The Hydrology of the Waitaha Catchment

A report for Electronet Services Ltd
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Measuring the flow in the Waitaha Gorge, Sept 2012
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1 Introduction

This report summarises hydrological information from within and around the Waitaha Catchment, as part of an investigation into the Waitaha Hydro Scheme (the Scheme) proposed by Westpower on the Waitaha River at the bottom of Kiwi Flat. The Scheme will take water from the bottom of Kiwi Flat and transfer it via a tunnel to a powerhouse situated below Morgan Gorge.

Flow information has been collected since March 2006 on the Waitaha River at the top of Kiwi Flat. Additional flow information has been collected by NIWA at Ivory Lake at the head of the catchment, and at the State Highway Bridge at the foot of the catchment. Further data has been sourced from neighbouring catchments with flow and rainfall recorders. Strong relationships exist between Waitaha flow and flow from the nearby Hokitika and Whataroa Catchments. These allow estimates of long term flow statistics to be made for the Waitaha site. These statistics can be used with confidence for assessing energy potential and environmental effects.

Further work has been done to quantify flow in the Whirling Waters tributary relative to the mainstem of the Waitaha River. Along with the continuous flow record from the top of Kiwi Flat, this information is needed to derive flows at the location of the Scheme intake at the bottom of Kiwi Flat.

Extreme rainfall occurs at the head of the Waitaha River with a number of New Zealand record rainfalls having occurred in this location. The annual rainfall is high by World standards, and is predicted to increase with climate change. Around 8.6% of the catchment (as measured at the flow recorder) is under permanent ice cover. This storage is released as meltwater in warmer months, providing reliable spring and summer flows. These key aspects provide a flow regime which allows good quantities of electricity to be generated on an annual basis. The same glacial features that provide reliable flow in warmer months, do however result in flows that drop to very low levels for short periods over winter.

A number of analyses are presented which have been used in various ecological, landscape and recreational reports on the Scheme.

Considerable amounts of sediment are moved down the Waitaha River during floods, and this is described in a separate NIWA report.
2 Catchment Description

The Waitaha River is located 38 km south of Hokitika and reaches from the West Coast to the Main Divide, with a total catchment area of 223 km². The Scheme is situated in the upper half of the catchment and utilises water from 117 km². Figure 1 shows the Kiwi Flat area, the Whirling Waters tributary and the location of the proposed powerhouse, with the Waitaha River draining to the left of the image.

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 other side of the divide from the Waitaha is the Cropp Valley, where extensive hydrological monitoring has been carried out for 33 years. This location holds a number of New Zealand rainfall records, including the greatest 12 month rainfall (18,442 mm), the greatest 30 day rainfall (3,800 mm), the greatest 24 hour rainfall (758 mm), and the greatest hourly rainfall (134 mm). The average annual total is among the highest yearly rainfalls in the World.

The elevation at the proposed intake is 238 m, and the catchment rises to around 2,200 m at its head. 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.

Figure 1 - 3D map of the Kiwi Flat area, looking upstream and east.
2.1 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. One small lake exists in the catchment, and has little effect on flows at Kiwi Flat.

The seasonal effect can be seen 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 cumecs 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 cumecs, 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 cumecs. 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 cumecs, in March they are 16.0 cumecs, while in July they are 8.2 cumecs.

Floods occur throughout the year every 8.6 days on average and it is typically around 2 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.
3 Flow and Rainfall information

The Scheme is 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.

3.1 Flow sites available for use in this study

Figure 2 shows the location of the main flow sites used in this report to derive data. The red straight lines indicate the approximate catchment boundaries for these sites.

Figure 2 - Location of the catchments with flow records used in this study
3.1.1 Cropp and Ivory

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 and was the centre of some intensive glaciology studies in the 1970’s. Rainfall and flow information was 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.

3.1.2 Hokitika

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 has 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.

3.1.3 Whataroa

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.

3.1.4 Poerua

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.

3.1.5 Amethyst

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.
3.1.6 Lower Waitaha

Flow information was measured from 1977 to 1984 on the Waitaha 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.

3.1.7 Waitaha at Kiwi Flat

As part of the Scheme, a flow recorder has operated on the Waitaha River at Kiwi Flat since March 2006, and 6 years of record up until April 2012 have been used in this study.

