CLUTHA FLOOD OF OCTOBER 1978

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ABSTRACT

Flows in the Clutha catchment during the October 1978 flood have been analysed and peak discharges are presented. Flood volumes are compared with rainfall for this and all earlier major floods. A flood prediction model, capable of accurately predicting flood hydrographs at the lakes and at Roxburgh from rainfall data, could be incorporated into a flood warning system. This storm is compared with the estimated probable maximum and it is shown that the efficiency of the October 1978 storm was equal to the highest previously recorded. The quantity of sediment deposited in Lake Roxburgh by this single flood was almost equal to two-thirds of the average amount transported annually. Three sets of sediment data are presented and comparisons made between them. Unless suspended sediment concentrations are assumed to have an upper limit of 12000 ppm the sediment volumes predicted using sediment concentration versus flow rating curves considerably exceed the volumes measured in Lake Roxburgh by both siltation survey and daily suspended sediment sampling.

INTRODUCTION

A stationary cold front across the south of the South Island in October 1978 caused heavy rain and widespread flooding. The Clutha River (45°S, 169°E) began rising on 13 October and peaked on the 14th and 15th, with particularly severe flooding in the head of the catchment and in the lower reaches.

Daily mean inflows into the lakes in the upper catchment were the largest recorded in the period since 1930, and have return periods of about 80 years in Wakatipu and Wanaka, with a slightly lower return period in Hawea. Fortunately, there had been little rainfall in the weeks prior to this storm and lake levels were relatively low, resulting in only moderate outflows. The maximum outflows from Lakes Wakatipu and Wanaka have return periods of only 3 and 7 years respectively and consequently the flood at Roxburgh was not large. It had a return period of about 20 years, and the daily mean flow was exceeded in 1958, 1957, 1948, 1919, and 1878. In contrast the return period of the flood at Balclutha exceeded 100 years. This is because unusually high rainfalls also occurred in the south east of the catchment resulting in very high flows from lower tributaries such as the Pomahaka River. Added to the Clutha flow this gave over 4500 m^3/s at Balclutha which was intermediate between the previous maxima in 1919 and 1878.

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SYNOPTIC SITUATION

On 12 October an extremely deep depression lay to the south of New Zealand. Early on the 13th a cold front associated with this depression moved onto the southern part of the South Island (Fig. 1).

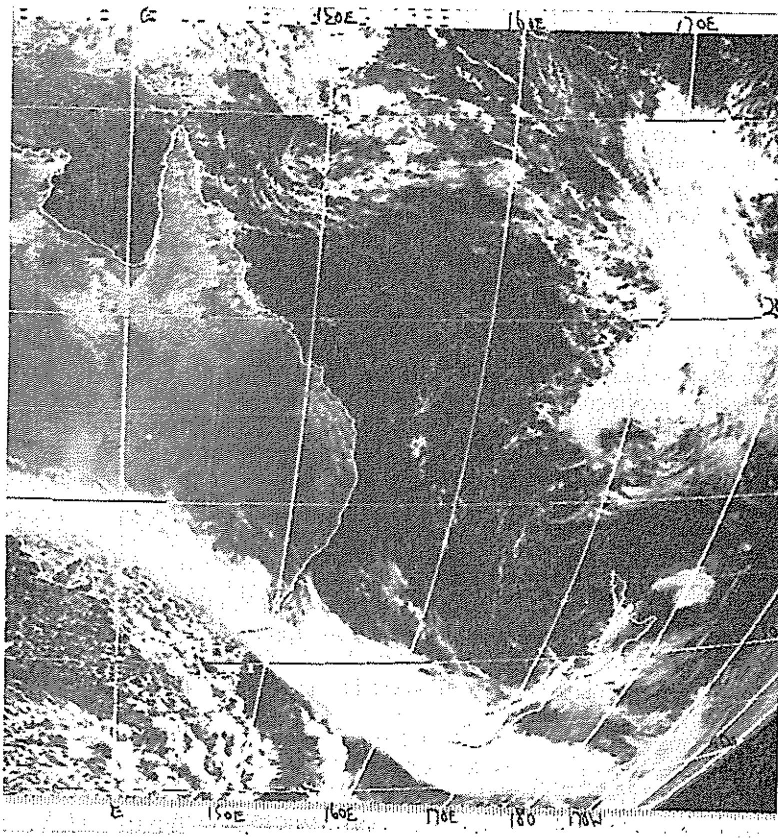


FIG. 1—Satellite photograph from GMS 1 of the weather situation at 0900 NZST on 13 October 1978. (With permission of the Director, NZ Meteorological Service.)

Two features contributed to the severity of the storm. The first, a blocking anticyclone just to the north east of New Zealand, caused a flow of moist warm air into the frontal system. The second was the stationary nature of the front, which was indicated by exceptionally strong high level winds parallel to the front (Hessell and Lopdell, 1979). The synoptic situation during this storm was very similar to that in other flood producing storms in 1946, 1952 and 1957. In each case a large anticyclone was to the north or west, and frontal systems lay NNE to ENE across the southern part of the South Island. A full description of meteorological aspects of the October 1978 storm has been publ'shed (Hessell and Lopdell, 1979).

