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VOLCANIC COVER DEPOSITS AND STREAMFLOW BEHAVIOUR IN THE CENTRAL NORTH ISLAND OF NEW ZEALAND[1]

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ABSTRACT

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Distribution in time and space of the catchment-outputs of water, dissolved matter and suspended matter of streams in the Lake Taupo basin of New Zealand has been investigated. The hydrological data base is formed by a small number of instrumented sites and relatively few gaugings on streams, that were not instrumented permanently.

It appears that the Lake Taupo catchment can be divided into regions with similar flow- and concentration duration characteristics. The forcing factor behind these flow duration characteristics is the presence of unconsolidated volcanic cover deposits in the catchment of a stream.

INTRODUCTION

This paper is the first in a series representing the results of an extensive research programme on the hydrology and water quality of the inflows into Lake Taupo (Fig. 1), carried out by the Water and Soil Division of the N.Z. Ministry of Works between 1976 and 1978. Lake Taupo (38°50′S, 175°50′E) which is with an area 616 km^2 the largest lake of New Zealand, is an important water resource, serving recreation, electricy supply, and drinking water purposes.

This paper gives the results of investigations on hydrological regionalisation on the basis of lithological characteristics.

GEOGRAPHICAL CHARACTERISTICS

Lake Taupo is situated in the volcanic plateau of the central North Island at an altitude of 360 metres. It has a total catchment area (excluding the lake) of 2670 km^2. The lake and its surroundings are the product of Quaternary volcanic activity (GRANGE, 1937, HEALY ET AL., 1964) and accompanying subsidence. To the north the underground consists of consolidated rhyolitic formations such as ignimbrites, dacites and breccias, while the southern part consists of andesitic deposits (Fig. 2). Permian-Mesozoic greywacke blocks form the catchment divide to the east and the west.

In the Lake Taupo basin the cover deposits consist of tephra (lapilli and various ashes) deposited by volcanic activity during the last 20 000 years (post Oruanui cover deposits, PULLAR ET AL., 1973). A map of the occurrence and average thickness of these deposits exists for a part of the central North Island of New Zealand including the Lake Taupo basin on a scale 1:250 000 (PULLAR, 1973).

In the lower parts surrounding Lake Taupo cover deposits may reach an average thickness of between 10 and 20 metres, where they overlie ignimbrites and older rhyolites. A large part of the cover deposits (Taupo pumice) was erupted during the volcanic explosions of around 130 A.D.. In the greywacke highlands the cover deposits are generally shallow, with an average thickness of less than 2 metres (Fig. 3). In all, about

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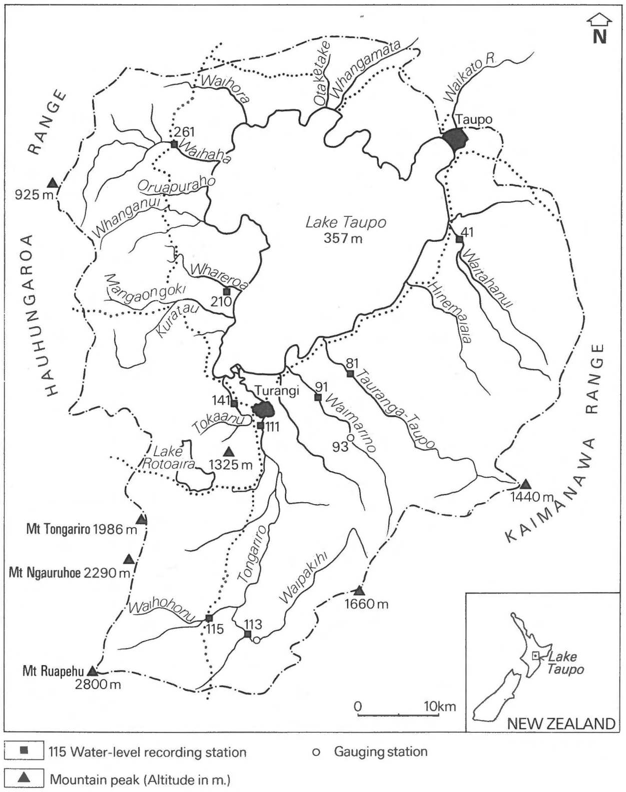

Fig. 1
Lake Taupo catchment and its location.

1500 km^2 of the Lake Taupo catchment are covered by 5 metres or more tephra, mainly Taupo pumice (PULLAR, 1973). Thick deposits are also found in the larger valleys like the Tongariro valley. To the south an increasing proportion of the tephra consists of andesitic ashes from the Tongariro volcanics, of which Mount Ngauruhoe (2290 m) is still active (Fig. 1).

The lowlands were originally covered by scrub and podocarp/hardwood forests (Fig. 4), but now large areas of these have been developed into agricultural grassland or exotic pine plantations. Dense mixed podocarp/hardwood forests still exist along southern and western sides of Lake Taupo. The greywacke ranges to the east are covered mainly by beech forests *(Nothofagus spp)*. The Tongariro volcanoes are covered by scrub with some patches of beech forest on the lower parts; they are virually bare at higher elevations. Precipitation (Fig. 3) increases with height from around 1100 mm.a^{-1} at the northern lake margin to more than 3000 mm.a^{-1} in the high mountain ranges of Lake Taupo. Seasonal variation is small with a maximum in winter. In the highlands a considerable part of the annual precipitation may fall as snow.

