REGIONAL FLOOD FREQUENCY ANALYSIS FOR SMALL NEW ZEALAND BASINS
1. MEAN ANNUAL FLOOD ESTIMATION

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ABSTRACT

One hundred and forty New Zealand basins with areas of less than 100 square kilometres were used to investigate regional methods for estimating mean annual floods for small ungauged basins. Besides the usual sample estimate of mean annual flood, data on slope, soil and hydrogeology were processed from the New Zealand Land Resources Inventory for each basin. Other variables used in the prediction of mean annual flood were basin area, and three rainfall statistics for each basin: 1-hour and 24-hour 5-year return period intensities, and mean annual totals. Multiplicative regression models using catchment characteristics were less precise than McKerchar and Pearson specific mean annual flood contour maps.

INTRODUCTION

Regional flood frequency analysis using the flood index method has two parts: estimation of mean annual flood (index flood) and estimation of dimensionless flood frequency growth curves. This paper addresses mean annual flood estimation for small New Zealand basins and Pearson (this volume) addresses dimensionless flood frequency.

Estimation of mean annual flood for basins where there are no records continues to be a weakness of regional flood frequency methods, despite efforts to improve estimators.

Beable and McKerchar (1982) developed a set of regression equations of the form

$$Q_m = a\, A^b\, P^c\, I^d,$$

where: Q_m is mean annual flood
A is basin area
P is mean basin rainfall
I is 24-hr rainfall intensity with a 2-yr return period
a,b,c and d are constants

Each equation was applicable for a "region" where regions were defined in terms of geographical differences, but adjusted to fit groups of adjacent basins where estimation errors for an overall equation were consistently either negative or positive. Factorial standard error of estimate for these equations was in the range 1.21 to 1.47, and equivalent to errors where Q_m is estimated from one to five years of record. These error statistics are likely to be underestimates because they do not include uncertainty about the placement of regions.

Mosley (1979) used morphologic reach and cross-section variables to estimate Q_m for 73 South Island rivers. The factorial standard error for the best equation using all 73 rivers was 1.71. This reduced to 1.52 for 63 non-braided rivers.

McKerchar and Pearson (1989) drew contour maps to use to estimate $Q_m/A^{0.8}$ (division by $A^{0.8}$ removes the effect of basin area) for any basin. The maps were developed using data from 343 basins. Proportional errors of estimates from the maps were defined by:

$$E = 100\,(Q_{mr} - Q_{ms})/Q_{ms},$$

where: Q_{mr} is the "regional" mean annual flood estimate inferred from the map, and Q_{ms} is the "at-site" estimate of mean annual flood, i.e. the estimate of Q_m from the flood series.

E values showed a mean of 8.6%, (i.e. the bias) and a root mean square error of ±55%

E values ranged from -69% to 578%. Nineteen sites, (i.e. 5% of sites) with E exceeding 70% were discarded as outliers. Statistics for the remaining 95% of sites were bias = –0.9% and root mean square error = ±22%, so that the standard error of estimate of Q_m from the maps was ±22%. This was an improvement over the Beable and McKerchar equations, which also discarded about 5% of the catchments as outliers.

Results were more variable for small basins than for larger basins. For all basins with areas less than 10 km², McKerchar and Pearson obtained the following:

	No. Basins	Bias (%)	Root Mean Square Error
All basins <10 km²	49	22	92
Outliers excluded	43	–0.7	34

Outline of problem

The error statistics for "all basins <10 km²" are unacceptably large for design flood estimation. With "outliers excluded" the error statistics are acceptable, but the question of what is an outlier is not resolved, and this raises doubt about the reliability of the method. Also, the outliers are disproportionately represented among the basins with area <10 km². Are the six records all in error, or are they conveying information about hydrological conditions not adequately represented by the contour maps? For example, the scale of the maps and the level of smoothing in their contours may mask much real variation between small basins. Can additional information be employed to improve regional estimates of flood statistics?

