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APPENDIX F

Hydrology Assessment – Tonkin & Taylor

REPORT

Reconsenting of Mangorei Hydroelectric Power Scheme

Hydrology Report

Prepared for
Trustpower Ltd
Prepared by
Tonkin & Taylor Ltd
Date
November 2020 (Final)
Job Number
1008726.200

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Table of contents

1 Introduction

1.1 Context

Trustpower Ltd (TrustPower) owns and operates the Mangorei Hydroelectric Power Scheme (Mangorei HEPS, or "MGR"), which is located mid-catchment in the Waiwhakaiho River catchment within the Taranaki region.

The current resource consents for the operation of the scheme were granted by Taranaki Regional Council (TRC) on 4 September 1996, and several were subsequently varied (in 2006, 2016 and 2017). All resource consents expire on 1 June 2021. Consequently, Trustpower has commenced a process to obtain replacement consents to permit operation of the scheme for a further term. This report, which is one of a series of technical assessment reports, addresses the hydrological aspects of the scheme.

1.2 Scope of assessment

The scope of the hydrological assessment includes the following:

i Description of the general hydrological setting of the Mangorei HEPS, including a detailed assessment of the existing flow regime of the Waiwhakaiho River

ii Description of the historical operation of the Mangorei HEPS, including diversion from the Waiwhakaiho River, Lake Mangamahoe levels, daily flow fluctuations at the power station

iii Description of the proposed operational regime of the Mangorei HEPS

iv A summary of the predicted effects of projected climate change on the Waiwhakaiho River flow regime and scheme operation

v Description of the hydrological effects of the scheme and its operation.

1.3 Scheme description and key locations

The Mangorei HEPS has a nominal capacity of 4.5 MW and is orientated around Lake Mangamahoe, a man-made lake that was created for water storage prior to hydro-electric generation use. The lake is formed by a 25 m high dam across the Mangamahoe Stream that was built in 1931 that replaced an older scheme established around the turn of the century (1995 AEE).

Most of the inflow (85%) to Lake Mangamahoe is sourced from a diversion on the Waiwhakaiho River that comprises an intake and tunnel on the left bank of the river. The balance of the lake inflow (15%) is derived from natural tributaries to the lake, principally the Mangamahoe Stream and Kent Road Stream. Water is returned to the Waiwhakaiho River via the MGR power station at Hydro Road some 5.9 km downstream of the diversion point, after passing through penstocks and the power tunnel from Lake Mangamahoe.

Lake Mangamahoe is also the source of New Plymouth's public water supply.

A residual flow is maintained in the Waiwhakaiho River below the intake weir at all times (understood to be for the purpose of fish passage), with the minimum residual flow determined by the time of year (per TRC Consent 2053-3.2) i.e.:

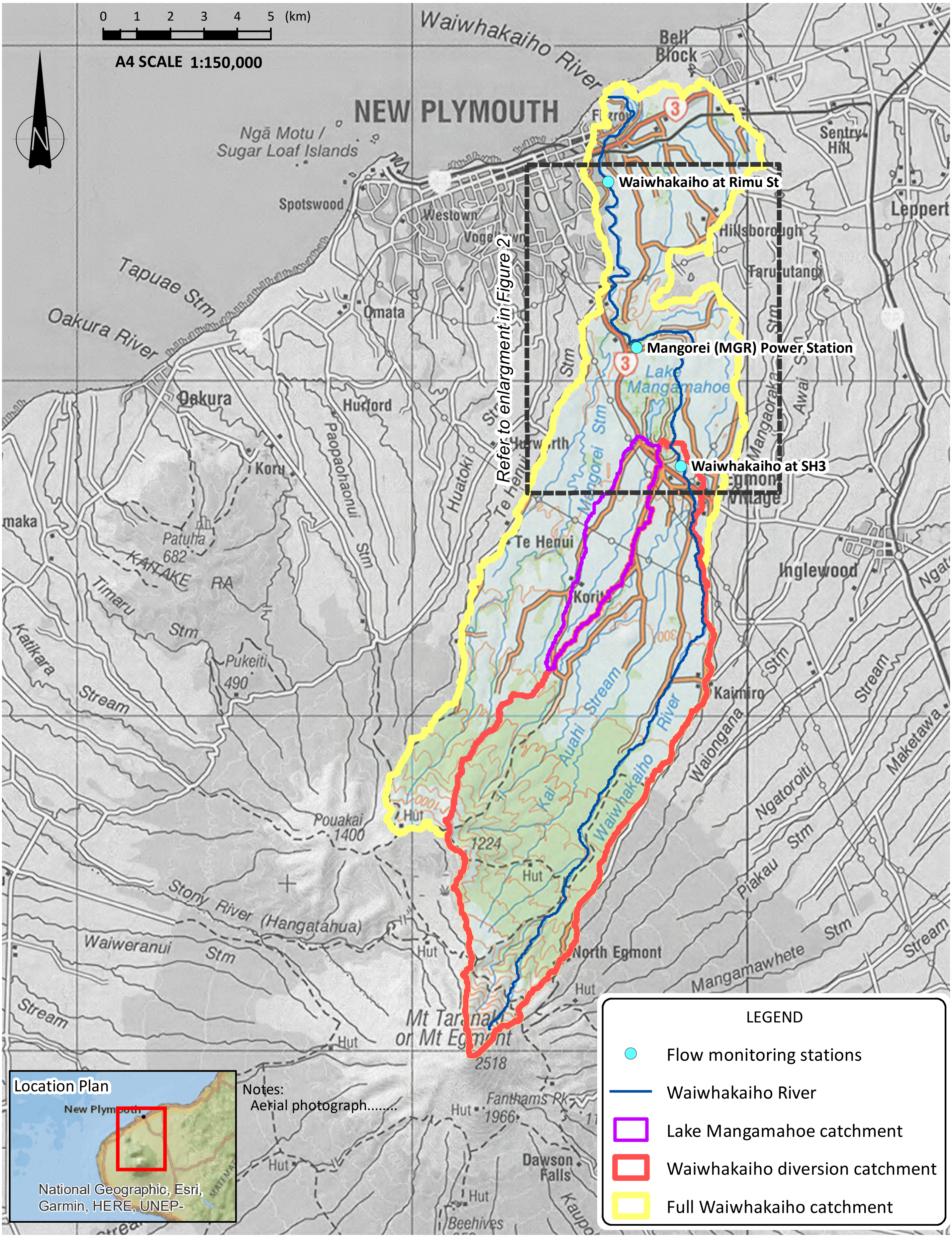
- 700 l/s between 1 January and 31 March;
- 600 l/s between 1 November and 31 December and during April; and
- 400 l/s between 1 May and 31 October.

This residual flow is augmented by groundwater seepage(s) and a number of minor tributaries downstream of the intake weir. Flows in the lower reaches of the Waiwhakaiho River below the scheme are supplemented by the Mangorei Stream. There is no residual flow, other than spillway discharges and seepage, down the Mangamahoe Stream, which was dammed to form the lake.

Figure 1.1 shows the location of the scheme and key features such as catchment extents and locations of relevant flow monitoring stations. Figure 1.2 is a more detailed map of the scheme environs that shows the main components of the hydro-electric power scheme. Figure 1.2 also shows the locations in the Waiwhakaiho catchment for which hydrology has been assessed for this report. These "hydrological nodes", numbered 1 to 8, and the rationale for their inclusion, are as follows:

1. Waiwhakaiho at SH3 (also called Waiwhakaiho at Egmont Village) – this is a long-term flow recording site, operated originally by NIWA (from February 1980 to December 2003) and taken over by Taranaki Regional Council (TRC) in December 2003. Located above the diversion and thus unaffected by the scheme
2. Waiwhakaiho diversion tunnel – representing flow diverted from Waiwhakaiho River into Lake Mangamahoe
3. Waiwhakaiho downstream of river intake – this is the residual river after flow has been diverted to Lake Mangamahoe via the Waiwhakaiho tunnel
4. MGR power station – generation discharge (converted into flow from output in MW)
5. Waiwhakaiho upstream of power station tailrace – representing the flow in the residual river upstream of the return flow from the power station
6. Waiwhakaiho downstream of power station tailrace – representing the flow in the river with the generation flow added back in
7. Waiwhakaiho at Rimu St – this is another long-term flow recording station operated by TRC; while river levels have been recorded from October 1992, rated flows are only available from April 2009. Represents flow in the lower river downstream of the scheme
8. Lake Mangamahoe – representing operation of the lake and level fluctuations.

Of the eight nodes for which hydrological information is presented in this report, five nodes have actual recorded data (i.e. nodes 1, 2, 4, 7 and 8) and the other three nodes (3, 5 and 6) have time-series records that have been derived from the recorded data. As explained in Section 3.2 later, the period of derived data is limited by the period for which the diversion tunnel flows are available for this report (i.e. from January 2013 to April 2020).



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Mangorei HEPS Hydrology Report
Location Map and Catchment Areas

FIGURE No.
Figure 1.1

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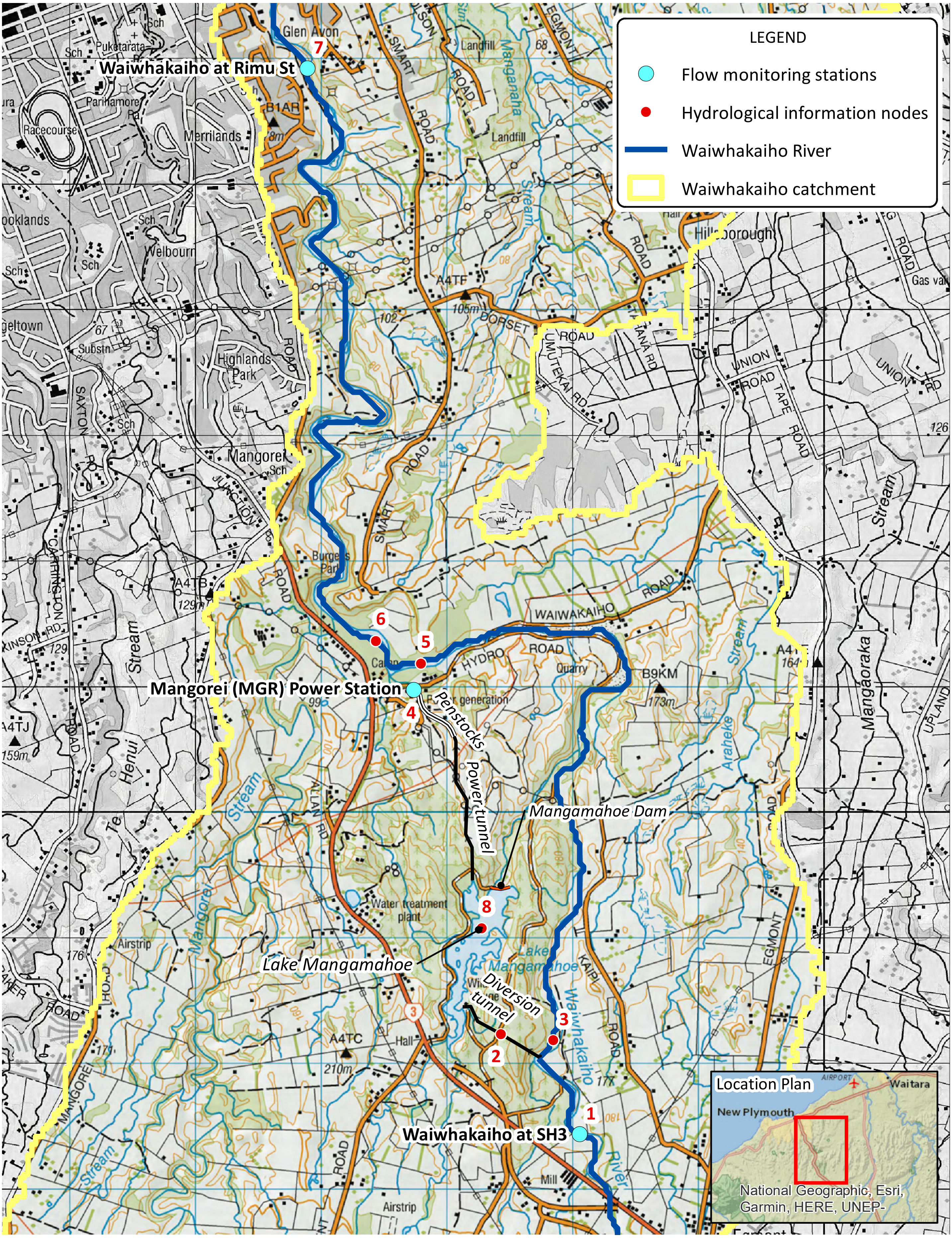

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Mangorei HEPS Hydrology Report
Mangorei HEPS and Environs

FIGURE No.
Figure 1.2

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2 Catchment characteristics and water resources

2.1 Waiwhakaiho catchment

2.1.1 Drainage and geology

The Waiwhakaiho River catchment is within the Taranaki region of New Zealand's North Island. The head of the catchment lies on the north-eastern slopes of Mount Taranaki. The headwaters (some 22 km upstream of the diversion weir) flow north-east down through meandering deeply incised gorges into the Taranaki ring plain. From there the river flows north, bypassing Lake Mangamahoe to the west. Downstream of its confluence with the MGR tailrace, the river has a flatter gradient, and flows for 11 km to reach the Tasman Sea, at the eastern edge of New Plymouth's urban boundary.

The majority of the Waiwhakaiho catchment lies over a pattern of ridges and valleys. The rivers coming off the slopes of Mt Taranaki have eroded a dendritic drainage pattern, radiating out from the summit, at elevation 2518 m above mean sea level. More than 75 per cent of the catchment is higher than 100 m above mean sea level.

The geology of the ring plain is dominated by past and present volcanic centres, with a large Pouakai ring plain being overlaid by formations arising from the present cone (TRC, 2011). Layers of conglomerates, breccia and tephra have been deposited over lahars and debris flows. The laharic deposits are very mixed and vary from concreted blocks through to uncompacted sands. A more detailed description of the geology and soils of the Waiwhakaiho catchment and the tributaries of Lake Mangamahoe is provided in another technical report (also included as part of this application) by Tonkin & Taylor (T+T) (2020) "Lake Mangamahoe Sediment Assessment".

2.1.2 Catchment area and cover

At its mouth the Waiwhakaiho River has a catchment of about 143 km^2. The assessed catchment areas to other locations of interest are:

- 60.5 km^2, Waiwhakaiho at SH3 flow recording site
- 62.2 km^2, at the Waiwhakaiho River diversion and tunnel intake, located about 1.6 km downstream of SH3
- 8.1 km^2, local catchment of Lake Mangamahoe, comprising Mangamahoe Stream (4.4 km^2), Kent Road Stream (2.7 km^2), and the lake surface and surrounding areas (~ 1.0 km^2)
- 66.6 km^2, Waiwhakaiho River immediately upstream of the MGR tailrace channel and Araheke Stream confluence
- 86.2 km^2, Waiwhakaiho River immediately downstream of the MGR tailrace channel
- 124 km^2, Waiwhakaiho at Rimu Street flow recording site
- 126 km^2, Waiwhakaiho River above its confluence with the Mangaone Stream

Figure 1.1 shows the extent of the Waiwhakaiho River catchment and its sub-catchments which are of interest. Figure 1.2 shows the locations of interest.

The flat areas of the catchment, including some drained swamplands to the east of the ring plain are dairy-farmed. The small town of Egmont Village lies at the eastern edge of the catchment. The valleys and ridges of the inland Taranaki hill country are mostly covered with native bush or scrub, and native forest also covers the slopes of Mount Taranaki.

2.1.3 Rainfall

Heavy rainfall events centred on Egmont National Park are a climatic feature of Taranaki. The main cone and the adjoining ranges are a prominent feature causing and attracting rainfall which may otherwise pass over the surrounding relatively low altitude landscape (TRC, 2011). These geographic features often result in unusually high rainfall intensities of relatively short duration, resulting in high volume discharges in all of the catchments draining onto the ring plain from the Egmont National Park.

Rainfall intensity varies significantly across the Waiwhakaiho catchment. The headwaters on the slopes of Mount Taranaki are in a mountainous region which is characterised by very high annual rainfall of up to 8,000 mm per annum. Near the coast the mean annual rainfall drops to approximately 1,600 mm, illustrating the steepness of the rainfall gradient caused by the orographic influence of Mt Taranaki. Based on the estimated mean flow at the river mouth, the catchment-wide mean annual rainfall is expected to be about 3,500 mm.

In a normal year, significant rainfall occurs in every month of the year, with the four months from January to April receiving roughly a quarter less rainfall than other months on average. The month of February is typically the driest month. Thus, coupled with the higher temperatures and evapo-transpiration rates in summer, there is a “dry” season from December to March in terms of flows.

2.2 Hydrometric data

Hydrometric data fundamental for characterising the hydrological environment are comprised of water level and flow records. Other hydrometric and climatic data such as rainfall, soil moisture, temperature, wind speed and direction, evaporation, and solar radiation are less significant, except to provide background and setting. This is because hydro-electric power schemes such as the Mangorei HEPS have the potential to modify the river flow regime. The scheme is not expected to have a material effect on other hydrometric variables.

Table 2.1 summarises the water level and flow recording sites in the Waiwhakaiho River catchment. This inventory is based on the national index of hydrological recording sites maintained by NIWA, and also includes long term sites managed by the TRC. For this report, data for the entire available record at each site has been obtained, i.e. from the record start date up to the end of April 2020 (the time a data “top-up” was requested from the relevant agency).

The longest flow record for the Waiwhakaiho River is kept at the SH3/Egmont Village site, with continuous data available from February 1980 (i.e. 40 years to date). The only other long-term flow recording site in the Waiwhakaiho catchment is on the main stem in the lower reaches at the Rimu Street site. Only 11 years of data (April 2009 to April 2020) is available to date. Records from these two sites have been analysed to characterise the flow regime of the Waiwhakaiho River in general. The SH3 site represents the middle reaches of the river above the Mangorei scheme while the Rimu Street site represents the lower reaches which are subject to the influence of the Mangorei scheme.

Figures 1.1 and 1.2 show the location of the recording sites.

In addition to the listed water level recorders in Table 2.1, Trustpower operates several other recorders as part of its SCADA (supervisory control and data acquisition) and operational control systems for the Mangorei scheme. Of relevance are the water level recorders at the intake headworks, power station tailrace, Lake Mangamahoe and in the Waiwhakaiho diversion tunnel. Details of several of the archived electronic records supplied by Trustpower for this report are provided in Table 2.2.

Table 2.1 Water level and flow recording sites in the Waiwhakaiho catchment

Site No.	Site Name	NZMS 260 (Map Ref.)	[1]Catchment Area (km^2)	Recording Agency	Record Start Date	Comment
39201	Waiwhakaiho at SH3	P19:082292	60.5	NIWA	14-Feb-80	Site managed by TRC from Dec 2003.
39212	Mangorei at Tailrace	P19:067327	N/A	NIWA	19-Dec-07	Recorder in tailrace channel
39232	Waiwhakaiho at Below Intake Weir	P19:078298	62.2	NIWA	29-Jan-08	Site not rated after March 2011 (levels only).
39237	Waiwhakaiho at Rimu St	P19:060376	~124	TRC	28-Oct-92	Rated flows only from 22 Apr2009. Prior to that only water levels.
39238	Waiwhakaiho at Egmont Village	P19:082292	60.5	TRC	2-Dec-03	Continuation of site no. 39201 (SH3) under TRC administration.
Note: 1 The catchment areas shown here based on measurements from LINZ topomap, and may differ from the catchment areas noted in the NIWA Site Index.						

Table 2.2 Selected time-series data for the Mangorei scheme provided by Trustpower

Variable	Description	Record Start Date	Comment
MGR_S1LAKE_LVL	Lake Mangamahoe level	18-Jul-2001	Lake level record
MGR_STN_LOAD	Mangorei power station discharge	16-Nov-2007	MW output converted into flow
MGR_NIWA_TR_Q	Mangorei tailrace flow	4-Mar-2014	NIWA data backup feed via web in SCADA
MGR-H4RIV_LVL	Waiwhakaiho River at tunnel intake	19-Nov-2007	Water level only, no flow
MGR_H4RIVLVL_BW	Waiwhakaiho River below intake weir	19-Nov-2007	Water level only. Related to consent compliance
MGR_WAIWHAKAIHO	Waiwhakaiho diversion tunnel	24-Jan 2013	Water level at downstream end of tunnel, which can be converted into flow via rating curve

All flow records contain a certain amount of intrinsic uncertainty, and this should be recognised when making interpretations from flow records. A comprehensive audit of the completeness and reliability of individual records has not been undertaken in this study. Nevertheless, it is understood that TRC has an objective to maintain its river flow records to particular quality standards and it has well-established procedures for auditing recorded flows.

2.3 Water use in the catchment

A list obtained from TRC (in August 2019) of the current consents for taking, diverting or damming surface water in the Waiwhakaiho catchment is presented in Table 2.3.

Excluding the consents for the Mangorei HEPS, the allowable surface take rates add up to 764 l/s, of which 97% (740 l/s) is associated with New Plymouth District Council's (NPDC) abstraction from Lake Mangamahoe for municipal water supply. Table 2.4 provides a tabulation of the mean monthly water takes from Lake Mangamahoe to NPDC's water treatment plant for the period from January 2013 to November 2019. The mean take is 366 l/s. The maximum take on a monthly basis is 463 l/s (equivalent to 40,000 m^3/day), which is substantially less than the consented take of 60,480 m^3/day. There is a minor seasonal bias in that the mean take over the 6 colder months from April to September is about 12% less than for the 6 warmer months of the year.

Water take in the catchment is dominated by the Mangorei HEPS which has consents to divert up to 10,000 l/s from the Waiwhakaiho River via a diversion weir, associated intake structures and diversion tunnel into Lake Mangamahoe. The scheme then has consents to use up to 864,000 m^3/day (equivalent of 10,000 l/s average rate) of water from Lake Mangamahoe for the purposes of hydro-electric power generation. However, the abstracted water is returned to the Waiwhakaiho

River below the dam, unlike the other takes which are generally for consumptive use. Further details of the temporal pattern of diversion from the Waiwhakaiho River to Lake Mangamahoe, including the conditions of consent that govern the take, is provided in Section 3.

Table 2.3 Surface water takes in the Waiwhakaiho catchment

Consent holder	Stated location	Stated purpose	Consented quantity	
			Rate	Volume
Mangorei Sawmill and Timber Supplies Limited	State Highway 3, Egmont Village	To take water from an unnamed tributary of the Waiwhakaiho River for the purpose of cooling saws and dispersing sawdust	2.0 l/s	58 m^3/day
New Plymouth District Council	Lake Mangamahoe, Junction Road, New Plymouth	To take up to 60,480 m^3/day of water at a maximum rate of 740 litres/second of water from Lake Mangamahoe in the Waiwhakaiho catchment for municipal water supply purposes	740 l/s	60,480 m^3/day
Trustpower Limited	Lake Mangamahoe, Junction Road, New Plymouth	To use up to 864,000 m^3/day of water from Lake Mangamahoe in the Waiwhakaiho catchment for hydroelectric power generation purposes	-	864,000 m^3/day
New Plymouth Golf Club Inc	Devon Road [State Highway 3], Fitzroy, New Plymouth	To take and use water from an unnamed lake system a tributary of the Waiwhakaiho River for golf course irrigation purposes	22 l/s	800 m^3/day

Table 2.4 Mean monthly NPDC water take from Lake Mangamahoe (in litres per second)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
2013	421	456	391	336	330	326	337	339	333	335	384	396	**365**
2014	389	454	405	361	345	338	347	348	356	360	357	391	**370**
2015	463	412	393	354	350	347	345	347	359	377	400	410	**380**
2016	418	442	389	365	348	347	343	343	345	354	358	379	**369**
2017	367	371	375	345	340	340	331	332	333	344	406	432	**360**
2018	401	381	372	348	343	338	330	327	332	348	352	368	**353**
2019	394	396	357	333	327	316	317	317	325	333	377	?	?
Minimum	367	371	357	333	327	316	317	317	325	333	352	368	353
Average	**408**	**416**	**383**	**349**	**340**	**336**	**336**	**336**	**340**	**350**	**376**	**396**	**366**
Maximum	463	456	405	365	350	347	347	348	359	377	406	432	380

2.4 Waiwhakaiho River flows and seasonality

Appendix A presents time-series plots of the entire flow record for the two gauges on the Waiwhakaiho River: SH3/ Egmont Village and Rimu Street.

Figures 2.1 and 2.2 (located at the end of Section 2) are plots of the time-series flows for these two sites from January 2013 to April 2020, the period used for Lake Mangamahoe water balance assessment, as described in Section 3.2 later. Continuous measurements of the flow diverted into the tunnel from the Waiwhakaiho River is only available from January 2013, and this effectively sets a limit on the start date for the water balance assessment. Figure 2.3 is a time-series plot of the superimposed flow records from both sites on the same time axis. As expected, both records are closely correlated in terms of timing and magnitude of floods and freshes. The flows at Rimu Street, however, has high frequency fluctuations that reflect the operation of the Mangorei power station. Intra-day low flows in the Rimu Street record are typically lower than at SH3.

Table 2.4 provides a tabulation of the mean monthly flows recorded at the SH3 site from March 1980 to April 2020, while Table 2.5 presents the mean monthly flows for the Rimu Street site from May 2009 to May 2020. Figure 2.4 is a histogram plot of the monthly mean flow (the river flow for a particular month averaged across all years) for both sites for their overlapping record period (2009 to 2020), which shows the seasonal pattern in the flow behaviour.

A strong seasonal pattern in the river flows is observed. For example, at SH3, the mean flow in the 6 months from May to October (of 9.4 m^3/s) is about 1.6 times the mean flow for the other six months of the year (5.9 m^3/s). The difference is slightly greater again in the lower reaches, i.e. at Rimu Street, the mean flow from May to October (14.2 m^3/s) is about 1.7 times the mean flow from November to April (8.4 m^3/s). An inference from this statistic is that in the summer months, the upper and middle catchment provides a relatively larger percentage of the overall river compared with the winter months. On average and in round terms, the mean monthly river flow at Rimu Street is about 50% greater than at SH3.

Table 2.4 Waiwhakaiho at SH3 mean monthly flows for full record 1980 to 2020

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
	Waiwhakaiho at SH3 (Node 1): Mean monthly river flow (m^3/s)												
1980	?	?	8.97	8.93	7.55	11.40	8.76	9.41	9.62	7.61	6.93	5.63	8.40?
1981	3.58	5.35	7.33	5.20	4.88	11.57	9.92	8.43	10.22	9.40	7.22	6.96	7.51
1982	3.69	5.86	5.45	4.31	8.16	8.42	5.07	3.95	12.14	4.96	6.68	15.33	7.00
1983	5.55	2.67	2.96	11.79	8.50	5.21	6.63	8.51	11.01	11.72	13.76	7.26	7.98
1984	5.20	3.83	8.71	4.42	7.38	5.25	11.52	7.75	4.55	5.51	5.88	8.96	6.62
1985	7.34	2.69	4.65	5.65	3.79	10.08	9.91	7.37	5.95	5.29	6.74	9.34	6.59
1986	17.18	9.72	3.61	5.96	9.50	7.86	10.06	10.76	9.21	13.10	3.90	4.69	8.81
1987	5.68	2.97	7.78	7.97	10.13	7.34	3.58	4.94	6.35	10.58	6.36	11.55	7.13
1988	2.89	2.80	6.06	3.34	9.65	11.02	12.61	12.04	11.59	14.37	9.69	6.51	8.59
1989	6.93	7.21	6.72	6.69	7.40	15.28	10.51	4.70	4.70	13.28	8.84	5.97	8.18
1990	8.75	3.27	20.81	8.86	9.50	7.02	9.13	12.56	5.22	9.38	10.83	3.74	9.15
1991	9.94	5.86	3.05	9.91	3.61	7.10	9.04	13.88	5.89	9.88	4.36	6.36	7.42
1992	10.40	10.89	6.60	3.91	5.84	5.45	10.84	13.47	8.28	12.22	4.70	10.94	8.64
1993	4.36	3.35	4.61	5.77	12.49	11.24	3.03	5.99	7.84	8.57	6.65	4.50	6.54
1994	4.50	3.07	5.92	5.13	8.53	14.02	8.39	10.52	9.16	6.05	17.61	4.87	8.15
1995	5.51	8.19	8.70	13.57	5.96	8.91	10.23	10.30	12.77	10.11	10.38	5.99	9.20
1996	6.35	7.89	4.97	12.07	8.03	8.24	11.10	10.50	10.52	11.12	8.42	10.37	9.13
1997	4.86	5.02	5.47	5.99	5.48	7.38	5.58	7.29	7.55	10.46	7.69	12.46	7.12
1998	6.87	7.61	5.53	6.13	8.75	10.30	21.51	6.23	12.28	37.63	5.72	6.72	11.33
1999	7.11	4.31	6.03	5.57	12.95	8.66	8.03	10.65	7.45	7.96	11.52	6.46	8.09
2000	9.04	3.12	2.20	7.63	8.33	7.03	5.52	6.05	10.64	13.44	3.22	6.14	6.89
2001	3.22	3.55	3.86	2.99	7.43	8.17	6.14	9.80	4.08	12.49	12.38	14.73	7.44
2002	4.72	7.24	5.38	4.09	7.78	12.96	9.31	10.37	13.99	5.34	6.12	8.26	7.96
2003	2.64	2.10	4.54	3.51	7.67	8.45	5.89	4.38	12.88	10.69	6.48	9.25	6.56
2004	5.68	23.94	4.94	6.61	8.32	13.32	9.15	8.29	13.08	10.49	5.28	7.85	9.64
2005	7.67	3.95	5.29	3.37	11.90	7.84	10.55	4.09	5.97	7.83	2.22	6.13	6.44
2006	5.54	2.62	2.61	6.13	8.73	8.59	7.51	10.28	4.48	10.30	16.07	6.74	7.49
2007	4.90	2.35	6.26	3.81	6.57	10.94	12.64	10.26	4.61	11.81	5.03	4.79	7.04
2008	3.74	3.09	5.73	9.80	5.04	8.42	20.57	13.43	8.21	15.25	10.24	6.90	9.25
2009	3.85	9.20	4.23	5.68	6.22	5.54	7.21	10.37	10.00	8.89	5.01	7.41	6.95
2010	3.63	4.20	3.09	3.31	9.45	12.75	3.90	12.68	19.12	5.95	2.62	11.16	7.66
2011	3.93	3.22	6.86	7.08	13.26	12.13	7.49	4.75	5.98	13.17	8.26	16.36	8.59
2012	6.46	7.32	10.39	2.78	7.37	8.34	12.70	7.97	8.27	9.84	4.52	7.05	7.77
2013	3.75	4.50	2.80	6.51	9.63	7.11	5.30	6.48	11.21	11.34	4.21	6.54	6.62
2014	7.77	2.19	2.26	9.06	6.45	11.19	5.05	9.75	6.16	7.18	7.59	6.96	6.82
2015	2.51	5.32	4.48	13.54	12.39	16.16	8.04	13.30	7.72	4.96	6.46	3.59	8.20
2016	5.35	5.43	4.79	5.13	11.64	9.16	11.98	8.80	13.06	9.68	15.07	7.09	8.94
2017	10.87	7.70	5.77	9.88	9.91	4.60	13.85	17.55	13.32	7.98	5.14	2.21	9.08
2018	7.42	6.79	6.41	7.13	11.22	5.97	12.34	10.76	5.78	5.75	6.60	4.50	7.57
2019	2.60	2.40	4.41	8.34	7.38	7.22	13.15	9.80	6.45	7.32	5.77	7.49	6.90
2020	2.21	2.58	2.85	4.30	?	?	?	?	?	?	?	?	?
Minimum	2.21	2.10	2.20	2.78	3.61	4.60	3.03	3.95	4.08	4.96	2.22	2.21	6.44
Average	5.85	5.38	5.68	6.63	8.37	9.19	9.34	9.21	8.93	10.22	7.55	7.64	7.87
Maximum	17.18	23.94	20.81	13.57	13.26	16.16	21.51	17.55	19.12	37.63	17.61	16.36	11.33

Table 2.5 Waiwhakaiho at Rimu Street mean monthly flows for full record 2009 to 2020

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
	Waiwhakaiho at Rimu Street (Node 7): Mean monthly river flow (m^3/s)												
2009	-	-	-	-	9.38	8.61	11.30	14.37	16.08	15.65	7.68	13.61	-
2010	5.36	6.08	3.82	3.93	14.68	19.79	6.42	19.30	29.67	8.92	2.88	15.13	11.35
2011	4.80	3.63	8.39	9.46	20.11	20.45	12.65	7.24	9.39	19.82	11.77	23.84	12.70
2012	9.83	9.84	15.74	3.68	9.87	13.38	19.37	15.25	13.77	16.08	7.30	11.01	12.14
2013	5.89	5.86	3.76	10.25	17.76	13.16	8.48	9.98	17.80	18.54	7.00	10.95	10.81
2014	12.18	2.84	2.92	13.14	10.42	18.38	8.89	14.53	9.32	11.46	12.43	12.93	10.82
2015	5.87	8.68	6.61	22.35	18.60	23.39	13.53	21.03	12.77	8.24	10.71	6.06	13.14
2016	7.34	6.35	5.99	7.18	15.74	13.84	17.65	13.66	18.78	13.85	20.69	11.38	12.72
2017	16.74	12.94	8.41	15.62	15.93	8.42	22.19	27.39	18.22	11.12	6.27	2.25	13.82
2018	8.49	7.62	8.20	9.13	16.09	8.83	15.62	15.31	7.12	6.65	8.21	5.15	9.73
2019	2.76	2.41	5.15	10.84	9.06	9.06	17.52	13.88	8.04	9.74	6.66	9.09	8.73
2020	2.32	2.71	3.23	4.83	11.47	-	-	-	-	-	-	-	-
Minimum	2.32	2.41	2.92	3.68	9.06	8.42	6.42	7.24	7.12	6.65	2.88	2.25	8.73
Average	7.42	6.27	6.57	10.03	14.09	14.30	13.96	15.63	14.63	12.73	9.24	11.04	11.60
Maximum	16.74	12.94	15.74	22.35	20.11	23.39	22.19	27.39	29.67	19.82	20.69	23.84	13.82

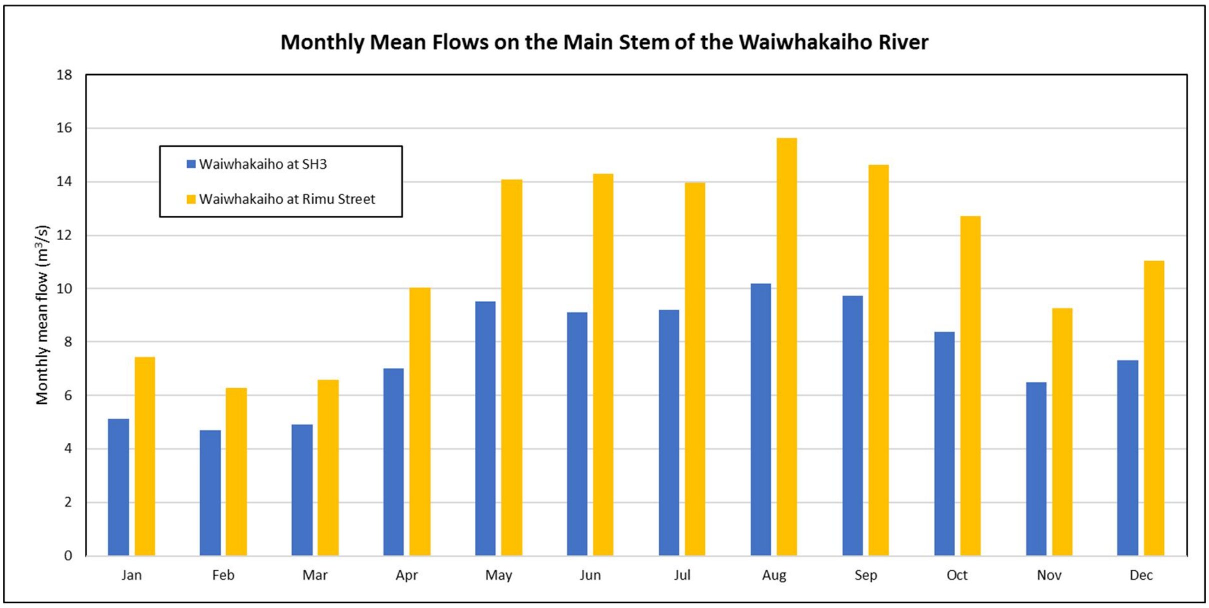

Figure 2.4 Waiwhakaiho River: mean flow distribution by month-of-year, for period 2009-2020

The Waiwhakaiho at SH3 flow record (1980 to 2020) is long enough for a trend analysis of its overall water resource availability on a year-to-year basis, and this is shown in Figure 2.5. There is significant variability in the yearly mean flows (shown by dark blue bars in Figure 2.4). However, the linear trendline (dotted black line) of yearly mean flows is almost perfectly horizontal, indicating no increasing or reducing trend.

Summer mean flows (taken as the flow averaged over December, January and February each year, and shown by the hatched red bars) indicate even greater inter-annual variability than the yearly mean flows. This variability is displayed more obviously in Figure 2.6 which shows the summer flow series and the 5-year and 10-year moving averages. The linear trendline fitted to the summer mean flows in Figure 2.5 suggests a decline of roughly 34 l/s per annum in the summer mean flow. However, this cannot be regarded as conclusive as the correlation is very weak ($R^2 = 0.0357$) and the inter-annual variability is large. Despite the apparent decline in summer flows, the yearly mean flows have not demonstrated a similar drop, and that is because winter flows have been increasing (see Figure 2.7), thus offsetting the possible decline in summer flows.

It is noted that the driest summer in the 40-year record for the Waiwhakaiho at SH3 occurred in 2019 (December 2018 to February 2019), while the most recent summer (December 2019 to February 2020) was the fourth driest. However, based on the average flow recorded between January and April each year, 2020 was the driest period on record (mean flow 2.98 m^3/s) followed by 2003 (mean flow 3.22 m^3/s).