Note: While further information past April 2012 now exists, the majority of analyses carried out by various ecological experts occurred in mid 2012, and the hydrological statistics provided to these studies have been ‘frozen’ to avoid any confusion that may result from slightly different values being shown in different reports. A recent check analysis was carried out which confirms that flow statistics calculated with data past April 2012 have barely changed.

Table 1 - Flow information in the Waitaha locality

<table>
<thead>
<tr>
<th>River</th>
<th>Site</th>
<th>Catchment Area (km²)</th>
<th>Currently operating?</th>
<th>Average flow expressed as mm of rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropp</td>
<td>Gorge</td>
<td>12.2</td>
<td>No</td>
<td>11,720</td>
</tr>
<tr>
<td>Hokitika</td>
<td>Colliers Creek</td>
<td>352</td>
<td>Water level only now</td>
<td>8,930</td>
</tr>
<tr>
<td>Hokitika</td>
<td>Gorge</td>
<td>367</td>
<td>Yes</td>
<td>8,820</td>
</tr>
<tr>
<td>Waitaha</td>
<td>SH Bridge</td>
<td>223</td>
<td>No</td>
<td>8,120</td>
</tr>
<tr>
<td>Waitaha</td>
<td>Top of Kiwi Flat</td>
<td>90</td>
<td>Yes</td>
<td>9,900*</td>
</tr>
<tr>
<td>Amethyst</td>
<td>Road Bridge</td>
<td>16</td>
<td>No</td>
<td>6,600</td>
</tr>
<tr>
<td>Poerua</td>
<td>Lower Gorge</td>
<td>148</td>
<td>No</td>
<td>7,130</td>
</tr>
<tr>
<td>Whataroa</td>
<td>SH Bridge</td>
<td>445</td>
<td>Yes</td>
<td>9,410</td>
</tr>
</tbody>
</table>

*Approximate values only due to the lack of accurate flood flow information
3.2 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 from 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 Waitaha valley), Ivory Glacier, Moonbeam Hut above Kiwi Flat, and at Harihari.

Table 2 - Rainfall information in the Waitaha locality

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

Note: Confidence in data quality relates to environmental conditions rather than operator expertise.
3.3 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 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 has 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). Flow gaugings have been measured as low as 4.5 cumecs and as high as 32 cumecs. This enables the flow range up to 40 cumecs to be calculated reliably. Ten rating changes have been observed over 6 years. In addition, 43 flow measurements have been completed for the Whirling Water tributary and 6 measurements at the State Highway Bridge.

A plot of the information collected during this period is shown in Figure 3. This plot is useful to observe the difference between summer and winter flows in the Waitaha, with spring and mid-summer flows consistently above 10 cumecs, usually peaking in December - January. The winter flows however, were often below this level.

*Note:* 1 cumec is 1 m$^3$/s or 1,000 litres per second (l/s).

![Figure 3 - Flow data from 2006 – 2012 for Waitaha at top of Kiwi Flat](image-url)
4 Comparison with nearby flow sites

To derive a longer flow record at Waitaha, it was necessary to derive relationships with neighbouring flow sites. This can be done 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.

Either method can easily be applied using rating curves in the hydrological software ‘TIDEDA’. This in turn provides the opportunity to merge from one relationship to another over time, such as when there are seasonal changes occurring at two sites to differing degrees.

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 ($r^2 = 0.82$) and the Whataroa Rivers ($r^2 = 0.86$).

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 cumecs) was graphed against the same exceedance from both the independent flow sites. This information is shown in Figure 4 for the flows of interest.

![Figure 4 - Comparison of flow duration curves](image)

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 5 shows the seasonal relationships between the Waitaha and Whataroa Rivers, and Figure 6 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.

Figure 5 - Seasonality of relationship between Waitaha and Whataroa flows

Figure 6 - 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, and 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 6. This has a good physical reason for occurring – the Hokitika catchment has much less permanent snow and 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 2 month transition period. This change in relationship was applied using rating curves in the TIDEDA software.

One single linear relationship (blue line, Figure 5) was applied to derive Waitaha flow from Whataroa flow.

4.1 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:

1. Where data existed for both the Hokitika and Whataroa Rivers, an average of the data derived from these two locations was used.
2. If a gap existed, then data from the other single site was used to fill the record.
3. 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.

