NIWA
Taihoro Nukurangi

Review of flood hydrology for the Waikanae and Otaki Rivers

NIWA Client Report: CHC2008-158
January 2009

NIWA Project: WRC09503

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Prepared for

Greater Wellington Regional Council

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Reviewed by:

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Approved for release by:

Murray Hicks

Executive Summary

- Flow records for the Waikanae and Otaki Rivers have been reviewed. Because of the mobile gravel beds, frequent shifts of the stage-discharge rating curves are required to reliably monitor low flows. Some extrapolation is necessary to estimate flood flows.

- Annual maxima flood flows for the Waikanae River for 34 years, and for the Otaki River for 54 years, have been examined for trend, shifts, persistence and periodicity: none was present.

- Flood quantiles are estimated using extreme value frequency methods. In comparison with estimates prepared in a 1991 report, the Waikanae estimates are slightly (5% - 8%) increased and are consistent with several larger floods in the latter part of the record. The Otaki estimates are increased by lesser amounts.

- Design flood hydrographs are prepared using characteristic hydrograph shapes derived from six of the largest recorded floods at each site.

- Since no advances in probable maximum precipitation methods in New Zealand have occurred since the 1991 report, it is recommended that the probable maximum flood estimates prepared in 1991 should continue to be accepted.

- Regional methods and a short term flow record are utilised to develop design flood estimates for the Muaupoko and Waimeha Streams respectively. The Waimeha estimate is particularly uncertain and further investigation is recommended for this stream.

- Increases in flood peak flows of order 10% and 20% as a consequence of global warming are suggested in 50 and 100 years respectively. However, the uncertainties are very large, and a valid strategy for the council may be to design flood protection works in such a way that they can be readily augmented should that be necessary in future to maintain a stated level of protection.

1. Introduction

Determination of flood hazard on the Kapiti Coast and provision of flood protection works is undertaken by the Greater Wellington Regional Council.

The author undertook a major study of the flood hydrology of the area that was detailed in a 1991 Hydrology Centre Report "Kapiti Coast flood plain management: hydrology and climatology".

This review of the flood hydrology was commissioned by Mr Kees Nauta, Kapiti Area Engineer for the Greater Wellington Regional Council. The agreed terms of the review involved updating sections of the 1991 report, and considering climate change influences.

Specifically, for the Waikanae and Otaki Rivers, the tasks involved were to:

1. Assemble and check updated rating curves and flow series.
2. Review 1991 report.
3. Extract annual maxima flood flows.
4. Examine data for trend, periodicity, persistence and shifts.
5. Undertake extreme value frequency analysis, using at-site data and other appropriate methods.
6. Provide design flood hydrographs for 50, 100 and 200 year events based on scaling of largest recorded flood hydrographs.
7. Comment on the PMF and regional flood estimates.

For Muaupoko and Waimeha Streams the study is to provide 50, 100, and 200 year peak flood flow estimates for the following sites.

- Muaupoko Stream, upstream of State Highway 1 at NZMG 2681900E 6032820N
- Waimeha Stream at NZMG 2682330E 6035212N

Climate change impacts for the Waikanae and Otaki flood frequencies using the latest published climate change information is to be included.

2. Review of 1991 report

This report provided a comprehensive coverage of the flood hydrology of the Otaki and Waikanae Rivers. Features of note were:

- Analysis of rating curves for the sites.
- Consideration of the magnitude of the largest known Otaki River flood that occurred in February 1955.
- Flood frequency estimates derived using Gumbel (Extreme Value Type 1) frequency analysis of the annual maxima for the two rivers.
- Augmentation of the flood frequency analysis results with regional flood frequency information. The regional information provided slight reductions in the magnitudes of the errors of estimate, but virtually no changes in the design flood estimates.
- Storm rainfall-runoff studies to estimate storm rainfall loss rates.
- Calibration of RORB rainfall-runoff models for both rivers and estimates of peak flood flows expected from probable maximum precipitation over the catchments.
- Use of regional methods to provide design flood estimates for a number of smaller streams.

Since 1991, a further 17 years of flood records have accumulated. Some understanding of effects of long-term climate oscillations on hydrological extremes has developed (McKerchar and Henderson 2003) and concerns about effects of global warming on flood frequency have grown.

3. Flow records

3.1. Waikanae River

Recorded water levels and stage-discharge rating curves for the Waikanae river were assembled for the period March 1975 to September 2008.

The archived rating curves for this site are presented in Figure 1, together with the gaugings used to prepare the curves. The gaugings are plotted with error bars of ±10% which is a typical range for 95% confidence limits for current meter gaugings of higher flows. The rating curves are well supported by gaugings up to about 140 m^3/s and moderate extrapolation is needed to estimate flows corresponding to the highest recorded levels.

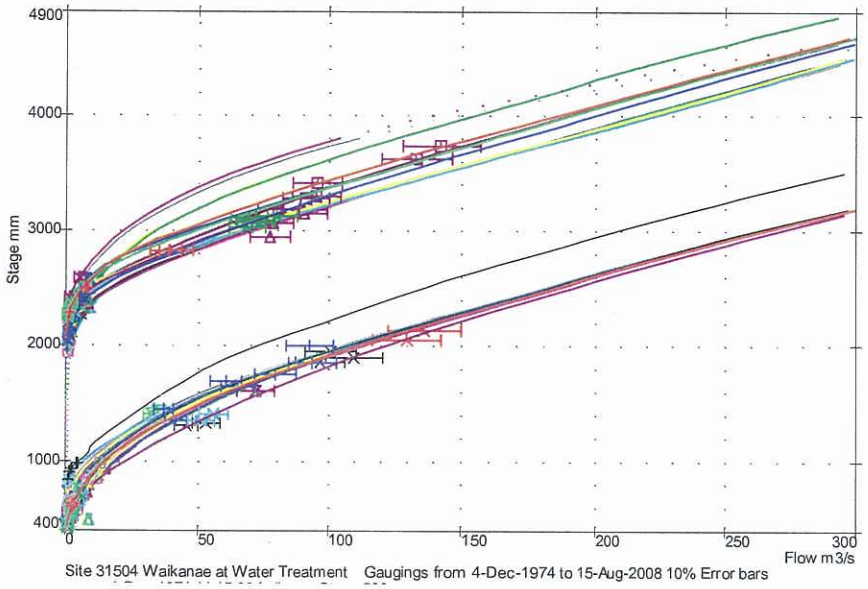

Figure 1: Rating curves for the Waikanae River at Water Supply Intake.

Because of the transport of sediment through this site, numerous rating curves are necessary to provide reliable assessments of low flows. A shift of the site and the datum in December 1999 accounts for the offset of the later ratings.