Soils throughout the Lake Taupo catchment have developed from volcanic ashes and can be grouped under vitric andosols (DUDAL, 1968). These soils are characterized by a coarse texture and are excessively drained.

Infiltration properties of the volcanic cover deposits and other lithologies

The average porosity of the recent tephra deposits in the Lake Taupo region is greater than 60%, because of the large numbers of macropores (PACKARD, 1957). This gives rise to exceptionally high water storage capacities and infiltration rates; rates in excess of 100 mm.hr^{-1} have been measured (SELBY, 1967). The other volcanic lithologies in the Lake Taupo region also have high water storage and infiltration capacities, although much less than those of the recent tephra. Some weathered older tephra deposits, especially those in the ranges to the east of the Lake Taupo have low infiltration rates.

Compared to the volcanic formations, the greywackes are impermeable and have little water storage capacity. Because of the difference between the actual and the under volcanic debris buried topography, the surface watersheds do not coincide with the groundwater divides. This makes it impractical to use the volcanic catchments for comparative mass-balance studies.

Greywacke formations form closed systems in which water-balances can be established, ignoring groundwater losses.

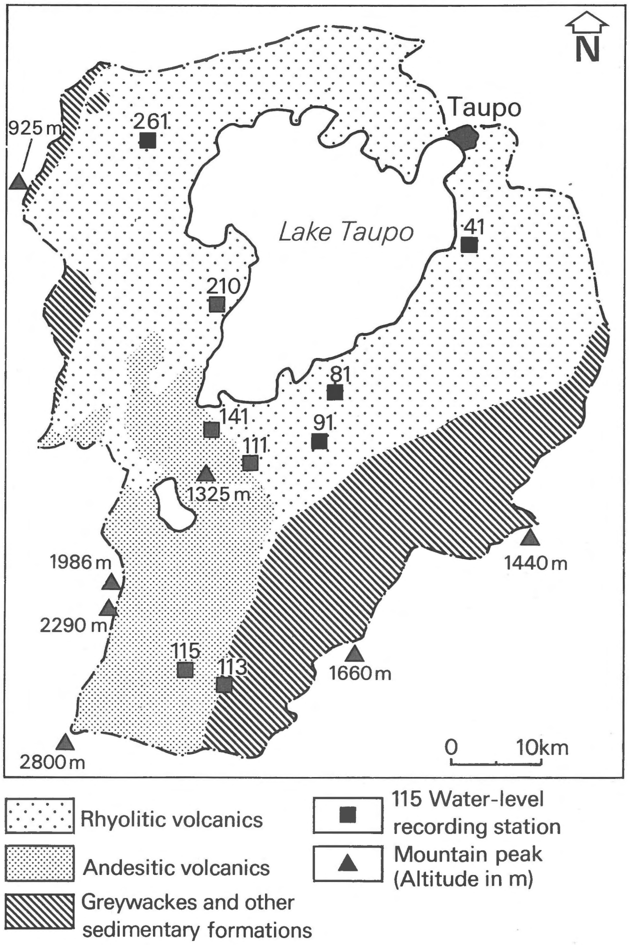

Fig. 2
Basal lithology of the Lake Taupo catchment.

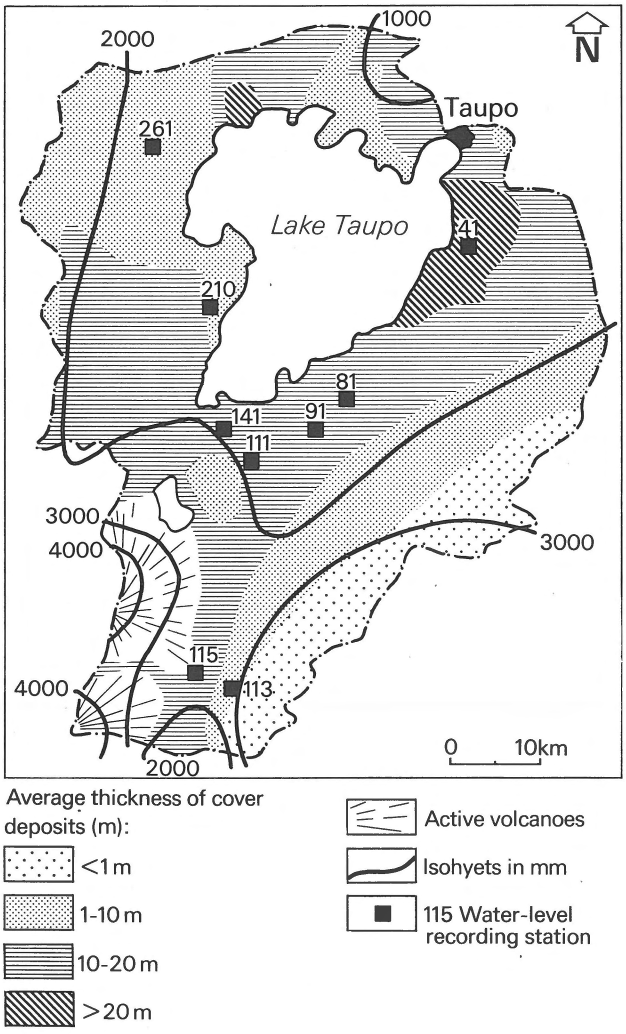

Fig. 3
Average thickness of the cover deposits in the Lake Taupo catchment.

