SOURCES OF STREAMFLOW IN A SMALL HIGH COUNTRY CATCHMENT IN CANTERBURY, NEW ZEALAND

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ABSTRACT

Camp Stream Basin, which has been investigated for its sources of streamflow, is located in the headwaters of Broken River, Craigieburn Range, Canterbury, New Zealand. It is a 234-acre basin with about half each if its area above and below bushline.

Discharge, temperature and specific conductivity readings at nine locations within the basin were taken during baseflow conditions and used to trace the sources of streamflow. The measurements used the dye-dilution method and the catchment area was sub-divided into three main zones: bush, transition (partly bush and alpine), and alpine.

The measurements indicated that all three zones contributed about equal parts to streamflow. On a unit area basis, however, the transition and alpine zones yielded almost 1½ times as much as the bush zone. Streamflow seemed to originate in little springs and creeks above the bushline, but in numerous seepage horizons near the channel in the bush.

Stream temperatures seemed to be affected only slightly by air temperatures. Conductivities showed a very strong relationship with discharge at the same location. New gauging methods on this basis are therefore suggested. This conductivity/discharge relationship varied considerably between the locations of measurement with a clear trend of increasing values of b (the regression coefficient) with distance from the mouth of the basis. The hypothesis is made that this conductivity/discharge relationship is characteristic of how physical and chemical weathering of vegetation cover, soil and parent material affects the water discharged from the catch area above the point of measurement. This is supported by conductivity measurements from seepages and creeks affluent to the stream; they showed generally much higher values in the bush zone than in the alpine.

Further studies to check this hypothesis are suggested.

INTRODUCTION

Camp Stream Basin has been selected as an experimental basin under the International Hydrological Decade. It is planned to study the full hydrological cycle within the catchment. Special studies

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will be made on the behaviour of small high-country catchments in the zone of easily erodible greywacke of Canterbury.

The present study was designed to investigate streamflow and its sources under low-flow or baseflow conditions. The study was aimed at determining where streamflow originates, and which areas of the catchment contribute most, which least.

No streamflow records were available before investigations started. A gauging station at the mouth of the catchment is under construction and should become operational during 1967. Analysis of future records is therefore expected to give much detailed information on the flow characteristics and hydrological behaviour of the catchment.

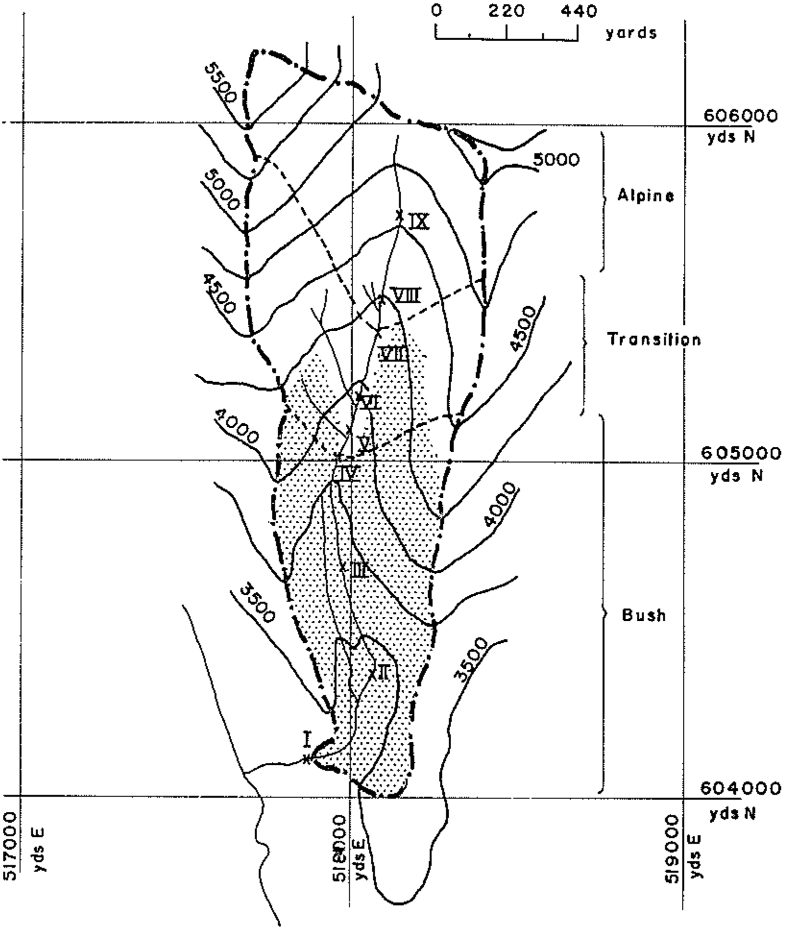

Fig. 1—Camp Stream Basin, Canterbury, showing indicated discharge-measuring stations (I–IX) and three main zones (bush, transition, alpine).