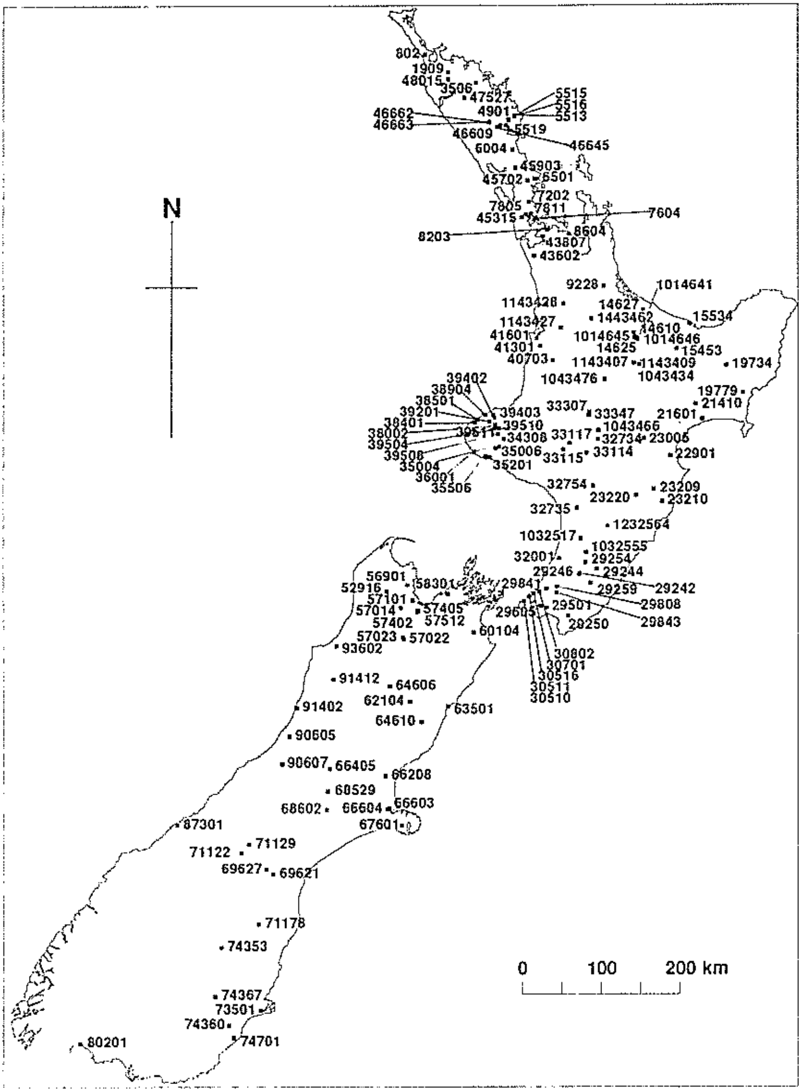

FIG. 1—Location of the 140 small (A ≤ 100 km²) New Zealand basins used in this study. Site numbers from Walter (1990).

The additional information available in the NZ Land Resource Inventory (Ministry of Works and Development, 1979) includes broad classes of rock type, overland slope, vegetation and soils. This information can be extracted from a database for any basin boundary, and this study sought to use it to improve estimates of mean annual flood for small basins.

METHOD

Data compilation

To assemble sufficient data for comprehensive analysis the area threshold was raised from 10 to 100 km². Data for 140 basins with areas less than 100 km², and at least six years of flow records were assembled (Fig. 1).

The data assembled for each basin were:

— Mean annual flood (Q_m): This quantity is the arithmetic mean of peak discharges for each of at least six years of record. These data were extracted from streamflow archives up to and including 1989 (Tideda: Rodgers and Thompson, 1991). Length of record (N years) is given beside the mean. Where possible the stage series are checked for consistency against records for adjacent basins. Reliability of the rating curves, which are calibration curves to transform stage to discharge, is problematical. Most of these small basins are fitted with weirs or bed-control structures calibrated using laboratory data. Where field calibration is limited to low flows, it is difficult to determine whether the adopted ratings are correct, especially at flood extremes beyond the range of conventional laboratory calibrations. This implies that annual maximum flood peak estimates for these basins are less reliable than those for basins with higher-stage current-meter gaugings (Potter and Walker, 1985).

— Area (A): Basin area is defined on the NZMS 260 (1:50000) or NZMS 1 (1:63360) map series, and listed in Walter (1990).

— Rainfall intensity (I_1 and I_{24}): Five-year return period rainfall depths for 1-hr and 24-hr duration storms were estimated from maps in Tomlinson (1980). These depths are areal means for each basin, but are not adjusted by areal reduction factors. In the Tomlinson maps I_1 is estimated from a sparse network of recording raingauges, whereas I_{24} is estimated using a much more comprehensive set of daily-read manual raingauges, and is more reliable.

