WESTPOWER LTD PROPOSED WAITAHA HYDRO SCHEME

CHANGES TO THE NATURAL ENVIRONMENT

HYDROLOGY

Dated July 2025

Report prepared for: Westpower Ltd

Report prepared by: Martin Doyle

Report reviewed by: Alasdair McKerchar (2013 analyses)

Graeme Horrell (2025 revision)

Statement confirming compliance with the Environment Court's Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2023

As an expert witness or peer reviewer, I have read, and I am familiar with the Environment Court's Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2023.

I have prepared my, or provided input into, an assessment of effects for the Waitaha Hydro Scheme in compliance with the Code of Conduct and will continue to comply with it in this Fast-track Approvals Act process. In particular:

- my overriding duty is to assist the decision-maker impartially on matters within my expertise;
- unless I state otherwise, my assessment is within my area of expertise, and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express; and
- I have not, and will not behave as, an advocate for the Applicants.

Declared interests are addressed in Appendix A.

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1. INTRODUCTION

1.1 Westpower Ltd (**Westpower**) proposes a run-of-the-river hydro-electric power scheme (**Scheme**) for the Waitaha River, approximately 60 km south of Hokitika on the West Coast of the South Island, New Zealand.

1.2 The Scheme would be run-of-river with no instream storage. The proposed Headworks include a low weir and intake structure situated at the top of Morgan Gorge that will divert water into a pressurised tunnel and desander. The pressurised water tunnel will convey the diverted water down to a Power Station below Morgan Gorge. Having passed through the turbines the diverted water will be returned via a tailrace discharging to the Waitaha mainstem in the vicinity of the confluence of Alpha Creek. The Scheme will divert up to a proposed maximum of 23 m^3/s (cumecs), while maintaining a minimum residual flow of 3.5 m^3/s immediately downstream of the intake. The hydro design includes a 10 m^3/s bypass valve to maintain water flow following Power Station outages. The abstraction reach would include approximately 2.5 km metres of the Waitaha River, including Morgan Gorge. Construction access to the headworks above Morgan Gorge would initially be via helicopter and / or on foot and then via an access tunnel (once it is completed), while an access road and transmission line corridor (average 15 m in width) would be required from the Waitaha Valley Road to the Power Station to enable a connection to the existing network. Further detail on the project design and project background information is set out in the **Project Overview Report** and the **Project Description**.

1.3 Westpower commissioned this report describing the hydrology of the Waitaha River and assessing the changes to the hydrological regime resulting from the Scheme. In addition, analyses, data and advice from this hydrological study have been provided to technical experts tasked with assessing the effects of the Scheme on the environment, the natural character and other values present in the Waitaha catchment. Westpower also commissioned a separate safety assessment of the river during operation of the Scheme included in the **River Safety Report**.

1.4 This report describes and assesses the following:

(a) monitoring the flow of the Waitaha River;

(b) derivation of a long-term flow record and analysis of data;

(c) the natural flow conditions of the Waitaha River;

(d) the effects of the Scheme during routine operation on the hydrological regime downstream of the intake and upstream of the power station;

(e) the effects from stopping and starting the Scheme;

(f) environmental effects.

1.5 The scope and approach of this assessment are set out in **Appendix B.**

2. EXISTING ENVIRONMENT

2.1 The hydrological environment of the Waitaha is detailed in **Appendix C**. Characteristics shown by the Waitaha are typical of rivers in South Westland draining the main divide, with rainfall, geology and freeze/thaw processes being the dominant drivers of flow conditions. Small lakes have little influence. The Waitaha and other rivers in this locality are unusual for New Zealand, in that winter provides the lowest flow. The elevation at the proposed intake is 238 m, and the catchment rises to around 2,200 m at its head, holding a heavy snowpack in winter. The catchment is steep and erosion is widespread. There are 19 small glaciers in the upper reaches of the Waitaha, and at the end of summer, snow exists only on these glaciers and as snow patches, typically above 1,900 m.

Rainfall

2.2 The upper catchment receives considerable rainfall, ranging from about 5,500 mm annually at the intake area above the Morgan Gorge, to around 12,000 – 14,000 mm at the divide. Neighbouring the headwaters of the Waitaha is the Cropp Valley, where a number of New Zealand rainfall records are held, from the largest 12-month rainfall (18,442 mm) to the largest daily rainfall (758 mm). The average annual total in this location is among the highest yearly rainfalls in the World.

Flow regime

2.3 The heavy rainfall and the effect of snow and ice together exert considerable influence on the nature of flow conditions in the Waitaha River. In spring and early summer, river flows are high and are discoloured with snowmelt. As the temperature cools over autumn into winter, river flows drop to very low levels and the river runs clear during dry periods. These low, clear conditions are illustrated in **Figure 1.**

2.4 Floods occur regularly throughout the year, occurring about 8.6 days on average. It is typically around 2 days from flood onset before river levels drop back to the point where the grey/brown flood discoloration (see **Figure 2**) reverts to the usual milky colour, although this depends on the nature of the heavy rainfall. Large floods are choked at the entrance to Morgan Gorge (see **Figure 3**), causing ponding on lower Kiwi Flat and slight attenuation of the flood peak below this point. This effect does not occur for small to moderate floods.

Figure 1 - Low winter flow with clear water at the top of Kiwi Flat in July 2009

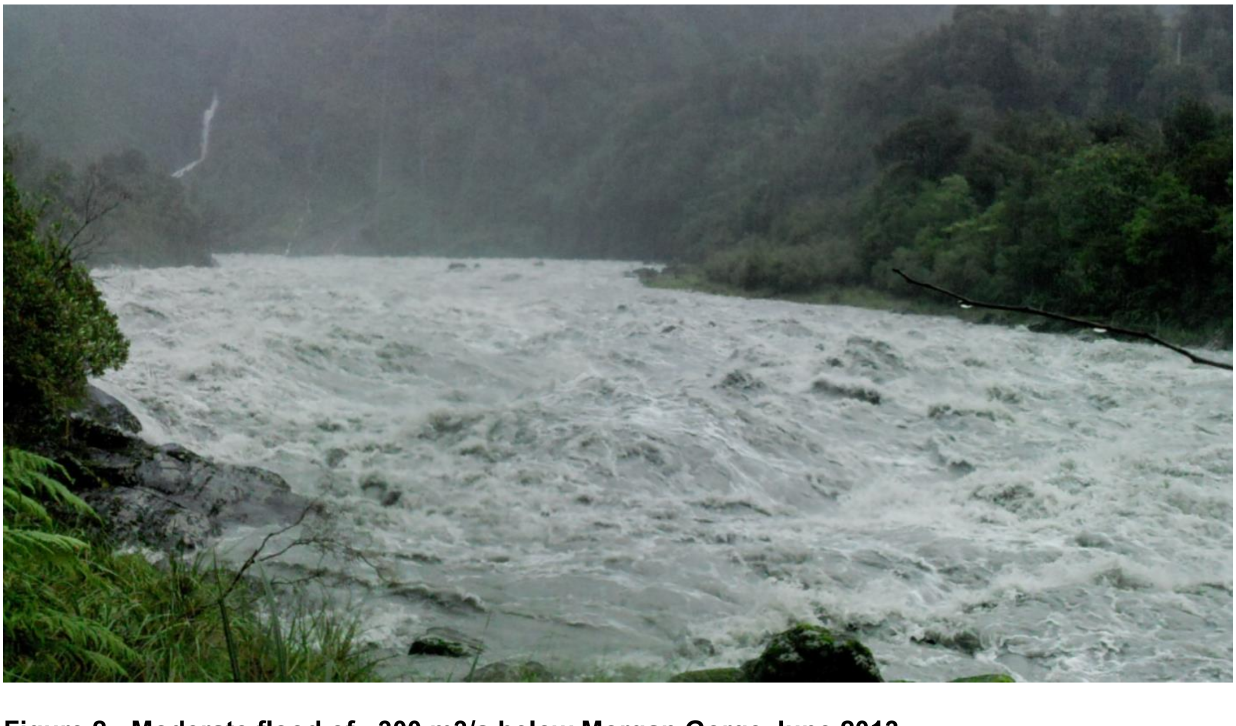

Figure 2 - Moderate flood of ~300 m3/s below Morgan Gorge June 2013

Figure 3 – Choked flood flow above Morgan Gorge in bottom picture, small flood/fresh for comparison top picture, same viewpoint.

3. INVESTIGATIONS

3.1 As detailed in **Appendix D**, flow data were collected over a six-year period, as well as observations of river conditions from Kiwi Flat down through the abstraction reach, and near the coast. Data were analysed to provide natural and post Scheme flow statistics. These were first reported in Doyle (2013) and this report updates that study.

Monitoring

3.2 Water level data were collected continuously over a period of six years commencing in 2006, using a datalogger on the Waitaha mainstem at the top of Kiwi Flat. These water level data were then converted to flow data using flow measurements. Numerous, regularly spaced visits were made over this time to measure the mainstem flow, as well the flow in the Whirling Waters tributary to quantify its contribution. Water level data were also collected at the entrance to Morgan Gorge to describe the choking effect of the gorge. Observations of the appearance of the river contributed to knowledge of the effects of freeze/thaw on flow. The temperature of the Waitaha River and Whirling Water tributary were also measured for 2 years and informal observations were made of periphyton cover, sediment deposition and Whio location over this time to help other studies. Finally, this monitoring programme also collected time sequenced photos at several locations to enable river conditions at those points to be compared with data from the continuous flow recorder.

Analysis of data

3.3 Analyses covered in Doyle (2013) consisted of three broad steps:

- Extending the flow record to derive the natural long-term hydrological statistics;
- Modelling the Scheme's proposed water take and establishing the effects on flow below the intake;
- Transposing these statistics to locations of interest e.g. the exit of Morgan Gorge.

3.4 In 2024, analyses were carried out confirming that the 2012 statistics shown in Doyle (2013) are still valid. The data (measured and synthesised), as well the statistics generated were provided to the various experts carrying out assessments of the effects of the proposed scheme.

Extending the flow record

3.5 Flow data from the neighbouring Hokitika and Whataroa catchments were first used to create flow data for the Waitaha for the period 1973 – 2012 (**Appendix E**), and for this report, up until 2024. A time variable correlation was used to account for the seasonal freeze/thaw differences between these rivers. The synthesised data proved to be a good match, further supported by comparison against nearly 12 months of further flow data collected after the original correlations were derived. The synthesised data can be used with confidence for wider statistics for flows up to 100 m^3/s, but should not be used for flood flows. Flood statistics are instead derived from regional relationships.

Modelling used to consider the effects of the Scheme

3.6 From the 39-year dataset of continuous flow at the top of Kiwi Flat (actual and synthesised), data were adjusted for inputs from other tributaries and a continuous record was created for the intake location (top of Morgan Gorge), and at sites of environmental interest in the 2.5 km abstraction reach. A simple time step model using the operational logic provided in the Project Description was then created to account for the proposed 23 m^3/s take, leaving a minimum residual flow of 3.5 m^3/s at all times, with the power station stopping generation when the natural river flow drops below 3.5 m^3/s. Analyses were then carried out to describe the changes in the flow regime brought about by the Scheme, and these formed the basis for a number of further studies.

Statistics derived in 2012 versus those derived in 2024

3.7 A number of environmental, landscape and recreational studies were carried out around 2013 based on the hydrological parameters described in Doyle (2013). Because of this, the statistics of 2012 were compared with the statistics calculated in 2024 to consider whether the new information is substantially different - if so, this may have required reanalysis of earlier studies. The difference between the statistics of 2012 and 2024 are minor and are detailed in **Appendix H**. Furthermore, data collected since April 2012 provided verification of the original methodology. This report recommends no changes be made to the earlier studies that were based on the 2012 hydrological statistics.

4. HYDROLOGICAL STATISTICS, NATURAL ENVIRONMENT

4.1 The following tables summarise the key hydrological statistics for the Scheme's proposed intake location at the top of Morgan Gorge. These have been derived from flow measured at the top of Kiwi Flat and the Whirling Waters tributary. They are taken from Doyle (2013) and have been verified by work done in 2024 as detailed in **Appendix H**.

4.2 The three tables in turn show the general hydrological flow statistics, the low flow statistics, and the flood flow statistics, all for natural conditions. Another useful statistic not shown in the tables is FRE3 – the number of times that the flow threshold of "3 times median flow" is exceeded per annum. This is not a flow but a frequency, in this case being 26.2 per annum.

Table 1 - General flow statistics for Waitaha River at top of Morgan Gorge (unaltered state)

Statistic	Flow (m^3/s)
90 percentile	9.05
Median flow	19.7
Average flow	34.6
10 percentile	62.5

Table 2 - Low flow statistics for Waitaha River at top of Morgan Gorge (unaltered state)

Return Period	Flow (m^3/s)
Mean Annual Low Flow (1 Day)	7.085
Mean Annual Low Flow (7 Day)	7.572
50-year low flow (1 Day)	5.039
50-year low flow (7 Day)	5.249

Table 3 - Flood flow statistics for Waitaha River at top of Morgan Gorge (unaltered state)

Average recurrence Interval	Flow (m^3/s)
Yearly (Mean Annual Flood)	812
20 years	1,177
50 years	1,299
100 years	1,380
200 years	1,518
500 years	1,665

5. CHANGES TO THE HYDROLOGICAL REGIME POST SCHEME

5.1 The Scheme proposes to take up to 23 m^3/s whilst leaving 3.5 m^3/s in the river at all times, unless the flow naturally drops below this level. Above the intake no change will be evident to the normal flow patterns, but in the abstraction reach (intake to power station), and when the river is naturally below 26.5 m^3/s, the flow will remain stable at 3.5 m^3/s, supplemented by tributary inflows. The only change to this will be if a flood or fresh occurs, the Scheme stops operating due to lower river conditions, a flood, or for some technical reason.