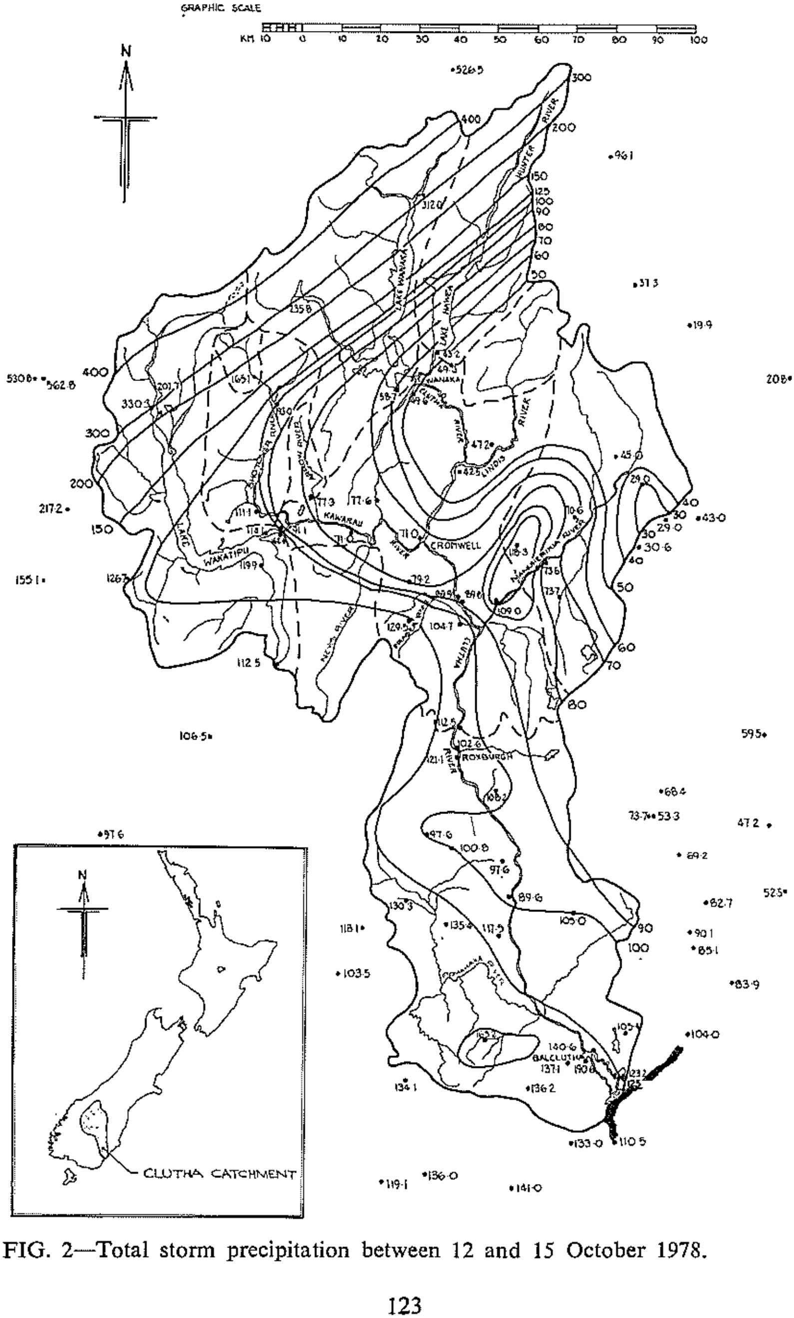


FIG. 2—Total storm precipitation between 12 and 15 October 1978.

RAINFALL

Rain began around the Clutha Lakes district early on 13 October, although some falls were recorded in catchments nearer the main divide from about mid-day on the 12th. By mid-day on the 13th higher intensity rain was falling on the entire catchment and maximum intensity was reached during the morning of the 14th. This caused flows to peak on the unregulated tributaries between 9.00 and 12.00 hours on the 14th. The rain had ceased over most of the catchment by 12.00 hours on the 14th giving a storm duration of 48 hours in catchments near the main divide, 36 hours around the lakes and 24 hours in the lower part of the catchment.

At Queenstown the highest daily fall was 87.1 mm on the 13th, with a two day fall of 105.6 mm on the 13th and 14th. These had return periods of under 50 years, and were exceeded in 1878 (twice) and 1949.

Rainfall data were obtained for 88 sites, from the New Zealand Meteorological Service and Ministry of Works and Development. The daily totals for the 13th and 14th and occasional small falls on the 12th and 15th were summed to give the total storm rainfall (Fig. 2). Catchment rainfalls for each flow measuring site were calculated from this map (Table 2).

An unusual feature of the distribution of rainfall was the high rainfall in south-eastern regions of the catchment and the generally higher rainfall in the southern parts of the catchment. It is probable that low pressures east of the Southern Alps as well as the presence of small wave depressions contributed to this rainfall distribution. Certainly the cold front was extremely active over the southeast of the catchments.

The accumulated rainfall from automatic recorders (N.Z. Met. S. and MWD) is shown in Figure 3 and an average temporal pattern of rainfall above Roxburgh was derived from these (Table 1).

Date	Time (hrs)	Percentage of total
13 October	3- 9	2.0
	9-15	10.9
	15-21	21.1
14 October	21- 3	25.9
	3- 9	27.0
	9-15	11.9
	15-21	1.2

TABLE 1—Clutha Catchment above Roxburgh. 6 hourly average rainfalls.

FLOWS

Flood flows

The rivers were generally low and steady in the period before 13 October, although very small freshes into the lakes occurred at about mid-day on the 12th. The flood rise was sharp in all the recorded upper Clutha tributaries, beginning at the start of the rainfall, 4.00 to 6.00 hrs on the 13th, and rising to a peak at 7.00 to 9.00 hrs on the 14th, except for the Lindis, Arrow, and Cardrona Rivers, which all peaked after mid-day. The Manuherikia peaked at about 5.00 hrs on the 15th. In this catchment the lag time of 27 hours between the rainstorm and the flood peak was unusually long.

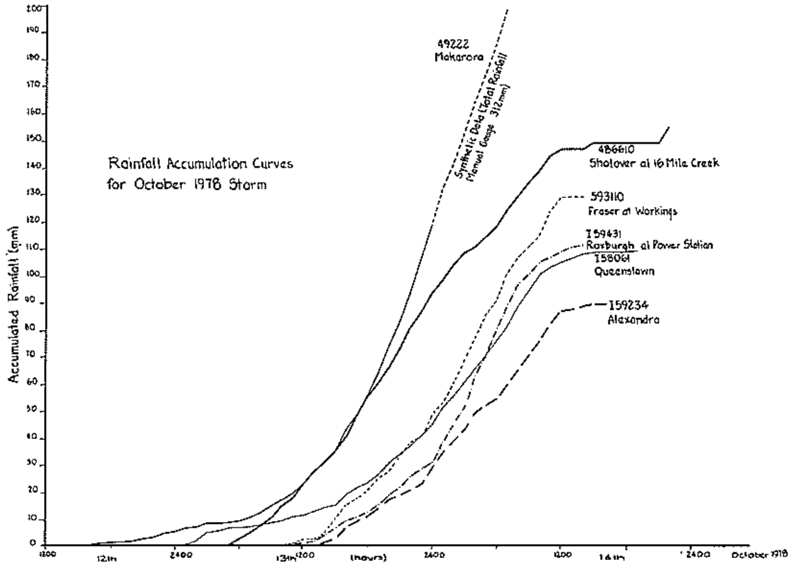


FIG. 3—Rainfall accumulation curves for October 1978 storm.

Generally the return period of the tributary flows was just under 100 years, slightly higher in the south and lower in the north. Fortunately the lakes were low at the beginning of the flood and the lake outflows which peaked more than a day after the inflow flood were relatively small. Peak and daily mean discharges with their estimated return periods are shown in Table 2.