4.2 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 7. 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 6 years from 2006. The plot can be seen in Figure 8, 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 good job of estimating flow for the Waitaha at Kiwi Flat, and can be used with confidence to derive long term flow statistics.
Figure 7 - Measured flow data compared to estimated flow data for 2011

Figure 8 - Flow duration curves of actual Waitaha flow versus estimated Waitaha flow
5 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 9.

![Whirling Waters vs Waitaha flow](image)

**Figure 9 - 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.
6 Flow statistics for the Waitaha River

6.1 Top of Kiwi Flat

As described in Section 4, flow data has been collected at Kiwi Flat since 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 3 shows low flow statistics relevant to decisions regarding residual flow levels. These were generated in the TIDEDA software using the Generalised Extreme Value (GEV) distribution.

**Table 3 - Low flow statistics at top of Kiwi Flat (GEV distribution)**

<table>
<thead>
<tr>
<th>Return Period</th>
<th>1 day average flow (cumecs)</th>
<th>7 day average flow (cumecs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Annual Low Flow</td>
<td>5.554</td>
<td>5.995</td>
</tr>
<tr>
<td>5 year low flow</td>
<td>4.458</td>
<td>4.680</td>
</tr>
<tr>
<td>10 year low flow</td>
<td>4.198</td>
<td>4.401</td>
</tr>
<tr>
<td>20 year low flow</td>
<td>4.021</td>
<td>4.213</td>
</tr>
<tr>
<td>50 year low flow</td>
<td>3.851</td>
<td>4.036</td>
</tr>
</tbody>
</table>

The average flow for the Waitaha at the top of Kiwi Flat is 28.3 cumecs, and the median flow is 16.0 cumecs

Figure 10 gives the expected long term flow duration curve. The blue line represents the flow distribution as calculated from the 6 years of actual Kiwi Flat data, and the red line is from the 39 years of synthetic data. This shows that the past 6 years were not representative of the flow conditions over the past 39 years. The 39 year plot shows greater flows were experienced for a given percentage of time than were for the past 6 years, except that the very lowest flows were less than those seen over past 6 years. This effect is further explained in Section 10.
To accurately quantify values in the flow distribution if needed for further calculations, Table 4 gives the same information as Figure 10.

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

<table>
<thead>
<tr>
<th>Exceedance percentiles</th>
<th>Site 901039 Waitaha synthetic flow at Kiwi Flat</th>
<th>From 19-Apr-1973 00:00:00 to 18-Apr-2012 24:00:00</th>
<th>Flow m³/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1163.30</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>249.63</td>
<td>179.09</td>
<td>137.62</td>
</tr>
<tr>
<td>20</td>
<td>109.43</td>
<td>90.80</td>
<td>77.78</td>
</tr>
<tr>
<td>30</td>
<td>68.56</td>
<td>55.78</td>
<td>51.30</td>
</tr>
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<td>40</td>
<td>61.44</td>
<td>51.30</td>
<td>47.54</td>
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<td>50</td>
<td>55.78</td>
<td>47.54</td>
<td>44.40</td>
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<td>60</td>
<td>51.30</td>
<td>44.40</td>
<td>41.81</td>
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<td>70</td>
<td>44.40</td>
<td>41.81</td>
<td>39.55</td>
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<td>41.81</td>
<td>39.55</td>
<td>37.56</td>
</tr>
<tr>
<td>90</td>
<td>39.55</td>
<td>37.56</td>
<td>35.81</td>
</tr>
<tr>
<td>100</td>
<td>37.56</td>
<td>35.81</td>
<td>34.22</td>
</tr>
</tbody>
</table>

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

Note: Above 100 cumecs, the flow distribution shown above should only be used as an indication. Maximum flows are estimates only.
6.2 Bottom of Kiwi Flat

Flow data is required for the Scheme at the bottom of Kiwi Flat, 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 km² 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 Figure 9 was used to predict Whirling Waters flow from Waitaha flow, and based on visual estimates and the knowledge gained from Whirling Waters gaugings, an allowance was made for the other tributaries as well. The following equation was derived to calculate flow at the bottom of Kiwi Flat (all units are cumecs):

\[
\text{Waitaha flow at bottom of Kiwi Flat} = (1.209 \times \text{Kiwi Flat Recorder Flow}) + 0.476
\]

Using this, a dataset was generated for the Scheme intake location, and flow statistics and other outputs for the bottom of Kiwi Flat were able to be calculated. Table 5 shows low flow statistics relevant to decisions regarding residual flow levels (again using the GEV distribution), and Figure 11 gives the expected long term flow duration curve.

