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SPATIAL VARIABILITY OF LOW FLOWS ACROSS A PORTION OF THE CENTRAL SOUTHERN ALPS, NEW ZEALAND

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ABSTRACT

Flows were measured at 48 tributaries of the Rakaia, Hokitika, Waitaha and Mikonui Rivers, on 21 March 1978, during a period of extreme summer low flow, and at 54 tributaries, on 17 July 1979, during winter low flow. Summer low-flow runoff varies approximately linearly with mean annual precipitation. Mean annual precipitation explained most of the observed variance in instantaneous specific discharge for summer low flow in a simple power-law relationship, and could usefully be used to interpolate between sites of measured summer low flows.

Winter low flows do not correlate with mean annual precipitation, with basin altitude, or with any other easily measured drainage-basin parameter. Winter and summer low flows in this region belong to distinct populations and should be treated separately in the prediction of extremes.

INTRODUCTION

Increasing competition for the water resources of the major rivers draining the Southern Alps has brought a demand for information on their low flow hydrology. Rivers draining the high alps along the main divide have two prominent seasonal low-flow periods: one in late summer, usually terminating prior to the autumnal equinox; and the other in mid-winter, usually reaching a minimum shortly after the winter solstice. Both periods are associated with sequences of persisting high-pressure weather systems which prevent or inhibit advection of moist air onto South Island. Low flows are due principally to an absence of rain, but summer low flow is accentuated by loss of soil moisture through evaporation, whereas winter low flow is accentuated by formation of ice in the soil. Much winter precipitation falls as snow and is largely unavailable for immediate runoff; in some areas the delayed runoff contributes to summer flow through the melting of glacier ice and late persisting snow. Although extremes of both summer and winter low flows are due to the persistence of similar synoptic conditions, the influence of ice, in adding to summer flow and subtracting from winter flow, suggests that the two should be considered separately.

This paper outlines the spatial variability of summer and winter low flows in drainage basins of the Rakaia, Hokitika, Mikonui and Waitaha

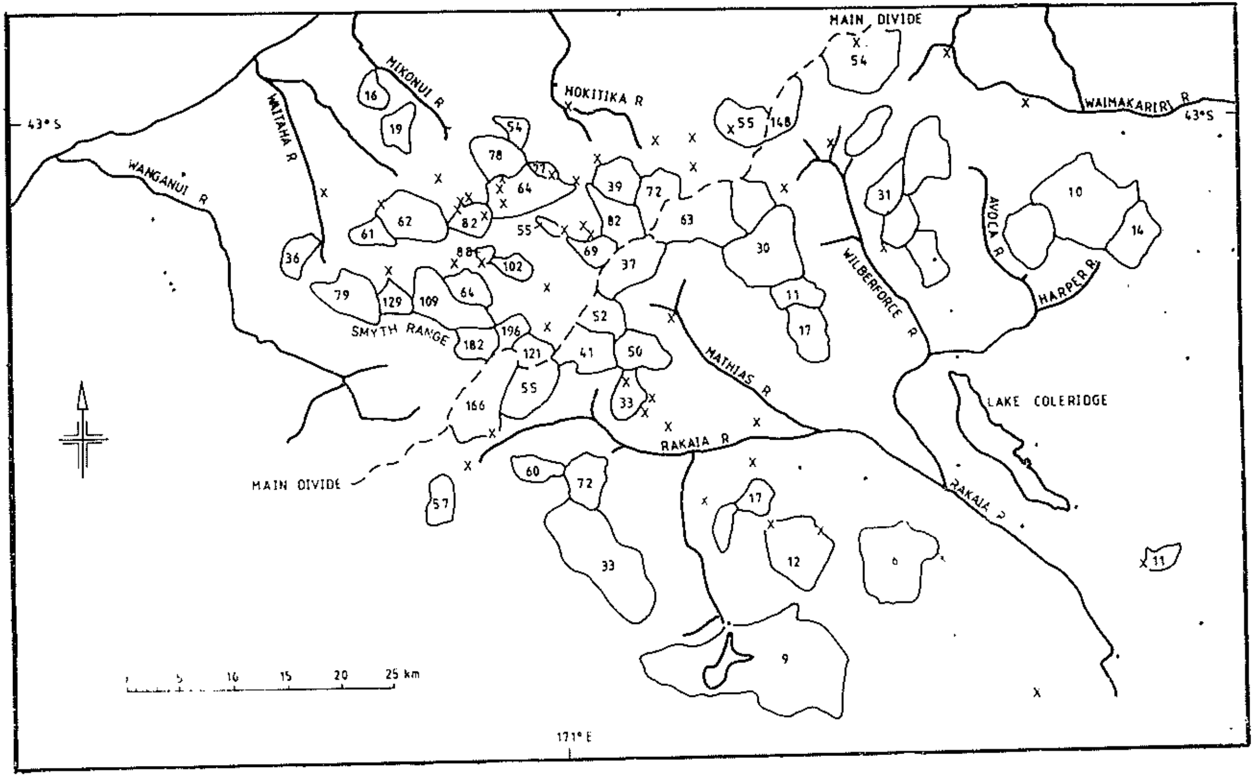

FIG. 1—Instantaneous specific discharge ($l\ s^{-1}\ km^{-2}$) for tributaries gauged on 21 March 1978.