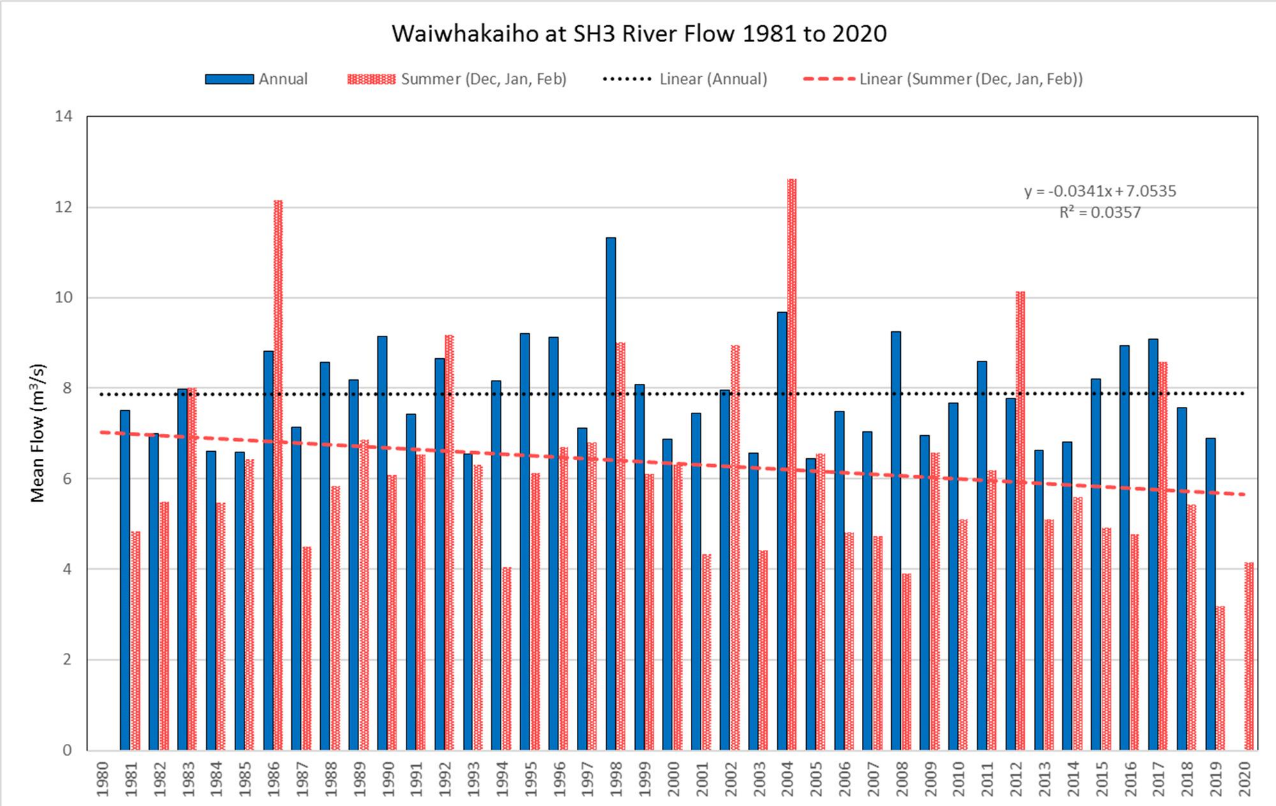

Figure 2.5 Waiwhakaiho at SH3 annual and summer mean flow series over 40 years, 1981 to 2020

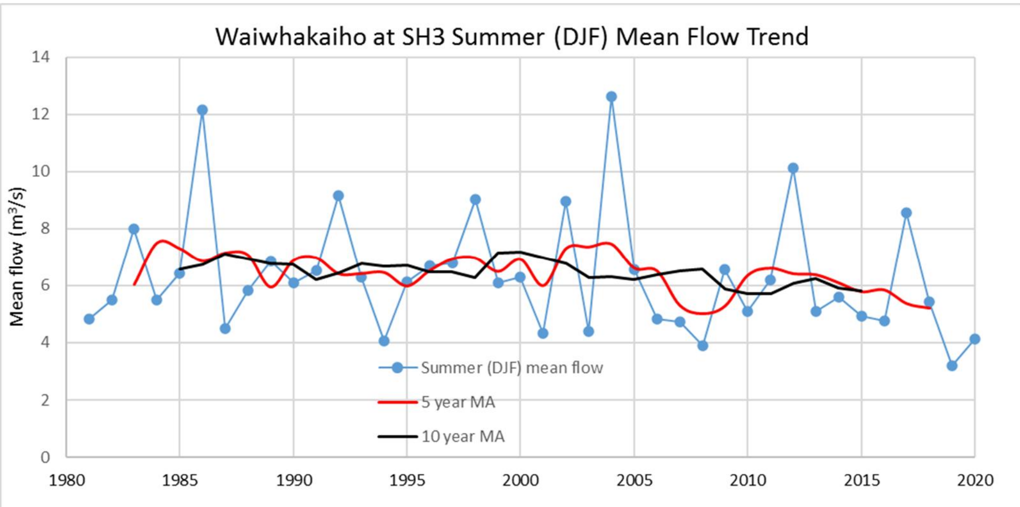

Figure 2.6 Waiwhakaiho at SH3 summer mean flow series 1981 to 2020. Summer mean flow is the averaged flow for December, January and February

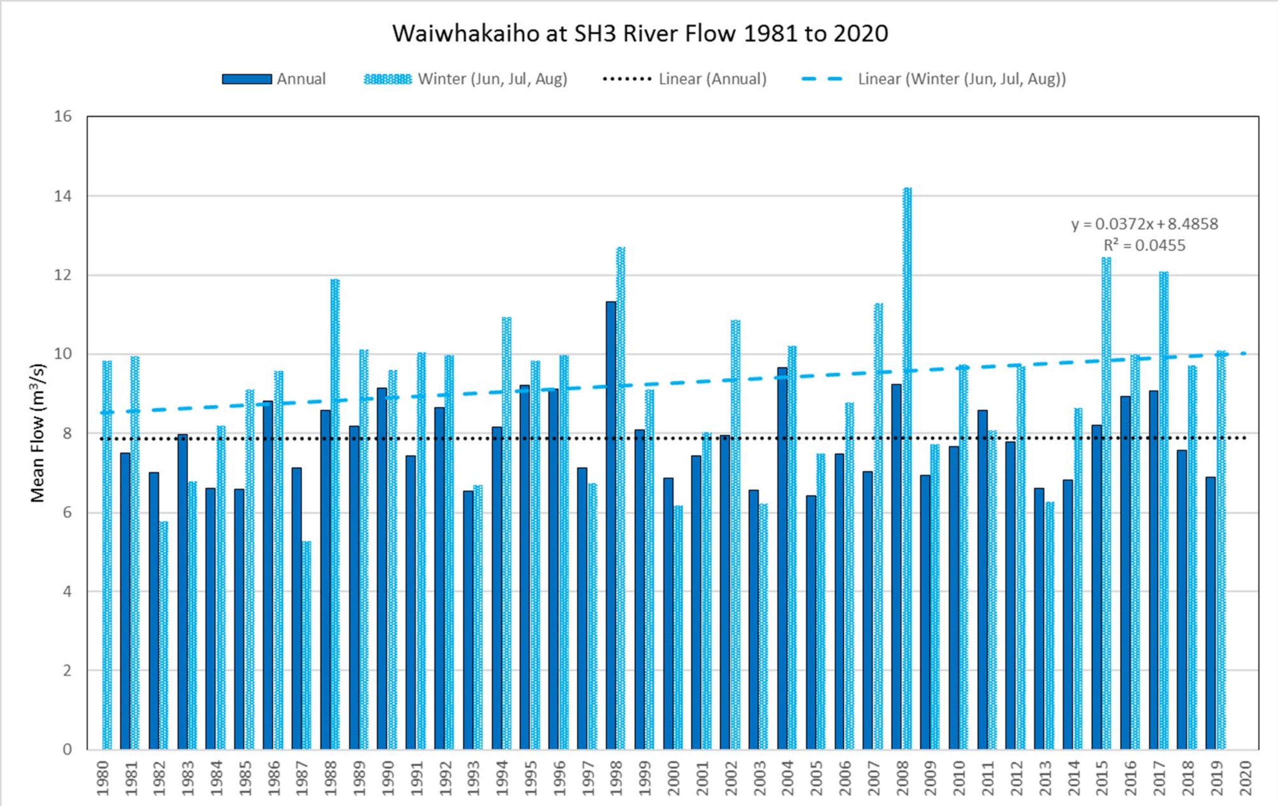

Figure 2.7 Waiwhakaiho at SH3 annual and winter mean flow series over 40 years, 1981 to 2020

2.5 Waiwhakaiho River flow duration

Time-series plots of flows (hydrographs) may be condensed into flow duration curves, which are effectively cumulative probability plots of the flow distribution, constructed from a complete ranked series (e.g. from the highest floe to the lowest flow) of the recorded flows. This flow duration curve may be considered the unique signature the flow record. Figure 2.8 presents flow duration plots of the Waiwhakaiho River at SH3 and Rimu Street for their overlapping record period i.e. April 2009 to April 2020. In Figures 2.9 and 2.10, a separate flow duration curve for each season (summer = Dec, Jan, Feb; autumn = Mar, Apr, May; winter = Jun, Jul, Aug; and spring = Sep; Oct; Nov) is plotted in addition the annual (full year) curve for the SH3 and Rimu Street sites respectively.

Table 2.6 tabulates the flow duration ordinates corresponding with the plots on Figures 2.9 and 2.10. The median flow is given by the flow that is exceeded 50% of the time i.e. 3.94 m^3/s for SH3 and 6.65 m^3/s for Rimu Street. A flow of 85 m^3/s at SH3, which is significant in terms of the operation of the intake headworks on the Waiwhakaiho River (it is the river flow above which the diversion is required to cease – see Section 3.1 Existing Consents), is exceeded only 0.82% of the time based on the full record from 1980 to 2020, and 0.68% of the time based on the more recent water balance period from January 2013 to April 2020 (see Section 3.2 regarding the water balance).

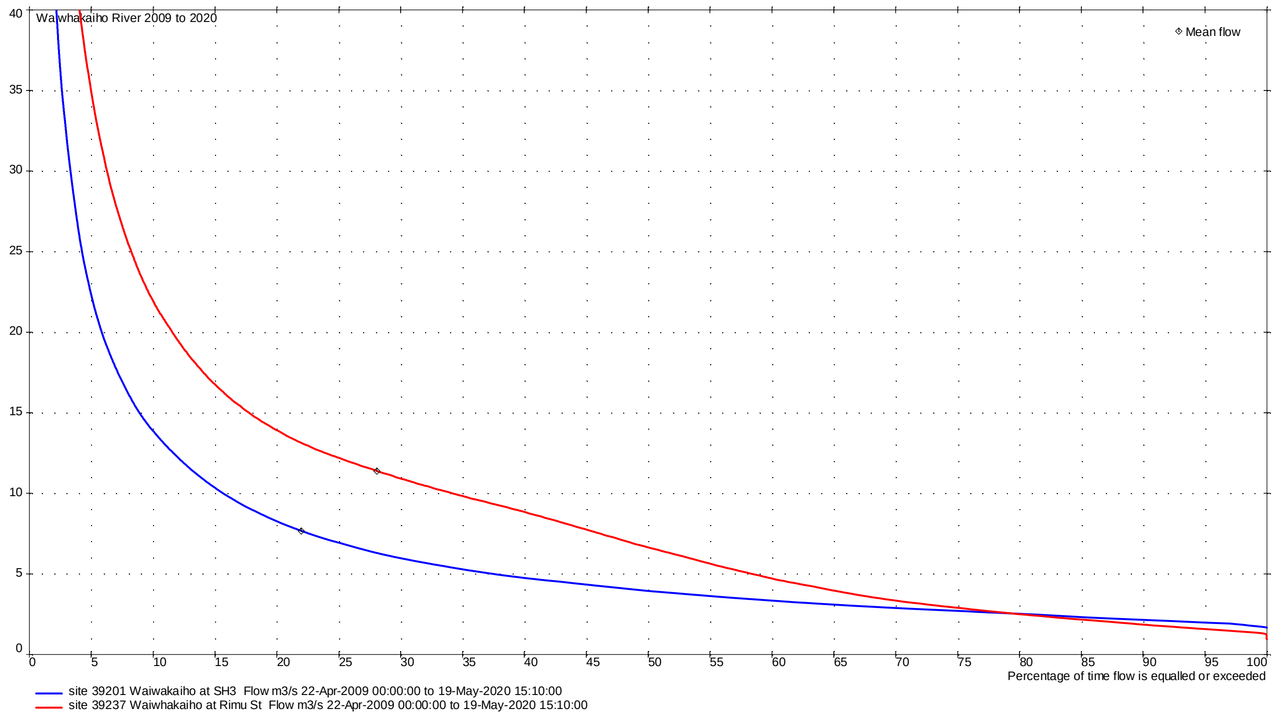

Figure 2.8 Waiwhakaiho River flow duration curves April 2009 to May 2020. Blue curve – Waiwhakaiho at SH3; red curve – Waiwhakaiho at Rimu Street. Mean flow on each curve is indicated by diamond marker.

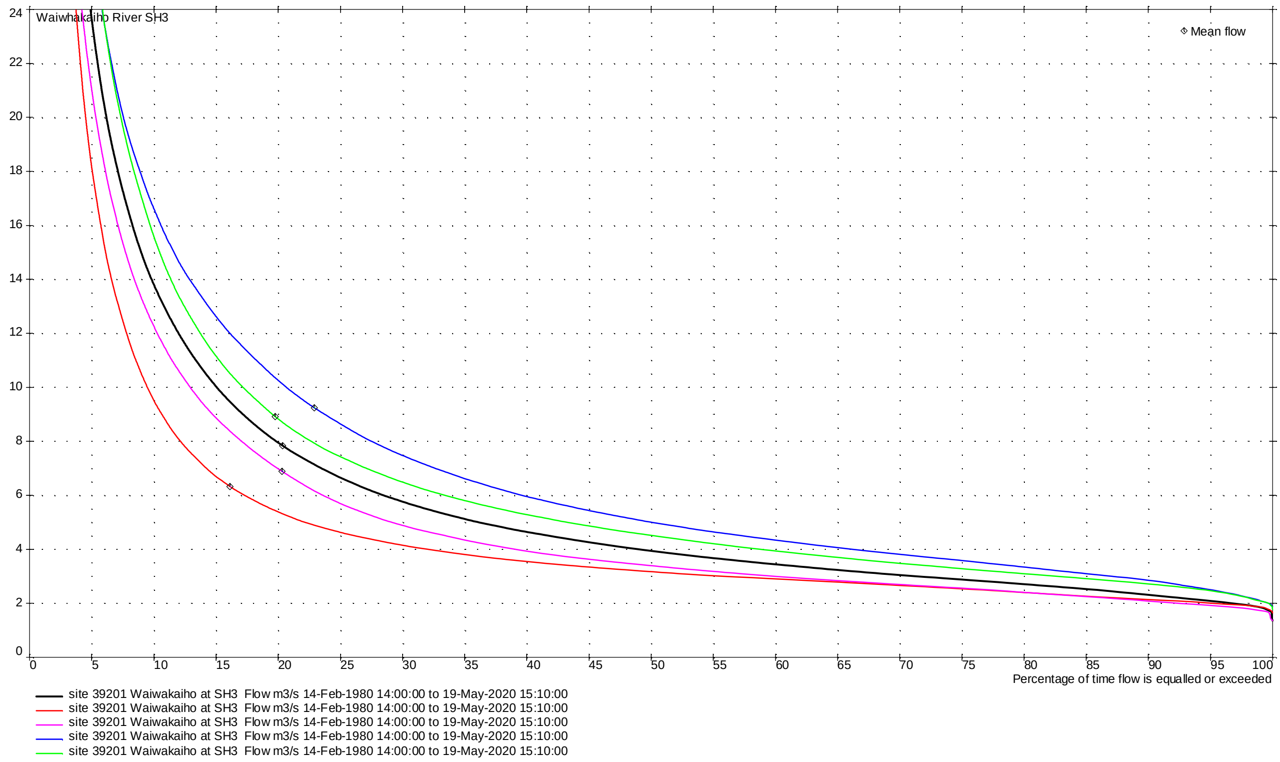

Figure 2.9 Waiwhakaiho River at SH3 flow duration curve, Feb 1980 to May 2020. Red curve – summer (D, J, F); magenta curve – autumn (M, A, M); blue curve – winter (J, J, A); green curve – spring (S, O, N); black curve – full year. Mean flow on each curve is indicated by diamond marker.

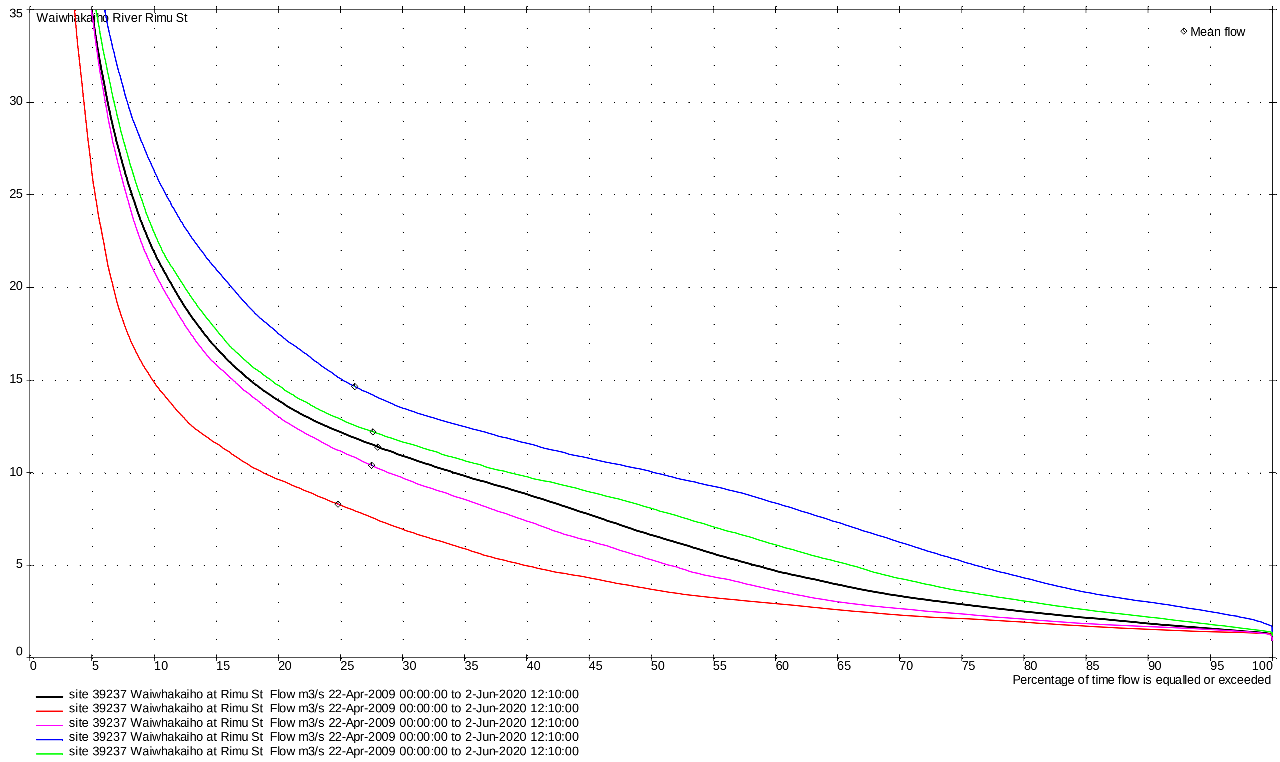

Figure 2.10 Waiwhakaiho River at Rimu Street flow duration curve Apr 2009 to May 2020. Red curve – summer (D, J, F); magenta curve – autumn (M, A, M); blue curve – winter (J, J, A); green curve – spring (S, O, N); black curve – full year. Mean flow on each curve is indicated by diamond marker.

Table 2.6 Waiwhakaiho River at SH3 and Rimu Street flow duration data (from full records)

% time flow is exceeded	Waiwhakaiho at SH3 (m^3/s)					Waiwhakaiho at Rimu St (m^3/s)				
	Annual	Summer DJF	Autumn MAM	Winter JJA	Spring SON	Annual	Summer DJF	Autumn MAM	Winter JJA	Spring SON
1	76.37	69.30	67.57	79.71	87.17	96.29	86.74	89.48	117.98	94.91
2	47.90	41.98	41.73	50.08	56.91	63.06	56.82	61.00	70.23	64.46
5	23.69	18.20	21.08	26.82	27.52	34.98	26.27	34.81	39.36	36.41
10	13.82	9.524	12.28	16.64	15.61	21.94	14.90	20.90	26.34	23.00
20	7.956	5.388	6.987	10.264	8.835	13.92	9.634	13.08	17.52	14.72
30	5.766	4.151	4.889	7.479	6.491	10.92	6.942	9.752	13.49	11.66
40	4.644	3.549	3.93	5.953	5.285	8.853	4.97	7.398	11.59	9.774
50	3.942	3.170	3.394	5.007	4.52	6.646	3.702	5.319	10.05	8.075
60	3.445	2.905	2.999	4.341	3.94	4.715	2.927	3.659	8.357	6.104
70	3.047	2.663	2.697	3.816	3.483	3.344	2.309	2.661	6.24	4.284
80	2.710	2.400	2.404	3.346	3.098	2.501	1.921	2.085	4.319	3.069
90	2.315	2.139	2.085	2.855	2.717	1.853	1.535	1.686	3.014	2.203
95	2.088	2.006	1.92	2.507	2.467	1.578	1.41	1.529	2.493	1.797
98	1.928	1.914	1.798	2.218	2.207	1.414	1.346	1.402	2.117	1.556
99	1.852	1.867	1.733	2.099	2.086	1.363	1.323	1.339	1.944	1.481

The flow duration curves and the data in the table indicate that, for both sites, winter (June to August) experiences the highest average flows, followed by spring and then autumn, with summer (December to February) being the driest season.

Figure 2.8, which compares the flow duration curves for the SH3 and Rimu Street sites, shows that the curves cross-over at about the 80th percentile exceedance flow. This indicates that under low flow conditions, the magnitude of the flow at SH3 is typically similar or higher than at Rimu Street downstream, despite the larger contributing catchment at the latter site. In contrast, the median flow at Rimu Street appears artificially elevated. It may be inferred that operation of the Mangorei scheme is, to a large extent, the cause of these behaviours. Comparison of Figures 2.9 and 2.10 show that the seasonal flow duration curves at Rimu Street are more “divergent” than at SH3 (for which the seasonal curves plot more uniformly and closer together). Again, the operation of the Mangorei scheme may be responsible for the difference in behaviour.

2.6 Waiwhakaiho River low flow characteristics

The flow records for SH3 and Rimu Street have been analysed to assess the frequency and severity of low flow events. As is current practice, these assessments are based on frequency analysis of the annual minimum 7-day averaged flows (rather than the minimum daily flow or minimum instantaneous flow).

Figures 2.11 shows the General Extreme Value (GEV) and Log Normal frequency distributions fitted to the annual 7-day low flow series for SH3 from 1981 to 2020. There is an obvious outlier in the series i.e. 1.42 m^3/s on 31 March 2009. By omitting this outlier, a better-fitting frequency distribution (GEV) is found, as plotted in Figure 2.12 (dashed red curve).

The 7-day mean annual low flow (7-day MALF) based on this series is 2.11 m^3/s (and is 2.095 m^3/s if the 2009 outlier is included), and the 5-year 7-day low flow 1.84 m^3/s. In Figure 2.12, the frequency distribution based on the annual 1-day low flow series is also shown for comparison (dotted blue curve). The 1-day MALF is 2.04 m^3/s, which is only marginally lower than the 7-day MALF of 2.11 m^3/s. Of the 39 annual minima, 30 (77%) have occurred between February and April, and 36 (92%) between December and April.

Substituting the 2009 outlier with an alternative value of 1.64 m^3/s as suggested by CH2M Beca (2020) changes the 7-day MALF by 0.5% and the low flow frequency results by less than 2%.

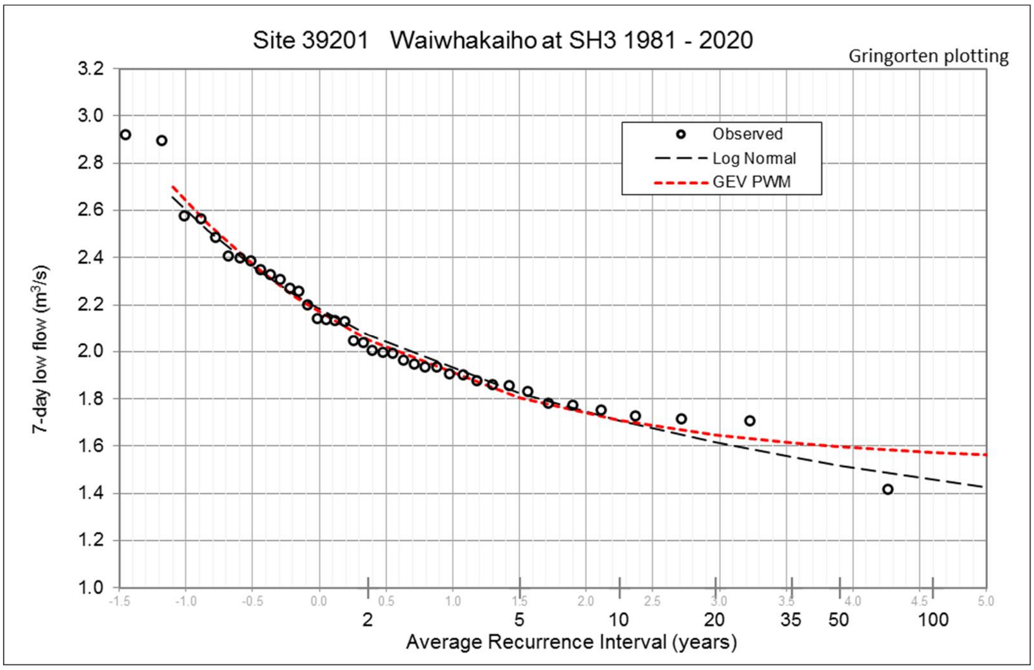

Figure 2.11 Waiwhakaiho at SH3 frequency analysis of 7-day low flows. General Extreme Value (GEV) and Log Normal (LN) frequency curves are shown.

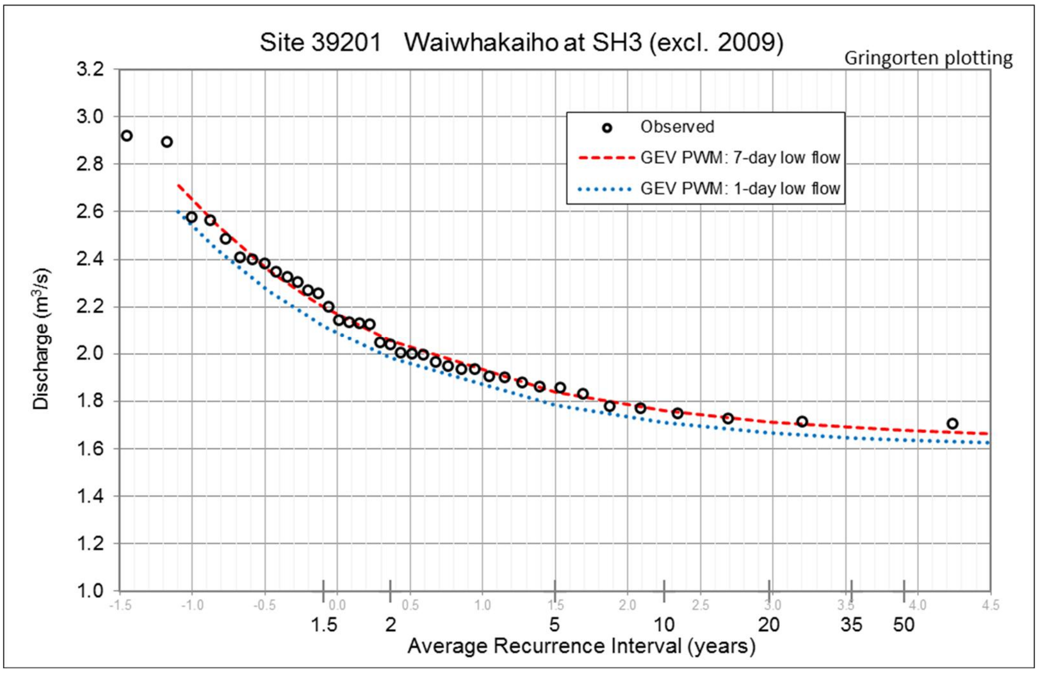

Figure 2.12 Waiwhakaiho at SH3 frequency analysis of 7-day low flows with the 2009 outlier omitted. The 1-day low flow curve is also shown for comparison. General Extreme Value (GEV) are good fites to both data series.

The Rimu Street site has a far shorter record of 11 years for frequency analysis of low flows 2010 to 2020. The fitted frequency curve to the 7-day annual low flow series, excluding the oddly high value of 3.68 m^3/s in March 2017, is shown in Figure 2.13. The 7-day mean annual low flow (7-day MALF) based on this series is 2.05 m^3/s (and is 2.20 m^3/s if the 2017 outlier is included). In Figure 2.13, the frequency distribution based on the annual 1-day low flow series is also shown for comparison (dotted blue curve). The 1-day MALF is 1.795 m^3/s, which is appreciably lower than the 7-day MALF, and the reason for this is that averaging over a shorter interval provides less opportunity for diurnal peaks from generation operation be included.

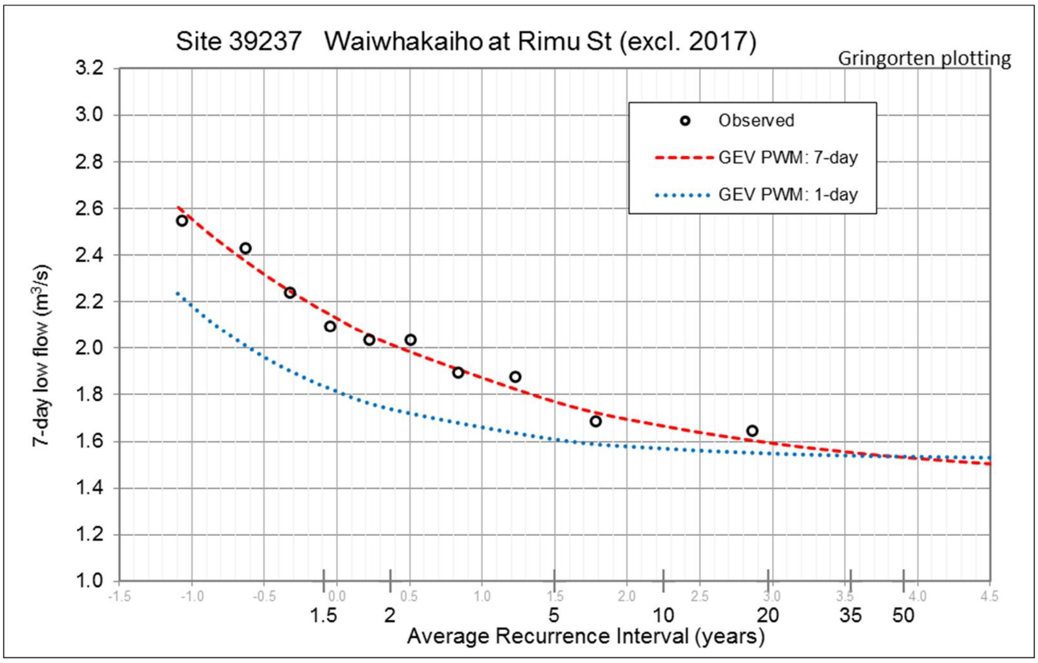

Figure 2.13 Waiwhakaiho at Rimu Street frequency analysis of 7-day low flows with the 2017 outlier omitted. The 1-day low flow curve is also shown for comparison.

The Waiwhakaiho at SH3 flow record (1980 to 2020) is long enough for a trend analysis of its annual minimum flow series, and this is shown in Figure 2.14. While there is significant variability in the annual minima (shown by the blue bars in Figure 2.14), the linear trendline (dotted blue line) fitted to this series suggests a decline of roughly 9 l/s per year. However, this cannot be regarded as conclusive as the correlation is reasonably weak ($R^2 = 0.11$) and the inter-annual variability is large. Nevertheless, any potential trend is significant in the derivation of a statistical index such as the 7-day MALF, which is conventionally determined from historical flow records that are assumed to be statistically stationary (non-trending). In percentage terms, the potential decline in 7-day MALF (0.4% per year) is roughly similar to the potential decline in summer flow (0.5% per year).

The annual minimum flow series for the Rimu Street site is also plotted in Figure 2.14 (orange bars). However, the record is too short for a meaningful trend assessment and furthermore, the low flows are affected by the operation of the Mangorei scheme.

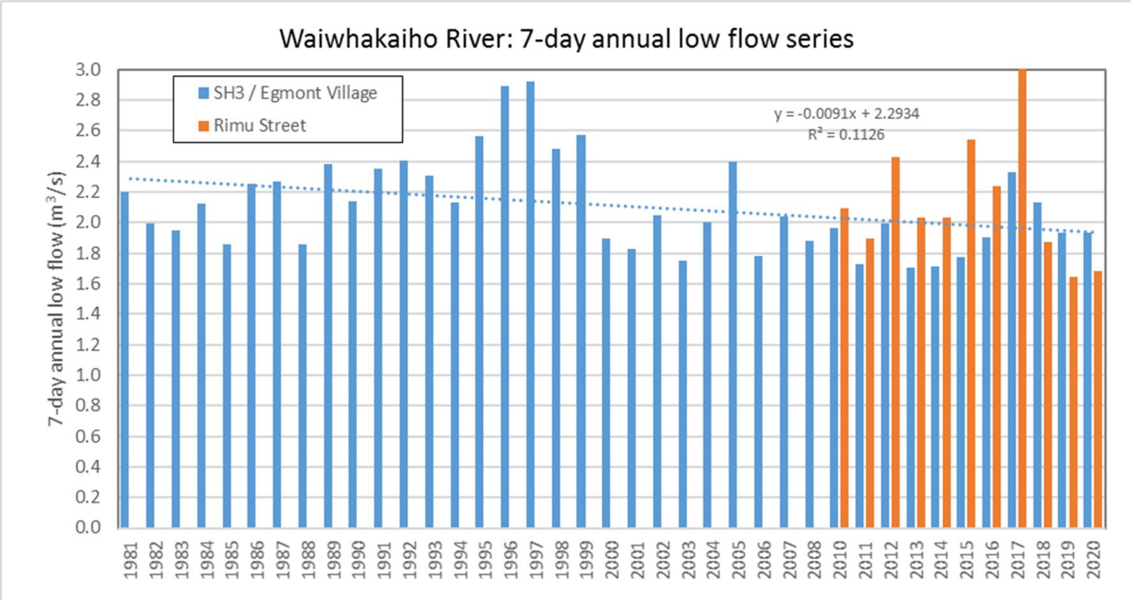

Figure 2.14 Waiwhakaiho River at SH3 and Rimu Street annual 7-day low flow series

2.7 Waiwhakaiho River flood flow regime

TRC's flow records for the SH3 and Rimu Street sites have been analysed to determine the frequency and magnitude of flood flows in the Waiwhakaiho River. These assessments are based on frequency analysis of the annual series of instantaneous maximum flows (i.e. the highest recorded flow in each year of record).

Figures 2.15 shows the Extreme Value Type 1 (EV1) frequency distribution fitted to the annual flood series for SH3 from 1980 to 2019. Figure 2.16 shows the EV1 distribution fitted to the shorter Rimu Street annual flood series from 2010 to 2019. The mean annual flood at SH3 and Rimu Street are, respectively, 333 m^3/s and 353 m^3/s. Large floods can occur at any time of the year, with the months of March and May/June experiencing the largest floods in the 40 year record for SH3. As described in more detail in Section 3.3, floods rise extremely quickly and recede rapidly as well, presenting challenges for managing the river intake and diversion to Lake Mangamahoe.

Table 2.7 summarises the peak flow estimates from these frequency distributions. The estimates for the lower river based on the Rimu Street record are less reliable than those based on the SH3 record because of the much shorter record length for Rimu Street. Notwithstanding, the available data indicates that floods recorded at Rimu Street are only slightly larger than at SH3 (roughly 10% larger), despite a contributing catchment that is almost twice the size compared with SH3. This is largely explained by the steep fall-off in storm rainfall depths and reduction in ground slopes from the headwaters of the catchment, as well as in-channel attenuation (storage), resulting in a marked decrease in the flood intensity from the upper catchment to the lower catchment.

