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FLOOD FREQUENCY ANALYSIS FOR THE WAIRAU RIVER, MARLBOROUGH

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ABSTRACT

Estimates of the sizes and frequency of floods in the Wairau River are necessary to review the capability of the Wairau River control floodway system. There are many data sources for flood review information, including water level records from four recorder sites operating over different time periods, various hydrological gaugings, pegged flood levels along stopbanks in major floods, river cross-sectional survey and rainfall records. All these were analysed to assess likely Wairau flood size and frequency, and the size of the recent large 1983 floods in particular.

The main findings were :

1) The 1 in 100 year return period flood for the Wairau (ie a flood having a 10% chance of occurrence in the next 10 years) is assessed as being 5500m^3/sec. This frequency of flood is commonly used for design of major river control works in New Zealand and is a suitable frequency for the Wairau.
2) The July 1983 flood is assessed as being 5800m^3/sec, a 1 in 150 year return period event, and the October 1983 flood as 4400m^3/sec, a 1 in 30 year return period event. These estimates are respectively 1200m^3/sec and 600m^3/sec less than previous estimates, and therefore more frequent events than considered before.
3) The various hydrologic and hydraulic analyses were complementary and also in good agreement with a review of the less accurate historical flood data from 1920 to 1960 which had previously underestimated flood size.

INTRODUCTION

Major river control works have been carried out on the Wairau River for over 130 years since soon after the start of Pakeha settlement of the main Wairau floodplain.

The expected flood size for the Wairau River works is the basis for designing the size of river control works. As the Wairau's regime has been changed by major diversions, channel aggradation, stopbank relocation and other river control works, levels for today's floods will be different from historical flood levels for the same size of flood.

The design flood size commonly used elsewhere in New Zealand to protect valuable populated land is a flood that has a 10% chance of occurring within the next 10 years. Such a flood will on average occur or be exceeded once every 100 years, and the term "100 year flood" is a more succinct but less clear description of its frequency of occurrence.

Previous estimates of design floods for river control works, and/or 1 in 100 year flood return period floods are given in Table 1. Each successive estimate

TABLE 1—Recommended design floods and 100 year return period floods for the Wairau River.

	Recommended Design Flood	1 in 100 year flood
(a) Vickerman and Lancaster (1924)	4700 m^3/sec	not given
(b) Vickerman and Lancaster (1927)	4200 m^3/sec	not given
(c) C C Davidson (1959)	5100 m3/sec	4600 m^3/sec
(d) L N Pascoe and P A Thomson (1984)	5100 m3/sec	5100 m^3/sec
(e) S N Rae (1988)	Not given	5220 m^3/sec

is based on more information, and there is a general increase in calculated flood size. However, Rae (1988) excluded the extremely large July 1983 flood from his analysis as being an outlier of several hundred years return period.

Flood measurement was improved by the Marlborough Catchment Board which was set up in 1957. The Board established a continuous water level recorder on the Wairau at Tuamarina in 1960. The design of the 1960 Wairau Valley Scheme river control works were without this recorder information. A gauging programme was carried out in the 1960's and early 1970's to establish a rating relationship for the site, but the gaugings were limited to smaller floods. Flood gaugings were virtually discontinued between 1974 and 1989. Ironically, this was a time of major changes just downstream of the Tuamarina recorder site with Wairau Diversion development, substantial gravel deposition in the lower Wairau, and river works. These channel changes would have changed the rating relationship, but to an unknown degree.

The actual size and expected frequency of floods measured at Tuamarina including the two very large 1983 floods was uncertain. The July 1983 flood was considered at the time to be so large and so rare that it would not be worthwhile to construct river works to control.

Apart from Tuamarina recorder records, other information is available to estimate the 1983 and other floods. This includes surveyed flood levels along the stopbanks, river cross-sectional survey, water level records at different sites within and adjacent to the catchment, and rainfall records. In this review, information from a wide variety of sources has been thoroughly examined. All hydrological gauging and recorder site water levels were examined, and hydraulic backwater/slope area analysis of recorded flood levels down long channel reaches. The answers given by these different analyses were in reasonable, but not perfect agreement, and value judgements were required to determine the final recommended flood sizes.

This paper is based on a joint study by Marlborough District Council staff (E B Williman, W J Noell and V Wadsworth) and Works Consultancy Services (H J Freestone, D C Maslin, M G Webby). Both organisations analysed different base data, and applied their own value judgements of the various information sources to come up with their own independent estimates of flood sizes and frequencies.

Works Consultancy Services (1993) prepared a report for the Marlborough District Council, in which the recommended flood sizes are very similar to those adopted by the Council as part of their Wairau River Floodways Management Plan.

A description of the catchment and how it responds to rainfall is detailed by Rae and Wadsworth (1990) in a paper describing the use of real time rainfall to forecast flood levels in the Wairau.

THE JULY 1983 FLOOD

Background

The July 1983 flood was extremely large and caused considerable concern as to its size and frequency of occurrence. Only the February 1868 flood is documented as being possibly of similar magnitude, and no estimates can be made of that event, which also caused exceptional flooding in the Waimakariri and other rivers.

Thomson (1983) initially estimated the July 1983 flood at 7765m^3/s, though later Pascoe and Thomson (1984) revised this estimate to 7000m^3/s. A flood of 7000m^3/s is larger than any other Wairau flood and amongst the largest documented floods in any river in New Zealand. The Marlborough Catchment Board therefore decided not to re-design the Wairau river control system to

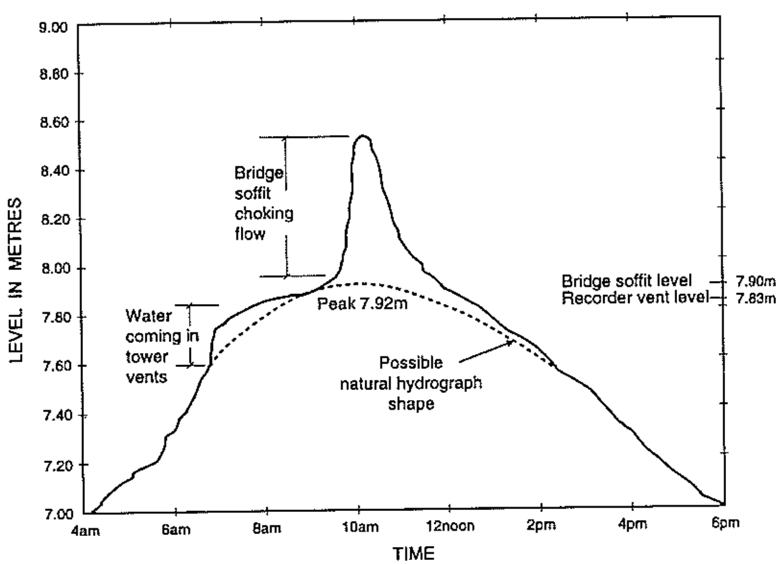

FIG. 1—July 1983 flood hydrography for the Wairau River at Tuamarina and projected hydrograph shape minus effects of the water tower vents and bridge soffit. Wave lap fluctuations have been removed.

cope with such a flood, and instead adopted the October 1983 flood, then estimated at 5100 m^3/s, as the design standard .