The 2360 m^3/s flood peak at Roxburgh and the 4760 m^3/s peak at Balclutha were the result of the addition of many tributary flows, the Shotover and the Pomahaka being the most signifcant. At Roxburgh the Shotover contributed about 800 m^3/s to the peak of the flood which can be compared to about 300 m^3/s from Lake Wanaka, nothing from Lake Wakatipu because the outlet was blocked by the Shotover flow, and nothing from Lake Hawea where the control gates were closed.

At Balclutha the Pomahaka contributed 1300 m^3/s to the peak flow of 4760 m^3/s. This was an unusually high flow from the Pomahaka and a return period of 170 years was derived for this flow using the method described by Beable (1978). Rainfall in the southeastern region of the catchment was the major factor in the severity of flooding in the Lower Clutha.

Recorder Operation and Ratings

The lake level recorders operated throughout the flood and the accuracy of the digital recorders (3 mm) has allowed extremely good definition of the inflow hydrographs.

The major river water level recorders (Fig. 4) also operated satisfactorily except for the partial failure of the water surface follower on the Kawarau at Chards Road and the destruction of the surface follower on the Shotover at Bowens Peak. The accuracy of the digital records from these major river sites is very good and comparison of them showed that minor rating changes occurred at the peak of the flood.

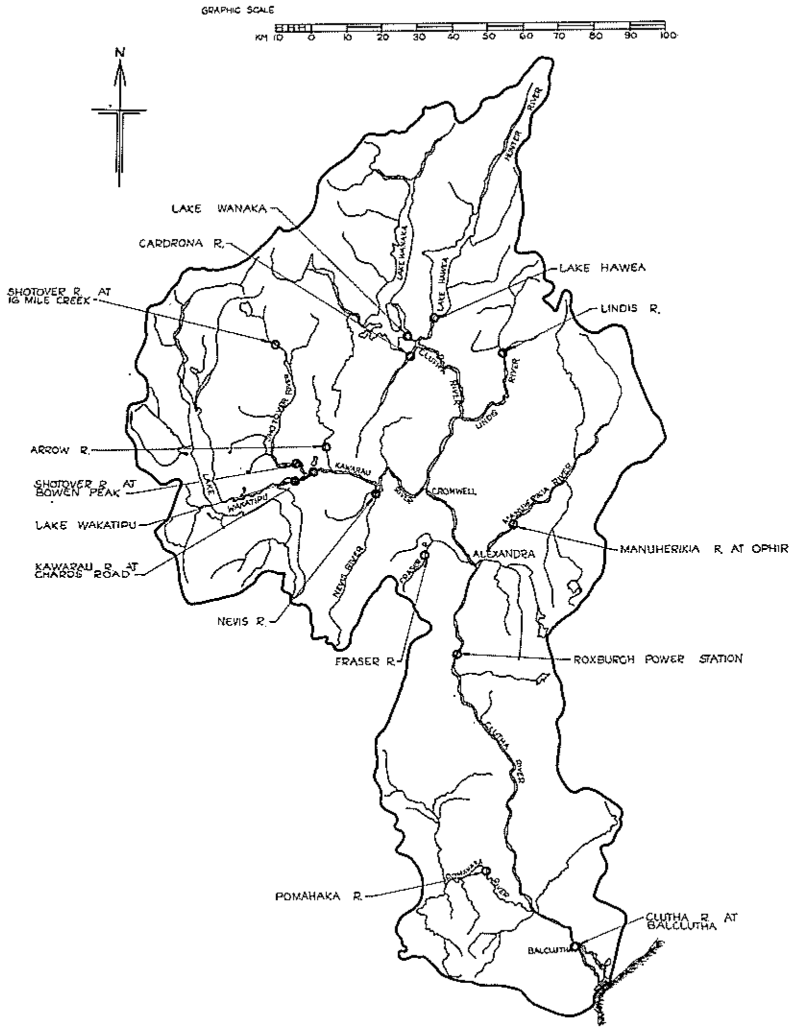
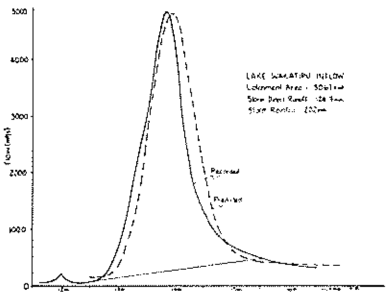
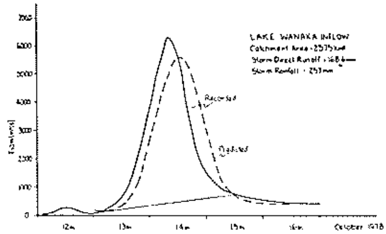


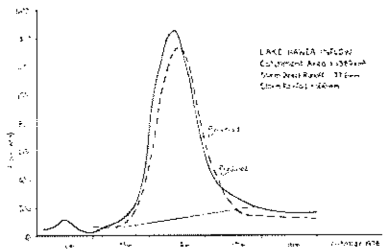
FIG. 4—Location of water level recording stations.

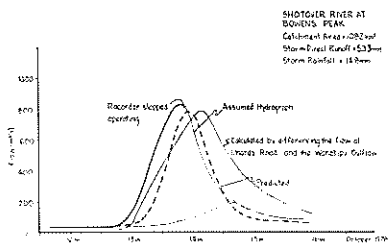
The severity of the flood in the southwestern part of the catchment caused severe bedload movement in tributary streams and consequently the ratings and derived flow records are uncertain. The Nevis River site was particularly unstable and remained so after the flood. The Arrow River at Tobins Track changed its rating at the peak of the flood but appeared to stabilise giving reasonably reliable records. Both the Lindis and Manuherikia Rivers were not subjected to such extreme flows and the records from these rivers are very good. The records from the Fraser River were not used as flows severely damaged the recorder and weir.

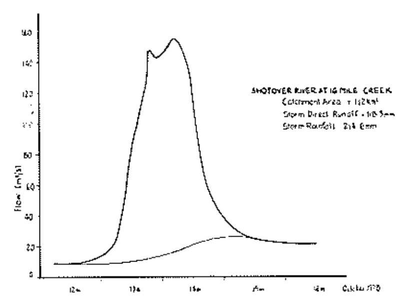
The MWD hydrological field party from Alexandra was active throughout the flood making gaugings at most of the sites. This was extremely valuable as it has allowed extrapolation of the ratings to be carried out with some confidence. A revision of the ratings for the sites above Roxburgh was carried out and this revealed changes in rating at most sites, as can be expected with such high flows.