TECHNIQUES

Measurements

Hydrological and water quality records of 8 river sites were used in this study. On six of them automatic stage height recorders were installed. Discharges of site 93 were correlated with those at recorder site 91 (Fig. 1) and the discharges at site 113 with those of a permanent recorder a few hundred of metres downstream of 113. Detailed information on water quality, mass transport etc of the streams in the Lake Taupo basin have been published in SCHOUTEN ET AL. (1981). This work also contains information on the analytical methods.

Sampling for dissolved and suspended matter was carried out on a routine basis fortnightly. Floods were gauged and sampled at each opportunity in such a way that from all of the investigated streams the one percent exceedence value of discharge was included.

In Table I some basic catchment characteristics of the investigated streams, and in Table II some mass transport and concentration data, are presented.

Discharge exceedence ratio

Streamflow data of a period of 24 months were used to construct flow duration curves for each of the investigated sites. The flow duration curve (SEARCY, 1959) may function as a compressed data base for the calculation of outputs of water and those water constituents that are strongly correlated with discharge. These flow duration curves were then used to calculate a number of parameters allowing the quantitative description of catchment runoff. R_i, the discharge exceedence ratio, may provide useful information on regional streamflow behaviour. It is calculated by dividing the flow values from the duration curves by the median flow.

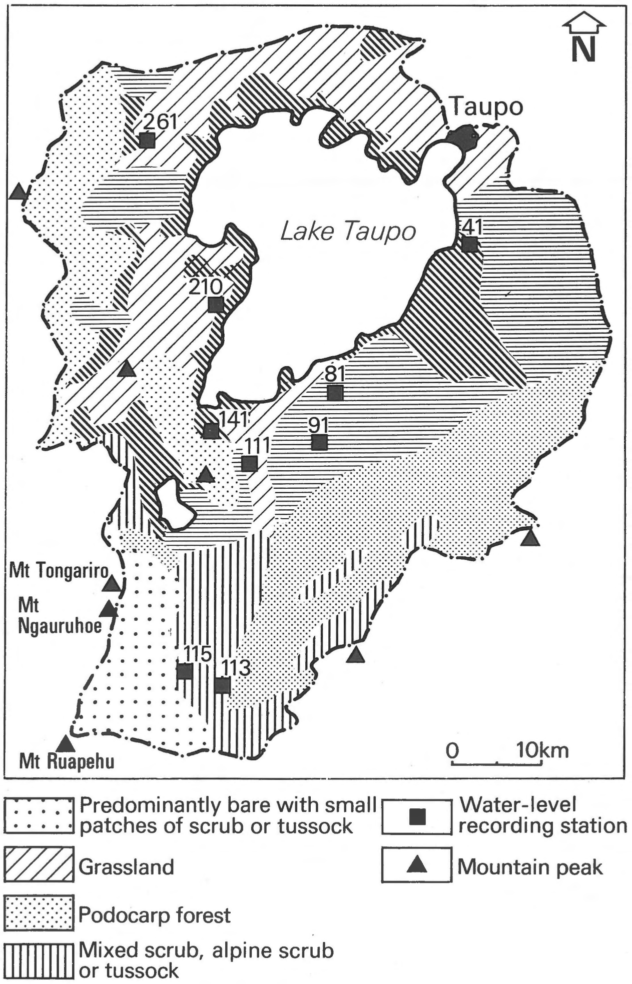

Fig. 4
Vegetation and land use.

Table I Catchment characteristics

Site NR	river site	Catchment area km^2	Altitudinal Range m	lithology	Estimated average dept of recent tephra m	vegetation
41	Waitahanui R. at Totara Bridge	190	361-1160	Taupo pumice over older volcanic deposits	15-30	Exotic pine plantations scrub
141	Tokaanu Stm. at Power House	29	367-1325	Recent andesitic and rhyolitic tephra over older andesits	5-15	Scruc. podocarp/hardwood forest
210	Whareora Stm. at lake	58	366-945	Recent rhyolitic and andesitic tephra over ignimbrites	5-15	Agricultural grassland some scrub and forest
115	Waihohonu R. at SH 1 Bridge	88	914-2663	Andesitic ashes, lavas and lahar deposits	5-15	Alpine scrub, tussock grasses, large areas of bare ground
261	Waihaha R. at SH 32 Bridge	133	488-1090	Rhyolitic tephra over older volcanic deposits (ignimbrites) and greywacke in headwaters	2-5	Podocarp forest
81	Tauranga-Taupo R. at Te Kono	199	396-1340	In middle reach, ignimbrites covered by thick recent volcanic deposits. In headwaters, greywacke covered by thin pumice cover	0.5-3	Exotic pine plantations in lower and middle reaches. Beech forests and mixed podocarp/beech forest in headwater
93	Waimarino R. at Te Pohatu	35	549-1520	Greywacke covered by rhyolitic and andesitic tephra	0.5-2	Beech forest and mixed podocarp beech forest
113	Waipakihi R. at Waikato Confluence	112	914-1638	Greywacke covered by andesitic and rhylotic tephra	0.3-1	Highland beech forest and alpine scrub and tussock