Rae (1988), when drawing flood frequency plots for the Wairau at Tuamarina, excluded the July 1983 flood as an outlier and the October 1983 flood was adopted as the maximum recorded flood, documented as 5000m^3/sec and assessed as having a frequency of once in 75 years.

Peculiarities of July 1983 Flood Hydrograph

The July 1983 flood water level record had a most peculiar shape at the peak of the flood hydrograph which has not been completely satisfactorily explained (Fig. 1). Sudden rises occur between 7.6 to 7.8 m in less than 10 min., and between 8.0 to 8.5 m in 30 mins. Sandwiched in between is a fairly constant level of 7.9 m for over two hours. These sharp changes represent most unlikely changes in flood flows in short periods. It has not been recorded on any other flood peak.

An explanation of the shape of the hydrograph lies in two factors. The vents of the water level recorder tower are at a level of 7.83 m and the soffit level of the bridge just downstream of 7.90 m. The vents in the water level recorder tower let water directly into the tower where the level is recorded by the float mechanisms. The water level recorded through the static tubes set in the main flow would be lower than at the tower where afflux has an effect. A difference of 0.23 m is realistic and thus water may start coming through the vents (at 7.83 m) when the recorded water level is at 7.60m. This would explain the sudden rise in water level from 7.6 to 7.8 m, and also the appearance of wave lap fluctuations in the water level record above 7.6 m. (Fig.1 is a transcript which was not able to copy the rapid wave lap fluctuations of the original pen record).

When the bridge soffit just downstream becomes submerged, flow resistance suddenly increases, causing the water level to rise substantially. The lowest beam soffit level of this slightly humped shape bridge is 7.90 m, and was observed submerged at the outer spans at the peak of the flood. The sudden rise in water level from 8.0 to 8.5 m is thus well explained by the submerging of the bridge beam soffit and associated large increase in bridge flow impedance.

The July 1983 flood is the only flood to have exceeded a stage of 7.6 metres for this to have occurred. The question remains as to what water level would have been recorded had the vents not let in water and the bridge soffit not become submerged. This level would be relevant to determining the flood size from the rating curve extrapolation. A smooth hydrograph, and allowing for 0.2 m afflux, has therefore been drawn on Fig.1, and this indicates a flood level of 7.92 m. for rating curve purposes.

July 1983 Flood Breakouts

Substantial breakouts of the Wairau River occurred upstream of the Tuamarina water level recorder and this flow bypassed the recorder. These breakouts were examined by:

1) a detailed backwater/slope area analysis of flood levels where breakout flowed into other defined river channels and floodways,
2) examination of levels and aerial photographs of flood flows across roads and overtopping stopbanks,
3) examination of the probable flow hydraulics through three stopbank breaches, and
4) consideration of seepage to groundwater and storage effects.

This assessment of breakouts and overflows gave a total of 800 m^3/s, which is less than the 1200 m^3/s estimated previously by Pascoe (1983). It will be presumed that they occurred simultaneously with the peak of the flood.

Rainfall

Quayle et al (1983) examined the rainfall intensity in the Nelson Marlborough area. For the important mid-catchment areas of the Branch, Waihopai, Hillersden and Northbank tributaries, the 48 hour rainfall of typically 200mm were assigned a return interval in excess of 50 years. This central area is nearly half the total catchment. The upper and lower areas of the catchment had less extreme rainfall.

Works Consultancy Services (1993) and Rae (1988) have also independently examined rainfall probabilities for this storm. For the important mid-catchment rain gauge sites of Wairau Valley, the Leatham and Waihopai Power Station the return interval for the 24 hour and 48 hours rainfalls is between 1 in 100 and 1 in 200 years, and significantly less for the peripheral rain gauges.

There is no evidence from the rainfall data of the July 1983 flood being extraordinarily rare.

Snowmelt

Rae (1988) discusses a popular viewpoint that snowmelt through warm rain melting snow added to an already extreme rainfall resulting in the July 1983 flood being of an extraordinarily rare nature. While snowmelt did occur, it was probably only a minor influence on the size of the flood.

The melting of snow requires considerable heat. Linsley et al (1958) indicates that from simple consideration of the latent heat and ice melt that rain falling at 10°C will melt approximately 12% of its own volume. Fitzharris, Stewart, and Harrison (1980), from studies of snowmelt in the Clutha 1978 flood, recommended that turbulent transfer of heat energy could account for a further similar amount of snowmelt. A 10°C storm rainfall temperature is a reasonable estimate for the Wairau catchment snow areas, based on measurements of air temperature 1500m above Christchurch of 60°C, (Quayle 1983).

Moore and Prowse (1988) studied the July 1983 storm in the Craigieburn catchment and calculated from meterological conditions that snowmelt would have contributed 21% of the storm run-off.

Such reasoning indicates that the snowmelt contribution to the Wairau July 1983 event may have been 20% to 25% of storm run-off, but will be restricted to those areas having significant snow. This area of snow is estimated as a quarter of the Wairau catchment.

The resulting snowmelt contribution to total storm runoff would be 5% to 6%. Even this may be an overestimate of snowmelt contribution to the flood peak as it was the 12 hour period of concentrated rainfall (and snowmelt) in the night hours of 5.00pm 9 July to 5.00am 10 July that had the major impact on the flood peak.

Snow in early winter (ie, early July) tends to be of low density, typically 0.2 (Fitzharris, Owens, and Chinn 1992). Visual assessment is likely to overestimate the water runoff from snowmelt, especially as this visual assessment will be over a longer period than the storm rainfall generating the flood peak.

This assessment is quite consistent with observations that snow of approx. half a metre depth at the Rainbow Skifield, stretching down to the bushline, was

TABLE 2—Analyses of major floods of the Wairau River for which hydraulic analysis is also available.

	Stage (m)	Rating Analysis (m^3/s)	MIKE 11 Comparative Study (m^3/s)	Backwater Analysis (m^3/s)	**Recommended** (m^3/s)
1/6/62	7.36	3860	-250=3600	3600	3600
8/8/63	6.52	2750	As is-2750	2600	2720
11/8/67	6.57	2790	As is=2790	2800	2800
17/9/70	6.82	3170	As is=3170	3150	3150
2/4/75	7.42	3840	-100=3750	4300	4000
10/7/83	7.92	4620	+200=4800	5400	5000
21/10/83	7.56	4145	+200=4350	4800	4400

washed away during the whole period of the event. The Wairau at Dip Flat recorder includes the Rainbow Skifield and a considerable area of winter snow-covered catchment. The July 1983 flood at Dip Flat was recorded as having a peak of 550 m^3/sec, assessed by Rae (1988) as a 1 in 13 year return period event. This is in good agreement with recorded rainfall 24 hour event frequency, without making any extra allowance for snowmelt.

