was detected at 9 out of the 10 stations. This drought was severe throughout the region where no particular spatial patterns in severity could be ascertained. Drought severities ranged from 1.3 at Kaitaia to 4.5 at Mangonui.

1925-1926 DROUGHT

10 rainfall stations had records long enough to calculate this drought and a drought was detected at all of these stations. It was not a particularly severe drought (averaging around 1.7) and severities were relatively uniform throughout the region. Severities ranged from 1.0 at Russell to 2.6 at Mangonui. This drought is associated with the occurrence of a medium ENSO event (SOI = -6.7).

1927-1928 DROUGHT

10 rainfall stations had records long enough to calculate this drought and it was detected at all of these stations. Drought severity appeared to be relatively uniform over Northland ranging from 1.6 at Puhipuhi to 3.3 at Dargaville. This drought is associated with the occurrence of a weak ENSO event (SOI = -1.3).

1928-1929 DROUGHT

11 rainfall stations had record lengths long enough to calculate this drought. This drought was detected at all of these stations. It was a low severity drought that appeared regionally uniform in severity. Severities ranged from 1.2 at Waipoua to 2.5 at Russell. This drought is associated with the occurrence of a weak ENSO event (SOI = -2.8).

1930-1931 DROUGHT

11 rainfall stations had record lengths long enough to calculate this drought and a drought was detected at all of these stations. It was severe at east coast stations in mid-Northland, for example Russell and Kawakawa, and was least severe at west coast stations. Severity

ranged from 1.1 at Waipoua to 4.3 at Russell. This drought event is associated with the occurrence of a severe ENSO event (SOI=-10.9).

1932-1933 DROUGHT

11 rainfall stations had rainfall records long enough to calculate this drought and a drought was detected at 9 out of the 11 stations. It was not detected on the two higher altitude stations. It was a fairly uniform drought, being relatively severe at most stations. Severities ranged between 1.5 at Mangawhai and 3.9 at Wairua.

1941-1942 DROUGHT

13 rainfall stations had rainfall records long enough to calculate this drought and a drought was detected at 12 out of the 12 stations. It was a low severity drought at most locations, except around Mangawhai and on the east coast between Kawakawa and Mangonui. At these locations it was more severe. Drought severity ranged from 1.1 at Wairua to 4.1 at Kawakawa. The regionally averaged drought severity was 1.8. This drought is associated with the occurrence of a severe ENSO event (SOI = -14.6).

1942-1943 DROUGHT

13 rainfall stations had rainfall records long enough to calculate this drought and the drought was detected at 12 of those 13 stations. The station where this drought was not detected was Cape Reinga. It was most severe in northern locations (except Cape Reinga), and least severe on the west coast. Drought severity ranged from 1.0 at Waipoua to 2.4 at Mangonui.

1945-1946 DROUGHT

13 rainfall stations had rainfall records long enough to calculate this drought and it was detected at all of these stations. This drought was the sixth most severe regional drought to occur in 93 years and was a high magnitude-short duration event. It was most severe at east coast stations and least severe at northern peninsula and west coast stations such as Dargaville and Waipoua. Severities ranged from 2.3 at Dargaville to 4.8 at Mangawhai. This drought is associated with the beginning of a ENSO event.

1946-1947 DROUGHT

13 rainfall stations had rainfall records long enough to calculate this drought and it was detected at 10 of these stations. It was not detected at Cape Reinga or the southern west coast stations such as Dargaville and Ruawai. It was a low, fairly uniform severity drought with severities ranging from 1.2 at Puhipuhi to 2.2 at Mangonui. This drought is associated with the occurrence of a medium ENSO event (SOI = -7.9).

1949-1950 DROUGHT

14 rainfall stations had rainfall records long enough to calculate this drought, and the drought was detected at all of these stations. This was the fourth most severe regional drought in 93 years and was the fifth in a succession of droughts that occurred throughout the 1940's. It was a particularly high magnitude event with a relatively short duration. It was most severe on east coast stations and some inland areas such as Pipiwai and Kaikohe. It was least severe on the west coast around Dargaville and Waipoua. Severities ranged from 1.9 at Waipoua to 5.0 at Russell.