$$R_i = \frac{q_i}{q_{50}} \qquad (1)$$

q_i is defined as the instantaneous discharge that is equaled or exceeded for i % of the time (i-percentile value of discharge). q_{50} is defined as the median value of discharge (equaled or exceeded for 50 % of the time).

In this way were calculated R_{95}, R_5, R_1, R_{max} (ratio of maximum discharge and q_{50}) and R_{mean} (ratio of the mean annual discharge and q_{50}). The advantage of presenting streamflow data in this way is that streams draining catchments of different area and rainfall characteristics can be compared.

Concentrations and concentration exceedences.

Strong correlations were found between discharge and many of the water constituents studied, the highest correlations being obtaned in general by log-log transformations. In cases where a strong correlation between a water quality component and discharge exists, a concentration duration curve can be constructed. A regression equation is obtained between the component and discharge and this equation is then applied to the flow duration curve. A factor c_i may then be defined as the concentration level that is equaled or exceeded for 1% of the year in a fashion analogous to q_i. However, log-log plots of some water quality parameters against discharge make it clear that there are often boundary values above or below which the concentration of the parameter in question no longer shows a strong correlation with discharge. In such cases, the regression equation is used in constructing the concentration duration curve over the region in which it is valid, and elsewhere a constant concentration value or a different regression equation may be used in the transformation. The constant is the mean over the part of the data where no correlation with discharge exists and which is characterized by a small standard deviation (e.g. base flow means of suspended matter SM). The individual components of the dissolved load are: HCO_3, Cl, SO_4, Na, Ca, K, Mg, H_4SiO_4 and some minor N and P components. The major solutes have a strong negative correlation with discharge and their behaviour may

Table II Annual transport and concentration duration parameters of streams draining into Lake Taupo

Stream site nr	Runoff mm.a.$^{-1}$	Dissolved matter t.Km.$^{-2}$a.$^{-1}$	Suspended matter t.Km.$^{-2}$a.$^{-1}$	Discharge q_{50} m^{3}s.$^{-1}$km.$^{-2}$	Electrical conductivity EC_{50} µSm.$^{-1}$	Suspended matter SM_5 g.m.$^{-3}$
41	1125	99	20	.035	59	31
141	1845	221	18	.055	90	20
210	780	48	30	.014	69	105
115	2140	131	615	.052	82	620
261	1310	59	48	.032	47	50
81	1400	58	67	.035	41	54
93	2070	62	60	.045	39	17
113	2500	67	76	.052	33	27

q_{50} = median discharge; EC_{50} = median conductivity; SM_5 = suspended matter concentration equaled or exceeded for 5% of the year.

be well represented by the behaviour of the electrical conductivity (EC). The EC is strongly positively correlated to most of the major ions individually (Ca, Mg, Na, SO_4, HCO_3); weak correlations exist for K and Cl.

The correlation coefficient of EC with discharge in the various investigated streams ranged between -0.80 and -0.98. Because of this concentration decrease with increasing discharge, EC_i is in fact the concentration that is calculated at discharge q_{100-i}.

Suspended matter SM has a strong positive correlation with discharge. Correlations range between 0.75 and 0.92. Generally no correlations exist at discharges below q_{20} but in most of the streams the concentration levels cannot even be measured accurately at those low discharges ($SM < 15$ g.m^{-3}).

Concentration exceedence ratios

In order to compare (on a geographical basis) stream-constituent concentrations of streams originating in different geochemical and physical environments, a variable has been calculated defined as the concentration exceedence ratio: This ratio is calculated analogous to R_i by dividing concentration exceedence by a standard concentration. For electrical conductivity this ratio is calculated as follows:

$$RC_i = \frac{EC_i}{EC_{50}} \qquad (2)$$

In case of suspended matter SM_{50} as a standard is meaningless, because for most of the investigated streams SM_{50} is below the level of accurate detection.

Concentrations of suspended matter at low discharges are generally not forced by discharge. Therefore it has been decided to use SM_5 as a standard to calculate the concentration exceedence ration.

$$RS_i = \frac{SM_i}{SM_5} \qquad (3)$$

Output exceedence proportion

Finally, it is useful to have a parameter indicating the proportion of the total stream output transported out of the catchment at discharges equal to or exceeding a certain level. These may be calculated by numerical integration over the whole or part of the flow duration curve.