5.2 When the river is naturally above 26.5 m^3/s, the flow through the abstraction reach will be greater than 3.5 m^3/s. During higher flows it will increase to the point that it closely resembles the natural flow regime. When flow reaches 250 m^3/s, generation will stop and natural flow conditions will exist throughout the river.

5.3 Below the power station the river will continue to behave almost exactly as it would naturally, except when the station changes generation rates. During these transition periods there will be either reduced flow or increased flow for a short period, with this effect reducing further downstream.

The effect of the Scheme on the residual flow regime during continuous operation

5.4 Hydrological statistics have been calculated for the abstraction reach to describe the effect of the take and can be compared to those for natural flow conditions. These are detailed in Appendix **G.**

5.5 The most obvious effect of the water take is the extension of periods of low stable flow conditions, when residual flow remains at 3.5 m^3/s downstream of the intake. Without considering normal shutdowns of the Scheme, periods when a kayaking flow is requested, or periods of floods when no take will occur, on average these flow conditions will occur for 66% of the time, or 241 days per annum.

5.6 There are three important points to note about the periods of low residual flow:

a) The 241 days per annum of residual flow will not occur as consecutive days, but normally as small intervals of time before a fresh or flood occurs.

b) The residual flow of 3.5 m^3/s is 300 m downstream of the intake supplemented by Anson Creek, and again by Glamour Glen. These two streams boost the residual flow below the Scheme intake considerably after rain, and for 50% of the time they add at least 0.7 m^3/s, hence the residual flow below Glamour Glen is at least 4.2 m^3/s for 50% of the time.

c) The river flow is very seasonal, and over the higher flows of late spring and summer the effect of the Scheme is much reduced, but conversely, in winter it is increased.

5.7 The vast majority of residual flow periods at the Scheme intake only last several days before being broken by a fresh. In particular, there are on average 14 times a year when the residual flow state lasts less than a day, 4 occurrences a year when the residual flow state lasts less than three days, and typically 1 occurrence a year when the residual flow state lasts 10 days. These values will vary from year to year depending on the timing and amount of rain, the size of the snowpack and temperature which melts it. Had the Scheme been operating over the past 51 years, the greatest period of unbroken residual flow would have lasted for 79 days during 1996. In comparison, in 1994 the longest period would have been 17 days.

5.8 There are on average 42 floods or freshes per annum greater than 30 m^3/s, the average interval between these peaks is 8.6 days, and the average flood duration is 55 hrs.

The effect the Scheme has on flood flows

5.9 For large floods, the Scheme has no effect on flow as no take will occur over this time, generation stopping at a flow of 250 m^3/s. For small floods and freshes, there is a slight reduction in flow through the abstraction reach, this becoming less significant as natural flow increases.

5.10 For small freshes, a useful indicator is the FRE3 statistic. This is used in ecological studies to indicate bed disturbance. It is the number of times that a flood of magnitude 3 x median flow occurs annually, on average. There is a slight drop in the FRE3 value between natural conditions and with the Scheme operating, from 26.2 to 23.6 times per annum.

6. CONCLUSION

6.1 Flow data has been collected at Kiwi Flat over a 6-year period, and many field visits and observations over this time have provided familiarity with the flow environment of that location. Data has been compared to other rivers and the flow record has been extended to 51 years. This allows confidence that a solid basis for analysis exists.

6.2 Various analyses have been carried out to describe the natural flow regime of the Waitaha River and relevant tributaries. The catchment is typical of most South Westland rivers draining the main divide, with heavy rainfall causing large floods, snow and ice contributing to the water balance, dry and cold winter periods creating low clear flows, and an extended period of elevated spring flow carrying fine sediment.

6.3 Simulations of the proposed flow take have been completed, and data, analyses and descriptions have been provided to various experts considering the effects of the Scheme.

6.4 Changes to the flow regime typically occur over a 2.5 km stretch of river (intake to power station) but occasionally extend downstream of the Power Station for short periods when the generation is to be stopped and started.

6.5 The hydrological analyses were reviewed in the 2013 report, and again in 2024 for this report.

APPENDIX A – QUALIFICATIONS AND EXPERIENCE – MARTIN CHRISTOPHER DOYLE

I have 45 years' experience monitoring and analysing river flow, rainfall, snow and ice across the South Island of New Zealand, Antarctica and the Solomon Islands, working variously for the Ministry of Works and Development, DSIR, NIWA, Nelson Catchment Board and Tasman District Council; with specific experience in the hydropower industry including compliance monitoring, and assessing and reporting on effects. In addition, I have consulted with the hydropower industry completing feasibility studies, monitoring and analysis.

Wider hydrological experience consists of virtually all aspects of hydrological monitoring, analysis and reporting, and preparing and assessing applications to take and discharge water for many purposes. I have been active in, or have led, many initiatives within the national hydrological community including the development of standards for measurement accuracy and consistency, safety procedures, guidelines for hydrological analysis, and software improvement and development.

My current role is Principal Hydrologist, Tasman District Council.

Relevant memberships and associations include:

- Steering Group member for the development of National Environmental Monitoring Standards
- Led the working groups to develop National Environmental Monitoring Standards for Water Level Measurement, and Stage-Flow rating curves
- Member of the MetService Reference Group
- Currently Chair the National Flood Warning Steering Group
- Member of the Severe Weather Science Advisory Panel
- Member of NZ Hydrological Society

Qualifications:

- NZCS Water Technology
- Grad. Dip. Engineering Hydrology
- Dip. Field Hydrology

Declared Interests

I, Martin Doyle, declare the following interests:

- I am the co-consent holder (with [redacted] of RC05216 for a small hydro-electric scheme in Macgregor Creek. [redacted] has provided a letter on our behalf stating that the consent can be fully exercised alongside the Waitaha Hydro Scheme;

- I have a business relationship with Westpower Ltd through the Amethyst Hydro Ltd. I am a co-director of Hari Hari Hydro Ltd, which has a 12% share and Westpower owns 88%. My share in Hari Hari Hydro Ltd creates a minority 6% share in the Amethyst Hydro Scheme.

APPENDIX B – SCOPE AND APPROACH OF THIS INVESTIGATION

This report is the culmination of a study which commenced in 2006 with the installation of a flow recorder at the top of Kiwi Flat to collect necessary information to assess feasibility of the Scheme and inform an application to build and operate the Scheme.

After a detailed investigation and period of analysis, flow statistics were first calculated in 2012 and provided in Doyle (2013). Considerable effort was put into a number of other studies and reports at that time, many of which were underpinned by the statistics provided by Doyle. These statistics were essentially 'locked' at that time, to ensure that all experts and people assessing the application at that time had access to identical information. Experience shows that even small changes made to statistics, unless that change is important, cause confusion for submitters and the regulators tasked with assessing an application such as this.

Earlier statistics versus later statistics

With reconsideration of the Scheme in 2024 and work being refreshed by various experts, the question arises whether the various 2013 expert reports that utilised hydrological information are still valid from the hydrological perspective in 2024. This report therefore commenced by extending the flow record from 2012 to 2024, using the same methodology detailed in Doyle (2013). Furthermore, since the original hydrological report was written, a further one year of flow data was collected at the Kiwi Flat flow recorder. This provided the opportunity to validate the original method of deriving synthetic flow data against a measured flow record not used in the creation of the correlations.

The changes seen between the 2013 and 2024 statistics are minor and detailed in **Appendix H**. Therefore, it is advised that the considerable investment in data collection, analysis and report writing that occurred in 2013 when the various experts gave evidence, remains valid from a hydrological standpoint, and the small changes to hydrological statistics seen in 2024 do not warrant re-evaluation of the original analyses.

Several figures provided in 2012 to the experts have been changed and these experts have been informed of these changes. Any necessary conclusions they make are covered in their reports.

It is recommended that the original hydrological statistics continue to be used, and therefore the data and statistics of Doyle (2013) are those used in this report.

APPENDIX C – DETAIL OF THE EXISTING ENVIRONMENT

Waitaha catchment

The Waitaha River is located 60 km south of Hokitika and reaches from the West Coast to just short of the Main Divide, with a total catchment area of 223 km^2. The Scheme is situated 18 km from the coast and utilises water from 117 km^2. The elevation at the proposed intake is 238 m, and the catchment rises to around 2,200 m at its headwaters.

The upper catchment receives considerable rainfall, ranging from about 5.5 m annually at the Kiwi Flat intake area, to around 12 – 14 m annually at the divide. Just on the eastern (upper) side of the Waitaha is the Cropp Valley, where extensive hydrological monitoring has been carried out for 45 years. This location holds a number of New Zealand rainfall records, including the largest 12-month rainfall (18,442 mm), the largest 30-day rainfall (3,800 mm), the largest 24-hour rainfall (758 mm), and one of the most intense hourly rainfalls (134 mm). The average annual total is among the highest yearly rainfalls in the World.

One small lake exists in the catchment and has little effect on flows at Kiwi Flat. There are 19 small glaciers in the upper reaches of the Waitaha, and at the end of summer, snow exists only on these glaciers and as snow patches, typically above 1,900 m. Of the 90 km^2 catchment above the Kiwi Flat flow recorder, 7.7 km^2 are covered by glacial ice (Hicks, 2013), which is 8.6% of the watershed as measured at this location. During drier periods in summer, the melt water that is released on hot days can boost baseflow by more than 5 m^3/s, while during winter the reduction in flow is generally 1 - 2 m^3/s. While the water released from snow or ice storage is not a significant part of the total precipitation for the river, the fact that this summer meltwater occurs during otherwise drier periods gives it an importance in excess of its contribution to the overall water balance of the catchment.

The nature of flow in the Waitaha River

The sometimes-intense rain and the effect of snow and ice together exert considerable influence on the nature of flow conditions in the Waitaha River. The river flows high in spring and early summer and is discoloured with snowmelt. Flows recede as the temperature cools over autumn into winter, when flows drop to very low levels and the river runs clear during dry periods.

These characteristics are similar to the neighbouring Hokitika Catchment and the more southern Whataroa Catchment which also have flow records, but contrast with the smaller and lower Amethyst Catchment which flows more evenly all year round. Tributaries of the Waitaha which are at lower altitude behave in a similar manner to the Amethyst.

The seasonal effect can be observed when looking at the monthly median flows at the top of Morgan Gorge. The median might be described as the ‘normal flow’, as half of the time the flows are below this level, and half above. The monthly median flow reaches a peak of 31.8 m^3/s in December as rising temperatures melt the seasonal snowpack (along with some ice), and the river is continuously discoloured, either showing the milky colour of snowmelt, or the darker colour of flood flows. By March the median flow has dropped to 20.8 m^3/s, as much of the available snow is gone, but the river still has a milky appearance. Flows continue to drop with reduced temperatures and reach a low point in July, when the median flow is 10.3 m^3/s. At this time, with no snow or ice melt occurring, the river runs clear if no recent rain has fallen.

Low flows are a notable winter feature of the Waitaha River. In December the lowest flows on average reach 17.8 m^3/s, in March they are 16.0 m^3/s, while in July they are 8.2 m^3/s.

Floods occur throughout the year every 8.6 days on average and it is typically around two days from flood onset before river levels drop back to the point where the grey/brown flood discoloration reverts to the usual milky colour, although this depends on the nature of the heavy rainfall.

The influence of snow and ice on Waitaha flows

At the end of summer, NIWA carry out their annual glacier snowline survey during which they photograph 50 index glaciers and estimate the loss or gain of ice. If the modern trend of glaciers reducing in size continues as expected, there will be an ongoing period of increased summer flow as the glaciers decline in size, until the glaciers cease to exist. Chinn (2001) estimated there was 108 Mm^3 of ice in the Waitaha Catchment. To give this perspective, if we assume (say) the glaciers melt entirely over 30 years, and the melting occurs evenly over the warmer six months, then the increase in summer flow would be on average 0.23 m^3/s. This is not especially significant to the flow regime, with snow being more influential.

Climate change

The Ministry for the Environment has an online tool to display the latest climate projections, updated in mid-2024 and based on work done by NIWA. The tool can be found at https://environment.govt.nz/facts-and-science/climate-change/climate-change-projections/. The predictions are broken into in three future periods; 2021 – 2040; 2041 – 2060; and 2080 – 2099, and are all compared to two base periods – in this case a base of 1995 – 2014 was used. The changes most relevant to the hydrology of the Waitaha catchment are rainfall and temperature, the latter being relevant for snow accumulation, as well as the freeze/thaw processes that lock up water as ice in cold periods and release it in warmer periods.

The rainfall indicators all show much the same thing. Total rainfall, number of very rainy days, and heavy rainfall are predicted to continually increase into the future, with the greatest increase shown for spring and winter. Autumn is considered to become drier for South Westland. Predictions of the number of dry days (leading to drought) has a less pronounced signal, with variability across seasons and forecast periods.