In the 1991 report, an alternative set of ratings was devised for the years 1975-1991. The influence of these alternative ratings on the flood frequency estimates is considered below.

Inspection of plotted flow hydrographs (not included) showed that the data were reasonably complete and that gaps in the series were unlikely to include periods of floods. This enabled preparation of a series of annual maxima for 34 years, from 1975

to 2008 (with the provision that no flood exceeding 240 m^3/s occurs in the last two months of 2008).

3.2. Otaki River

As detailed in the 1991 report, the Otaki River has had recorders at three successive recorder sites, successively named Gorge (from 1958), Tuapaka (from 1972) and Pukehinau (from 1980). The report presented plots of the rating curves for Tuapaka and Pukehinau and maxima for the Gorge site for 1958-1971 were taken from an unpublished Ministry of Works & Development Report (Curry and Edhouse 1983).

Curry and Edhouse used correlation with the Waiohine River to estimate maxima for 1956, 1957, 1970, 1971 and 1972. These estimates were not used in the 1991 report because the correlation was approximate and the values for 1970 and 1971 were especially low. With the benefit of hindsight, the early 1970s have been identified as an exceptionally dry period for the North Island. In fact the flood maximum of 504 m^3/s recorded for 2007, also a dry year, is the second lowest after the 1971 estimate of 425 m^3/s. Thus in the present study, the full record is used.

The full set of rating curves for the Pukehinau recorder site, with gaugings and error bars, is presented in Figure 2. As for the Otaki, there are numerous ratings with regular shifts, consistent with movement of the gravel bed. These sets of data were used to prepare a set of annual maxima estimates for the 54 year period 1955-2008, with the provision that no flood exceeding 870 m^3/s occurs for October-December 2008.

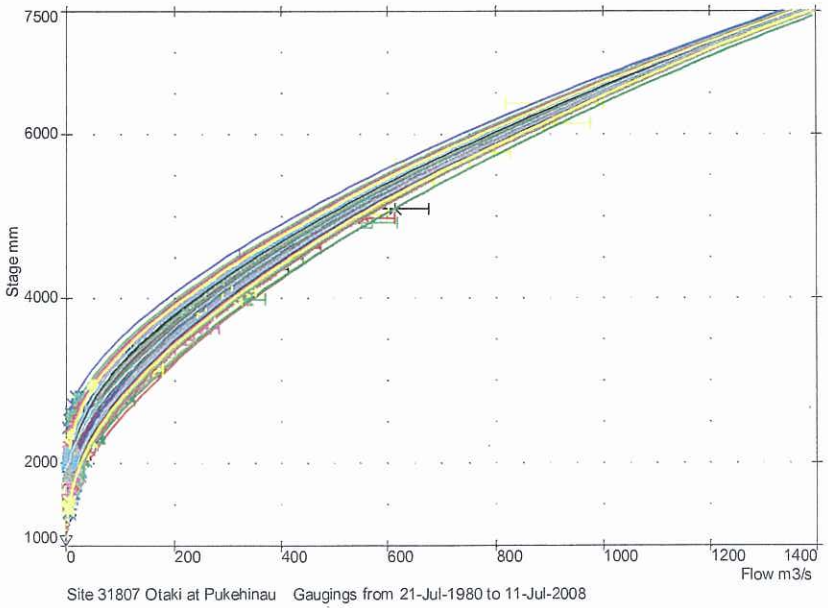

Figure 2: Rating curves for the Otaki River at Pukehinau.

4. Trend, shifts, persistence and periodicity

To examine the annual maxima, the series as listed in Appendix 1 are plotted in Figure 3. For the Otaki, easily the largest flood occurred in 1955: the estimated size of this flood derives from a slope-area estimate and it is subject to substantial uncertainty as discussed in the 1991 report. The second largest flood recorded in January 2005 is also prominent as the largest recorded for the Waikanae.

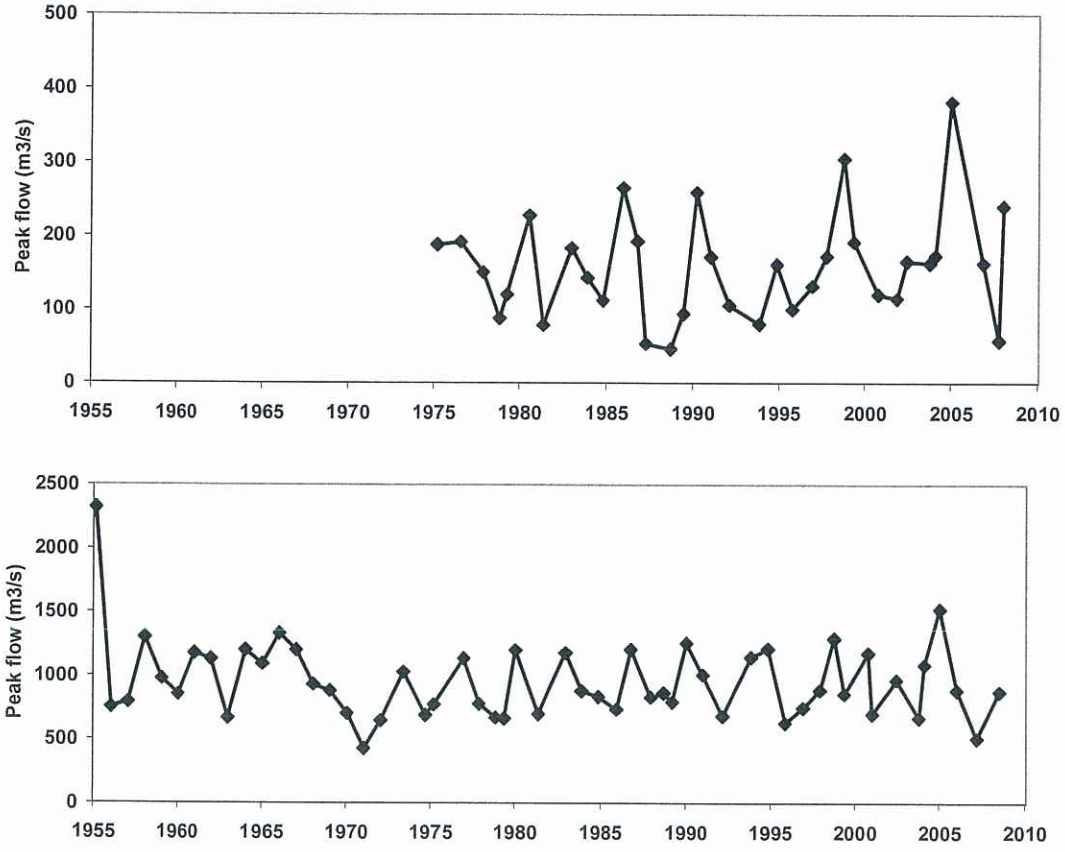

Figure 3: **Annual maxima estimated for Waikanae River (upper plot) and Otaki River (lower plot).**

From inspection of Figure 3, no trends or cycles are apparent in the data. Also, from the boxplots in Figures 4 and 5, no significant shifts corresponding to IPO phases (McKerchar and Henderson 2003) are evident. For the Waikanae River, a slight increase in the median is evident in Figure 4, but a Mann-Witney U test of the difference betweens the two phases had a P value of 0.48, indicating no evidence of significant difference between the two phases.