Mass-flow duration curves may be constructed by applying the regression equations, that describe the relationship between constituent concentration, and discharge, on the flow-duration curves. Integration over the entire massflow curve ($c_i \times q_i$) gives the total output of that component over the period considered.

The output exceedence proportion is defined as follows:

$$M_i = \frac{Q_i}{Q_y} \times 100\ \% \qquad (4)$$

Q_i = the absolute value of output exceedence, calculated by numerical integration of q, respectively of q × c, over the upper i time of the flow-duration curve. Q_y = total annual stream output.

M_i is thus the percentage of annual stream-output that is transported during the parts of the year in which discharges are greater than or equal to q_i. In case of water the output exceedence proportion is referred to as MQ_i, in case of dissolved constituents MD_i, and in case of suspended matter MS_I.

Meaning of q_5 and M_5 indicators of flood runoff

In the Lake Taupo area, rainfall may result in increases in streamflow within 3 to 12 hours after the rain started. Floods with discharges of more than twice the mean discharge occur in the Lake Taupo basin between 0.02 and 10 percent of the year. It has arbitrarily been decided to define floods as periods when discharges are greater than or equal to q_5. The flood output exceedence proportion is thus M_5, which forms a quantitive estimate of the proportion of annual output that

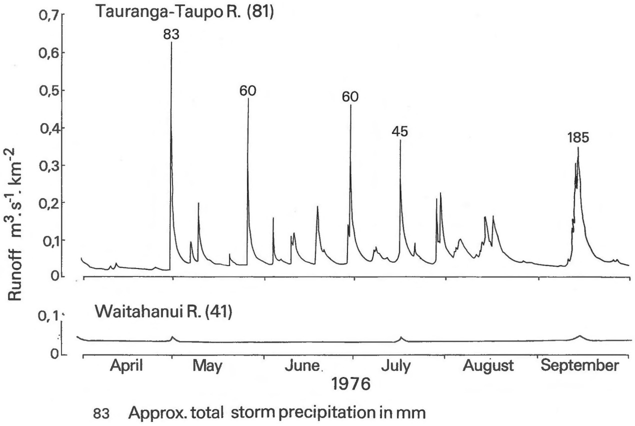

Fig. 5
Annual runoff plots of the Waitahanui River (41) and the nearby Tauranga-Taupo River (81).

occurs during rainstorms and floods in the Lake Taupo region. An obvious advantage of calculating flood flow in this way is that all calculations can be carried out directly from the flow duration curve without any manual or complex computerised bas-flow separation.

RESULTS

Differences in streamflow response to rainfall

The different response to rainfall of streams draining catchments with thick deposits of volcanic ashes and other airborne volcanic debris (streams 41 and 115) and those with only shallow tephra covers (81 and 113) is demonstrated in Figs 5 and 6. These figures show each the annual runoff plots of two nearby stream systems with a very different response. There is remarkably little variation in the annual flow curve of 41 (Fig. 5). In contrast, stream 81, at a distance of about 20 km, has at least 10 floodpeaks with discharges more than twice the mean discharge. A comparable picture appears in Fig. 6 where stream 115, although considerably more responsive than 41, has less frequent and less pronounced floodpeaks than the nearby 113. Both streams 115 and 113 are in a high rainfall area. Stream 115 drains a catchment with vast areas of permeable (andesitic) volcanic debris, ashes and lava flows and lahar deposits, while 113 drains a catchment of greywacke mountains covered by shallow tephra deposits ($\leqslant$ 1 m on average).

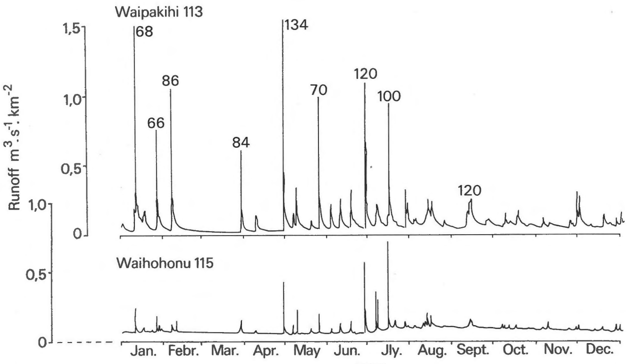

Fig. 6.
Annual runoff plots of the Waipakihi River (113) and the nearby Waihohonu River (115).

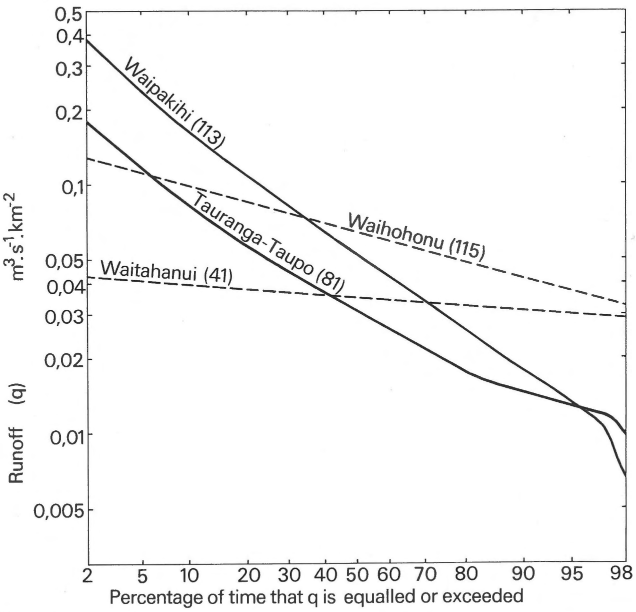

Fig. 7
Flow-duration curves of streams with a contrasting flow behaviour.