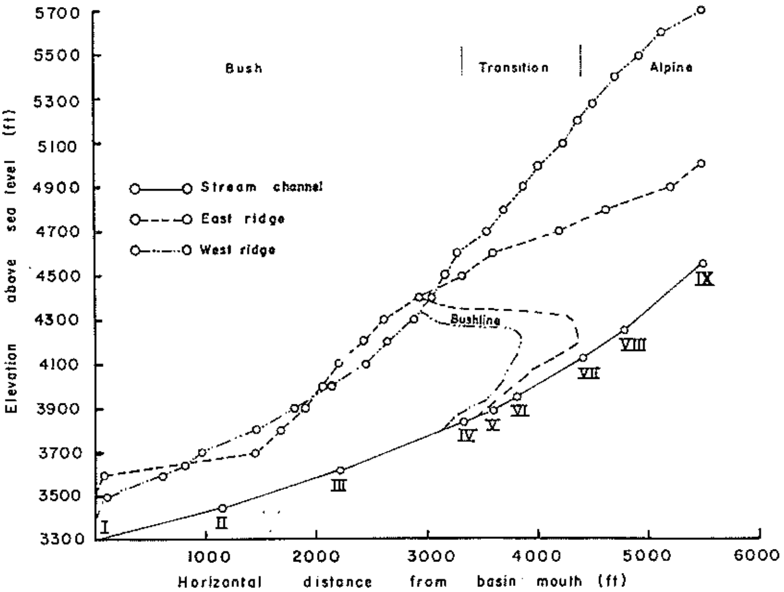

Fig. 2—Longitudinal profiles of channel and ridges, Camp Stream Basin.

A suitable method of measuring streamflow in this turbulent mountain stream was tested, and flow measurements were then taken at various points by sub-dividing the catchment into three main zones; bush, transition (mixed bush, grassland and scree) and alpine (open grasslands and screes). Even though only a limited number of measurements was taken during a 6-month period (September 1965–March 1966) some interesting observations were made.

Description of the Catchment

Camp Stream Basin has an area of 234 acres, is about 2,000 yards long and 500 to 600 yards wide. Its mouth lies at 3,300 ft above sea level and the highest points reach 5,500 ft above sea level. The catchment is generally south-oriented but is clearly composed of a south-east and a south-west facing slope, one on each side of the stream (Fig. 1). Nearly half (48%) of the area is covered with native bush (*Nothofagus solandri* var. *cliffortioides*), the bushline varying between 4,200 ft and 4,400 ft above sea level. The alpine portion of the catchment consists of large screes and scattered patches of tussock grasslands. A more detailed description is given by Holloway and O'Loughlin (pers. comm., 1966).

Topographically the catchment is quite uniform. It is oblong with one pronounced channel. The longitudinal profile of the stream channel is regular (Fig. 2) and slopes rise steadily from 13% near the mouth to 41% near the top of the channel. The confining ridges to the east and west differ considerably from each other; they are shown in Fig. 2 in their vertical location above the channel. The highest ridge points were found to be approximately in the falling line above the fork of the two highest located springs or the beginning of a well-defined stream channel (Station IX). In the alpine zone the west ridge extends twice as high above the channel as the east ridge. Below bushline, however, both are similarly elevated above the stream.

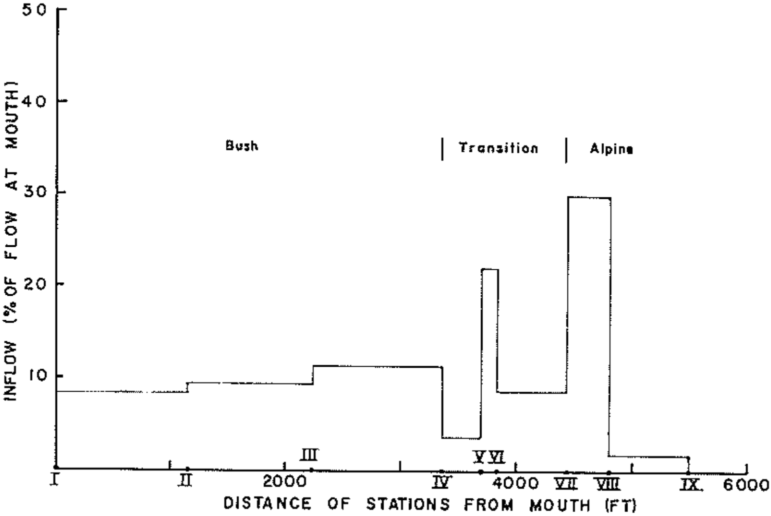

Fig. 3—Average increase in streamflow between stations at baseflow conditions.