It is concluded from this inspection that the data are free of trend, shifts, persistence and periodicity and that standard extreme value analysis methods are applicable.

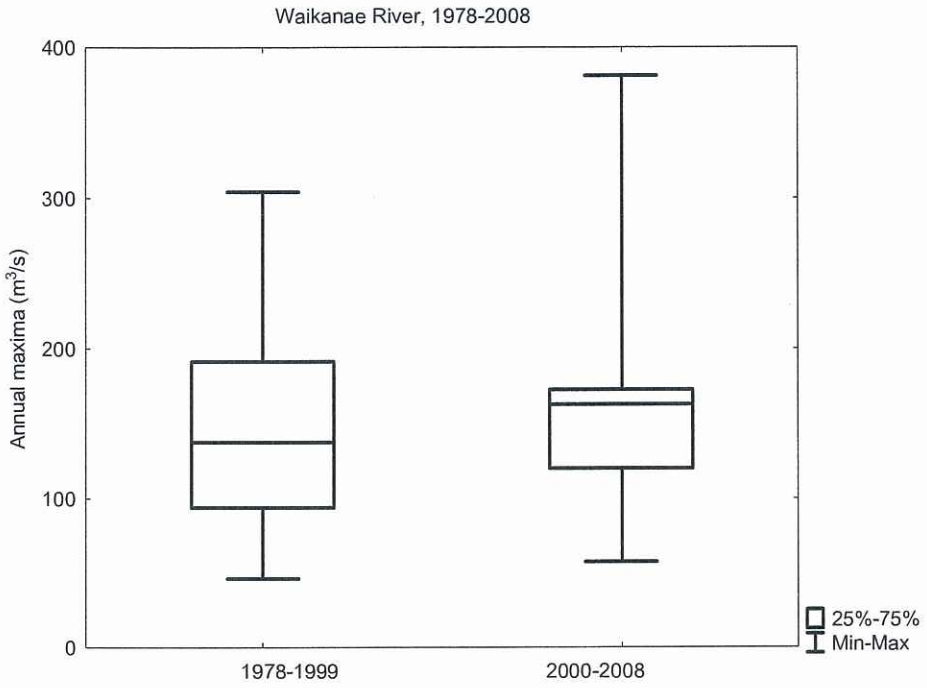

Figure 4: **Box plots of Waikanae River annual maxima according to IPO phases (McKerchar and Henderson, 2003).**

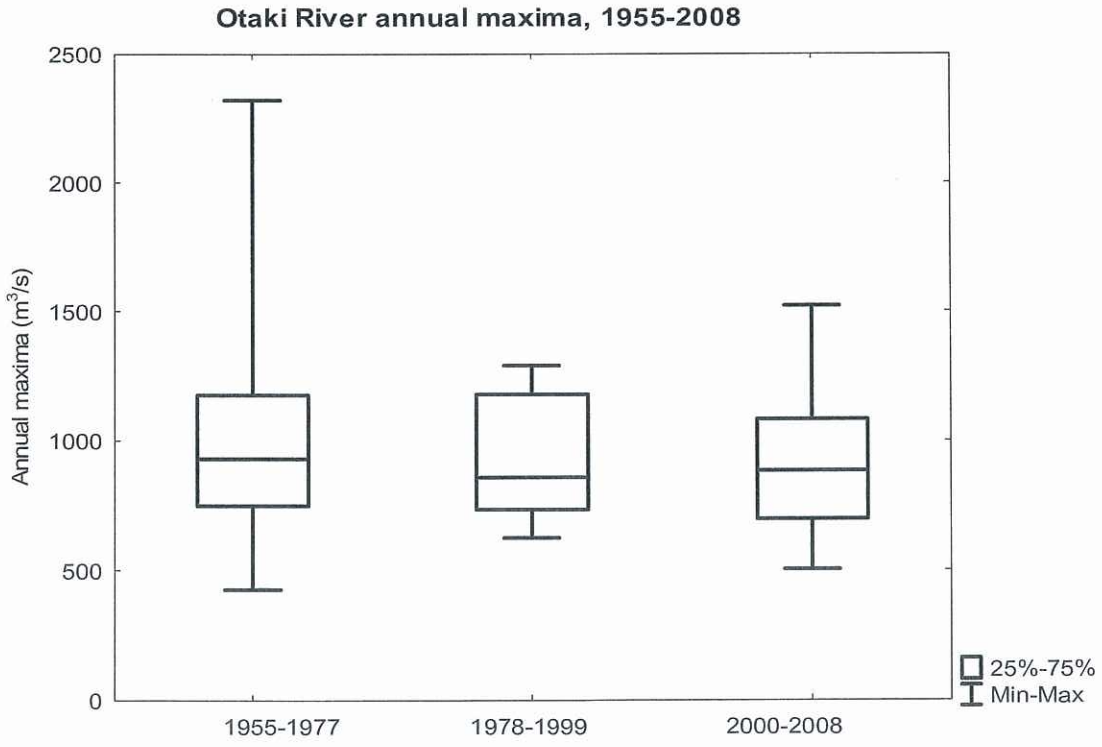

Figure 5: **Box plots of Otaki River annual maxima according to IPO phases (McKerchar and Henderson, 2003).**

5. Extreme value frequency analysis

Plots of the frequency analyses of the annual maxima with Gumbel (Extreme Value Type 1) frequency curves fitted by the method of probability weighted moments are presented in Figures 6 and 7.