Temperature is discussed as the number of hot days and average daily temperature. Both variables are predicted to increase overall, mainly for summer. During spring and winter the signals were not strong, these being key periods for production of meltwater and freezing of ice.

The overriding message with climate change is that the weather will be more unpredictable and hold greater extremes. The Waitaha River can expect average flow to increase, and larger and more frequent floods particularly in spring and winter. Late summer flows may reach slightly lower levels than previously, on account of snow being melted earlier in that period. Slightly warmer winter temperatures imply that less winter snow accumulation is likely and winter runoff may increase during low flow periods, as well as floods.

ENSO Cycle

The El Niño Southern Oscillation (**ENSO**) phenomenon involves temperature changes in the Pacific Ocean waters coupled with alterations of atmospheric pressure and wind patterns. Tropical surface water off the coast of South America warms up in an El Niño, during which stronger than normal westerly winds occur over New Zealand. These yield enhanced rainfall in western New Zealand. In a La Niña, westerly winds are reduced on average and rainfall is enhanced in the north and east, and reduced in the west and south. Renwick et al (2010) describe the Inter-decadal Pacific Oscillation (**IPO**) as essentially a long-term modulation of the ENSO cycle, bringing 20-30 year periods of stronger and more frequent El Niño events, alternating with periods of stronger La Niña conditions. A positive phase (favouring more westerly wind) existed from the late 1920s to mid–1940s and from the late 1970s to late 1990s. A negative phase (La Niña, so favouring less rain on the West Coast) existed from the late 1940s to mid-1970s, and since 2000.

The six years of hydrological data collected on Kiwi Flat were therefore obtained during a negative phase of the IPO, which implies the flow will be lower than normal. In fact, this effect can be seen in the data and is described in **Appendix F**.

The six-year flow record has been adjusted by the use of correlations to the Hokitika and Waitaha catchments to provide a data set going back to 1973. This means the statistics used in this report are derived from data which has an approximate balance of El Niño and La Niña influence. The effect of the IPO cycle on the statistics generated can therefore be considered neutral.

APPENDIX D – DATA COLLECTION

Hydrological investigations firstly focussed on two aspects:

- Collection of continuous flow data in the Waitaha River over a six-year period;
- Collation of other hydrological information from within the Waitaha catchment and the surrounding area.

Flow information for the Waitaha River at Kiwi Flat

Operation of a flow recorder at the top of Kiwi Flat commenced with concession approval from the Department of Conservation (**DoC**) on 23 March 2006. This study uses data from then until April 2012, providing a complete 6-year record. This record was then adjusted to provide a flow record at the bottom of Kiwi Flat – the location of the proposed intake.

There were 24 days of missing record due to low battery voltage which was of no consequence; otherwise, the station operated successfully over that time. A series of flow measurements have been carried out to create and maintain the relationship between water level and flow (the rating curve). Ten rating changes were observed over 6 years. Flow gaugings have been measured as low as 4.5 m^3/s and as high as 32 m^3/s, enabling the flow range up to 40 m^3/s to be calculated very reliably, and up to 100 m^3/s with reasonable confidence. In addition, 43 flow measurements have been completed for the Whirling Water tributary and six measurements at the State Highway Bridge.

A plot of the flow information collected during this period is shown in **Figure 1**. This plot is truncated at 40 m^3/s and is useful to observe the difference between summer and winter flows in the Waitaha, with spring and mid-summer flows consistently above 10 m^3/s, usually peaking in December - January. The winter flows however, are typically below this level.

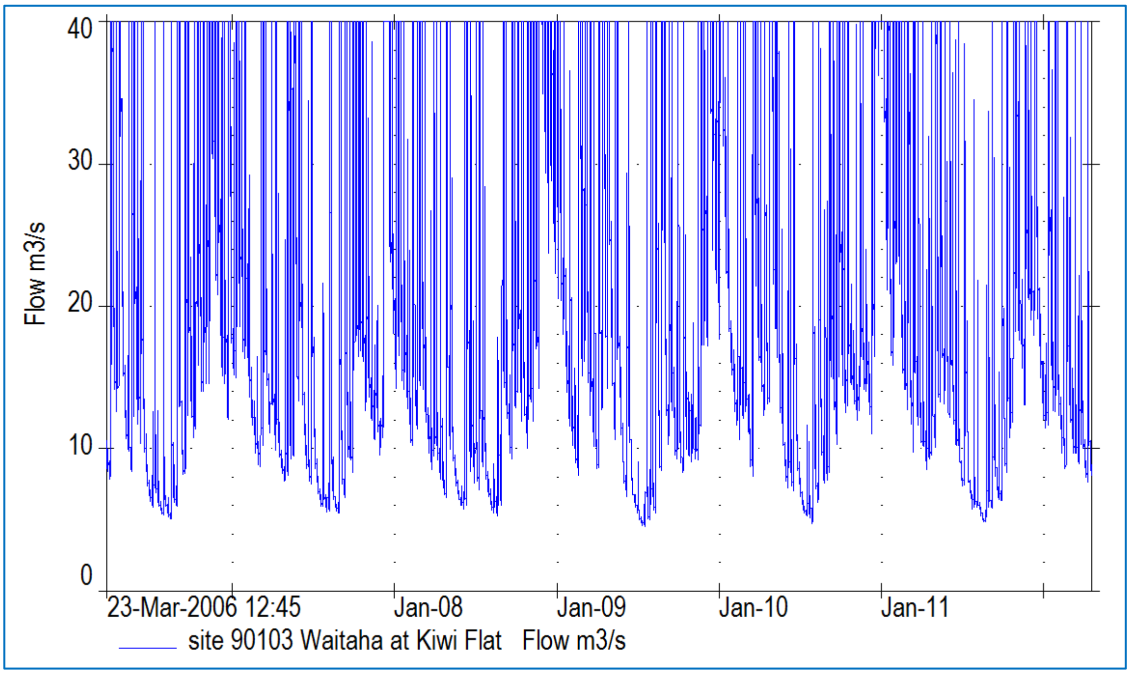

Figure 1 - Flow plot for Waitaha River at top of Kiwi Flat

Additional Flow and Rainfall information

The analysis was able to benefit from long term flow monitoring that has been carried out in neighbouring catchments, and from rainfall stations that have operated within and just outside of the catchment.

Cropp and Ivory flow

The Cropp Valley is a small 12.2 km^2 catchment just 4 km NNE from the head of the Waitaha. The flow information from the Cropp, while of interest, is of less relevance to the Scheme as the site is at high elevation, and the flow information in later years is of poor quality due to an unstable river bed, and eventually the site was closed. In a similar locality, the Ivory Glacier exists at the very head of the Waitaha Valley and was the centre of some intensive glaciology studies in the 1970's. Rainfall and flow information were also collected at this time, but there are many gaps in the record. The Ivory Glacier has reduced greatly in size since the early studies.

Hokitika flow

The Hokitika Catchment is immediately east of the Waitaha. At the location of the Hokitika Gorge flow station, the river is 4.1 times the size of the Waitaha at Kiwi Flat, and the flow has been measured since 1971. However, only data since 1973 have been used in this study on account of gaps and poorer quality information in the first few years of the Hokitika record. As it has a similar altitudinal range and shares some of the seasonal characteristics seen in the Waitaha, the Hokitika data provides valuable information. Around 4% of the catchment above the Hokitika Gorge site is covered by glaciers, and its aspect is more northerly, these two features differing from the Waitaha.

Whataroa flow

Further south, the Whataroa River has good quality flow information which commenced in 1985. At the flow recorder, the catchment is 4.9 times the size of the Waitaha at Kiwi Flat. Glaciers cover 12.2% of this area, compared to the Waitaha which has 8.6% coverage above the recorder. The Whataroa record is valuable for this reason, having the most similar seasonal characteristics to the Waitaha of all the local rivers that are monitored. In addition, the Whataroa has the same western aspect as the Waitaha, albeit some 40 km further south. Whataroa flow data has been used with the permission of Meridian Energy who partially funds the river flow site.

Poerua flow

Located between the Waitaha and Whataroa, the Poerua River was monitored for a period from 1983 to 1987. Because there was no concurrent record with the Waitaha River, the flow data from this location has only been used for regional flood statistics.

Amethyst flow

The Amethyst Creek backs onto the lower part of the Waitaha, and nearly 4 years of flow information has been collected from this 16 km^2 mid altitude catchment. This information is useful when looking at the nature of the inflows in the mid - lower Waitaha River.

Lower Waitaha flow

Flow information was measured from 1977 to 1984 on the Waitaha River at the State Highway Bridge, near the coast. However, half of the catchment at this site is lowland and in a lower rainfall area, so it is not fully representative of the study area.

Table 1 - Flow information in the Waitaha locality

River	Site	Catchment Area (km^2)	Currently operating?	Average flow expressed as mm of rainfall
Cropp	Gorge	12.2	No	11,720
Hokitika	Colliers Creek	352	Water level only now	8,930
Hokitika	Gorge	367	Yes	8,820
Waitaha	SH Bridge	223	No	8,120
Waitaha	Top of Kiwi Flat	90	No	9,900
Amethyst	Road Bridge	16	No	6,600
Poerua	Lower Gorge	148	No	7,130
Whataroa	SH Bridge	445	Yes	9,410

Nearby rainfall information

Rainfall data has been collected in the Cropp catchment since 1979, and is of good quality for an alpine gauge (these gauges suffer reduced catches due to wind effects and snowfall). An additional alpine gauge exists in the neighbouring Tuke catchment, and lowland gauges at Ross Township, and Whataroa.

Rain gauges that are now closed, but for which historical information is available, existed at Ferguson's Farm (the uppermost farm in the northern side of the Waitaha Valley), Ivory Glacier, Moonbeam Hut above Kiwi Flat, and at Harihari.

Table 2 - Rainfall stations within and next to the Waitaha Catchment

Catchment	Site	Altitude (m)	Annual rainfall (mm)	Confidence in data quality (1 = good, 5 = poor)
Cropp	Waterfall	975	11,522	3
Cropp	Cropp Hut	860	10,610	3
Waitaha	Ivory Lake	1400	11,080	4
Waitaha	Moonbeam Hut	410	7,400	5
Waitaha	Fergusons Farm	90	4,300	3
Tuke	Tuke hut	975	10,510	3
Ross	Township	30	3,320	1
Harihari	NZFS	45	3,850	2
Whataroa	SH Bridge	90	5,640	2

Note: Confidence in data quality relates to environmental conditions rather than operator expertise

APPENDIX E – DERIVING A LONG-TERM FLOW RECORD

To derive a longer flow record of the Waitaha River, it was necessary to either create computer models of flow derived from inputs such as rain, snow and glacial melt, or derive relationships with neighbouring flow sites. The latter approach is strongly preferred in this case due to the complexity of the hydrological processes, and because there were 6 years of concurrent flow data in the Waitaha and two neighbouring catchments with relatively similar characteristics. The relationship can be derived in two ways: by mathematical regression or by forming a relationship using the same exceedances from concurrent flow duration curves. The latter is the recommended method and has been used for this study.

Initial correlations of daily mean flow show that the relationship between the Waitaha River and the Cropp River is poor, as is that for the Ivory. The relationship with the Amethyst River is better (r^2 = 0.62), but not as good as those from the Hokitika River (r^2 = 0.82) and the Whataroa River (r^2 = 0.86).

Consequently, relationships were developed between the Waitaha, and each of the Hokitika and Whataroa Rivers. In each case, the flow exceedance in 1% steps from Waitaha (up to 30 m^3/s) was graphed against the same exceedance from both the independent flow sites. This information is shown in **Figure 1** for the flows of most interest.

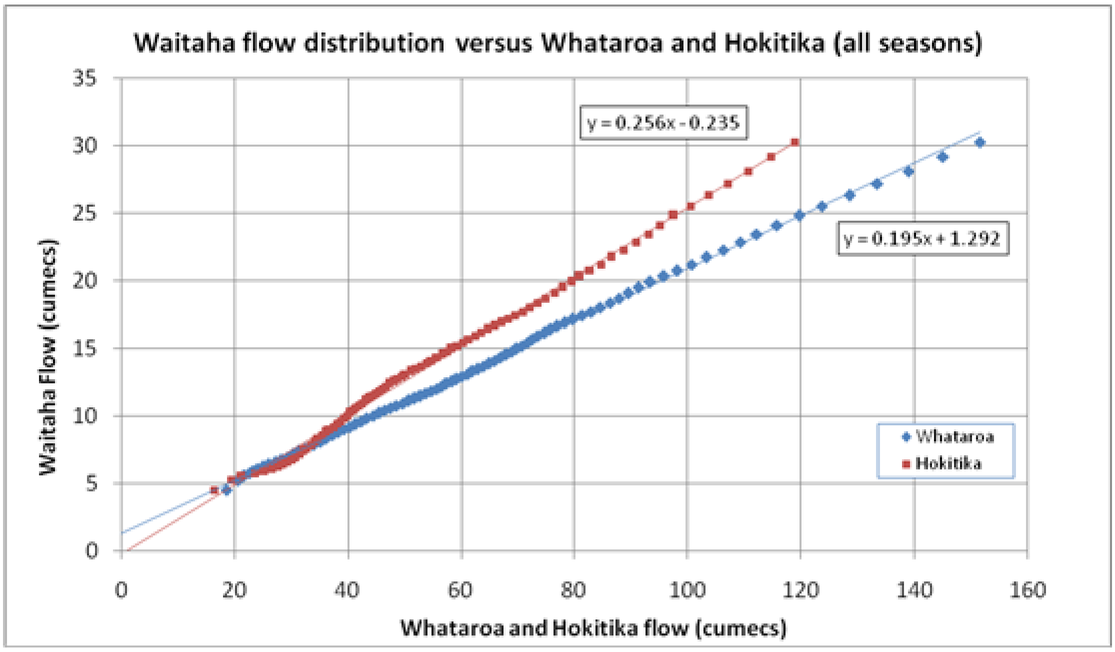

Figure 1 - Comparison of flow duration curves

It can be seen that the relationship between the Waitaha River and Hokitika River is non-linear at the bottom end. It is thought that this occurs on account of the reduced freeze/thaw processes that occur in the Hokitika compared to the Waitaha River.

