Falls Dam Inflows

1975 - 2012

Prepared for

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1. Introduction

In April 2002, Raineffects Limited provided a report to Pioneer Generation titled "Falls Dam Inflows. The Derivation of Falls Dam Inflows from an upstream Measuring Site on the Manuherikia River". At the time Pioneer Generation Ltd was investigating the possibility of a combined irrigation/power scheme into Falls Dam which has subsequently been installed.

OPUS International Consultants Ltd (OPUS) is now investigating the possibility of increasing storage in Falls Dam to provide for extended areas of irrigation and increased reliability of supply to the schemes for which it provides storage. Part of its investigation includes testing the reliability of the storage for irrigation water provision in any season. To do this, OPUS requires a long, continuous, inflow series into Falls Dam to properly test this reliability.

There are no inflow records for Falls Dam so any inflow series is of necessity a derived flow series utilising whatever information is available. OPUS has requested that Raineffects Ltd provide this inflow series along with a report describing the processes and analyses utilised in deriving this inflow series. The report is to include a review of losses from the Falls Dam inflows including dam seepage, evaporation from the lake surface and losses due to the Mt. Ida race abstractions from the catchment upstream of Falls Dam for the Hawkdun-Idaburn irrigation scheme. Losses to groundwater are not considered here because it is assumed that Falls Dam has been constructed on bedrock wihich would force any shallow groundwater to the surface again and would be part of the Falls Dam inflows. In addition, a review of potential impacts of predicted climate change due to anthropogenic global warming is to be included both in terms of whether it has already started to occur and what the situation may be by 2090, the timeframe that is included on the Ministry for the Environment Climate Change website.

The daily inflow record provided to Pioneer Generation Ltd in 2002 had a number of gaps due to missing record in the records used to derive that inflow series. For this analysis, the series is to be continuous which means that all gaps in existing records need to be filled and this will be achieved through derivation of flows using records from adjoining catchments that are mostly unaffected by upstream abstractions.

2. Available Flow Data

2.1 General

There are three main datasets which will be used in this analysis for generation of an inflow series from 1975 to 2010. These include the recent data from 75251 Manuherikia at Downstream of Forks, 75244 Falls Dam at Dam (lake level), and 75243 Manuherikia at Below Falls Dam. A discussion on the accuracy/reliability of these three sites was included in the 2002 Raineffects Ltd report so only a summary of this will be included here. However a brief review of the earlier Manuherikia at Downstream Forks data will be provided here.

2.2 Site 75244 Falls Dam at Dam

This is the lake level record. Records for this site began on 17 August 1999 and the record was collected by NIWA until December 2003. Since then, Pioneer Generation Ltd has collected the data.

There were issues with the data collected by NIWA. There was some misreading of levels when data was downloaded from the sites and this in turn resulted in at least 1 year of much higher than actual levels being stored in the data files. This has now been addressed by NIWA and the records now seem to be more likely. Another issues with all data collected here is that there are readings which are well above the level of the morning glory spillway. When processing the data for use in this study, the maximum level assumed to be possible was the level of the spillway so when readings showed that the lake level was above the level of the spillway, the level was readjusted to the spillway level and the inflows were assumed to be equal to the outflows measured at the site 75243 Manuherikia at Below Falls Dam.

The Pioneer Generation record began in November 2003 and is continuous through to present. Both the NIWA and Pioneer Generation data were collected at 15 minute intervals. For this exercise average daily readings are sufficient. Given the issues Pioneer Generation have had with this data collection, I would recommend that its current data collection methods be reviewed and that backups of the data be held off-site so that if in future there is an issue with a computer, the data are guaranteed to still be available.

2.3 Manuherikia at Below Falls Dam

This record began on 3 February 1999 and continues to present. NIWA undertake the data collection at this site and there are no gaps in the record. There have been 13 rating changes identified at this site during the period with the highest and lowest gaugings being 36.775 m^3/s and 0.610 m^3/s respectively.

2.4 Manuherikia at Downstream of Forks (1975 – 1994 and 1998 - 2004)

This site is not required for inflow deviation for the recent data collection period (1999 – present) but is required to derive inflows for the period 1975 to 1993. This site has been installed and closed twice with the first record period being from May 1975 to December 1993 and the second from December 1998 to April 2004.