The lack of seasonal distribution of major Wairau floods also indicates snowmelt is unlikely to be an important factor. In the list of the 15 largest known floods over 3000 m^3/sec, 11 different months are represented. August, a month of maximum snow accumulation, is not included while February, a month of little snow, has had 2 major flood events.

The July 1983 rainfall pattern was double peaked, typical of many major flood-producing storms, in which the first peak provides the very saturated soil moisture conditions and the second intensive rainfall generates the flood peak. Snowmelt was not required to provide initial saturated ground conditions.

WATER LEVEL RECORDER SITE ANALYSIS

Lower Wairau at Ferry Bridge 1936 - 1960

General

The Wairau River Board recorded flood levels at the Ferry Bridge from 1936 to 1960. This data was the main basis for Davidson's (1959) flood frequency assessment for the Wairau Valley Scheme. Although the site has provided the best available information in 1959, it is not a good one. A 400m wide unbridged grass flood berm flanks the bridged 120m main river channel, so only the main river channel can be gauged. In major floods the grassed berm may carry over a third of the flow. Flood water levels on the berm are typically 0.5 m higher from that in the main channel, but this is undoubtedly variable.

Flood Gaugings and Rating Curves

Only one flood gauging was carried out in the 1936-1960 period, that in 1938, at a flood flow of 1050 m^3/sec, and a visually estimated flow of 150 m^3/sec across the berm. The main channel water level was less than berm level and so certainly lower than berm flow level. This gauging and some occasional guagings at Tuamarina upstream in the 1950's were the basis for the Davidson (1959) rating curve. Flood slope area measurements in 1958 of a downstream reach helped establish the top end of the rating curve. This single flood stage rating curve was applied to the whole 1936-1960 flood level record.

Proportion of Flow on Berms

The flow proportion on the grassed berm is influenced by channel conditions upstream of the recorder site. Examination of historical aerial photographs, plans and reports has shown that these channel conditions varied, affecting the proportion of flow on the berm. Major channel works were carried out in 1927 in the area which affected the proportion of flow, and channel changes would have continued to occur naturally for many years after 1927. An aerial photograph of the area in 1943 shows the flow pattern quite different to a later 1947 photograph. The 1947 photograph (Fig.2) also shows the grassed berm being ploughed so as to encourage scour of the berm, and in a Wairau River Board report of this period it is stated as having eroded by 0.6 m. More recently, cross-section resurvey shows the berm building up with silt.

The water level recorded at Ferry Bridge thus did not measure the variable proportion of flood flowing at different levels on the grassed berm opposite. The greater the flood the less reliable this Ferry Bridge recorder record is likely to be.

Flood Breakouts

The record also was not able to measure flood breakouts upstream which happened regularly in major floods, especially between Tuamarina and Ferry Bridge. Both in the 1939 flood and in the 1954 flood, major breaches in excess of 60m occurred as well as other breaches and overtopping. Such breakouts are difficult to estimate but were clearly substantial. Significant unmeasured flood overflows into the old Opawa 20km flood channel 20 km upstream were also documented for the 1939 and 1954 floods - perhaps of the order of 100 m^3/sec. The 1945 and 1955 floods also had substantial overtopping but mainly downstream of Ferry Bridge recorder.

Mean Annual Flood Estimates

The mean annual flood peak for the 24 years of record was calculated at 1890 m^3/sec using Davidson's rating curve applied to annual flood peak stages. This is some 10% less than the mean annual flood of 2100 m^3/sec for the 1960-1991 Tuamarina record. Similarly the number of floods above 1420 m^3/s averages 1.1 per year for Ferry Bridge but 1.5 per year for the Tuamarina recorder site, suggesting that the Ferry Bridge record is low. This average error of 10% will not be consistent and estimates for larger floods with higher flow proportions on the grass berm may be greater than this.

Summary

The 1936-1960 record at Ferry Bridge was the major basis of Davidson's 1959 design estimate for the Wairau Valley Scheme. While it was the best data available it was not as reliable as the later 1960-1991 Tuamarina record; it appears to have underestimated the 1936-1960 flood flows on average by approx 10%, and perhaps major floods by more.

Site Description and Downstream Channel Changes

The site was established by the Marlborough Catchment Board in 1960 at the S H 1 bridge where the channel is reasonably constricted and upstream of tidal influence.

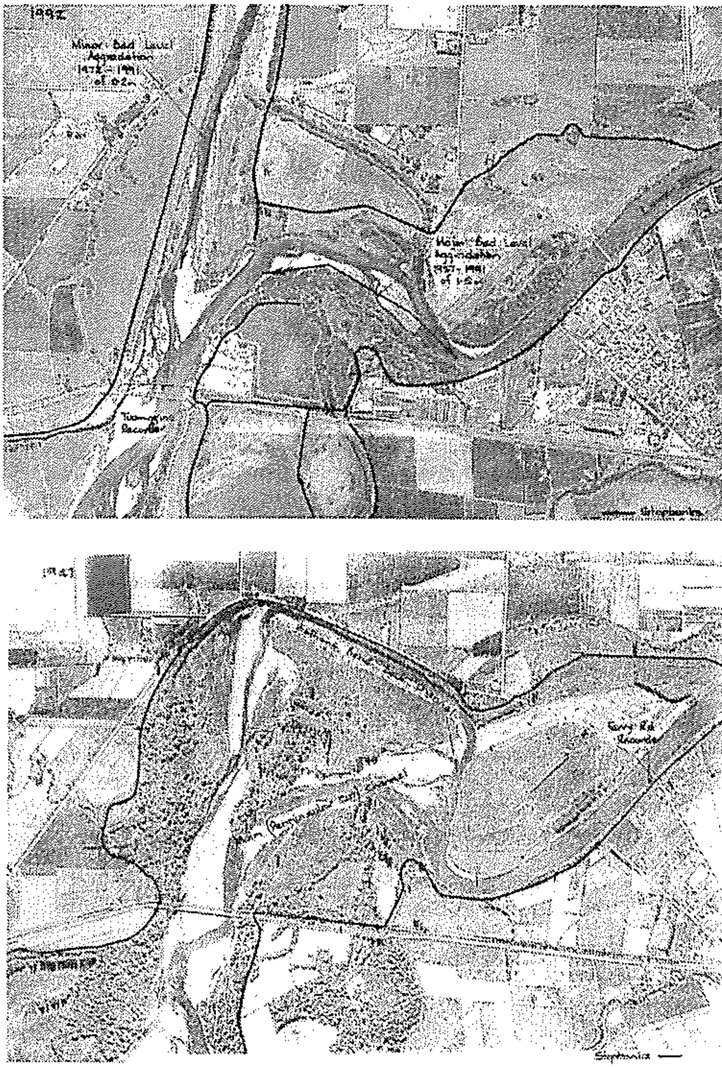

FIG. 2—Aerial photographs of the Wairau River between Tuamarina and the Ferry Road bridge a) 1947 b) 1992.