1953-1954 DROUGHT

18 rainfall stations had records long enough to calculate this drought and it was detected at 14 of the 18 stations, not being detected at higher altitude stations or southern east coast stations. It was a low magnitude and short duration event but was more severe on the west coast around Waipoua and Dargaville. Severities ranged from 1.3 at Russell to 3.0 at Dargaville. This drought event is associated with the occurrence of a medium ENSO event (SOI = -8.0).

1961-1962 DROUGHT

18 rainfall stations had long enough records to calculate this drought and it was detected at 13 of the 18 stations, not being detected at higher altitude stations or inland around Kaikohe and Pipiwai. It was most severe at northern peninsula stations and least severe in southern areas on the west coast and around Russell-Kawakawa. Drought severities ranged from 1.0 at Ruawai to 3.1 at Cape Reinga.

1963-1964 DROUGHT

19 rainfall stations had records long enough to calculate this drought and it was detected at 16 of the 19 stations. It was not detected at Cape Reinga, Mangawhai or Waimatenui. It was quite severe at inland and west coast areas and less severe on the east coast. Drought severities ranged from 1.5 at Kawakawa, to 3.2 at Ruawai. This drought is associated with the occurrence of a weak ENSO event (SOI = -4.5).

1967-1968 DROUGHT

All 20 of the core rainfall stations had record lengths long enough to calculate this drought. This drought was detected at 18 of the 20 stations, not being detected for two southern Northland stations Ruawai and Maungataroto. Severities were higher for inland and high altitude stations, but in general, the drought severities were fairly uniform across the region and it was a low order drought for most locations. Severities ranged from 1.0 at Manganui, to 3.6 at Kaitaia.

1969-1970 DROUGHT

This drought was not a localised drought but was not regional in nature either. It was caused by anomalous meteorological patterns over New Zealand and it is known that this drought was particularly severe throughout other parts of New Zealand (Hill 1971, Finklestein 1971). This drought is associated with the end of an ENSO event (SOI = -6.6).

For Northland, this drought was a low severity drought that was only detected at 13 out of 20 rainfall stations. It was not picked up at southern Northland areas, south of Whangarei or at west coast locations. It was most severe at high altitude stations, such as Puhipuhi, Waimatenui and Taus Falls and inland areas. The severity of this drought had a distinct spatial pattern.

1972-1973 DROUGHT

This drought was detected at all 20 rainfall stations except for Waimatenui, and was a moderately severe drought. The drought was most severe on the east coast averaging around 3.0 and particularly severe at Puhipuhi where the severity was 6.5. It was less severe around inland and west coast stations particularly those located south of Whangarei, averaging around 2.0. Drought severities ranged from 1.3 at Taus Falls to 6.5 at Puhipuhi. This drought was associated with the occurrence of a medium ENSO event (SOI = -8.167).

1973-1974 DROUGHT

This drought was detected at all the core rainfall stations except Onerahi. It was a moderately severe drought with severities ranging from 1.3 at Wairua to 3.9 at Waiharara. The drought was most severe for northern east coast and northern peninsula stations. It was also quite severe for west coast stations. It appeared to be least severe around Whangarei and inland of Whangarei.

1977-1978 DROUGHT

This drought was detected at 16 out of 20 rainfall stations. It was not detected at northern east coast stations from Kawakawa to Kaitaia. It was quite a severe drought particularly at inland and high altitude stations. It was least severe from Waipoua to Dargaville. Drought severity ranged from 1.0 at Waipoua to 4.0 at Taus Falls. This drought is associated with the occurrence of a severe ENSO event (SOI = -11.3).

APPENDIX G

PROPERTIES OF THE ALLSTATIONS TIME SERIES

All the following statistical analysis was undertaken on Minitab on the Vax computer at Waikato University. The unsmoothed, unaltered annual rainfall time series from allstations was used.