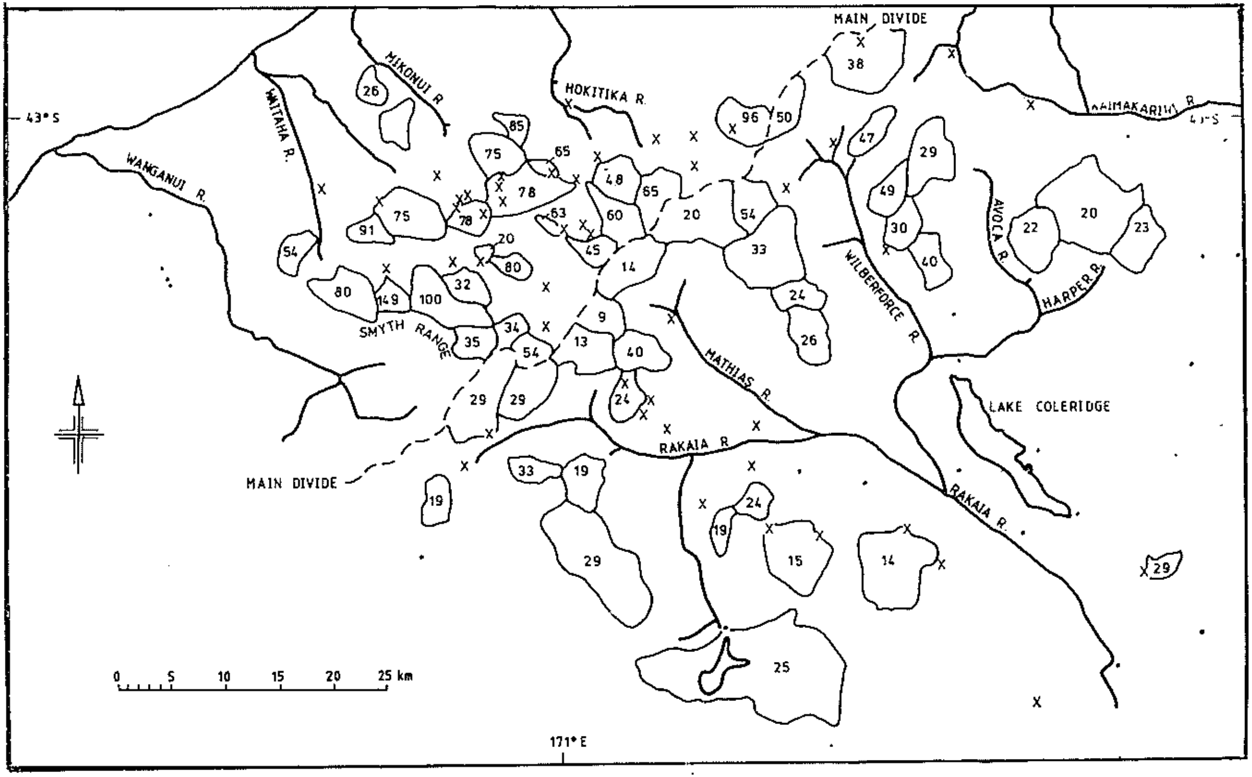

FIG. 2—Instantaneous specific discharges ($l\ s^{-1}\ km^{-2}$) for tributaries gauged on 17 July 1979.

TABLE 1—Simultaneous Low Flow Discharges for Tributaries of the Rakaia, Hokitika, Waitaha and Mikonui Rivers—21 March 1978 and 17 July 1979