To accurately quantify values in the flow distribution if needed for further calculations, Table 6 gives the same information as Figure 11.

Table 5 - Low flow statistics for Waitaha at bottom of Kiwi Flat (GEV distribution)

<table>
<thead>
<tr>
<th>Return Period</th>
<th>1 day average flow (cumecs)</th>
<th>7 day average flow (cumecs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Annual Low Flow</td>
<td>7.085</td>
<td>7.572</td>
</tr>
<tr>
<td>5 year low flow</td>
<td>5.934</td>
<td>6.210</td>
</tr>
<tr>
<td>10 year low flow</td>
<td>5.568</td>
<td>5.812</td>
</tr>
<tr>
<td>20 year low flow</td>
<td>5.304</td>
<td>5.529</td>
</tr>
<tr>
<td>50 year low flow</td>
<td>5.039</td>
<td>5.249</td>
</tr>
</tbody>
</table>

The average flow for the Waitaha at the bottom of Kiwi Flat is 34.6 cumecs, and the median flow is 19.7 cumecs.
Figure 11 - Flow duration curve for Waitaha at bottom of Kiwi Flat

Table 6 - Flow distribution table for Waitaha at bottom of Kiwi Flat

<table>
<thead>
<tr>
<th>Exceedance percentiles</th>
<th>Site 901059 Waitaha synthetic at bottom of Kiwi Flat</th>
<th>From 19-Apr-1973 00:00:00 to 18-Apr-2012 24:00:00</th>
<th>Flow m³/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1406.90 302.21 216.93 166.82 132.75 110.22 94.49 83.34 74.73 67.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>62.48 57.94 51.01 48.28 45.88 43.76 41.84 40.15 38.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>37.22 36.00 34.86 33.80 32.85 31.96 31.16 30.42 29.71 29.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>28.40 27.80 27.20 26.65 26.12 25.60 25.10 24.63 24.18 23.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>23.35 22.94 22.53 22.14 21.77 21.41 21.05 20.70 20.38 20.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>19.75 19.44 19.14 18.84 18.53 18.24 17.95 17.67 17.41 17.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>16.87 16.61 16.36 16.09 15.84 15.59 15.32 15.07 14.82 14.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>9.05 8.78 8.52 8.26 8.02 7.77 7.50 7.21 6.88 6.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>4.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Note: Above 100 cumecs, the flow distribution shown above should only be used as an indication. Maximum flows are estimates only.
6.3 Waitaha at State Highway Bridge

Flow information was collected at the very bottom of the Waitaha catchment at the State Highway Bridge for 7 years from 1977. The catchment area at this location is 223 km² compared to 117 km² at the bottom of Kiwi Flat.

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 relatively short lived. 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 12. The kink at the bottom of the curve appears to be the result of one unusual rating curve in the flow record.

![Flow duration curve for Waitaha at State Highway Bridge](image)

**Figure 12 - Flow duration curve for Waitaha at State Highway Bridge**

Other flow statistics are shown in Table 7, and are compared with the upper catchment. The State Highway Bridge values have been calculated from only 7 years of record.

<table>
<thead>
<tr>
<th>Location</th>
<th>MALF 7day (cumecs)</th>
<th>Median flow (cumecs)</th>
<th>Average flow (cumecs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waitaha at Top of Kiwi Flat</td>
<td>6.0</td>
<td>16.0</td>
<td>28.3</td>
</tr>
<tr>
<td>Waitaha at bottom of Kiwi Flat</td>
<td>7.6</td>
<td>19.7</td>
<td>34.6</td>
</tr>
<tr>
<td>Waitaha at State Highway Bridge</td>
<td>9.7</td>
<td>29.6</td>
<td>56.9</td>
</tr>
</tbody>
</table>
## 7 Flood Flows

Flood estimates are required for the design of the Scheme intake. No flood flows have been physically measured at Kiwi Flat, therefore neighbouring catchments were analysed for their flood statistics using the standard approach in McKerchar and Pearson (1989). From these, estimates were made for the Waitaha at the bottom of Kiwi Flat.