A different way of expressing the previously described differences in streamflow behaviour are flow duration curves (Fig. 7).

Flow duration parameters

Table III shows for each of the streams the fraction of the median flow that is equaled or exceeded for 95 % of the year (R_{95}). In streams draining catchment with a tephra cover of more than 5 m the R_{95} ranges between 0.7 and 0.9. Thus, for more than 95 % of the year discharges are equaling or exceeding at least 70 % of the median flow.

In regions with very shallow cover deposits ($\leqslant$ 1 m) R_{95} is only about 0.2, making streams in those areas less reliable sources of water. Floods in streams draining forested catchments with thick tephra deposits such as 41 and 141 are rare (Fig. 5) and generally of less significance as their counterparts in neighbouring catchments with shallow tephra cover.

The R_1 values in streams from catchments with thick cover deposits range between 1.3 and 2.1; in those draining areas with shallow cover deposits R_1 values reach even 10. In Table III it can be observed that maximum values of R show a similar pattern. For instance, in all of the period that the Waitahanui (41) was monitored only once a discharge of twice

Table III Discharge exceedence ratios.

Stream site nr.	R_{95}	R_5	R_1	R_{max}	R_{mean}
41	0.9	1.2	1.3	2	1.0
141	0.9	1.5	2.0	2	1.1
210	0.8	2.1	2.7	4	1.1
115	0.7	2.1	3.4	21	1.3
261	0.4	3.3	5.6	28	1.3
81	0.4	3.3	7.1	19	1.3
93	0.3	4.3	9.8	26	1.5
113	0.2	4.4	10.1	58	1.5

R_i = ratio of the discharge equaled or exceeded for i% of the year and the median discharge.

its mean annual flow was observed. This occurred during a complex subtropical storm with extensive rainfall of moderate intensity (more than 150 mm in a 5-day period) in February 1976.

Forested catchment areas with only thin tephra deposits are drained by streams with R_i values in excess of 5. Thus for at least 1% of the year the discharges are equal or exceeding 5 × the median flow. An extreme value of R_{max} of 58 was measured in stream 113, which is in sharp contrast with the maximum values of 2 measured in streams 41 and 141. Typical for the streams with a high flow variability is that the mean annual flow is higher than the median flow. The mean annual flow will be equaled or exceeded for only a short period of a year in those streams. In terms of R: for streams with a high streamflow variability R_{mean} varies between 1.3 and 1.5.

Concentrations of dissolved matter

There is a little difference in concentration behaviour of total dissolved solids between the streams draining the Lake Taupo basin (Table IV). In streams draining catchments with thick tephra cover the variation is slightly smaller (RC ranging between 0.8 and 1.1) than in stream draining areas with thin tephra deposits (RC ranging betweeen 0.6 and 1.3).

A relatively important increase in discharge leads to a slight decrease in concentration of dissolved matter for all streams in the area. This means that flood sampling is not very critical for the estimation of the total dissolved load outputs.

Tabel IV Concentration exceedence ratios.

Stream site nr.	RC_5	RC_{99}	RS_1	$RS_{0.1}$
41	1.1	0.9	1.3	1.9
141	1.0	0.8	2.8	5.4
210	1.1	0.8	2.1	5.4
115	1.3	0.6	2.1	5.3
261	1.2	0.7	2.6	6.2
81	1.3	0.6	4.1	19.7
93	1.3	0.6	5.4	21.5
113	1.3	0.6	2.7	7.9

RC = electrical conductivity; RS = suspended matter

Tabel V Output exceedence proportions.

Stream site nr.	MQ_5 %	MD_5 %	MS_5 %	MQ_1 %	MS_1 %	$MS_{0.1}$ %
41	6	4	20	1	5	0.6
141	8	5	34	2	14	2.8
210	11	8	40	3	19	1.2
115	10	6	50	3	19	9
261	18	12	67	6	41	17
81	21	14	80	7	50	17
93	26	15	91	9	69	21
113	27	17	77	10	53	22

MQ = streamflow; MD = dissolved matter; MS = suspended matter.