To test for a seasonal difference caused by seasonal freeze/thaw, data was compared from flow duration curves for the sites using winter data only, against summer data only. **Figure 2** shows the seasonal relationships between the Waitaha and Whataroa Rivers, and **Figure 3** shows the same for the Waitaha and Hokitika Rivers. The blue data points are those from winter months and the red those from summer months. Each point on the plot represents a certain flow exceedance for the flow range up to 30 m^3/s.

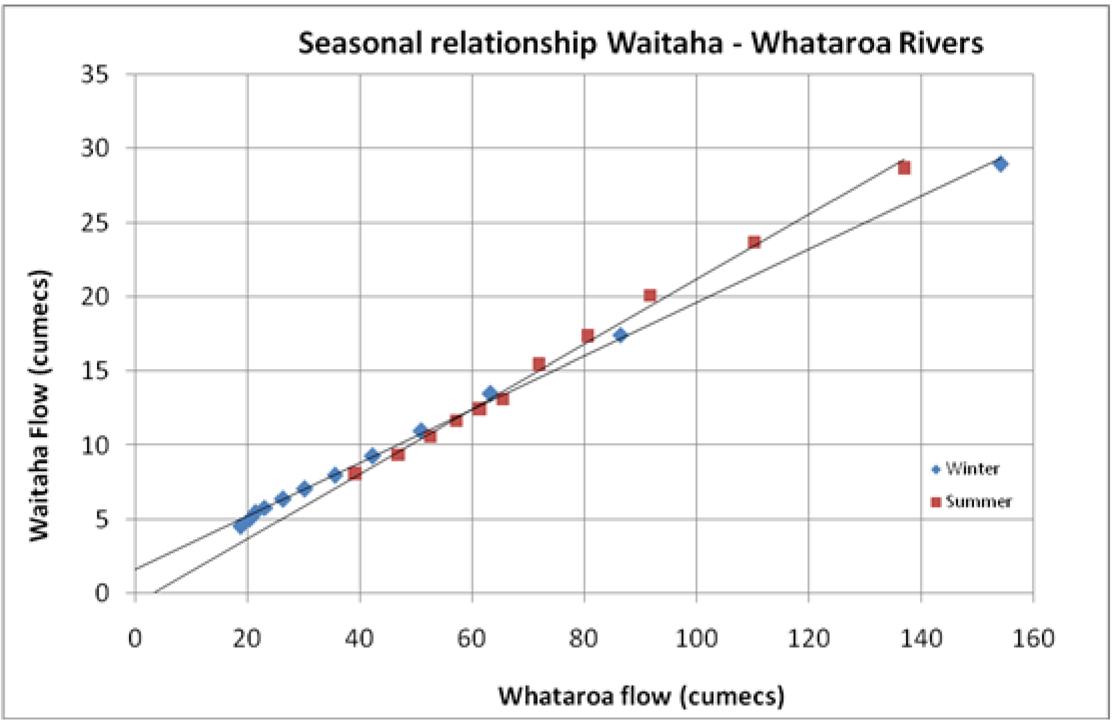

Figure 2 - Seasonality of relationship between Waitaha and Whataroa flows

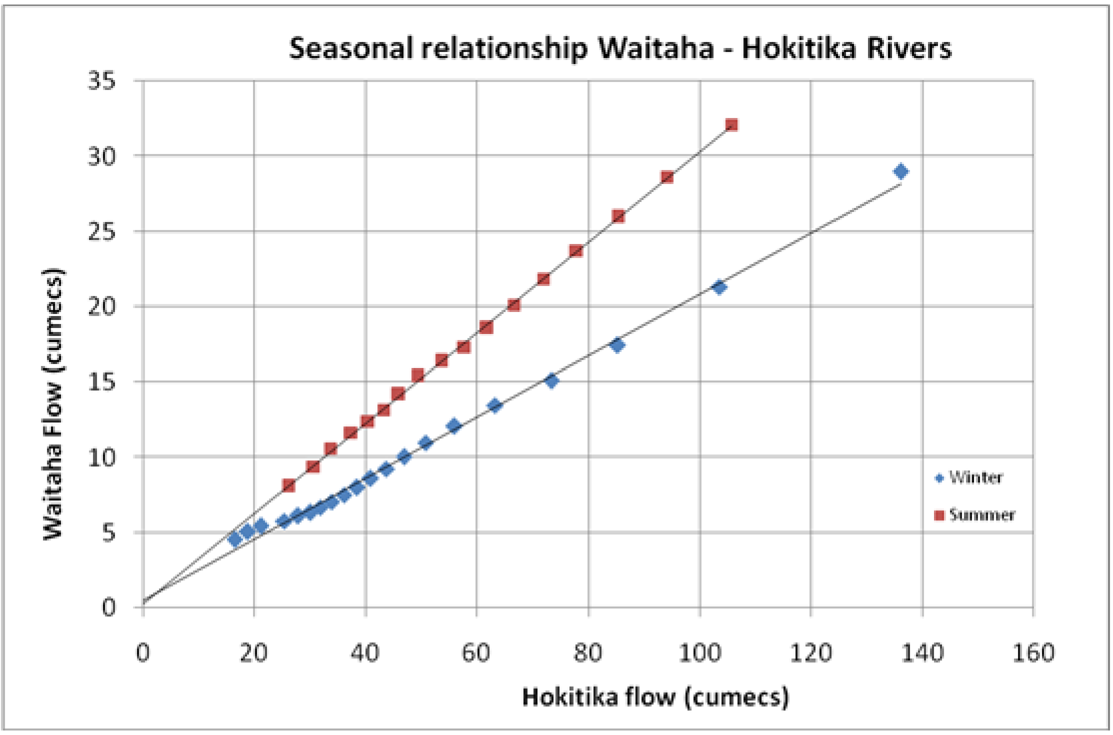

Figure 3 - Seasonality of relationship between Waitaha and Hokitika flows

There is some small evidence of seasonality in the Waitaha – Whataroa relationship, but it is influenced heavily by several data points, hence the effect is considered to be negligible.

In comparison, there is clear evidence of seasonality in the Waitaha – Hokitika relationship, as seen in **Figure 3**. This has a good physical reason for occurring – the Hokitika catchment, as a percentage, has less snow and permanent ice cover than the Waitaha.

Further comparisons were done which showed that the months over which the Hokitika-Waitaha relationship changed were April and May going into winter, and October and November going into summer. Accordingly, the winter and summer relationships shown above were applied to Hokitika flow data to estimate Waitaha flow data. Linear relationships were used, and the change from one relationship to another was smoothed in a linear fashion over the two-month transition period.

One single linear relationship (blue line, **Figure 2**) was applied to derive Waitaha flow from Whataroa flow.

Deriving flow data for the Waitaha River

It is necessary to extend the flow record at Waitaha for the purpose of estimating long term flow statistics. The relationships described above were each used to generate a synthetic (estimated) flow record for the Waitaha for the same period that records existed at the parent sites. Some gaps existed in the parent datasets, so a final version of the synthetic Waitaha dataset was generated in this manner:

- Where data existed for both the Hokitika and Whataroa Rivers, an average of the data derived from these two locations was used;
- If a gap existed, then data from the other single site was used to fill the record; and
- Prior to December 1985, only Hokitika data existed and this was used.

No periods existed where both Hokitika and Whataroa had a gap at the same time.

Comparisons of synthetic data compared to actual data

The final Waitaha synthetic dataset was created as described above. Plots of the actual Waitaha flow data for 2011 overplotted with the synthetic data are provided in **Figure 4**. The blue line shows the actual Kiwi Flat data and the red line shows the estimated flow data.

A further comparison was carried out by overplotting flow duration curves of the actual Waitaha flow data with the synthetic Waitaha flow data for the six years from 2006. The plot can be seen in **Figure 5**, with the blue line showing the actual Kiwi Flat data and the red line showing the estimated flow data.

It can be seen that the relationships developed do a very good job of estimating flow for the Waitaha River at Kiwi Flat, and can be used with confidence to derive long term flow statistics.

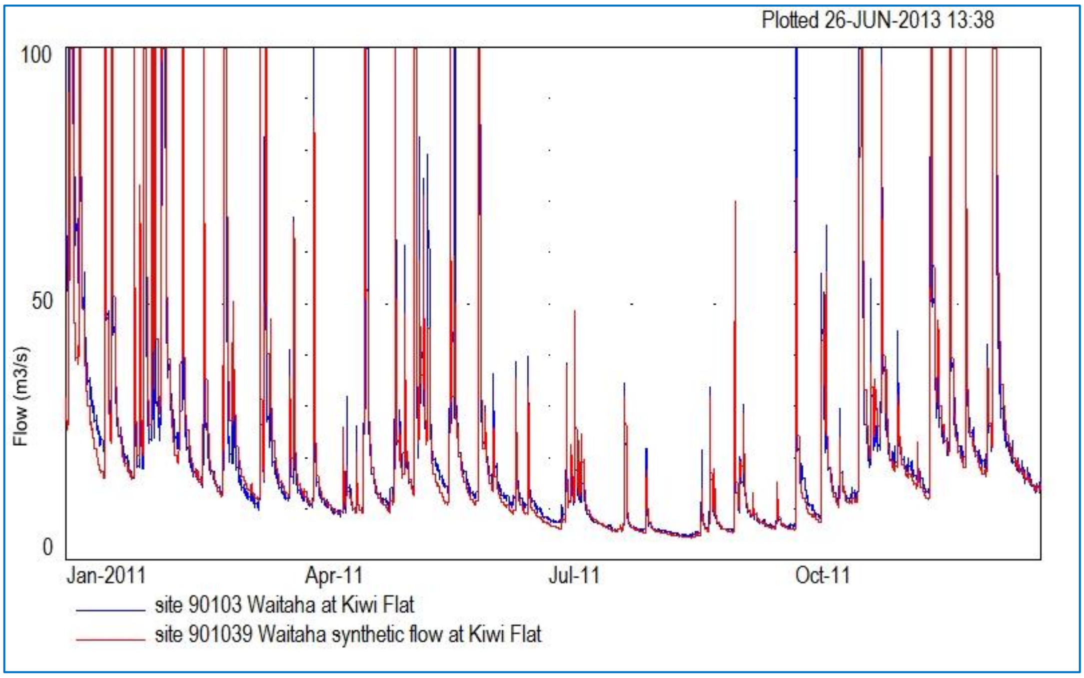

Figure 4 - Measured Waitaha flow data compared to estimated flow data for 2011

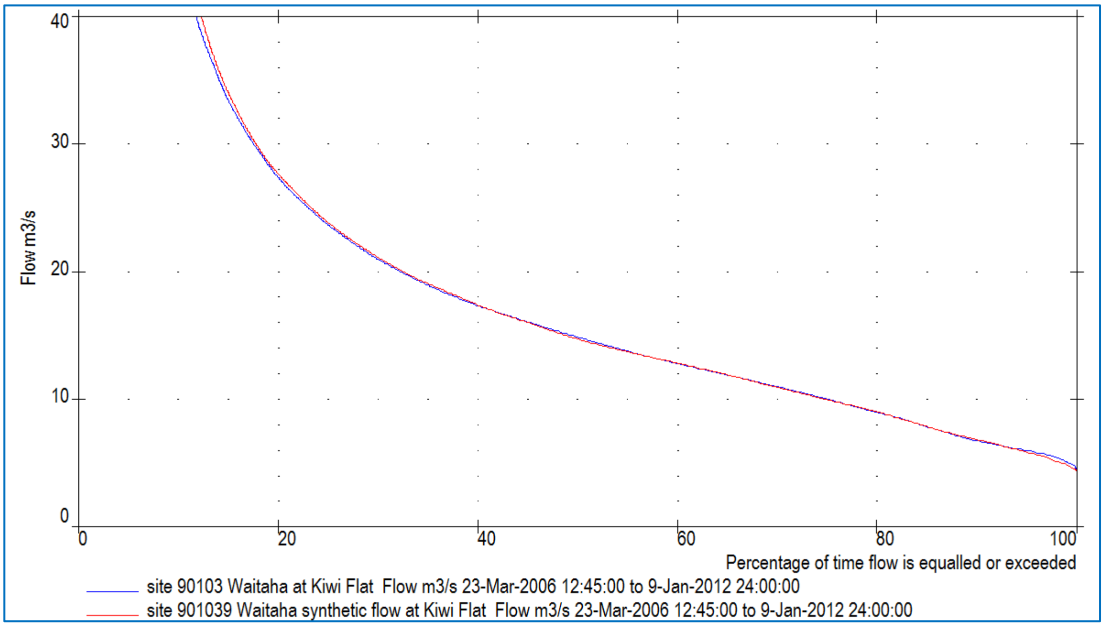

Figure 5 - Flow duration curves of actual Waitaha flow versus estimated Waitaha flow

Estimation of Whirling Waters flow

Flow data for the Waitaha River was collected at the top of Kiwi Flat, where the best recording site is situated. The Whirling Waters Tributary joins the Waitaha River on Kiwi Flat, adding an extra 21.5 km^2 of catchment area, with small tributaries flowing onto Kiwi Flat adding a further 5.0 km^2. Estimates of this extra flow need to be made to calculate the flow at the proposed Scheme intake.