— Mean annual rainfall (P): An areal mean annual rainfall was estimated from the map of 1951–1980 normals in NZ Met. Serv. (1985).

— Hydrogeology (H): Derivation of a basin estimate of "hydrogeology" is explained in Hutchinson (1990). In summary, each combination of rock types in the Land Resource Inventory is assigned a scalar number ranging from 1 for low to 8 for high bedrock infiltration capacity and transmissibility. Low values are assigned to strongly indurated sedimentary rocks, and igneous and metamorphic rocks. Medium values are assigned to pyroclastics, loess, crushed argillites, "soft" volcanics, and weakly indurated sediments. High values are assigned to ashes, breccia, scoria, lapilli, alluvium, colluvium, glacial till, peat and wind-blown sand. A basin mean is calculated as a sum weighted by the proportion of basin area occupied by each class.

— Slope (S): The Land Resource Inventory classifies parcels of land into seven slope classes A...G defined as:

A — 0–3°, flat to gently undulating
B — 4–7°, undulating
C — 8–15°, rolling
D — 16–20°, strongly rolling
E — 21–25°, moderately steep
F — 26–35°, steep
G — >35°, very steep

Areally weighted mean slope is calculated as:

$$S = 1.5\, S_a + 5.5\, S_b + 11.5\, S_c + 18\, S_d + 23\, S_e + 30.5\, S_f + 38\, S_g$$

where S_a, S_b, ... S_g are the decimal proportions of the catchment area occupied by ground in the slope classes A, B, ... G respectively.

— Soil Properties: A soil description applies to each Land Resource Inventory parcel. Three soil properties considered to affect rapid runoff were (MJ Duncan, pers. comm., 1991):

— Soil drainage (D): a scalar ranging from 1 to 7, 1 representing very poor drainage, 5 representing well drained, 7 representing excessive drainage.

— Depth-weighted macroporosity (DWP): Macroporosity determined in the laboratory from field samples applies to a particular soil horizon. A depth-weighted value was calculated as an index of macroporosity for the whole horizon. Typically macroporosities are in the range 0 to 30%.

— Minimum porosity (MP): Minimum porosity for each soil class was estimated.

Area-weighted estimates of these three quantities were calculated.

All the data are assembled in the Appendix, and summary statistics are given in Table 1.

TABLE 1—Summary of basin characteristic statistics of 140 basins listed in Appendix.

CHARACTERISTIC	Q_m (m^3/s)	A (ha)	I_1 (mm)	I_{24} (mm)	P (mm)
MINIMUM	0.054	1.420	13	45	550
MAXIMUM	389.2	9963	128	660	11700
MEAN	49.3	3061	34	154	1968
STANDARD DEV	69.1	2891	13	72	1301

CHARACTERISTIC	H	S (deg)	D	DWP (%)	MP (%)
MINIMUM	1.0	1.5	1.0	1.2	0.0
MAXIMUM	8.0	35.4	7.0	29.3	26.0
MEAN	4.4	19.7	4.3	13.9	8.7
STANDARD DEV	2.5	8.0	1.1	6.1	5.0

Analysis proposed

Multiple regression is proposed for the analysis using the form

$$Q_m = a\, X_1^{\,b}\, X_2^{\,c} \ldots$$

where: X_1, X_2 ... are basin characteristics (e.g. Area A, mean annual rainfall P, hydrogeology H, etc), and a, b, c ... are coefficients determined by multiplicative regression.

Analysis with subsets of the data is proposed, with the subsets defined as: a) arbitrary splits of the data, e.g. into four sets with high rainfall P and high minimum porosity MP, high P and low MP, low P and high MP, low P and low MP; with the high/low splits for P and MP taken as the median value. b) Clusters of data using the algorithm K-means of SYSTAT (Wilkinson, 1986), which splits data into groups such that between-group variation is maximised and within-group variation minimised. Variation is measured as the Euclidean distance between data for a basin and the group mean. These methods avoid splits based on loose geographic regions.

RESULTS

Data statistics

The compiled data statistics (Table 1) reflect the very large range of hydrological conditions encountered across the country.