Mean annual flood 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 $Q_{bar}/A^{0.8}$ 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 8.

Note: the synthetic flow data created in Section 4 and the flow data collected at Kiwi Flat should not be compared to the flood statistics below. The actual data collected has only been measured to 32 cumecs, and the synthetic data is derived from this with flows accurate up to 40 cumecs.

### Table 8 – Flood statistics for the Waitaha River at the bottom of Kiwi Flat

<table>
<thead>
<tr>
<th>Average recurrence Interval</th>
<th>Flow (cumecs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Annual Flood</td>
<td>812</td>
</tr>
<tr>
<td>20 years</td>
<td>1,177</td>
</tr>
<tr>
<td>50 years</td>
<td>1,299</td>
</tr>
<tr>
<td>100 years</td>
<td>1,380</td>
</tr>
<tr>
<td>200 years</td>
<td>1,518</td>
</tr>
<tr>
<td>500 years</td>
<td>1,665</td>
</tr>
</tbody>
</table>
8 Analyses for environmental reports

A variety of hydrological analyses are required as inputs to other studies, in particular freshwater ecological modelling, landscape and recreational values. Flow data has been collected at Kiwi Flat since 2006, and correlations with the Hokitika and Whataroa Rivers have enabled a dataset of Waitaha flow to be constructed going back to 1973. All environmental analyses relating to the consultation and subsequent applications for the hydro project use the hydrological data for the period 1973 – 2012.

8.1 Residual flow conditions between the proposed intake and powerhouse

To determine the effect of the Scheme on river conditions downstream of the intake and above the powerhouse, the following three scenarios were modelled:

1. A take of 19 cumecs with a residual flow of 3.5 cumecs (at the Scheme intake)
2. A take of 21 cumecs with a residual flow of 3.5 cumecs (at the Scheme intake)
3. A take of 23 cumecs with a residual flow of 3.5 cumecs (at the Scheme intake)

8.2 Flow duration curves of residual flow

The percentage of time (and hence days per annum) that the river below the intake and upstream of the powerhouse will be in a state of residual flow can be calculated using a flow duration curve of this residual flow data. Figure 13 shows the flow duration curves at the Scheme intake of the natural flow data (blue), the residual flow from a take of 19 cumecs (red), the residual flow from a 21 cumec option (green), and the residual flow from a 23 cumec option (purple/pink). The vertical axis shows the flow in cumecs, and the horizontal axis shows the percentage of time that each flow has been exceeded. All plots apart from the natural flow plot assume a residual flow of 3.5 cumecs.

As an example, the natural flow of the river at the Scheme intake is above 4.8 cumecs for 100% of the time, above 11.8 cumecs for 80% of the time, and above 23.3 cumecs for 40% of the time. From this, it can also be said that at the Scheme intake a flow range of 11.8 – 23.3 cumecs occurs for 40% of the time (80% minus 40%).
The following data can also be taken from the graph in Figure 13, for the three possible levels of take:

- For a take of 19 cumecs (red), residual flow at the Scheme intake will occur for 57% of the time (100% minus 43%)
- For a take of 21 cumecs (green), residual flow at the Scheme intake will occur for 62% of the time (100% minus 38%)
- For a take of 23 cumecs (purple/pink), residual flow at the Scheme intake will occur for 66% of the time (100% minus 34%)

![Graph showing residual flow percentages for different take levels.](image)

**Figure 13 - Percentage of time residual flow occurs for takes of 19, 21 and 23 cumecs (using all months)**

The percentage of time in a state of residual flow can also be converted to days per annum. This data is summarised in Table 9 below:

**Table 9 - Time spent in a state of minimal residual flow for takes of 19, 21 and 23 cumecs**

<table>
<thead>
<tr>
<th>Level of take (residual flow is 3.5 cumecs)</th>
<th>Percent of time river in residual flow state at the Scheme intake</th>
<th>Days per annum river in residual flow state at the Scheme intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 cumecs</td>
<td>57%</td>
<td>208</td>
</tr>
<tr>
<td>21 cumecs</td>
<td>62%</td>
<td>226</td>
</tr>
<tr>
<td>23 cumecs</td>
<td>66%</td>
<td>241</td>
</tr>
</tbody>
</table>
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 below the intake.