1. NORMALITY

The standard test for calculating normality is by using normal scores. If the sample is from a normal distribution the points will roughly fall on a straight line. The straightness of the plot can be measured by the correlation coefficient. Bray and Lai (1987) state that a very powerful test for normality, which is essentially equivalent to the Shapiro-Wilks test, can be based on this correlation. If the correlation coefficient falls below the appropriate value in the table provided in their text, the hypothesis of normality if rejected at a particular significance level.

Normal scores were calculated for the allstations time series and a normal probability plot constructed. According to the methodology stated above, the hypothesis of normality is not rejected for the allstations time series at $\alpha = 0.01$ (given a correlation of 0.977).

2. AUTOCORRELATION

Autocorrelation refers to the correlation of data series with the same series shifted by some interval and, hence, is a measure of the persistence in the time series. The correlogram is the graph of the serial correlations as ordinates plotted against the values of the relevant lags as abisscae (O'Mahoney 1961). If a time series is random the correlogram presents no systematic appearance. If it consists of a simple harmonic the correlogram reproduces that harmonic (Kendall 1944). The correlogram thus provides a criterion for distinguishing between various kinds of oscillatory series. The correlogram will show a period equal, within limits of error, to that of the fundamental period of the system (Kendall 1944). The period can be determined from upcross to upcross

Raudkivi (1979) gives a simple approximation for the confidence limits on the autocorrelation coefficient (r) as $\pm$ 2/sqrt n (at the 0.05 significance level). If the computed value of r lies outside these limits it is considered significantly different than zero indicating persistence in the data.

Autocorrelations in the form of a correlogram were computed for the unmodified annual time series from allstations (Figure G1). A maximum lag of 20 years was specified. Under

Raudkivi's (1979) criterion, r has to lie outside the range +/-0.24 before persistence in the data is significant.

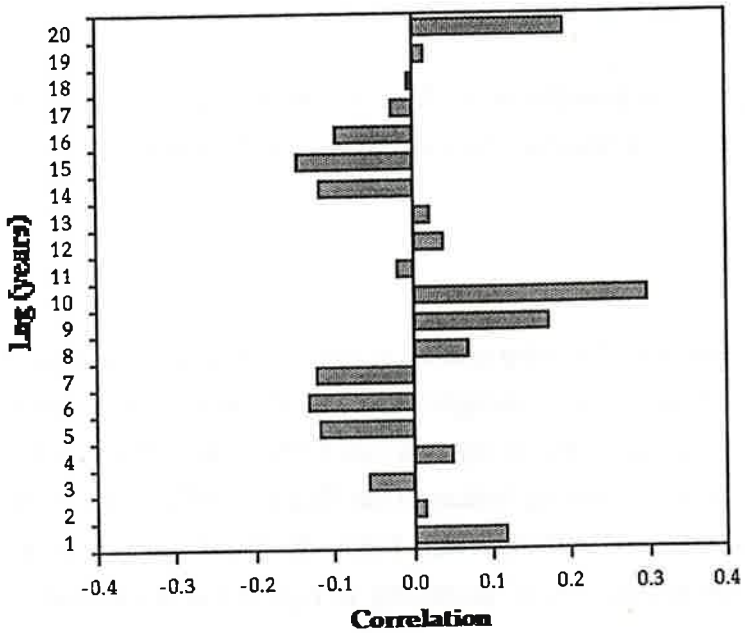


Figure G1 Correlogram for allstations annual rainfall time series

The autocorrelograms of the annual and seasonal rainfall time series show very little serial correlation at low time lags, indicating minimal 1st or 2nd order persistence in annual rainfall totals.

However, a fairly distinct 10-year periodicity can be seen in the correlogram, which could indicate that there is such a cycle in the annual rainfall time series. $r = 0.295$ at 10-years, which is significantly different from zero at $\alpha = 0.05$, which indicates that rainfall totals at time=0 may be related (statistically) to annual rainfall totals that occurred 10 years prior.