Concentration of suspended matter

Below concentrations of ca. 15 $g.m^{-3}$ the relative error in the measurement was too high to tell much about any relation between suspended matter and other variables. However, during periods with discharges in excess of q_{20} there is an exponential rise in suspended matter concentrations with increasing discharges. In streams with little streamflow variabilities RS_1 varies between 1.3 and 2.1, in those with high flow variabilities RS_1 ranges between 2.7 and 5.4. At higher discharges the differences become more pronounced; concentration exceedence proportions at discharges that are equaled or exceeded for about 8 hours per year ($RS_{0.1}$) for streams with little flow variability it ranges between 1.8 and 5.4, while in streams with high flow variability it ranges between 8 and 21 (Table IV).

Output exceedence

Flood outputs defined as the proportion of annual mass transports taking place during 5 % of the year with the highest discharges, are shown in Table V. If mass transport is evenly distributed over the year than MQ_5, MD_5 and MS_5 are all equal to 5 %. In streams draining catchments with thick cover deposits outputs of water and dissolved matter are evenly distributed over the year (streams 41 and 141). In contrast, streams draining catchment with shallow cover deposits (81, 93 and 113) have exceedence proportions of water ranging between 20 and 30 % and of dissolved matter ranging between 14 and 17 %.

Outputs of suspended matter are moderately to extremely concentrated during periods of floods. In Table V the output exceedence proportions of suspended matter are shown of 5, 1, and 0,1 % of the year. In streams draining areas with shallow cover deposits the outputs of suspended matter are virtually confined to floods. During periods of high discharges totalling about 4 days per year (MS_1), still more than half of the annual suspended matter outputs are transported. Streams draining areas with thick deposits have considerably more equaly distributed suspended matter outputs. When compared to the distribution of the annual outputs of water and of total dissolved matter, the suspended matter outputs are considerably more concentrated during the periods of high discharges.

DISCUSSION

Origin of flow in relation to its exceedences.

Catchments with thick deposits of tephra are characterized by streams that are not much affected by seasonal and daily fluctuations. Considerable groundwater storage in combination with extreme infiltration properties evens out the effects of rainstorms and wet periods. Springs form the dominant source of all streamflow. Streams draining catchments with thick cover deposits, such as 41, 141, and 115, originate from a small number of large springs in the lower and middle parts of their catchments. Springs with discharges over 0.1 $m^3.s.^{-1}$ are no exception and they are characterized by a very small range in flow rate, even after extended droughts. The Waitahanui (41) is a good example of such a stream. In the central part of its catchment a spring area provides ca. 4 $m^3.s^{-1}$ or more than half of its total flow. Upstream of this spring area the streamflow is only 0.22 $m^3.s^{-1}$ on average, adding to a depth of runoff of about 160 $mm.y^{-1}$, while the depth of runoff predicted from rainfall for that part of the catchment would be at least 1200 mm. In these types of streams, minor rises in discharge that may occur shortly after a rainstorm, can be explained by direct channel precipitation and inputs from roads and logging tracks.

Areas with only shallow cover deposits overlying impermeable formations have diffuse sources of streamflow, and derive their baseflow from a large number of small springs and seepages. During extended periods of dry weather these sources dry out one by one, resulting in very low minima. Streams rise to flood conditions within 10 hours after the intense showers began. Hortonian overland has never been observed in any of the catchments investigated, but as access in the dense forests is difficult, small areas of overland flow may have escaped attention. A possibility is that locally the shallow deposits become saturated during rainfall and contribute to streamflow in a way described by HEWLETT & NUTTER (1970). Virtually bare rock areas on the crests of the ridges are also expected to be sources of partial area contributions. However, the highly permeable thin tephra mantle, overlying impermeable subsoils, in the densely forested mountain ranges to the east and west of Lake Taupo, are very conducive to rapid throughflow. Root channels, animal burrows and litter layers etc., may serve as potential pathways for excess rainfall (WEYMAN, 1970; MOSLEY, 1978). Because of the lack of observations of overland flow the rapid throughflow and litterflow are regarded to be most likely explanations for the rapid response to rainfall of the streams 81, 93, 113 and to a lesser extent 216.

The effects of land use and other factors upon flow exceedence

Although in the Lake Taupo Basin the occurence and thickness of cover deposits form the most important factor in explaining the flow variability of the streams, some deviations of the general rule can only be explained by other factors. Small agricultural grassland catchments are sensitive for summer thunderstorms with high rainfall intensities. Investigations by SELBY (1973) and PITTAMS (1970) in small catchments (< 10 km^2) showed that, especially in summer, the response to rainfall in grassed catchments was considerably higher than in scrub covered catchments. As a result of compaction by cattle, sheep and heavy machinery in combination with repellency of the surface after prolonged drying, the average infiltration rates decreased markedly. Occasionally that much, that Hortonian overland flow initiated large-scale gullying. Intense rainfall during the summer results from erratic thunderstorms. However, the impact of these very localised phenomena on the annual flow duration of the streams that drain larger catchments (area > 30 km^2) will be small.

The effects of large-scale forestry on streamflow variability are very small, if present, in the Lake Taupo Catchment. It appears that the soil infiltration properties in the logged catchments have not changed and the excess precipitation is able to percolate to the groundwater. Stream 41 drains a catchment that largely has been logged and replanted with exotic pines. Its behaviour is not different from streams 141 and 210 which drain native forest land and agricultural grassland respectively.