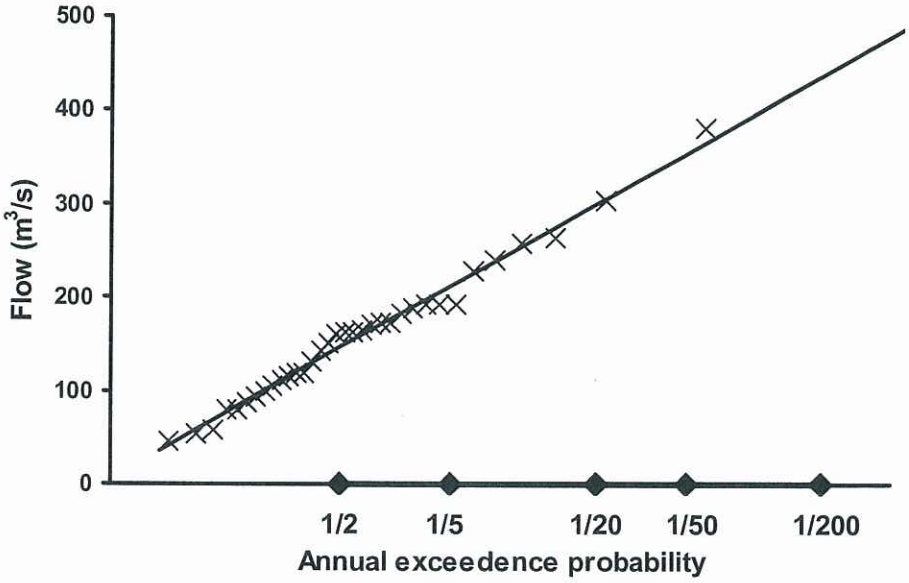

Figure 6: **Frequency analysis of annual maxima for the Waikanae River for 1975-2008 with a Gumbel frequency curve fitted.**

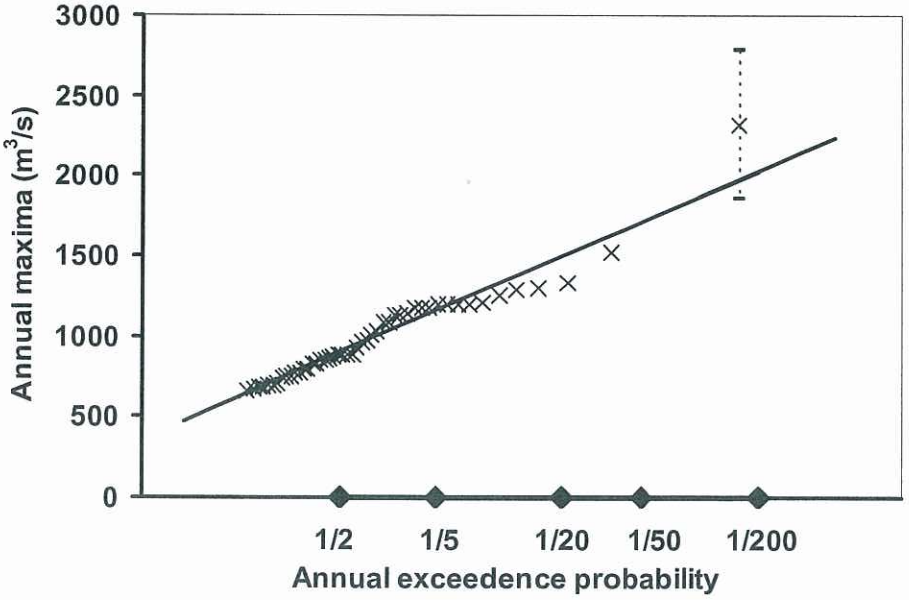

Figure 7: **Frequency analysis of annual maxima for the Otaki River for 1955-2008 with a Gumbel frequency line fitted. The largest peak, for 1955, is estimated by slope-area methods and is taken as the largest since 1920.**

For the Waikane River (Figure 6) the Gumbel curve is an excellent fit to the data and provides a sound basis for extrapolation to estimate low probability flood magnitudes. Flood quantiles are summarised in Table 1, together with 95% confidence intervals for the estimates.

Table 1: Flood quantile estimates for the Waikanae River derived from Figure 6.

AEP	Return period (yrs)	Flood peak (m^3/s)	95% confidence limits (%)
0.5	2	150	±13
0.2	5	210	±14
0.05	20	300	±18
0.02	50	350	±19
0.01	100	400	±20
0.005	200	440	±21

For the Otaki River (Figure 7), the Gumbel frequency line provides a reasonable fit to the annual maxima series. This fitting process uses the estimated annual maxima for the 54 years 1955-2008. The 1955 maximum, which is a slope-area estimate, is substantially larger than the other values in the series. However, the uncertainty of slope-area estimates is large and following the 1991 report, this flood is plotted in Figure 7 as the largest since 1920. Recognising the large uncertainty, it is plotted with errors bars of ±20% and these encompass the Gumbel line.

Flood quantiles from Figure 7 are listed in Table 2 together with 95% confidence intervals for the estimates.

Table 2: Flood quantile estimates for the Otaki River derived from Figure 7.

AEP	Return period (yrs)	Flood peak (m^3/s)	95% confidence limits (%)
0.5	2	900	±7
0.2	5	1160	±8
0.05	20	1500	±11
0.02	50	1710	±12
0.01	100	1870	±13
0.005	200	2030	±14

6. Alternative set of Waikanae ratings used in the 1991 report

An alternative set of ratings was used in the 1991 to prepare flood frequency estimates. The practical effect of these alternative ratings was negligible: for example the 1/100 AEP flood estimate was 3% higher than the estimate obtained using the ratings that are archived by the regional council. The archived set of ratings is used in the present review.

7. Comparison with 1991 estimates

For the Waikanae, Table 3 presents a comparison of the 1991 estimates with the updated estimates given in Table 1.

Table 3: **Comparison of Waikanae flood quantiles with those in the 1991 report (Table 2.2).**

AEP	Return period (yrs)	Flood peak (Table 1) (m^3/s)	Flood peak (1991 report) (m^3/s)
0.5	2	150	140
0.2	5	210	202
0.05	20	300	281
0.02	50	350	333
0.01	100	400	371
0.005	200	440	408

The increases in these estimates are of order 5% - 8%. These increases reflect the doubled length of record from 17 to 34 years, and are consistent with the two largest floods occurring in the latter part of the record (Figure 3). They are well within the range of the confidence limits in Table 1.

For the Otaki, Table 4 presents a similar comparison.

The slight (typically 5% - 6%) decreases in these estimates are well within the range of the confidence limits in Table 2.

Table 4: **Comparison of Otaki River flood quantiles with those in from the 1991 report (Table 1.3).**

AEP	Return period (yrs)	Flood peak (Table 2) (m^3/s)	Flood peak (1991 report) (m^3/s)
0.5	2	900	938
0.2	5	1160	1150
0.05	20	1500	1440
0.02	50	1710	1630
0.01	100	1870	1770
0.005	200	2030	1910

8. Design flood hydrographs

8.1. Waikanae River

To derive typical flood hydrographs, flood hydrographs for the six largest annual maxima were selected: these hydrographs are plotted in Figure 8. These plots show very fast rising and falling hydrographs: this river typically rises above 100 m^3/s and falls below this threshold within 12-15 hours. Each hydrograph was divided by its peak value and replotted as the scaled peaks in Figure 9. Also plotted on this graph is the median of the six events which is taken as a characteristic event.