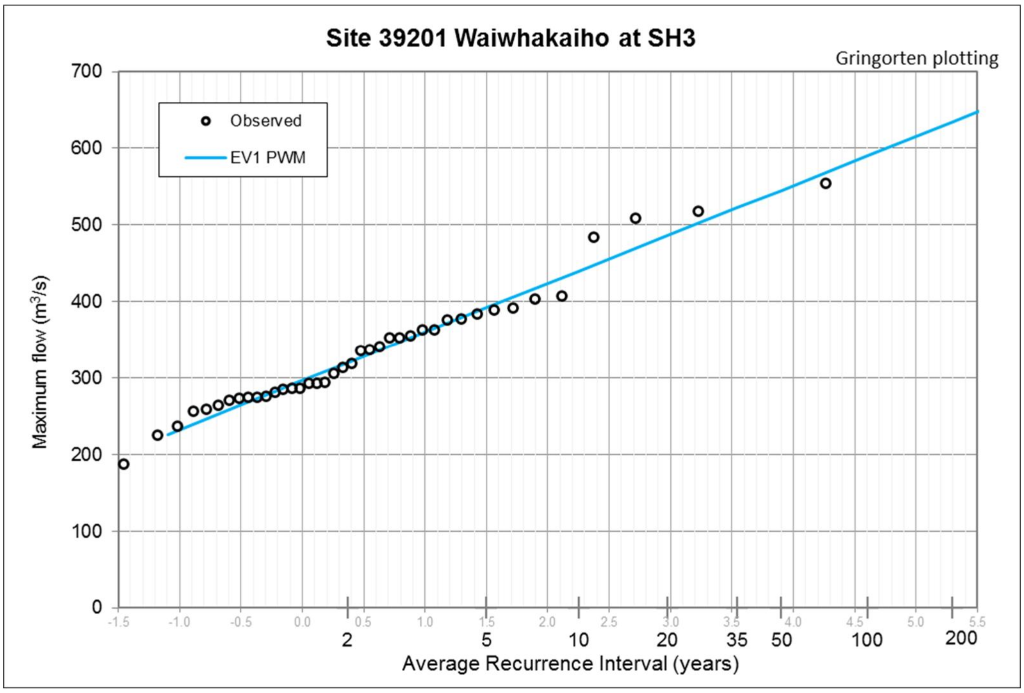

Figure 2.15 *Waiwhakaiho at SH3 flood frequency analysis based on annual flood series 1980 to 2019*

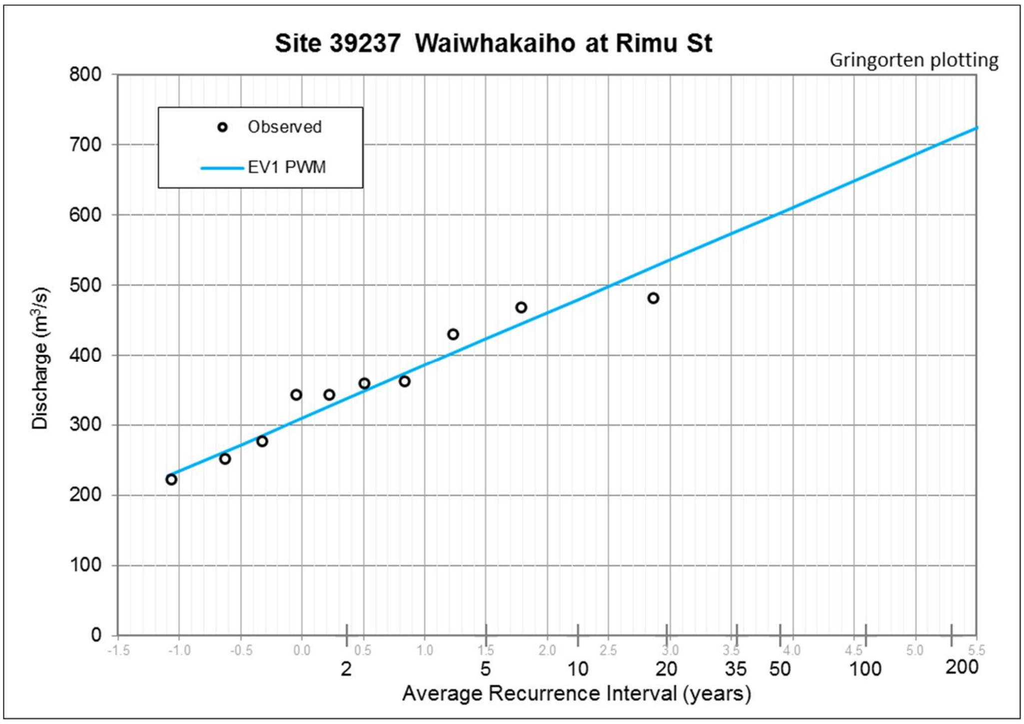

Figure 2.16 *Waiwhakaiho at Rimu Street flood frequency analysis, annual flood series 2010 to 2019*

Table 2.7 Waiwhakaiho River flood frequency

Location	Catchment Area (km^2)	Mean annual flood		5-year ARI flood		20-year ARI flood		100-year ARI flood	
		(m^3/s)	($m^3/s/km^2$)	(m^3/s)	($m^3/s/km^2$)	(m^3/s)	($m^3/s/km^2$)	(m^3/s)	($m^3/s/km^2$)
Waiwhakaiho at SH3	60.5	333	5.5	392	6.5	486	8.0	590	9.7
Waiwhakaiho at Rimu St	124	353	2.8	423	3.4	534	4.3	~660	~5.3

A plot of the annual flood series recorded for the Waiwhakaiho River at SH3 (1980 to 2019) is shown in Figure 2.17. The largest floods on record are the June 1980, March 1990, May 2007 and May 2015 events. There is no apparent trend in the SH3 flood series. The shorter Rimu Street annual flood series is also plotted (2010 to 2019) in Figure 2.17.

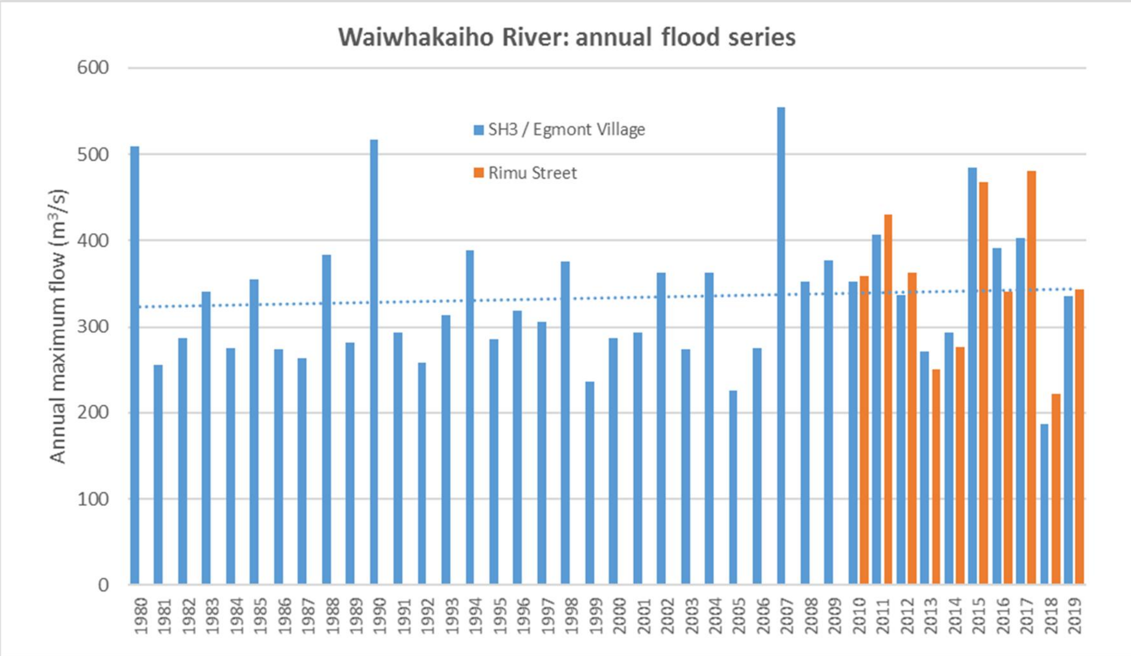

Figure 2.17 Waiwhakaiho River at SH3 and Rimu Street annual flood series

2.8 Summary

Table 2.8 below provides a selection of the key flow statistics for the Waiwhakaiho at SH3 and Rimu Street flow recording sites. As the statistics are influenced by the period of record used, values for common (overlapping) periods are also presented in the table in addition to statistics based on the full available record.

Table 2.8 Summary of flow statistics for the Waiwhakaiho River at SH3 and at Rimu Street

Site and Record Period	Flow Statistic					
Waiwhakaiho at SH3 (Catchment = 60.5 km^2)	100-year ARI Flood (m^3/s)	Mean Annual Flood (m^3/s)	Mean Flow (m^3/s)	Median Flow (m^3/s)	7-day Mean Annual Low Flow (m^3/s)	7-day 5 Year Low Flow (m^3/s)
Full Record: 14/2/1980 – 19/5/2020	590	333	7.84	3.94	2.11	1.84
Overlap with Rimu St: 22/4/2009 – 19/5/2020	-	346	7.67	3.95	2.10	-
[1] Water balance period: 24/1/13 – 30/4/2020	-	338	7.54	4.01	1.93	-
Waiwhakaiho at Rimu St (Catchment ≈ 124 km^2)	100 year ARI Flood (m^3/s)	Mean Annual Flood (m^3/s)	Mean Flow (m^3/s)	Median Flow (m^3/s)	7-day Mean Annual Low Flow (m^3/s)	7-day 5 Year Low Flow (m^3/s)
Full Record: 22/4/2009 – 19/5/2020	~660	353	11.39	6.65	2.05	1.77
[1] Water balance period: 24/1/13 – 30/4/2020	-	340	11.06	6.71	2.01	-

[1] Refer to Section 3.2 regarding the water balance period

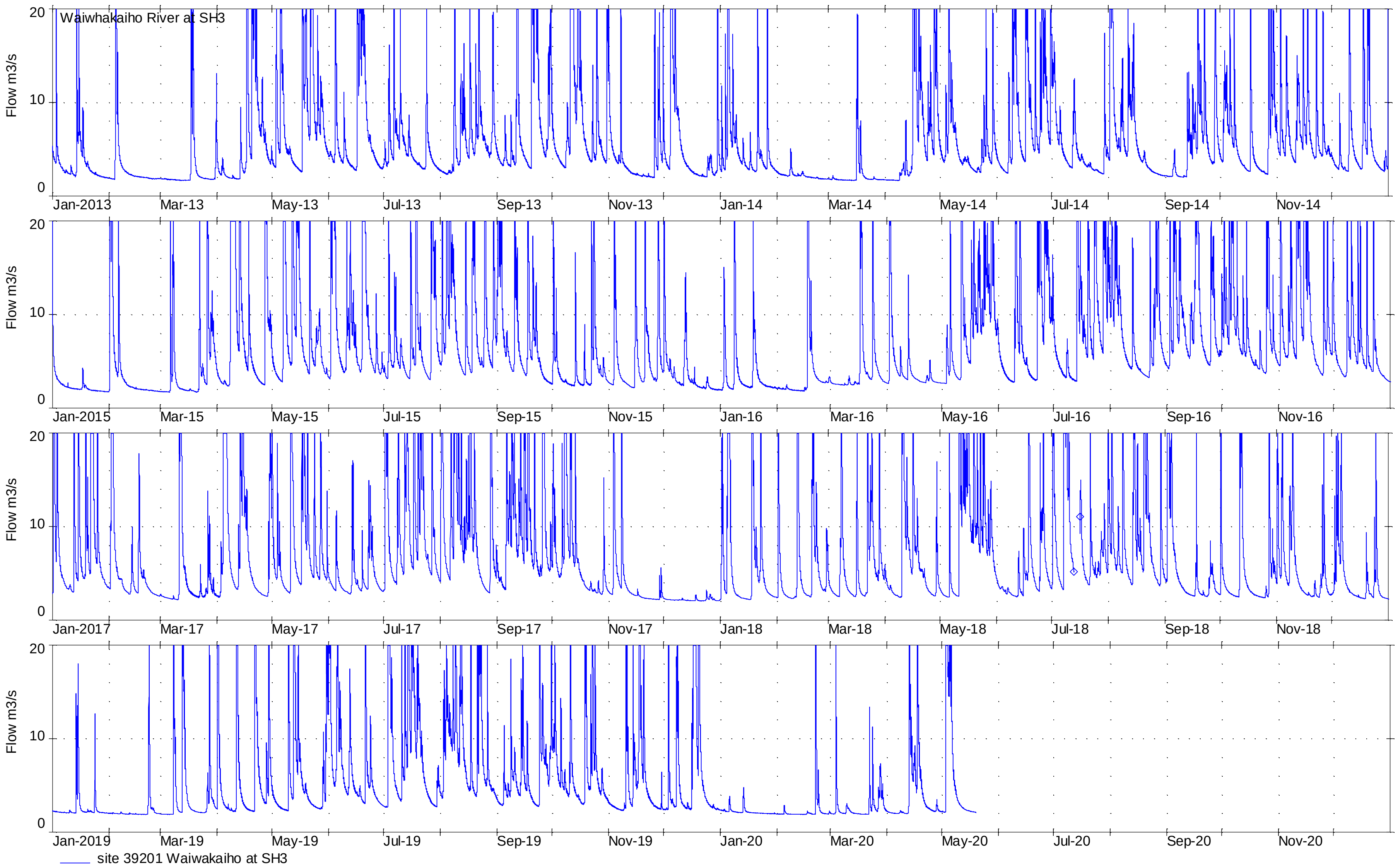

Figure 2.1 *Waiwhakaiho River at SH3 – flow record from January 2013 to May 2020*

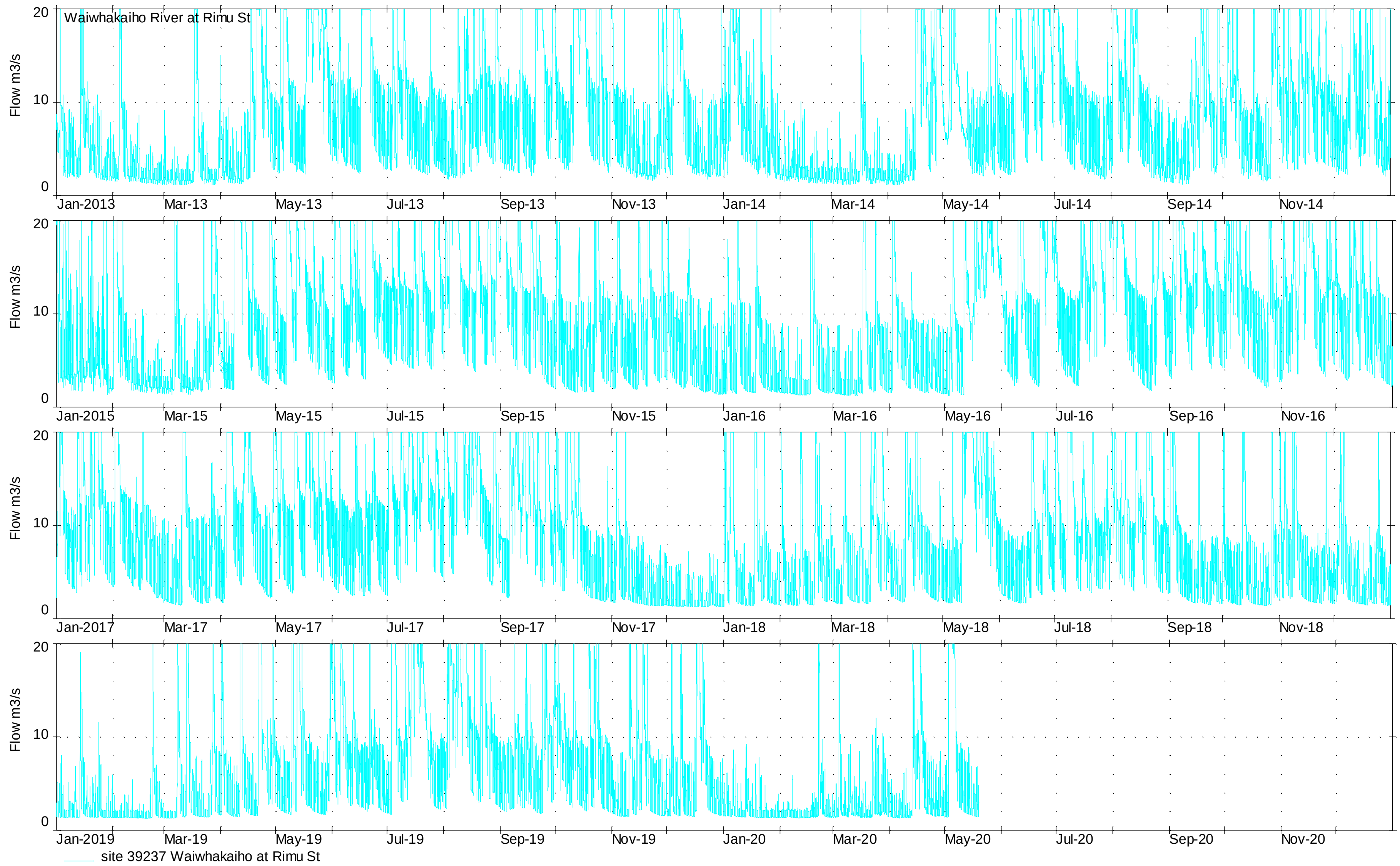

Figure 2.2 *Waiwhakaiho River at Rimu Street – flow record from January 2013 to May 2020*

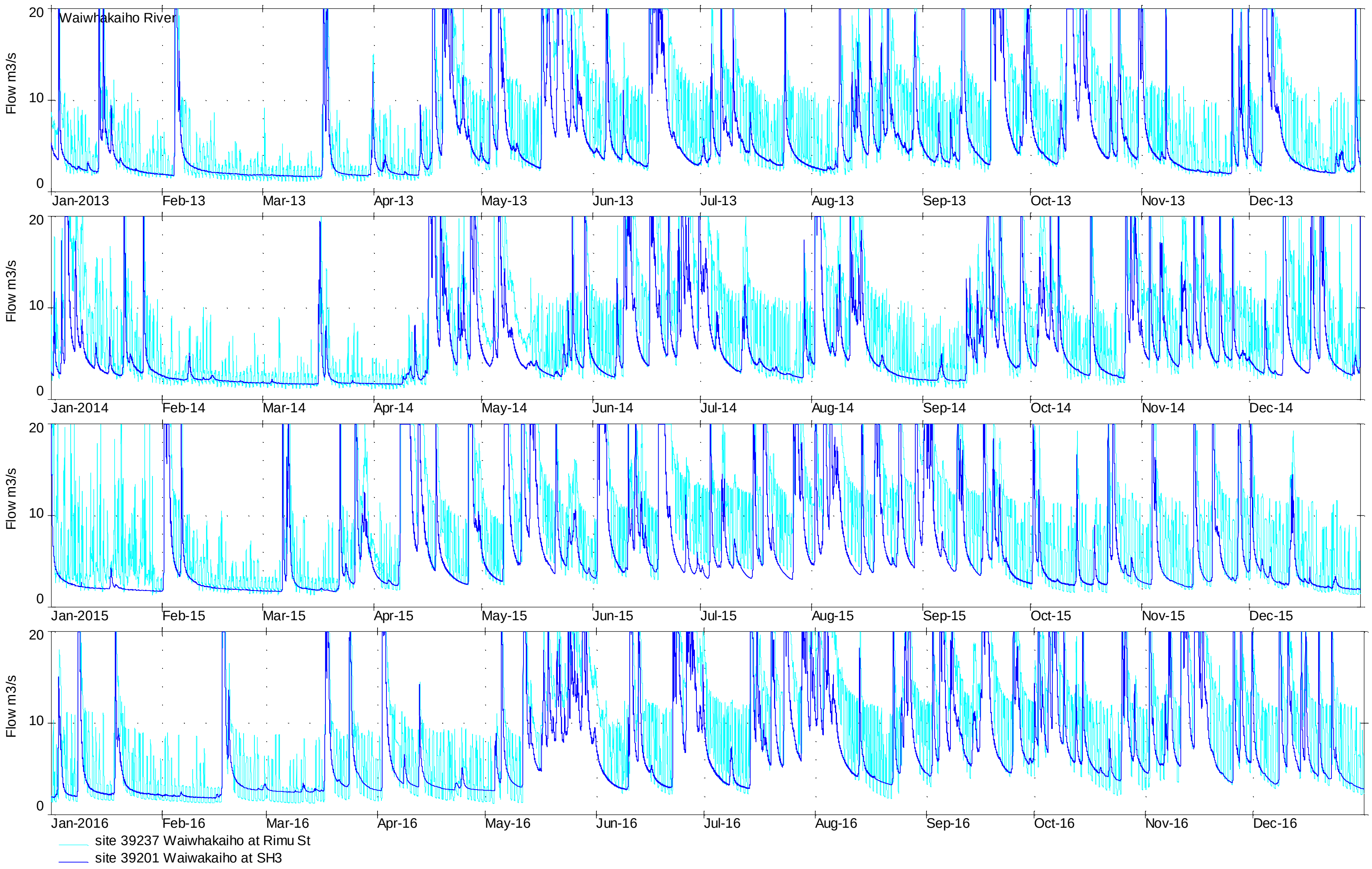

Figure 2.3 *Waiwhakaiho River flow time series at SH3 (blue hydrograph) and at Rimu Street (cyan hydrograph) from 2013 to 2016*

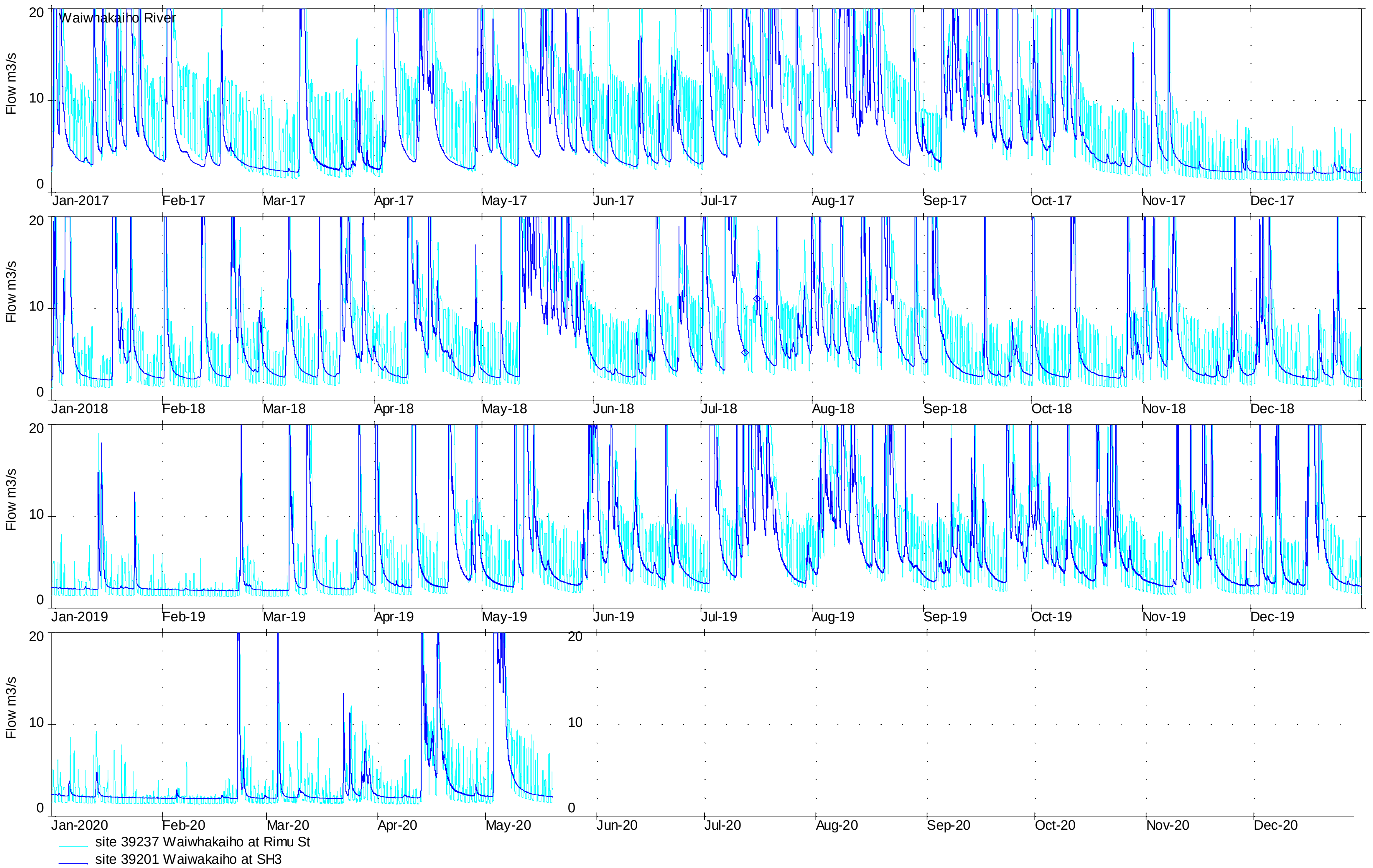

Figure 2.3a Waiwhakaiho River flow time series at SH3 (blue hydrograph) and at Rimu Street (cyan hydrograph) from 2017 to 2020

3 Current Mangorei HEPS Operating Regime

3.1 Existing consents

Figure 3.1 presents a schematic layout of the Mangorei scheme that shows the main components of the scheme and the relevant consent conditions for their operation that are associated with taking, diverting, using and damming surface water. Table 3.1 provides a summary of these consent conditions. All consents expire on 1 June 2021.

Table 3.1 Consent conditions relevant to hydrological operation of the Mangorei scheme

Consent number	Purpose	Relevant Special Conditions	Comment
2053 – 3.2	To divert up to 10 cubic metres per second of water from the Waiwhakaiho River via a diversion weir and associated intake structures into Lake Mangamahoe through the Mangorei HEPS and back into the river approx. six kilometres downstream of the diversion point.	1. That the consent holder shall maintain a continuous generation flow release of at least 950 litres/second between 8:00 am and 6:00 pm each day. 2. That the consent holder shall maintain, each 12-month period, the following minimum residual flows in the Waiwhakaiho River below the diversion weir: i) at least 700 litres/second between 1 January and 31 March; iii) at least 600 litres/second between 1 November and 31 December and during April; and iv) at least 400 litres/second between 1 May and 31 October. 3. No water shall be diverted when the flow in the Waiwhakaiho River is greater than or equal to 85 cubic metres per second.	Consent was granted 4 September 1996 and varied on 19 April 2013 to allow an increase in the diversion to 10 m^3/s from 7 m^3/s. It was varied again on 1 August 2017 to change the reporting date of the bathymetry survey.
2054 – 3	To dam the Mangamahoe Stream in the Waiwhakaiho Catchment to form Lake Mangamahoe to act as a reservoir of water for hydroelectric power generation purposes.	2. That the consent holder shall maintain a minimum lake level of 750 mm below the crest of the Mangamahoe spillway except during lake weed maintenance periods.	Consent was granted 4 September 1996.
2056 – 3.1	To use up to 864,000 cubic metres/day of water from Lake Mangamahoe in the Waiwhakaiho catchment for hydroelectric power generation purposes.	1. That the consent holder shall, as far as reasonably practicable, spread its generation during daylight hours in order to maximise the beneficial effect of artificial flows in the lower Waiwhakaiho River.	Consent was granted 4 September 1996 and varied on 16 June 2016 to increase the daily use to 864,000 m^3/day (10 m^3/s) from 735,000 m^3/day (8.51 m^3/s).
4888 – 1	To discharge up to 150,000 litres/second of water from Lake Mangamahoe via a spillway into the Mangamahoe Stream under emergency conditions associated with hydroelectric generation purposes.		Consent was granted 4 September 1996.

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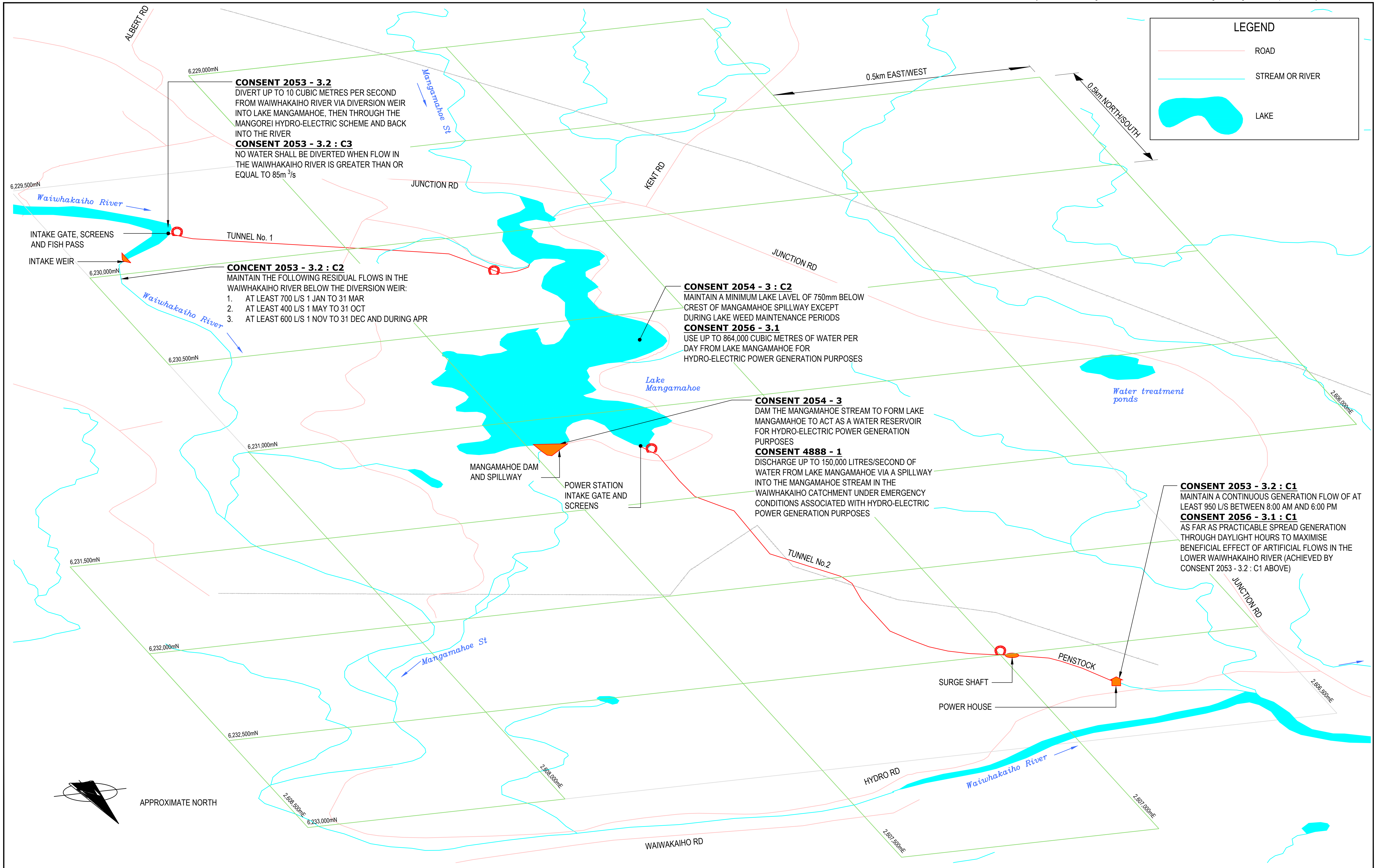

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PROJECT RECONSENTING OF MANGOREI HYDRO-ELECTRIC POWER SCHEME

TITLE MANGOREI HYDRO-ELECTRIC POWER SCHEME SCHEMATIC LAYOUT

UNDER REVISION 1

SCALE (A3) N.T.S FIG No. FIGURE 3.1 REV 1

Among the special conditions, the most operationally significant ones are for the diversion from the Waiwhakaiho River into the intake tunnel and the residual flow that must remain downstream of the diversion.

3.2 Scheme water balance

To understand the implications of the scheme's operation on river hydrology and to provide confidence in the reliability of the derived flow data for subsequent assessments, a water balance analysis for the scheme has been completed in which the sum of inflows to Lake Mangamahoe from all sources is tallied with the sum of the outflows from the lake for a particular period of time. If there is a significant discrepancy, then it is likely that there is a systematic error or bias in one of more of the flow records used in the water balance.

Table 3.2 summarises the water balance for Lake Mangamahoe (inflows and outflows) and the Mangorei HEPS. The selected "accounting" period is from 24 January 2013 to 30 April 2020, a timespan of about 7.3 years. A longer timespan would have been preferable but not possible as it is necessarily limited to the period for which all flow series required for the water balance assessment exist. In this case, the Waiwhakaiho diversion tunnel flow record, which began on 24 January 2013, is the limiting factor. Key observations from the water balance investigations are as follows:

- Differences in lake storage at the start and end of the accounting period do not materially affect the water balance because of the relatively small surface area of the lake (approx. 0.25 km^2) and the limited operating range (0.75 m). (NB. The lake level at the end of the accounting period is 150 mm higher than at the start, which corresponds with a storage increase of about 36,000 m^3, and that translates to an equivalent accumulation rate of 0.00016 m^3/s over the 7.3 year accounting period.). Evaporation is more than offset by direct rainfall on the lake surface.
- Besides the flow diverted into the lake from the Waiwhakaiho River, inflow to the lake is derived from local tributaries, comprising Mangamahoe Stream (4.4 km^2), Kent Road Stream (2.7 km^2) and lake margins, as well as direct rainfall on the lake surface (see Figure 1.1). The total local lake catchment area is 8.1 km^2, while at the point of diversion the Waiwhakaiho River has a catchment of 62.2 km^2.
- The power station discharge (generation flow) is most reliably represented by Trustpower's MGR_STN_LOAD record converted into flow using rating curves that recognise the upgraded turbine performance post-June 2016. The tailrace flow records (site no. 39212 and MGR_NIWA_TR_Q) were found to be less reliable.
- The power station bypass valve also contributes to the discharge from the station and discharges a flow of 1.15 m^3/s when fully open.
- Correlations of the difference between generation flow and Waiwhakaiho tunnel flow with the Waiwhakaiho at SH3 river flow on a monthly basis suggest that the mean tunnel flow may be underestimated by between 0.2 and 0.3 m^3/s (based on the updated tunnel stage-discharge rating curve – see next point)
- At a finer time scale (hourly), the tunnel flows initially appeared underestimated for flows of less than 2 m^3/s, and slightly overestimated between 2 m^3/s and 5 m^3/s. Adjustments were made to the tunnel stage-discharge rating curve to attempt to correct this. However, further analysis showed that the tunnel likely has hysteretic[1] hydraulic behaviour for which a looped rating curve would be more appropriate, i.e. for a given water level the tunnel flow

[1] Hysteresis refers to a lag between input and output in a system upon a change in direction. In the current context when the river flow increases or decreases it takes a while for the water level or pressure in the tunnel to stabilise.

varies depending on whether the flow is increasing or decreasing. There is insufficient data at the current time to develop such a looped rating relationship for the tunnel.

- Compared with the full record mean flow for the Waiwhakaiho River at SH3 of 7.84 m^3/s (see Table 2.6), the mean flow for the accounting period of 7.54 m^3/s is 4% lower, which suggests that the lake inflows and outflows may be slightly higher than shown in Table 3.2 over the longer term.

Table 3.2 Component mean flows for Lake Mangamahoe 24 January 2013 to 30 April 2020

ID	Item description	Mean flow (m^3/s)	Notes
A	Waiwhakaiho diversion tunnel flow	3.54	Head measured at downstream end of tunnel and converted into rated flow. Uncertainty in flow because of hysteretic hydraulic behaviour, with rising limb flow overestimated and other flows slightly underestimated
B	Local catchment inflow	0.44	Estimate based on local catchment area of 8.1 km^2 (includes lake surface) and on the specific mean flow yield between Waihwhakaiho at SH3 and Waiwhakaiho at Rimu St (56 l/s/km^2 – see item L below) with a reduction to 54 l/s/km^2 for the expected lower mean catchment rainfall for Mangamahoe Stream compared with the Mangorei Stream
C	Sum of lake inflows = A + B	3.98	Inflow is likely underestimated
D	Power station discharge	3.82	From station load converted to flow
E	Power station bypass valve	0.01	The bypass valve is opened for around 1% of the time, typically between 8 am and 6 pm on days when there is no generation during these hours (to meet consent condition)
F	Spill flow, leakage/seepage from dam	~ 0.03	Nominal allowance only. Expected to be minimal
G	NPDC water take to WTP	0.36	Equal to 31,500 m^3/day. From records provided by NPDC
H	Sum of lake outflows = D + E + F + G	4.22	This is greater than sum of inflows by 0.24 m^3/s, i.e. apparent error of about 6%
J	Waiwhakaiho at SH3 (60.5 km^2)	7.54	Specific mean flow 125 l/s/km^2 equal to runoff of 3.93 m p.a.
K	Waiwhakaiho at Rimu Street (123.7 km^2)	11.06	Specific mean flow 89 l/s/km^2 equal to runoff of 2.82 m p.a.
L	Intervening catchment (63.2 km^2) between SH3 and Rimu Street = K - J	3.52	The Mangorei Stream (32.9 km^2) constitutes the bulk of the intervening catchment. Specific mean flow 56 l/s/km^2 equal to runoff of 1.76 m p.a.

The residual error in the scheme water balance is 0.24 m^3/s, which at about 6% of the Lake Mangamahoe outflow (or inflow), is considered acceptable. As noted above, most of the discrepancy is likely from underestimation in the tunnel inflow. However, there is a possibility that the local catchment inflow could also be underestimated from uncertainties in the river flow records at SH3 and Rimu Street used to calculate the local catchment yield.

While the discrepancy in the overall lake water balance is relatively small (0.24 m^3/s), the discrepancies could be much greater on a sub-daily time scale (e.g. hourly) because the hysteretic hydraulic behaviour in the tunnel is not able to be modelled by a simple rating curve. Diverted flows from the Waiwhakaiho River are overestimated at the initial river flow increase (rising limb of hydrograph) and underestimated thereafter, resulting in an uncertainty greater than ±1 m^3/s in the diverted flow on an instantaneous basis.

3.3 Diversion from Waiwhakaiho River

3.3.1 Intake headworks

Figure 1.2 shows the location of the river intake and diversion tunnel (also referred to as *Tunnel 1* or *Waiwhakaiho Tunnel*) within the Waiwhakaiho catchment. The river intake works comprises a low concrete weir in the river bed with a fish pass located adjacent to the right bank (see photo in Figure 3.2) and a concrete intake structure/building set into the true left bank about 60 m upstream of the weir (see photo in Figure 3.3) that houses mechanical gates and other equipment that control flow into the diversion tunnel.