3. RUNS TEST

A well known non-parametric test of homogeneity of data series, is the runs test (Thom 1966). This test is made by counting the number of runs (u) above and below the median or middle value of a natural ordered series. Too many runs is an indication of an oscillation, while too few runs would be an indication of a trend or shift in the median (Thom 1966).

The results of the runs test for the allstations annual rainfall time series using the median (1554) as the middle value is as follows:

The observed number of runs = 34
The expected number of runs = 36
The null hypothesis of no runs can not be rejected at $\alpha = 0.05$.

4.0 LINEAR TRENDS

Linear regression analysis of a variable vs time is useful for delineating linear trends in time series. The results of a linear regression analysis of the annual rainfall time series from allstations as the dependent variable (Y) and time as the independent variable (X) are given below.

Linear regression equation: Rainfall = 1625 - 1.04 Time.
r^2 = 0.7 % not significant at α = 0.05 level
r = 0.26

There is a slight negative linear relationship of annual rainfall with time, however, the r^2 value of 0.7 is not significantly different from zero at α = 0.05.

APPENDIX H

SUMMARY OF NORTHLAND RIVER CATCHMENT CHARACTERISTICS

The following provides a brief summary of applicable information about the river catchments used in Chapter Six.

EAST COAST DRAINING RIVERS

i. Waitangi River

The Waitangi River drains a total catchment area of approximately 308 km^2 and is situated south east of the Bay of Islands. The discharge data used is from station 3722, a NIWA flow recorder station, situated in the lower reaches of the river, with a catchment area behind it of 302 km^2. It is one of the New Zealand representative catchments. The following description of the catchment is largely taken from a report written by the Northland Catchment Commission (NCC) in 1987 entitled *The Water Resources of the Waitangi Catchment*, and pertains to the catchment area behind station 3722, of 302 km^2.

Topography: Low rolling hills, with the upper reaches of the catchment reaching 200-400 m in height.

Geology: Mixed sedimentary-volcanic geology. Approximately $^1/_3$ of the surficial geology of the catchment is volcanic rocks, a third is greywacke and a third is alluvium and other sedimentary rocks. The lower catchment consists of predominantly Waipapa Group greywacke, which forms the basement geology for most of the catchment. The middle of the catchment consists of greywacke, limestones, sandstones and flood plain -surficial deposits. The upper catchment consists of mainly welded volcanic rocks with pockets of scoria, and also argillite.

Soil Predominantly yellow brown earths, which are moderately to strongly leached or podzolised formed on sedimentary rocks. Podzolised yellow brown earths have formed on areas of steep land are subject to gully erosion. Red and brown loams have formed on volcanic rocks. Alluvial-recent soils have developed on the floodplains which occupy approximately 4% of the catchment.

Vegetation Predominantly pastoral, covering approximately three quarters of the catchment. The rest of the catchment consists of scrubland (manuka, kanuka, gorse) and a very small area of native forest.

Climate — Annual mean rainfall totals range between 1600-2000 mm dependent on location within the catchment.

ii. Awanui River

The Awanui River drains a total catchment area of approximately 260 km^2. It is located in northern Nothland, bounded by the Mangamukas. The discharge data used is from station 1316, a NIWA water level recorder station, situated in the lower reaches of the river, with a catchment area behind it of 222 km^2. It is one of the New Zealand representative catchments. The following information pertains to the catchment area behind station 1316, of 222 km^2

Topography — Mainly rolling - steep in upper catchment

Geology — Mixed geology, although is predominantly (around 70-80%) sedimentary in nature. Approximately 50% of the catchment is made up of mid-tertiary aged sandstone which is moderately to widely fractured, interbedded with mudstone. Approximately 20% of the catchment consists of limestone rocks, around Kaitaia and further south. Around 20% of the catchment is of volcanic origin, predominantly the upper reaches of the catchment, aged at around 65-200 million years old. A considerable amount of recently deposited alluvium is found alongside the Awanui river, forming the Awanui plains and swampland.