TRIBUTARY	GAUGING SITE (Grid refer. §)	†AREA km^2	SUMMER LOW FLOW (SPEC. DISCHARGE) $l\ s^{-1}km^{-2}$	WINTER LOW FLOW (SPEC. DISCHARGE) $l\ s^{-1}km^{-2}$	BASIN PRECIPITATION (MEAN ANNUAL) $mm\ a^{-1}$	ALTITUDE m	GEOLOGY
Rakaia Basin							
Avoca River	S65:955147	20.9	-	29	3300 ± 300	1250	Indurated sandst./mudst.
Boundary Stream	S66:827018	12.2	-	40	2000 ± 200	1160	,, ,,
Bristed Stm	S65:863108	12.7	31	49	3100 ± 200	1130	,, ,,
Cameron River*	S73:646687	56.9	33	29	2200 ± 300	1070	,, ,,
Cattle Stm	S65:593937	20.0	41	13	4600 ± 300	1040	,, ,,
Centre Creek	S66:034034	22.2	-	22	1700 ± 200	970	,, ,,
Charlies Stm	S73:713752	6.5	-	19	1600 ± 200	1130	,, ,,
Chimera Stm	S65:802952	17.2	17	26	2300 ± 300	1070	,, ,,
Dry Acheron Stm	S74:147731	6.1	11	29	1400 ± 200	950	,, ,,
Fanghill Stm	S65:887063	12.2	-	30	2400 ± 200	1040	,, ,,
Glenfalloch Stm	S73:753826	7.3	17	24	1600 ± 200	1040	,, ,,
Griffiths Stm*	S65:796186	13.4	148	50	7500 ± 300	1220	,, ,,
Hamilton Creek	S66:111057	18.1	14	23	1600 ± 200	950	,, ,,
Harper River	S66:110057	50.1	10	20	1800 ± 200	910	,, ,,
Jagged Stream*	S73:603848	13.3	72	19	3300 ± 300	1310	,, ,,
Jerusalem Stm	S65:671953	15.7	50	40	4000 ± 300	1040	,, ,,
Kirk Stream	S72:440837	10.1	57	19	4500 ± 300	1490	,, ,,
Lake Stream	S73:718678	114.0	9	25	1000 ± 150	760	,, ,,
Louper Creek*	S72:516888	18.1	55	29	5600 ± 300	1130	,, ,,
Mathias North	S65:690072	32.4	63	20	5700 ± 400	1070	,, ,,
Mathias South	S65:618997	11.6	52	9	5100 ± 400	1220	,, ,,
Mathias West	S65:633032	25.6	37	14	5800 ± 400	1040	,, ,,
Moa Creek	S65:799057	34.0	30	33	4000 ± 200	820	,, ,,
Ramsay River*	S72:486868	32.5	166	29	6600 ± 400	1280	,, ,,
Reischek Stream*	S72:503851	9.3	60	33	4000 ± 300	1520	,, ,,
Smite River	S73:785727	30.7	12	15	1500 ± 200	1040	,, ,,
Totara Stream	S73:618891	11.0	33	24	3600 ± 200	1370	,, ,,
Turtons Stream	S73:877699	37.7	6	14	900 ± 100	1010	,, ,,
Unknown Stream	S65:771113	13.6	-	54	5100 ± 200	1130	,, ,,
Weka Stream	S65:853163	8.2	-	47	4500 ± 200	1310	,, ,,
Wilberforce River	S58:851222	35.2	54	38	7100 ± 400	1070	,, ,,

TRIBUTARY	GAUGING SITE (Grid refer. §)	AREA km^2	SUMMER LOW FLOW (SPEC. DISCHARGE) $l\,s^{-1}km^{-2}$	WINTER LOW FLOW (SPEC. DISCHARGE) $l\,s^{-1}km^{-2}$	BASIN PRECIPITATION (MEAN ANNUAL) $mm\,a^{-1}$	ALTITUDE m	GEOLOGY
Hokitika Basin							
Biddy Creek	S65:559080	2.6	55	63	8800 ± 300	850	Schist
Cataract Creek	S65:562077	9.9	69	45	7300 ± 300	1070	,,
Cropp River	S65:575127	29.4	64	78	10100 ± 200	1000	,,
Frews Creek	S65:598147	14.5	39	48	8300 ± 300	730	,,
Hokitika River	S65:665147	14.8	72	65	7500 ± 500	1100	,,
Mungo River	S65:727177	17.3	55	96	8100 ± 400	970	,,
Noisy Creek	S65:553136	3.4	77	65	10200 ± 200	1250	,,
Price River	S64:527053	6.6	102	80	8600 ± 400	1220	,,
Vincent Creek	S65:580130	11.7	82	60	7600 ± 300	970	,,
Whitcombe River*	S64:540976	11.3	121	54	5700 ± 400	1160	Schist-sandst./mudst.
Mikonui Basin							
Bullock Creek	S57:367251	8.7	16	26	3500 ± 400	460	Granite
Dickson Creek	S64:469180	16.6	78	75	8250 ± 400	610	Schist
Red Granite Creek	S57:413216	11.4	19	-	4200 ± 400	460	Granite
Scamper Creek	S64:492192	6.1	54	85	7500 ± 500	700	Schist
Tuke River	S64:454101	10.6	82	78	9800 ± 200	1220	,,
Waitaha Basin							
County Stream*	S64:420019	18.4	109	100	8900 ± 500	1220	Schist
Douglas Creek	S64:308076	7.7	36	54	4800 ± 400	400	,,
Ivory Stream*	S64:477048	2.5	88	20	9200 ± 200	1520	,,
Little Waitaha R	S64:394125	23.4	62	75	8300 ± 500	640	,,
MacGregor Stream	S64:342085	8.8	61	91	7000 ± 400	790	,,
Moonbeam Torrent	S64:382039	7.5	129	149	8400 ± 800	820	,,
Reid Creek	S64:454045	10.4	64	32	9100 ± 500	1400	,,
Whirling Waters	S64:327046	22.4	79	80	8200 ± 800	760	,,
Wanganui Basin							
Evans River*	S64:447962	9.8	182	35	8500 ± 400	1250	Schist-sandst./mudst.