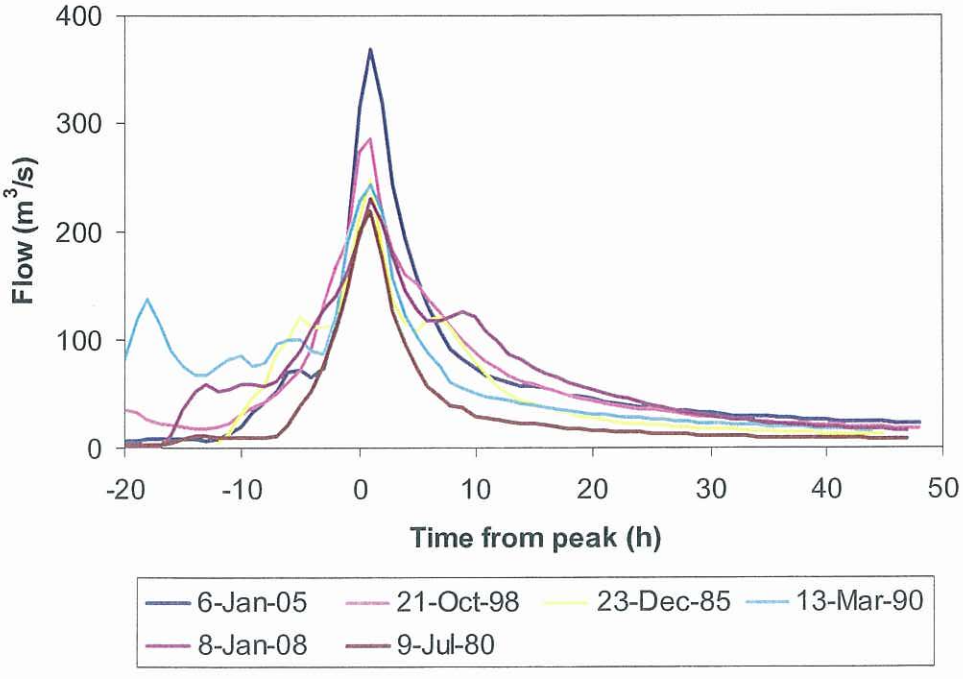

Figure 8: **Hydrographs for the six largest annual maximum floods for the Waikanae River.**

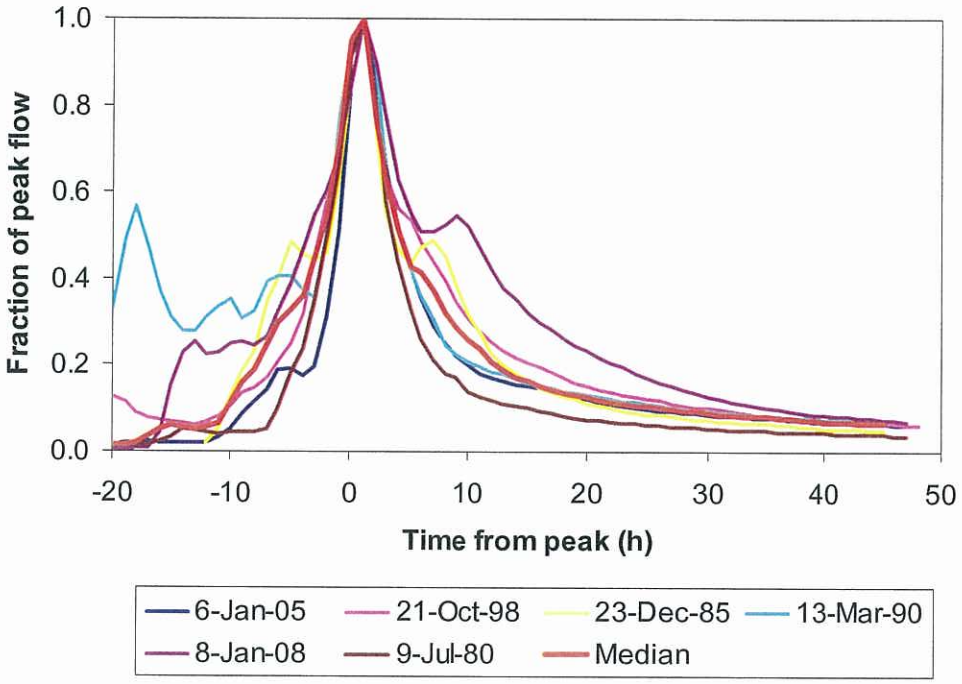

Figure 9: **Waikanae River flood hydrographs from Figure 8 divided by their respective maxima, with median hydrograph overplotted.**

Finally, the median hydrograph in Figure 9 was multiplied by the 50, 100 and 200 year peak estimates from Table 3 to give a set of design hydrographs, as plotted in Figure 10. Hourly values for the hydrographs are listed in Appendix 2. These hydrographs are recommended for design purposes.

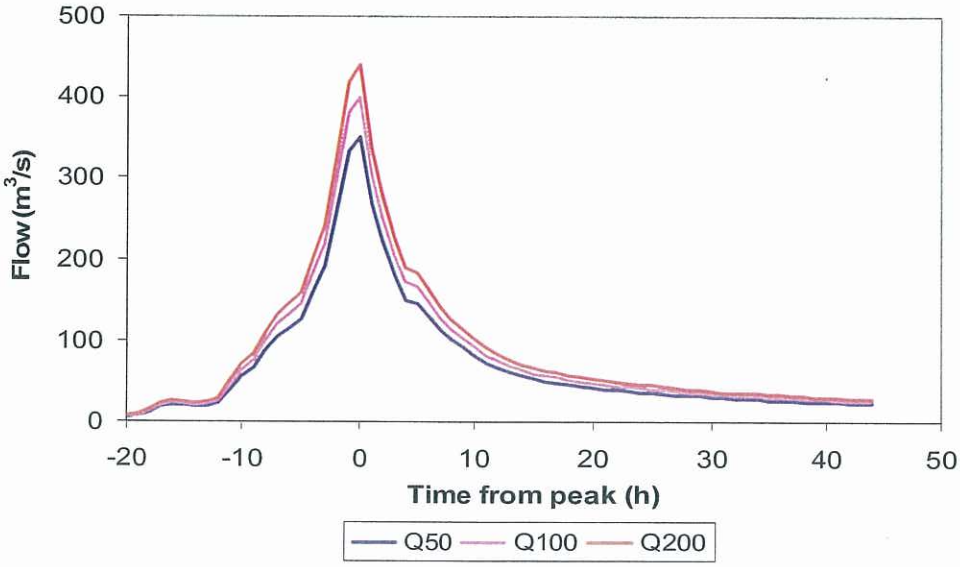

Figure 10: **Waikanae River hydrographs for 50, 100 and 200 year return period floods.**

8.2. Otaki River

As for the Waikanae, to derive typical flood hydrographs, flood hydrographs for the six largest annual maxima were selected: these hydrographs are plotted in Figure 11. Each was divided by the peak value and then plotted and the six scaled peaks are shown in Figure 12. These hydrographs show considerable variability in shape. Also plotted on this graph is the median of the six events which is taken as a characteristic hydrograph.