Soil — The predominant group of soils found is the yellow-brown earths which cover the rolling hills and undulating terraces. Brown granular loams are found on the upper reaches of the catchment on basalt geology.

Vegetation — Predominantly pastoral, with approximately 15% of the catchment in wildlands, forest and scrub. A small portion of the catchment is urban (Kaitaia township).

Rainfall — Annual mean rainfall ranges between 1300 mm for parts of the lower catchment to 1900 mm for the upper catchment.

iii. Mangaparerua River

The Mangaparerua River is a small river that joins with the Kerikeri River discharging on the east coast into the Kerikeri Inlet. The discharge data used is from station 3506, a NIWA water level recorder station, situated in the mid-reaches of the river, with a catchment area behind it of 11.1 km^2. This is one of the New Zealand representative catchments. The following description of the catchment is largely taken from a report written by the NCC in 1979, entitled *Kerikeri Inlet Catchments*, and pertains to the catchment area behind station 3506 of 11.1 km^2.

Topography — An easy rolling dissected plateau, with approximately 95% of the land between 100-300 m and no land rising above 400 m.

Geology — Just about all of this catchment consists of rocks of volcanic origin. 90% of the volcanics is Horeke Basalts and the remaining 10% Parahaki Volcanics (rhyolite). The basement rock is sedimentary greywacke (Waipapa Group).

Soils — Largely volcanic soils, red brown loams with brown granular clays. There is a small pocket of non-volcanic soils, namely yellow brown earths to the extreme north east of the catchment, which are weak to moderately podzolised.

Vegetation — The predominant vegetation is pastoral exotic grasses with some pockets of scrub and pasture and second growth forest.

Rainfall — The mean annual rainfall for this catchment is around 1950 mm, ranging between 1800-2100 mm.

iv. Ngunguru River

The Ngunguru River is a small river draining to the east coast, above Whangarei. The discharge data used is from station 4901, a NIWA water level recorder station, situated in the mid reaches of the river, with a catchment area behind it of 12.5 km^2. It is one of the New Zealand representative catchments. The following description of the catchment pertains to the catchment area behind station 4901 of 12.5 km^2.

Topography — The Ngunguru basin is characterised by mainly rolling country with rocky gorges. The altitudinal range is 152-312 m.

Geology — Dissected and fissured greywacke and argillite with chert

Soils — Northern yellow-brown earths from greywacke

Vegetation — Predominantly native forest with second growth forest. The rest is exotic grasses-pasture.

Rainfall — The average annual precipitation is approximately 1870 mm, ranging between 1700 to 2200.

WEST COAST DRAINING RIVERS

v. Mangakahia River

The Mangakahia River drains a total catchment area of approximately 800 km^2 of central Northland, before its confluence with the Northern Wairoa River which then discharges into the Kaipara Harbour. The discharge data used is from station 46618, a NIWA water level recorder station, situated in the upper reaches of the river with a catchment area behind it of 241 km^2. It is one of the New Zealand representative catchments. The following description of the catchment is largely taken from the Department of Lands and Survey Maps, NZMS P06/07, detailing the geology, soil types and landuse of the Mangakahia-Dargaville area, and pertains to the catchment area behind station 46618 of 246 km^2

Topography — Relatively steep rising to 700 m in height, characterised by waterfalls, gorges and sharp ridges similar to most typical, steep, headwater catchments. There are relatively few areas of alluvial deposits. 80% of the catchment would be between 300-700 m high.

Geology — Comprises of a mixture of volcanic and sedimentary geology. Volcanic rocks form approximately 75% of this part of the catchment. The two main types of volcanic rock present are the Tangihua Volcanics and the Waipoua Basalts. The Tangihua Volcanics are the oldest rocks that occur in Northland and form all the prominent hills and ranges in the catchment. They are closely to widely fractured and fissured. The Waipoua Basalts are found in the northwest of the catchment forming the Tutumoe Plateau and are deeply weathered rocks. The sedimentary rocks include tertiary mudstone, claystone, sandstone, crushed argillite. They are mostly found on the more rolling flatter land.