For example, mean annual rainfalls range from 550 to 11700 mm/yr, mean basin slopes from 1.5 to 35 degrees, depth-weighted macroporosity ranges from 1.2% to 29.3%, and minimum porosity ranges from 0% to 26.6%.

Hydrogeology and drainage, both measures of infiltration, are near their upper bounds for volcanic ash-covered Central North Island basins where $Q_m/A^{0.8}$ are low. For example for Mangakara (site number 1043434), hydrogeology H = 7.5, soil drainage D = 6.2, and the porosity measures (DWP = 26.1%, MP = 16.8%) are amongst the highest for all the 140 basins, and $Q_m/A^{0.8}$ is 0.36 (Q_m in m³/s, A in km²) . In contrast, for two basins in Northland (Pukewaenga, 46662 and Pukeiti, 46663) intensity I_{24} = 155 mm is almost identical to Mangakara (I_{24} = 150 mm), but $Q_m/A^{0.8}$ = 5.0 and 5.4 respectively, and for both basins hydrogeology H = 4.0, soil drainage D = 1.0, depth-weighted macroporosity DWP = 2.1% and minimum porosity MP = 0.1%. The low values of the latter three parameters reflect the poor drainage and low porosities of the heavy clayey soils in these basins.

Another basin with unusually low values for $Q_m/A^{0.8}$ is Maryburn (71122) in the central South Island. Here $Q_m/A^{0.8}$ = 0.17, and the intensity estimate is I_{24} = 80 mm. Hydrogeology H = 8.0, soil drainage D = 5.0, depth weighted macroporosity DWP = 20.1% and minimum porosity MP = 15.5%, are all greater than the respective means across all basins (Table 1). This basin has been discarded as an outlier in previous studies.

For many basins at the extremes of the dataset, there is an inverse correlation between the flood parameter $Q_m/A^{0.8}$, and the Land Resource Inventory — derived quantities, soil drainage D, depth-weighted macroporosity DWP and minimum porosity MP. This study seeks to verify this correlation across a large sample of data, and to use it to provide better estimates of Q_m for ungauged basins.

Correlations

For logarithms (base 10) of data, correlation coefficients (Table 2) are generally positive. Correlation of log (Q_m) with area is notable, but otherwise its correlations are weak. Correlations between the three rainfall parameters and between the three soil parameters are also notable. These suggest that just one rainfall and one soil parameter may be sufficient as independent variables.

TABLE 2—Correlation matrix for logarithms of basin characteristics.

	Q_m	A	P	I_1	I_{24}	H	S	D	DWP	MP
Q_m	1.000									
A	0.879	1.000								
P	0.500	0.262	1.000							
I_1	0.372	0.062	0.754	1.000						
I_{24}	0.441	0.160	0.804	0.883	1.000					
H	−0.131	−0.006	0.060	0.076	0.094	1.000				
S	0.082	0.110	0.054	−0.052	−0.032	−0.431	1.000			
D	0.064	0.219	0.151	−0.011	0.057	−0.017	0.248	1.000		
DWP	0.116	0.287	0.204	0.025	0.103	0.064	0.209	0.876	1.000	
MP	0.145	0.298	0.155	0.032	0.109	−0.001	0.245	0.895	0.884	1.000

Regression analysis

Table 3 gives a selection of regression results using all the data. The results given are the best result, in terms of minimum standard error, for 1, 2, 3, and 4 variables. The standard errors and factorial standard errors, of similar magnitude to those reported for country-wide equations in Beable and McKerchar (1982), are too large for the results to be used for design flood estimation.

TABLE 3—Multiplication regression results for prediction of Q_m using all 140 basins. "t" is Student's statistic; "R^2" is coefficient of determination; and "s.e." is standard error.