Figure 3.2 Intake weir on Waiwhakaiho River looking upstream (photo credit: Riley 2019)

Figure 3.3 Intake structure on left bank of Waiwhakaiho River (photo taken looking downstream)

Section 3.3.3 provides further information on the flow regime in tunnel.

3.3.2 Residual river flows

The river level below the intake weir is continuously recorded by Trustpower (MGR_H4RIVLVL_BW) and is used by Trustpower to guide management of the residual flow (in accordance with special condition 2 of consent number 2053–3.2). There is no stage-discharge rating curve for this site. Instead measured water levels are compared against thresholds to confirm that an adequate residual flow is being provided (TRC, 2019).

3.3.3 Waiwhakaiho tunnel flows

As described in Riley (2019), there are currently several (four or more) water level or depth sensors associated with the intake headworks. The water depth at the downstream end of the diversion tunnel has been continuously measured from 24 January 2013, and these measurements have been converted into a flow time-series using a stage-discharge rating curve constructed from a number of actual flow measurements conducted in the channel immediately downstream of the tunnel outlet.

Figure 3.4 plots hourly tunnel flows against the contemporaneous river flows recorded at SH3 for the full period of available data (24 January 2013 to 30 April 2020, 63,682 points). As expected, the plot shows that the tunnel flows generally increase steadily with increasing river flow, but begins to taper off at a tunnel flow of around 6.5 m^3/s reaching around 8 m^3/s at a river flow of about 20 m^3/s. A diversion of 9 m^3/s or higher is achieved only 0.1% of the time. A diversion flow of 7 m^3/s (the previous maximum consented diversion before it was increased to 10 m^3/s by consent variation) or greater is achieved 6.3% of the time.

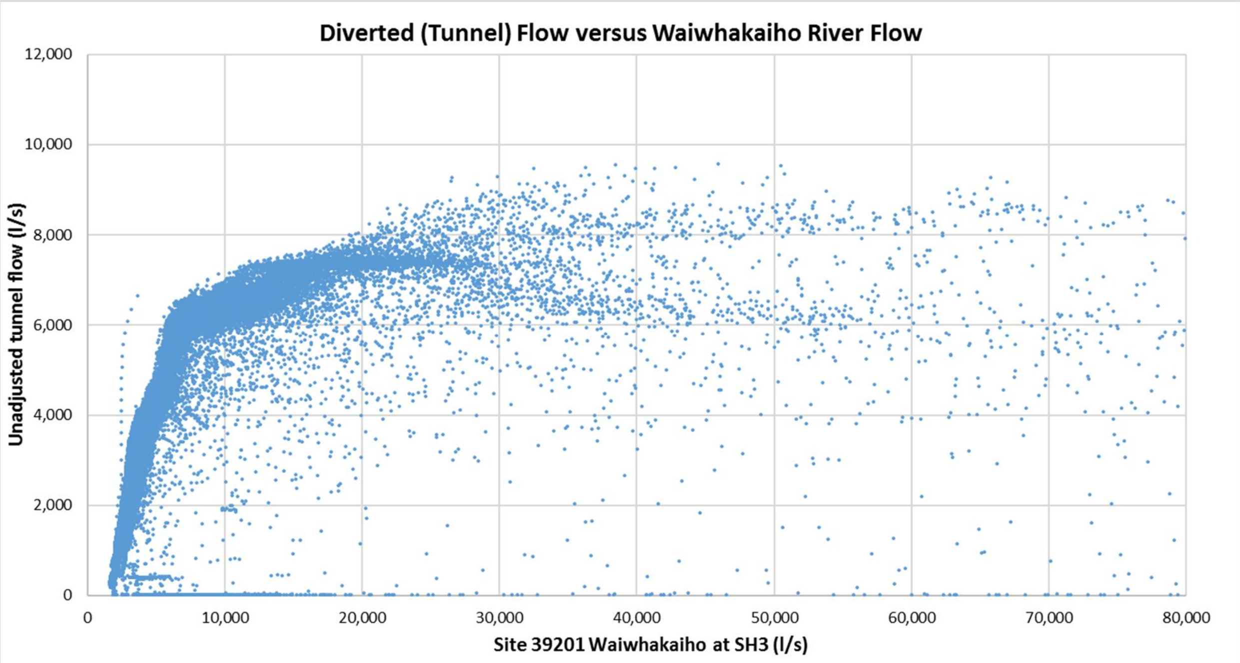

Figure 3.4 Unadjusted diversion tunnel flow versus Waiwhakaiho River flow at SH3. Hourly data from January 2013 to April 2020

Analysis of this tunnel flow record allows the maximum theoretical flow capture into the tunnel to be compared against the actual flow capture. This analysis also uncovers the discrepancies in the tunnel flow data caused by hysteresis in the hydraulic behaviour of the flow as described in Section 3.2 earlier, i.e. tunnel flows are overestimated at the initial river flow rise (often resulting in spuriously low or negative inferred residual flows) and underestimated in the subsequent phases of the hydrograph e.g. in the recession. The obvious discrepancies in the raw (or unadjusted) tunnel flow series were filtered out before being applied in subsequent analyses.

Figure 3.5 plots the shortfall in the actual diversion flows (based on the adjusted tunnel hourly flow series 2013 to 2020) compared with the maximum theoretical diversion as a function of the river flow at SH3. This plot shows shortfalls peaking around 3.5 m^3/s at a river flows of around 10 to 12 m^3/s. It is considered that these shortfalls are mostly related to hydraulic limitations at the current intake headworks as described by Riley (2019), which prevent the maximum consented take to be realised, particularly for diverted flows above approximately 6.5 m^3/s.

Figure 3.6 presents the flow duration curve for the adjusted tunnel flow series for the period January 2013 to April 2020. Separate flow duration curves are provided for summer (Dec, Jan, Feb), autumn (Mar, Apr, May), winter (Jun, Jul, Aug) and spring (Sep, Oct, Nov). Figure 3.7 (located at the end of Section 3) shows a hydrograph plot of entire tunnel flow (adjusted) record and Table 3.3 presents a tabulation of the mean monthly tunnel flows.

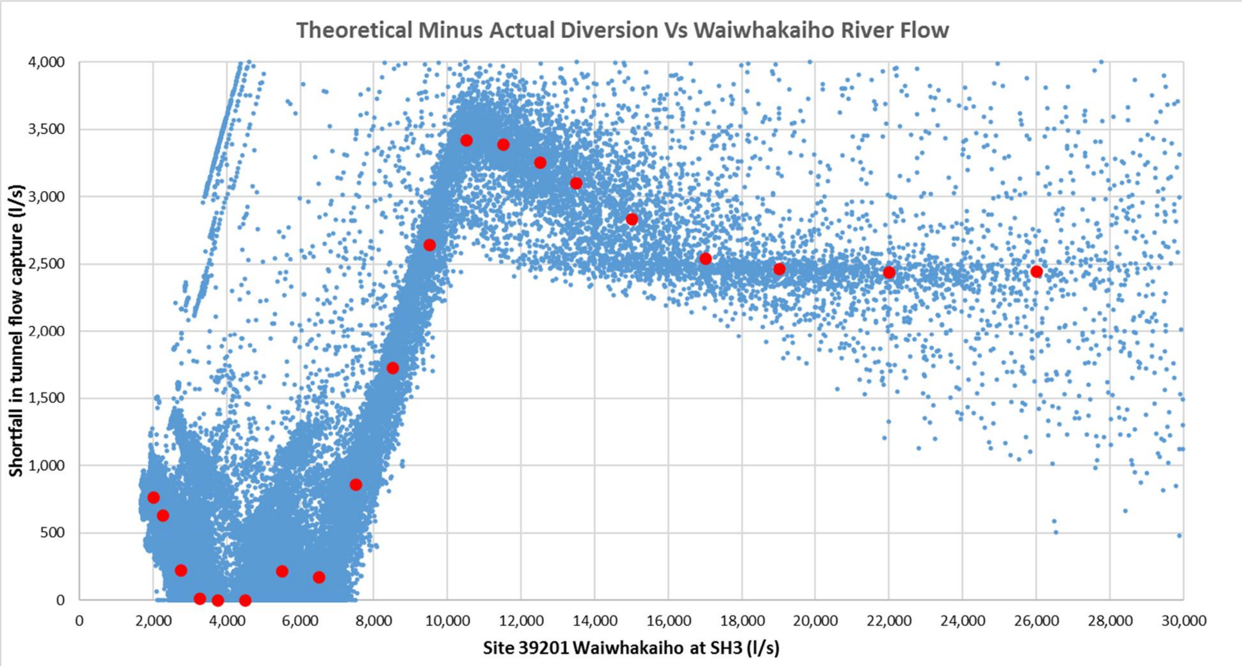

Figure 3.5 *Shortfall in actual tunnel flow compared with theoretical allowable flow capture per consent conditions. Hourly flows from January 2013 to April 2020. The red dots indicate the median values of the distribution.*

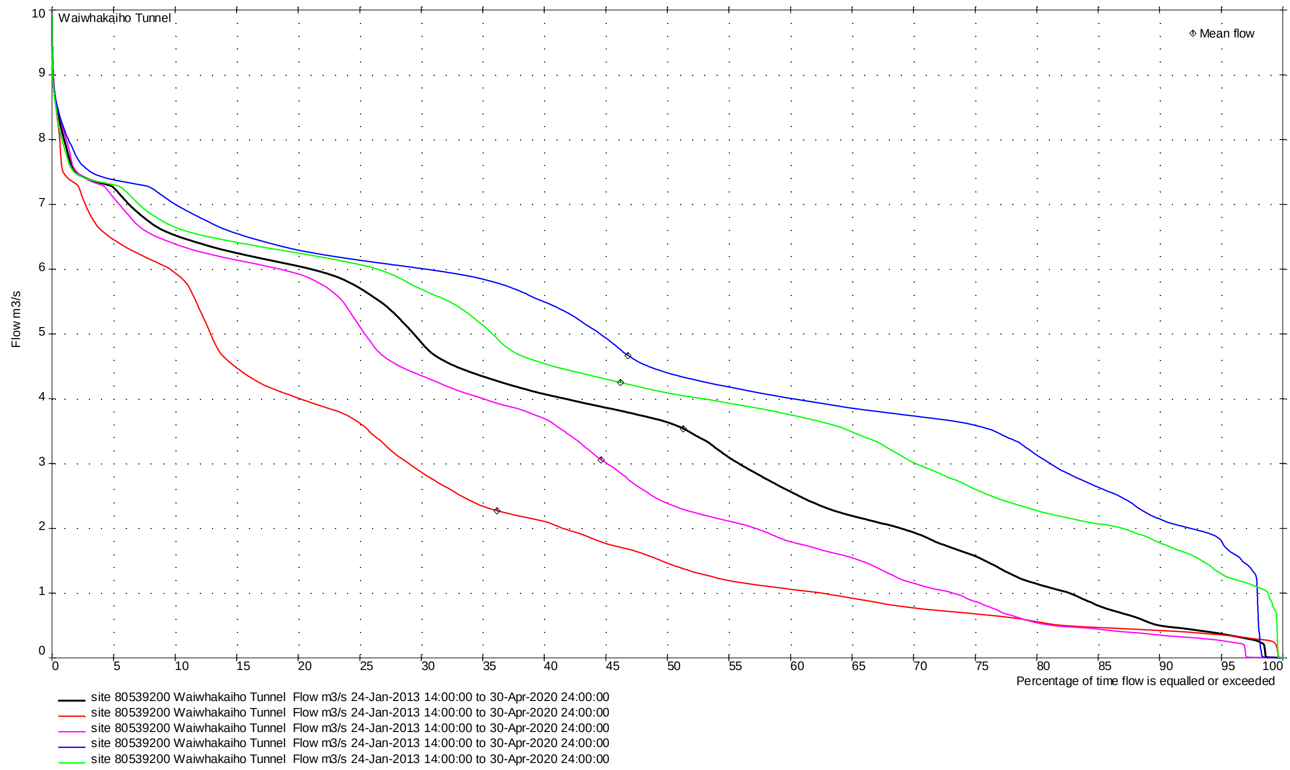

Figure 3.6 Waiwhakaiho tunnel (diversion) flow duration curve (m^3/s), Jan 2013 to Apr 2020. Red curve – summer (D, J, F); magenta curve – autumn (M, A, M); blue curve – winter (J, J, A); green curve – spring (S, O, N); black curve – full year. Mean flow on each curve is indicated by diamond marker.

Table 3.3 Waiwhakaiho tunnel mean monthly flows (adjusted flows) 2013 to 2020

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
	Waiwhakaiho Diversion Tunnel (Node 2): Mean monthly diverted flow (m^3/s)												
2013	?	1.20	0.99	3.19	4.71	4.27	3.79	4.15	4.36	4.75	2.51	3.01	3.37
2014	3.27	0.68	0.67	2.76	2.08	5.20	3.81	4.18	3.79	4.34	5.23	3.61	3.31
2015	1.12	1.86	2.05	3.83	4.78	4.76	4.61	5.43	4.94	3.27	3.60	2.52	3.57
2016	2.11	1.20	1.70	2.17	4.47	4.61	4.86	4.68	5.49	5.11	5.33	4.34	3.85
2017	4.55	3.45	2.59	4.31	4.95	3.76	5.41	5.34	5.69	4.48	2.49	0.92	4.00
2018	3.21	3.32	3.65	3.98	5.22	3.88	5.22	5.73	3.61	3.22	3.81	2.96	3.99
2019	1.08	0.69	2.03	3.18	3.50	4.66	3.78	5.86	4.74	5.04	3.47	3.43	3.47
2020	0.71	0.70	1.43	2.18	?	?	?	?	?	?	?	?	?
Minimum	0.71	0.68	0.67	2.17	2.08	3.76	3.78	4.15	3.61	3.22	2.49	0.92	3.31
Average	2.29	1.64	1.89	3.20	4.24	4.45	4.50	5.05	4.66	4.32	3.78	2.97	3.65
Maximum	4.55	3.45	3.65	4.31	5.22	5.20	5.41	5.86	5.69	5.11	5.33	4.34	4.00

The adjusted tunnel flow series has been used to generate synthetic flow series for key locations (nodes) in the Waiwhakaiho catchment that are affected by the Mangorei scheme operation but are ungauged, i.e.

- Waiwhakaiho downstream of river intake – this is the residual river after flow has been diverted to Lake Mangamahoe via the Waiwhakaiho tunnel
- Waiwhakaiho upstream of power station tailrace – representing the flow in the residual river immediately upstream of the return flow from the Mangorei power station
- Waiwhakaiho downstream of power station tailrace – representing the flow in the river with the power station discharge added back in.

These are presented and analysed in Section 3.6.

3.4 Lake Mangamahoe

3.4.1 General description

Lake Mangamahoe (the lake) is a man-made lake created in 1931 for hydro-electric generation purposes. Two embankment dams impound the lake i.e. the 25 m high Mangamahoe Dam (main dam) at the northern extent of the lake, and a lower (6 m high) saddle dam located on the western side of the lake. Riley (2020) provides a more detailed description of the storage lake, the dams and, particularly, the flood passage performance at the main dam informed by a detailed flood assessment. Figure 3.8 shows a photo of the Mangamahoe Dam and spillway. Table 3.4 summarises the key levels associated with the management and operation of the lake.

Table 3.4 Lake Mangamahoe key threshold levels for Trustpower's operation of the scheme

Elevation (RL m)	Significance of level	Comment
152.10	Dam crest level	From Riley (2020). Based on 2015 survey
151.03	100-year ARI flood level in the lake	From Riley (2020). The Probable Maximum Flood level is 1.04 m higher (see Section 3.4.6).
150.27	Effective weir elevation with flashboards upright	From Riley (2020). Based on 2015 survey
149.87	Effective weir elevation with flashboards tipped	From Riley (2020). 400 mm below level above
149.78	Crest level of concrete spillway weir at Mangamahoe Dam	From TRC (2019). Note an alternative level of 149.80 m was indicated in CH2M Beca (2020)
149.03	Minimum lake operating level, except during lake weed maintenance period	Per consent 2054-3, i.e. 750 mm below spillway crest level. An alternative level of 149.05 m was indicated in CH2M Beca (2020)

Figure 3.8 Mangamahoe Dam (on right in background) and spillway (on left in foreground)

Figure 3.9 shows the lake storage versus water level relationship for Lake Mangamahoe developed by CH2M Beca (2020). A spillway crest level at Mangamahoe Dam of RL 149.80 m (top of concrete weir and not top of flashboards) is noted by CH2M Beca, which is 0.02 m higher than the level noted in TRC (2019). At a level of RL 150.20 m, which is 0.42 m above the crest level of the concrete weir but 0.07 m below the top of the flashboards (RL 150.27 m), the lake surface area was estimated by Riley (2020) to be 0.249 km^2.

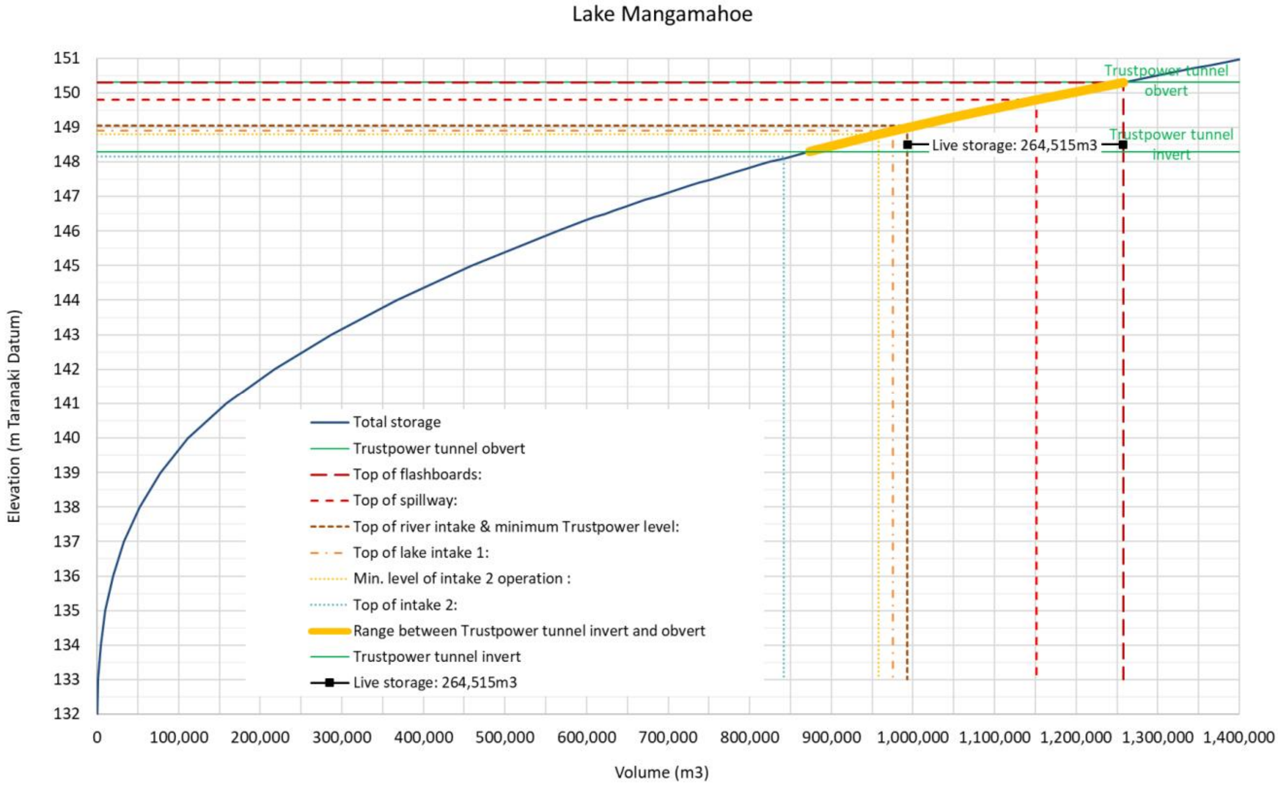

Figure 3.9 Level – storage relationship for Lake Mangamahoe as determined by CH2M Beca (2020).

3.4.2 Lake inflows and outflows

Inflows to the lake are sourced mainly from the Waiwhakaiho River via the diversion tunnel and two local tributaries, Mangamahoe Stream and Kent Road Stream, all of which enter at the southern part of the lake. Water is discharged from the lake mainly through the power tunnel intake (feeding Tunnel 2 and the penstocks to the Mangorei power station) located at the northern extent of the lake and west of the Mangamahoe Dam. The mean discharge to the power station over the last 7 years (specifically January 2013 to April 2020) is 3.82 m^3/s. Water is also abstracted by NPDC for potable water supply, and the rate of the raw water take to the treatment plant has averaged 0.366 m^3/s between 2013 and 2019. Section 3.2, and Table 3.2 in particular, presents a water balance analysis for the Mangorei scheme that is based on reconciling the inflows into and outflows out of Lake Mangamahoe.

An indeterminate amount of flow is discharged from the spillway at the Mangamahoe Dam through leakage underneath the flashboards (see photo in Figure 3.10) and as spill flow during high flow and flood events that exceed the generation capacity of the power station. Any seepage through the embankment dams and from the lakebed also contributes to the outflow from the lake. Averaged out over the long term, these are anticipated to be relatively minor compared with the water takes for generation and water supply.

Figure 3.10 Tipping flashboards mounted on the crest of the concrete spillweir at Mangamahoe Dam. Note the discrete leakage points at the interface between the flashboards and the concrete weir

3.4.3 New Plymouth District Council water supply

Table 2.4 in preceding Section 2.3 provided a tabulation of the mean monthly water take by NPDC for the period January 2013 to November 2019. While the mean monthly take rates have varied between 316 l/s and 463 l/s (2013 to 2019), the hourly take rates vary over a slightly greater range e.g. between about 200 and 600 l/s for 2019, though, for about 70% of time the hourly flows are between 300 and 400 l/s.

NPDC has access to storage in Lake Mangamahoe below the minimum operating level of the Mangorei HEPS, as shown in Figure 3.11 taken from CH2M Beca (2020). The lower of the two water supply intakes can operate down to RL 148.15 m, which is 0.88 m below the Mangorei scheme minimum operating level.

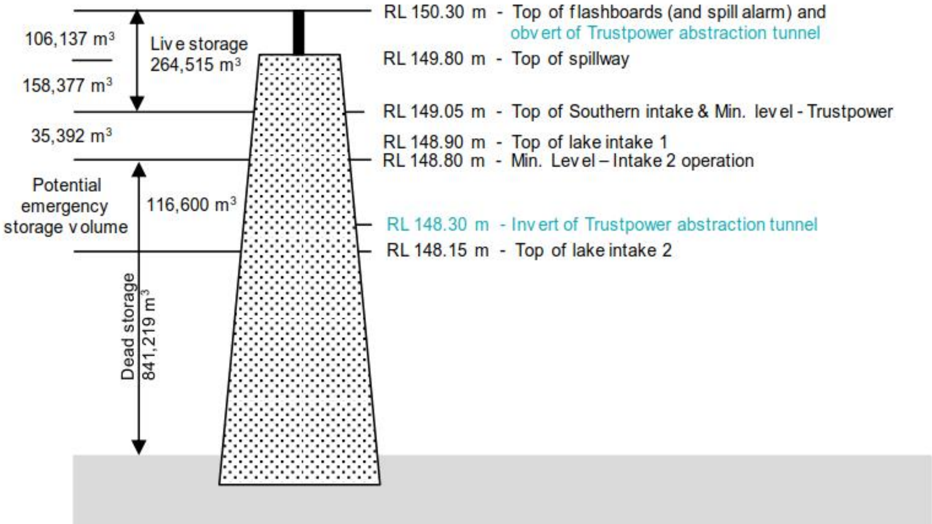

Figure 3.11 Lake Mangamahoe threshold levels for NPDC's water supply operation. This figure from CH2M Beca (2020). Note that several levels in this figure differ slightly from Riley (2020).

3.4.4 Lake level fluctuations

Figure 3.12 (located at the end of Section 3) presents a plot of the water level time-series for Lake Mangamahoe for the water balance period (January 2013 to April 2020). The full available record, from July 2001 to April 2020, is plotted in Appendix A.

Lake levels are required to be generally within 0.75 m of the concrete crest level of the Mangamahoe Dam spillway (RL 149.78 m), except during lake weed maintenance periods. As can be seen in the plot in Figure 3.12, lake levels are often higher than the spillway crest. Such levels do not necessary indicate spilling as there are flashboards, approximately 0.5 m high, mounted on the crest of the spillway that permit a higher operating level. Spill events occur when the water level exceeds the top of the flashboards (RL 150.27 m). In the last seven years, notable sustained spill events occurred in May 2014 and July 2019, with the highest reservoir levels recorded on 28 August 2017 (RL 150.84 m) and 20 June 2015 (RL 150.53 m).

The plot in Figure 3.12 shows that the water level did not fall below the minimum operating level of RL 149.03 m, and the lowest recorded water level was RL 149.09 m on 28 November 2019.

The high frequency fluctuations in the lake level time-series have a diurnal (daily) frequency and reflect the pattern of generation at the Mangorei power station to meet power demand on a daily basis. To illustrate this, Figure 3.13 shows a segment of the water level time-series for a 3-month period February to April 2019. The amplitude of the daily fluctuations for February 2019, which was a dry month (mean flow at SH3 of 2.40 m^3/s compared with full record mean of 7.84 m^3/s), is relatively small at around 120 mm, compared with typically about 400 mm for April 2019 for which the mean flow at SH3 was 8.34 m^3/s, which is close to the annual mean flow. Therefore, it may be surmised there is a positive correlation between the amplitude of the daily lake level fluctuations and the rate of inflow to the lake.

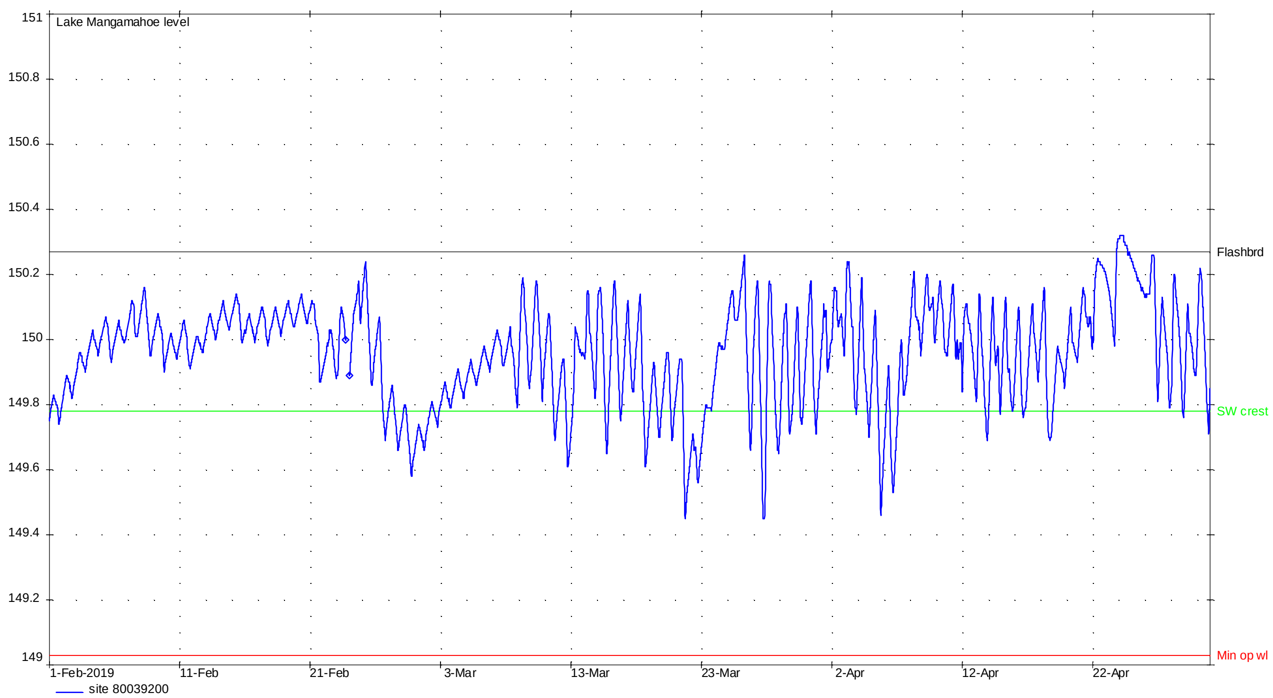

Figure 3.13 Lake Mangamahoe water level time-series February 2019 to April 2019. Lower threshold line (red) is the minimum operating level, middle threshold line (green) the crest level of the concrete spillway, and upper threshold line (black) the top of the flashboards on the spillway.

3.4.5 Lake level duration and seasonality

Figure 3.14 presents a level duration plot of Lake Mangamahoe water levels for the water balance period (January 2013 to April 2020). Separate level duration curves for each season (summer = Dec, Jan, Feb; autumn = Mar, Apr, May; winter = Jun, Jul, Aug; and spring = Sep; Oct; Nov) are plotted in addition the annual (full year) curve.

The lake levels have generally fluctuated within a 1 m operating range between RL 149.3 m and RL 150.3 m.

Comparison of the seasonal level duration curves indicate negligible differences across the seasons. However, as noted in the preceding section, there is a pattern of daily fluctuations in the lake level record, and the amplitude of the fluctuations is likely to be correlated with the magnitude of the lake inflow. As the inflows have a strong seasonal pattern (see Section 2.4), a sympathetic seasonal pattern can be expected in the magnitude of the daily fluctuations. These repetitive high frequency fluctuations do not show up in the flow duration curves.

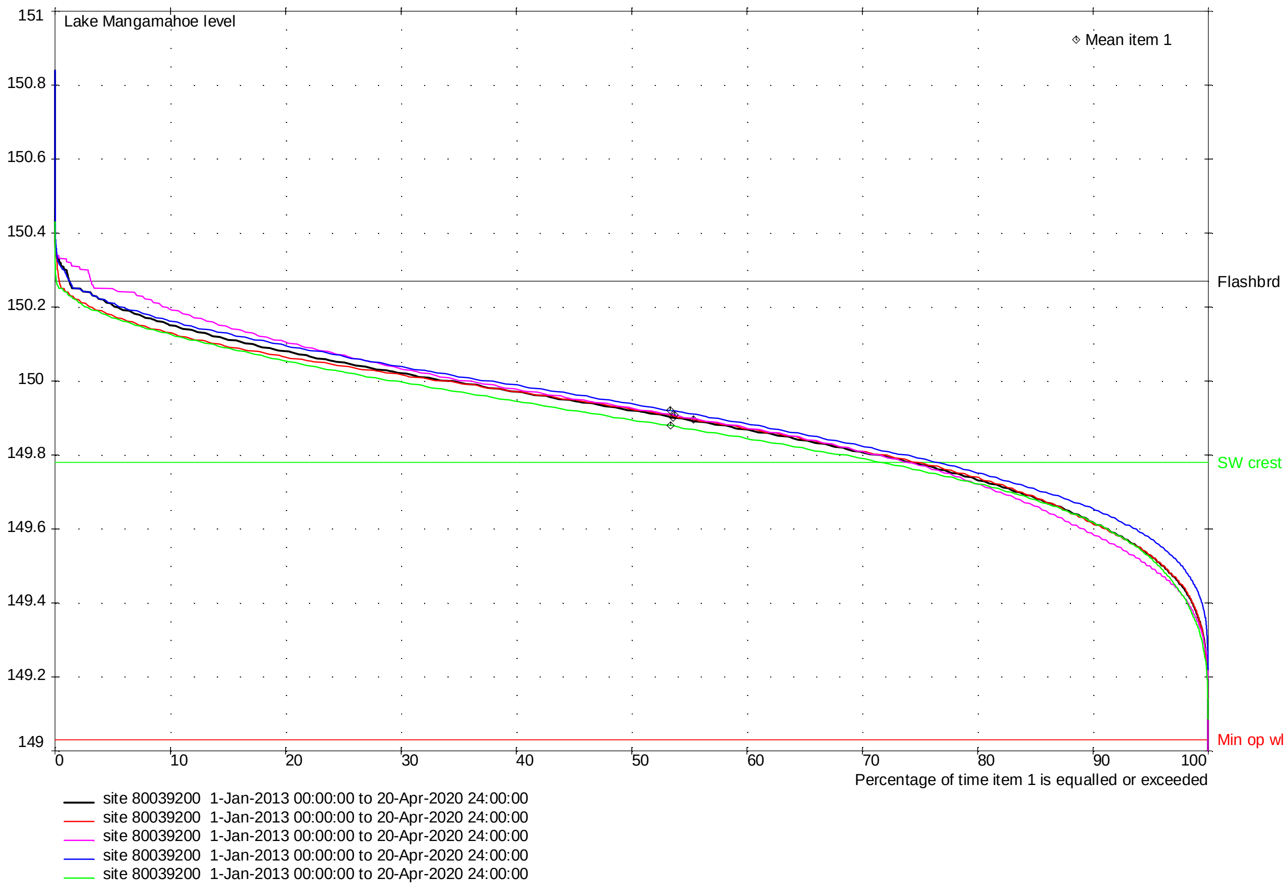

Figure 3.14 Lake Mangamahoe level duration curves (in RL m), Jan 2013 to Apr 2020. Red - summer (D, J, F); magenta - autumn (M, A, M); blue - winter (J, J, A); green - spring (S, O, N); black - full year. Lower threshold line (red) is the minimum operating level, middle threshold line (green) the crest level of the concrete spillway, and upper threshold line (black) the top of the flashboards.

3.4.6 Flood management

Flood inflows to Lake Mangamahoe are derived mainly from a local catchment of 8.1 km^2. The flow diverted from the Waiwhakaiho River via the diversion tunnel is unlikely to exceed about 9 m^3/s, and when the Waiwhakaiho River is in flood, the diversion is required to cease (i.e. when river flow > 85 m^3/s). A single concrete-lined spillway with a crest width of 30.63 m adjacent to the right abutment of the dam provides flood passage. There is no auxiliary or emergency spillway.

Riley (2020) summarises the main modifications made to the dam and spillway since 1980:

- In 1980, 300 mm high timber boards were added to the top of the concrete weir in the spillway to increase storage
- The main dam was raised in 1988, and some modifications to the spillway were made with the addition of 200 mm high flashboards to the existing 300 mm high flashboards
- Further significant modifications were made to the spillway in 2005 to increase the spillway chute capacity. The design criteria adopted was to contain the 1,000-year flood event without the spillway chute walls overtopping, and for the chute overtopping, in greater events, to be remote from the dam embankment.
- In 2011, seven new counterweighted flashboards were installed and is the current arrangement. The top of the flashboards is at RL 150.27 m, which is 0.49 m above the concrete weir crest level (RL 149.78 m). The effective crest elevation when the flashboards are tipped is RL 149.87 m. The tipping flashboards occupy 24.4 m (80%) of the 30.63 m wide spillway crest and the remainder is comprised of fixed (non-tipping) flashboards.

A record of the spillflow from Mangamahoe Dam cannot be readily developed from the lake level record by applying a level versus discharge rating curve. This is because tipping of the flashboards results in an effective weir crest elevation that varies with time. Furthermore, the seven flashboard sections are operated in two independent groups.

Key conclusions from the Riley (2020) flood assessment are as follows:

- The spillway at Mangamahoe Dam is able to convey the 100-year ARI flood with a freeboard of 1.07 m to the dam crest
- The spillway can just pass the Probable Maximum Flood, the freeboard to the dam crest being just 0.03 m at the peak of the flood
- In the Probable Maximum Flood, the peak outflow discharged from the spillway is 160 m^3/s, and in the 100-year ARI flood the peak outflow is 59 m^3/s.

3.4.7 Residual flow

No residual flow is required below the Mangamahoe Dam. Unintended residual flows, for the major part, are provided through leakage underneath the flashboards at the spillway crest, and through seepage losses from the dam embankment and lakebed.

3.5 Mangorei power station

3.5.1 Power station flows

The Mangorei power station (see photo in Figure 3.15) has a complement of four turbine-generator sets, i.e. 3 x 1.3 MW units and 1 x 700 KW unit (TBC). It has a nominal capacity of 4.5 MW, and can discharge a peak generation flow of just under 10 m^3/s.

When the power station is unable to generate during the day (8 am to 6 pm), for example from network or station outage, a bypass valve is opened to release a flow of 1.15 m^3/s to maintain a flow in the tailrace as required by consent (cf. 0.95 m^3/s required).

Figure 3.15 Mangorei Power Station. Twin penstocks visible in the background at top right and tailrace in the mid-foreground

Figure 3.16 (located at the end of Section 3) shows a time-series plot of the power station discharges for the water balance period (January 2013 to April 2020). The generation flow is derived from station load (in MW) using an output versus discharge rating curves. Separate hydrographs are provided for the generation flow and the station bypass flow. Table 3.5 presents a tabulation of the mean monthly generation and bypass flows. The station bypass flow is relatively minor i.e. on average, it represents about 0.3% of the total station discharge.

Figure 3.17 presents the flow duration curve for the generation flow. Separate flow duration curves are provided for summer (Dec, Jan, Feb), autumn (Mar, Apr, May), winter (Jun, Jul, Aug) and spring (Sep, Oct, Nov). There is a significant difference in the discharged flow volume across the seasons, for example the median (50^{th} percentile) winter flow is more than 5 times the median (50^{th} percentile) summer flow. Generation ceases for about 30% of the time on average.