Forty-three flow measurements have been made in Whirling Waters and these were correlated with concurrent flows from the Amethyst and Waitaha Rivers. The Amethyst provides a slightly better correlation than the Waitaha, however the Amethyst has only a short period of flow record (3.5 years) and therefore cannot be used to derive a long-term record for the Whirling Waters. For this reason, the Waitaha equation is used. The relationship between Waitaha and Whirling Waters is shown in **Figure 6**.

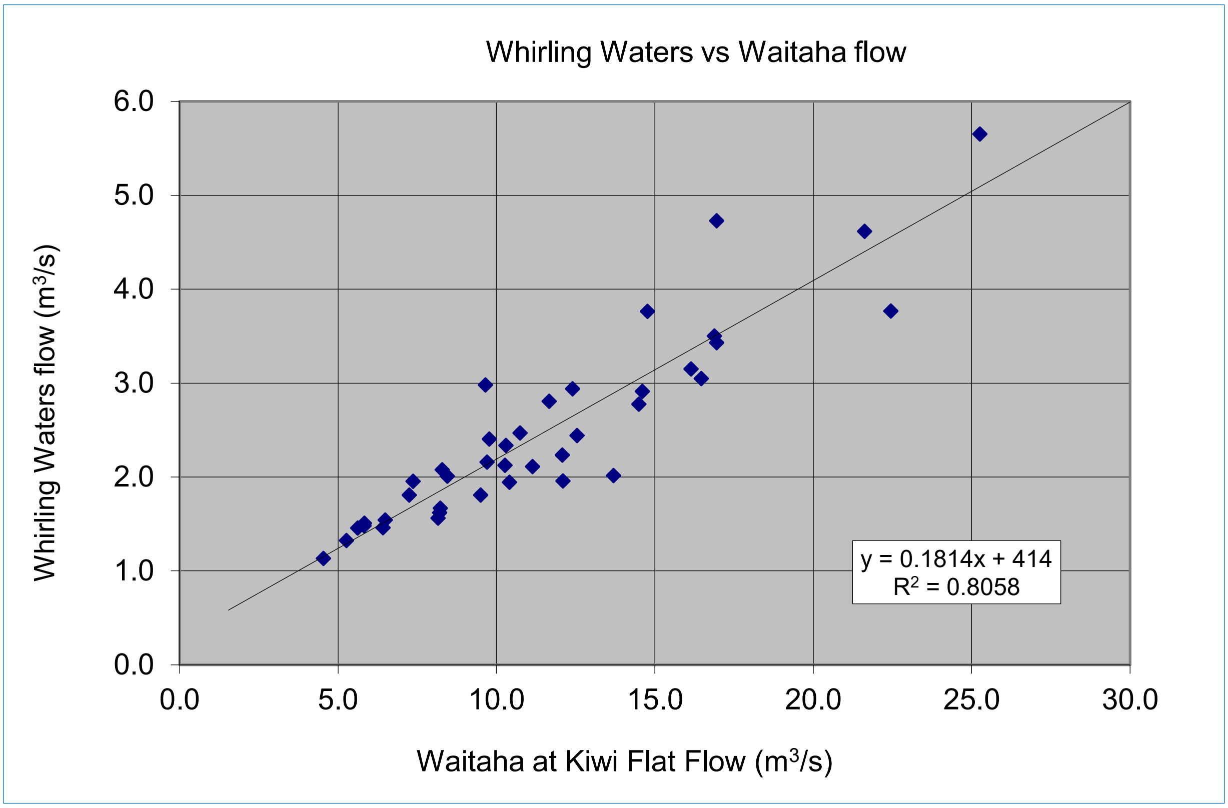

Figure 6 - Correlation between Whirling Waters and Waitaha at Kiwi Flat

There is slight evidence of seasonality in the Whirling Waters - Waitaha flow relationship, but because only individual measurements of flow have been made for the comparison rather than a record of continuous flow data, no attempt was made to apply a seasonal factor to the long-term Whirling Waters flow estimate. However, low flows always occur in winter, so the low flow estimates for Whirling Waters are *de facto* seasonally adjusted.

APPENDIX F – NATURAL FLOW STATISTICS FOR THE WAITAHA RIVER

Top of Kiwi Flat

As described in **Appendix D,** flow data were collected over a six-year period starting in 2006, and correlations with the Hokitika and Whataroa Rivers have enabled a dataset of Waitaha flow to be constructed going back to 1973. Flow statistics and other outputs were calculated from this. **Table 1** shows low flow statistics for natural flow at the top of Kiwi Flat.

Table 1 - Low flow statistics at top of Kiwi Flat (GEV distribution)

Return Period	1-day average flow (m^3/s)	7-day average flow (m^3/s)
Mean Annual Low Flow	5.554	5.995
5-year low flow	4.458	4.680
10-year low flow	4.198	4.401
20-year low flow	4.021	4.213
50-year low flow	3.851	4.036

The average flow for the Waitaha at the top of Kiwi Flat is 28.3 m^3/s, and the median flow is 16.0 m^3/s.

Figure 1 shows the expected long term flow duration curve. The blue line represents the flow distribution as calculated from the six years of actual Kiwi Flat data, and the red line is from the 39 years of synthetic data. This shows that above 10 m^3/s, the past six years of measured flow data were not representative of the flow conditions over the previous 39 years. The 39-year plot shows greater flows were experienced for a given percentage of time than were for the past six years, except that the very lowest flows were slightly less than those seen over past six years. This effect is further explained in **Appendix C**.

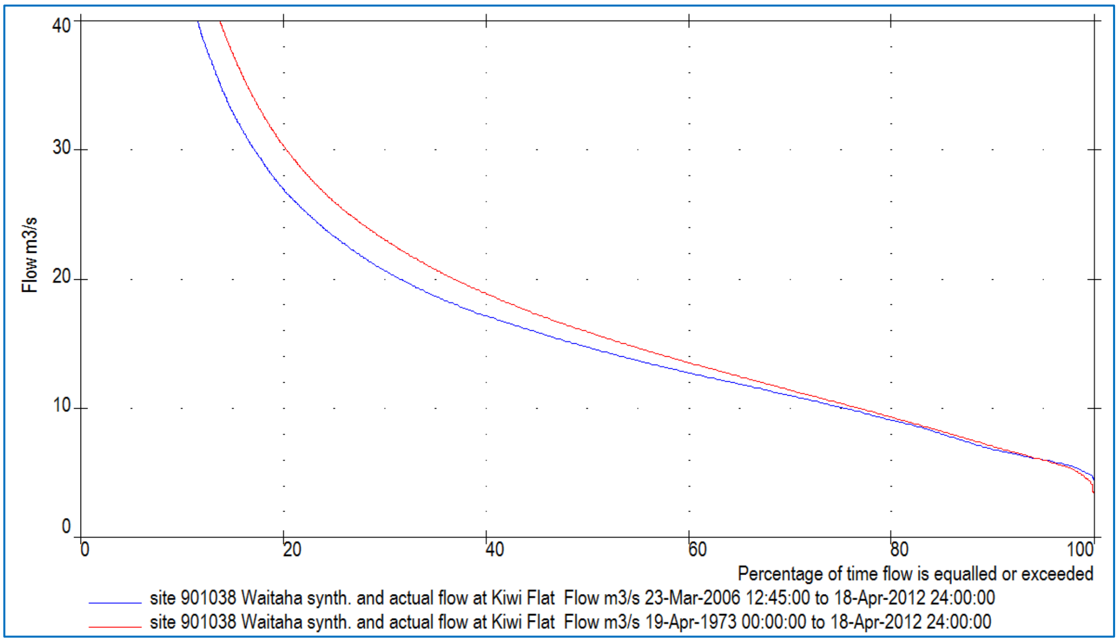

Figure 1 – Waitaha flow duration curve for past six years, versus the past 39 years

To accurately quantify values in the flow distribution if needed for further calculations, **Table 2** gives the same information as **Figure 1.**

Table 2 - Flow distribution table for Waitaha at top of Kiwi Flat

Exceedance percentiles

Site 901039 Waitaha synthetic flow at Kiwi Flat
From 19-Apr-1973 00:00:00 to 18-Apr-2012 24:00:00
Flow m^3/s

	0	1	2	3	4	5	6	7	8	9
0	1163.30	249.63	179.09	137.62	109.43	90.80	77.78	68.56	61.44	55.78
10	51.30	47.54	44.40	41.81	39.55	37.56	35.81	34.22	32.82	31.54
20	30.40	29.39	28.45	27.57	26.78	26.05	25.39	24.77	24.18	23.63
30	23.10	22.61	22.11	21.66	21.21	20.79	20.37	19.98	19.62	19.27
40	18.92	18.59	18.25	17.93	17.62	17.32	17.02	16.74	16.46	16.20
50	15.95	15.69	15.44	15.19	14.94	14.70	14.46	14.23	14.01	13.78
60	13.57	13.35	13.14	12.92	12.71	12.50	12.29	12.07	11.87	11.66
70	11.44	11.23	11.02	10.82	10.62	10.42	10.21	10.00	9.79	9.57
80	9.35	9.13	8.91	8.69	8.48	8.25	8.01	7.78	7.56	7.33
90	7.09	6.87	6.66	6.44	6.24	6.03	5.81	5.57	5.29	4.78
100	3.55									

Values in the exceedance table are not exact. They are good approximations based on linear interpolation of 2000 classes.

Note: Above 100 m^3/s*, the flow distribution shown above should only be used as an indication. Maximum flows are estimates only.*

Top of Morgan Gorge

Flow data is required to estimate effects below the intake at the top of Morgan Gorge, so the long-term synthetic dataset generated for the top of Kiwi Flat was adjusted to include the Whirling Waters and other small tributaries down the length of Kiwi Flat. In total, this is another 26.5 km^2 of catchment area, or an additional 29%. However, because the rainfall is less in this area compared to upstream of the Kiwi Flat recorder, the typical flow increase will be less than this.

The correlation shown in **Appendix E** (Figure 6) was used to predict Whirling Waters flow from Waitaha flow. To obtain flow at the bottom of Kiwi Flat, visual estimates of additional minor inflows were made, and by adjusting known nearby flows to catchment size, an allowance was made for the other Kiwi Flat tributaries as well. The following equation was derived to calculate flow at the bottom of Kiwi Flat (all units are m^3/s):

Waitaha flow at bottom of Kiwi Flat = (1.209 x Kiwi Flat Recorder Flow) + 0.476

Using this, a dataset was generated for the Scheme intake location, and flow statistics and other outputs for that location were calculated. **Table 3** shows low flow statistics relevant to decisions regarding residual flow levels (again using the GEV distribution), and **Figure 2** gives the expected long term flow duration curve.

To accurately quantify values in the flow distribution if needed for further calculations, **Table 4** gives the same information as **Figure 2**.

Table 3 - Low flow statistics for Waitaha at bottom of Kiwi Flat (GEV distribution)

Return Period	1-day average flow (m^3/s)	7-day average flow (m^3/s)
Mean Annual Low Flow	7.085	7.572
5-year low flow	5.934	6.210
10-year low flow	5.568	5.812
20-year low flow	5.304	5.529
50-year low flow	5.039	5.249

The average flow for the Waitaha River at the bottom of Kiwi Flat is 34.6 m^3/s, and the median flow is 19.7 m^3/s.