Discharge Measurements

In order to study the origin of streamflow in this experimental basin instantaneous discharge measurements were made at nine different locations of the stream. Measuring Stations I to III were located entirely in the bush. Stations IV to VI were in the transition zone near bushline and Stations VII to IX were entirely in the open, alpine zone of the catchment. Each was regarded as being located at the mouth of a sub-catchment. It was assumed that differences in streamflow between stations were attributable to the catch area between the stations. By observing the increase in discharge from the top Station IX to Station I at the mouth it was possible to make inferences on the contributions to streamflow from various areas within the catchment.

TABLE 1 — Stream discharge at nine measuring stations in Camp Stream on eight selected dates in 1965/66

	27.9.65			16.10.65			13.11.65			16.11.65			30.11.65			14.12.65			25.1.66			25.2.66		
Station	*litre/ sec*	*%*	*inflow %*	*litre/ sec*	*%*	*inflow %*	*litre/ sec*	*%*	*inflow %*	*litre/ sec*	*%*	*inflow %*	*litre/ sec*	*%*	*inflow %*	*litre/ sec*	*%*	*inflow %*	*litre/ sec*	*%*	*inflow %*	*litre/ sec*	*%*	*inflow %*
I	39.4	100		37.2	100		77.6	99		89.7	100		64.0	100		19.1	—		18.8	100		10.03	100	
			10			1			1			8			10			—			7			11
II	35.5	90		36.9	99		78.2	100		82.8	92		57.8	90		21.5	100		17.5	93		8.95	89	
			9			8			4			8			11			23			19			4
III	31.8	81		33.7	91		75.5	96		75.5	84		50.5	79		16.6	77		13.95	74		8.52	85	
			7			11			13			10			11			12			10			15
IV	29.0	74		29.6	80		65.1	83		66.4	74		43.3	68		13.9	65		11.95	64		7.02	70	
			7			9			3			2			2			3			5			3
V	26.6	67		26.6	71		62.5	80		64.4	72		42.2	66		13.4	62		11.03	59		6.75	67	
			23			21			24			23			20			20			19			25
VI	17.1	43		18.6	50		44.0	56		43.7	49		29.4	46		9.05	42		7.58	40		4.25	42	
			5			12			7			5			13			8			6			9
VII	15.1	38		10.6	28		38.3	49		39.6	44		21.5	33		7.38	34		6.42	34		3.36	33	
												41			27			21			31			30
VIII										2.96	3		3.9	6		2.79	13		0.63	3		0.36	3	
															2			1			1			2
IX													2.75	4		2.54	12		0.34	2		0.13	1	
	snowmelt						snowmelt			snowmelt														

Stream discharge measurements were obtained using the chemical or dye-dilution method which was first developed in France (Dumas, 1952, 1953a, 1953b; Dodero, 1953). The principle and procedures used in this study can be found in Keller (1966). Since at least 20 minutes were necessary for one gauging and since the nine stations extended over more than a mile in distance and 1,000 ft in elevation, four to five hours passed from the first to the last measurement. For the purpose of the study simultaneous observations were necessary, and the streamflow survey had therefore to be restricted to baseflow conditions when only negligible changes in discharge could be expected during a period of five hours. It was found that flow conditions 18 to 24 hours after a storm changed only very slowly and a set of measurements could be taken. Gaugings were made from September 1965 to March 1966. In spring Stations VIII and IX were under snow and no measurements were taken. Baseflow conditions at various times of the year and at high and low levels were observed (Table 1). In some instances snowmelt in spring was quite consistent during a few hours so that a series of measurements during relatively high flows was possible.

In order to speed up the gaugings and also to estimate discharge reasonably well, little stage markers were permanently established at the measuring stations. When a number of measurements was available a stage/discharge relationship was established, and the flow was estimated quite accurately as long as the cross section near the stage marker remained stable and unchanged. Each discharge measurement was supplemented with air and water temperature readings as well as water quality samples for electrical conductivity analysis.