§ Grid references based on the national thousand-yard grid of the 1:63360 topographical map series (NZMS 1).

* Basin has more than 10% of area covered by permanent snow or ice.

Rivers in the central Southern Alps. Influences of precipitation, altitude, and geology on low flows are examined by empirical correlation and inspection. An explanation of the statistically significant correlation between specific discharge in summer low flow and mean annual precipitation is outlined, and its implications explored. The possibility of using the distribution of precipitation as a guide to interpolating between measurements of summer low flow is discussed.

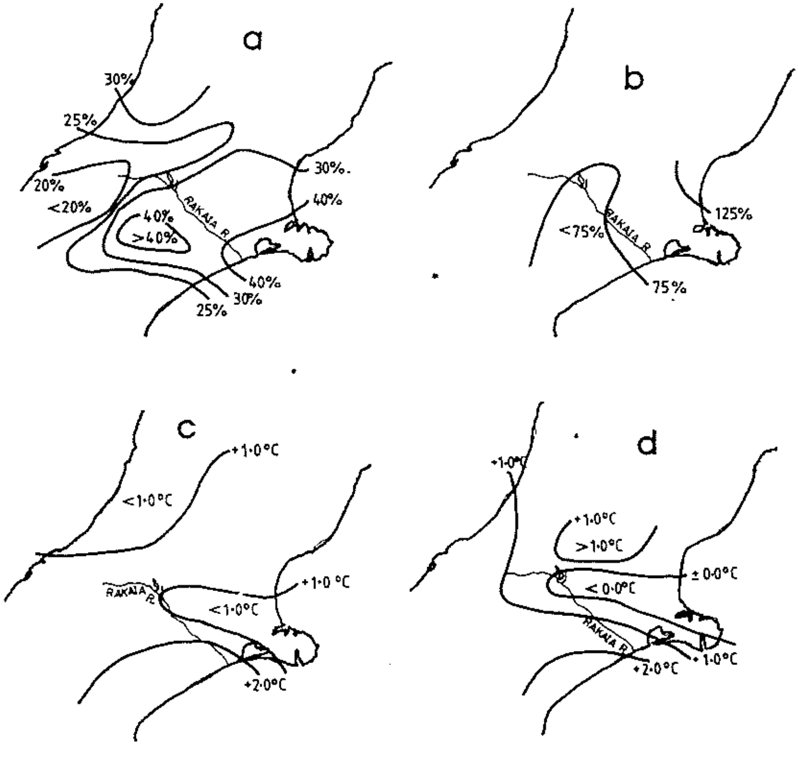

FIG. 3—Departures from 1941-1970 climatological normals for central South Island:
(a) rainfall for the period 21 January 1978 to 21 March 1978
(b) rainfall for the period 17 June 1979 to 17 July 1979
(c) daily mean temperature for the period 17 June 1979 to 17 July 1979
(d) daily minimum temperature for the period 17 June 1979 to 17 July 1979
(information compiled by New Zealand Meteorological Service)

LOW-FLOW DATA

Summer

Following a prolonged summer drought in 1977-78, 48 tributary rivers and streams in the drainage basins of the Rakaia, Hokitika, Mikonui and Waitaha Rivers were gauged on 21 March 1978 (Fig. 1, Table 1). At this time, the flows of the Rakaia (91.8 m^3 s^{-1}) and Hokitika (21.5 m^3 s^{-1}) Rivers were extremely low. The probability of exceedence for these flows is 0.96 at both sites.

Sites for gauging were selected with local knowledge, and by examination of 1:63360 topographic maps, using the following criteria:

(1) The cross-section was likely to be wadable.
(2) There was little likelihood of loss to groundwater.
(3) There appeared to be space to land a helicopter.
(4) The sites were spread uniformly over the area of interest

Winter

For comparison, all but one of the above tributary streams, and an additional seven, were gauged in winter low flow on 17 July 1979 (Fig. 2, Table 1). These low flows generally were not as extreme as those of the previous summer: flow of the Rakaia River was 117 m^3 s^{-1}, and that of the Hokitika River, 26.8 m^3 s^{-1}. The probabilities of exceedance for these flows are 0.78 and 0.91 respectively.