Changes to the river bed and channel both at the site and downstream may have affected the stage - discharge rating relationship. At low flows the bed level in the immediate vicinity of the recorder is the main control determining water levels. As the flow increases, it is the channel conditions further downstream that become the main control on the stage - discharge relationship, and in major floods the channel quite some distance downstream will influence water at the recorder.

The bed and downstream channel for a considerable distance downstream are regularly changing by a variety of mechanisms (Fig.2).

(a) In the vicinity of the bridge, gravel waves during floods, and/or regular gravel extraction change mean bed level by up to 0.8 m.

(b) At Bothams Bend 1.3 km downstream the Wairau Diversion was constructed in 1963 as a 20m wide pilot cut within an overall 300m wide floodway. The entry to the 300m wide floodway was created by knocking down the existing river stopbank. This would have had an immediate effect on major flood levels and this influence would have been transmitted back up to the Tuamarina recorder.

(c) Development of the Diversion occurred. Regular river cross-sectional survey of the Diversion indicates it has substantial changes following its initial 1963 pilot cut (Neilson 1993). In the upper 2km of the Diversion, from 1963 to 1975, erosion of the pilot cut into a channel was approximately matched in volume by siltation on the berm. In this period the influence of diversion development on the stage-discharges relationship at Tuamarina would have been small. Since 1975 erosion enlargement of the Diversion channel has outweighed deposition of silt on the berms, and had some influence.

(d) In the 1km from the Tuamarina recorder downstream to the Diversion proper, the channel has aggraded by 0.2m and flow on the berm has been restricted by stopbanking work in 1972 and 1985. The influence of this will oppose the Diversion enlargement further downstream.

(e) Changes in the lower Wairau River channel below the confluence are less well documented. The recent 1992 river cross-sectional survey and the initial 1957 surveys are the only complete surveys of this vital reach of the river down to Ferry Bridge. For the kilometre downstream of the channel bifurcation the lower Wairau has aggraded by typically 1.5 metres between 1957 and 1992. Further downstream this aggradation lessens to typically 1 metre almost all the way to the estuary 10 kilometres downstream. Other information indicates this siltation has occurred since 1967, coinciding with the increase in flows down the Diversion and decreased flows in the lower Wairau.

These changes to the lower Wairau will have decreased the stage-discharge relationship of floods at Tuamarina , thus tending to counterbalance the diversion enlargement effect on the Tuamarina stage-discharge rating.

These changes to the bed and channel at, and downstream of, the Tuamarina recorder, may have regularly changed the stage-discharge rating relationship.

Flood Gauging

Between 1961 and 1974 some 50 gaugings have been taken at the recorder of flows greater than 100 m^3/sec up to a maximum of 2300 m^3/sec. Those taken since 1972 were by jet boat, usually 200 metres downstream of the recorder, where the measured cross section of these gaugings was not that of the recorder site. The other 38 gaugings were taken from the bridge. One gauging was also taken in 1983.

Simultaneous (or close to simultaneous) gauging of the Diversion at Rarangi Bridge and the lower Wairau at Ferry Bridge have been carried out, with five of these between 1967 and 1969, and another four between 1985 and 1990. These gaugings were combined to give total Wairau flows and were of sizes between 700 and 2100 m^3/sec.

Flood Breakouts

During the period of Tuamarina record from 1960 to 1992 the flood breakouts that have bypassed the recorder probably totalled less than 50 m^3/sec and are not included in this analysis. The July 1983 breakout, estimated at 800 m^3/s, was an exception and this has been discussed.

Analysis

The gauging data was analysed to determine initial flood stage-discharge rating relationships for the Tuamarina site, then later adjusted by examination of other data.

Separate stage-area and stage-velocity curves were drawn up for the various gaugings; these curves can be extrapolated to high stages more precisely than a lumped flow extrapolation. There has been considerable variation in the waterway area, as the river bed level has varied by up to 0.8m. These variations show little trend with time and are typical of gravel bed rivers as waves of gravel move through. This area variation should affect the stage-discharge rating for moderate floods only. At large floods and high stages the control on the stage rating would be further downstream and will not mirror the area changes measured at the narrow bridge cross section itself.

It is noted that:

1) The highest gauged floods are 2300 m^3/sec at a 6.2m stage.
2) High stage gaugings were regularly carried out only in 1968 - 1974 period.
3) Most gaugings had no data on vertical angle or horizontal angle correction, and the jet boat gaugings had limited positional accuracy.

Based on the gauging information, twelve different stage rating relationships were recommended between 1960 and 1990, but with only three relationships for the high flood range above the 6 metre stage. Indeed a justifiable approach could have been extend into a single rating curve at high stages; i.e. from the gauging data there is no evidence of any differences in high flood ratings (above 6 metres) for the record period 1960-1993, in spite of Diversion development and other downstream changes.

DIVERSION AT RARANGI BRIDGE

Site Record

The 8 years of record from 1968 to 1976 of water levels of the Wairau Diversion near Rarangi bridge were used in conjunction with the lower Wairau

TABLE 3—Regional flood analyses for subcatchments of the Wairau River.

Sub Catchment of Wairau Zone	% Of Wairau Flood Flow	Recorder Site	Length of Record years	$\overline{Q}$ m^3/sec	Assessed $Q_{100}/\overline{Q}$ for recorder	Average $Q_{100}/\overline{Q}$ ratio for zone	Contribution to $Q_{100}/\overline{Q}$ for Wairau at Tuamarina
Richmond Range Northbank	24%	Motueka Wairoa Pelorus Collins	18 29 9 26	292 707 377 31	2.72 2.35 2.3 2.84	2.55	0 .61
Upper Wairau	16%	Dip Flat	32	342	2.32	2.32	0.37
Branch	22%	Branch	20	464	2.45	2.45	0.54
Waihopai	20%	Craiglochart	30	4.30	2.43	2.43	0.49
0ther southern bank tributaries	18%	Waihopai at Craiglochart Taylor at Weir	30 32	4.30 68	2.43 4.00	3.0	0.54
				Total $Q_{100}/\overline{Q}$ for Wairau at Tuamarina			2.55

record at Dicks Road to check the Tuamarina record. The Diversion has steadily and progressively enlarged here. Over the 1968 - 1980 period channel surveys show 140 m^2 of channel enlargement occurred.

Flood Gauging and Rating Relationship

Some 37 gaugings at flows above 200 m^3/sec have been taken at Rarangi bridge between 1963 and 1990. For the 1968-1990 period 5 rating curves based on the gauging data were assessed, and used with the stage record to determine hydrographs for all floods in the 1968-76 period. The five rating curves derived depict a progressively changing bed, and while more than five rating curves are appropriate there is limited information available to determine them.