Table 3.5 Mangorei power station mean monthly generation and bypass flows 2013 to 2020

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
	Mangorei power station discharge: Mean monthly generation flow (m^3/s)												
2013	2.72	1.60	1.27	3.82	5.92	5.12	4.29	4.82	5.34	5.77	2.87	3.57	4.05
2014	3.67	1.07	1.06	3.12	2.24	6.17	4.39	4.86	4.09	4.64	5.59	3.69	3.72
2015	1.40	2.34	2.25	5.34	5.89	5.97	5.31	6.78	5.53	3.46	3.91	2.65	4.24
2016	2.38	1.50	1.95	2.40	4.79	4.68	5.21	4.81	5.53	4.98	5.38	4.18	4.00
2017	4.70	3.67	2.65	4.49	5.17	3.70	6.00	6.07	6.03	4.51	2.52	1.18	4.23
2018	3.15	3.07	3.68	4.03	5.53	3.96	5.47	5.78	3.45	3.08	3.75	2.82	3.99
2019	1.37	0.89	2.09	3.28	3.49	4.43	3.82	5.66	4.29	4.70	3.22	3.33	3.40
2020	1.02	0.86	1.50	2.21	-	-	-	-	-	-	-	-	-
Minimum	1.02	0.86	1.06	2.21	2.24	3.70	3.82	4.81	3.45	3.08	2.52	1.18	3.40
Average	2.55	1.87	2.06	3.59	4.72	4.86	4.93	5.54	4.90	4.45	3.89	3.06	3.95
Maximum	4.70	3.67	3.68	5.34	5.92	6.17	6.00	6.78	6.03	5.77	5.59	4.18	4.24
Year	Mangorei power station discharge: Mean monthly bypass flow (m^3/s)												Annual
2013	0.012	0.000	0.090	0.012	0.015	0.006	0.002	0.000	0.001	0.000	0.000	0.000	0.012
2014	0.000	0.000	0.000	0.099	0.147	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.023
2015	0.001	0.000	0.029	0.029	0.005	0.000	0.000	0.005	0.000	0.000	0.000	0.009	0.007
2016	0.000	0.000	0.000	0.008	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.001
2017	0.000	0.001	0.000	0.001	0.006	0.000	0.000	0.002	0.000	0.009	0.000	0.000	0.002
2018	0.000	0.007	0.000	0.000	0.002	0.004	0.001	0.000	0.000	0.002	0.000	0.013	0.003
2019	0.000	0.006	0.003	0.092	0.002	0.000	0.177	0.001	0.000	0.008	0.006	0.000	0.027
2020	0.000	0.000	0.000	-	-	-	-	-	-	-	-	-	-
Minimum	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Average	0.002	0.002	0.015	0.034	0.026	0.002	0.026	0.001	0.000	0.003	0.001	0.003	0.011
Maximum	0.012	0.007	0.090	0.099	0.147	0.006	0.177	0.005	0.001	0.009	0.006	0.013	0.027
Year	Mangorei power station discharge (Node 4): Mean monthly generation + bypass flow (m^3/s)												Annual
2013	2.73	1.60	1.36	3.83	5.94	5.12	4.29	4.82	5.34	5.77	2.87	3.57	4.07
2014	3.67	1.07	1.06	3.22	2.39	6.17	4.39	4.86	4.09	4.64	5.59	3.69	3.75
2015	1.40	2.34	2.28	5.36	5.90	5.97	5.31	6.78	5.53	3.46	3.91	2.66	4.25
2016	2.38	1.50	1.95	2.41	4.79	4.68	5.21	4.81	5.53	4.98	5.38	4.18	4.00
2017	4.70	3.67	2.65	4.50	5.18	3.70	6.00	6.07	6.03	4.52	2.52	1.18	4.23
2018	3.15	3.08	3.68	4.03	5.54	3.96	5.47	5.78	3.45	3.08	3.75	2.83	3.99
2019	1.37	0.89	2.09	3.37	3.49	4.43	4.00	5.66	4.29	4.71	3.23	3.33	3.42
2020	1.02	0.86	1.50	-	-	-	-	-	-	-	-	-	-
Minimum	1.02	0.86	1.06	2.41	2.39	3.70	4.00	4.81	3.45	3.08	2.52	1.18	3.42
Average	2.55	1.88	2.07	3.82	4.74	4.86	4.95	5.54	4.90	4.45	3.89	3.06	3.96
Maximum	4.70	3.67	3.68	5.36	5.94	6.17	6.00	6.78	6.03	5.77	5.59	4.18	4.25

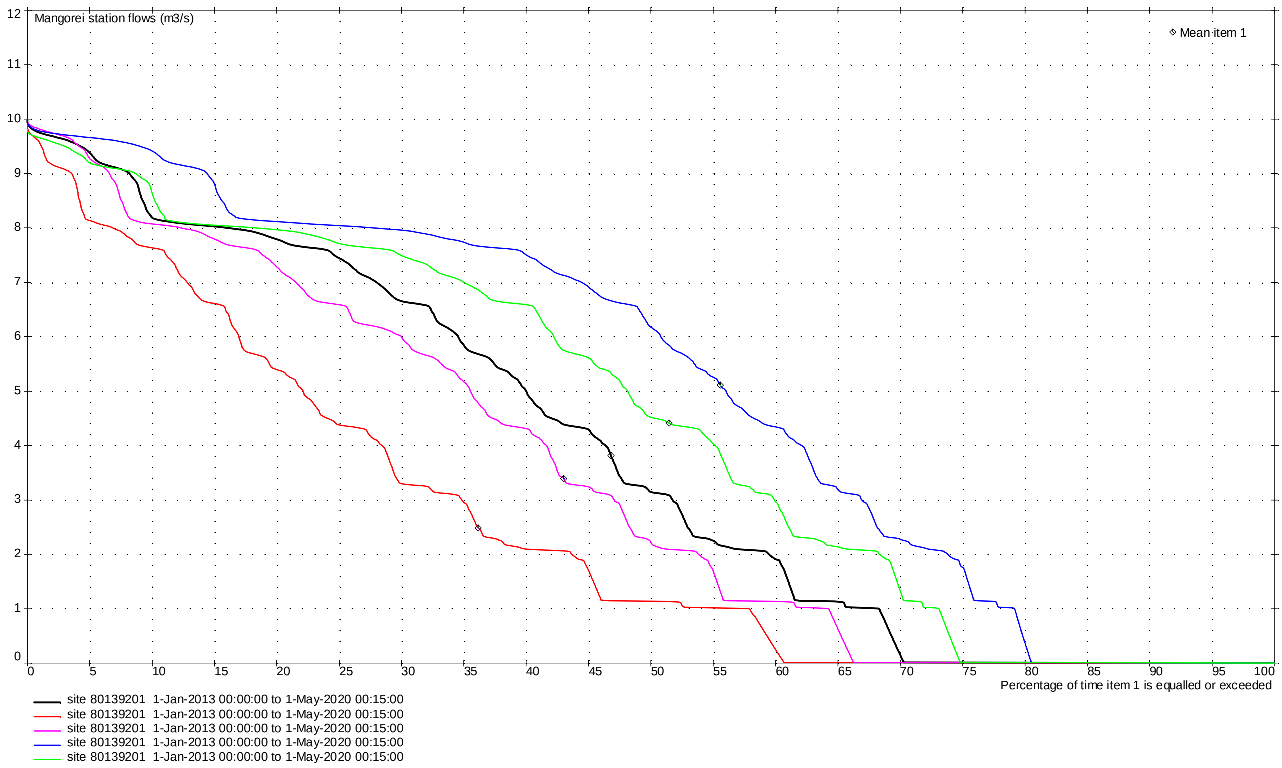

Figure 3.17 Mangorei generation flow duration curves (in m^3/s), Jan 2013 to Apr 2020. Red curve – summer (D, J, F); magenta curve – autumn (M, A, M); blue curve – winter (J, J, A); green curve – spring (S, O, N); black curve – full year. The mean flow for each curve is indicated by the diamond marker.

3.5.2 Daily flow ramping

The current consent conditions for the Mangorei HEPS do not set any constraints on generation flow ramping in the power station discharge, only that a continuous release of at least 0.95 m^3/s must be maintained between 8 am and 6 pm each day.

Figure 3.18 is a hydrograph plot of the generation flows for a 2-week period in July 2019 that illustrates the typical generation pattern during winter when river flows are generally higher. The contemporaneous flow in the Waiwhakaiho River at Rimu Street, located about 7.5 km downstream of the power station, is also plotted in Figure 3.18. It can be seen that the generation regime can have either a purely diurnal (daily peak) or a semi-diurnal (two peaks per day) pattern. There is an 8 to 10-hour period of no generation at night on most days. During the fresh from 3 to 6 July 2019, maximum generation (~8.2 m^3/s) was sustained for two full days. The generation pattern is clearly reflected in the recorded flow at Rimu Street, with a short lag (1 to 1.5 hours) and only minor attenuation (smoothing) of the generation pulse.

Figure 3.19 shows the Mangorei generation flows for a 2-week period in February/March 2019 that illustrates the typical operation during a very low flow period. Generation is maintained at a low level generally from 8 am to 6 pm each day.

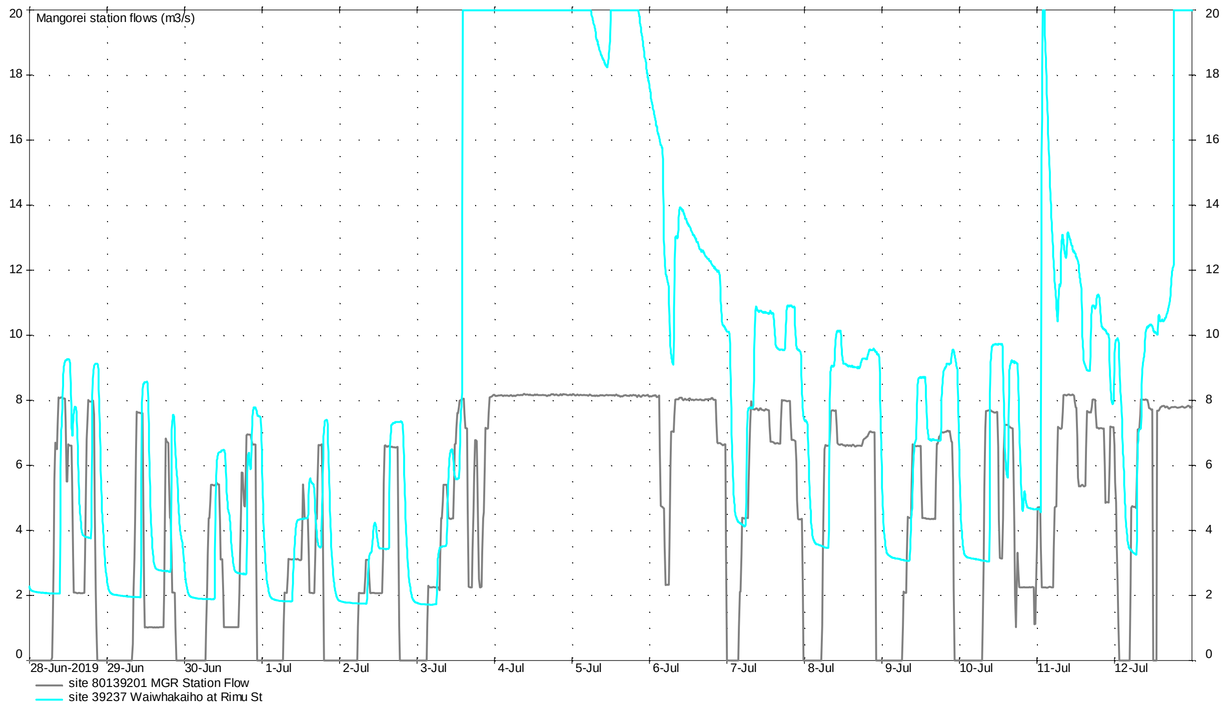

Figure 3.18 Mangorei power station discharge (grey) versus Waiwhakaiho River flow at Rimu Street (cyan) for 2-week period, 28 June to 12 July 2019

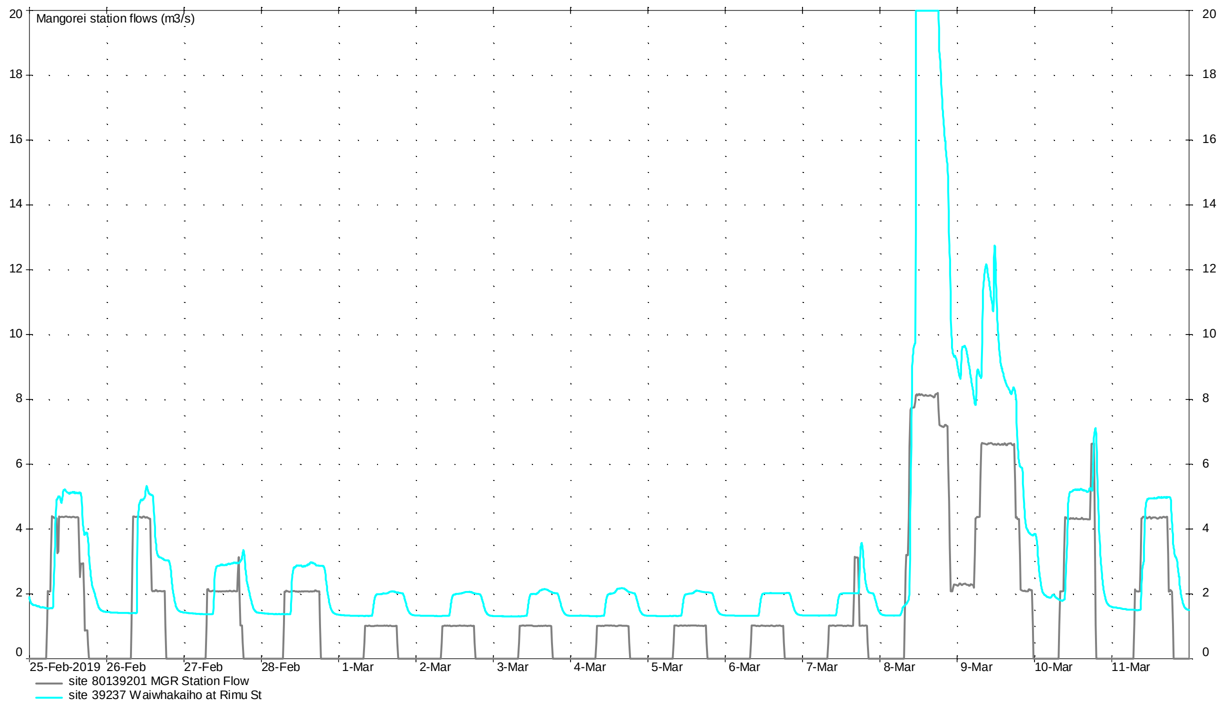

Figure 3.19 Mangorei power station discharge (grey) versus Waiwhakaiho River flow at Rimu Street (cyan) for 2-week period, 25 February to 11 March 2019.

3.6 Flow regime downstream of river intake

3.6.1 Synthetic time-series flows for ungauged locations

Closure of the water balance for the Mangorei HEPS to within 5% (see Section 3.2) provides a level of confidence in the derivation of flow series for key locations (nodes) in the Waiwhakaiho catchment that are affected by the scheme operation, i.e.:

- Waiwhakaiho River downstream of diversion (Node 3)
- Waiwhakaiho River upstream of Mangorei tailrace (Node 5)
- Waiwhakaiho River downstream of Mangorei tailrace (Node 6).

Nodal locations are shown in Figure 1.2.

Flow records for Waiwhakaiho at SH3, the diversion tunnel (noting the uncertainty in the tunnel flows, as discussed in Section 3.3.3), and the power station (both generation and bypass) are used to generate synthetic time-series flows for the above nodes for the water balance period January 2013 to April 2020.

Figure 3.20 (located at the end of Section 3) is a time-series plot that compares the flow in the Waiwhakaiho River at SH3 with the flow in the Waiwhakaiho River immediately downstream of the diversion tunnel (i.e. Node 3) for the full record period.

Figure 3.21 (also located at the end of Section 3) is a time-series plot that compares the flow in the Waiwhakaiho River immediately upstream of the confluence with the Mangorei tailrace (Node 5) with the river flow immediately downstream of the tailrace confluence (Node 6) for the full record period. The large flow fluctuations in the latter (flow below the tailrace confluence) has a daily frequency and are caused by the operation of power station in response to the daily power demand.

3.6.2 Mean monthly flows and seasonality

Table 3.6 provides a tabulation of the mean monthly flows for the water balance period (January 2013 to April 2020) for four locations (nodes) on the main stem of the Waiwhakaiho River, i.e. at SH3, above the MGR tailrace, below the MGR tailrace and at Rimu Street. Figure 3.22 is a histogram plot of the monthly mean flows (flows for a particular month averaged across all years) for each location, which shows the seasonal pattern in the flow behaviour, and for a particular month, the average change in the mean flow from upstream (SH3) to downstream (Rimu Street).

Table 3.7 provides a tabulation of the mean monthly flows for the period January 2013 to June 2019 for four key locations (nodes) associated with the Mangorei HEPS, i.e. at SH3 (representing the river flow upstream of the tunnel intake); within the diversion tunnel; just downstream of the tunnel intake (representing the residual river flow after diversion); and at the power station (generation plus bypass flow). Figure 3.23 is a histogram plot of the monthly mean flows (flows for a particular month averaged across all years) for each location, which shows the seasonal pattern in the flow behaviour, and for a particular month, the relative magnitude of scheme component flows.

Table 3.6 Waiwhakaiho River mean monthly flows at four locations (Nodes 1, 5, 6 and 7)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
	Waiwhakaiho at SH3 (Node 1): Mean monthly river flow (m^3/s)												
2013	3.75	4.50	2.80	6.51	9.63	7.11	5.30	6.48	11.21	11.34	4.21	6.54	6.62
2014	7.77	2.19	2.26	9.06	6.45	11.19	5.05	9.75	6.16	7.18	7.59	6.96	6.82
2015	2.51	5.32	4.48	13.54	12.39	16.16	8.04	13.30	7.72	4.96	6.46	3.59	8.20
2016	5.35	5.43	4.79	5.13	11.64	9.16	11.98	8.80	13.06	9.68	15.07	7.09	8.94
2017	10.87	7.70	5.77	9.88	9.91	4.60	13.85	17.55	13.32	7.98	5.14	2.21	9.08
2018	7.42	6.79	6.41	7.13	11.22	5.97	12.34	10.76	5.78	5.75	6.60	4.50	7.57
2019	2.60	2.40	4.41	8.34	7.38	7.22	13.15	9.80	6.45	7.32	5.77	7.49	6.89
2020	2.21	2.58	2.85	4.30	-	-	-	-	-	-	-	-	-
Minimum	2.21	2.19	2.26	4.30	6.45	4.60	5.05	6.48	5.78	4.96	4.21	2.21	6.62
Average	5.31	4.61	4.22	7.99	9.80	8.77	9.96	10.92	9.10	7.74	7.26	5.48	7.73
Maximum	10.87	7.70	6.41	13.54	12.39	16.16	13.85	17.55	13.32	11.34	15.07	7.49	9.08
Year	Waiwhakaiho at above MGR tailrace (Node 5): Mean monthly river flow (m^3/s)												Annual
2013	?	3.57	1.93	3.75	5.62	3.34	1.77	2.69	7.68	7.32	2.02	3.97	3.97
2014	5.02	1.58	1.67	7.01	4.84	6.97	1.56	6.34	2.77	3.37	3.00	3.82	4.00
2015	1.50	3.82	2.70	10.88	8.62	12.72	3.97	8.96	3.40	2.04	3.43	1.33	5.27
2016	3.61	4.57	3.35	3.23	8.05	5.25	8.03	4.73	8.59	5.26	10.97	3.25	5.74
2017	7.17	4.94	3.72	6.48	5.78	1.12	9.60	13.72	8.66	4.08	3.02	1.34	5.82
2018	4.75	4.03	3.21	3.73	6.88	2.63	7.47	5.90	2.54	2.90	3.32	1.83	4.11
2019	1.63	1.80	2.73	5.87	4.44	3.03	10.57	4.73	2.19	2.89	2.76	4.64	3.96
2020	1.57	2.00	1.59	2.37	-	-	-	-	-	-	-	-	-
Minimum	1.50	1.58	1.59	2.37	4.44	1.12	1.56	4.73	2.19	2.04	2.76	1.33	3.96
Average	3.61	3.29	2.61	5.41	6.32	5.01	6.14	6.72	5.12	3.98	4.07	2.88	4.70
Maximum	7.17	4.94	3.72	10.88	8.62	12.72	10.57	13.72	8.66	7.32	10.97	4.64	5.82
Year	Waiwhakaiho at below MGR tailrace (Node 6): Mean monthly river flow (m^3/s)												Annual
2013	?	5.20	3.32	7.64	11.67	8.54	6.10	7.57	13.14	13.22	4.93	7.61	8.10
2014	8.77	2.65	2.74	10.32	7.29	13.26	5.99	11.31	6.91	8.09	8.67	7.57	7.81
2015	2.92	6.21	5.01	16.39	14.66	18.87	9.37	15.89	9.01	5.54	7.41	4.01	9.60
2016	6.04	6.12	5.34	5.68	12.97	10.03	13.38	9.64	14.27	10.35	16.52	7.51	9.83
2017	11.98	8.69	6.43	11.07	11.07	4.85	15.77	20.00	14.85	8.69	5.58	2.53	10.15
2018	7.97	7.17	6.95	7.84	12.54	6.66	13.06	11.80	6.05	6.04	7.14	4.70	8.18
2019	3.02	2.71	4.86	9.32	8.00	7.54	14.73	10.50	6.53	7.68	6.04	8.04	7.45
2020	2.61	2.93	3.16	4.62	-	-	-	-	-	-	-	-	-
Minimum	2.61	2.65	2.74	4.62	7.29	4.85	5.99	7.57	6.05	5.54	4.93	2.53	7.45
Average	6.19	5.21	4.73	9.11	11.17	9.96	11.20	12.39	10.11	8.51	8.04	6.00	8.73
Maximum	11.98	8.69	6.95	16.39	14.66	18.87	15.77	20.00	14.85	13.22	16.52	8.04	10.15
Year	Waiwhakaiho at Rimu Street (Node 7): Mean monthly river flow (m^3/s)												Annual
2013	5.89	5.86	3.76	10.25	17.76	13.16	8.48	9.98	17.80	18.54	7.00	10.95	10.35
2014	12.18	2.84	2.92	13.14	10.42	18.38	8.89	14.53	9.32	11.46	12.43	12.93	10.82
2015	5.87	8.68	6.61	22.35	18.60	23.39	13.53	21.03	12.77	8.24	10.71	6.06	13.14
2016	7.34	6.35	5.99	7.18	15.74	13.84	17.65	13.66	18.78	13.85	20.69	11.38	12.72
2017	16.74	12.94	8.41	15.62	15.93	8.42	22.19	27.39	18.22	11.12	6.27	2.25	13.82
2018	8.49	7.62	8.20	9.13	16.09	8.83	15.62	15.31	7.12	6.65	8.21	5.15	9.73
2019	2.76	2.41	5.15	10.84	9.06	9.06	17.52	13.88	8.04	9.74	6.66	9.09	8.74
2020	2.32	2.71	3.23	4.83	11.47	-	-	-	-	-	-	-	-
Minimum	2.32	2.41	2.92	4.83	9.06	8.42	8.48	9.98	7.12	6.65	6.27	2.25	8.74
Average	7.70	6.17	5.53	11.67	14.38	13.58	14.84	16.54	13.15	11.37	10.28	8.26	11.33
Maximum	16.74	12.94	8.41	22.35	18.60	23.39	22.19	27.39	18.78	18.54	20.69	12.93	13.82

Table 3.7 Mangorei Scheme mean monthly flows 2013 to 2020

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
	Waiwhakaiho at SH3 (Node 1): Mean monthly river flow (m^3/s)												
2013	3.75	4.50	2.80	6.51	9.63	7.11	5.30	6.48	11.21	11.34	4.21	6.54	6.62
2014	7.77	2.19	2.26	9.06	6.45	11.19	5.05	9.75	6.16	7.18	7.59	6.96	6.82
2015	2.51	5.32	4.48	13.54	12.39	16.16	8.04	13.30	7.72	4.96	6.46	3.59	8.20
2016	5.35	5.43	4.79	5.13	11.64	9.16	11.98	8.80	13.06	9.68	15.07	7.09	8.94
2017	10.87	7.70	5.77	9.88	9.91	4.60	13.85	17.55	13.32	7.98	5.14	2.21	9.08
2018	7.42	6.79	6.41	7.13	11.22	5.97	12.34	10.76	5.78	5.75	6.60	4.50	7.57
2019	2.60	2.40	4.41	8.34	7.38	7.22	13.15	9.80	6.45	7.32	5.77	7.49	6.89
2020	2.21	2.58	2.85	4.30	-	-	-	-	-	-	-	-	-
Minimum	2.21	2.19	2.26	4.30	6.45	4.60	5.05	6.48	5.78	4.96	4.21	2.21	6.62
Average	5.31	4.61	4.22	7.99	9.80	8.77	9.96	10.92	9.10	7.74	7.26	5.48	7.73
Maximum	10.87	7.70	6.41	13.54	12.39	16.16	13.85	17.55	13.32	11.34	15.07	7.49	9.08
Year	Waiwhakaiho Diversion Tunnel (Node 2): Mean monthly diverted flow (m^3/s)												Annual
2013	?	1.20	0.99	3.19	4.71	4.27	3.79	4.15	4.36	4.75	2.51	3.01	3.37
2014	3.27	0.68	0.67	2.76	2.08	5.20	3.81	4.18	3.79	4.34	5.23	3.61	3.31
2015	1.12	1.86	2.05	3.83	4.78	4.76	4.61	5.43	4.94	3.27	3.60	2.52	3.57
2016	2.11	1.20	1.70	2.17	4.47	4.61	4.86	4.68	5.49	5.11	5.33	4.34	3.85
2017	4.55	3.45	2.59	4.31	4.95	3.76	5.41	5.34	5.69	4.48	2.49	0.92	4.00
2018	3.21	3.32	3.65	3.98	5.22	3.88	5.22	5.73	3.61	3.22	3.81	2.96	3.99
2019	1.08	0.69	2.03	3.18	3.50	4.66	3.78	5.86	4.74	5.04	3.47	3.43	3.47
2020	0.71	0.70	1.43	2.18	-	-	-	-	-	-	-	-	-
Minimum	0.71	0.68	0.67	2.17	2.08	3.76	3.78	4.15	3.61	3.22	2.49	0.92	3.31
Average	2.29	1.64	1.89	3.20	4.24	4.45	4.50	5.05	4.66	4.32	3.78	2.97	3.65
Maximum	4.55	3.45	3.65	4.31	5.22	5.20	5.41	5.86	5.69	5.11	5.33	4.34	4.00
Year	Waiwhakaiho at below tunnel intake (Node 3): Mean monthly river flow (m^3/s)												Annual
2013	?	3.27	1.79	3.27	4.85	2.83	1.44	2.23	6.78	6.42	1.77	3.50	3.47
2014	4.46	1.50	1.57	6.28	4.40	6.05	1.24	5.58	2.33	2.84	2.45	3.34	3.51
2015	1.40	3.46	2.41	9.75	7.61	11.36	3.37	7.85	2.82	1.73	2.98	1.14	4.64
2016	3.25	4.20	3.05	2.91	7.07	4.52	7.04	4.05	7.49	4.49	9.70	2.75	5.04
2017	6.30	4.39	3.33	5.69	5.00	0.86	8.44	12.20	7.54	3.49	2.69	1.27	5.11
2018	4.19	3.53	2.76	3.21	5.93	2.23	6.51	5.02	2.16	2.52	2.86	1.56	3.55
2019	1.52	1.70	2.45	5.23	3.90	2.50	9.48	3.94	1.74	2.36	2.36	4.08	3.46
2020	1.49	1.88	1.46	2.10	-	-	-	-	-	-	-	-	-
Minimum	1.40	1.50	1.46	2.10	3.90	0.86	1.24	2.23	1.74	1.73	1.77	1.14	3.46
Average	3.23	2.99	2.35	4.80	5.54	4.34	5.36	5.84	4.41	3.41	3.54	2.52	4.11
Maximum	6.30	4.39	3.33	9.75	7.61	11.36	9.48	12.20	7.54	6.42	9.70	4.08	5.11
Year	Mangorei power station discharge (Node 4): Mean monthly generation + bypass flow (m^3/s)												Annual
2013	2.73	1.60	1.36	3.83	5.94	5.12	4.29	4.82	5.34	5.77	2.87	3.57	4.07
2014	3.67	1.07	1.06	3.22	2.39	6.17	4.39	4.86	4.09	4.64	5.59	3.69	3.75
2015	1.40	2.34	2.28	5.36	5.90	5.97	5.31	6.78	5.53	3.46	3.91	2.66	4.25
2016	2.38	1.50	1.95	2.41	4.79	4.68	5.21	4.81	5.53	4.98	5.38	4.18	4.00
2017	4.70	3.67	2.65	4.50	5.18	3.70	6.00	6.07	6.03	4.52	2.52	1.18	4.23
2018	3.15	3.08	3.68	4.03	5.54	3.96	5.47	5.78	3.45	3.08	3.75	2.83	3.99
2019	1.37	0.89	2.09	3.37	3.49	4.43	4.00	5.66	4.29	4.71	3.23	3.33	3.42
2020	1.02	0.86	1.50	2.21	-	-	-	-	-	-	-	-	-
Minimum	1.02	0.86	1.06	2.21	2.39	3.70	4.00	4.81	3.45	3.08	2.52	1.18	3.42
Average	2.55	1.88	2.07	3.62	4.74	4.86	4.95	5.54	4.90	4.45	3.89	3.06	3.96
Maximum	4.70	3.67	3.68	5.36	5.94	6.17	6.00	6.78	6.03	5.77	5.59	4.18	4.25

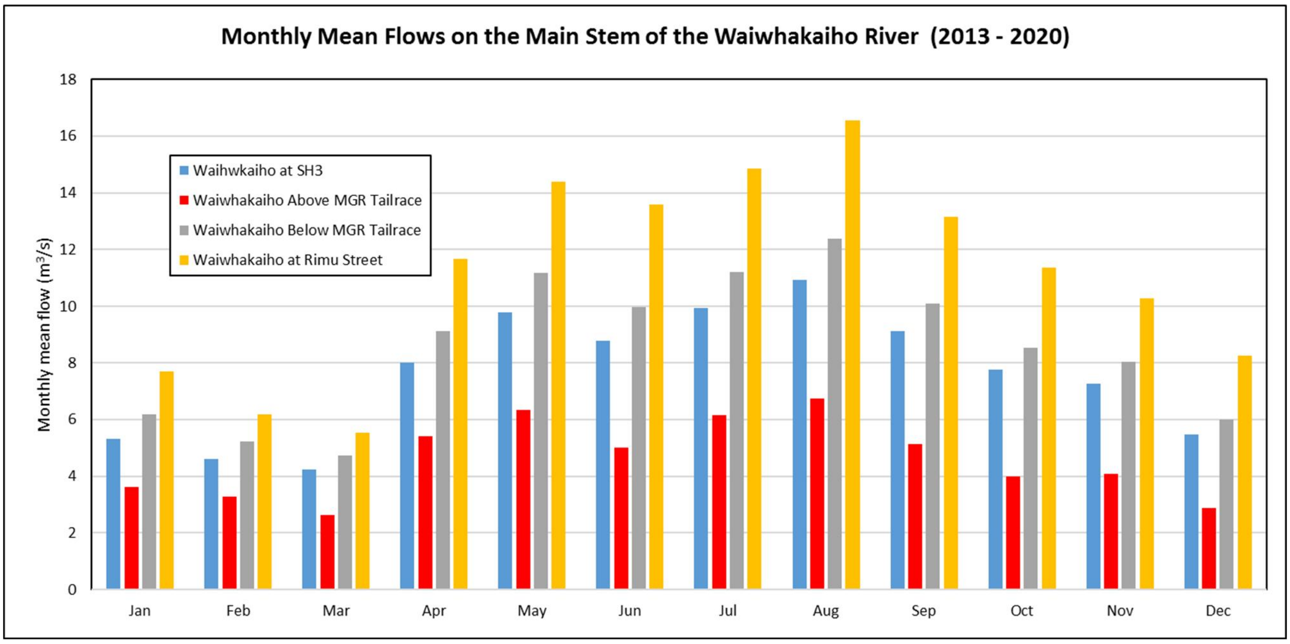

Figure 3.22 Waiwhakaiho River: mean flow distribution by month-of-year for four nodal locations

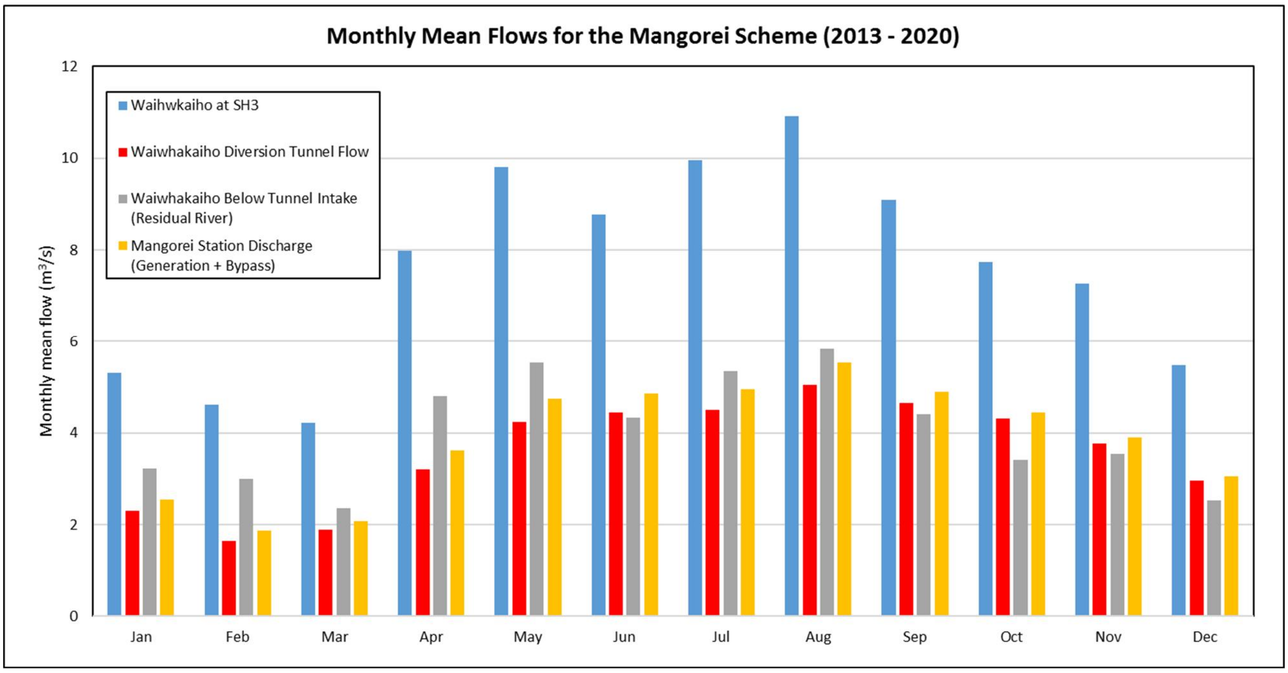

Figure 3.23 Mangorei Scheme: mean flow distribution by month-of-year for scheme components

3.6.3 Flow duration

Flow duration curves are presented in this section for three locations below:

- Waiwhakaiho River downstream of diversion tunnel – Figure 3.24
- Waiwhakaiho River upstream of Mangorei tailrace confluence – Figure 3.25
- Waiwhakaiho River downstream of Mangorei tailrace confluence – Figure 3.26

In each figure, the separate flow duration curves for summer (December to February), autumn (March to May), winter (June to August) and spring (September to November) are presented in addition to the annual (full year) curve. These flow duration curves are for a common data period, January 2013 to April 2020.

Further, Figure 3.27 compares the flow duration curves (full year) for three nodal locations associated with the headworks of the Mangorei scheme: Waiwhakaiho at SH3, Waiwhakaiho below diversion tunnel intake (residual river) and in the diversion tunnel.

Figure 3.28 compares the flow durations (full year) for five nodal locations on the main stem of the Waiwhakaiho River i.e. at SH3, downstream of the diversion tunnel intake, upstream of the power station tailrace, downstream of the power station tailrace, and at Rimu Street.

Finally, Figure 3.29 compares the flow duration curve for Waiwhakaiho at Rimu Street with the Mangorei generation discharge. This comparison shows the relative contribution of the power station outflows to the flow recorded at Rimu Street.