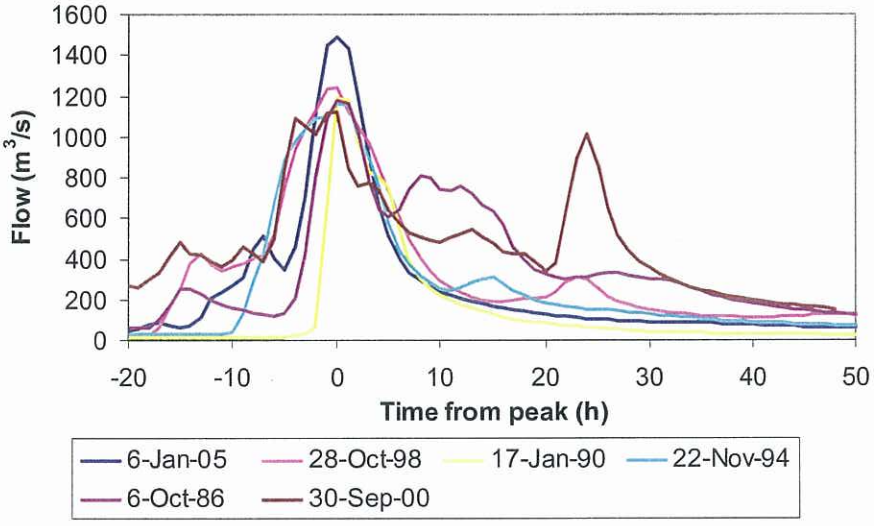

Figure 11: Hydrographs for the six largest annual maximum floods for the Otaki River recorded since 1980 at the Pukehinau recorder.

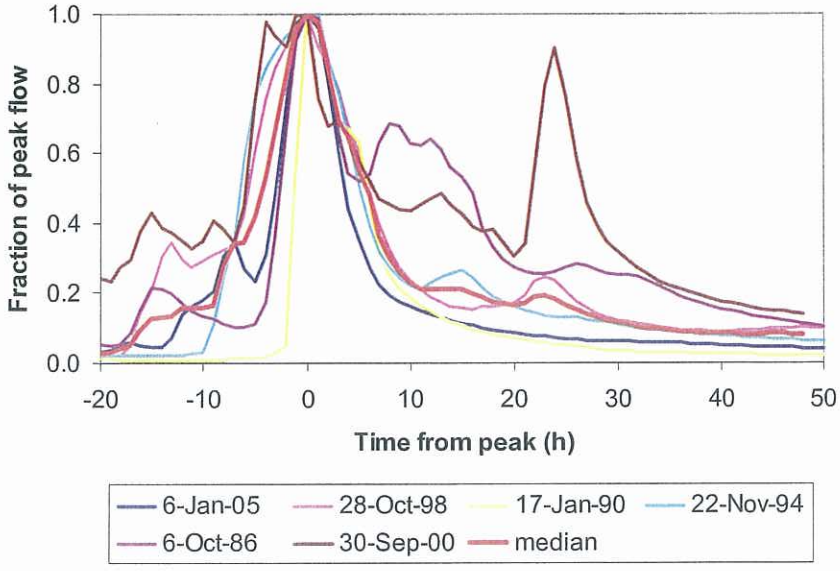

Figure 12: Otaki River flood hydrographs from Figure 11 divided by their respective maxima, with median hydrograph overplotted.

Finally, the median hydrograph in Figure 12 was multiplied by the 50, 100 and 200 year peak estimates from Table 4 to give a set of design hydrographs, as plotted in Figure 13. Hourly values for the hydrographs are listed in Appendix 2. These hydrographs are recommended for design purposes.

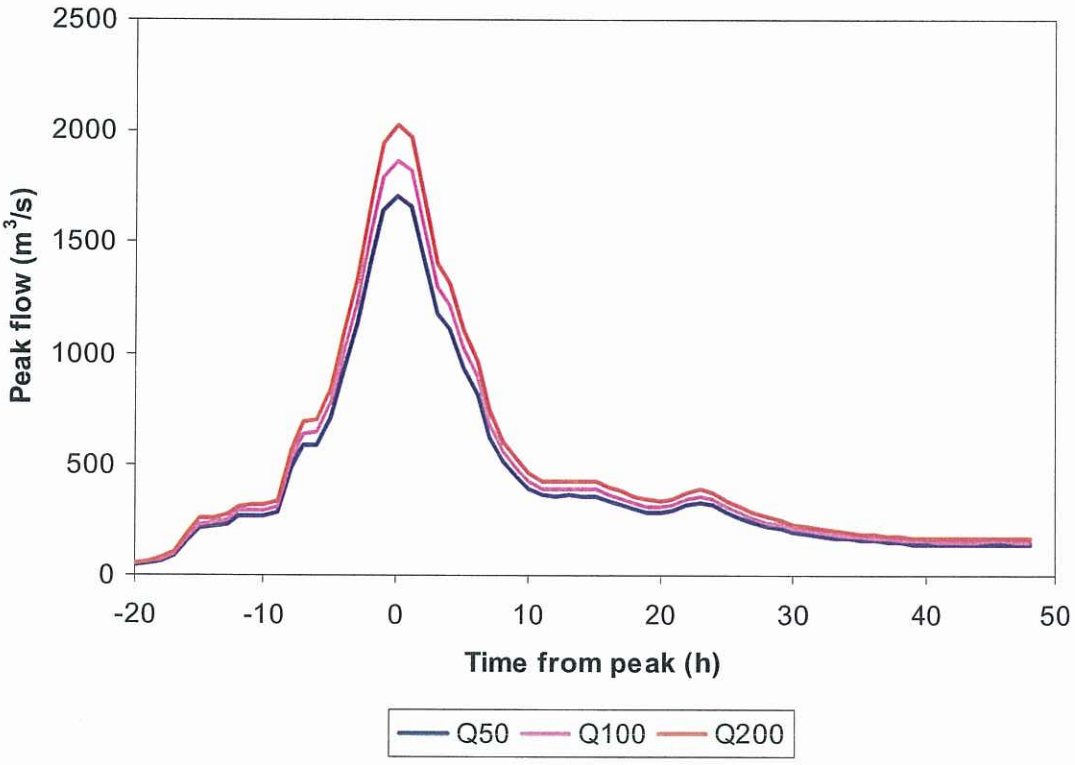

Figure 13: Otaki River hydrographs for 50, 100 and 200 year return period floods.