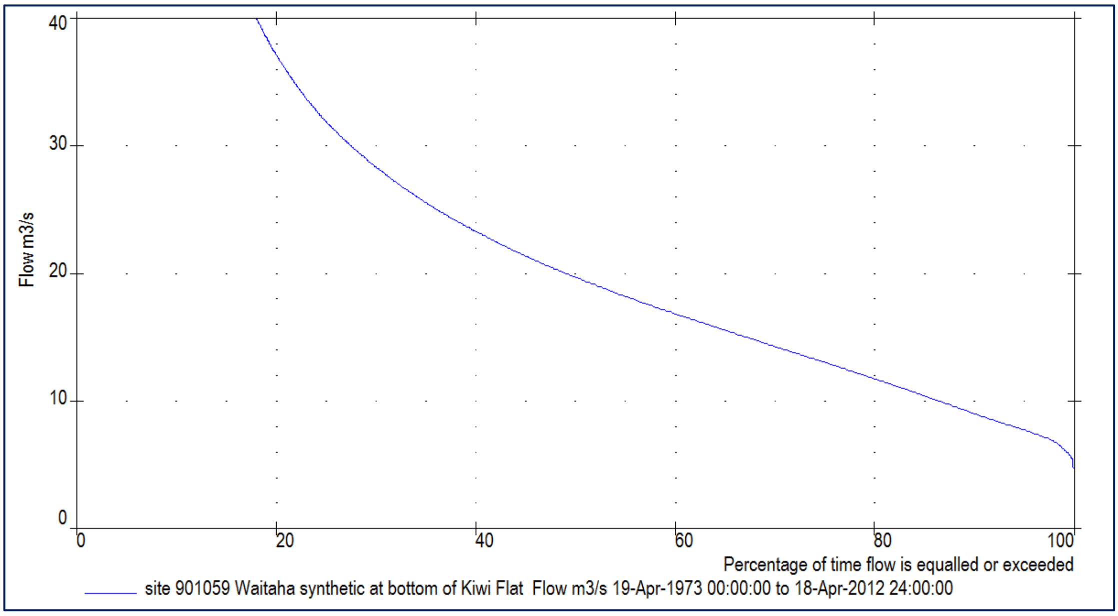

Figure 2 - Flow duration curve for Waitaha River at bottom of Kiwi Flat

Table 4 - Flow distribution table for Waitaha River at bottom of Kiwi Flat

Exceedance percentiles

Site 901059 Waitaha synthetic at bottom of Kiwi Flat
From 19-Apr-1973 00:00:00 to 18-Apr-2012 24:00:00
Flow m^3/s

	0	1	2	3	4	5	6	7	8	9
0	1406.90	302.21	216.93	166.82	132.75	110.22	94.49	83.34	74.73	67.89
10	62.48	57.94	54.13	51.01	48.28	45.88	43.76	41.84	40.15	38.60
20	37.22	36.00	34.86	33.80	32.85	31.96	31.16	30.42	29.71	29.04
30	28.40	27.80	27.20	26.65	26.12	25.60	25.10	24.63	24.18	23.76
40	23.35	22.94	22.53	22.14	21.77	21.41	21.05	20.70	20.38	20.06
50	19.75	19.44	19.14	18.84	18.53	18.24	17.95	17.67	17.41	17.13
60	16.87	16.61	16.36	16.09	15.84	15.59	15.32	15.07	14.82	14.56
70	14.30	14.04	13.80	13.56	13.32	13.07	12.81	12.56	12.30	12.04
80	11.78	11.51	11.25	10.98	10.72	10.44	10.16	9.88	9.61	9.33
90	9.05	8.78	8.52	8.26	8.02	7.77	7.50	7.21	6.88	6.26
100	4.76									

Values in the exceedance table are not exact. They are good approximations based on linear interpolation of 2000 classes.

Note: Above 100 m^3/s, the flow distribution shown above should only be used as an indication. Maximum flows are estimates only.

Waitaha at State Highway Bridge

Flow information was collected at the very bottom of the Waitaha catchment at the State Highway Bridge for seven years from 1977. The catchment area at this location is 223 km^2 compared to 117 km^2 at the top of Morgan Gorge. This record is not used in this study but is shown here for completeness.

The nature of the flow generated in the lower catchment is quite different to that seen in the upper catchment. No glaciers exist in this area and any snowfall is short lived, and groundwater interacts with the lower river. Without the influence of meltwater, the flows derived from the lower catchment have more winter flow and less summer flow relative to the increase in catchment area. A flow duration curve for the data collected at this location is shown in **Figure 3**. The kink at the bottom of the curve appears to be the result of one unusual rating curve in the flow record.

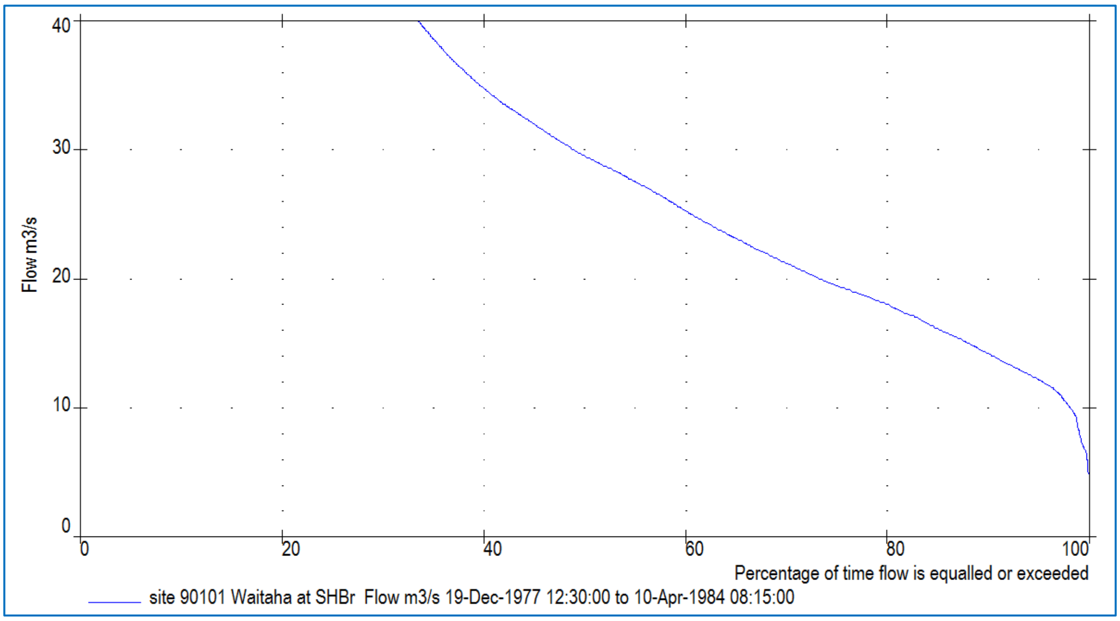

Figure 3 - Flow duration curve for Waitaha River at State Highway Bridge

Other flow statistics derived from the 7-year flow record at State Highway Bridge are shown in **Table 5**, and are compared with the upper catchment. The upper catchment numbers have been calculated from 39 years of record.

Table 5 - Flow statistics for Waitaha River at State Highway Bridge

Location	MALF 7day (m^3/s)	Median flow (m^3/s)	Average flow (m^3/s)
Waitaha at Top of Kiwi Flat	6.0	16.0	28.3
Waitaha at bottom of Kiwi Flat	7.6	19.7	34.6
Waitaha at State Highway Bridge	9.7	29.6	56.9

Flood Flows

The floods recorded in the flow record at Kiwi Flat are not calibrated to flow measurements, rather they originate from estimates of velocity, both from experience and from a 1-D hydrodynamic model (M. Hicks, pers. comm). To provide flood statistics therefore, a regional comparative approach was used as in McKerchar and Pearson (1989). From the neighbouring flow stations estimates were made for the Waitaha at the top of Morgan Gorge.

Mean annual flood (MAF) flows were first calculated for the Hokitika, Cropp, Poerua, Taramakau, Whataroa and lower Waitaha Rivers. These values were then divided by the individual catchment areas to the power of 0.8. After consideration of the $MAF/A^{0.8}$ ratios from all these rivers, an estimate of 18 was made for the same ratio at Kiwi Flat.

Each of the annual flood series were analysed using the Gumbel distribution. Ratios between various return periods and the mean annual flood for each river were then calculated, and from these, regional ratios were selected and used to calculate flood sizes for the Waitaha at the bottom of Kiwi Flat, as shown in **Table 6**.

Note: The synthetic flow data shown in Appendix E and the flow data collected at Kiwi Flat should not be compared to the flood statistics below. The actual data collected has only been calibrated to 32 m^3/s with a comfortable accuracy up to 100 m^3/s, and the synthetic data is derived from a relationship focussed on these lower flows.

Table 6 – Flood statistics for the Waitaha River at the bottom of Kiwi Flat

Average recurrence Interval	Flow (m^3/s)
Mean Annual Flood	812
20 years	1,177
50 years	1,299
100 years	1,380
200 years	1,518
500 years	1,665

APPENDIX G – RESIDUAL FLOW CONDITIONS AND STATISTICS

To assess the effects of the Scheme, a variety of hydrological analyses of flow conditions were required as inputs to other studies, in particular freshwater ecological modelling, sediment, landscape and recreational values. A simulation model was used to determine the conditions the Scheme will create below the intake, using the flow data for the period 1973 – 2024.

Flow duration curves of residual flow below the intake

The percentage of time (and hence days per annum) that the river below the intake and upstream of the power station will be in a state of residual flow can be calculated using a flow duration curve of this residual flow data. **Figure 1** shows the flow duration curves at the Scheme intake of the natural flow data (blue), and the residual flow from a take ranging from 0 to 23 m^3/s (red). The vertical axis shows the flow in m^3/s, and the horizontal axis shows the percentage of time that each flow has been exceeded.

As an example, it can be seen that the natural flow of the river at the Scheme intake is above 4.8 m^3/s for 100% of the time and above 23.5 m^3/s for 40% of the time. It can also be said that at the Scheme intake the natural flow range of 12 – 23.5 m^3/s occurs for 40% of the time (80% minus 40%).

It can also be seen that for a take of 23 m^3/s (red), the residual flow at the Scheme intake will occur for 66% of the time (100% minus 34%).

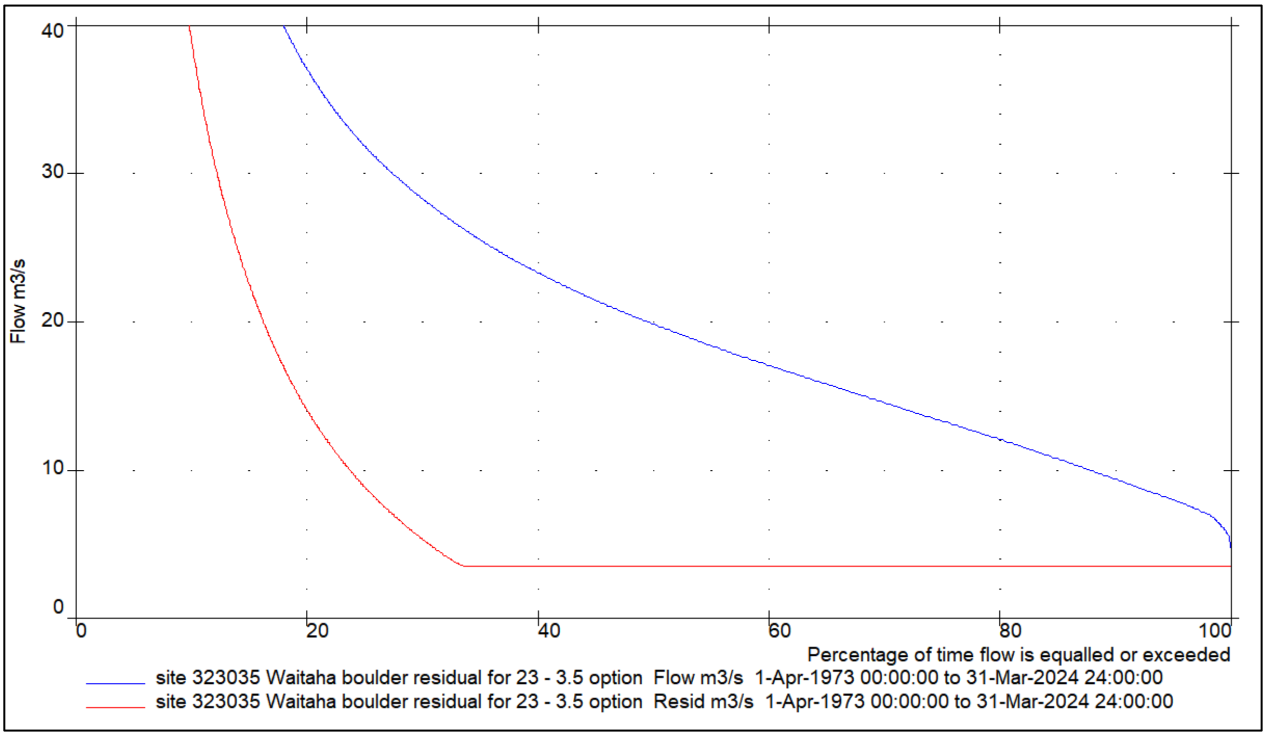

Figure 1 - Percentage of time residual flow occurs for a take ranging from 0 to 23 m^3/s (using all months).

The percentage of time in a state of residual flow can also be converted to a length of time. In this case, 66% of time equals 241 days per annum.

There are three important points to note about this data:

1. The days of residual flow will not occur as consecutive days but as small intervals of time before a fresh or flood occurs. These arrive every 8.6 days on average, and because the take is a small amount of flow relative to a flood flow, the Scheme will have negligible impact on the occurrence or frequency of these floods below the intake.
2. The residual flow of 3.5 m^3/s is supplemented 300 m downstream of the intake by Anson Creek, and again by Glamour Glen. These two streams boost the residual flow below the Scheme intake considerably after rain, and for 50% of the time they add at least 0.7 m^3/s, hence the residual flow below Glamour Glen is at least 4.2 m^3/s for 50% of the time. **Figure 2** shows the flow in the Waitaha River from the top of Kiwi Flat to just downstream of the power station, for two flow scenarios while the power station is operating. The drop in flow at the intake occurs at 2.2 km on the horizontal axis, and the increase in flow from Anson Creek and Glamour Glen shows between this point and the 4.7 km mark which is the power station location. At this point the flow in the river increases back to its natural state.
3. The data shown above is taken from all of the year, but the river flow is very seasonal. For instance, the flow duration curve in **Figure 3** compares the residual flow data for the summer months of December, January and February (red), to that for the winter months of Jun, July and August (cyan). The natural flow condition is shown for comparison in blue.