The data given in Table 1 suggest that during the summer months about one-third of the total discharge at the mouth of the catchment originated from open grasslands and scree slopes (alpine zone), another third was added in the transition zone near timberline and the remaining third came from bush-covered slopes. During the snowmelt season in spring, however, larger amounts (40% to 50%) had their origin in the alpine zone of the catchment.

TABLE 2 — Contributions to streamflow during baseflow conditions in summer from three zones of Camp Stream Basin

Zone	*Area (approx.)*			*Water Yield (approx.) % of flow at mouth*		
	acres	*ha*	*% of total*	*per Zone*	*per acre*	*per ha*
Alpine zone	69	28	30	33⅓	0.48	1.2
Transition zone	69	28	30	33⅓	0.48	1.2
Bush zone	96	38	40	33⅓	0.34	0.87
Total	234	94	100	100	0.43	1.06

Considering the contributions to streamflow on a unit area basis, the alpine zone and the transition zone, each covering 30% of the catchment, yielded almost $1\frac{1}{2}$ times as much as the bush-covered slopes.

Inflow into the main channel was analysed in more detail in order to locate the major sources of streamflow. Fig. 3 shows very clearly two prounounced sources. The first may be called the Camp Stream spring, located just west of and below Station VIII. It yielded about 30% of the flow at the mouth of the catchment or almost the full contribution from the alpine zone. The second source entered the stream between Stations VI and V from the west, adding on the average about 22% to the flow. All along the rest of the channel no concentrated inflow was observed; it consisted mainly of seepage horizons at or near the banks of the channel. The steady and well distributed inflow was noticeable in the bush. Dozens of little seepages added consistently to the flow, resulting in a steadily increasing discharge. Near and above the bushline, however, contributions to the flow were discontinuous.

Even though only few data on streamflow and water yield were available, they indicate that the sub-alpine mountain beech bush tends to distribute the precipitation available to streamflow evenly and release it again in numerous seepage horizons; under screes and patches of alpine grassland the water available for streamflow seems to concentrate in surface or sub-surface channels and flow into the main stream as creeks. No simple reason can be given to explain the water yield of the alpine zone, which appeared to be noticeably larger than that of the sub-alpine bush slopes (bush zone). A compound interaction of various factors is believed to account for most of this apparent difference in water yeld: increasing precipitation, decreasing temperature and hence decreasing potential evapotranspiration with altitude; deep seepage losses from the channel. Precipitation gradients over a range of altitudes as taken from climate studies in the area (Morris, 1965a, 1965b) showed that this alone would account only for part of the difference.

Temperature Measurements

Additional information taken during discharge measurements was instantaneous temperatures of air and water. Air temperatures varied between 0° and 18°C, water temperatures between 2° and 10°C. It seemed important to know to what extent water temperatures were affected by air temperatures. A relationship between air and water temperatures was established for all readings during the study period using a regression equation of the type:

$$y = a + bx, \text{ where}$$

$y =$ the water temperature in °C
$x =$ the air temperature in °C
$a =$ a constant, and
$b =$ the regression coefficient.

TABLE 3 — The regression parameters of the air/water temperature relationship in Camp Stream

	Stations							
Regression Parameters	I	II	III	IV	V	VI	VII	overall
Constant a	1.958	1.571	2.829	2.070	1.496	1.953	1.814	2.0772
Regression coefficient b	0.3894	0.4021	0.3037	0.3508	0.4467	0.3371	0.3817	0.3711
Correlation coefficient r	0.902	0.8323	0.8408	0.8446	0.8403	0.8597	0.913	0.874

In a first analysis this relationship was established separately for each station except for Stations VIII and IX where not enough data were available. The regression parameters are given in Table 3. Statistical analysis showed that no significant difference between stations existed and that the data from all stations can be well represented by a single straight line:

$$y = 2.0772 + 0.3711x.$$

The regression coefficient b of 0.3711 indicates a rather small effect of air on water temperature. The main reasons are probably high altitude, southerly aspect and the V-shaped topography of the catchment, the narrow and well-confined streambed, and a closed bush canopy over the lower portions of the stream.

With a correlation coefficient of $r = 0.874$ the overall relationship is quite well defined. A small but steady effect of air on water temperature in all parts of the catchment is regarded as characteristic of this steep, narrow, turbulent mountain stream.