In the Lake Taupo Catchment the effects of urban development are still small and are mainly concentrated around the township of Taupo. Alpine processes, such as snowmelt in areas of frozen soils, may have effects for the streamflow of the Waihohonu Stream (115).

Origin of dissolved load in relation to its exceedences

In systems, relatively undisturbed by man, processes in the soils and rocks produce groundwater of a very constant chemical composition. The groundwater is in equilibrium with its chemical and biological environment. This is the case in the Lake Taupo area where the impact of pollution generated by man is still very small.

Atmospheric water, even after brief contact with the vegetation and the soil has generally lower dissolved matter concentrations than spring waters. The negative correlation that exists in the area between discharge and concentration of total dissolved matter can be explained by the mixing of atmospheric water with brief residence times and groundwater from springs, durings floods.

Origin of suspended matter in relation to its exceedences

In the Lake Taupo basin suspended matter originates mainly from active erosion in the main stream channels and from tributary channels. Erosion from overland flow has never been observed. Another important source of suspended matter is the biological activity in or nearby the channels. Growing matter (algae), decaying vegetation and fauna deliver substantial amounts of particulate matter to the streams. Rainfall and slight increases of discharge are adequate to cause strong increases in the organic matter content of the water.

Apart from a few exceptional situations, the maximum carrying capacity for transporting suspended matter is never reached in the Lake Taupo area. Even the fast flowing mountain streams reach rarely suspended concentrations in excess of 1000 $g.m^{-3}$. The exceptions are situated in the active volcanic region to the SW (stream 115) and some small streams with active gullying in their headwaters.

As stream channels and riparian areas form the source area of suspended matter in the Lake Taupo basin it is important to investigate the various types of stream channels. In the areas of thick cover deposits the streams are entrenched in the cover deposits and occasionally cut deep gorges in the underlying ignimbrites. The bed material consists of fine sands and pumice with very low specific densities. There is a near continuous flow of material in motion, some of it as bed load.

Slight increases in discharge are able to loosen large quantities of fine ashes from the banks resulting in strong increases of suspended matter. Only because of the low frequency and magnitude of floods in the streams in the area of thick cover deposits, the annual mass transports and the output exceedences of suspended matter remain rather low (Table II). Streams draining areas with shallow cover deposits have in their head waters a typical torrent character with large boulders in the stream bed. These streams change into pool and riffle type streams in the middle and lower reaches. The flow beds of these streams contain only coarse gravel or rocks and during most of the year their waters are of extreme clarity and free of suspended matter.

During floods the rivers reach to the banks which normally are not touched by the water. These banks contain fluvially transported volcanic ashes and lapilli and layers of tephra and form the main suplly of suspended matter.

The stream channels and riparian areas alongside the streams if they contain volcanic deposits are extremely vulnerable to the activities of man. In practice it makes little difference whether these activities are related to urban, agricultural, or forestry developments. Any concentration of water (for instance road drainage) or destruction of protective vegetation along the streambanks or changes in the infiltration capacities of upstream areas, may result in streambank collapse and occasionally in severe gullying.

The very high outputs of the streams draining the Tongariro volcanoes in the SW of the Lake Taupo basin (for instance stream 115) are caused by a combination of a large supply of fresh ashes on steep slopes, absence of vegetation, and alpine conditions with frost and snowmelt.

Application in a regional sampling and gauging programme

Streams originating from areas with cover deposits more than 10 m thick require only a small number of gaugings and concentration measurements in a year to estimate annual mass transports. If in these region floods are not well sampled the error caused by this omission remains small.

Areas where cover deposits are thin (< 1 m) and where the underlying strata are relatively impermeable gauging will result in a biased estimate of the true annual runoff. Automatic stage height recording is therefore required to measure flow accurately in these stream. The estimation of total dissolved loads is simple and inexpensive in these streams, because of the small range in concentration (RC_i values) and the negative correlation of dissolved matter with discharge. Only a relatively small set of samples, well chosen over a wide range of discharges, is required. From these data regression equations describing the relationship between concentration and discharge can be established. Obtaining accurate estimations of the outputs of suspended matter and particulate nutrients forms the most difficult and expensive part of the programme. Obtaining samples of maximum discharges is required because of the wide range in concentrations and the positive correlation that exists between concentrations and discharge.

CONCLUSIONS

- As a result of the high storage capacity and infiltration characteristics of the ashes and pumice, streams originating in areas with cover deposits of over 5 m thick on average are characterized by very evenly distributed mass transport in terms of water, dissolved, and suspended matter.
- In about 75% of the Lake Taupo basin, namely those parts that are covered by thick unconsolidated deposits, it is relatively simple and inexpensive to measure total annual outputs from streams.
- In streams with a high streamflow variability special attention has to be given to sampling and gauging of peak floods. Up to 60% of the annual mass transport of suspended matter takes place within periods totalling less than 4 days per annum.
- On the basis of the map of PULLAR (1973) a regional sampling and gauging programme for the Lake Taupo basin could be designed, in which the average thickness of cover deposits was considered.

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