Note: The flow provided for Anson Creek and Glamour Glen are estimates based on catchment size adjustment of flow data collected at similar neighbouring catchment of Whirling Waters, MacGregor Creek and Amethyst Creek.

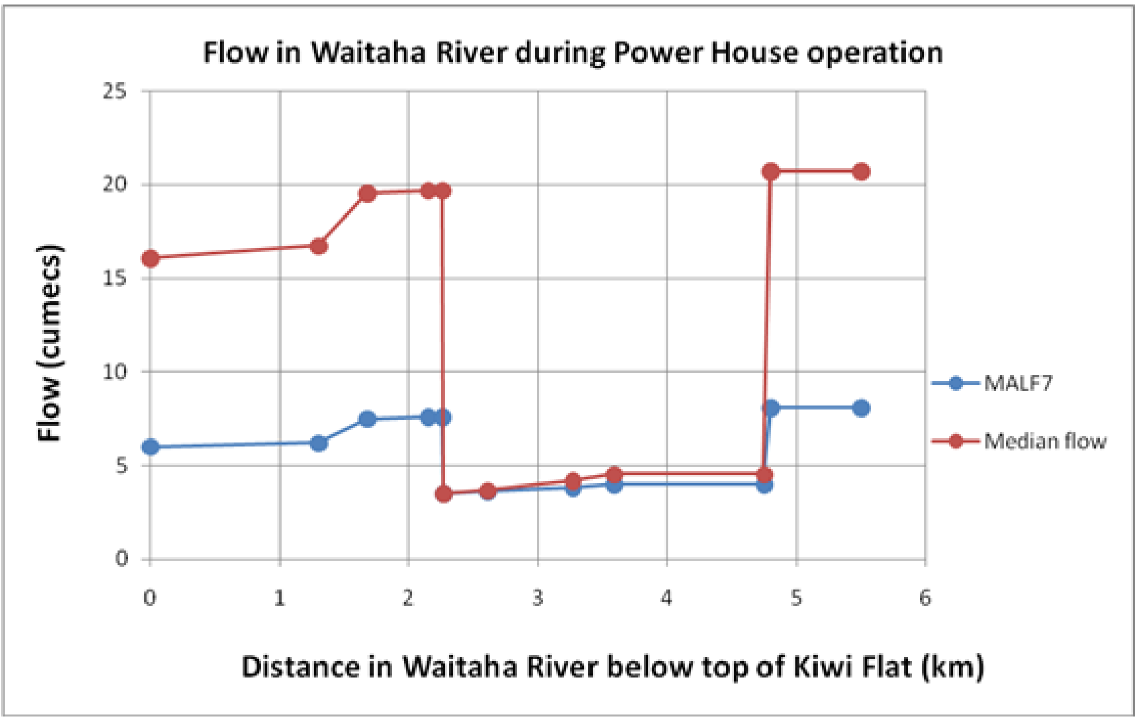

Figure 2 - Flow in Waitaha River during operation of the Scheme

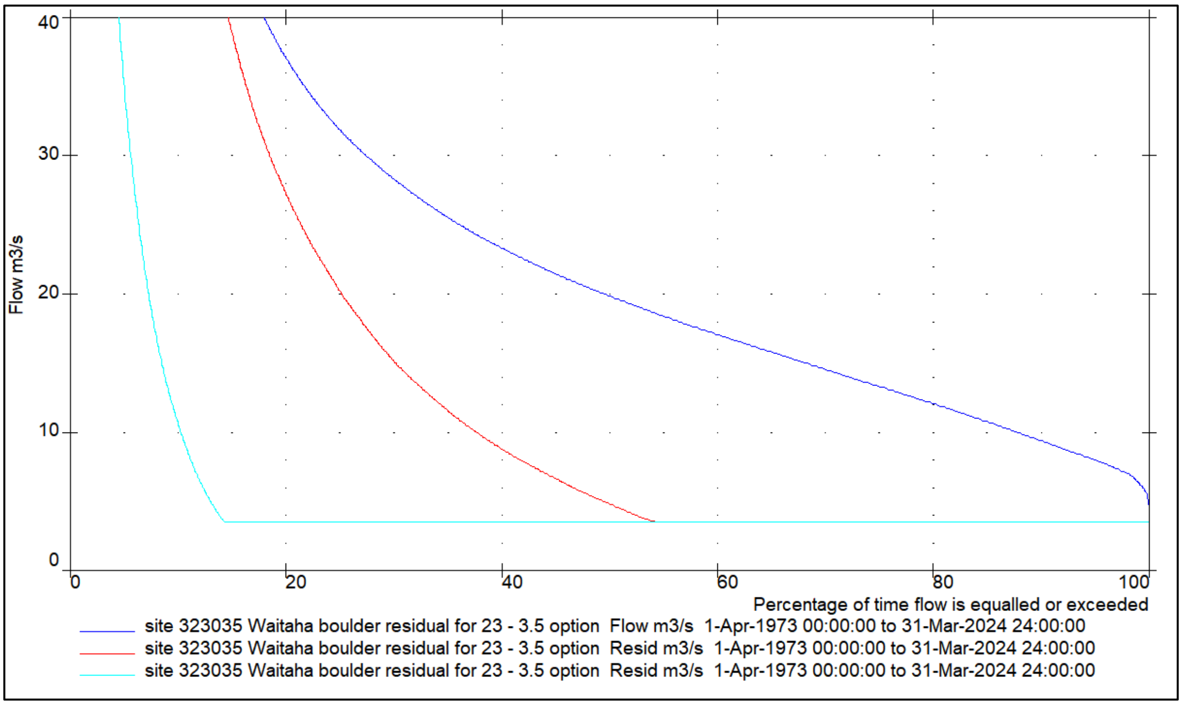

Figure 3 - Percentage of time residual flow occurs over summer (red) and winter (cyan). Natural flow over all of the year is blue

Histogram of low flow periods

To illustrate the length of time that the river will remain in a state of residual flow immediately below the intake, **Figure 4** shows a histogram created from the 51-year dataset. The horizontal axis shows the length of time that the river is in residual flow below the intake before a fresh or flood occurs, while the vertical axis shows the average number of times per annum each of these time periods occurs.

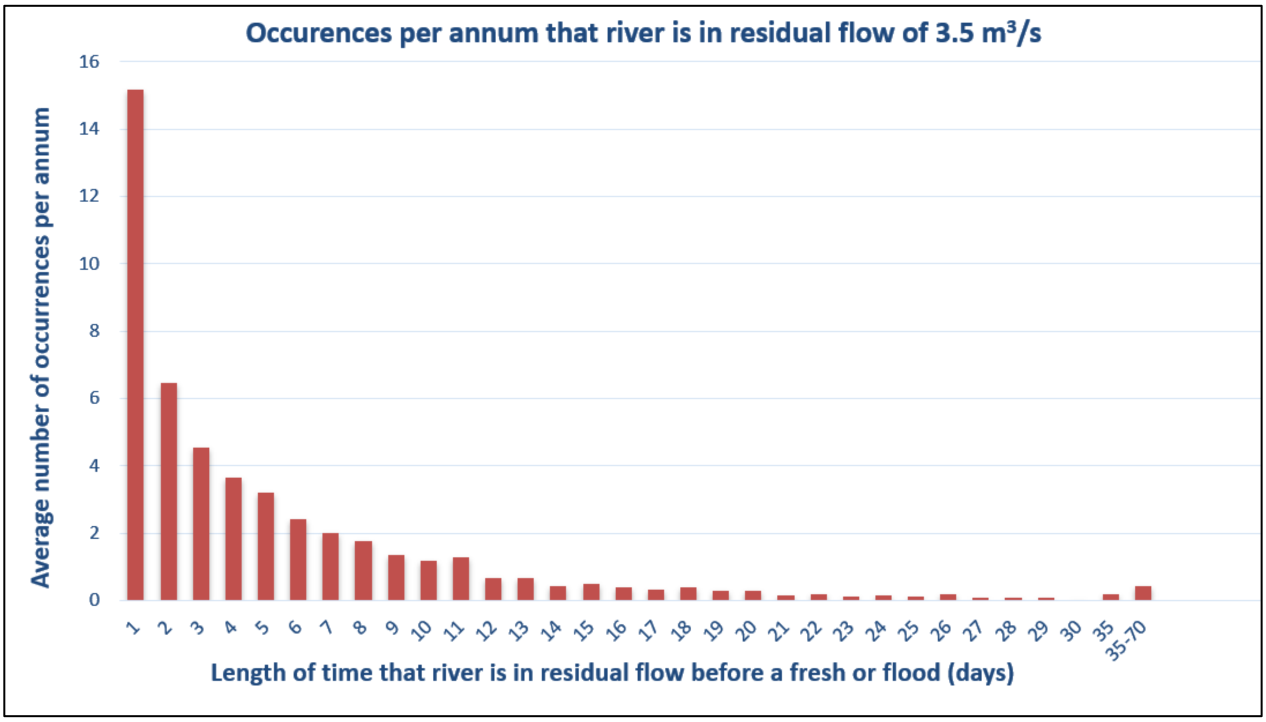

Figure 4 - Histogram showing frequency of residual flow periods before a fresh occurs, calculated from data 1973 – 2024.

It can be seen that the vast majority of residual flow periods at the Scheme intake only last several days before cessation by the next fresh. In particular, there are on average 15 times a year when the residual flow state lasts less than a day, 4.5 occurrences a year when the residual flow state lasts less than three days, and typically 1.2 occurrences a year when the residual flow state lasts 10 days.

These values will vary from year to year depending on the timing and amount of rain, the size of the snowpack and temperature which melts it. Had the Scheme been operating over the past 51 years, the greatest period of unbroken residual flow would have lasted for 79 days during 1996. In comparison, in 1994 the longest period would have been 17 days.

There are on average 42 floods or freshes per annum greater than 30 m^3/s, the average interval between these peaks is 8.6 days, and the average flood duration is 55 hrs.

FRE3 Analyses

FRE3 is defined as the number of floods per year that exceed three times the median flow, and is used as an indicator of ecological disturbance in the river. The following analyses in **Table 2** give FRE3 values for the natural flow at the top of Morgan Gorge, both above and below the intake. For these analyses a five-day period was used as a ‘stand down’ before another flood was counted. The FRE3 values are changed only slightly, which shows that the proposed take will have little effect on the frequency of even smaller floods flowing through the abstraction reach.

Note: The FRE3 values shown below are from the 2013 analysis and are virtually identical to the 2025 FRE3 values (26.3 and 23.6). Because the 2013 values are used in other reports they are quoted here.

Table 2 - Values of FRE3 for natural flow and after various take options

Flow scenario at intake	FRE3 value (occurrences per annum)
Natural flow	26.2
With a take of 23 m^3/s	23.6

APPENDIX H – VERIFICATION OF THE 2012 STATISTICS

The statistics provided in Doyle (2013) were finalised in 2012, and utilised in a variety of ecological, landscape, economic and recreational assessments, as well as for the purpose of engineering design. These assessments provided the basis for the 2014 application to build a hydroelectric power station on the Waitaha River. By necessity, once the statistics were provided, they were 'locked', so that all parties had access to the same data and information. Since the original report was written however, further flow information has been collected at Kiwi Flat and neighbouring rivers, which provides the opportunity to validate the original relationships used in the 2013 analyses. Furthermore, new statistics have been calculated using data up until 2024 and these have been compared to those provided in 2013, to see if they have changed in any significant manner.

Some small changes are seen; however, it is important to note that small changes will occur year-on-year, and this report advises against re-examining the many studies done in 2013 simply to accommodate several minor changes in the underlying flow statistics. The various studies that made up the application of 2014 therefore, remain valid from a hydrological perspective.

Additional data collected since 2013

Since the original hydrological report was written, a further one year of flow data was collected at the Kiwi Flat flow recorder, located at the top of Kiwi Flat. As well as this, continuous flow data have been collected at two regional flow recorders nearby, on the Hokitika and Waitaha catchments. This offered the opportunity to test the original correlations used to create synthetic data against new data not used in the derivation of the predictive equations. New synthetic data for Waitaha up until 2024 was created using the method of 2013, and this was then compared to the measured data at Kiwi Flat for the period April 2012 until May 2013.