Conductivity Measurements

Measuring the specific conductivity of discharging water has three main purposes: to give a measure of dissolved minerals in the water (Metson, 1956); to estimate the discharge of minerals in solution (Durum, 1953); make conductivity (and also resistivity) measurements to investigate the size of affluents to a stream. Ravier (1954) and Bonnin (1958) found that conductivity is proportional to the mixture of the main stream with the affluent water. This feature was tested in the laboratory and can be expressed as follows:

Assuming: $c_1 < c_{1+2} < c_2$

$$\frac{q_1}{q_2} = \frac{c_2 - c_{1+2}}{c_{1+2} - c_1}, \text{ or } (q_1 + q_2)c_{1+2} = q_1c_1 + q_2c_2 \quad . \qquad (1)$$

Where q_1 = discharge of stream above confluence, in litres/sec.
q_2 = discharge of affluent, in litres/sec.
c_1 = conductivity of stream above confluence, in micromhos ($\text{ohm}^{-1}\text{cm}^{-1}10^{-6}$)
c_2 = conductivity of affluent, in micromhos
c_{1+2} = conductivity of stream below confluence, in micromhos.

If the conductivity is known of the main stream above and below the confluence (c_1, c_{1+2}) and also of the affluent (c_2), inferences to the relative size of this affluent can be made. Alternatively, if the size of the affluent is known, inferences to its conductivity can be made. Water samples of 100 ml were therefore taken from the stream just before each discharge measurement, kept cool and taken to the laboratory where the readings with a conductivity meter at 25°C were made. The measurements were recorded in micromhos ($\text{ohm}^{-1}\text{cm}^{-1}10^{-6}$).

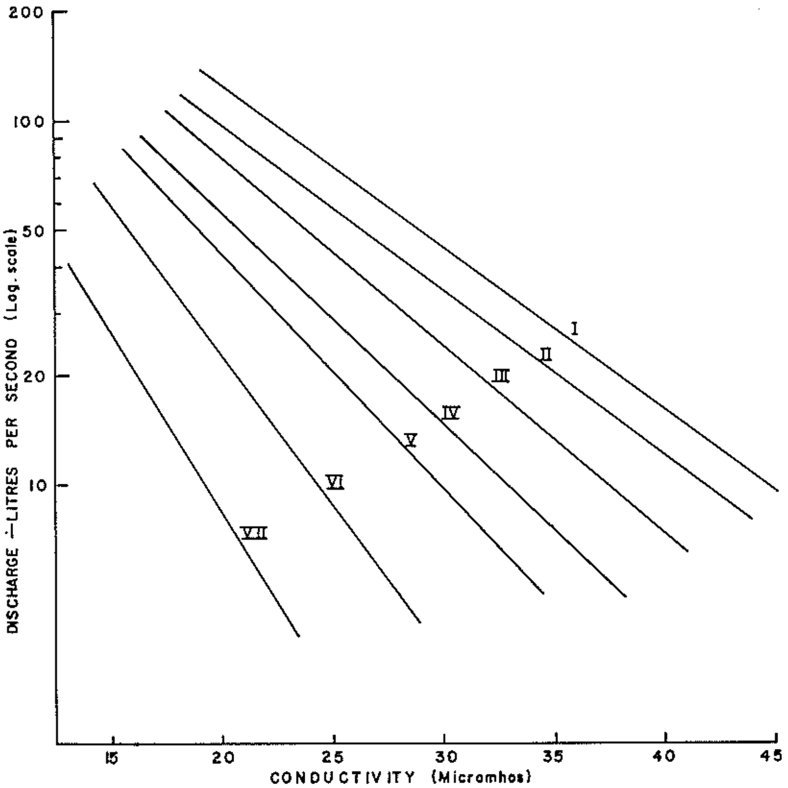

Fig. 4—Discharge as a function of conductivity at seven measuring stations in Camp Stream.

In a first survey conductivity values were related to discharge. Regressions were calculated separately for each station. The equations were of the type:

$$y = a + bx,$$

where y was $\log_{10}$ of the discharge (given in litre/sec.), and x was the conductivity (given in micromhos). In Table 4 the regression parameters are given, and in Fig. 4 the regressions of Stations I to VII are illustrated. A clear relationship between discharge and conductivity is apparent.