PRIOR PRECIPITATION HISTORY

Summer 1977-78

The summer of 1977-78 was unusually dry: for two months from 21 January to 22 March, NZ Meteorological Service stations in the central South Island received only 20-40 percent of their normal rainfall (Fig. 3a), and no significant rain fell in the central Southern Alps between 3 and 18 March. On 18-19 March, just three days prior to the gauging, some rain fell uniformly over most of South Island, bringing 15-20 mm of rain to the study area, but this had no noticeable effect on flow of the Rakaia or Hokitika Rivers and probably was insufficient to overcome the soil-moisture deficit.

Winter 1979

The winter of 1979 was not exceptional: precipitation for the period 17 June to 17 July, preceding the winter gaugings, was close to normal for central Westland and the Upper Rakaia basin. To the southeast of the area, however, precipitation was only half to three quarters of its normal values (Fig. 3b). Whether all of the precipitation fell as snow at higher altitudes is not known.

Mean temperatures for the month before the gaugings were warmer than normal, probably by between 1 and 2 Celsius degrees (Fig. 3c). Daily minimum temperatures also averaged warmer than normal, but by a lesser amount (Fig. 3d), except in the vicinity of the meteorological site at Lake Coleridge which averaged 0.4 C° below normal.

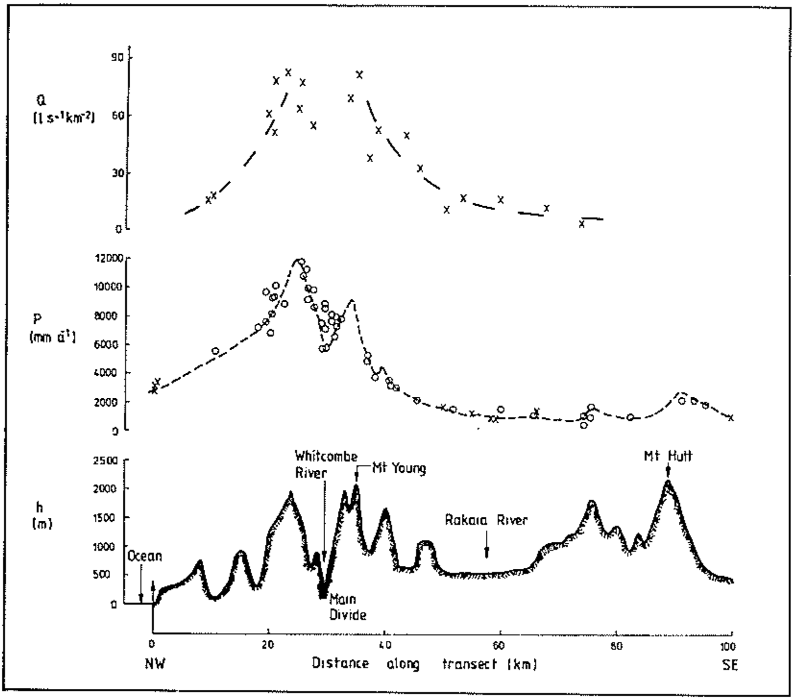

FIG. 4—Rakaia transect showing variations in mean annual precipitation (P) and instantaneous specific discharge at summer low flow (Q) across the Rakaia transect. Height (h) in metres above sea level.

VARIABILITY OF SUMMER LOW FLOWS

Eleven of the tributaries with major areas of permanent snow and ice have significantly higher specific discharges for summer low flow compared with adjacent snowfree basins (Table 1). In these basins winter precipitation stored as snow and ice is released by melting in spring and summer. Summer low flows of these tributaries are more dependent upon areas of snow cover, on air temperatures, and on aspect to the summer sun, than on summer drought.

The spatial distribution of specific discharge in summer low flow for the tributaries with less than 10 percent cover of snow and ice appears to follow, in general form, the distribution of annual precipitation across the central Southern Alps outlined by McSaveney (1978) and by Griffiths and McSaveney (1983a) (Fig. 4). The measured summer specific discharges are highest for tributaries draining the most westward mountain ranges, where precipitation also is a maximum. Low-flow runoff and precipitation decrease exponentially both east and west from these ranges.