There are a number of gaps in the record from 1975 to 1993 which will need to be filled for a continuous inflow series into Falls Dam from 1975 to 1993 to be derived.

The latest installation was close to the original site with similar problems of many ratings due to an unstable riverbed. While there was good recording equipment installed the mobile riverbed has caused problems.

The recent record is probably more accurate than the older record because of better technology and improved data collection procedures but it will be shown later that lack of high flow gaugings at this site in the recent collection period may mean the higher stages of the rating may not be well defined.

The early part of this record (1973 – 1994) was collected by the Minstry of Works and its successors. Digital recorders were installed for the whole record but there are still gaps in it. Gaugings were conducted on a relatively regular basis (usually monthly) and both high and quite low flow measurements were made. The riverbed at the site is quite mobile so many ratings are included in the record period. There will be further discussion of this later in this report.

2.5 Other Data

There are other datasets used in this analysis including daily flow data for the Mt. Ida water race, flow records for Dunstan Creek at Gorge and flow data for Lindis at Lindis Peak.

2.5.1 Dunstan Creek at Gorge

This record will be used to fill gaps in the early Manuherikia downstream of Forks record from 1975 to 1994. The early Dunstan Creek site operated from March 1973 to April 1994. Initially it was operated by Ministry of Works staff but during the 1980's, the Otago Catchment Board and its successor the Otago Regional Council operated it until it closed in April 1994.

The record has many gaps throughout. Originally a digital recorder was installed here while the Monistry of Works operated it but after the Otago Catchment Board took it over, the record was measured on a chart recorder which is not known for its accuracy.

2.5.2 Lindis at Lindis Peak

This site opened in September 1976 and has operated continuously since then. The recording equipment used has always been the most accurate available at the time. Originally the Ministry of Works operated the site but now it is operated by NIWA Alexandra for Contact Energy Ltd and the Otago Regional Council. There are some gaps mainly in the early part of the record. Its accuracy should be good.

2.6 Potential Errors in Data Analysis due to Data Quality

The 2002 report discusses these errors so only a summary of that discussion is included here because the same errors apply.

Flow ratings at high and very low flows at most sites are not properly defined because gaugings have not been undertaken at these flows at most sites to confirm the ratings. This can result in underestimating or overestimating flows at these extreme ends of the ratings.

The frequency of rating changes in the river sites mean that there will be times rating changes occur that are not picked up due to the gauging frequency of once in 4-7 weeks. Some ratings are changed on the strength of 1 or 2 gaugings.

In the 2002 report, there was a discussion on the Mt. Ida Race abstraction. This is addressed later in this report but the losses to inflows to Falls Dam because of this abstraction are already incorporated in the lake level and Manuherikia at Below Falls Dam measurements. Recent records allow a better estimate of what flows are being abstracted. Improving race efficiencies in transporting the water into the Ida Valley and beyond are identified and discussed in Section 4.3 of this report and the implications for flows into Falls Dam due to this abstraction are discussed.