Soils — The brown granular loams are found on geology of volcanic origin. Yellow brown earths are found on the sedimentary rocks, and are weakly to strongly leached dependant on vegetation and slope. Recent soils are found on the floodplains.

Vegetation — Predominantly rough pasture on the less steep land surrounding the river of around 200-400 m high. The headwaters are bushed in native and exotic forestry (approx 30%) and scrubland-manuka is found on those areas inhabitable for much else.

Rainfall — The mean annual rainfall is around 2000 mm, although ranges from 1500 mm in the lowlands to 2800 mm in the upper reaches of the catchment.

vi. Wairua River

The Wairua River drains a total catchment area of approximately 700 km^2 of central Northland, with its headwaters a few kilometres inland of the east coast before it joins with the Mangakahia River and becomes the Northern Wairoa River. The discharge data used is from station 46644, a NRC water level recorder station, situated in the lower reaches of the river, with a catchment area behind it of 544 km^2. The following description of the catchment is largely taken from a report written by the NRC in 1989 entitled *The Water Resources of the Wairua River Catchment* and pertains to the catchment area behind station 46644, of 544 km^2.

Topography — The Wairua River catchment is uplifted to the north and east, in its upper reaches, giving rise to steep hills in this area, where the highest point is around 462 m at Puhipuhi. Low lying areas between 100-200 m account for approximately half of the catchment area.

Geology — The upper reaches of the catchment consists mainly of greywacke and argillite which make up approximately a third of the catchment. There are also pockets of welded volcanic rocks in the upper parts of the catchment. A large part of the middle catchment consists of recent alluvium and peat around the Hikurangi Swamp area, and argillite in the northern part of the catchment. There are more volcanic rocks, largely basalts, in the lower part of the catchment, associated with volcanic cones.

Soil — The main soil types are recent soils and yellow brown earths. Red brown loams, brown granular loams have formed on the volcanic rocks.

Vegetation — The dominant vegetation is pasture, with pockets of intensive horticulture. However, there is also small areas in exotic and native forestry in the headwaters of this catchment. Substantial areas of scrub, manuka and gorse also exist, in the upper reaches of the catchment.

Rainfall — The mean annual rainfall is around 1900 mm ranging between 1400 mm in lower topography areas and 2500 mm in the eastern ranges forming the eastern boundary of the catchment.

vii. Mangamuka River

The Mangamuka River drains a forested catchment, with its headwaters inland of the Mangataniwha Range, draining into the Hokianga Harbour. The discharge data used is from station 48015, a NIWA water level recorder station, situated in the lower reaches of the river, with a catchment area behind it of 23.3 km^2. The following description of the catchment is largely taken from the Department of Lands and Survey Maps, NZMS O04/05

detailing detailing the geology, soil types and landuse of the Kaitaia-Rawene area, and pertains to the catchment area behind station 48015, of 23.3 km^2.

Topography — Very steep

Geology — The catchment is predominantly volcanic in nature comprising very hard basalt and dolerite, that is closely to moderately fractured, approximately 60-200 million years old. There are also isolated blocks of sandstone, mudstone and limestone of mid-early tertiary age (20-45 million years old).

Soils — Made up almost entirely of steepland volcanic soils, that are weakly to strongly leached. There is a narrow strand of recent soils formed on alluvium by the river.

Vegetation — The catchment is just about entirely forested. Most of the forest is indigenous forming the Raetea State Forest. Exotic forestry is found on the steep slopes in the northern half of the catchment. There is also a small percentage of scrubland.