No. Variables	Variable Name	Coef. b,c,d	s.e. of coef	t	R	R^2	s.e.	Factorial s.e.	Const log a	Multiplier a
1	A	0.856	0.040	21.7	0.879	0.773	0.411	2.57	0.279	1.90
2	A	0.808	0.031	26.2	0.930	0.866	0.317	2.07	−3.029	9.35×10^{-4}
	I_{24}	1.559	0.160	9.7						
3	A	0.805	0.028	28.7	0.944	0.890	0.288	1.94	−2.961	10.9×10^{-4}
	I_{24}	1.635	0.146	11.2						
	H	−0.422	0.077	−5.5						
4	A	0.848	0.026	32.5	0.956	0.913	0.257	1.81	−2.449	$35.6\times10_{-4}$
	I_{24}	1.679	0.131	12.9						
	H	−0.397	0.069	−5.8						
	DWP	−0.606	0.102	−6.0						

The data set was partitioned in a number of ways, including splitting the data into one of four groups depending on whether mean rainfall P and minimum porosity MP were above or below their median values. The most promising was to split between "high infiltration" and "low filtration" with low infiltration basins arbitrarily defined as having hydrogeology H $<$ 7 and soil porosity DWP

$< 11\%$. Standard error for 44 "low infiltration" basins was ± 0.184, but this error is still too large for the results to be of practical use (factorial standard error of 1.53).

Other analyses

Other analyses, including cluster analysis, and use of an "infiltration" parameter, a sum of standardised values of D, DWP and MP, did not improve predictive capability.

DISCUSSION

This study was founded on the notion that the basin data from the Land Resource Inventory would provide a country-wide estimator for mean annual flood which would be superior to the set of equations for the regions in Beable and McKerchar and the contour maps in McKerchar and Pearson. This hope arose because highly permeable basins such as those in the central North Island, which had the highest values for hydrogeology, drainage and the permeability parameters, have low values of $Q_m/A^{0.8}$, whereas other basins where infiltration rates were low (e.g. sites 46662, 46663, both in Northland) had low values for hydrogeology, drainage and permeability and quite high values of $Q_m/A^{0.8}$.

The results achieved are negative: it could not be demonstrated that basin data inferred from Land Resource Inventory (slope, hydrogeology, soil drainage, soil porosity) were useful in improving estimators for mean annual flood. This null result is a disappointment because it closes off what was perceived to be a promising line of investigation. Even though some extreme basins (e.g. Maryburn) seemed to have basin parameters which qualitatively explained their flood statistics, the variability of basin properties and particularly basin annual flood series is too large to obtain predictive equations.

After area, storm rainfall intensity, quantified by the five-year return period 24-hour duration rainfall from Tomlinson's (1979) maps, clearly remains the most important variable, but for small basins where critical storm duration is much less than 24 hours, this statistic is limited. The 1-hour storm rainfall statistic, based on a much smaller sample of records from automatic raingauges, is apparently less accurate and less useful.

RECOMMENDATIONS AND CONCLUSIONS

Parameters which characterise the hydrogeology, slope and infiltration properties of basins can be obtained from the NZ Land Resource Inventory.

The analysis undertaken could not devise predictors using these parameters for mean annual flood for small basins that were improvements over the contoured maps in McKerchar and Pearson.

Two further lines of enquiry will be investigated for small basin mean annual flood estimation in future:

1. Continued statistical approach with basin geometry and geomorphological variables used in the multiplicative regressions.
2. More deterministic approaches using physically-based rainfall-runoff models in conjunction with small-scale thunderstorm rainfalls.

In the meantime, the McKerchar and Pearson contour maps are recommended for estimating mean annual flood. Examples of robust regional flood frequency procedures for small basins are given in Pearson (this volume).

APPENDIX. Basin characteristics for 140 basins with areas less than 100 km².