9. Comment on Probable Maximum Flood and regional flood estimates

Probable maximum flood (PMF) estimates for the Waikanae and Otaki Rivers were presented in the 1991 report. They derive from Probable Maximum Precipitation (PMP) estimates given in Appendix C of the report. Since 1991, there has been no significant work on PMP in New Zealand that would lead to revision of the estimates. Therefore, it is recommended that the 1991 PMF estimates continue to be accepted.

In the 1991 report, regional flood frequency methods contributed information that slightly revised the flood frequency estimates for the Waikanae and Otaki Rivers. Within the additional 17 years of data available, the contribution of regional information to the estimates will be reduced, to the extent that it is not worth pursuing.

10. Design flood flows for Muaupoko and Waimeha Streams

For Muaupoko and Waimeha Streams the study is to provide 50, 100, and 200 year peak flood flow estimates for the following sites.

- Muaupoko Stream, upstream of State Highway 1 at NZMG 2681900E 6032820N
- Waimeha Stream at NZMG 2682330E 60352123N

For the Muaupoko, the topographic catchment is well defined on the NZMS260 1:50,000 map sheet R26 and the catchment area is estimated to be 6.2 km^2. Using the regional method described in McKerchar and Pearson (1989), together with a revised regional maps for the Wellington region in the 1991 report, the estimates of the required flood peaks are set out in Table 5.

Table 5: Flood frequency estimates for Muaupoko Stream above SH1 Bridge. M&P refers to McKerchar and Pearson (1989).

Item	Units	Value	Std error +/-(%)	Source of estimate
Area A	km^2	6.2		
$Q_b/A^{0.8}$		2.5		Figure 4.1 in 1991 report
Mean annual flood Q_b	m^3/s	10.8	25	
Q_{50}/Q_b		2.0		Figure 4.8 & Table 5.1(a) in M&P
Q_{100}/Q_b		2.2		Figure 4.8 in M&P
Q_{200}/Q_b		2.4		Figure 4.8 & Table 5.1(a) in M&P
Q_{50}	m^3/s	22	25	Table 5.1(b) in M&P
Q_{100}	m^3/s	24	28	Table 5.1(b) in M&P
Q_{200}	m^3/s	26	30	Table 5.1(b) in M&P

For the Waimeha at map reference NZMG 2682330E 6035212N, the drainage network for the Waikanae urban area is not defined on the NZMS260 1:50,000 map sheet R26 and the catchment area cannot be estimated reliably without a detailed survey of the area. However, for a period of approximately three years over 2004-2006, the council operated a recorder on the Waimeha at 147 Te Moana Road. This recorder was some 900 m downstream of the site at which the estimate is required and there appears to be minimal contributing catchment area between. The recorder site was extensively gauged, mostly in the range 100-200 l/s. Over the three years of recording the baseflow is well-sustained, indicating substantial spring flows and the

mean flow is 0.158 m^3/s. There have been no high stage gaugings for the site and thus the mean of the three annual peak flows of 0.75 m^3/s provides a very preliminary estimate of mean annual flood Q_b. With this value, the design estimates as in Table 6 follow.

Table 6: Flood frequency estimates for Waimeha Stream at stated map reference. M&P refers to McKerchar and Pearson (1989).

Item	Units	Value	Std error +/-(%)	Source of estimate
Mean annual flood Q_b	m^3/s	0.75	24	Sample statistics from record
Q_{50}/Q_b		2.0		Figure 4.8 & Table 5.1 in M&P
Q_{100}/Q_b		2.2		Figure 4.8 in M&P
Q_{200}/Q_b		2.4		Figure 4.8 & Table 5.1(a) in M&P
Q_{50}	m^3/s	1.5	25	Table 5.1(b) in M&P
Q_{100}	m^3/s	1.7	28	Table 5.1(b) in M&P
Q_{200}	m^3/s	1.8	30	Table 5.1(b) in M&P

11. Climate change impacts

Guidance from the Ministry for the Environment (MfE 2008) discusses the expected effects of global warming on heavy rainfalls. For the Wellington region, projected temperature increases for 50 and 100 years are respectively 0.9 and 2.1 degrees Celsius, albeit with substantial errors of estimate. With a one degree increase in temperature, the atmosphere can hold about 8% more moisture and therefore an 8% increase in storm rainfalls is anticipated for each degree rise in temperature (MfE 2008). Estimation of increases in flood flows requires detailed catchment modelling, but for the stated temperature and storm rainfall changes, increases may be expected to be of the order of 10% and 20 % in 50 and 100 years respectively.

12. Summary

The flow records for the Waikanae and Otaki Rivers appear to be of reasonable quality, given the mobile nature of the gravel river beds. The flood data are somewhat uncertain due to the influence of gravel movement at high flows and this is evident when the raw recorded data are plotted. Nevertheless, the lengths of record now available are sufficient to provide reasonable estimates of flood quantiles, without the need to resort to lower reliability regional methods.

The annual maxima flood data are free of trend, shifts, persistence and periodicity and standard extreme value analysis methods are applicable.

The flood quantiles for the Waikanae River derived in this study have increased marginally over those of the 1991 report. This is not unexpected, given a doubling of the length of record from 17 to 34 years.

For the Otaki River, the estimates are virtually unchanged.

Corresponding design flood hydrographs are derived for both recorder sites. These hydrographs are derived by taking median values of a sample of the largest flood hydrographs after scaling. The Otaki hydrographs show considerable variability from storm to storm. An alternative process of deriving design hydrographs by rainfall runoff modelling was not used because of the sparse coverage of the rainfall records for the Otaki catchment.

As there have been no significant developments in PMP estimation methods in New Zealand since the 1991 report was prepared, the PMF estimates in that report remain valid.

Regional methods and a short term flow record are utilised to develop design flood estimates for the Muaupoko and Waimeha Streams respectively. The Waimeha estimate is particularly problematic. The peak flow estimates from extrapolated ratings are uncertain. Also, on the available maps, the topographic catchment area for the Waimeha Stream is ill-defined, and it is recommended that urban drainage details for the Waikanae urban area be investigated to better define the drainage paths through the area, in particular considering contingencies such as the blockages of culverts.