Comparison of predicted versus measured data

To compare the measured data not used to derive the correlations to the derived (synthetic) data, a plot over time of the two is shown in **Figure 1.**

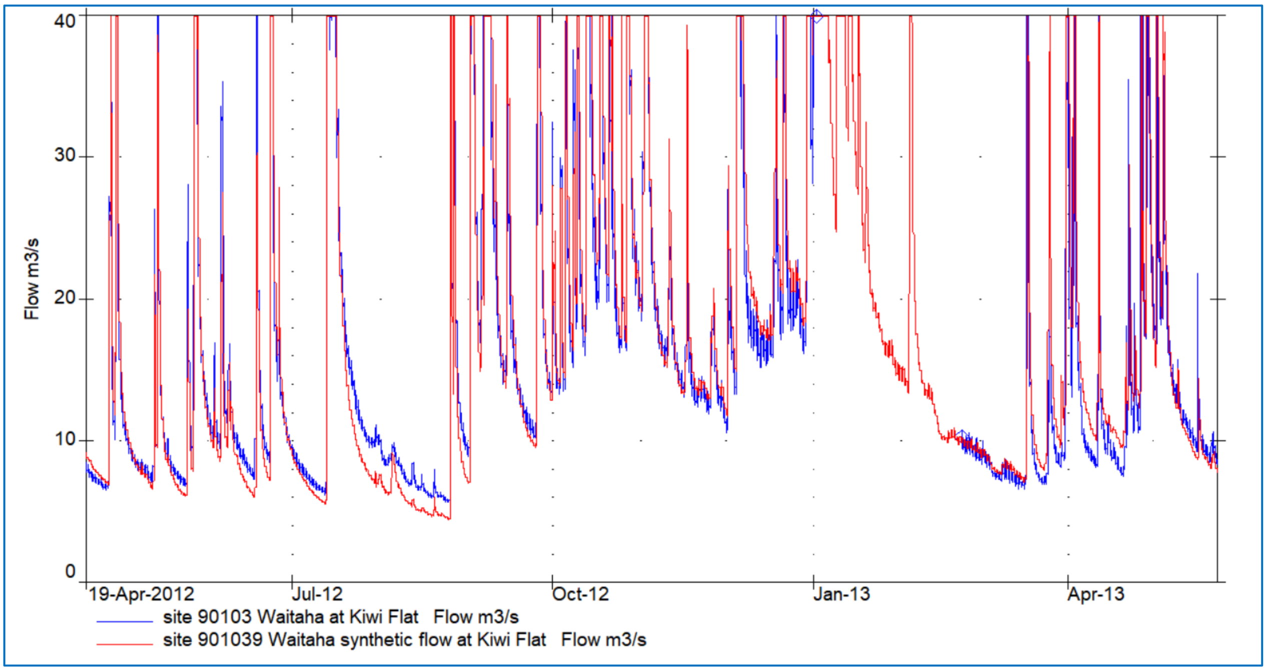

Figure 1 - Comparison of measured flow versus derived flow

The measured data is blue, and the derived (synthetic) data is red. A gap existed in the measured data through January and February 2013. The results are good – while the flows diverged through one period in 2012, this is to be expected following individual storms which can vary significantly across a region.

A flow exceedance plot provides an excellent 'one glance' summary of changes in a flow regime. **Figure 2** shows the exceedance plot for residual flow at the area known as the boulder garden. This is below Morgan Gorge and is referred to in various reports considering the effects of the flow take. The plot as created in 2013 is almost identical to that created in 2024.

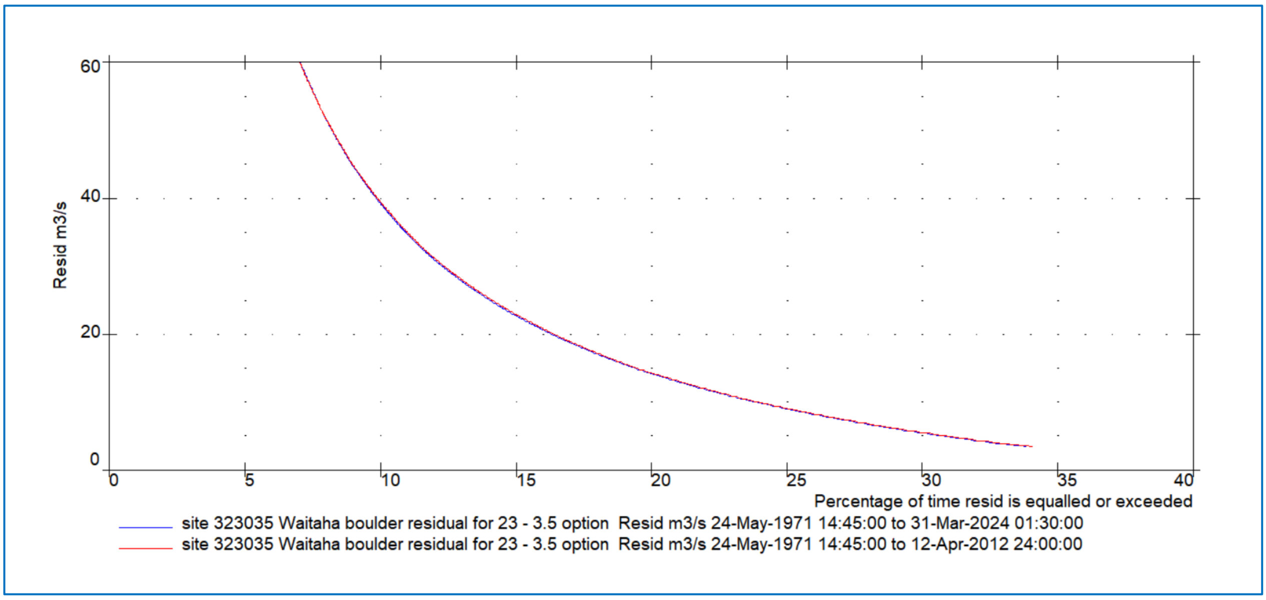

Figure 2 - Flow exceedance plot comparing the analysis of 2013 with the 2024 analysis. Note: flow is truncated at 60 m^3/s, and exceedance truncated at 40 percent to provide better detail.

Comparison of statistics created in 2013 and 2024

It is necessary to compare the long-term flow statistics derived in 2024 against those provided in 2013, to see if they have changed in any significant manner. It is important to note that small changes are inevitable, and change year to year. It can be seen that any changes are minor, and it is advised that the many studies done in 2013 do not need to be reassessed on the basis of new *hydrological* information provided in 2024, as the underlying flow statistics are considered virtually unchanged. Ultimately however, authors of the various reports utilising hydrological statistics will need to make their own decisions on this matter, and for that purpose, comparisons of the key statistics are shown in the following sections.

FRE3 values created 2013 versus 2024

FRE3 is a flow statistic important when considering frequency of bed disturbance. It is the number of times that a flood of magnitude 3 x median flow occurs annually, on average. The values calculated in 2024 remain virtually unchanged to the values provided in 2013. Median flow is itself virtual unchanged. These values are shown in **Table 1**.

Table 1 - Comparison of FRE3 and median flow values (2013 versus 2024) – note that flows are m^3/s, while the FRE3 values are occurrences per annum.

Flow scenario	Median Flow 1973 - 2013	Median Flow 1973 – 2024	FRE3 value 1973 - 2013	FRE3 value 1973 – 2024
Natural flow below the intake	19.75	19.89	26.2	26.3
Residual flow below the intake	3.50	3.50	23.6	23.6

Mean Annual Low Flow statistics created 2013 versus 2024

Mean Annual Low Flow (**MALF**) is another statistic that is widely used in ecological studies. It refers to the average of each annual flow minima as measured using a 1-day moving average (MALF1), or the same but using a 7-day moving average (MALF7). **Tables 2** and **3** show that MALF1 and MALF7 have changed by +3.2% and +3.4%. This change is perhaps the largest of any changes seen 2013 – 2024, but is still small.

Table 2 - Comparison of MALF1 derived in 2013 versus that derived in 2024

	Calculated 2013	Calculated 2024
Return Period	1-day average flow (m^3/s)	1-day average flow (m^3/s)
Mean Annual Low Flow	7.09	7.32
5-year low flow	5.93	6.10
10-year low flow	5.57	5.71
20-year low flow	5.30	5.43
50-year low flow	5.04	5.15

Table 3 - Comparison of MALF7 derived in 2013 versus that derived in 2024

	Calculated 2013	Calculated 2024
Return Period	7-day average flow (m^3/s)	7-day average flow (m^3/s)
Mean Annual Low Flow	7.57	7.83
5-year low flow	6.21	6.38
10-year low flow	5.81	5.95
20-year low flow	5.53	5.64
50-year low flow	5.25	5.33

It is worth discussing the changes in MALF1 in relation to the in-stream habitat assessment report. To put this into perspective, an individual flow gauging is rarely assessed as better than +/- 5%, and the measurements that make up the in-stream habitat flow assessment curves are unlikely to be better than +/- 10%. The parameter MALF1 is shown as an indicator on many of these curves, but importantly, it is not used to create the curves, these being formed from data independent to that provided in Doyle (2013).

Histogram of low flow periods

The 2013 hydrological report provides a graph of the length of time that the river will remain in a state of residual flow immediately below the intake. This was updated as **Figure 3** as a 2013 – 2024 comparison, using the scenario of 23 m^3/s being taken. This time, the figure has been created with a log scale on the vertical axis to allow better visibility of the periods residual flow occurs for longer, these being more critical than the short periods. It can be seen that there are generally more short periods of residual flow apparent, and less long periods compared to the 2013 analysis.

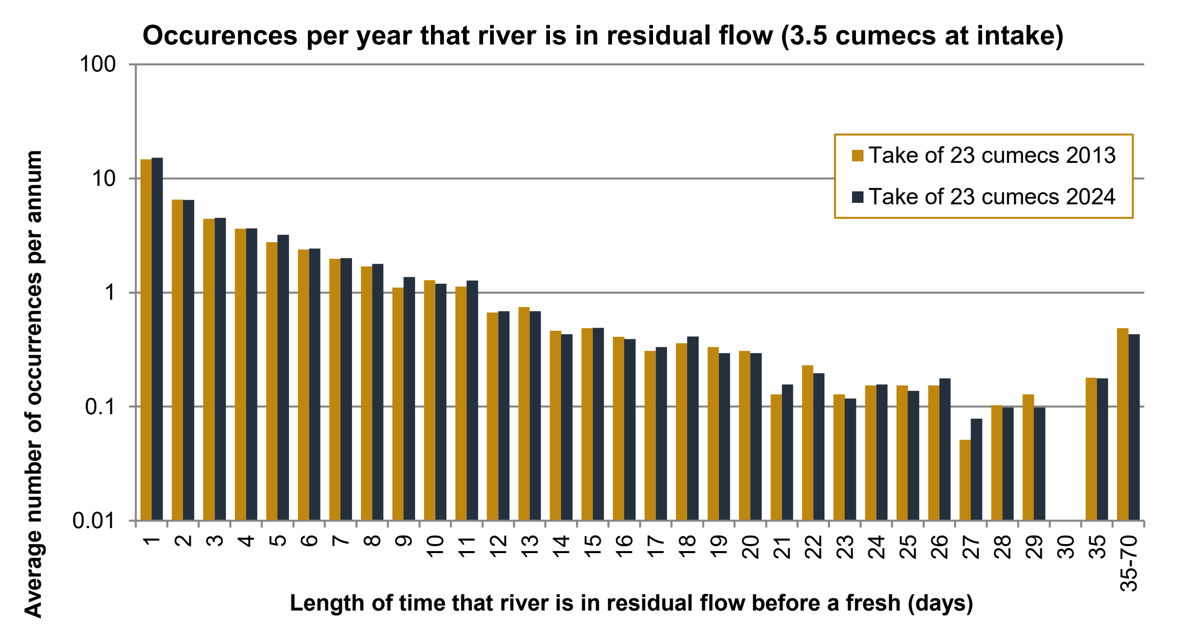

Figure 3 – Comparison of histograms showing frequency of residual flow periods before a fresh occurs (2013 analysis versus 2024 analysis)

Correction: Description of flood duration

There is one minor correction to make to the 2013 report. The last sentence of section 8.3 (2013 report) concludes that “there are on average 42 floods or freshes per annum greater than 30 cumecs, the average interval between these peaks is 8.6 days, and the average flood duration is 41 hrs.”

When this analysis was run again for the period 1973 – 2013, the average flood duration was found to be 55 hrs. The reason for the incorrect number provided in the 2013 report was due to the analysis being run on data at the Kiwi Flat flow recorder, not at the proposed intake. Using the full period from 1973 – 2024, the following statement is true:

There are on average 43 floods or freshes per annum greater than 30 cumecs, the average interval between these peaks is 8.4 days, and the average flood duration is 55 hrs.

Note that in the 2013 report, the term ‘cumec’ was used instead of the unit m^3/s. The two are interchangeable.

APPENDIX I – REFERENCES

AusHydro. (2025): Waitaha Hydro Project – Downstream Flow Modelling, May 2025

Chinn, T.J. (2001): *Distribution of the glacial water resources of New Zealand*. Journal of Hydrology (NZ) 40(2), pp 139-187

Doyle (2013) *The hydrology of the Waitaha Catchment*, Report for Electronet Services Ltd, September 2013.

Hicks, D.M. (2013): *Sediment investigations relating to a proposed HEP Scheme on the Waitaha River.* NIWA Client Report No. CHC2013-063

McKerchar. A.I,; Pearson, C.P. (1989): *Flood frequency in New Zealand*. Pub No. 20, Hydrology Centre, DSIR, Christchurch

Ministry for the Environment (2024): Aotearoa New Zealand climate projections, https://environment.govt.nz/facts-and-science/climate-change/climate-change-projections/

NIWA (2013): See: www.niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/seven-station-series-temperature-data (accessed 17 Sept 2013)

Renwick, J., Mladenov, P., Purdie, J., McKerchar, A., Jamieson, D. (2010): "*The effects of climate variability and change upon renewable electricity in New Zealand*. In: Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives". Nottage, R.A.C., Wratt, D.S., Bornman, J.F., Jones, K. (eds). New Zealand Climate Change Centre, Wellington, pp 70 - 81

Willsman, A.; Chinn, T.; Lorrey, A. (2012): *New Zealand Glacial Monitoring: End of summer snowline survey 2011. NIWA Client Report No. CHC2012-052*