Site	Q_m (m^3/s)	A (ha)	I_1 (mm)	I_{24} (mm)	P (mm)	H	S (deg)	D	DWP (%)	MP (%)
802	1.26	250	31	120	1200	8.000	12.500	4.9	21.3	14.4
1909	64.55	2858	34	135	1780	1.00	24.633	4.3	10.4	8.3
3506	53.60	1110	38	140	2320	1.000	8.540	4.4	9.7	4.3
4901	61.09	1250	50	200	1900	1.000	18.900	4.0	10.0	7.6
5513	3.09	63	46	190	1800	1.000	18.000	5.0	13.0	12.1
5515	0.642	16	46	190	1800	1.000	18.000	4.0	10.1	7.6
5516	0.756	13	46	190	1800	1.000	18.000	4.0	10.1	7.6
5519	51.80	1390	46	190	1700	1.020	15.700	3.6	9.0	6.7
6004	170.31	5977	44	180	1470	3.713	18.793	3.6	10.9	6.8
6501	18.53	813	42	195	1600	5.040	24.260	3.7	10.0	6.7
7202	26.34	957	32	135	1500	4.404	10.128	2.0	6.4	3.0
7604	31.15	1108	30	125	1290	3.127	9.020	1.0	1.2	0.8
7805	118.21	8240	29	130	1400	5.180	10.700	2.3	5.4	2.6
7811	21.50	1196	30	125	1320	5.756	8.206	2.9	7.1	2.7
8203	1.48	30	34	120	1250	8.000	1.500	4.0	13.1	5.9
8604	69.15	4072	38	150	1300	2.170	24.489	4.5	11.8	9.8
9228	42.24	792	44	150	1730	3.308	33.203	4.2	11.0	8.1
14610	17.89	5713	40	160	1670	6.159	14.952	4.7	22.1	14.6
14625	23.94	7389	40	160	1500	7.008	19.679	6.4	26.7	21.6
14627	34.67	6880	42	200	2470	6.000	19.835	6.0	20.0	15.7
1014641	20.21	7598	40	190	1920	6.238	20.013	5.7	28.3	17.0
1014645	2.02	81	40	160	1600	8.000	5.500	7.0	29.3	26.6
1014646	1.53	92	40	160	1500	8.000	5.500	7.0	29.3	26.5
15453	43.88	4505	42	200	1800	4.660	30.947	6.9	28.2	26.3
15534	1.86	267	40	150	1320	8.000	23.233	6.0	19.6	16.5
19734	37.51	3050	31	160	1750	4.909	24.085	5.4	20.7	14.4
19779	5.48	398	28	150	1500	4.040	22.768	3.0	5.9	2.3
21410	56.62	5029	28	155	2020	5.299	26.510	3.8	16.9	8.8
21601	45.91	2141	26	165	1660	4.092	27.930	3.1	14.1	6.5
22901	21.68	1844	28	170	1030	4.492	20.273	3.1	8.6	3.5
23005	1.33	52	28	165	2400	6.000	23.000	6.0	22.1	15.1
23209	10.22	2339	22	95	900	2.566	16.746	4.0	11.5	6.4
23210	59.25	4373	36	160	1390	4.784	17.116	2.9	12.2	5.9
23220	83.60	8460	34	150	1400	4.987	17.668	4.6	14.6	8.6
29242	111.34	4025	48	160	2520	1.510	31.663	5.0	15.7	9.3
29244	31.38	3632	20	105	1240	3.980	24.911	3.5	11.2	6.0
29246	282.00	7578	56	200	3140	1.477	34.953	5.0	14.8	9.1
29250	32.81	1557	33	140	1950	1.057	28.550	5.0	16.7	9.1

APPENDIX Continued. Basin characteristics for 140 basins with areas less than 100 km^2.