LOWER WAIRAU AT DICKS ROAD

Site Record

There are 12 years of water level record from 1964 to 1976 for the lower Wairau at Dicks Road, where the river is confined to a single 130m wide main channel with no significant berms. Flows in excess of 500 m^3/sec have been gauged at Ferry Bridge, but only half these were in the 1964-1976 Dicks Road period of record. A water level correlation was determined between Dicks Road and Ferry Bridge 700 m upstream.

A single rating curve at Dicks Road was derived to cover the 12 year period. This rating curve was in good agreement with the 1967 backwater model. There should be more than one rating curve for the period, for river bed surveys show a rise in bed level of 1 metre between 1967 and 1989, but the data are too sparse

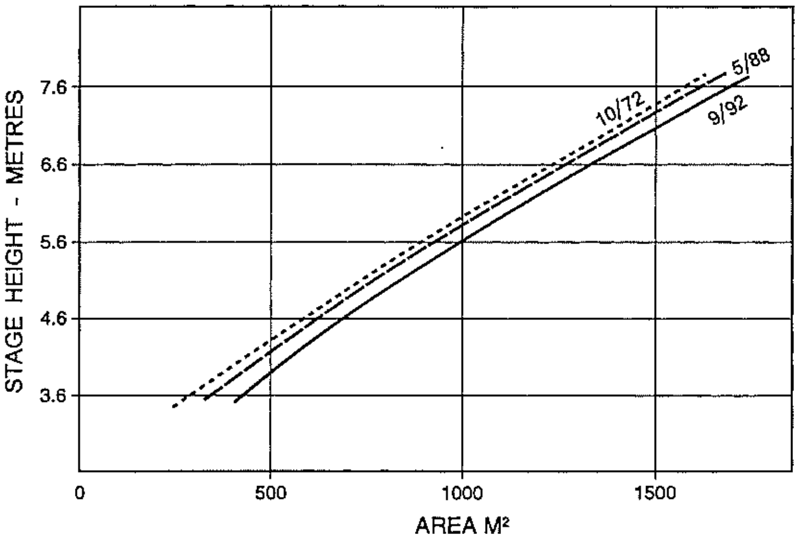

FIG. 3—Stage-area relationships at cross-section 23.5, 300 m downstream of the Tuamarina recorder. For the Tuamarina recorder 0.4 m should be added to the stage height.

to construct further rating relationships. This rating curve, together with the stage record, allowed hydrographs of all floods in the 1964-1976 period to be assessed.

Combined Analysis

The construction of hydrographs for the lower Wairau and Diversion enabled the combined total to be compared with the Tuamarina record for the 8 year overlap period from 1968 to 1976. This provides a check on the proposed stage rating curve for Tuamarina. Comparison of ten floods of between 1900 m^3/s and 4000 m^3/s showed differences in flood estimates for Tuamarina of -13.0% to +8%.

The -13.0% to +8% difference between the combined Lower Wairau and Diversion record compared to the proposed Tuamarina record was considered a reasonable check and acceptable. The 5 floods recorded in the 1969-70 period compared 10% low while the 3 floods in the later 1974-75 period plotted 6% high. This could suggest rapid silting up of the lower Wairau channel, and that the mismatch of estimates may reflect rapid reduction in the lower Wairau capacity rather than inaccuracies in the proposed Tuamarina stage ratings.

BACKWATER ANALYSIS OF RECORDED FLOOD LEVELS

Background

The lower Wairau and Diversion are both generally long reaches of fairly straight uniform channels of moderate velocity on which reasonable flood flow estimates can be made and calibrated against gauged flows. For the four largest floods and for various other floods since 1957, flood peak levels have been measured by pegging and levelling deposited silt marks after the flood. Some moderately large floods have been simultaneously pegged and gauged during the event. Floods gauged and pegged at the same time were used to calibrate computer hydraulic backwater models using the RICODA programme. Where measurements and estimates were made for both the lower Wairau and Diversion for the same event, their total gives the Wairau flow at the Tuamarina recorder. The detailed results are reported by Noell (1992).

DIVERSION

Some 15 different hydraulic backwater models were set up, this being a model for each set of cross-section surveys between 1963 and 1990. Four large gauged floods of over 780 m^3/s , (two in August 1990, one in October 1972 and one in September 1970) were the main bases for calibration of Mannings "n" roughness. These floods all calibrated well using a central channel roughness "n" = 0.021. The calibration of berm roughness was less definitive, and a roughness value of 0.040 was adopted and used for modelling the important 1983 and 1975 floods.

In the modelling, the problem of combining two distinct different zones of the "main channel" and the "berm" is an area of possible error, and an increase in hydraulic roughness was made, similar to the approaches made by Ackers (1993) and Smart (1993) for composite channels.

Seventeen different floods were modelled and assessed, and in most cases each flood was modelled using models of cross sections surveyed before and after the flood. The recommended assessment was taken as an average of these two.

The models were generally restricted to the 1800 m reach upstream of Rarangi bridge. Downstream of the bridge the steep slope and resulting high velocities lead to mathematical instability of the computer programme in predicting water levels. Further upstream flood levels have only been measured for a few floods, as the channel has only had defined stopbanks since 1985.

Until recently the flood slope in this reach was very flat, being in the order of 1:3000. These backwater flood assessments may therefore have significant error, especially for the 1983 floods which are over twice the size of flood flows on which the model was calibrated.

Lower Wairau

Here four different hydraulic backwater models were set up, one model for each set of survey cross-section data.

This deep silt-bedded channel calibrated well at a Mannings "n" of 0.021. These calibrations were based on four gauged floods, in 1957, 1963, 1967 and 1990. The flows of between 500 and 1000 m^3/s are much lower than major floods.

One problem was assessing the effect of steadily growing thick willow trees overhanging the main river. The overhanging branches increasingly impede the flood waters as the water level rises. In 1948 aerial photographs showed such trees lining 30% of the total bank length. This had increased to 55% in 1972 and 85% in 1991. Little impedance occurred at the moderate flood flows at which the model was calibrated. The presumed increase in hydraulic friction was catered for by assuming an increase in Mannings "n" of .001 for every metre rise in water level for each bank that was heavily tree-lined. Thus at major flood levels, where trees lined both banks, the channel Mannings "n" was increased from 0.021 to 0.025. This assessment was guided by the work of Hicks and Mason (1991) who show for other NZ willow lined rivers a significant increase of Mannings "n" hydraulic roughness with rise in water level. The only way of confirming this estimate is to peg flood levels in a major flood that is simultaneously gauged.

Overall Results

The backwater modelling and gauging analysis agreed well for moderate floods. For the highest 3 floods in 1975 and 1983 the backwater modelling estimated higher flood sizes. This could be due to underestimation of Manning's "n" at high flood levels, or stopbank silt debris marks may not well represent channel flood levels in major floods.

BOTHAMS BEND AREA HYDRAULIC ANALYSIS

Background

The high stage-rating relationship at Tuamarina is influenced by channel control changes downstream, especially the opening of the Diversion as a pilot cut from Bothams Bend in 1963, the blocking off of Bothams Bend back channel and other berm stopbanking in 1972, and the construction of further stopbanks on the berms in 1985. With few flow gaugings at high stages during this period, the influence of the channel changes is poorly recorded.