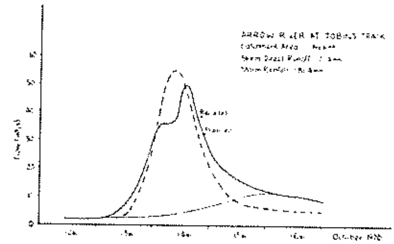












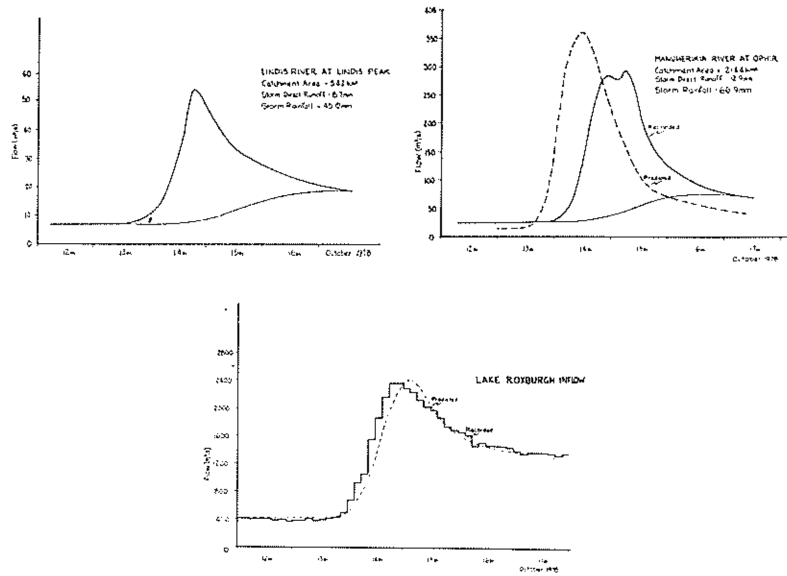


FIG. 5—(A to I)—Comparison of predicted and measured flood hydrographs. (Note: Lindis catchment is not modelled separately by flood prediction model.)

Analysis of Runoff

The flood hydrographs (Fig. 5) were integrated after the subtraction of baseflow to give the volume of direct runoff for each catchment. The volume of direct runoff is compared to the storm rainfall in Table 2 and on Figures 6 and 7.

The records from the new flow recording stations in the Lindis, Nevis, and Shotover at 16 Mile Creek are especially valuable. The Lindis and Nevis records ind:cate that these tributaries have the same runoff characteristics as the other tributaries between the Lakes and Roxburgh. The record on the Shotover at 16 Mile Creek showed that the percentage runoff for this catchment is similar to the Wanaka catchment. This runoff from the Upper Shotover catchment is significantly higher than that from the whole Shotover catchment, and demonstrates that the upper regions of the Shotover have similar hydrological characteristics to the Wanaka catchment, whereas the larger portion in the drier region of the lower catchment is similar to the Nevis, Arrow, and Lindis.

Snowmelt

Contrary to the suggestion by Hessell and Lopdell (1979), hydrological records show no evidence that snowmelt contributed any more significantly to this flood than to any other. All floods in catchments with perennial snow contain contributions from both rainfall and snowmelt. For snowmelt to contribute significantly to a flood the runoff volume for a given storm precipitation must be higher than that recorded in a normal event. Figures 6 and 7 show that, in this flood, runoff volumes were no higher than expected and were very close to the average precipitation versus runoff relationship derived from the analysis of past floods.

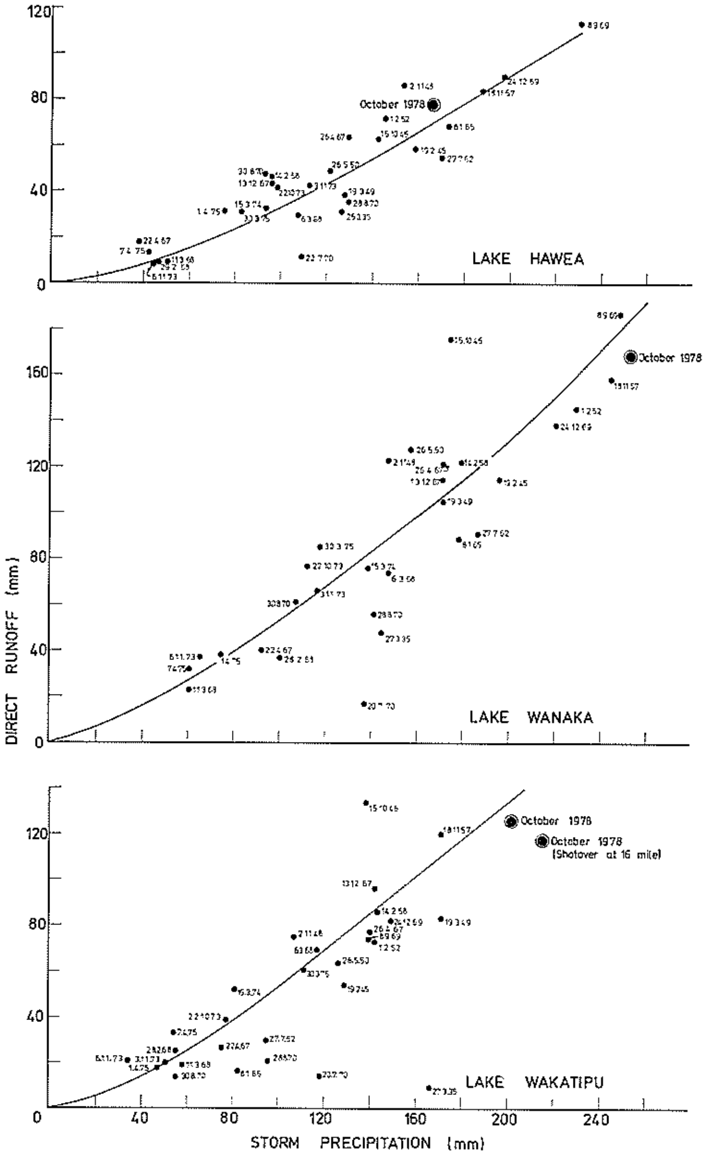


FIG. 6—Precipitation-runoff relationship, Lakes Hawea, Wanaka and Wakatipu.