Rainfall — This catchment is characterised by high mean annual rainfalls, due to its location and steep topography. Mean annual rainfall is approximately 2400 mm.

viii. Manganui River

The Manganui River drains a catchment area south of Whangarei before its confluence with the Northern Wairoa River which then discharges into the Kaipara Harbour. The discharge data used is from station 46651, a NIWA water level recorder station, situated in the middle reaches of the river, with a catchment area behind it of 411 km^2. The following description of the catchment is largely taken from the Department of Lands and Survey Maps, NZMS P06/07 and Q08/09 detailing the geology, soil types and landuse of the Mangakahia-Dargaville and Maungataroto-Kaipara areas respectively, and pertains to the catchment area behind station 48015, of 411 km^2

Topography — Rolling to hilly topography - flat areas beside river. Most areas below 250 m in height.

Geology — A sedimentary catchment, with 80-90% of the rocks being fined grained micaceous sandstones with interbedded mudstone that is finely to moderately fractured. There are also small pockets of closely fractured muddy limestone and closely fractured and thinly bedded mudstone. Very low yields of water are associated with this geology. Alluvium forms the river plain deposits.

Soils — Predominantly yellow brown earths with deep clay profiles, that are weakly to moderately leached forming the soils of the rolling hilly land. Recent soils have formed on the alluvial river terraces and floodplains.

Landuse — Predominantly pastoral, undeveloped or scrub. There are small pockets of shrubland and forest.

Rainfall — Mean annual rainfall generally lower than the above catchments, averaging around 1250 mm.

APPENDIX I

NORTHLAND REGIONAL COUNCIL RESPONSE TO DROUGHTS

REPORT ON REVISED PROCEDURES FOR COUNCIL RESPONSE TO DROUGHT AFFECTED WATER SUPPLIES

Memorandum from Environmental Manager dated 21 June 1991.

1 INTRODUCTION

At its meeting on 5 February the committee received a report and Draft Policy on Procedures for Council response to droughts affecting water supplies.

It resolved to receive the report, and after discussion on early warning and publicity aspects of droughts, requested modifications to the draft drought response procedure.

2 POLICY ON DROUGHT RESPONSE - SECOND DRAFT

The attached second draft of the proposed drought response plan differs from the first in the following areas:

- greater emphasis on Regional Councils on data collection network.
- greater emphasis on publicity and early warning of potential drought problems.

3 SCENARIO

3.1 The most likely scenario is one in which monitoring stream flows and rainfall records indicates progressively a trend towards shortages. At a certain stage complaints will begin about streams or bores running dry as a result of drought and probably concerns about 'overuse' by other upstream users.

4 ACTION AND PROCEDURES

4.1 As monitoring reports come to hand indicating possible serious water shortages in parts of or over the whole region, contact will be initiated with the media warning of the need for water conservation measures. Checks on storage in water reserves and possibly location of supplementary supplies, especially where shortages have restricted water use activities in the past, will be encouraged.

REPORT ON REVISED PROCEDURES FOR COUNCIL RESPONSE TO DROUGHT AFFECTED WATER SUPPLIES Continued

4.2 If and when in due course serious drought conditions begin to take effect and/or complaints are received, on-site checks are to be made to confirm the cause of shortage to be drought related and whether other competing users are complying with their water rights. All unauthorised users are to be stopped and;

4.3 If all upstream rights are being complied with and there is still inadequate water at the site THEN:

4.4 Rapidly extend the investigation to adjoining catchments until the boundary of the affected area has been determined. Notify the Regional Councillor for that constituency

4.5 Then identify name and address of every water user in that area and;

4.6 Call a meeting of all water users in that area including the relevant constituency Regional Councillor for the purpose of:

(a) explaining the problems and;

(b) promoting water saving measures

(c) preparing an action plan with their co-operation

4.7 The ACTION PLAN will generally include:

(a) suspending unnecessary uses

(b) A programme for progressive (10%) reductions for all users

(c) A grouping of users, usually into three, to prepare for sharing of pump hours

(d) Appointing a Council nominee for each catchment who has the respect and confidence of the local community and who will assist with the policing of the restrictions

(Note: A water shortage could result from failure of an existing public water supply system. In this event, and unless this Council is called for assistance, the initiative should be left with the district council).