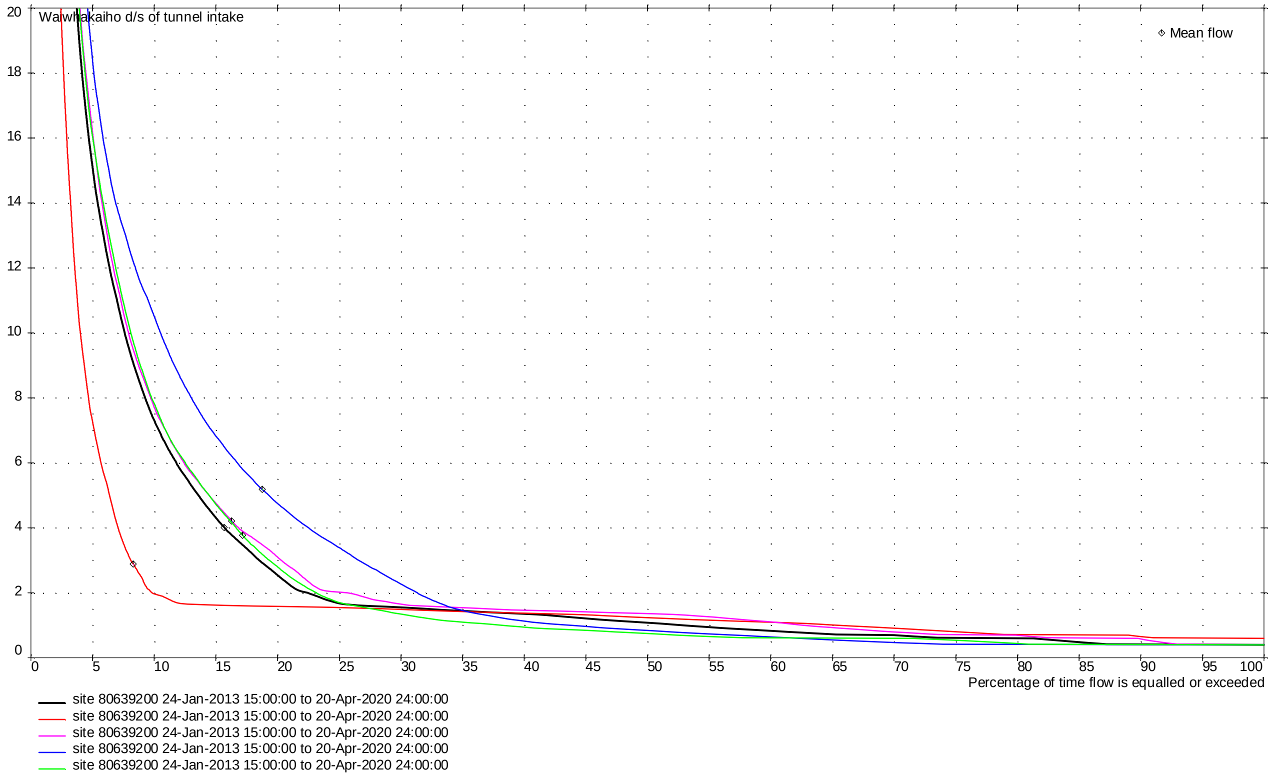

Figure 3.24 *Waiwhakaiho River downstream of tunnel diversion (start of residual river): flow duration curve January 2013 to April 2020. Red curve – summer (D, J, F); magenta curve – autumn (M, A, M); blue curve – winter (J, J, A); green curve – spring (S, O, N); black curve – full year*

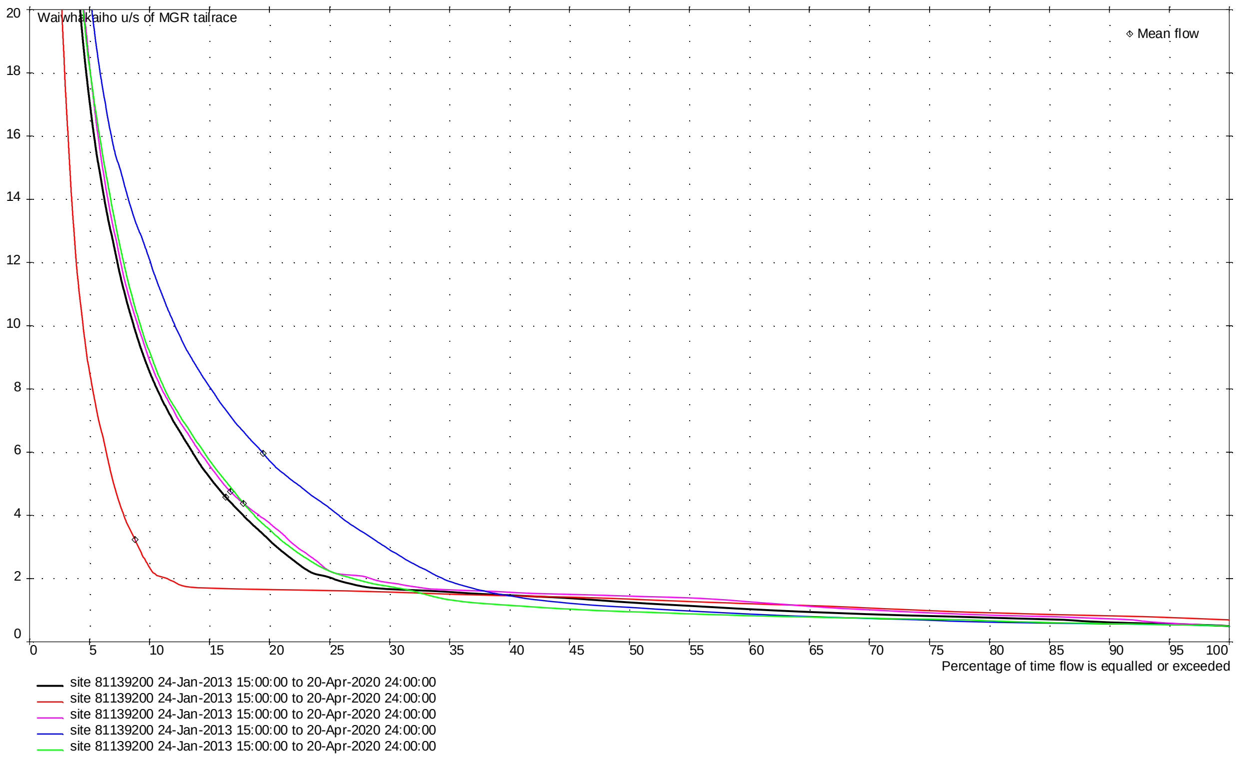

Figure 3.25 *Waiwhakaiho River upstream of MGR tailrace confluence (end of residual river): flow duration January 2013 to April 2020. Red curve – summer (D, J, F); magenta curve – autumn (M, A, M); blue curve – winter (J, J, A); green curve – spring (S, O, N); black curve – full year*

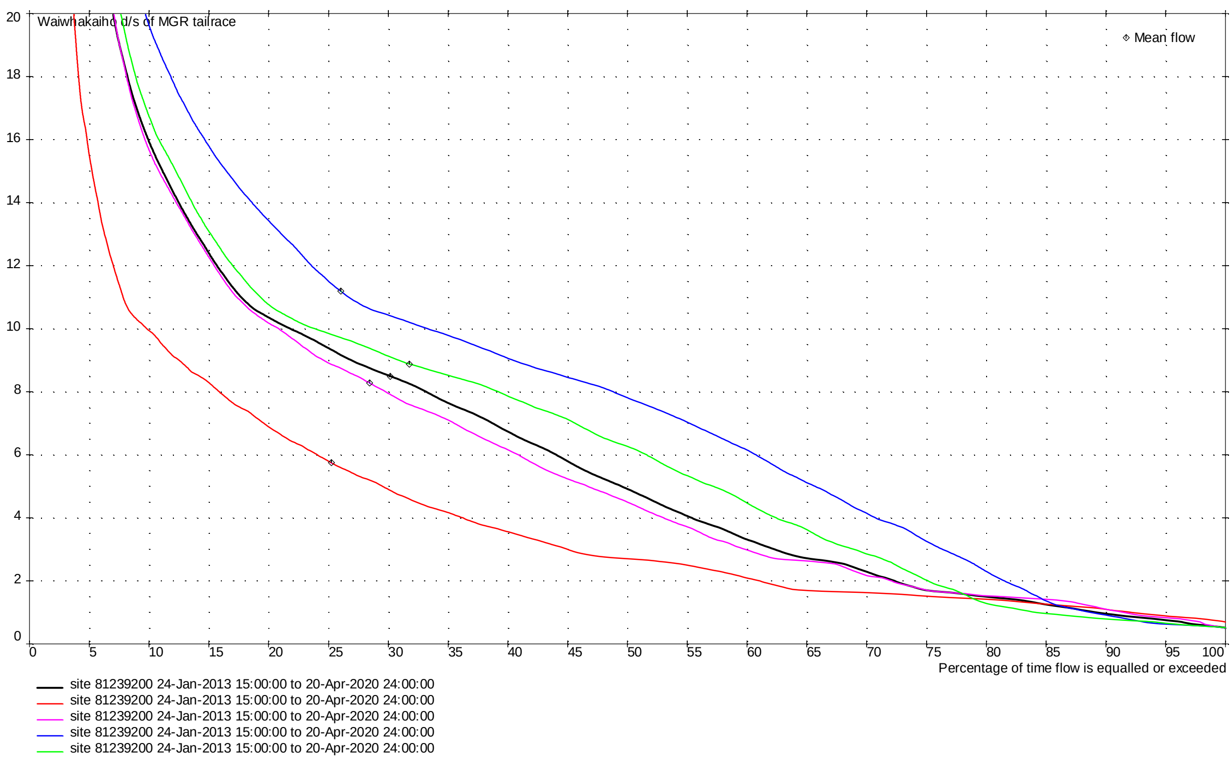

Figure 3.26 *Waiwhakaiho River downstream of MGR tailrace confluence: flow duration January 2013 to April 2020. Red curve – summer (D, J, F); magenta curve – autumn (M, A, M); blue curve – winter (J, J, A); green curve – spring (S, O, N); black curve – full year*

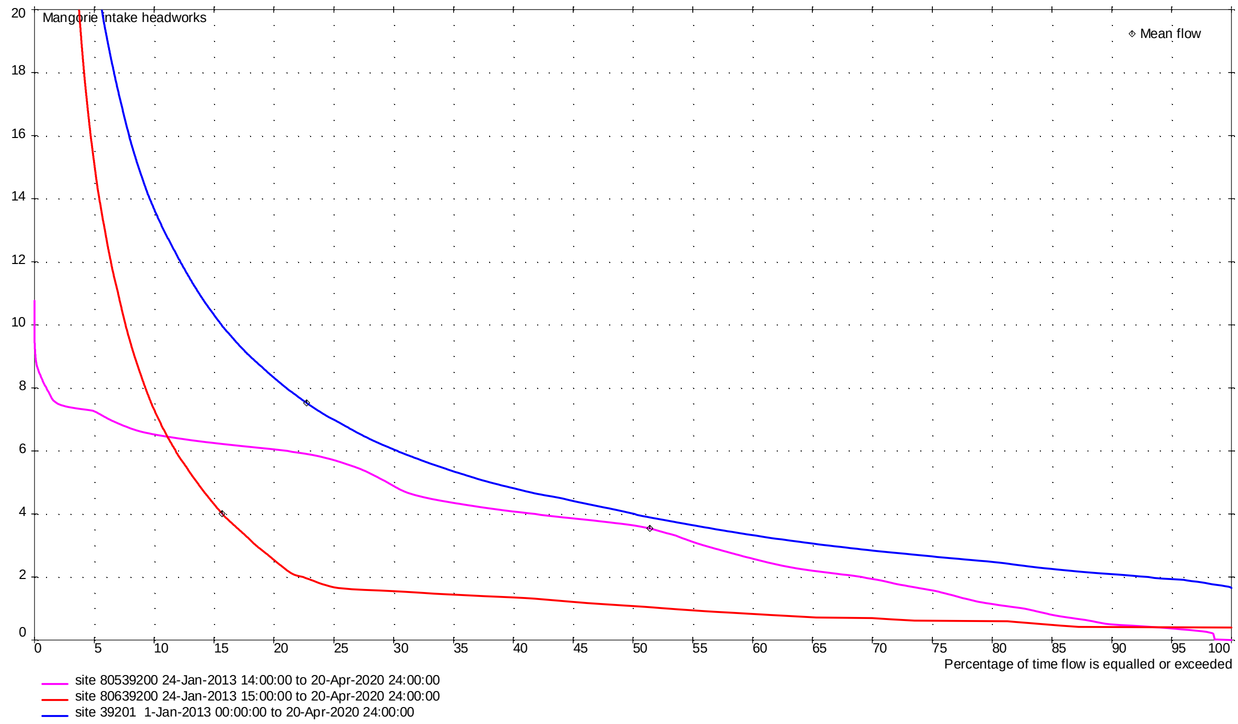

Figure 3.27 Flow duration curves at the Mangorei headworks, comprising Waiwhakaiho at SH3 (scheme inflow, blue curve); Waiwhakaiho below tunnel diversion (river residual flow, red curve); and flow in the diversion tunnel (magenta curve), for period January 2013 to April 2020

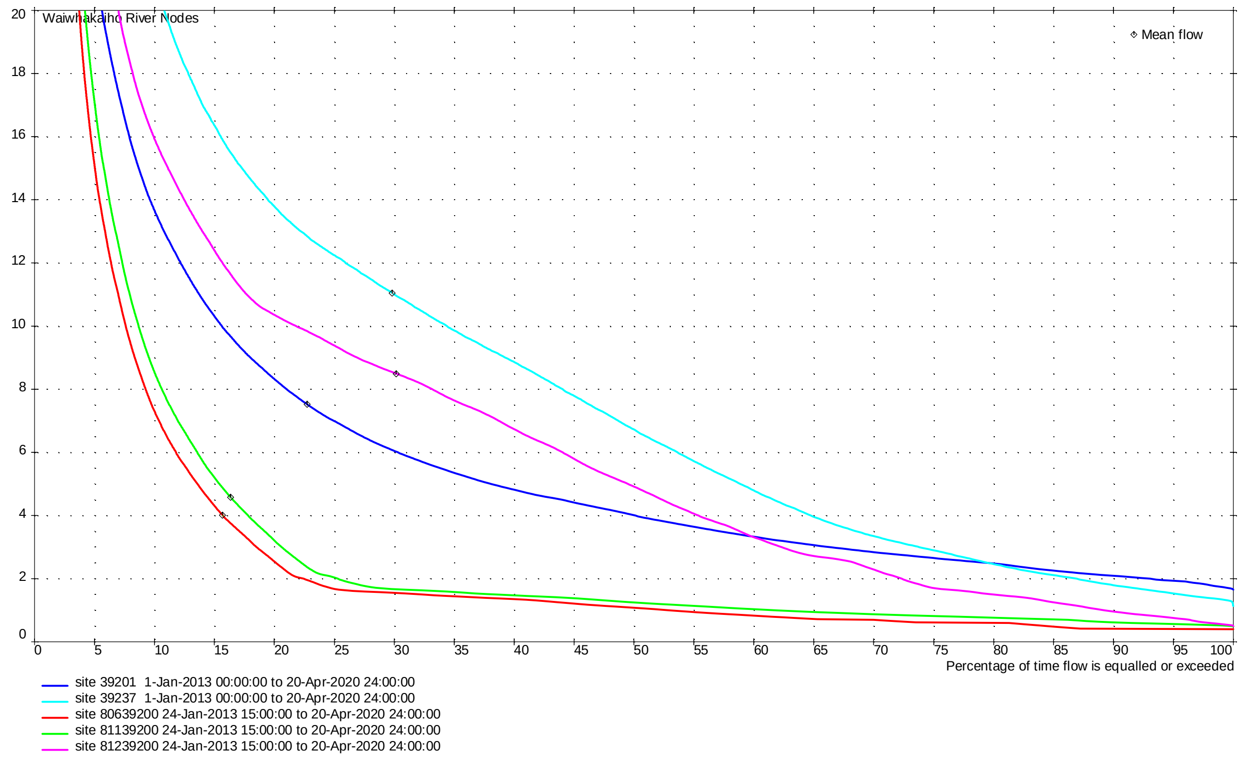

Figure 3.28 Waiwhakaiho River flow duration: at SH3 (blue curve); downstream of the diversion tunnel (red curve); upstream of the MGR tailrace (green curve); downstream of the MGR tailrace (magenta curve); and at Rimu Street (cyan curve), for period January 2013 to April 2020

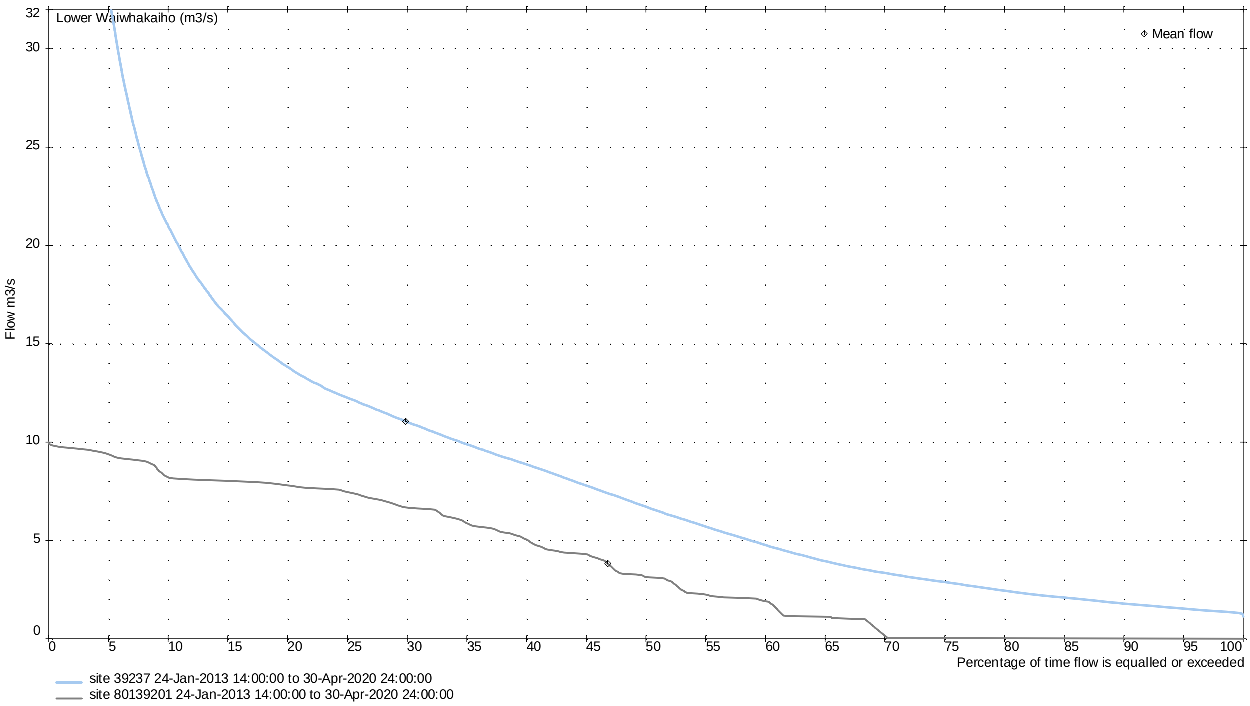

Figure 3.29 Waiwhakaiho at Rimu Street (blue curve) and Mangorei generation flow (grey curve) flow duration curves for period January 2013 to April 2020

3.7 Summary of flow statistics

Table 3.8 presents provides a selection of the key flow statistics for the nominated nodal locations in the Waiwhakaiho catchment (see Section 1.3 and Figure 1.2). These statistics are influenced by the period of record used, and are based on the water balance period 24 January 2013 to 30 April 2020.

Table 3.8 Summary flow statistics for key locations (nodes) in the Waiwhakaiho catchment

Node	Location	Catchment (km^2)	Flow value for statistic (m^3/s)					
			Mean	Max.	25% exc.	Median	75% exc.	Min.
1	Waiwhakaiho at SH3	60.5	7.54	484	7.01	4.01	2.65	1.66
2	Waiwhakaiho diversion tunnel	[1] 62.2	3.54	10.0	5.71	3.64	1.57	0
3	[4] Waiwhakaiho d/s of intake	62.2	4.10	432	1.68	1.09	0.61	0.40
4	Mangorei power station	-	3.82	9.98	7.46	3.15	0	0
5	[4] Waiwhakaiho u/s of tailrace	69	4.45	471	1.98	1.25	0.82	0.49
6	[4] Waiwhakaiho d/s of tailrace	86	8.34	486	9.42	4.88	1.67	0.51
7	Waiwhakaiho at Rimu Street	124	11.06	481	12.26	6.71	2.89	1.14
8	[3] Lake Mangamahoe	[2] 8.1	149.90	150.84	150.05	149.92	149.77	148.09

Notes
1 Catchment area of the Waiwhakaiho River at the intake to the diversion tunnel.
2 Local catchment to Lake Mangamahoe excluding diversion.
3 "Flow values" shown on this row are lake levels in RL m.
4 Flow statistics for these sites based on hourly averaged flows, while finer-grained data (typically 15-minutes) used for other sites.

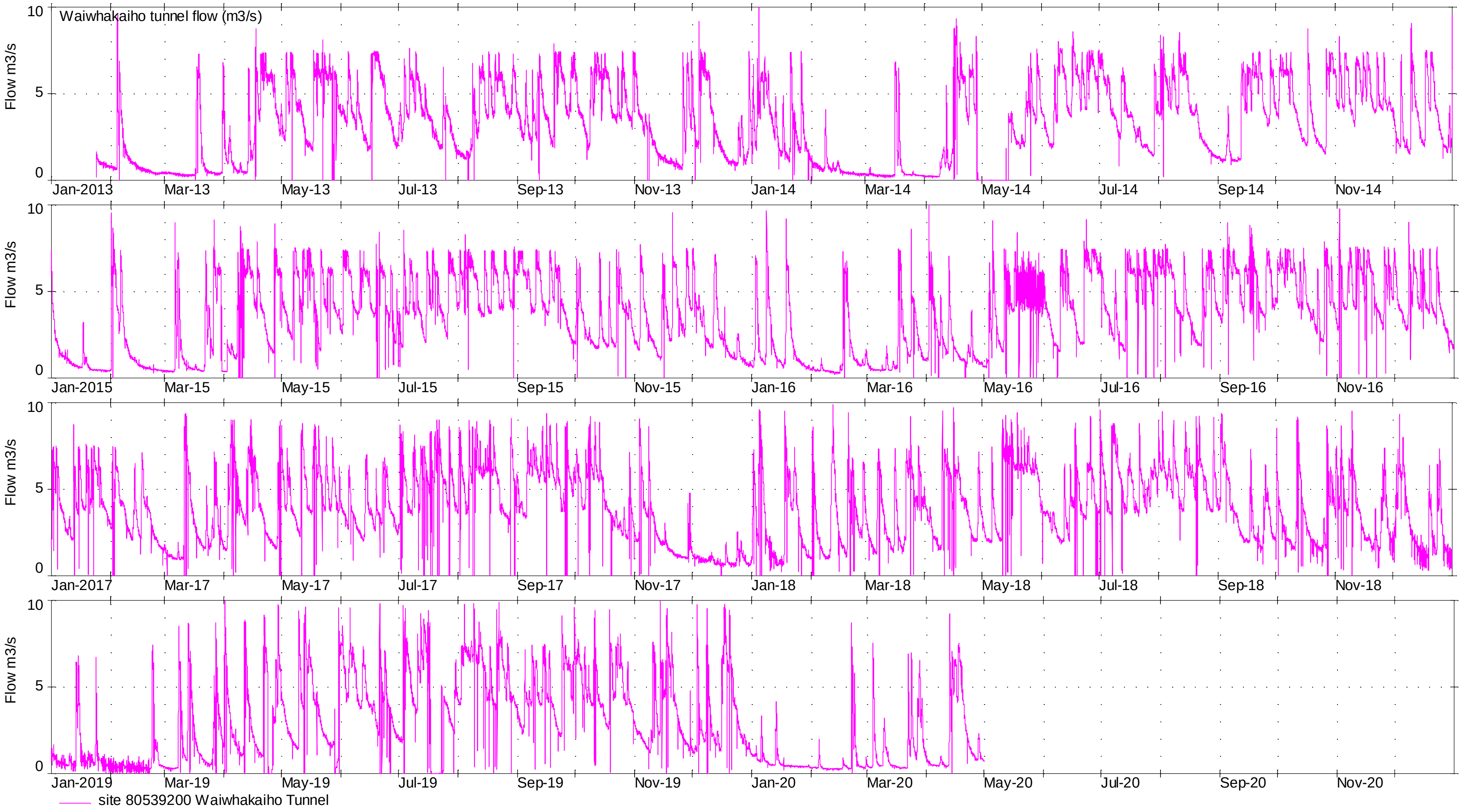

Figure 3.7 Waiwhakaiho diversion tunnel flow time series from 2013 to 2020 (approximate, with uncertainties arising from unrepresented hysteretic stage-discharge hydraulic behaviour in the tunnel)

Figure 3.12 *Lake Mangamahoe water level time-series from January 2013 to April 2020. Lower threshold line (red) represents minimum operating level, middle threshold line (green) the crest level of the concrete spillway, and upper threshold line (black) the top of the flashboards on the spillway crest.*

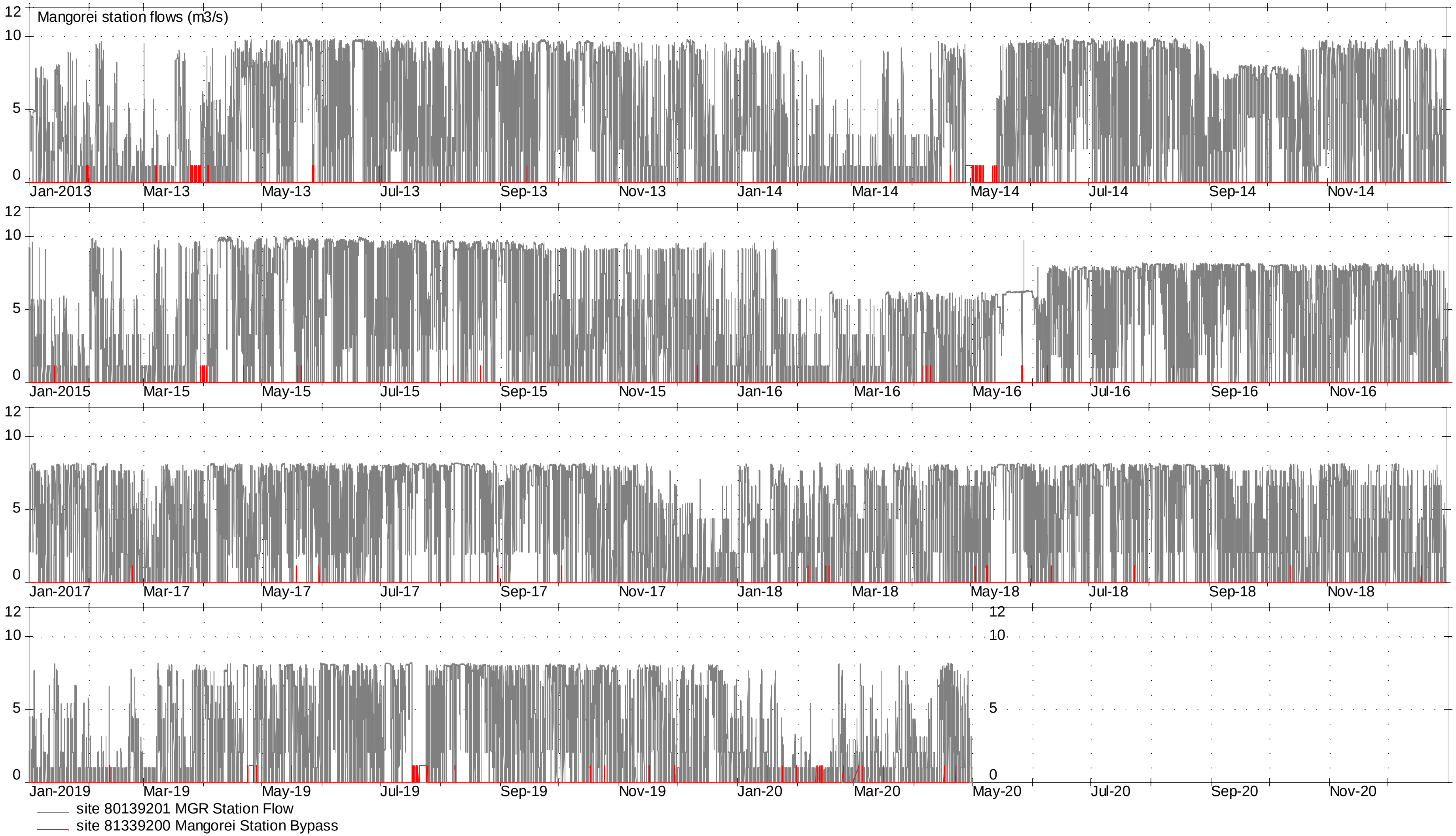

Figure 3.16 Mangorei power station discharge time-series from January 2013 to April 2020. Reduction in peak discharges after mid-2016 is associated with turbine upgrading work. The station bypass discharge is plotted as the red hydrograph

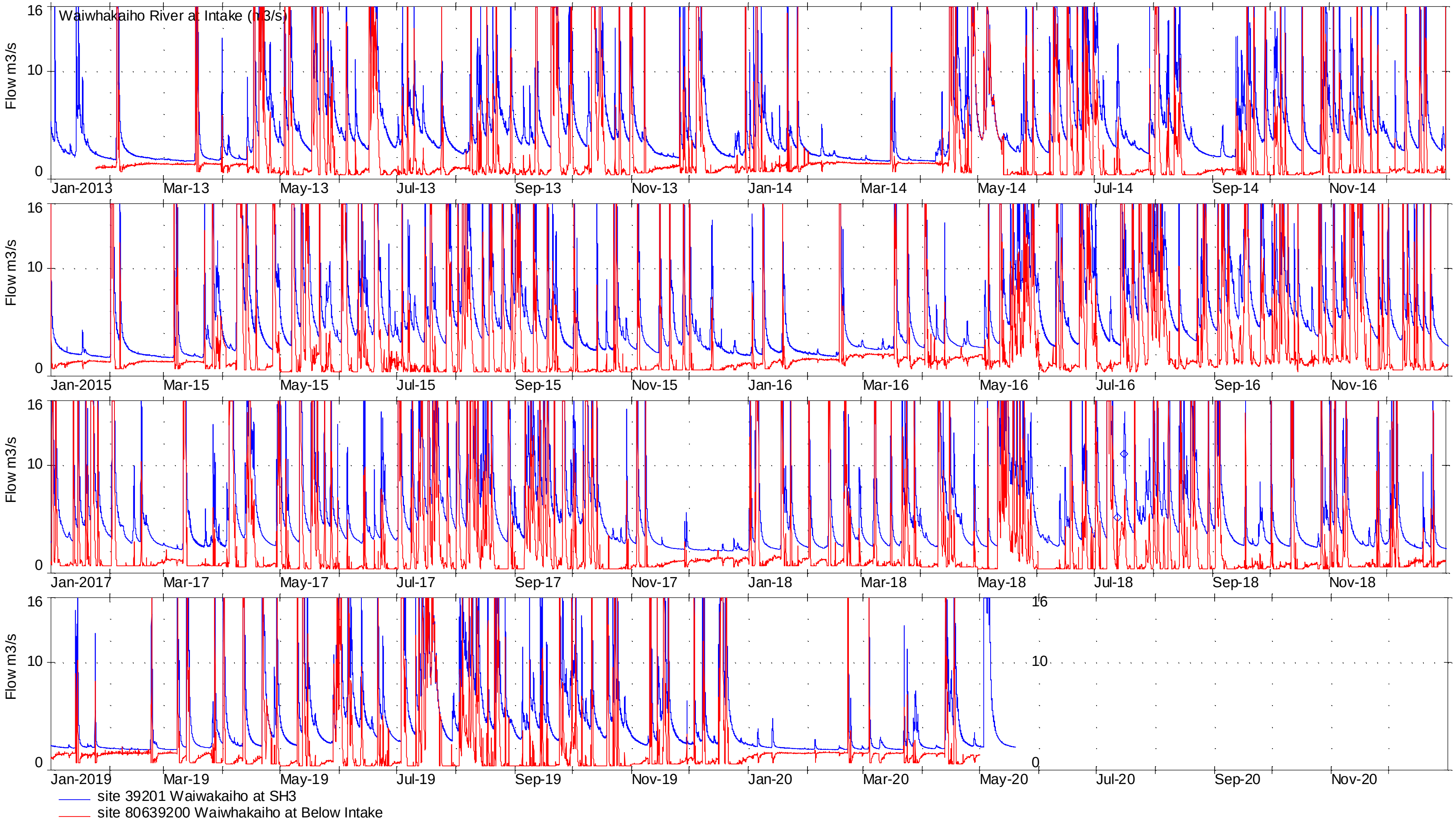

Figure 3.20 *Waiwhakaiho River flow time-series at SH3 (blue hydrograph) and immediately downstream of diversion tunnel i.e. residual river after take (red hydrograph) from 2013 to 2019. The latter is a derived (synthetic) record.*

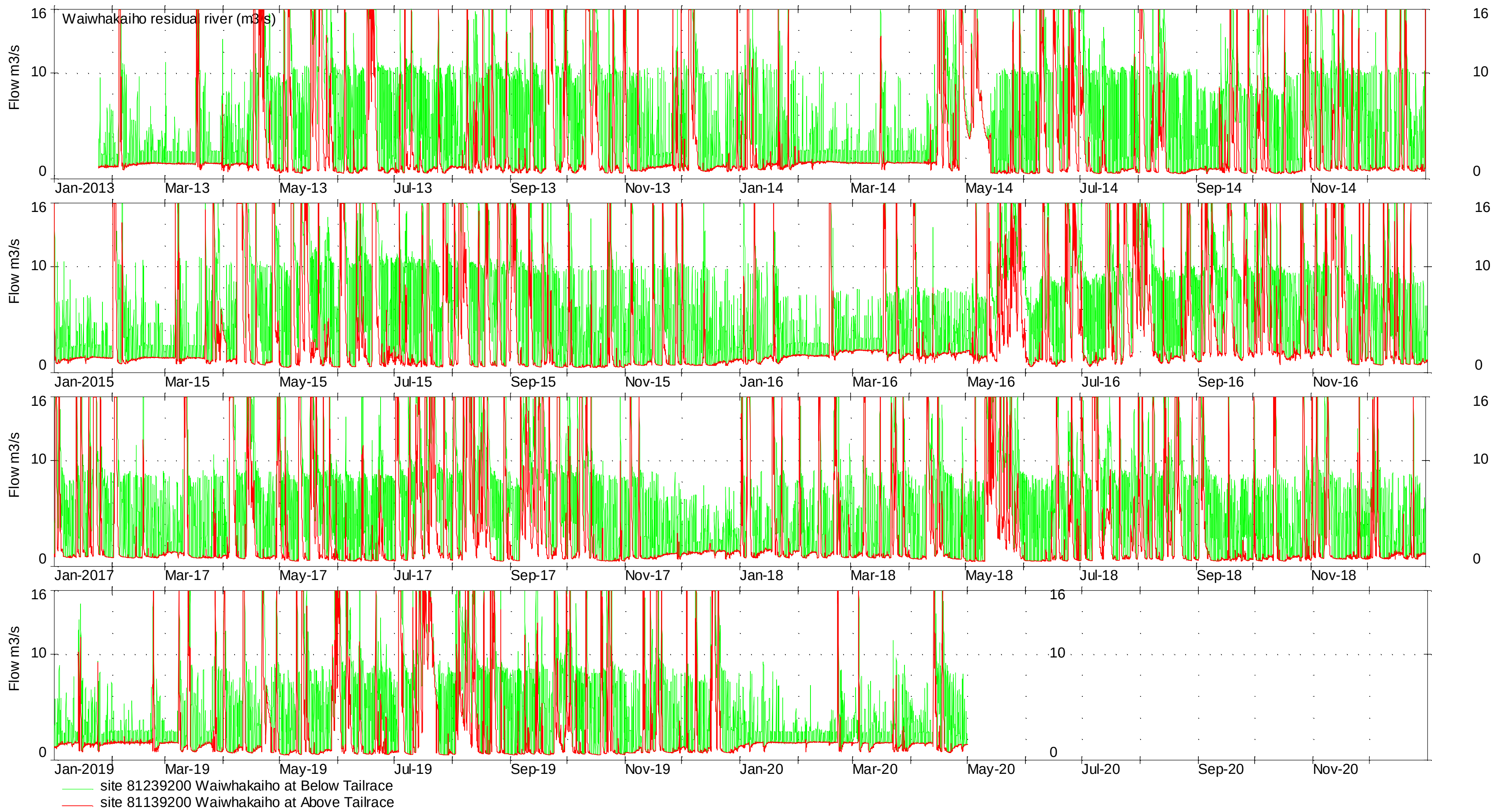

Figure 3.21 *Waiwhakaiho River flow time-series immediately upstream of MGR tailrace channel (red hydrograph) and immediately downstream of tailrace (green hydrograph) from 2013 to 2019. Both time-series are derived records.*

4 Proposed Mangorei HEPS Operating Regime

4.1 Proposed consent conditions

No changes are proposed to the current suite of consent conditions that relate to hydrological operation of the Mangorei scheme (set out in Table 3.1).

4.2 Future operating regime

Status quo in respect of the hydrological operation of the scheme is proposed to be retained, therefore the future operating regime should remain the same as it has been in recent years. However, the actual behaviour of the scheme and its effects on the downstream river flow regime will be subject to natural variability in the climate and thus the inflow patterns in the Waiwhakaiho catchment. There is an implicit assumption that future hydro-climatic conditions are reasonably represented by recent historical observations.

4.3 Implications of predicted climate change

In this section, the predicted changes in the future climate for the Taranaki region are based on the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment as interpreted by the Ministry for the Environment (MfE 2018). The potential impacts on the water resources of the Waiwhakaiho River and the operation of the Mangorei HEPS have been inferred from these predictions.

Climate projections for New Zealand have been prepared by MfE for three future periods: 2031 – 2050, 2081 – 2100 and 2101 – 2120, all expressed as changes relative to a baseline "present day" period of 1986 – 2005. These future 20-year periods are centred around 2040, 2090 and 2110, and so the climate projections are referred to as the 2040, 2090 and 2110 predictions. Given that the maximum term of the renewed consents will be 35 years (end of period around 2056), predictions for 2040 are more relevant than for 2090 or 2110 (apart from the greater uncertainty of these more distant projections) and have generally been adopted for the current assessment.

The IPCC 5th Assessment considered four emissions scenarios, known as representative concentration pathways (RCPs). These RCPs include one mitigation pathway (RCP2.6), two stabilisation pathways (RCP4.5 and RCP6.0) and one pathway with very high greenhouse gas concentrations (RCP8.5), i.e. essentially "business as usual". While there is no likelihood assigned to each scenario (i.e. no statement is made whether any one scenario is more likely than another), it is standard practice to adopt a midrange scenario for assessment of potential impacts. The midrange scenarios are RCP4.5 and RCP6.0.

4.3.1 Temperature and rainfall

Table 4.1 presents the predicted changes in the mean temperature and rainfall for 2040 and 2090 relative to the baseline period (1986 – 2005) for the Taranaki region. These predictions are from the MfE (2018) publication, and include the ensemble average as well as the range (5th percentile to 95th percentile) of predictions over all models within the ensemble used (viz. 37 models for RCP4.5 and 18 models for RCP6.0). While the mean temperature change is, in general, relatively uniform within a region, the mean change in rainfall is spatially more variable, and the tabulated rainfall values are for New Plymouth. Predictions for 2090 are shown in addition to those for 2040 to indicate the trend with time.