2. The residual flow of 3.5 cumecs 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 cumecs, hence the residual flow below Glamour Glen is at least 4.2 cumecs for 50% of the time. Figure 14 shows the flow in the Waitaha River from the top of Kiwi Flat to just downstream of the powerhouse. 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 4.8 km mark which is the powerhouse location. At this point the flow 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 15 shows data for the summer months of December, January and February only. The effect of the Scheme during these months is much reduced.

![Flow in Waitaha River during Power House operation](image)

**Figure 14 - Flow in Waitaha River during operation of the Scheme**
Figure 15 - Percentage of time residual flow occurs for takes of 19, 21 and 23 cumecs (using summer months only)
8.3 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 16 shows a histogram created from the 39 year dataset. The horizontal axis shows the length of time that the river is in residual flow below the intake before a fresh occurs, while the vertical axis shows the average number of times per annum each of these time periods occurs. Scenarios are shown for takes of 19, 21 or 23 cumecs. A residual flow of 3.5 cumecs is assumed in each case.

![Histogram showing frequency of residual flow periods before a fresh occurs](image)

Figure 16 - Histogram showing frequency of residual flow periods before a fresh occurs

It can be seen that 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 3 days, and about 1 occurrence a year when the residual flow state lasts 10 days. An increased take results in slightly more occurrences for any given duration of residual flow. The random nature of hydrological processes means the plot is not smooth from one period to another. For instance the take of 21 cumecs shows the greatest frequency for residual flow periods of one day or less, but the least frequency for flow periods lasting 3 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 39 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 cumecs, the average interval between these peaks is 8.6 days, and the average flood duration is 41 hrs.
8.4 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 10 give FRE3 values for the natural flow at the bottom of Kiwi Flat, and for flow below the intake for the three possible take options of 19, 21 and 23 cumecs. For these analyses a 5 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.

<table>
<thead>
<tr>
<th>Flow scenario</th>
<th>FRE3 value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural flow at intake</td>
<td>26.2</td>
</tr>
<tr>
<td>With a take of 19 cumecs</td>
<td>24.2</td>
</tr>
<tr>
<td>With a take of 21 cumecs</td>
<td>23.8</td>
</tr>
<tr>
<td>With a take of 23 cumecs</td>
<td>23.6</td>
</tr>
</tbody>
</table>
9 The influence of snow and ice on Waitaha flows

As is typical for rivers draining the Southern Alps, winter snow accumulation and summer snow melt strongly influence the Waitaha’s runoff regime. Mean monthly flows show a significant cycle, with high summer values and low winter values. This is at variance with typical electricity loads, which typically are higher in winter and lower in summer. This mismatch in supply and demand places considerable value on seasonal water storage in the southern lakes.

9.1 The effect of a receding snowpack

Of the 90 km² catchment above the Kiwi Flat flow recorder, 7.7 km² 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 cumecs, while during winter the reduction in flow is generally 1 - 2 cumecs. While the water released from snow or ice is not a significant part of the total precipitation for the river, the fact that the meltwater occurs during otherwise drier periods gives it a value in excess of its contribution to the water balance of the catchment.

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. At the end of 2011, there had been 6 successive years of neutral or loss conditions (Willsman, 2012). If this trend continues, there will be a period of increased summer flow as the glaciers decline in size, until the glaciers cease to exist. Chinn (2001) estimated there was 108 Mm³ of ice in the Waitaha Catchment. To give this some perspective, if we assume (say) the glaciers melt entirely over 30 years, and the melting occurs evenly over the warmer 6 months, then the increase in summer flow would be 0.23 cumecs. This is not especially significant to the Scheme, especially as some of this would not need to be used during times of higher flows.

In comparison, Chinn’s paper reported that the much larger Tasman Glacier in the Waitaki River Catchment contributed 4.3 cumecs during summer.
10 Climate change

International science is in general agreement that warming of the climate is likely as the result of man-made emissions to the atmosphere, and rising temperatures are evident in New Zealand temperature records. NIWA’s long-running ‘seven-station’ series shows New Zealand’s average annual temperature has increased by about 1 °C over the past 100 years (NIWA, 2013).