Site	Q_m (m^3/s)	A (ha)	I_1 (mm)	I_{24} (mm)	P (mm)	H	S (deg)	D	DWP (%)	MP (%)
29254	330.17	7875	56	180	3180	1.489	35.165	5.0	14.4	9.0
29259	0.219	23	24	90	1000	4.030	22.400	2.0	9.6	4.5
29501	87.17	2305	29	150	3010	1.577	29.666	5.0	15.1	9.0
29605	76.36	7973	26	120	1980	1.924	23.422	3.6	13.3	7.1
29808	285.09	8724	48	200	3210	1.000	34.928	5.0	14.7	9.2
29841	69.00	4384	25	110	1830	1.422	25.903	4.4	16.5	8.7
29843	85.28	3795	28	135	3080	1.004	32.000	5.00	15.4	9.4
30510	0.054	5	20	100	1150	1.000	23.000	5.0	8.1	5.7
30511	0.085	7	20	100	1150	2.000	17.300	5.0	8.1	5.7
30516	7.42	910	22	100	1180	2.341	17.481	4.5	9.7	7.6
30701	38.11	4469	23	110	1260	2.506	19.223	3.1	7.4	5.6
30802	53.63	3847	26	125	1510	2.622	19.891	3.7	9.7	6.5
32001	18.23	1680	22	80	1150	2.951	18.900	4.1	12.5	7.9
1032517	99.50	5660	28	115	1600	1.800	26.600	4.9	14.5	9.3
1032555	219.57	5730	30	190	2200	2.104	28.900	4.9	15.4	9.1
1232564	71.68	6230	28	130	1200	4.114	20.000	4.5	15.0	8.9
32734	7.01	1542	32	160	2800	6.480	20.021	6.2	25.0	21.2
32735	33.32	6158	20	80	980	4.669	8.905	2.9	10.7	1.3
32754	65.72	9950	22	85	1100	4.240	26.500	3.7	10.1	6.1
33114	3.57	5311	24	100	1360	7.431	10.916	5.1	25.2	9.8
33115	17.72	3278	24	115	1520	5.941	22.030	4.8	13.9	8.6
33117	27.47	2063	24	145	2390	6.389	10.199	4.9	15.9	8.7
33307	47.75	8184	26	115	2650	6.665	16.112	5.4	25.5	12.1
33347	28.07	2714	30	125	2990	5.613	24.301	5.3	23.0	11.4
34308	149.50	8463	36	280	2580	7.773	5.257	4.6	15.6	11.3
35004	73.01	4960	32	200	2680	7.259	8.110	4.2	13.0	9.3
35006	27.69	2000	32	180	2200	7.814	7.890	3.5	9.5	6.2
35201	68.52	4100	32	200	2400	7.692	6.210	4.3	13.9	8.9
35506	104.87	5960	36	200	2200	7.466	5.590	4.5	14.6	9.2
36001	35.91	3098	40	200	2490	4.766	7.877	3.8	12.1	7.4
38002	183.86	4128	64	300	5010	4.866	24.136	3.6	8.5	5.9
38401	55.14	2492	44	170	2610	7.230	20.160	3.9	9.8	7.4
38501	103.73	3912	42	170	2760	6.985	19.734	3.7	8.9	6.7
38904	16.62	2007	36	150	2060	7.662	12.463	3.6	10.0	7.6
39201	329.50	5910	64	280	4320	6.597	15.553	4.0	10.2	6.7
39402	61.94	4903	48	180	2220	7.849	10.636	4.7	14.5	9.7
39403	81.46	3778	48	240	2730	7.415	6.372	4.3	11.5	7.7
39504	174.74	7734	44	260	3230	7.190	8.951	4.5	14.8	10.0
39508	53.90	1924	56	320	3920	6.162	10.694	4.1	12.9	7.8
39510	67.36	1092	60	280	4830	6.408	9.446	4.3	11.1	6.8
39511	94.70	1844	64	300	4650	6.557	14.794	4.0	10.5	6.4
40703	4.31	1411	26	120	1940	6.303	19.484	4.3	14.0	6.3
41301	51.64	9510	26	135	2400	4.937	25.470	4.2	10.7	5.3

APPENDIX Continued. Basin characteristics for 140 basins with areas less than 100 km^2.