A notable feature of the tabulated values is the large spread in the possible future outcomes across the range of global circulation models (GCMs) used for predictions.

Table 4.1 Predicted changes in the seasonal and annual mean temperature and mean rainfall for the Taranaki region (extracted from MfE 2018)

Future time period and emissions scenario	Summer (DJF)	Autumn (MAM)	Winter (JJA)	Spring (SON)	Annual
[1] Change in mean temperature (in °C) for future period relative to baseline period (1986 – 2005)					
2040, RCP4.5	0.9 (0.4, 1.5)	0.9 (0.4, 1.4)	0.9 (0.6, 1.2)	0.8 (0.3, 1.1)	0.9 (0.5, 1.2)
2040, RCP6.0	0.9 (0.3, 1.6)	0.9 (0.3, 1.2)	0.8 (0.3, 1.2)	0.7 (0.2, 1.2)	0.8 (0.3, 1.2)
2090, RCP4.5	1.5 (0.7, 2.7)	1.5 (0.8, 2.2)	1.5 (0.9, 2.1)	1.3 (0.7, 1.9)	1.4 (0.9, 2.1)
2090, RCP6.0	1.9 (1.0, 3.9)	1.9 (1.0, 2.9)	1.9 (1.2, 2.8)	1.6 (1.0, 2.3)	1.8 (1.1, 2.9)
[1,2] Change in mean rainfall (in percent) for future period relative to baseline period (1986 – 2005)					
2040, RCP4.5	0 (-9, 8)	1 (-9, 12)	4 (-6, 15)	1 (-0,10)	2 (-5, 7)
2040, RCP6.0	-1 (-13, 8)	1 (-12, 12)	5 (-5, 15)	-1 (-9, 8)	1 (-5, 8)
2090, RCP4.5	2 (-10, 14)	2 (-8, 12)	5 (-9, 18)	0 (-8, 9)	2 (-5, 10)
2090, RCP6.0	2 (-23, 23)	4 (-17, 30)	9 (-8, 33)	2 (-14, 18)	4 (-13, 26)

Notes:
1 The values in each column represent the ensemble average, and in brackets the range (5th percentile to 95th percentile) over all models within that ensemble, which consists of 37 global climate models for RCP4.5 and 18 global climate models for RCP6.0.
2 MfE (2018) does not provide a prediction of the mean rainfall changes for entire regions as a whole or as an average, but provides predictions for one or two specific locations within a region. For the Taranaki region, the predicted changes are given for New Plymouth.

By 2040, the mean temperature in Taranaki is projected to increase by around 0.9 °C for both RCP4.5 and RCP6.0. By interpolating between the 2040 and 2090 predictions, the projected mean temperature increase by 2056 (end of 35 year term from 2021) is approximately 1.1 °C. There is little variation across the seasons, with spring experiencing a slightly lower increase.

By 2040, the mean rainfall for New Plymouth (representing the Taranaki region – see note 2 in Table 4.1) is predicted to increase by about 5% in winter and remain relatively unchanged for the other seasons. By 2090, the mean rainfall is projected to increase by between 5% and 9% in winter and by around 2% to 4% for the other seasons.

MfE (2018) also provides the predicted increase in the number of “hot days” per year (maximum temperature ≥ 25 °C), by region, for two future periods viz. 2040 and 2090 under the four RCPs. These predictions are presented in Table 4.2 and indicate a doubling of the average number of hot days by 2040, and 3 to 4 times as many hot days compared with the present by 2090.

Table 4.2 Average number of “hot days” (maximum temperature ≥ 25 °C) per year for Taranaki (extracted from MfE 2018)

For Taranaki region	Present day (1986 – 2005)	Future period 2040		Future period 2090	
		RCP4.5	RCP6.0	RCP4.5	RCP6.0
Average number of “hot days” per year	6.5	13.5	13.4	19.7	26.6

The average number of “cold nights” (minimum temperature ≤ 0 °C) per year is also given in MfE (2018). For Taranaki, the average number of cold nights are projected to decrease from 6.3 to around 2.7 by 2040 (average of RCP4.5 and RCP6.0) and to about 1.2 by 2090 (average of RCP4.5 and RCP6.0).

Projected changes in extreme (storm) rainfall depths, expressed as a function of the predicted mean temperature increase, are described in Carey-Smith et al (2018). A range of storm durations (from 1 hour to 5 days) and different average recurrence intervals (ARIs) from 2 years to 100 years were considered. Figure 4.1 shows, for example, the estimated percentage change in storm depth per °C warming for the 50-year ARI event for all of New Zealand. It may be seen that for the Waiwhakaiho catchment, the increase in storm depth is around 10% for a short duration event (1 hour) and progressively reduces for longer duration events, i.e. to around 5% for the 5-day rainfall. As noted earlier, the predicted mean temperature increase for Taranaki by 2040 is about 0.9 °C (and 1.1 °C by 2056). Given the direct linkage between storm rainfall depth and flood size, a similar increase in the peak flood flows (i.e. 5% to 10%) may be expected by 2040.

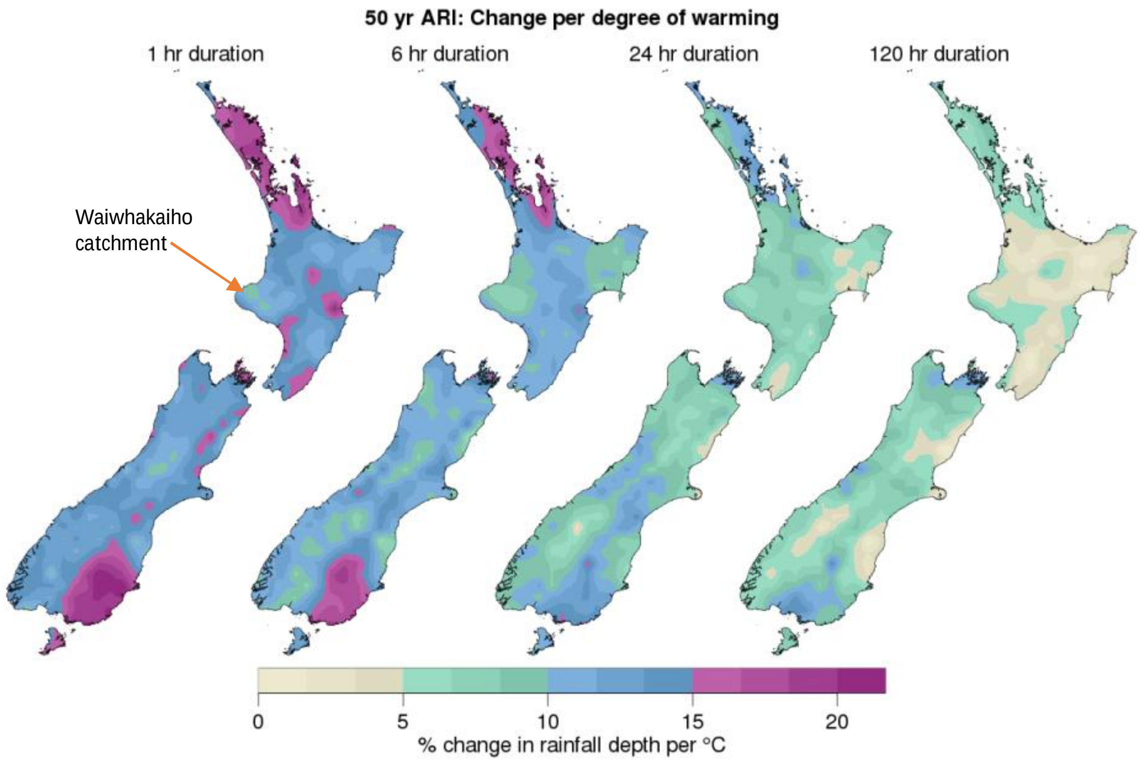

Figure 4.1 *Change in the 50-year rainfall event magnitude for four different event durations. Taken from Carey-Smith et al (2018)*

At the other end of the scale, the average number of "dry days" (rainfall less 1 mm/day) is also predicted to change under a future climate. Figure 4.2 shows the frequency of dry days increases with RCP and time for much of the North Island including the Taranaki region. Associated with the increase in dry days will be increased occurrence of drought, as shown by the maps of the change in potential evapotranspiration deficit (PED) presented in MfE (2018). These maps (not shown here) indicate an increase of PED of roughly around 50 mm for the Waiwhakaiho catchment.

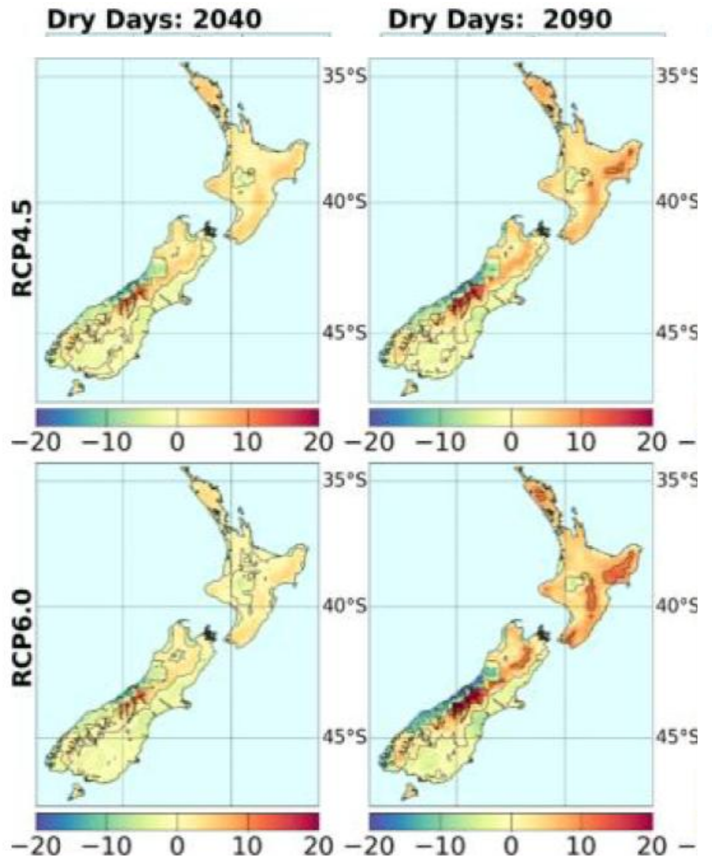

Figure 4.2 *Projected changes in the annual number (in days) of "dry days" (rainfall less than 1 mm/day) compared with the baseline period (1986 – 2005) for RCP4.5 and RCP6.0 for two future time periods 2040 and 2090. Taken from MfE (2018)*

4.3.2 Implications for Mangorei HEPS

By 2040, based on the two midrange climate change scenarios (RCP4.5 and RCP6.0), the mean temperature in the Waiwhakaiho catchment is expected to be about 0.9 °C warmer relative to present day (1986 – 2005 baseline). This warming would be accompanied by a modest increase in the evapo-transpiration rates in the catchment, which has the potential to reduce catchment runoff and thus the river flow, particularly over the summer and autumn seasons. In addition, the projected increases in the number of "hot days" and "dry days" are likely to further reduce and prolong summer low flows. However, averaged over the year, this flow reduction could be offset to a large extent by the projected increase in mean rainfall in the winter months (of about 5% by 2040, per Table 4.1).

Therefore, in terms of the flow in the Waiwhakaiho River, the anticipated net result is that:

- for the winter months, there is a high likelihood of increased mean flow
- there is also a high likelihood of a reduction in the summer mean flow
- furthermore, both the frequency and duration of low flow events are likely to increase (and droughts likely to become more severe)
- peak flood discharges may also increase with the predicted increase in storm rainfall depths.

Some of these changes, particularly incidence of prolonged and reduced low flows in the Waiwhakaiho River through summer and early autumn, will be reflected in the pattern of diverted flows into Lake Mangamahoe. Flow derived from the local lake catchment, including from the Mangamahoe Stream and the Kent Road Stream, will also be subject to the anticipated changes described above. However, these changes are not expected to be large enough to significantly affect the current operating regime of the Mangorei HEPS including the lake level management.

It is interesting to observe that, of the four anticipated changes, there is emerging evidence from analysis of the 40-year long flow record at SH3 (1980 to 2020) that the first three already appear to be occurring viz.:

- Figure 2.7 shows a weak trend of increasing winter mean flow (increase of about 0.4% per year)
- Figure 2.5 shows a weak trend of decreasing summer mean flow (decrease of about 0.5% per year)
- Figure 2.14 shows a similar weak trend of decreasing 7-day annual flow (decrease of about 0.4% per year)

These apparent trends are in general agreement with the theoretically predicted changes caused by climate change.

Another noteworthy observation is that the decreasing summer mean flow is almost exactly offset by the increasing winter mean flow such that the annual mean flow (whole year average) appears to be reasonably stable over the 40-year record period. However, there is evidence of ongoing seasonal re-distribution of the flow.

In relation to extreme flood flows, there is no evidence yet in the SH3 flow record of increasing annual maximum discharges (see Figure 2.17) in accordance with climate change predictions. That noted, trends in such extremes typically require a much longer record than is available to detect. In any case, a separate analysis of the 60 largest floods in the SH3 record seems to indicate an increasing frequency of the smaller floods around the mean annual flood size (refer to Figure 4.3 which shows higher density of floods in the latter decades).

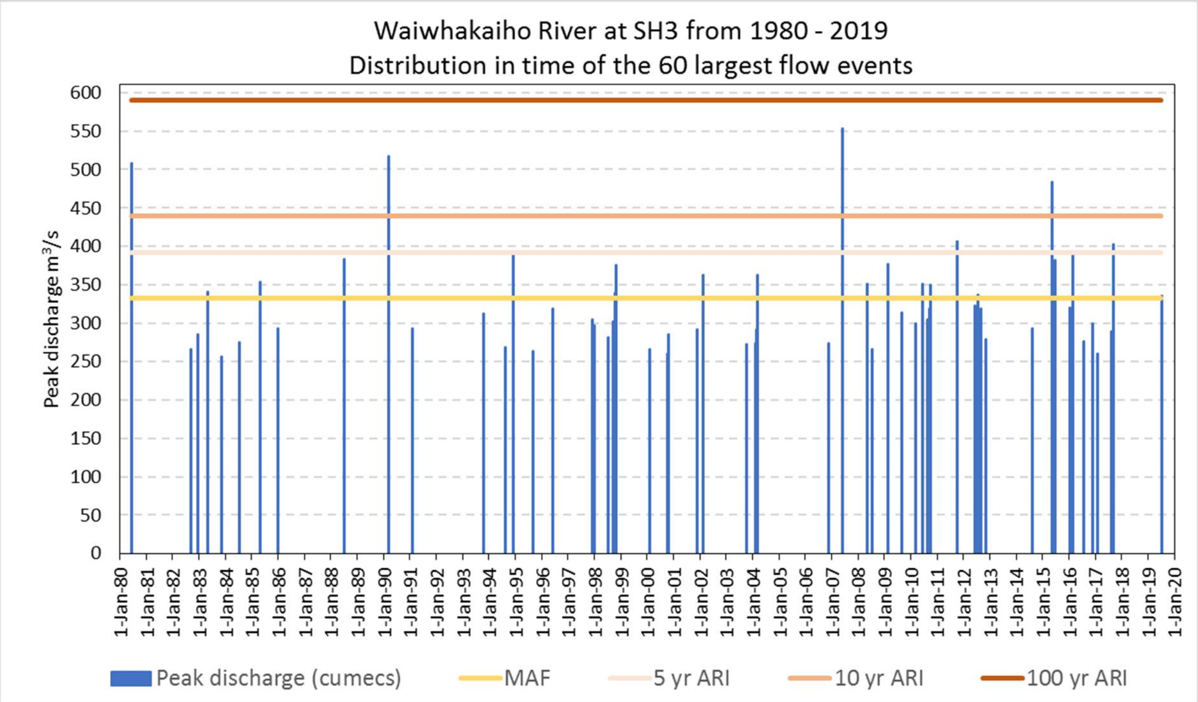

Figure 4.3 *Distribution of the 60 largest flows recorded for the Waiwhakaiho River (SH3) between 1980 and 2019, with mean annual flood (MAF), 5, 10 and 100-year ARI flow thresholds indicated*

5 Hydrological Effects of the Mangorei HEPS

5.1 Introduction

The preceding Sections 2 and 3 of this report present a large amount of hydrological information on, respectively, the Waiwhakaiho catchment and its water resources, and the hydrological operation of the Mangorei scheme. The latter effectively quantifies the "hydrological footprint" of the scheme. A key objective of these hydrological summaries and analyses is to inform studies by other experts on a range of environmental and socio-economic aspects potentially affected by the existing scheme.

As a preface, it is noted that there are few direct hydrological effects (i.e. effects that can be categorised as adverse or beneficial strictly from a hydrological perspective such as flooding). Rather there is greater scope for hydrological changes, which can manifest as consequential effects on a range of environmental and socio-economic values (e.g. ecology, natural character, recreation and cultural). This section summarises the hydrological effects and changes resulting from the operation of the scheme. Note that descriptions below use effect and change interchangeably even though there is a difference[2].

Effects may be categorised into *historical* effects, which are effects of the scheme on the pre-existing environment before the scheme was built, and *ongoing* effects, which are effects that persist in the current built environment. The Mangorei HEPS now forms part of the existing environment and it is clear that historical effects associated with its construction were much more significant than ongoing (or current) effects. A precis of the historical effects of the scheme, which are part-and-parcel of the existing baseline environment, is presented in Table 5.1.

Table 5.1 Summary of historical hydrological changes arising from the Mangorei HEPS (ongoing/current effects are indicated by green shading)

Aspect	Comments (based on recent operational regime 2013 to 2020)
Diversion of Waiwhakaiho River	
· Creation of residual river 5.9 km long	Diversion of up to 10 m^3/s from the Waiwhakaiho River has created a length of residual river between the river intake and the tailrace confluence ("Meeting of the Waters") some 5.9 km downstream. The diverted water is not permanently lost but is returned to the river (via the tailrace) where it flows for another ~11 km before reaching the sea. The residual river represents 15% of the entire length of the Waiwhakaiho River from its source.
· Changed flow regime in residual river	Mean flow in the residual river is reduced by 3.5 m^3/s (46%) compared with no diversion occurring (7.6 m^3/s), and the block of flow removed comprises baseflows up to moderately high flows (see Figures 3.27 and 3.28), resulting in reduced and prolonged low flows.
· Increased flow to Lake Mangamahoe	Diverted flow from Waiwhakaiho River has increased the flow volume to the Mangamahoe Stream catchment (and thus the lake) seven-fold compared with pre-existing conditions, though without substantially increasing the flood flows.
Presence of Mangamahoe dam	
· Dambreak hazard	As with any dam there is a potential flooding hazard posed to downstream areas in the unlikely event of a dam failure. This aspect is dealt with in the Assessment of Environmental Effects.
· Diversion of Mangamahoe Stream	The dam effectively diverts flow from the Mangamahoe Stream catchment (8.1 km^2) into the man-made lake for hydro-electric generation and water supply use. Inflow to the residual reach of the Waiwhakaiho River from Mangamahoe Stream now comprises

[2] A change doesn't necessary represent an adverse effect (but it can). However, there are hydrological effects that can arise from particular changes to the flow regime, e.g. flooding and erosion.

Aspect	Comments (based on recent operational regime 2013 to 2020)
	spill flows, leakage and seepage from the dam, and runoff from the remaining 1 km^2 catchment below the dam.
Creation of Lake Mangamahoe	
· Inundation of land	The lake occupies an area of about 0.25 km^2. The result has created a key recreational amenity, water supply and renewable energy resource.
· Lake sedimentation	Sedimentation can reduce hydro lake storage capacity over time, with the bulk of the deposition (around 2000 m^3/year on average) occurring in the southern arm of the lake "upstream" of the water supply pipeline.
· Lake level fluctuations	Daily ramping of generation results in a complementary diurnal fluctuation in lake levels that has an amplitude that varies from as little as 120 mm during summer low flows to over 400 mm for normal flow periods.
Power station operation	
· Modified flow regime in lower river	Under normal (non-flood) flow conditions operation of the Mangorei scheme creates large swings in the scheme outflow on a daily basis, as generation is ramped up and down to complement the energy demand profile. As illustrated in Section 3.5.2, these diurnal outflow patterns propagate downstream to the lower Waiwhakaiho River with only minor attenuation (smoothing) of the generation pulse. In the lower river, these fluctuations are a significant feature of flow regime caused by the Mangorei scheme.
· Potential effects from daily flow ramping	With the diurnal fluctuation in the river flow, there is a complementary fluctuation in the river level (up to around 450 mm as measured in the Waiwhakaiho River at Rimu Street).

5.2 Current effects

As noted earlier, the Mangorei scheme and its historical impacts are considered part of the existing environment. Nevertheless, there will be ongoing effects. Current hydrological effects from the proposed continued operation of the Mangorei HEPS include the following (refer to Table 5.1 for additional detail):

- Modified flow regime in the residual river
- Lake sedimentation on lake storage
- Diurnal lake level fluctuations
- Modified flow regime in the lower river (below the tailrace) including daily flow fluctuations.

It is noted that flow diversion from the Waiwhakaiho River is not expected to have a material effect on the morphology of the river channel, either in the residual river or in the lower river downstream of the tailrace. This is because the maximum flow able to be diverted of 10 m^3/s represents only a small percentage of the flood flows generally considered to be responsible for morphological change, i.e. floods around the mean annual flood size, which is about 350 m^3/s for the lower Waiwhakaiho River (see Table 2.8). That is, a reduction of up to 10 m^3/s in the flood flow is not expected to have an effect on morphological processes.

6 Summary and Conclusions

The current consents for the operation of the Mangorei HEPS expire on 1 June 2021. Trustpower has commenced a process to obtain replacement consents to permit operation of the scheme for a further term. An assessment of the effects of the scheme on the environment is required to support the consent application. This report, which is one of a series of technical assessment reports, addresses the hydrological aspects of the scheme.

This report has sought to:

- Describe the general hydrological setting of the Mangorei HEPS and provide an assessment of the existing flow regime of the Waiwhakaiho River, covering the mean flow, flow-duration, low flows and floods
- Describe the historical operation of the Mangorei HEPS, including diversion from the Waiwhakaiho River, Lake Mangamahoe levels, and daily flow fluctuations at the power station
- Describe the proposed operating regime of the Mangorei HEPS (essentially unchanged from the current operation)
- Outline the predicted effects of projected climate change on the river flow regime and operation of the scheme
- Describe the hydrological effects of the Mangorei HEPS and its operation.

The main points and conclusions from this assessment are as follows:

<u>Hydrology and water resources of Waiwhakaiho River</u>

(i) Flow records from two gauges are available to characterise the hydrology and water resources of the Waiwhakaiho River. The longer record, Waiwhakaiho at SH3, has 40 years of data commencing in 1980 and is representative of the middle reaches of the river upstream of the Mangorei scheme, while the shorter record at Rimu Street has 11 years of data starting in 2009 and is representative of the lower river downstream of the scheme's return flow.

(ii) Flow in the Waiwhakaiho River is characterised by frequent and rapidly rising freshes followed by strong sustained baseflows, with a very high runoff per unit catchment area by national standards (i.e. averaging 4.1 m p.a. at SH3 based on the long term mean flow of 7.84 m^3/s).

(iii) The 7-day MALF above the diversion is estimated to be 2.11 m^3/s based on the 40-year flow record at SH3. However, a trend analysis of both the annual low flow and the mean summer flow series provides some evidence, which is inconclusive because of the weak correlations and large inter-annual variability, that both have declined with time, at a rate of around 0.4 – 0.5% per year. Any potential trend in low flow indices has a significant implication in the context of setting residual flow.

(iv) It is notable that the driest summer in the 40-year SH3 record occurred in 2019 (December 2018 to February 2019), while the most recent summer (December 2019 to February 2020) was the fourth driest. However, based on the average flow between January and April each year, 2020 was the driest period on record (mean flow 2.98 m^3/s).

(v) Despite the apparent decline in summer flows, there isn't a corresponding decline in the mean flow on a yearly basis, as the decline is being offset by an apparent increase in winter flows. However, there is no discernible trend in the annual flood series (i.e. floods do not seem to be getting larger, based on the 40-year record, which is considered short for detecting trends).

Hydrological operation of the Mangorei scheme

(vi) Time-series data recorded by Trustpower allow the hydrological operation of the Mangorei scheme to be characterised, and of these, the Waiwhakaiho diversion tunnel flow record (commencing in January 2013) is the shortest, which limits the assessment of the scheme water balance to the past 7 years (2013 to 2020).

(vii) Hysteresis in the hydraulic behaviour of the tunnel flow (i.e. different behaviour on increasing versus decreasing river flows), which is not able to be modelled, results is a reasonably large uncertainty in the tunnel flow record. While the current consent allows a maximum diversion of 10 m^3/s, hydraulic constraints at the intake and tunnel limit the practical diversion to around 9 m^3/s and also cause shortfalls in the actual versus allowable diverted flow.

(viii) For the water balance period, the mean flow of the Waiwhakaiho River just upstream of the tunnel intake is 7.64 m^3/s, and an estimated 46% of this flow (3.54 m^3/s) is diverted into Lake Mangamahoe. The local lake catchment contributes about 11% of the total lake inflow of about 3.98 m^3/s. Outflow from the lake is dominated by the draw-off to the power station (~91%) followed by the take to NPDC's water treatment plant (~8.5%).

(ix) A residual flow is maintained below the diversion and the minimum flow specified by current conditions varies between 0.4 and 0.7 m^3/s depending on the month of the year. Flow gaugings by TRC (2019) confirm that the required residual flow is being provided.

(x) Lake levels are required by consent to be no lower than 0.75 m of the spillway crest level at Mangamahoe Dam (RL 149.78 m). Half metre high flashboards mounted on the spillway crest allow a larger operating range. Analysis of the data 2013 to 2020 shows that lake levels have generally fluctuated within a 1 m range (RL 149.3 m to RL 150.3 m), and that the lowest level in that period was RL 149.09 m, which is above the minimum consented operating level (RL 149.03 m), noting that NPDC can draw the lake lower still for water supply.

(xi) Operation of the Mangorei power station is characterised by large diurnal variations in the station outflow as generation is ramped up and down to complement the energy demand profile. These diurnal outflow patterns propagate downstream to the lower Waiwhakaiho River with only minor attenuation (smoothing) of the generation pulse, and are also reflected in the lake level record as daily fluctuations with typical amplitude of 100 mm to 400 mm.

Proposed operating regime of the Mangorei scheme

(xii) Status quo with respect of the hydrological operation of the scheme is proposed to be retained, therefore the future operating regime should remain the same as it has been in recent years. However, the actual behaviour of the scheme and its effects on the downstream river flow regime will be subject to natural variability in the climate and thus the inflow patterns in the Waiwhakaiho catchment.

(xiii) In the Taranaki area, the future climate is predicted to be warmer (e.g. by around 0.9 C by 2040) with higher rainfall in winter (e.g. about 5% more). Coupled with a predicted increase in the number of both "hot days" and "dry days", this is anticipated to result in a reduced summer mean flow and increased frequency and duration of low flow events. However, the reduction in summer flows is expected to be offset by an increase in the winter mean flow. Flood discharges may also increase with the predicted increase in storm rainfall depths.

(xiv) The apparent trends detected in the 40-year Waiwhakaiho River flow record at SH3 suggest that the predicted hydrological consequences of climate change (apart from floods) have already manifested in the river flows. However, these changes are not expected to be large enough to significantly affect the current operating regime of the Mangorei HEPS including the lake level management.

Hydrological effects of the Mangorei scheme

(xv) Diversion of up to 10 m^3/s from the Waiwhakaiho River has created a length of residual river between the river intake and the tailrace confluence ("Meeting of the Waters") some 5.9 km downstream. The diverted water is not permanently lost but is returned to the river (via the tailrace) where it flows for another ~11 km before reaching the sea.

(xvi) Mean flow in the residual river is reduced by 3.5 m^3/s (46%) compared with no diversion occurring, and the block of flow removed comprises baseflows up to moderately high flows, resulting in reduced low flows.

(xvii) The most notable hydrological feature in the lower river and in Lake Mangamahoe from operation of the scheme is the diurnal fluctuations caused by daily flow ramping at the Mangorei power station.

7 Applicability

This report has been prepared for the exclusive use of our client Trustpower Ltd, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

We understand and agree that our Trustpower Ltd will submit this report as part of an application for resource consent and that Taranaki Regional Council as the consenting authority will use this report for the purpose of assessing that application.

Tonkin & Taylor Ltd

Report prepared by:

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David Leong

Technical Director Hydrology and Hydraulics

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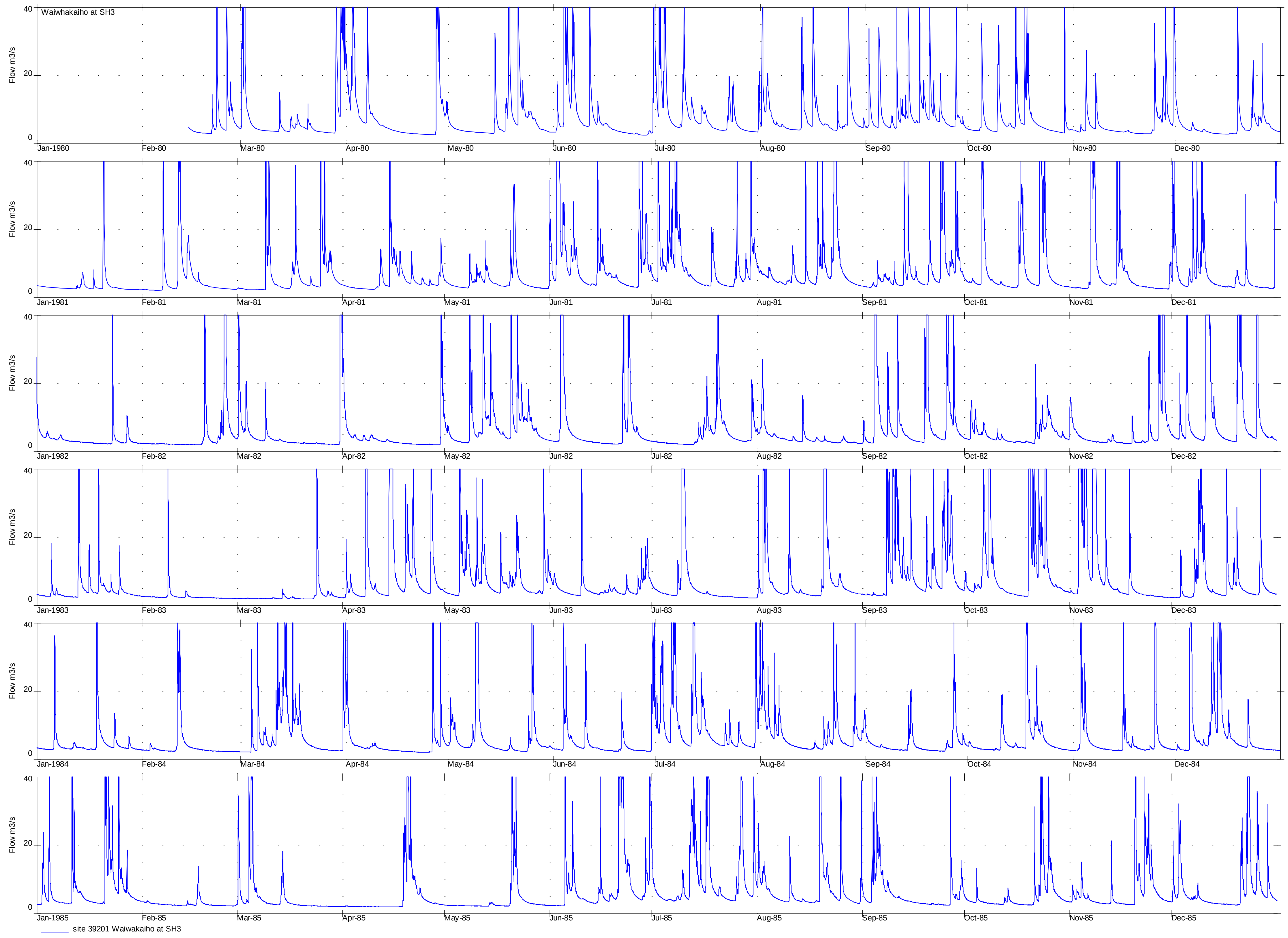
Appendix A: Hydrograph Plots

A1 Waiwhakaiho River at SH3 flow time-series 1980 to 2020

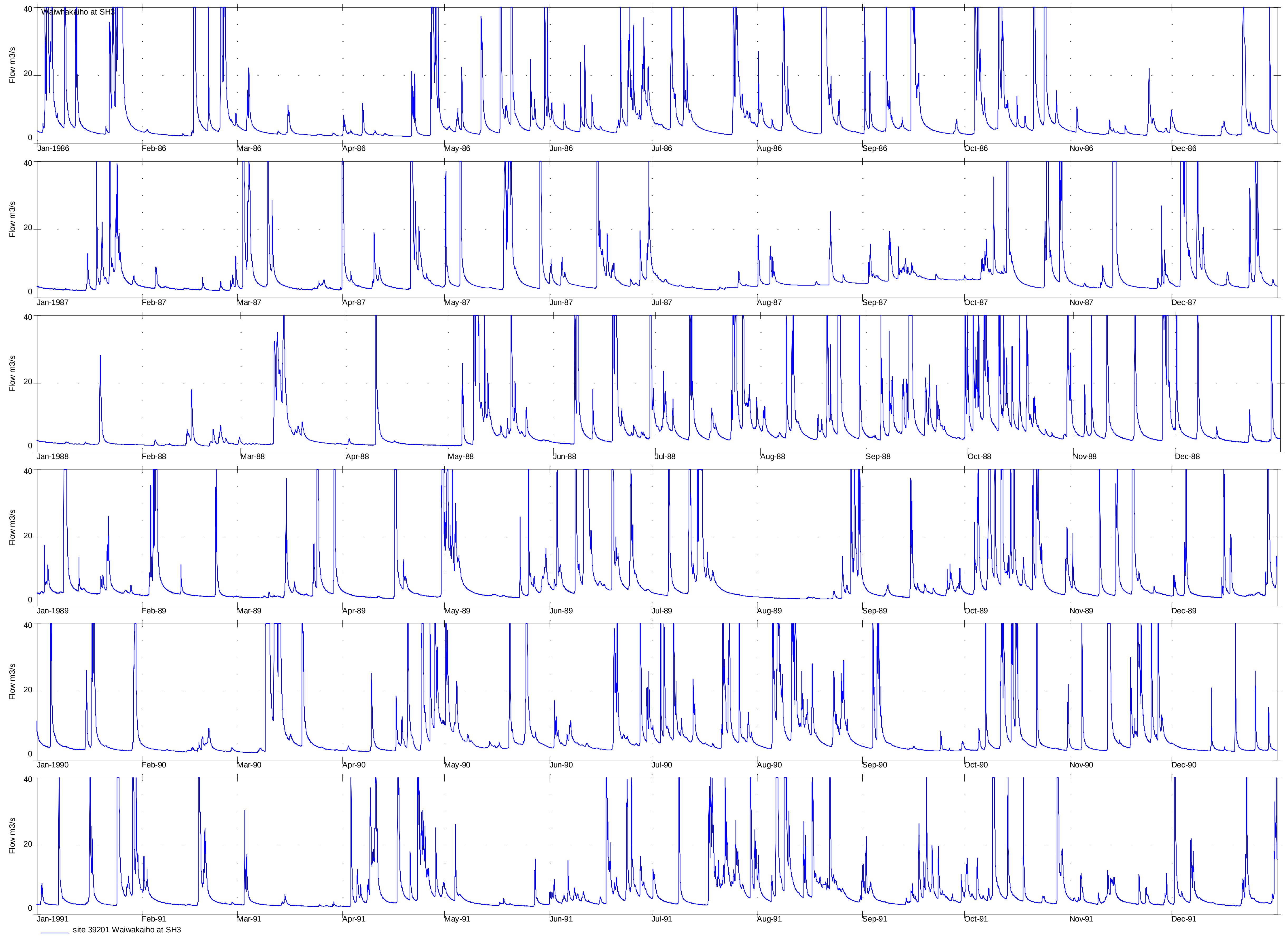
A2 Waiwhakaiho River at Rimu Street flow time-series 2009 to 2020