The coefficients of determination demonstrate that a good fit was obtained by using a logarithmic scale for discharge values. Only Station VII shows a rather poor fit which is probably due to the quite steep regression line ($b = -0.0973$). Good fit and relatively small errors in the lower portions of the catchment suggest the development of a new gauging method based on conductivity measure-

TABLE 4 — Regressions for the conductivity/discharge relationship at seven stations in Camp Stream

Station	*Equation*	*Standard Error of*				*Coefficient of Determination,* r^2
		a	%	*b*	%	
I	$y=2.9505-0.0432X$	0.0788	2.7	0.00297	6.9	0.913
II	$y=2.9503-0.0476X$	0.0793	2.7	0.00251	5.3	0.945
III	$y=2.9131-0.0505X$	0.0749	2.6	0.00256	5.1	0.961
IV	$y=2.8975-0.0585X$	0.1130	3.9	0.00441	7.5	0.912
V	$y=2.9315-0.0644X$	0.1224	4.2	0.00481	7.5	0.904
VI	$y=2.9963-0.0822X$	0.1718	5.7	0.00775	9.4	0.862
VII	$y=2.8713-0.0973X$	0.3998	13.9	0.02153	22.1	0.546

ments. This would eliminate engineering structures. Discharge estimates based on the data available in the present study would be as accurate as about 8% at the stations distant from the source. The standard error of estimates at stations close to the source of the stream would increase to about 15%. The smaller the value of b (regression coefficient) the better are the discharge estimates.

The regression coefficient or slope of the regression line (b) becomes less steep with increasing distance from the source of the stream. Fig. 5 shows b with its standard error in relation to the

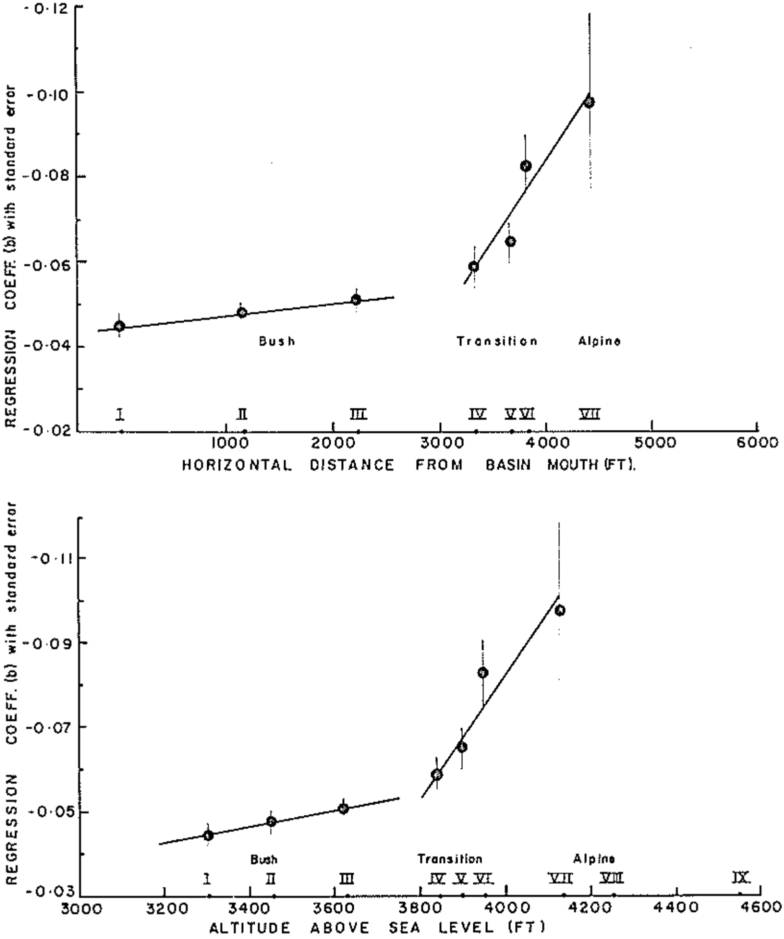

Fig. 5—The conductivity/discharge relations as a function of distance from the mouth and of altitude.

location of the respective measuring station. A general trend of increasing b with horizontal as well as vertical distance from the mouth of the catchment is noticeable.

No clearcut interpretation of these relationships was possible, but assuming that the geology of the parent material is uniform and that any change in conductivity of the stream water is negligible during its discharge in the stream channel, the following concept is suggested: physical and chemical weathering of vegetation cover, soil, and parent material seem to be the main factors which affect conductivity of discharging water. Weathering processes in turn depend on climatical and geological conditions. Low conductivity values are expected to derive from relatively fast percolation and contact with vegetation cover, mineral soil, and parent material over a short period of time; high conductivity values, on the other hand, derive from relatively slow percolation and long-term contact with vegetation cover, mineral soil, and parent material.