Site	Q_m (m^3/s)	A (ha)	I_1 (mm)	I_{24} (mm)	P (mm)	H	S (deg)	D	DWP (%)	MP (%)
41601	6.62	879	26	105	1590	3.702	23.433	3.6	9.5	4.4
1043434	4.16	2159	32	150	1570	7.501	19.777	6.2	26.1	16.8
1043466	38.09	9589	40	170	3170	6.910	15.677	5.2	16.9	11.4
1043476	0.153	5	29	110	1400	8.000	18.000	7.0	28.9	18.1
1143407	0.599	169	34	145	1700	7.462	24.103	5.7	23.1	15.1
1143409	0.227	34	34	145	1700	7.300	24.900	4.0	9.5	4.6
1143427	2.68	311	26	140	2200	4.824	21.900	4.2	11.8	5.1
1143428	3.77	1464	28	120	1390	7.992	10.128	3.1	9.2	4.7
1443462	5.76	999	32	120	1410	6.932	20.277	5.0	19.4	14.8
43602	12.51	1786	32	120	1380	7.700	9.774	5.0	20.1	12.8
43807	23.85	1250	34	120	1280	5.103	8.373	2.6	6.8	5.6
45315	40.32	4646	29	125	1570	5.440	15.029	3.1	8.4	3.5
45702	32.73	821	40	190	1770	4.000	22.138	2.6	6.1	5.2
45903	2.03	88	42	175	1400	4.000	11.500	2.0	2.4	1.7
46609	56.98	1213	44	170	1770	1.324	15.978	4.1	10.3	7.0
46645	9.28	336	42	160	1670	4.557	9.080	4.4	13.9	7.0
46662	2.34	39	42	155	1550	4.000	11.500	1.0	2.1	0.1
46663	0.18	1	42	155	1550	4.000	11.500	1.0	2.1	0.1
47527	23.48	1003	34	155	1760	3.998	17.621	3.2	10.2	4.4
48015	75.06	2178	34	135	1750	1.000	26.188	4.0	8.8	7.4
52916	97.27	4681	48	290	3710	1.476	35.392	5.0	21.7	14.0
56901	47.46	4659	42	200	2390	1.063	28.037	5.0	13.0	9.4
57014	61.63	8238	31	110	1270	7.959	23.553	4.6	13.2	9.0
57022	2.76	514	23	90	2150	8.000	23.067	5.0	14.7	10.1
57023	1.21	279	23	90	2150	8.000	29.931	5.0	14.7	10.1
57171	61.66	5800	34	110	1000	8.000	18.268	3.2	6.9	4.0
57402	0.130	4	33	105	1100	8.000	11.500	3.0	6.4	4.2
57405	0.297	7	33	105	1100	8.000	18.000	3.0	6.4	4.2
57512	0.199	3	33	195	1100	8.000	23.000	3.0	6.4	4.2
58301	30.02	1725	31	165	1460	1.021	28.855	5.0	21.0	13.9
60104	73.93	6502	18	105	950	1.072	31.100	5.0	13.9	11.7
62104	14.10	2074	28	150	1640	1.500	29.750	5.0	23.2	18.2
63501	3.34	169	40	200	1000	1.000	30.905	5.0	14.7	10.1
64606	92.67	7404	48	210	2300	1.485	29.522	4.5	20.1	15.1
64610	35.13	4191	34	160	1150	3.083	23.054	3.8	11.5	9.0
66208	1.83	260	18	100	800	8.000	23.000	3.0	8.1	5.4
66405	0.68	90	28	105	1600	1.000	30.500	5.0	22.5	17.1
66603	1.18	218	15	95	800	3.240	28.600	5.0	13.2	8.9
66604	1.42	326	15	95	800	3.650	25.600	5.0	13.4	9.1
67601	6.79	321	26	120	1300	1.708	30.500	4.9	9.5	7.2
68529	2.762	619	19	90	1100	1.900	29.250	5.0	23.7	17.9
68602	10.48	5500	18	110	1000	5.230	12.800	4.6	14.7	11.3
69621	16.72	2297	17	80	980	2.193	24.482	4.4	17.8	14.0

APPENDIX Continued. Basin characteristics for 140 basins with areas less than 100 km^2.

Site	Q_m (m^3/s)	A (ha)	I_1 (mm)	I_{24} (mm)	P (mm)	H	S (deg)	D	DWP (%)	MP (%)
69627	1.39	128	16	70	850	1.000	27.900	5.0	24.3	18.1
71122	3.96	5008	16	80	950	8.000	8.550	5.0	20.1	15.5
71129	22.09	9963	24	140	1560	3.927	24.111	5.0	22.0	15.9
71178	38.19	7870	18	60	900	1.160	28.820	5.0	18.7	14.6
73501	44.33	4500	14	100	1100	1.330	18.900	4.1	10.2	7.9
74353	3.01	2406	13	45	550	1.000	15.711	4.3	10.0	7.8
74360	2.03	286	16	65	750	3.000	11.500	3.0	8.1	5.5
74367	2.02	58	17	70	1180	1.000	9.225	2.0	5.6	1.0
74701	6.77	959	14	60	830	1.684	16.518	4.7	6.4	4.2
80201	30.53	7160	19	78	1200	3.611	17.244	3.2	8.9	5.8
87301	389.18	9780	56	440	7200	2.770	29.300	4.7	19.9	13.0
90605	28.85	438	48	220	3400	7.062	14.943	4.1	17.7	9.2
90607	193.82	1233	128	660	11700	2.393	33.740	4.0	18.0	11.6
91402	19.13	1660	40	130	2600	3.250	24.500	4.2	12.4	8.2
91412	0.828	66	28	110	2200	8.000	30.500	5.0	14.7	10.1
93602	143.57	1964	60	260	5670	1.000	16.023	2.7	12.3	8.0

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