3. Falls Dam Inflow Calculation

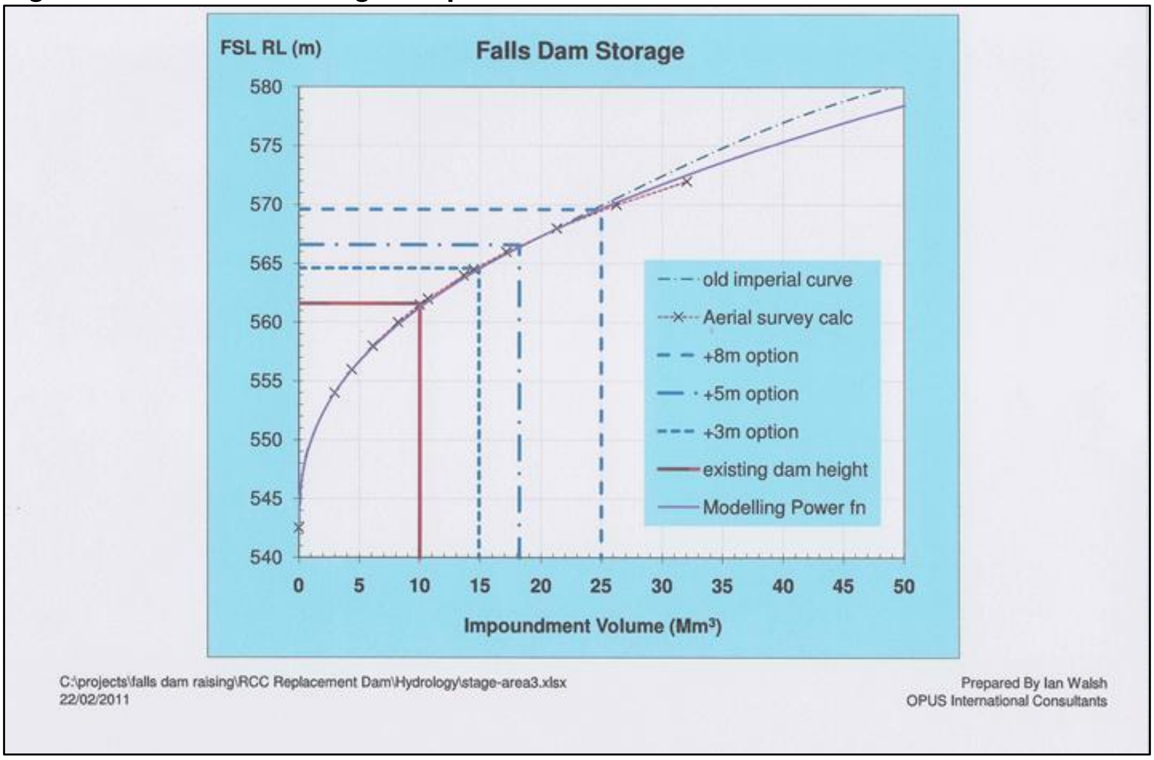
3.1 General

The inflow to Falls Dam record derived in the 2002 report was a synthetic record derived from a relationship between Falls Dam inflows and the records for the Manuherikia Downstream of Forks. The most recent part of the derived inflow record (2.5 years) was calculated directly by using Falls Dam levels and the outflows from Falls Dam measured at the Manuherikia at below Falls Dam site. For this updated series, a similar process was undertaken but there has been a number of changes in the records, the relationships between inflows and the Manuherikia Downstream of Forks and below Falls Dam data, and in the relationship between water level and storage in Falls Dam.

3.2 Falls Dam Storage

In the 2002 analysis, the relationship between Falls Dam level and storage (volume in cubic metres) was taken from an old Ministry of Works elevation/storage curve. OPUS has provided new elevation/storage and elevation/area relationships. The elevation/storage graph is provided below.

Figure 1. Elevation/Storage Graph for Falls Dam



The new relationships are:

Falls Dam Storage = 7200 (Falls Dam level -542.43)$^{2.47}$

The lake level/area curve has the relationship:

Lake Area = 2.47 (7200) (Falls Dam Level -542.54)$^{1.47}$

A daily record of water storage was calculated for the period of record from August 1999 to 2010 using the first equation.

3.3 Falls Dam Inflows August 1999 – December 2010

Using the available Falls Dam level and Manuherikia below Falls Dam records, an inflow record for Falls Dam for the period August 1999 to December 2010 (11.5 years) can be derived using the relationship:

Inflows = "Outflows" multiplied by the "Change in Storage".

3.4 Falls Dam Inflows April 1975 – December 1993

3.4.1 Relationship Derivation

The 2002 report described how a relationship was derived between Falls Dam Inflows and Manuherikia Downstream of Forks flows. This was calculated over the period 14 August 1999 to 31 December 2001. When this record was first used in the original 2002 report, the highest gauging was 11.929 m^3/s and the lowest 0.610 m^3/s. When the 2002 analysis was undertaken, the inflows derived during high flow periods when the lake was full using the simple formula

"Inflows = outflows plus the change in storage"