REPORT ON REVISED PROCEDURES FOR COUNCIL RESPONSE TO DROUGHT AFFECTED WATER SUPPLIES Continued

4.8 After the Meeting:

(a) contact the media for assistance with dissemination of information

(b) send formal letters to each person affected ORDERING the necessary restricted/or suspension of use, and;

(c) stating the date on which the situation will be reviewed - not more than 14 days from date of letter.

4.9 Continue to liaise with
- Council nominee
- General Manager
- Regional Councillor
- Hydrologist

to keep up with compliance with ORDER and success of restrictions and progress of drought.

APPENDIX J

QUESTIONNAIRE

Introduction

The term *drought*, as used in this questionnaire, refers to a severe precipitation deficiency where monthly rainfall is considerably lower than what is typically experienced. Examples include the 1982-83, 1986-87, 1990-91 and 1991-92 droughts. Such a definition distinguishes "drought" from the expected dry spells experienced in Northland due to the seasonal climate.

Please complete this questionnaire and send back to me in the enclosed addressed envelope:

Questions

1. What type of farming have you been most associated with? (dairying, beef, sheep, other)

   .....

2. What are the predominant impacts of drought on agriculture in Northland? (dairying, beef, sheep).

   .....
   .....
   .....
   .....
   .....

   Which type of farming, in your opinion, is most adversely affected and why?

   .....
   .....
   .....

3. How do recent droughts in Northland (eg. 1990-91, 1991-92) compare to historical droughts (eg. those in the 1960's and 1970's)? In your opinion are droughts becoming more or less frequent or severe?

.....

.....

4. Which is the most severe drought in Northland, in terms of agricultural impacts that you can remember? Why? Please specify how many years you have lived in Northland.

.....

5. How do you perceive the impacts of drought in comparison with other hazards? (such as flooding, frosts, cyclones). Do droughts yield greater or lesser impacts on agriculture?

.....

.....

.....

6. Do you believe that a climate change (in the form of global warming) is occurring or will occur? Why or why not?

.....

.....

.....

If a global warming is occurring do you think that it is affecting the frequency and severity of drought in Northland?

.....

7. In your opinion, have the majority farmers in Northland in the past taken measures to adapt to drought? (for example: drought resistant grasses, alteration of farm management practices, pasture irrigation). Or have they, for the most part, simply accepted the impacts of drought.

.....

If farmers have taken measures to alleviate the impacts of drought, what type of measures in the past have been favoured?

.....

.....

.....

8. Of late, dairy farmers in Northland have shown an interest in pasture irrigation, in order to increase their production during summer and autumn months. What are your thoughts on this scheme in terms of minimising the impacts of drought? Is this a good way of planning for drought?

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.....

.....

9. Should local, regional and national government be adopting a more pro-active approach to drought planning and water resource management in terms of the design of drought contingency plans?

.....

.....

.....

10. Is present water resource management in Northland during drought events adequate (in terms of maintaining water quality, abstractions and residual flow)?

.....

.....

11. Would you, as a farmer or someone closely associated with farming, be interested in some sort of drought prediction bulletin that could assist in the risk management of climate-sensitive agricultural activities? For example, a bulletin that provides broad indications of likely climate trends over Northland for the ensuing season or on a monthly time scale. Why or why not?

.....

.....

.....

.....

If you are interested in the above, who do you think should provide this service? Why? Should this service cost those who use it?

(a) Regional Government

.....

(b) National Government

.....

(c) National Institute of Water and Atmosphere (NIWA)

.....

12. Is there a need for a better database, in terms of hydrological, agricultural meteorological data? Why? Who should be responsible for gathering and evaluating and disseminating this data?

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13. Other Comments?

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.....

.....

If you have any other information that might be of help to this study, please include it.

* * * * * * *

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