At low discharge (baseflow) most of the discharging water would seem to be derived from water deeply percolated through soil and parent material. With increasing flow more water from shallower horizons would be added, and would in turn lower the overall conductivity of the discharging water. During storms a large portion of the discharge might even come from sub-surface and surface run-off, resulting in still lower conductivity values.

Neglecting the direct effect of the vegetation cover, the regression coefficient of the discharge/conductivity relationship at one particular place seems to be a characteristic of the effects of chemical and physical properties of the soil and parent material in the catchment above. Large values of b would indicate a low degree of chemical and physical weathering (high percolation rates) of soil and parent material; low values chemically and physically well-weathered (relatively low percolation rates) soils and parent material.

Assuming a balance of physical and chemical weathering in the Camp Stream Basin, relatively low percolation rates and chemically well-weathered soils would be expected in the lower bush-covered zone (relatively warm), whereas higher percolation rates and a lower degree of chemical weathering would be expected near bushline and in the alpine zone (relatively cold). Future soil survey on chemical as well as physical soil properties in conjunction with temperature gradients and distribution of precipitation in the catchment would be very useful for checking this hypothesis.

As a check of the foregoing analysis, a few samples were therefore taken from seepages and creeks before they joined the main stream. They were grouped according to their location between Stations I and IX as well as left or right hand side of the stream. Their conductivity values are summarized in Table 5.

TABLE 5 — Average conductivity values as sampled from affluent seepages and creeks of Camp Stream. Numbers of samples in ( )

Zone	*Location between Station*	*Conductivity (micromhos) at 25°C of affluents from*	
		True left hand side (SW facing slope)	*True right hand side (SE facing slope)*
Bush	I–II	81.5 (6)	72.5 (5); 24.6 (8)*
Bush	II–III	59.5 (14)	—
Bush	III–IV	69.5 (9)	52.1 (7)
Transition	IV–V	—	39.3 (7)
Transition	V–VI	51.5 (6)	32.7 (16)
Transition	VI–VII	57.0 (4)	25.0 (9)
Alpine	VII–VIII	—	18.5 (12)
Alpine	VIII–IX	20.9 (6)	—

* This value was taken from the small creek in the lower part of the catchment. Its source is in a little swamp and the channel runs parallel to the main stream for about 500 yards before it joins it.

All samples were taken between December 1965 and April 1966 during low-flow conditions. They indicate the same pattern as outlined before. Relatively high conductivity values were observed in waters originating in the lower bush-covered parts of the catchment. They drop considerably moving up stream. An interesting observation is made in the transition zone: on the left hand side of the stream where bush covers the slopes up to Station VII (see Fig. 1) higher conductivity values were measured than on the right hand side where waters originate in the open grassland and scree slopes.

In a second survey discharge measurements and conductivities of the main stream were used to make inferences about the conductivity of the affluents from the side. This is done assuming that discharge is the sum of all inflows into the channel and that losses from the channel are negligible. Equation (1) was used as outlined above to estimate average conductivity of affluent waters between stations by taking q_1 as discharge at up-stream station in litre/sec., q_{1+2} (q_1+q_2) as discharge at down-stream station in litre/sec., c_1 as conductivity at up-stream station in micromhos, and c_{1+2} as conductivity at down-stream station in micromhos. From equation (1)

$$c_2 = \frac{q_1}{q_2}(c_{1+2} - c_1) + c_{1+2} = \frac{q_{1+2} \cdot c_{1+2} - q_1 \cdot c_1}{q_2} \quad . \qquad (2)$$

At various periods of baseflow (including some snowmelt) from September 1965 to April 1966 the average conductivity of affluent waters between stations was calculated according to equation (2). The results are summarized in Table 6.