Precipitation has been measured at a number of sites in a broad tran-

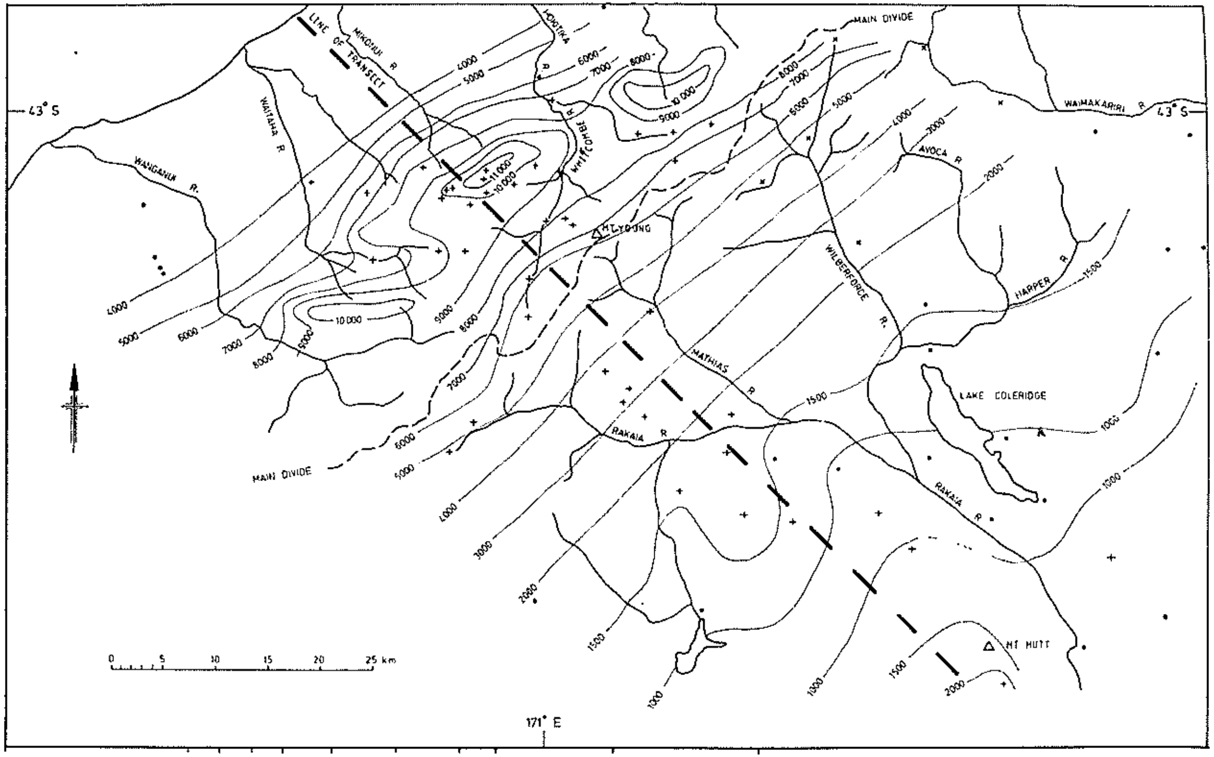

FIG. 5—Isohyetal map of mean annual preciptation (mm)
- . NZ Meteorological Service raingauge.
- + Ministry of Works and Development raingauge
- x North Canterbury Catchment Board raingauge.

Line of transect (Fig. 4 from NW to SE.

sect across the central Southern Alps in the vicinity of Rakaia River (Griffiths and McSaveney, 1983a). Thirty-year normals (1941-70) have been computed for the Meteorological Service gauges by NZ Meteorological Service (1973, 1975) and for the remainder of the sites by Griffiths and McSaveney (1983a). From these data an isohyetal map of mean annual precipitation was prepared (Fig. 5). Where raingauge density is low, or precipitation gradients high, contouring was aided by the predictive equations of Griffiths and McSaveney (1983a) for rainfall on the westernmost ranges of the area, and the observation of McSaveney (1978) that precipitation decreases exponentially from this value.

Drainage-basin mean annual precipitation (Table 1) was obtained from the isohyetal map by planimetering the basin areas between isohyets. As the positions of some isohyets are uncertain, a standard error of the estimate of precipitation (Table 1) was approximated crudely by dividing a subjective assessment of the total uncertainty range by three (i.e., assuming a 99% probability level). Empirical relationships between specific discharge at summer low flow and basin mean annual precipitation were explored, using the Family Regression Program in the General Statistics Package for the HP 9825 calculator, which fitted the following models:

$Q=a + bP$

$Q=A + b/P$

$Q=1/(a + b/P)$

$Q=a + bP^{0.5}$

$Q=a \exp (bP)$

$Q=aP^{b}$

$Q=a + b\ln P$

$Q=a + bP + cP^{2}$

in which Q is summer low flow ($l s^{-1}\ km^{-2}$) of basins with less than 10% permanent snow and ice; P is mean annual precipitation (mm); and a, b, and c are constants. Most variance in the data is statistically explained by the simple power-law:

$$Q=0.007\ P^{1.024} \qquad (1)$$

The coefficient of variation (r^2)=0.9; and the percentage standard error of the estimate (S.E.) ≈ ± 30%.