Hydraulic analysis was therefore carried out as a guide as to the influence these changes would have on the rating relationship at Tuamarina recorder. The

TABLE 4—Wairau at Tuamarina annual flood estimates 1960 - 1991.

DATE	STAGE (m)	FLOW (m^3/sec)	RANKING (1960-1991)	RANKING (1920-1991)
05.08.60	4.63	1070	29	
06.03.61	4.55	1020	31	
01.06.62	7.36	3600	4	7
08.07.63	6.52	2720	7	
22.11.64	5.44	1620	20	
19.11.65	4.58	1080	27=	
26.04.66	5.00	1300	23	
11.08.67	6.57	2800	6	
10.04.68	6.50	2700	8	
11.09.69	5.91	2080	15	
17.09.70	6.82	3150	5	11
04.10.71	5.70	1850	18	
09.10.72	6.32	2440	11	
12.08.73	4.50	740	32	
06.04.74	6.42	2550	9	
02.04.75	7.42	4000	3	5=
07.12.76	6.14	2230	12	
29.06.77	5.35	1320	24	
14.05.78	5.52	1490	21	
07.05.79	5.12	1100	26	
17.08.80	5.06	1050	30	
06.10.81	5.31	1280	25	
04.06.82	4.58	700	33	
10.07.83•	7.92	5000	1	1
22.10.83*	7.56	4400	2	3
16.12.84	5.80	2010	16=	
20.04.85	5.88	2090	14	
25.01.86	5.80	2010	16=	
20.01.87	5.05	1360	22	
24.07.88	6.27	2500	10	
11.06.89	5.60	1840	19	
12.08.90	6.01	2210	13	
02.09.91	4.71	1080	27=	

• Breakout and overflows of 800 m^3/sec need to be added to the July 1983 flood, thus giving it a total of 5800 m^3/sec.

* The October 1983 flood is also included because of its significance.

area is very complex hydraulically, with a bifurcation into two main parallel channels and also four distinct berm areas that carry high flows. The MIKE 11 computer programme capable of network analysis was used to model the situation.

The data base was limited to a set of cross sections in 1991 and a set of 1957 cross sections. Two moderate floods in 1990 were documented for model calibration.

The 1957 cross-sectional data was used to construct a model, which was then used in a comparative sense to reflect the Diversion opening in 1963 and the Bothams Bend channel block and berm banking in 1972. Similarly the 1991 model was used in a comparative sense to assess the effect of the Botham island berm stopbanking in 1985 and the natural enlargement of the "outlet" into the Diversion from 1983-1991. The available data was insufficient to quantitatively compare 1957 conditions with 1991 conditions, or in between periods.

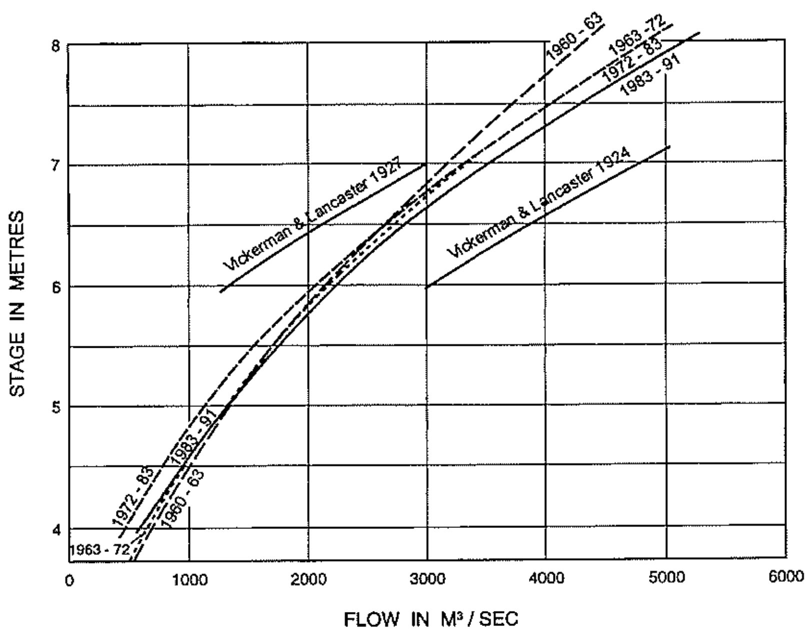

FIG. 4—Recommended flood stage-rating relationships for the Wairau at Tuamarina -

a) 1960 - 1963 pre-diversion

b) 1963 - 72 to the blocking of Bothams Bend

c) 1972 - 83 to diversion development due to the 1983 floods, and

d) 1983 - 91.

The 1924 and 1929 flood stage-rating relationships of Vickerman and Lancaster are also plotted.

Diversion Opening Change in April 1963

The Mike 11 model (on 1957 data) indicated that the opening of the diversion in 1963 would increase the flow at Tuamarina by 400 m^3/sec at the 6 metre stage, and by 1000 m^3/sec at the 8 metre stage. In actuality the gauging data indicated little difference in flow at the 6 metre stage, suggesting that at the 6 metre stage the downstream diversion opening was at least counterbalanced by gravel deposition closer to recorder.

It is likely that while the flow rating remained much the same at the 6 metre stage, it increased by the order of 500 m^3/sec at the 8 metre stage.

Bothams Bend Blocking February 1972

The Mike 11 model (on 1957 data) indicated that the closing of the Bothams Bend back channel and other associated banking work would reduce the flow by 200 m^3/sec at the 6 metre stage and 300 m^3/sec at the 8 metre stage. Flow gauging data indicated little if any decrease at the 6 metre stage. The decrease at the 8 metre stage is likely to be approximately 100 m^3/sec.

Diversion Development 1983-1991

The MIKE 11 hydraulic model had an "outlet" into the Diversion. Stage rating relationships for this outlet were determined by Noell (1992) from his backwater analysis of the Diversion. The MIKE 11 model, based mainly on 1991 cross section data but with different "outlet" ratings, was used to assess the effect of the Diversion development from 1983 to 1991. This showed that both at the 6m and 8m level an increase in flow of 200 m^3/sec would be expected. The limited flow gauging data tended to support this.

Bothams Bend Berm Works 1985

The Mike 11 model (on 1991 data) indicated that the berm stopbanking work carried out in 1985 had no effect on flow amount at the 6 metre level, and only a small reduction of 100 m^3/sec at the 8 metre level.

SUMMARY OF RECOMMENDED TUAMARINA STAGE-RATING RELATIONSHIPS

Moderate Stage Flood Ratings

Flood flows up to 6 metre stage at Tuamarina (approx 2100m^3/sec) can be considered as the moderate flood range. The gauging analysis is in reasonable agreement with the backwater/slope area hydraulic analysis, and the stage ratings determined from the gauging analysis are appropriate.