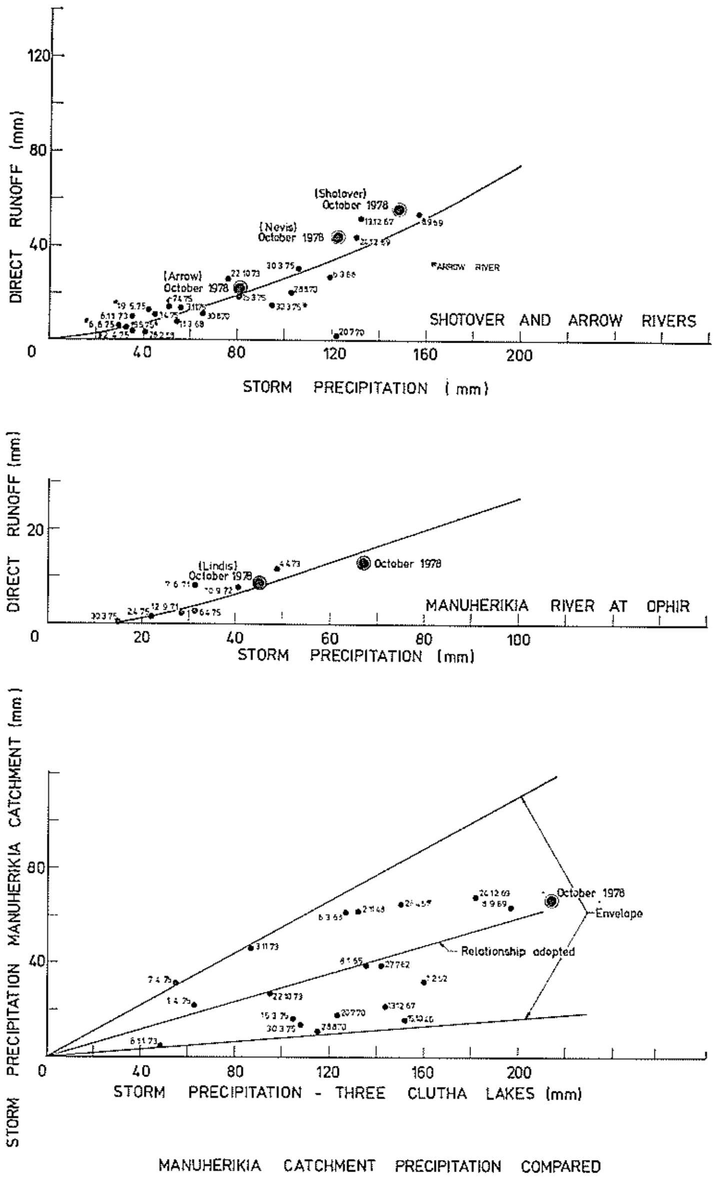


FIG. 7—(a) Precipitation-runoff relationships, Shotover and Arrow Rivers.
(b) Precipitation-runoff relationship, Manuherikia River.
(c) Relationship between storm precipitation in Manuherikia and Clutha Lakes catchment.

However, in the Fraser catchment, a 100 mm loss in snowpack at one point was reported by Harrison (1979). Similar amounts would have occurred in other high altitude catchments and this leads one to conclude that the area of seasonal snowpack is not sufficiently large to influence the volume of runoff from large catchments.

Catchment	Area (km^2)	Rainfall (mm)	Direct runoff (mm)	Mean annual flow (m^3/s)	Instantaneous peak (m^3/s)	Daily mean peak (m^3/s)	Estimated return period of daily mean (years)
Wakatipu Inflow	3067	202	125	156	4800	3200	80
Wakatipu Outflow	3067			156	400	396	3
Wanaka Inflow	2575	253	169	191	6290	4212	80
Wanaka Outflow	2575			191	693	688	7
Hawea Inflow	1389	166	78	63	1460	1114	50
Hawea Outflow	1389			63	12	12	—
Shotover at 16 Mile	112	215	118	15	155	111	—
Shotover at Bowens Peak	1082	148	57*	38	830	622	20
Arrow	196	81	21.4	2.8	52	38	—
Nevis	689	121	44**	15	450	318	—
Kawarau at Chards Road	4366	—		200	800	667	—
Lindis	542	45	8.7	5.7	55	35	—
Clutha at Lowburn	6211	—		280	928	870	—
Clutha at Clyde	1090	—		473	1900	1580	—
Manuherikia at Ophir	2144	67	12.9	14	292	213	6
Clutha at Roxburgh	15857	125		490	2370	1995	20
Clutha at Balclutha	20306	—		552	4760	4000	135
Pomahaka at Burkes Ford	1924	127	76	24	1300	1083	170

* Estimated from Wakatipu outflow and Kawarau River at Chards Road flow.
** Value uncertain because of rating changes.

TABLE 2—Catchment rainfall, runoff and peak discharges.

FLOOD PREDICTION MODEL

Introduction

Design floods and the probable maximum flood for the Clutha Valley Development were derived using a deterministic model described by Jowett and Thompson (1977). This model uses unit hydrographs for gauged catchments and synthetic unit hydrographs for ungauged ones to predict tributary flows. Direct runoff volumes are estimated from catchment storm rainfalls and the rainfall-runoff curves (Figs. 6 and 7). These tributary flows are routed through the lakes, where appropriate, and to Roxburgh without attenuation as kinematic waves. The wave celerity assumed in the model is 2 m/s and values measured during the October flood showed that the celerity varied from over 2 m/s in the Kawarau to about 1.5 m/s in the main Clutha River. Alteration of the kinematic wave velocity has little effect on the predicted flood hydrographs.

This model was applied to the rainfall records of the October 1978 storm and the predicted flood flows compared with the recorded flows (Fig. 5). An improved and extended flow recording network allowed checks to be made on predicted flows for catchments where no data have previously been available. These checks proved that the model predicted the peak flood flows to $\pm 10\%$ for the majority of gauged catchments and flood volumes to better than 10%.

This is as good as can be expected when it is considered that the peak flows recorded at many of the sites have an accuracy of about $\pm 20\%$ because of the unstable nature of the river channel in such large floods.