10.1 Change in rainfall resulting from climate change

Advice contained in the Ministry for the Environment (2008) report, was that precipitation for South Westland between 2008 and 2040 will increase by some 5%, and by 2090 it should increase by nearer to 8%. In addition, the seasonality of precipitation would change, with more rain in autumn, winter and spring, but the summer months will remain similar to now. Rising temperatures imply that less winter snow accumulation is likely and that greater winter runoff may be expected.

The effect on the average flow in the Waitaha River will be an increase which is slightly less than the 5% (by 2040) and 8% (by 2090) precipitation predictions in the Ministry for the Environment report. It is only possible to talk in broad terms about the effect this will have on residual flows. More rain in general should shorten the overall time that the river will be in a state of residual flow below the intake. However, if this rain fell in storms that were larger in size but further apart in time the effect on residual flow could be detrimental.

In summary, the climate change influences of more precipitation and enhanced runoff, especially in winter, appear to be a favourable influence for hydroelectric power generation on rivers draining the Southern Alps.

10.2 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 6 years of hydrological data collected on Kiwi Flat was 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 earlier in Section 6.1.
The 6 year flow record has been adjusted by the use of correlations (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 can therefore be ignored.
11 Bibliography


12 Acknowledgements

Alistair McKerchar reviewed this report and made a valuable contribution to sections 9 and 10. Andrew Willsman and John Porteous have both been helpful to the project, providing information relating to glaciers and downloading data during the IFIM study. Kathy Walter has promptly supplied FoRST funded data from the National Hydrological Archive. Meridian Energy partially fund the Whataroa River flow site and they have generously allowed the use of this information. West Coast Regional Council staff provided advice on local hydrology issues and have obligingly updated their website when asked.
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumec</td>
<td>Cubic metres of river flow per second, or m$^3$/s. One cumec is 1,000 litres/second.</td>
</tr>
<tr>
<td>Flow duration curve</td>
<td>A plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest.</td>
</tr>
<tr>
<td>Flow distribution table</td>
<td>A flow duration curve expressed as a table</td>
</tr>
<tr>
<td>Fresh</td>
<td>A small but visible increase in flow or a minor flood, often used to describe a break in the state of low flow, or a ‘freshening’ of the river state.</td>
</tr>
<tr>
<td>FRE3</td>
<td>The number of floods per year that exceed three times median flow.</td>
</tr>
<tr>
<td>GEV</td>
<td>Generalised Extreme Value – a statistical distribution used to derive hydrological statistics</td>
</tr>
<tr>
<td>Gumbel</td>
<td>A statistical distribution used to derive hydrological statistics</td>
</tr>
<tr>
<td>Gauging</td>
<td>A flow gauging is a near instantaneous measurement of flow carried out by measuring river velocities across a section of river. A gauging is used to derive a rating curve.</td>
</tr>
<tr>
<td>MALF</td>
<td>The Mean Annual Low Flow is calculated by finding the lowest instantaneous flow in each year of record, and determining the arithmetic mean of all these values.</td>
</tr>
<tr>
<td>MALF (1 day)</td>
<td>The one day Mean Annual Low Flow is calculated by finding the lowest flow averaged over a 24 hour period in each year of record, and determining the arithmetic mean of all these values.</td>
</tr>
<tr>
<td>MALF (7 day)</td>
<td>The seven day Mean Annual Low Flow is calculated by finding the lowest flow averaged over a 7 day period in each year of record, and determining the arithmetic mean of all these values.</td>
</tr>
<tr>
<td>Median flow</td>
<td>The river flow which occurs 50% of the time, that is, half of the time it is below this value, and half above.</td>
</tr>
<tr>
<td>Rating curve</td>
<td>The relationship between water level and flow which is used to derive a continuous flow record from a continuous water level record.</td>
</tr>
<tr>
<td>Residual flow</td>
<td>The flow retained in the river between the intake and powerhouse following abstraction.</td>
</tr>
<tr>
<td>Reach</td>
<td>A section of river</td>
</tr>
<tr>
<td>Take</td>
<td>The water ‘taken’ from the river at the intake prior to being returned from the powerhouse</td>
</tr>
<tr>
<td>TIDEDA</td>
<td>Software used to store and analyse hydrological data</td>
</tr>
</tbody>
</table>