High Stage Flood Ratings

At flood levels above 6 metres stage, channel changes further downstream and on the berm become more apparent. Such changes are at flows above the level at which gaugings have been taken. The backwater analysis and the MIKE 11 comparative hydraulic analysis are more useful in assessing high stage ratings.

Table 2 lists the major floods on which backwater analysis information is available, together with the gauging analysis, and the comparative MIKE 11 analysis. The final column shows the overall final recommended values in which approximately equal weighting has been given to the hydraulic backwater analysis and the gauging data analysis.

Four different stage-discharge relationships are recommended for higher stages above 6 metres (Fig.4), and the "recommended" flood flows above derive from them. The four rating relationships are for 1960-63 (Pre diversion), 1963-72 (To Bothams Bend blocking), 1972-83 (To diversion development due to 1983 floods), and 1983-92 (Current situation).

There are variations to these below the 6 metre stage level, which have not been shown for clarity. Also plotted are Vickerman and Lancaster assessed 1924 and 1927 flood stage-discharge relationships.

HISTORICAL FLOODS

Background

Blenheim and the Wairau Floodplain have experienced at least one damaging flood every decade since European settlement. In the early days so regularly did floods occur and so ineffective were the flood control works that Blenheim had the name the Beaver or Beavertown. The size of floods was virtually impossible to estimate because they were uncontained and widespread. The February 1868 flood was an extremely large with water from hill to hill across the plain. The floods of 1904, 1911 and 1916 were also large and damaging, despite the intensive river works from 1877 to 1902.

The blocking of flood flows into the Opawa Channel distributary in the Conders area constrained the Wairau almost exclusively to the mainstem Wairau. These works were carried out in the 1914-1919 period. From 1920 there was a significant improvement in estimating flood size, with further improvements in 1936 with the recording of flood levels at Ferry Bridge, and 1960 with the Tuamarina water level recorder.

Constraining virtually all flow down the mainstem Wairau from 1920 led to newspaper reporting of the 1926, 1939, 1954, 1975 and July 1983 floods in turn as being the largest Wairau flood since 1868. (This report ranks them as (in order) 1983, 1926, 1954, 1939, 1975 and not as being progressively larger).

The floods in the 1920-1960 period are examined in more detail.

Vickerman and Lancaster

Vickerman and Lancaster (1924) (consulting engineers to the Wairau River Board) made flood flow estimates based largely on water levels measured at the railway bridges at Tuamarina (mainstem Wairau) and (for prior to 1920) over the Opawa in Blenheim. The stage-discharge relationship that they developed for Tuamarina however differed substantially for their later 1927 report from their 1924 report (Fig.4). The November 1926 flood had a 7 metre level at Tuamarina railway bridge. The 1927 rating curve showed the flood as 3050 m^3/s plus an estimated 1150 m^3/s overflow totalling 4200 m^3/sec; whereas the 1924 rating would have indicated 4800 m^3/s + 1150 m^3/sec overflows, totally 6000 m^3/s. It is the smaller flood estimate that has been quoted by Rae (1988), and Davidson (1959).The effect of these different flood flow assessments was to necessitate quite different recommendations as to river control works required.

The 1923 flood levels recorded by Vickerman and Lancaster in the upper Conders area were very similar to those observed in July 1983. The 1923 Wairau Flood is now assessed as 3500 m^3/s, and unfortunately coincided with an extremely large flood in the Taylor/Omaka/Opawa system causing considerable damage. (This 1923 event, and the 1868 event are the only 2 known

TABLE 5—Estimates for historical floods 1920 - 1960 of the Wairau River.

Date	Flow (m^3/sec)	Ranking 1920-1991
May 1923	3500	8
Nov 1926	4500	2nd
Dec 1939	4000	5th =
Jun 1954	4200	4th
Feb 1955	3400	9
Jan 1945	3250	10

occasions when the weather pattern changed from the ESE or NNW and brought major floods to both the Wairau floodplain river systems.)

Vickerman and Lancaster's flood estimates for floods prior to 1920 are even less accurate due to the divided flow in the mainstem Wairau and Opawa.

1929 Flood

The 1929 flood was not a major flood, but flood levels were measured at various recognisable sites on the Wairau river including Ferry Bridge and Tuamarina railway bridge. The flood did not breakout anywhere, but was just at stopbank level for long stretches from Tuamarina downstream. This 1929 flood had a level of 6.4m at Tuamarina bridge and was quoted as being 2000 m^3/sec - clearly based on the 1927 Vickerman and Lancaster rating curve. The 1924 V & L rating curve would have indicated 3700 m^3/sec.

At Ferry Bridge the recorded flood level of 4.63m (15.2 ft) would indicate 2800 m^3/sec by Davidson's (1959) 1936-1960 stage rating. At Tuamarina, on today's stage rating a flow of 2700 m^3/sec would be indicated. The analysis carried out herein has shown that the rating curve at Tuamarina Bridge is reasonably stable and the modern rating curves can be used as a guide to these 1920 floods. This 1929 flood is thus a "benchmark" on which to calibrate floods, its size recommended to be 2800 m^3/s rather than the 2000 m^3/s of Wairau River Board documents.

The 1923 and 1926 Wairau floods were recognised at the time as being substantially bigger than the 1929 flood. They would have been underestimated by Vickerman and Lancaster's 1927 stage-discharge relationship. Using the 1960-1963 stage rating as a guide, the 1926 flood would be 3400 m^3/s plus 1150 m^3/sec breakout = 4500 m^3/sec (up from 4200 m^3/sec) and the 1923 flood as 3500 m^3/sec (up from 3000 m^3/sec).

1939 and 1954 Floods

A photograph at the Tuamarina rail bridge of the 1939 flood at close to the height of its long peak shows the flood level to be 7.4m. Using the 1960-1963 stage rating as a guide and approx 100 m^3/sec outflowing at Conders indicates 4000 m^3/s for this flood. This is up from the 3500 m^3/s estimate by Davidson (1959), in good agreement with the suggestion that Davidson's major flood estimates may be 10% or more low.

The 1954 flood estimate of 3800 m^3/sec by Davidson is similarly likely to be 10% or more underestimated. Davidson (1983 personal communication) has stated that contemporary estimates of the 1954 flood ranged up to 4360 m^3/sec. His later observations of the 1962 flood, assessed at 3600 m^3/s, led him to subsequently consider that the 1954 flood had exceeded 4000 m^3/s. A flood figure of 4200 m^3/s is now suggested.

The other major floods of the period in 1945 and 1955 may also have been underestimated but there is no other evidence on which to revise Davidson's figures, and his estimates of 3250 and 3400 respectively are kept.

Floods in New Zealand 1920 - 1953

The Soil Conservation and River Control Council published a book in 1957 that summarised all known floods between 1920 and 1953 in New Zealand. The data source was government files and newspaper reports.

The four largest Marlborough floods of the period had flow estimates as follows:

(i) May 1923. The Wairau was assessed as 4700 m^3/sec (including overflow estimates) with the river being at 6.8 metres at the rail bridge (probably based on Vickerman and Lancaster 1924 rating).