Runoff Prediction

Runoff volumes for all lakes were very slightly lower than predicted (Figs. 6 and 7). At Lake Wakatipu the Shotover flowed back into the Lake for just over 24 hours and this certainly reduced peak flows downstream by restricting the lake outflow. The prediction for the Arrow River differs slightly in shape because the temporal pattern of the rainfall in this catchment differed from the average pattern assumed. In the Manuherikia the flood peak was recorded at 5.00 hrs on the 15th whereas the predicted peak is at 12.00 hrs on the 14th. This was caused by the modelling assumption that rainfall occurs at the same time over the whole Roxburgh catchment. In the Manuherikia catchment the actual start of rainfall was at 13.00 hrs on the 13th compared with the assumed start time of 0 hrs on the 13th. If this is allowed for, the timing of the predicted flow matches the recorded flow and the remaining difference is caused by variations in the temporal pattern. The smaller catchments are more sensitive to this type of variation, but when summed to give total river flow, the difference becomes less important.

Use of a Model in a Flood Warning System

The storm rainfall ceased at about mid-day on 14 October. Tributary streams and lake inflows were at their peak at this time and inflow into Roxburgh was rapidly rising.

The peak discharge at Balclutha was recorded at about the same time as the peak inflow into Lake Roxburgh; 20.00 hrs on the 14th. This timing indicates that it would be possible to set up a flood warning system capable of accurately predicting flood flows at Roxburgh and Balclutha 8 to 12 hours in advance. Such a system would require a network of telemetered automatic rain gauges supplemented by telephone reports from observers. The benefit of this may not be large in the upper part of the Clutha, but in the lower Clutha, considerable damage could be averted if 8 hours flood warning were available and flood peaks accurately predicted.

Future Model Development

Discrepancies in timing between recorded and predicted flows were caused by assuming that the rainfall occurs over the whole catchment at the same time and with the same temporal pattern. This assumption was made because it is difficult to define different temporal patterns within the catchment for the case of a hypothetical design storm.

It would be possible to incorporate different temporal patterns in the model, supplying accumulated rainfall data for various areas of the catchment, if the model is to be used for flood forecasting. It would however, almost double the amount of input data required. Further refinement could be achieved by varying flood wave celerities in various parts of the river rather than assuming an average 2 m/s, but this has very little effect on the predicted flows.

PROBABLE MAXIMUM PRECIPITATION

The probable maximum storm for the Clutha is described by Jowett and Thompson (1977) as a double event with the main rainfall of 336 mm in 48 hours following a storm of about one half that size. Fortunately there was no storm preceding the storm of 13-14 October 1978 but this two day storm otherwise had characteristics similar to that selected as the probable maximum.

The temporal pattern of the October storm is compared with Jowett and Thompson's (1977) 48 hour probable maximum precipitation (PMP) in Figure 8. The similarity is clear and the intensities recorded in the October storm indicate that the PMP may underestimate the maximum intensities.

The dew point temperature recorded at both Haast and Hokitika during and before the storm was 12°C. This can be compared to the dew point temperature of 12-13°C at Queenstown during the 1878 flood and a maximum of 16°C given by Jowett and Thompson (1977).

The total storm rainfall over the 3 lakes was 213.4 mm which is about equal to the highest recorded in 1957 but lower than the 1878 rainfall. The moisture maximisation factor for this storm is calculated with an inflow barrier of 2000 m and is 1.56. The October 1978 storm maximised rainfall is 333 mm which can be regarded as equal to the PMP estimate of 336 mm.

The October 1978 storm has been shown to give a maximised rainfall equal to the PMP but the intensities in this recent storm were proportionally greater than those estimated for the probable maximum. The probable maximum flood (PMF) was re-estimated with these increased intensities. This resulted in minor increases of up to 8% in the Kawarau, 5% at Roxburgh and 2% in the Upper Clutha, all of which are far less than the uncertainties of the estimate associated with the method, and in particular the areal distribution. However the October 1978 flood confirmed many of the assumptions made in estimating the PMF. The runoff from the ungauged catchments was as predicted, the rainfall in the Manuherikia catchment was 0.3 times the rainfall over the lakes and generally the flow prediction model was able to accurately represent the actual situation.

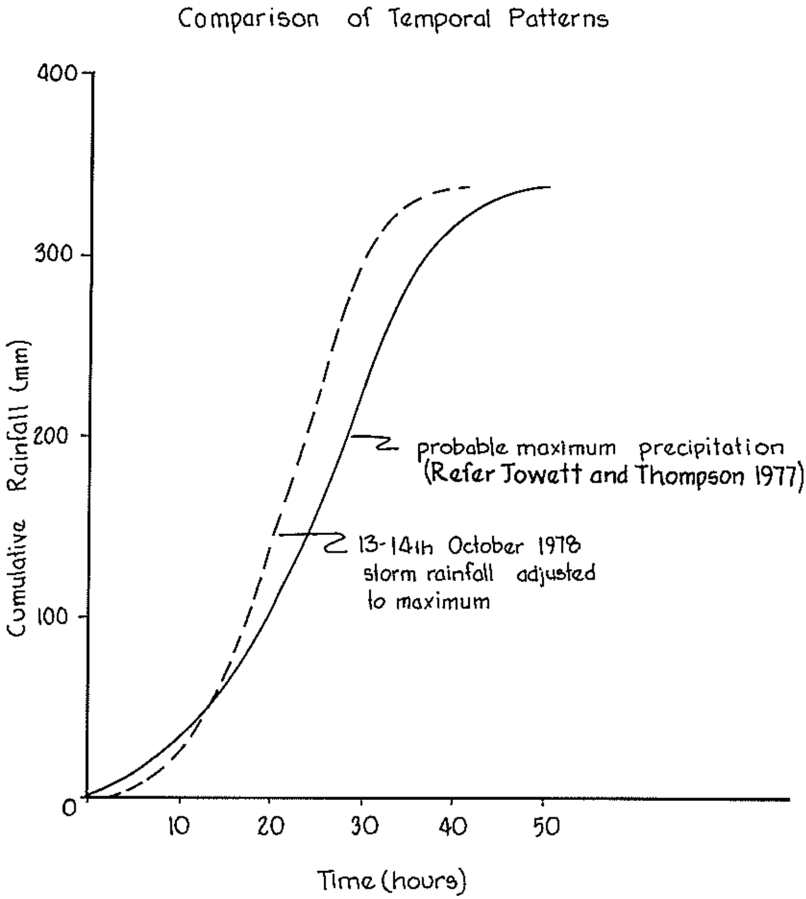


FIG. 8—Comparison of temporal patterns.