TABLE 6 — Calculated average conductivity of affluent waters between stations in Camp Stream

	Dates and average conductivity (micromhos at 25°C) of affluent waters between stations										
	27.9.65	5.10.65	16.10.65	16.11.65	30.11.65	14.12.65	25.1.66	15.2.66	2.3.66	17.3.66	15.4.66
I–II	41.9	22.8	—	—	34.9	20.4	40.5	67.9	—	45.4	39.0
II–III	34.7	19.6	64.3	37.2	38.7	43.0	50.0	59.8	—	—	—
III–IV	58.2	29.0	37.6	42.8	36.9	57.3	43.3	57.7	—	—	—
IV–V	44.0	57.4	21.3	17.9	—	51.3	79.6	—	—	—	—
V–VI	22.0	24.3	20.6	21.5	28.1	33.9	34.1	37.1	—	43.6	42.8
VI–VII	58.3	24.9	18.4	—	28.1	47.6	66.1	59.2	41.5	88.0	104.0
VII–VIII	—	—	—	—	14.7	8.7	17.8	20.5	10.8	21.6	18.6
VIII–IX	—	—	—	—	31.5	43.9	34.4	30.0	20.5	21.6	—

A considerable variation was noticed during spring and early summer. Later in the summer season, however, the values were becoming more constant and approached the observed figures. Comparing the observed (Table 5) with the computed conductivities (Table 6) of inflow between stations the following are noted:

Stations I to IV, bush zone: in summer the computed values approach the figures from samples and show a similar pattern. The creek from the little swamp with its confluence between Stations I and II is probably the reason for the relatively low average computed values.

Stations IV to VII, transition zone; wide variations are observed during the early summer months. Summer values between Stations V and VI are similar to those sampled on the right hand side, and between VI and VII similar to those sampled on the left hand side. This indicates that the bulk of inflow between these stations comes from that side of the stream where differences between computed and sampled figures are least.

Stations VII to IX, alpine zone; both figures correspond quite closely. Between Stations VIII and IX however the computed values approach only in late summer the observed figures. This could mean that a seepage of relatively high conductivity which was never sampled in the field, stopped flowing in early summer.

Sampling for conductivity in the field had the advantage that any sizeable inflow was exactly located, but hidden inflow could not be sampled. Computed average conductivity on the other hand had the advantage of including hidden seepages and being calculated from data already available. There was, however, no possibility of locating type and place of inflow exactly between stations.

CONCLUSIONS

Discharge measurements at various locations along the main channel during prevailing baseflow conditions in this high country catchment combined with conductivity measurements proved to be useful for finding location and type of sources of streamflow. The sources in turn seem to behave differently according to their relative location in the catchment and to vegetation cover.

For the Camp Stream Basin the following conclusions are drawn:

- — each of three zones (bush, transition, alpine) seems to contribute about equal parts to the flow at the mouth of the basin;
- — on a unit area basis this contribution is almost 1½ times as high in the transition and alpine zone as in the bush;

- — streamflow in the alpine and transition zone seems to originate rather in surface and sub-surface channels and in the bush zone in evenly distributed seepage horizons;
- — air temperature affects stream temperature slightly but steadily (reasons for this are probably topographical characteristics and the high altitude of the basin, as well as the fact that the lower portion of the stream is completely under a bush canopy);
- — a prounced relationship between discharge and conductivity was found for each of the points of measurement in the catchment;
- — this suggests new gauging methods which — after calibration — would not need any structure in the stream;
- — the conductivity/discharge relationship changes with distance from the mouth of the basin and while given discharge variations are associated with noticeable changes in conductivity near the mouth of the catchment, only minor changes are observed in the head of the catchment;
- — this suggests that the combined effect of chemical and physical weathering of vegetation cover, soil, and parent material on the conductivity (as a measure of total soluble salts) of percolating waters is more pronounced in the bush zone of the lower altitudes than in the transition and alpine zones of the higher altitudes of the basin;
- — this interpretation is supported by conductivity measurements from seepages and small creeks before they enter the main stream. The affluent waters showed considerably higher conductivities in the bush than in the transition and alpine zones.

This study was a start and is not regarded as being complete in itself. It is suggested that this information be contrasted with climatic data (*inter alia* temperature gradients and precipitation distribution within the catchment) and with a survey of the physical and chemical properties of the soil. It might also be of interest to study the influence of organic materials on conductivity of percolating and discharging waters (which should include chemical changes from top to bottom of the vegetation cover). Miller (1961, 1963) made such a study in a location close to the sea, but the results are not applicable to Camp Stream.

Geological conditions have not been investigated to explain the streamflow pattern in Camp Stream. Information on different types of aquifer in the catchment could well explain further some of the characteristics found in the present study. Kilpatrick (1964) in a similar investigation found that during high baseflow the contributions of rock and gravel aquifers were about equal; during low baseflow, however, all flow originated from the rock aquifer which showed a lower transmissibility. Whipkey (1965) found in a plot study much steadier flows from silt loam and clay layers than from coarse textured horizons. These studies show that information on geology and soil give much valuable data to explain the origin of streamflow, especially under low-flow conditions.

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