(ii) November 1926. The Wairau was assessed as 3000 m^3/sec + 1150 m^3/sec overflows (probably based on Vickerman and Lancaster 1927 rating).

(iii) December 1939. Not mentioned.

(iv) January 1945. Stated as probably larger than the 1939 flood.

This publication generally confirms previous findings but also shows the inconsistent nature of newspaper flood reports.

REGIONAL FLOOD CHARACTERISTICS

Regional characteristics of flood frequency are a useful check, particularly if the catchment record appears to have an outlier. Beable and McKerchar (1982) defined hydrologically similar regions in which a flood of recurrence period Q_i can be directly related to the mean annual flood $\bar{Q}$. The ratio of $Qi/\bar{Q}$ varies from hydrological region to region.

McKerchar and Pearson (1989) subsequently refined the definition of hydrological regions by instead drawing contour lines of the $Q_i/\bar{Q}$ ratio. They demonstrate that the ratio of $Q_{100}/\bar{Q}$ for the highest rainfall areas of the West Coast is less than 1.8, while that for the driest East Coast area exceeds 5. Their plot of contour ratios for the Wairau catchment spans the contour lines of 2.5 and 3.0 and is to quite a coarse scale. The available records of sub catchments and adjacent catchments were examined in more detail (Table 3).

The expected ratio of $Q_{100}/\bar{Q}$ for the Wairau at Tuamarina from this use of adjacent regional records is assessed as 2.55.

Some or all of these records may be less reliable than for the Wairau at Tuamarina. These records could be considered as cross checks of each other. The Waihopai and Branch water level records are both known for significant bed movement at high stages and uncertainty of their major flood stage rating relationships. The $Q_{100}/\bar{Q}$ ratio should increase from the wetter northern Richmond Range area to the drier southern Waihopai subcatchment but the records do not show this, with the assessed $Q_{100}/\bar{Q}$ ratios plotting randomly between 2.3 and 2.8, (except for the hydrologically different Taylor). This may be due to errors in those other regional river records.

This regional records analysis is certainly adequate to indicate the expected ratio for the Wairau to be in the range of 2.45 to 2.7. As the $\bar{Q}$ for the Wairau at Tuamarina is assessed as 2100 m^3/s, this regional rivers analysis check would indicate a Q_{100} flood as being 2.55 x 2100 = 5350 m^3/s.

FLOOD FREQUENCY ANALYSIS

Recorded Annual Peaks

The highest annual flood peaks at Tuamarina recorder from 1960 to 1991, as determined by the recommended stage-discharge relationships, are shown in Table 4. Estimates of other major historical floods since 1920 are shown in Table 5.

Changing Calendar Year

The method of plotting annual flood peaks and fitting a Gumbel distribution to them is valid for any "year" period chosen. Although the Jan-Dec calendar year is commonly used, the Sept-Aug "year" was also examined. The major October 1983 flood then lies in a separate year from the July 1983 flood and is included as an annual flood peak, and the sets of moderately large floods in the 1970 and 1967 period also fall in two separate years.

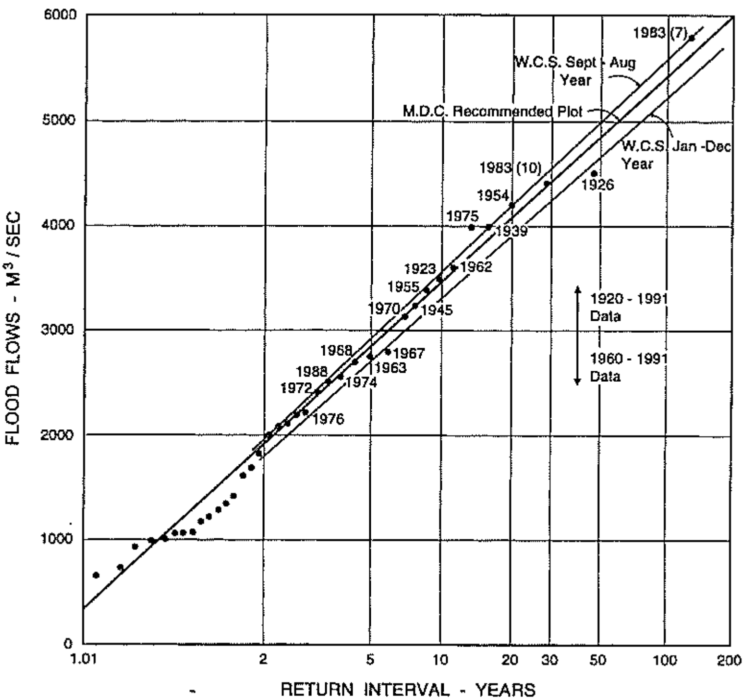

FIG. 5—Flood frequency analysis for the Wairau River at Tuamarina - 1920 - 1991.

The Sept - Aug year recorded higher annual floods, with the mean annual floods averaging 2200 m^3/sec compared to 2010 using the Jan - Dec 'year'. As both "years" are equally valid, a mean annual flood of 2100 m^3/sec is recommended.

Distribution Plot

The flood peak data was plotted up as a Gumbel (EVI) distribution, using the Gringorten plotting position method to which a line was fitted by eye (Fig. 5).

Data from two sets were included. For flows above 3000 m^3/s the 72 year data base from 1920 - 1991 was used, including both 1983 floods (justified on the assumption of a Sept-Aug year). For flows below 3000 m^3/s only the 32 year detailed Tuamarina record is included. Also plotted is analysis for a "Jan - Dec year" and a "Sept - Aug year" based only on the Tuamarina 1960 - 1991 record.

Key features of this combined plot are:

1) Good fit of the data to a Gumbel plot.
2) The July 1983 flood does not plot as an outlier.
3) The 1 in 100 year return period flood is 5500 m^3/s, in good agreement with the regional flood frequency analysis.
4) The 1 in 2.33 return flood plots as 2100 m^3/s, i.e., the mean annual flood.
5) Good agreement with the analysis based only on Tuamarina 1960-1991 record.

CONCLUSIONS

The main findings of this study are:

1) The 1 in 100 year return period flood recommended for design of river control works is 5500 m^3/s, and is larger than previous estimates.
2) The July 1983 flood is assessed at 5800 m^3/s, a 1 in 150 year return period event. The current standard of river control works is to the October 1983 flood assessed as 4400 m^3/s, a 1 in 30 year return period event.
3) Flood size estimates from a variety of hydrologic and hydraulic data bases were complementary and in good agreement with the limited data base of the 30 year water level recorder at Tuamarina. This broader analysis of many data bases considerably improved the confidence in the recommended flood sizes and frequency analysis.
4) The flood stage rating at Tuamarina has been moderately constant despite the extensive channel changes downstream. The downstream effect of enlargement of Diversion capacity through scour has been counterbalanced by deposition in the Lower Wairau.

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