SEDIMENT

Sediment measurements

Siltation surveys of Lake Roxburgh in July 1978 and in February 1979 enabled calculation of the total volume of sediment deposited in the lake in the seven month period. Daily surface suspended sediment samples which were taken upstream and downstream of the lake during this period enabled the suspended sediment trap efficiency of the lake to be estimated. (Trap efficiency is defined here as the proportion of inflowing suspended sediment deposited in the reservoir.) Thus for the above period these two sets of measurements allowed calculation of the total sediment yield of the Clutha catchment above Roxburgh.

A second estimate of the sediment yield was obtained solely from the daily surface suspended sediment samples, assuming that bed load was equivalent to 10% of the suspended load. (This assumption was based on the work of Thompson (1976) who found that slightly less than 10% of the material deposited in Lake Roxburgh was of gravel size.)

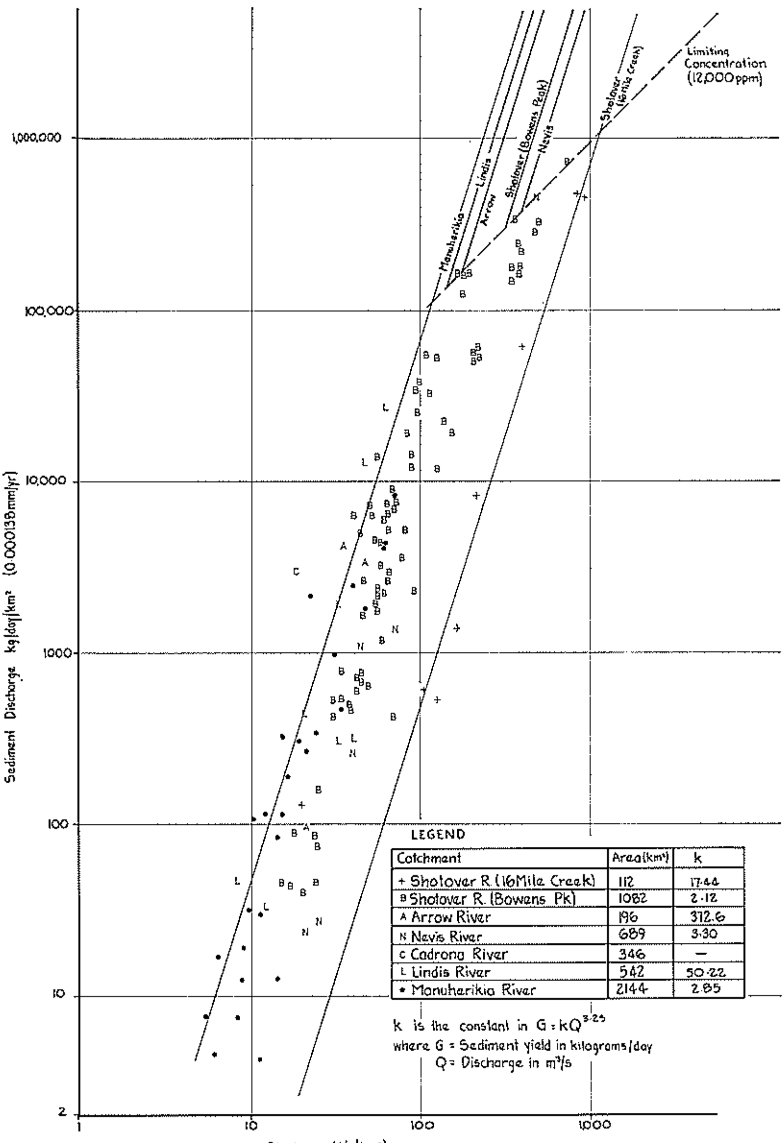


FIG. 9—Suspended sediment rating curves, Clutha tributaries above Roxburgh.

Suspended sediment rating curves which had been derived (Fig. 9) for the major tributaries of the Clutha river above Roxburgh were used to derive a third estimate of total sediment yield. This was obtained by accumulating the sediment yields of the tributaries; bed load was again assumed to be equivalent to 10% of the suspended load.

In addition to the seven month period, the latter two methods (i.e., the daily suspended sediment samples and the accumulated tributary sediment yields) were used to give estimates of the volumes of sediment transported during the actual flood period (13-16 October 1978).

Siltation Measurements—Lake Roxburgh

Siltation surveys showed that $2.284 \times 10^6\ m^3$ of sediment were deposited in Lake Roxburgh between July 1978 and February 1979. Assuming an average density of $1.27\ t/m^3$ as calculated by Thompson (1976) the amount of sediment deposited in Lake Roxburgh was 2.90 Mt for the seven month period. For the period 1961-1979 siltation surveys show that deposition has been $1.36 \times 10^6\ m^3/yr$ (1.73 Mt/year).

Daily Sediment Sampling

In 1977 a programme of daily sediment sampling from the Manuherikia and Clutha Rivers at Alexandra and twice daily sampling from the tailrace at Roxburgh was undertaken so that the trap efficiency of Lake Roxburgh could be calculated.

The surface sediment data collected can be converted to average concentrations using relationships derived by D. M. Hicks (pers. comm.). When these are multiplied by the flow they give the sediment discharge yields shown in Table 3.

Thus the average suspended sediment trap efficiency over the 18 month period September 1977 to March 1979 was calculated as 82%. A slightly lower figure of 78% was derived for the period July 1978 to February 1979.

	Input to Roxburgh (tonnes × 1000)	Discharged from Roxburgh (tonnes × 1000)	Trap Efficiency %
15 July 1978	11	2	82
August	462	65	86
September	168	23	85
October	1569	513	67
November	390	36	91
December	118	15	87
January	316	18	94
15 February 1979	78	4	95
	3.10 Mt	.68 Mt	78

TABLE 3—Suspended sediment in Lake Roxburgh from daily sediment samples.

Thus the amount of suspended sediment deposited in Lake Roxburgh, as calculated from daily sediment samples, is 2.02 Mt in the period 15 July 1978 to 15 February 1979. If bedload (10% of suspended sediment) is added to this value, the total deposition in Lake Roxburgh is 2.73 Mt.

In the same manner the suspended sediment quantities into and out of Lake Roxburgh over the period of the October flood (13th to 16th) were calculated as 1.10 Mt and 0.45 Mt respectively. This gave an estimate of 0.76 Mt of sediment deposited in Lake Roxburgh over the four days of the flood.