There is a small but significant difference in the relationship between precipitation and specific discharge on the western side of the main divide from that on the eastern side (Fig. 6). West of the divide the best of the empirical relationships is:

$$Q = 0.0001\ P^{1.48} \qquad (2)$$

$r^2 = 0.68$, S.E. $\simeq \pm 30\%$

East of the main divide it is

$$Q = 0.004\ P^{1.10} \qquad (3)$$

$r^2 = 0.92$, S.E. $\simeq \pm 20\%$

indicating that western basins tend to provide significantly less low flow for a given annual precipitation. This is equivalent to more runoff occurring quickly in the western basins. At one western basin, the Cropp River, 50-65% of storm rainfall, for storms of between 50 and 500 mm

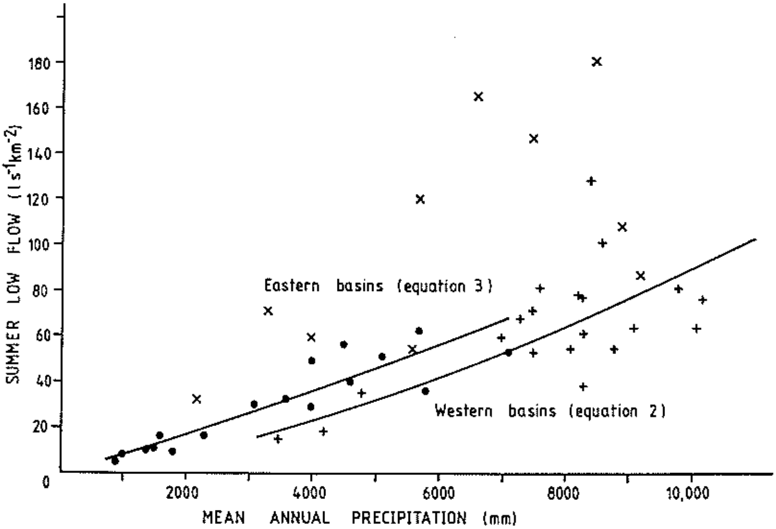

FIG. 6—Relationship between simultaneous summer low flow (*l* s^{-1} km^{-2}) and mean annual precipitation (mm) for basins, east and west of the main divide. Basins with more than 10% permanent ice or snow X; basins east of the main divide •; western basins +.

rainfall, runs off within 45 minutes of rain ceasing (Griffiths and McSaveney, 1983b). This rapid runoff appears to be due to a number of factors: extremely steep slopes and channels; a very high drainage density; and a combination of abundant impermeable gleyed soils, open cracks in the rock regolith, and very highly permeable sandy soils.

The difference in the relationships between precipitation and discharge for eastern and western basins probably is a result of a difference in regolith thickness. In the western Southern Alps, steep slopes, frequent heavy rain and resultant slope instability and channel-scouring floods are not conducive to a thick regolith. East of the divide there also are steep slopes, but they are relics of past glaciation. Their foot-slopes generally are mantled in deep regolith from scree accumulation, and there are also extensive loess sheets mantling the lesser slopes. The extensive thick regolith of the eastern Alps can be expected to store and delay runoff, as is observed. This difference in regolith thickness should result in regionally different recession constants east and west of the divide. The small but significant differences in the exponents and coefficients in equations 2 and 3 confirm this.

VARIABILITY OF WINTER LOW FLOW

Statistical correlation between specific discharge at winter low flow and annual precipitation is poor, with r^2 not exceeding 0.4 in any of the eight models tested. At the time of the winter gaugings, most of the basins were covered by snow, and largely frozen. Consequently, we might expect gauged flow to be related to snow depth, percentage snow cover, and soil temperature. No measurements of these variables are available. Soil temperature and amount of snow, however, might generally be causally correlated with basin elevation.

The altitude of the stream channel midway between the gauging site and the head of the basin, as measured from 1:63,360 topographic maps with 100-foot contours (Table 1), was used as a surrogate variable to test the influence of variables such as snow cover and temperature.

The eight correlation models failed to reveal any significant relationship between altitude and winter flow data. In all models, r^2 was less than 0.1. Correlation between winter and summer low flows also was tested, but no statistical relation was found. For a given average basin altitude, however, specific discharge at winter low flow is generally about three times greater west of the main divide than in the east. It is apparent that winter and summer low flows belong to distinctly different populations whose variances are determined by different factors. Specific discharge at winter low flow does not appear to correlate with any known, easily measured basin parameter.