Global warming is expected to result in intensification of severe storms because a warmer atmosphere can contain more moisture. As a consequence, increases in flood peak flows of order 10% and 20% are suggested in 50 and 100 years respectively. However, the uncertainties are very large, and a valid strategy for the council may be to design flood protection works in such a way that they can be readily augmented should that be necessary to maintain a stated level of protection.

13. References

Curry R.J.; Edhouse C.J. (1983). Flood frequency analysis for the Otaki River using data from the SHB, Gorge, Tuapaka and Pukehinau hydrological recording stations. Hydrology Centre Internal Report WS850.

McKerchar, A.I.; Henderson R.D. (2003). Shifts in flood and low-flow regimes in New Zealand due to interdecadal climate variations. *Hydrological Sciences Journal 48(4)*: 637-654.

MfE. (2008). Climate change effects and impacts assessment: a guidance manual for Local Government in New Zealand, 2nd edition. NZ Climate Change Office, Ministry for the Environment, Wellington, 149p. available from: www.mfe.govt.nz/publications/climate/climate-change-effect-impacts-assessments-may08/

Appendix 1: Annual maxima for Otaki and Waikanae Rivers

Flood peak (m^3/s)	Date	Flood peak (m^3/s)	Date
2320	25/02/1955		
750	13/01/1956		
790	11/01/1957		
1300	10/01/1958		
975	09/01/1959		
850	08/01/1960		
1175	13/01/1961		
1130	12/01/1962		
665	11/01/1963		
1200	10/01/1964		
1090	08/01/1965		
1330	07/01/1966		
1200	13/01/1967		
930	12/01/1968		
880	10/01/1969		
700	09/01/1970		
425	08/01/1971		
645	07/01/1972		
1026	12/05/1973		
687	27/09/1974		
771	31/03/1975	188	06/03/1975
1134	20/12/1976	192	16/07/1976
776	06/11/1977	150	22/11/1977
669	12/11/1978	88	12/11/1978
661	07/05/1979	120	11/04/1979
1197	20/01/1980	227	09/07/1980
697	21/05/1981	79	21/05/1981
1178	25/12/1982	183	11/12/1982
879	05/11/1983	143	05/11/1983
832	25/11/1984	112	18/10/1984
734	23/12/1985	265	23/12/1985
1203	04/10/1986	192	05/10/1986
829	03/12/1987	53	01/04/1987
864	13/09/1988	46	13/09/1988
790	24/03/1989	94	12/06/1989
1254	17/01/1990	259	13/03/1990
1005	24/01/1991	171	24/01/1991
680	16/03/1992	106	5/02/1992
1145	20/11/1993	80	20/11/1993
1210	22/11/1994	161	08/11/1994
625	20/11/1995	100	15/10/1995
745	18/12/1996	132	19/12/1996
884	16/12/1997	172	04/10/1997
1290	28/10/1998	305	21/10/1998
854	28/05/1999	192	28/05/1999
1175	01/10/2000	120	02/10/2000
698	26/01/2001	115	22/11/2001
965	18/06/2002	165	18/06/2002
665	03/10/2003	163	03/10/2003
1082	12/02/2004	173	12/02/2004
1522	06/01/2005	381	06/01/2005
883	18/01/2006	162	17/11/2006
504	17/03/2007	58	08/10/2007
870	07/07/2008	240	08/01/2008

Appendix 2: Hourly flows for the design hydrograph for the Waikanae River.

Hours from peak	50 year hydrograph (m^3/s)	100 year hydrograph (m^3/s)	200 year hydrograph (m^3/s)
-20	6	7	8
-19	7	8	9
-18	12	14	16
-17	19	22	24
-16	21	24	27
-15	20	23	25
-14	19	22	24
-13	20	23	25
-12	23	27	29
-11	41	47	51
-10	56	64	70
-9	67	76	84
-8	88	100	110
-7	106	121	133
-6	116	132	146
-5	127	145	159
-4	159	182	200
-3	192	219	241
-2	254	290	319
-1	333	381	419
0	350	400	440
1	268	306	337
2	222	254	279
3	180	205	226
4	150	172	189
5	146	167	184
6	131	149	164
7	113	129	142
8	101	115	126
9	91	104	115
10	83	95	104
11	73	83	91

Hours from peak	50 year hydrograph (m^3/s)	100 year hydrograph (m^3/s)	200 year hydrograph (m^3/s)
12	67	76	84
13	61	70	77
14	57	65	72
15	53	60	66
16	51	58	64
17	48	55	61
18	46	53	58
19	44	50	55
20	42	48	53
21	41	47	51
22	39	45	49
23	38	44	48
24	37	42	46
25	36	41	45
26	35	40	44
27	33	38	42
28	32	37	41
29	32	36	40
30	31	35	39
31	30	34	37
32	29	33	37
33	29	33	36
34	28	32	35
35	28	32	35
36	27	31	34
37	26	30	33
38	26	29	32
39	25	29	32
40	24	28	31
41	24	28	30
42	24	27	30
43	23	26	29
44	23	26	28

Appendix 3: Hourly flows for the design hydrograph for the Otaki River.

Hours from peak	50 year hydrograph (m^3/s)	100 year hydrograph (m^3/s)	200 year hydrograph (m^3/s)
-20	46	51	55
-19	53	58	63
-18	66	73	79
-17	91	100	108
-16	163	178	193
-15	214	234	254
-14	220	241	261
-13	229	250	272
-12	265	290	314
-11	266	291	316
-10	270	296	321
-9	283	309	336
-8	476	520	565
-7	585	640	695
-6	590	645	700
-5	715	782	849
-4	915	1000	1086
-3	1125	1230	1336
-2	1420	1553	1685
-1	1643	1797	1950
0	1710	1870	2030
1	1664	1820	1976
2	1435	1569	1703
3	1186	1297	1407
4	1110	1214	1318
5	932	1019	1106
6	820	897	973
7	626	685	744
8	513	561	609
9	442	484	525
10	391	428	465
11	360	394	428
12	357	391	424
13	361	394	428

Hours from peak	50 year hydrograph (m^3/s)	100 year hydrograph (m^3/s)	200 year hydrograph (m^3/s)
14	358	392	425
15	358	392	425
16	337	369	400
17	320	350	380
18	302	331	359
19	288	315	342
20	282	309	335
21	292	319	347
22	318	348	378
23	328	358	389
24	318	347	377
25	286	313	340
26	259	283	308
27	238	260	283
28	221	242	262
29	210	229	249
30	198	216	235
31	188	206	224
32	180	197	214
33	172	189	205
34	166	182	197
35	160	175	190
36	156	171	185
37	152	166	181
38	149	163	177
39	146	160	173
40	143	157	170
41	142	155	168
42	142	155	168
43	141	155	168
44	140	153	167