Suspended Sediment Rating Curves

Fifteen suspended sediment gaugings were made during and after the flood and concentrations of up to 11336 ppm were measured. In the wetter catchment of the Shotover at 16 Mile Creek, the sediment yield for a given specific discharge is noticeably less than from the other Clutha catchments (Shotover at Bowens Peak, Nevis, Lindis, Manuherikia, and Arrow). These remaining catchments show a slight trend for the yield to be lower in the wetter catchments and higher in the dryer. Previous studies by Jowett (1979) in the Tongariro have indicated that rivers may have an upper limit on the concentration of sediment they carry. If the rating curve of the Shotover River at Bowens Peak is extrapolated to give the concentration for a flow of 786 m^3/s, the value derived is 80000 ppm. This compares with the measured value of 11336 ppm. A maximum value of about 12000 ppm occurred on five other occasions, four on the Shotover and once on the Nevis, for quite different flows.

It is evident from Table 4 that if unbounded logarithmic extrapolation of the rating curve is used, the sediment yields for the catchment are very much higher than the amount deposited in Lake Roxburgh. If an upper limit of 12000 ppm is assumed for the concentration then the sediment yield agrees with the amount deposited in Lake Roxburgh.

Estimates of the total sediment yield for the Roxburgh catchment were made for the period of the storm, assuming a limiting concentration of 12000 ppm, and are shown in Table 5.

Catchment	With Logarithmic extrapolation			Maximum concentration limited to 12000 ppm		
	Max. Yield (1000 t/d)	Max. Daily Mean Yield	Total Yield 13 to 16th October	Max. Yield (1000 t/d)	Max. Daily Mean Yield	Total Yield 13 to 16th October
Shotover at 16 Mile Crk	239	118.6	191	150	46	92
Shotover at Bowens Pk	8000	3441	3826	880	639	835
Nevis at Wentworth	1903	625	636	489	303	317
Arrow at Tobins Trk	139	57	65	54	38	47
Lindis at Lindis Pk	22	8.5	16	22	8.5	16
Manuherikia at Ophir	296	137	241	296	137	241

TABLE 4—October 1978 flood suspended sediment yield (tonnes × 1000).

Catchment	Area (km²)	15 July 1979 to 15 Feb. 1979 Total Yield (tonnes × 1000)	Unit Yield (tonnes/km²)	13 to 16 Oct. 1978 Total Yield (tonnes × 1000)	Unit Yield (tonnes/km²)
Shotover	1082	1955	1807	835	770
Nevis	689	367	533	317	460
Arrow	196	116	592	47	240
Lindis	542	67	123	16	30
Manuherikia at Ophir	2144	386	180	241	110
Clutha above Lowburn	2066	289	140	83	40
Kawarau above Cromwell	494	272	550	99	200
Lower Manuherikia and Roxburgh	1613	194	120	210	130
	8826	3.65 Mt		1.85 Mt	

TABLE 5—Suspended sediment yield entering Lake Roxburgh.

Comparison of Estimates

Three methods of calculating sediment volumes and yields have been used in the preceding sections, each giving slightly differing results. Trap efficiencies shown in Table 6 for the siltation survey method and the rating curve method are derived from the daily suspended sediment samples for the appropriate period. In each method the bedload is assumed to be equivalent to 10% of the suspended sediment load.

	15 July 1978 to 15 Feb. 1979			13 to 16 Oct. 1978	
	Siltation Survey	Suspended Sediment Rating Curves	Daily Suspended Sediment Sampling	Suspended Sediment Rating Curves	Daily Suspended Sediment Sampling
Suspended Sediment Input	3.30 Mt	3.65 Mt	3.10 Mt	1.85 Mt	1.1 Mt
Bedload (assumed 10% of susp. sediment)	0.33 Mt	0.37 Mt	0.31 Mt	0.19 Mt	0.11 Mt
Total sediment deposition in Lake Roxburgh	2.90 Mt	3.22 Mt	2.73 Mt	1.26 Mt	0.76 Mt
Suspended Sediment discharged from Roxburgh PS	0.73 Mt	0.80 Mt	0.68 Mt	0.78 Mt	0.45 Mt
Suspended Sediment Trap Effiency	78%	78%	78%	58%	58%

TABLE 6—Comparison of estimates.

Thompson (1976) gave possible errors in the siltation survey as ± 10%. Thus the amount surveyed may have been as high as 3.3 Mt allowing ±5% error in the estimated density.

Errors in the estimate using suspended sediment rating curves derive from both the estimate of flow and the estimate of sediment yield for flow. Errors in both could be large, and may be as high as 10% for flow and 10% for sediment yield. Thus the estimate of deposition using this method is 3.2 Mt ± 20%.

Daily sediment sampling will have an error associated with it which is the result of sampling a continuous time series at fixed intervals of time.

Thus the three methods give results which agree to within 20%, i.e., the limits of their errors.

Summary

The average rate of sediment deposition between 1961 and 1979 in Lake Roxburgh is 1.73 Mt/year and is slightly lower than the earlier figure of 1.84 Mt/year (1961-1974) given by Thompson (1976).

The average trap efficiency for suspended sediment, calculated from sediment samples taken daily from the Clutha and Manuherikia Rivers, and twice daily from the Roxburgh tailrace, is 82%. This figure is much higher than the figure of 50% which was calculated by Thompson (1976) using Churchill's method.

In the seven month period from July 1978 to February 1979 siltation surveys showed that 2.90 Mt was deposited in Lake Roxburgh. Almost the same amount was calculated using flow records and sediment rating curves, assuming that a sediment concentration of 12000 ppm was not exceeded. However, if unbounded logarithmic extrapolation had been used, the total estimated catchment sediment yield of over 8 Mt would have been very much higher than that deposited in Lake Roxburgh.

Of the 2.90 Mt deposited in the Lake over the seven months, about 1.0 Mt was deposited in the October flood.

CONCLUSION

Some valuable lessons have been learnt from a close study of the 13-14 October 1978 storm and resulting flood.

Precipitation during this storm closely matched, when maximised, that earlier calculated as the probable maximum, and its temporal pattern (intensity) has led to a slight increase in estimate of the probable maximum flood.

The flood prediction model, developed for design flood derivation, accurately predicted the flood hydrographs into the lakes and at Roxburgh using the distribution of rainfall (in time and space) and the lake levels at the beginning of the storm.

More accurate flow forecasts can be achieved by using the accumulated rainfall for individual catchments rather than assuming an average over the whole catchment.

The quantity of sediment transported during this flood was approximately two-thirds of the mean annual amount transported. The quantity transported by the 20 year return period flood in the Shotover River was 0.835 Mt which is 30% of the total deposited in Lake Roxburgh between July 1978 and February 1979 and approximately 70% of the amount deposited during the October flood.

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