ANOMALOUS FLOWS

Within the total data set of summer and winter low flows, one basin, Moonbeam Torrent, a tributary of the Waitaha River, stands out as an anomaly, with much higher specific discharges in summer and winter low flows (129 and 149 $l\,s^{-1}$ km^{-2} respectively) than would be expected in comparison with surrounding measurements (Figs 1, 2). Its two adjacent basins, Whirling Waters (79 and 80 $l\,s^{-1}$ km^{-2}), and County Stream (109 and 100 $l\,s^{-1}$ km^{-2}), draining the north flank of the Smythe Range to Waitaha River also have moderately high specific discharges in low flow during both summer and winter, with little difference in measured low-flow discharges between the two seasons. This stands in marked contrast to the neighbouring Evans River (182 and 35 $l\,s^{-1}$ km^{-2}) and Reid Creek (64 and 32 $l\,s^{-1}$ km^{-2}) draining the same range, which have high seasonal contrast in low flow. Only one, albeit unlikely, explanation is offered—that the anomalous basins experienced localised heavier rain than elsewhere, not long before *each* of the two gaugings. This hypothesis cannot be tested without repeating the surveys.

GEOLOGY AND LOW FLOW

Similar simultaneous low-flow gaugings have been carried out in Northland (Waugh, 1970) and in Taranaki (McKerchar and Dymond, 1981). In both studies, geology was inferred to be the primary control on regional low-flow variability. This does not appear to be the case in the central Southern Alps. The bedrock east of the main divide is well-indurated sandstone and mudstone, while, to the west, the bedrock is schist, with granite in the far west (Table 1). The magnitude of changes in mean annual precipitation across the region, from less than 1,000 mm a^{-1} in the east to more than 10,000 mm a^{-1} in the west, appears to mask any geological control of low flow.

USES OF THE PRECIPITATION—LOW FLOW RELATION

Correlation between summer low flow and mean annual precipitation for basins with less than 10% permanent snow or ice, suggests that knowledge of mean annual precipitation might be useful in interpolating between, or extrapolating from, measured values of specific discharge at summer low flow, or *vice versa.*

The standard errors of the estimates for equations 2 and 3 indicate that low flows may be interpolated with standard errors of ± 20 to ± 30 percent. Such precision in interpolation between measurements of low flow could be adequate for many practical applications in the Southern Alps.

As the spatial distribution of specific discharge at summer low flow follows that of mean annual precipitation, simultaneous low-flow gaugings also indicate the spatial distribution of precipitation. However, this knowledge is not particularly useful. Summer low-flow measurements provide a supplementary aid to interpolating between sites of precipitation measurements, but they cannot usefully substitute for them. At best, the effort of a day measuring low flows provides an estimate of long-term annual precipitation with a standard error of about ± 20%. Direct measurement of precipitation entails a minimum of two working days, one to set out gauges, and another, after some interval, to retrieve them. For this effort, however, the Rakaia transect study suggests that for the central Southern Alps the 30-year normal annual precipitation may be estimated to better than about ± 10% after an interval of as short as six days involving a major storm rainfall, or 30 days with more typical storm magnitudes. Thirty years of continuous readings are required to reduce this to ± 3-4%.

DISCUSSION

The results from the study indicate that specific discharge at extreme summer low flow is spatially well correlated with basin mean annual precipitation in the central Southern Alps, yet there can be no direct causal connection. The indirect cause may lie with regional uniformity in the recession constant, and an observed correlation between storm rainfalls and mean annual precipitation in the central Southern Alps. If the recession constant is approximately uniform over each of the eastern and western regions and storm rainfall (and hence the area under the recession curve) correlates with mean annual precipitation, then the flow at any instant also must correlate with mean annual precipitation.

CONCLUSIONS

1. In tributaries of the Rakaia, Hokitika, Mikonui and Waitaha Rivers, specific discharge in extreme summer low flow varies approximately linearly with mean annual precipitation.

2. Most of the variance (90% of the variance in logarithms) in specific instantaneous discharge at low flow ($Q\ l\,s^{-1}\,km^{-2}$), measured in 48 tributaries on 21 March 1978 during an extreme summer drought, is explained by variation in estimated basin mean annual precipitation ($P\ mm\ a^{-1}$) in the empirical relationship:
   $Q = 0.007\ P^{1.034}$
   There are small but significant differences in the exponent and coefficient of the power law for tributaries east and west of the main divide.
   In the west:
   $Q = 0.0001\ P^{1.48}$
   And in the east:
   $Q = 0.004\ P^{1.10}$
   These differences probably result from different regional recession constants reflecting differences in regolith thickness, which controls catchment storage, east and west of the main divide.
3. Specific discharge at summer low flow may be interpolated between points of measurement in the central Southern Alps with a standard error of about ± 20 to ± 30 percent, using information on long-term mean annual precipitation.
4. Winter low flows, as measured on 17 July 1979, are not related to precipitation, basin altitude, or summer low flow and do not appear to correlate with any known, easily-measured basin parameter. Low flows of western basins, however, were typically 3 times those of eastern basin for the same average basin altitude.
5. Winter and summer low flows are members of different populations and so should be treated separately in the prediction of extremes.

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