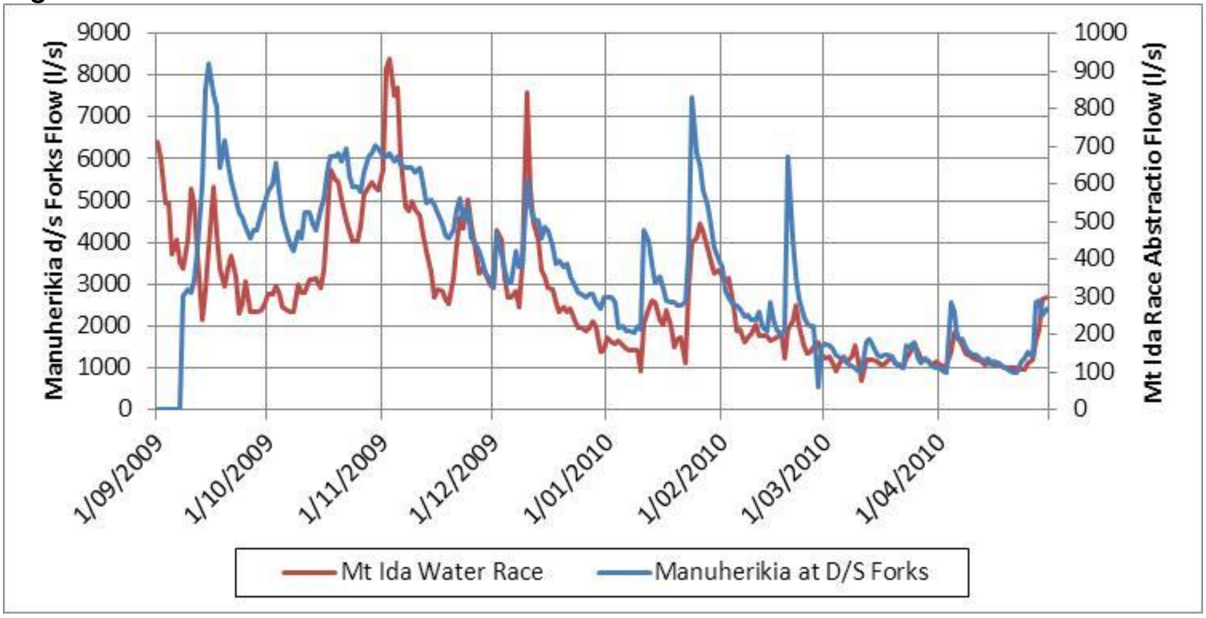
were consistent with a scaled version of the upriver flows at the Manuherikia at Downstream of Forks site. Using this relationship, it was possible to derive daily inflows for the full period of the Manuherikia at Downstream of Forks record.

For this latest analysis, the record available was 14 August 1999 to 14 April 2004. In the intervening time since the first analysis, a number of gaugings have been undertaken at the Below Falls Dam site including both high (36 cumecs) and low flow gaugings and this has considerably altered the ratings at this site. This change in ratings has resulted in there now being very poor correlation between the Downstream of Forks daily mean flows and derived Falls Dam inflows using all the data between the above two dates and even the limited dataset used in 2002. This is brought about by the changed flows at the Below Falls Dam site due to these rating changes while the ratings at the Forks site remain unchanged. This has led to extreme differences at high flows especially but also at low flows and these effectively destroy the correlation in spite of excluding data for the reasons given in the early report. These reasons include deleting data when there are obvious rating changes, deleting data when inflows to Falls Dam are less than measured flows at the Forks site and any data where it is obvious there is a rating or lake level problem or freezing in wintertime. An example of some of the high flow extremes is on 4/1/2000, the Forks flow was 8.795 cumecs, the Below Falls Dam flow 48.403 cumecs and the calculated inflow to Falls Dam 50.695 cumecs. Flows at the Forks site on 3 and 5 January 2000 were 6.35 cumecs and 9.621 cumecs respectively so it was not a timing issue. There are many such examples in the record from 1999 to 2004.

To ensure the data being correlated was as correct as possible, it was decided that the data needed to be corrected for irrigation abstraction by the Mt Ida Water Race scheme and these abstractions needed to be added back into the derived record. Once these data were corrected, the process of eliminating data which did not meet a set of criteria for likely differences in mean flows between the Forks site and calculated inflows could occur.

A review of the Race abstraction data provided (2007 - 2011) showed that the abstractions generally related to available flow and this is consistent with previous descriptions of how the Race operates. Figure 2 shows the calculated Falls Dam daily mean inflows compared to measured water abstractions for the Mt Iida Water Race scheme for the 2009/2010 irrigation season. The patterns are very similar so the assumption that abstraction for this scheme is related to water availability is assumed to be valid. The abstraction data which are discussed in more detail in Section 4.3 of this report showed that the mean abstraction during September to April in the 4 seasons of available record was 390 l/s.