A3 Lake Mangamahoe level time-series 2001 to 2020

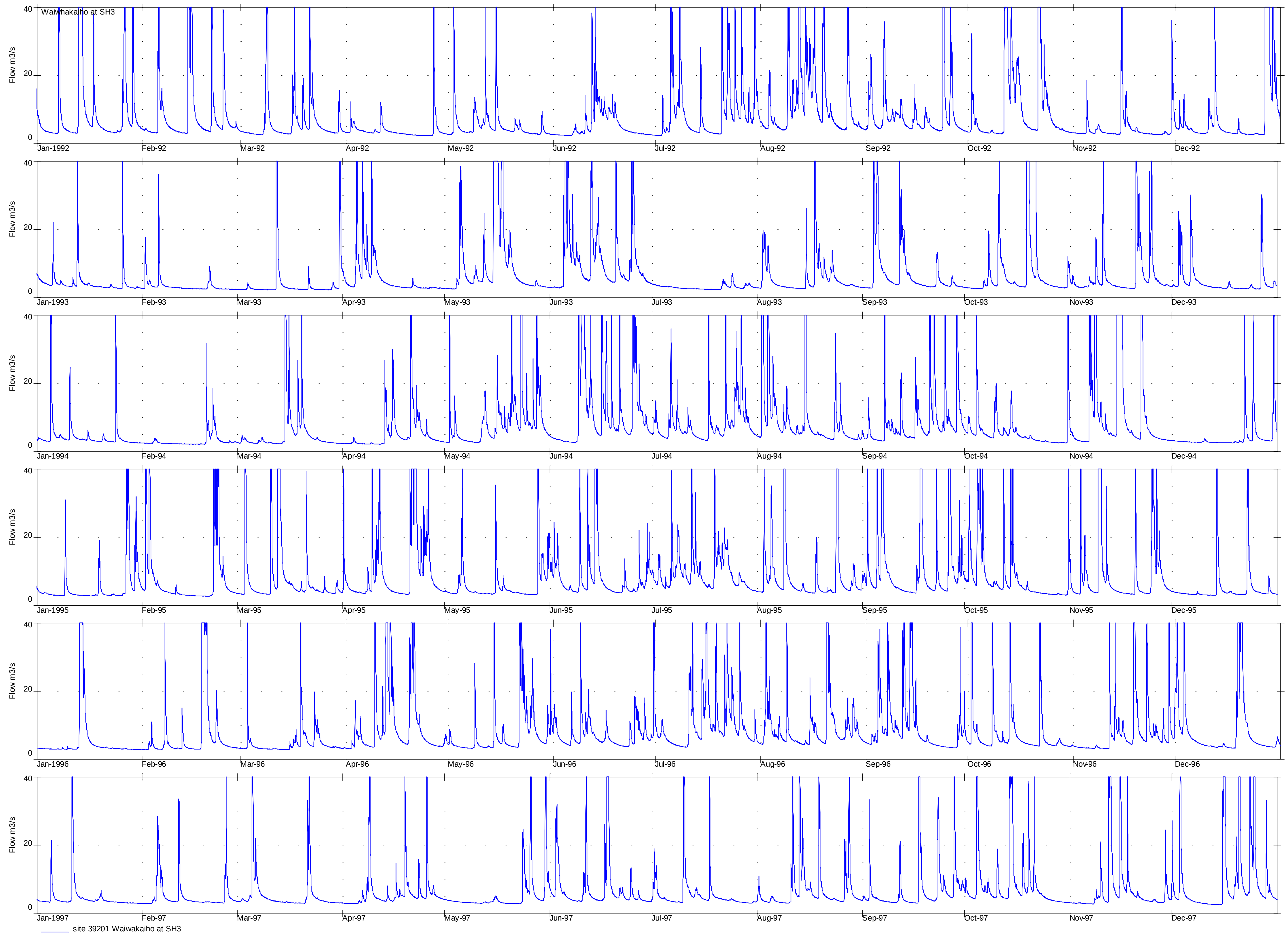
Appendix A1: Waiwhakaiho at SH3 – Flow Hydrographs Page 1 of 7



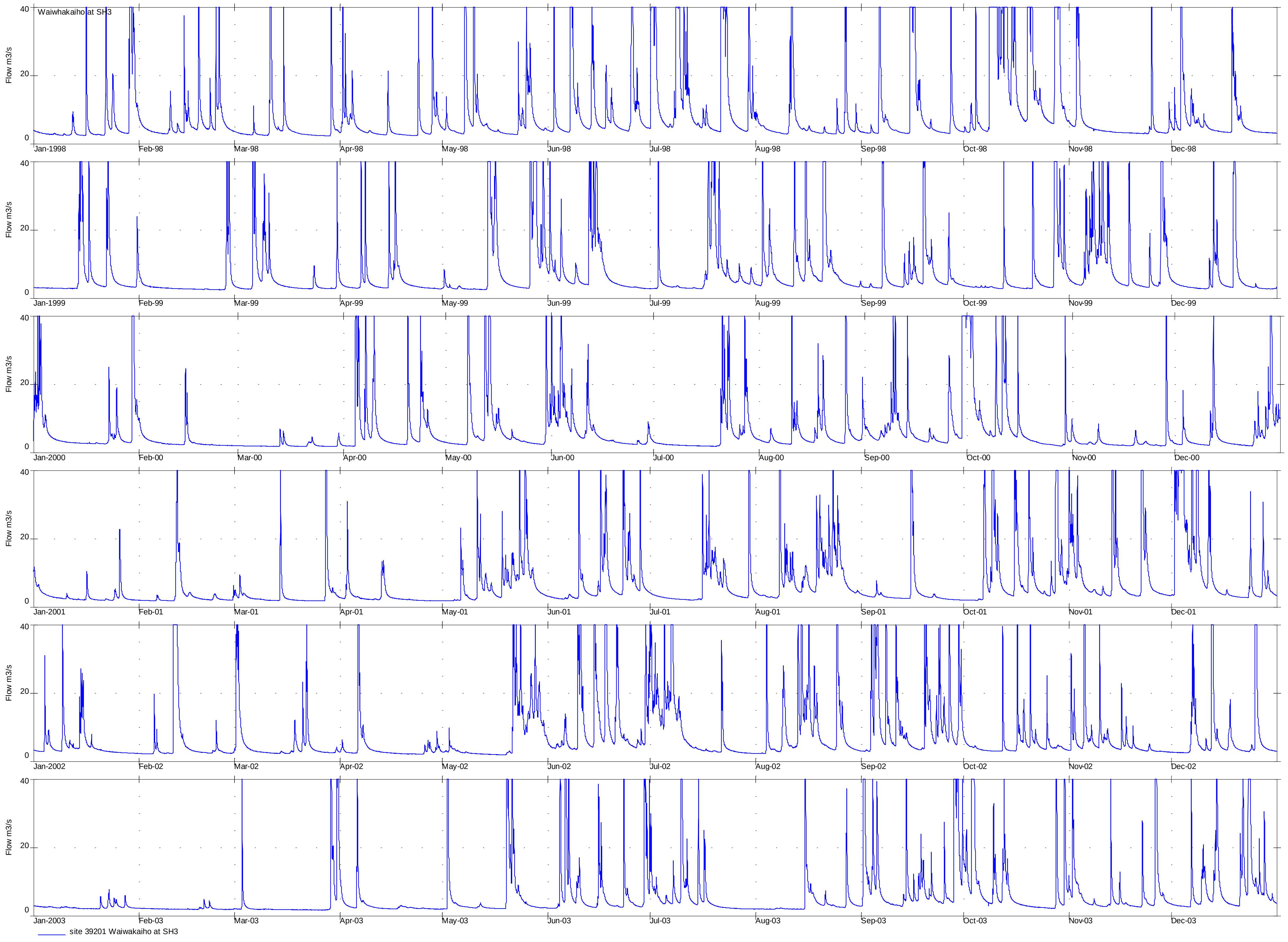
Appendix A1: Waiwhakaiho at SH3 – Flow Hydrographs Page 2 of 7



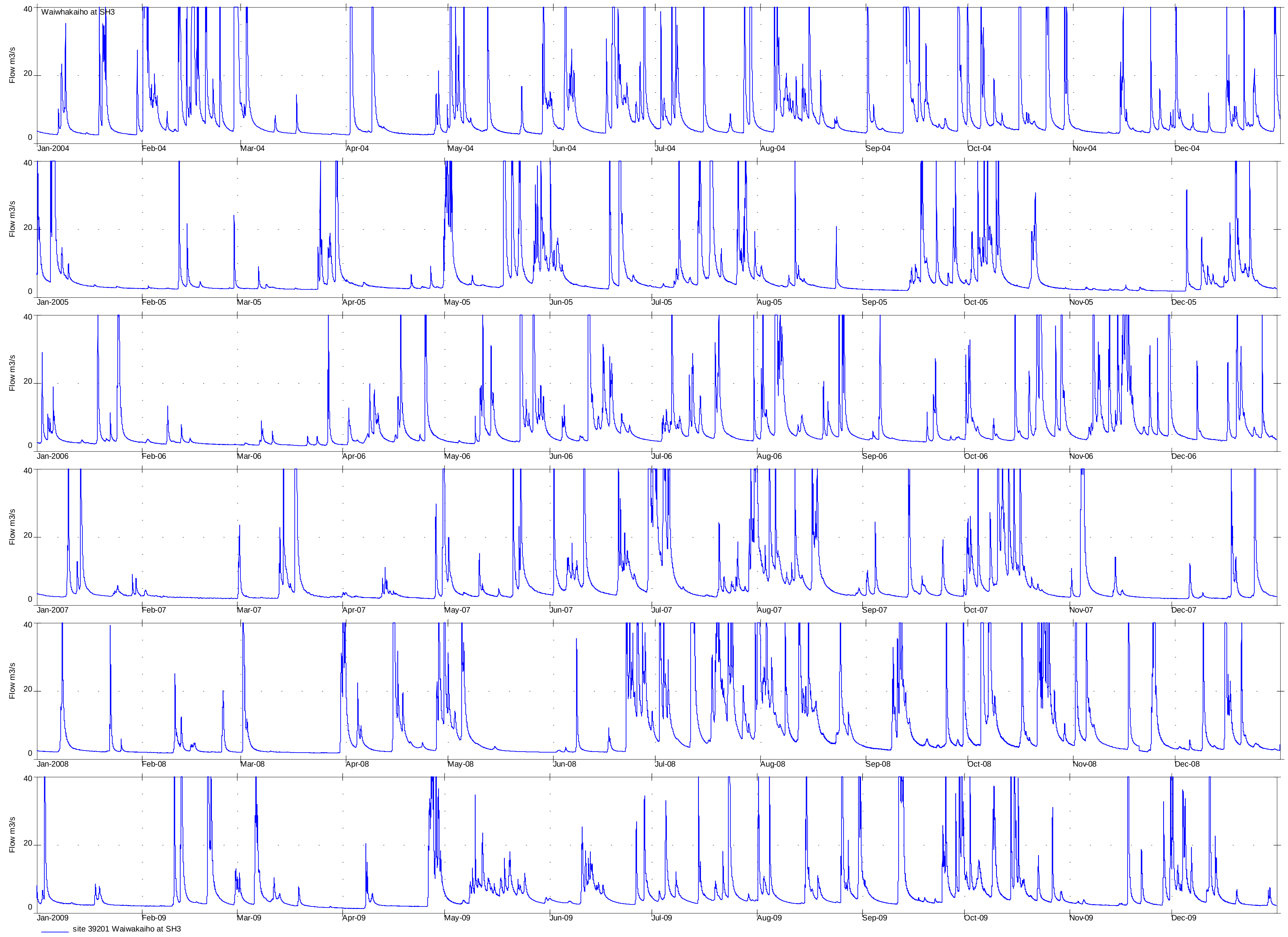
Appendix A1: Waiwhakaiho at SH3 – Flow Hydrographs Page 3 of 7



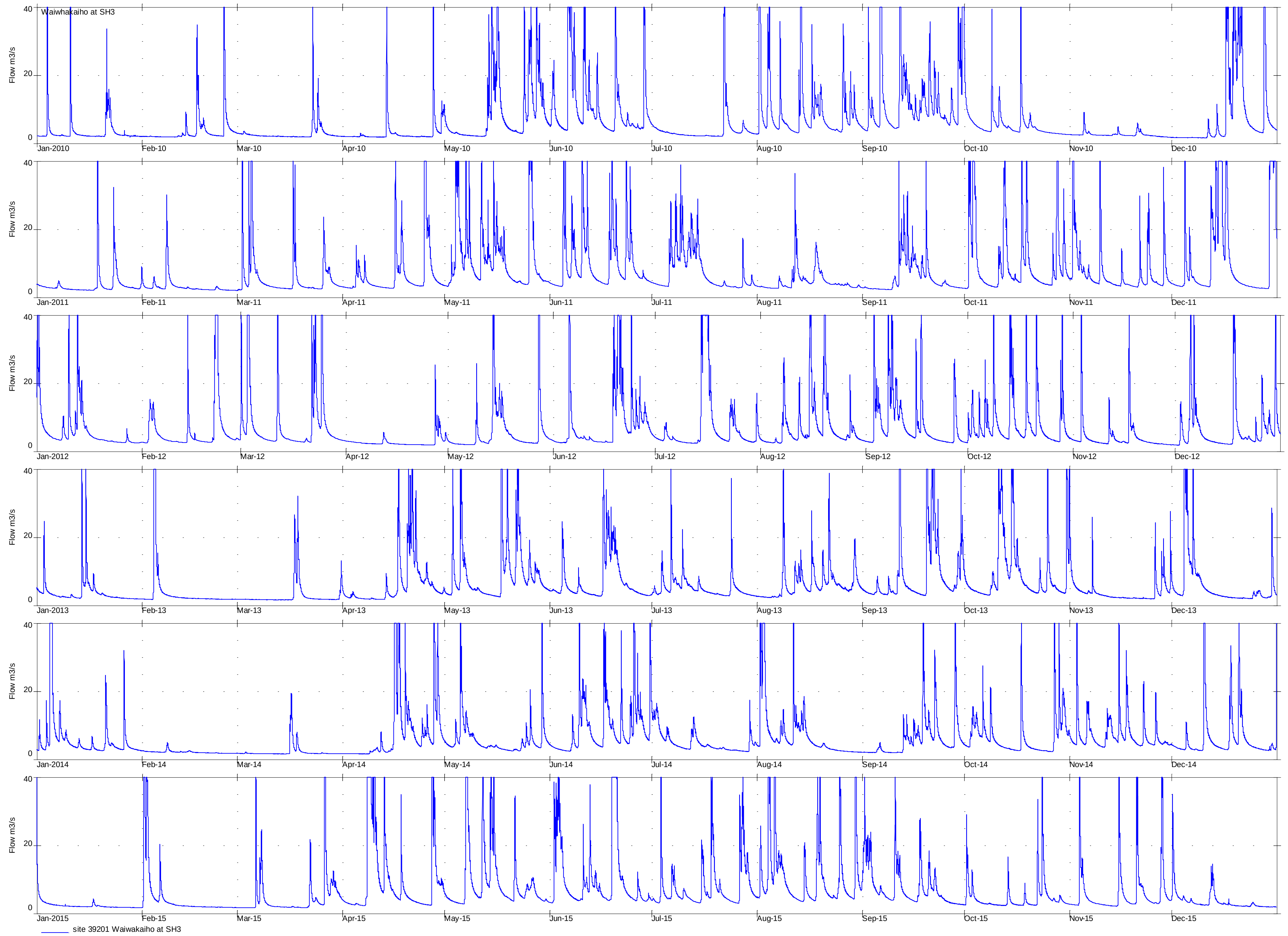
Appendix A1: Waiwhakaiho at SH3 – Flow Hydrographs Page 4 of 7



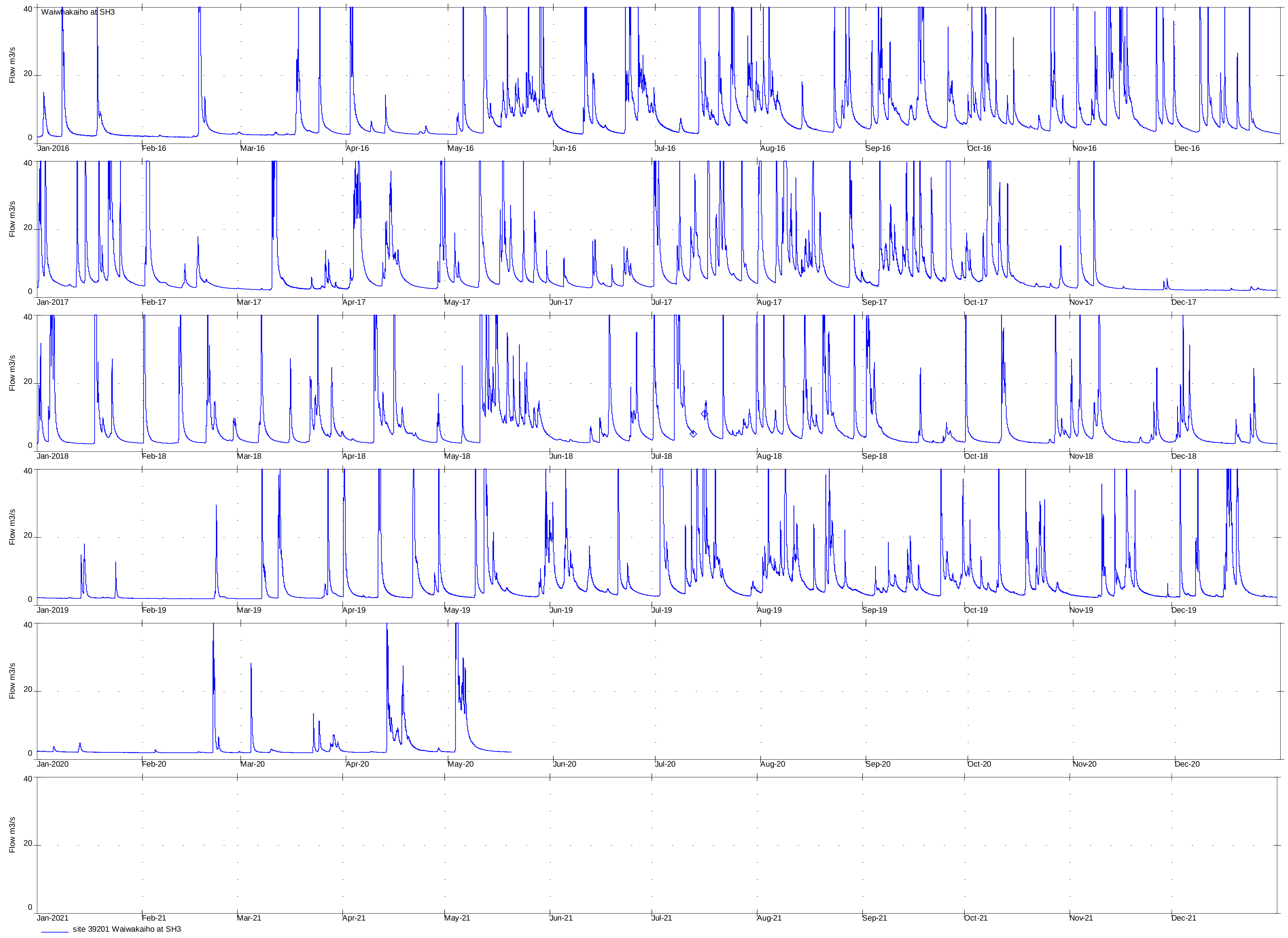
Appendix A1: Waiwhakaiho at SH3 – Flow Hydrographs Page 5 of 7



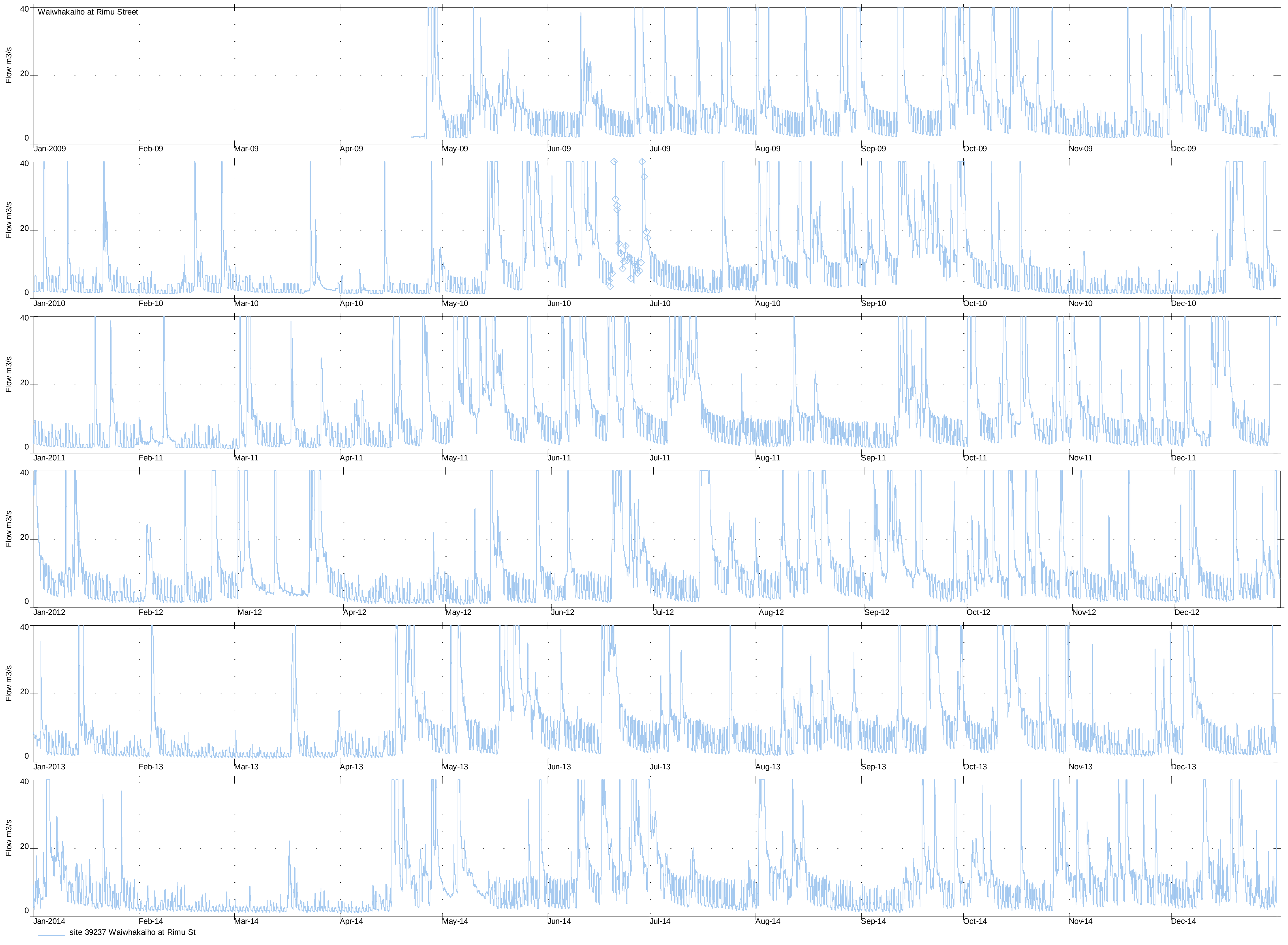
Appendix A1: Waiwhakaiho at SH3 – Flow Hydrographs Page 6 of 7



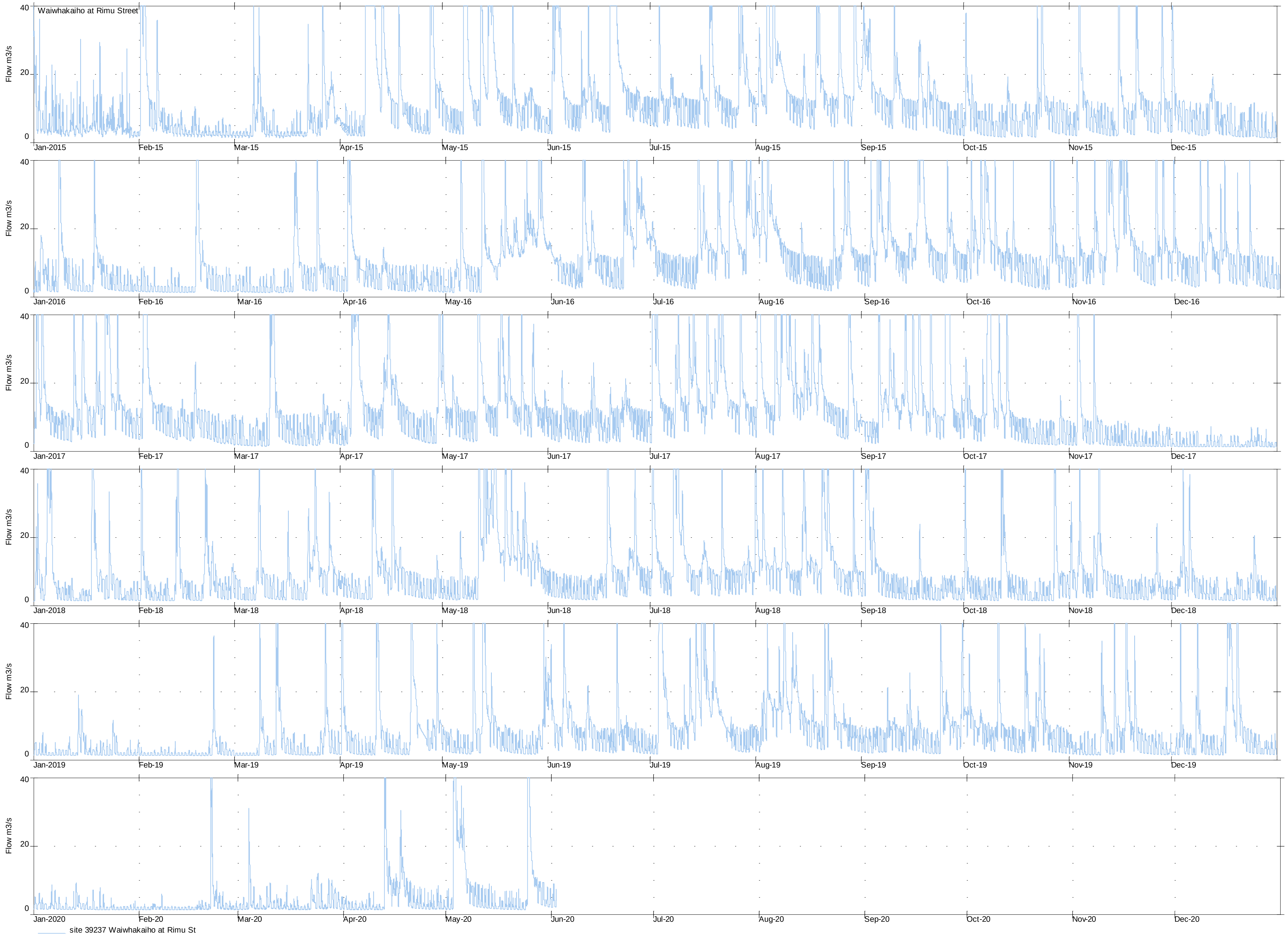
Appendix A1: Waiwhakaiho at SH3 – Flow Hydrographs Page 7 of 7



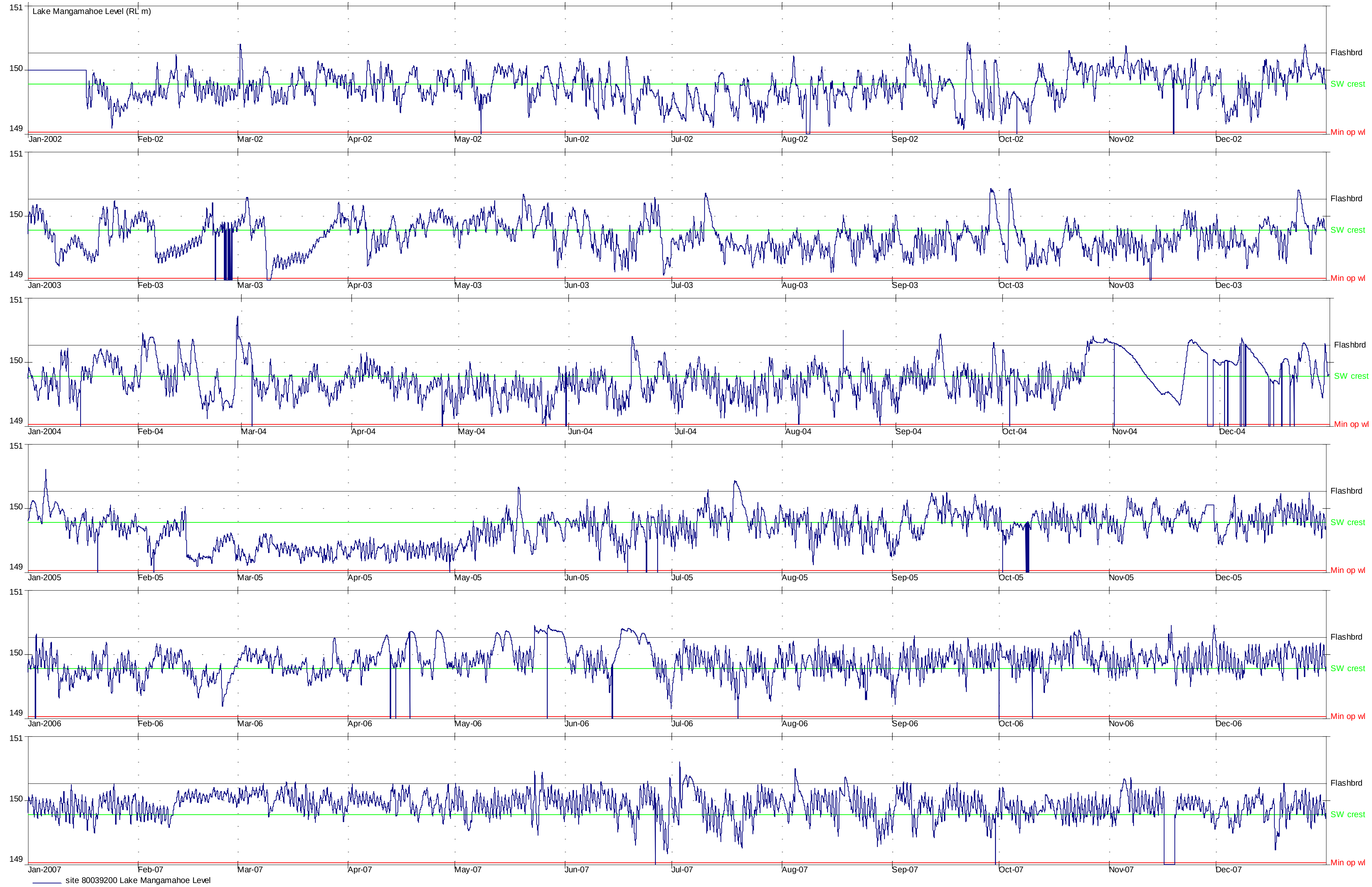
Appendix A2: Waiwhakaiho at Rimu Street – Flow Hydrographs Page 1 of 2



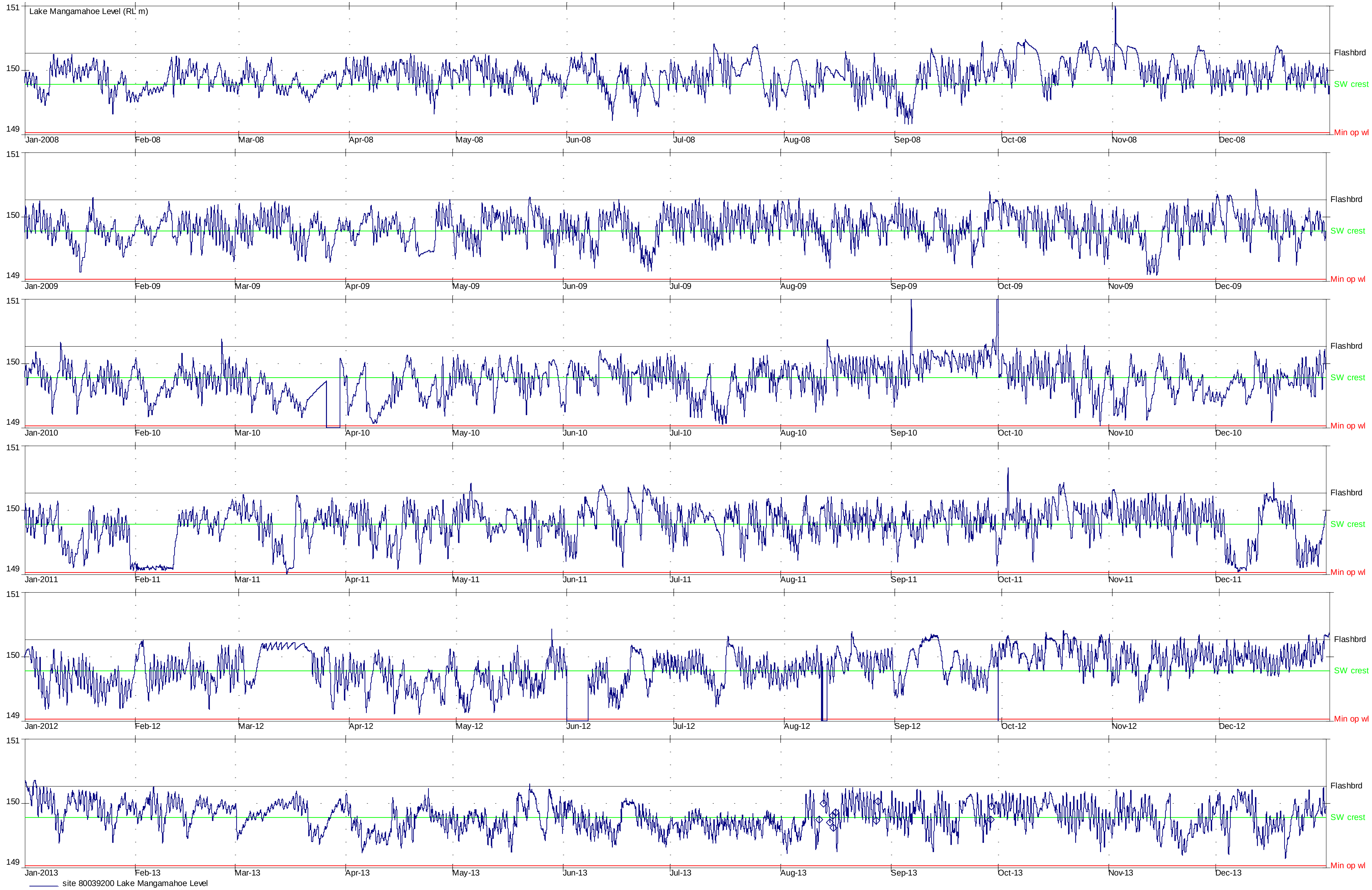
Appendix A2: Waiwhakaiho at Rimu Street – Flow Hydrographs



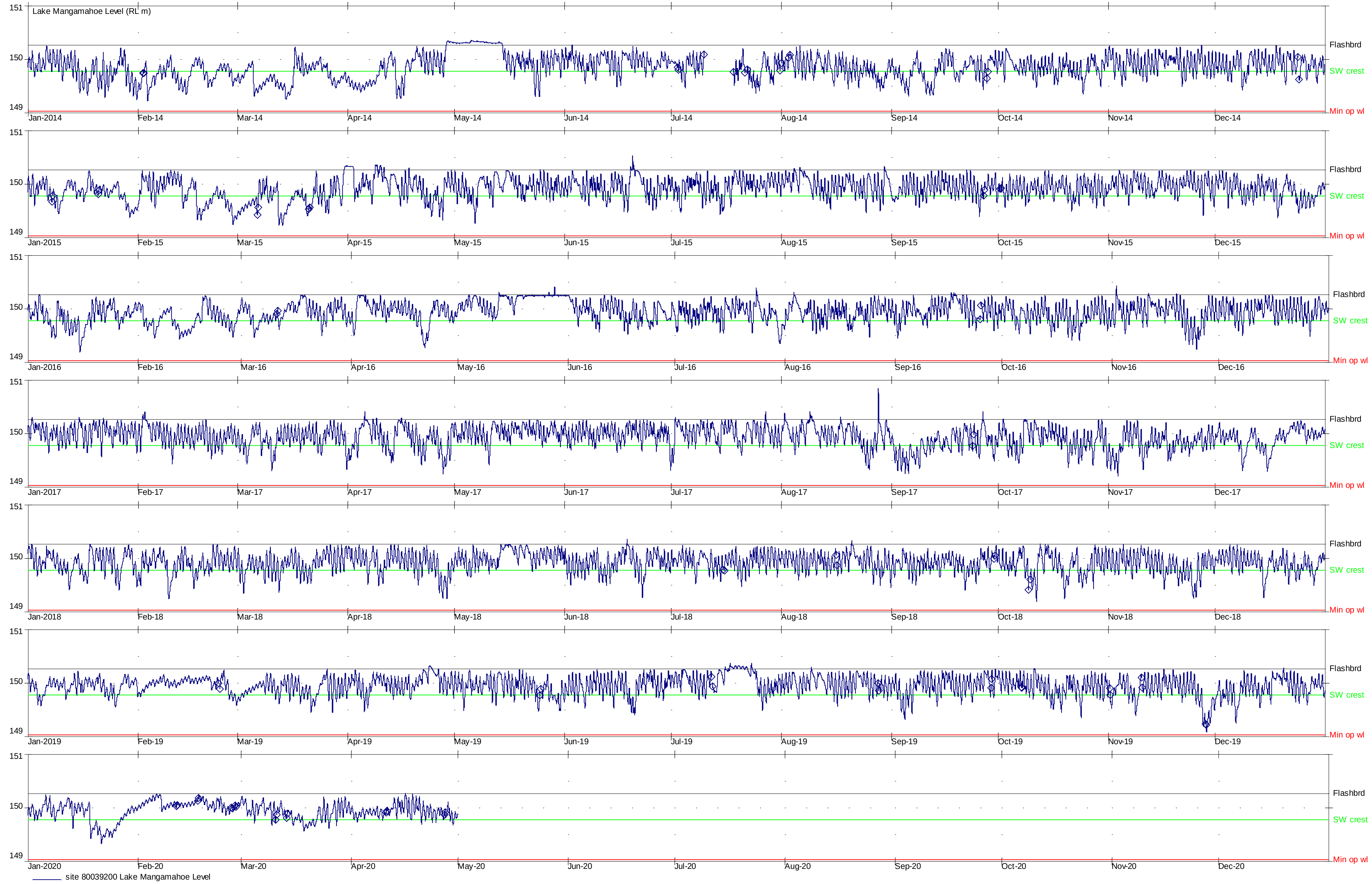
Appendix A3: Lake Mangamahoe – Water Level Hydrographs Page 1 of 3 (Note that gaps /errors not filtered out from data earlier than January 2013)



Appendix A3: Lake Mangamahoe – Water Level Hydrographs Page 2 of 3 (Note that gaps /errors not filtered out from data earlier than January 2013)



Appendix A3: **Lake Mangamahoe – Water Level Hydrographs** **Page 3 of 3** (Note that gaps /errors not filtered out from data earlier than January 2013)



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