Figure 2. Mt Ida Water Race Abstractions and Calculated Falls Dam Inflows



In order to determine an abstraction record for the Mt Ida Water Race scheme for the period August 1999 to April 2004 for the Falls Dam inflow and Manuherikia downstream of Forks correlations, it was assumed that the Manuherikia downstream of Forks site data would be a good indicator of water availability in the catchment. To derive this abstraction record using these data, it was assumed that the abstractions for the Mt Ida Water Race scheme would be based on the proportion of mean flow at the Forks site that was available on any particular day during the irrigation season. The mean flow for the Forks site for the irrigation season September to April during the period to be correlated (August 1999 to April 2004) was 2900 l/s.

The ratio of the daily flow at the Forks site to the mean summertime flow of 2900 l/s during the period August 1999 to April 2004 was then multiplied by the mean Mt. Ida Water Race abstraction of 390 l/s to give an estimate of abstraction. The maximum rate of abstraction was not allowed to exceed 850 l/s (30 heads). These abstraction flows were then added to the derived inflows for Falls Dam and this made the summertime inflows unmodified as were the winter inflows.

The new criteria that were then used to eliminate the daily flows which were not considered to be correct are based on calculated mean catchment rainfalls and the expected range of flows between the Manuherikia Downstream of Forks site and Falls Dam inflows.

The catchment area of the Manuherikia Downstream of Forks is 174km^2 and that for Falls Dam is 359 km^2, about double that at the Forks. An analysis of the rainfall isohyetal map for the catchment shows that the mean annual catchment rainfall for the Forks site is 1000mm while that for the remaining area downstream to Falls Dam (185km^2) is 850mm. The lower rainfall in the area downstream of Forks indicates that runoff rates in that section will also be less.

The average flow at the Forks site for the August 1999 to December 2003 period was 2.824 cumecs and that for the same period for the derived inflows was 4.863 cumecs, 72% more than that at the Forks.

At this point, assumptions need to be made as to the likely maximum and minimum increase in flows between the Forks and Falls Dam so that inconsistent flows can be eliminated. These are based on the above discussion and are undertaken on the daily recorded corrected for Mt Ida Water Race abstractions. The assumptions made were:

(a) The maximum average daily natural inflow at Falls Dam will not be greater than twice that at the Forks.
(b) The minimum average daily natural inflow at Falls Dam will not be less than 40% greater than the flow at the Forks.

Any pairs of flows that did not fall within these criteria were excluded from the analyses.

Correlations between derived Falls Dam inflows and Forks flows from the remaining data were good with the winter relationship being

Falls Dam Inflows = 1.758 Manuherikia Downstream of Forks with an R^2 value of 0.967 and the summer relationship being

Falls Dam Inflows = 1.757 Manuherikia Downstream of Forks with an R^2 value of 0.969

These two formulae are very close which is what would be expected if all the data were natural data.

The summer values then had the estimated Mt. Ida Water Race abstractions subtracted from them and the resultant relationship was

Falls Dam Inflows = 1.581 Manuherikia Downstream of Forks with an R^2 value of 0.961. This is the relationship that will be used to derive Falls Dam inflows in summer and the winter relationship to be used will be that given above.

3.4.2 Flow Derivation

There are six gaps of varying length in the 1975 – 1993 Manuherikia Downstream of Forks record and they vary from 2 days to more than 90 days. Adjoining catchments were reviewed to see if they had records that could be used to fill these gaps. The only sites which had records that were being collected at the same time as the Forks site were Lindis at Lindis Peak and Dunstan Creek at Gorge.

Dunstan Creek is a major tributary of the Manuherikia River and joins that river downstream of Falls Dam from the western side. It will experience similar weather and climate patterns to that for the Manuherikia catchment upstream of Falls Dam since the headwaters of both streams are adjacent to each other. Data from Dunstan Creek was initially collected by the Ministry of Works and its successors but was subsequently handed over to the Otago Catchment Board to continue this data collection in the mid 1980's. Its record began in March 1973 and the early record ended in April 1994. A graph of the two sites for the 1981 year shows that generally the flow pattern is the same (see Figure 3) but the correlation between the two sites was not so good as Figure 4 shows. This correlation had an R^2 value of 0.838.

Figure 3. Manuherikia Downstream of Forks and Dunstan Creek at Gorge Flows-1981

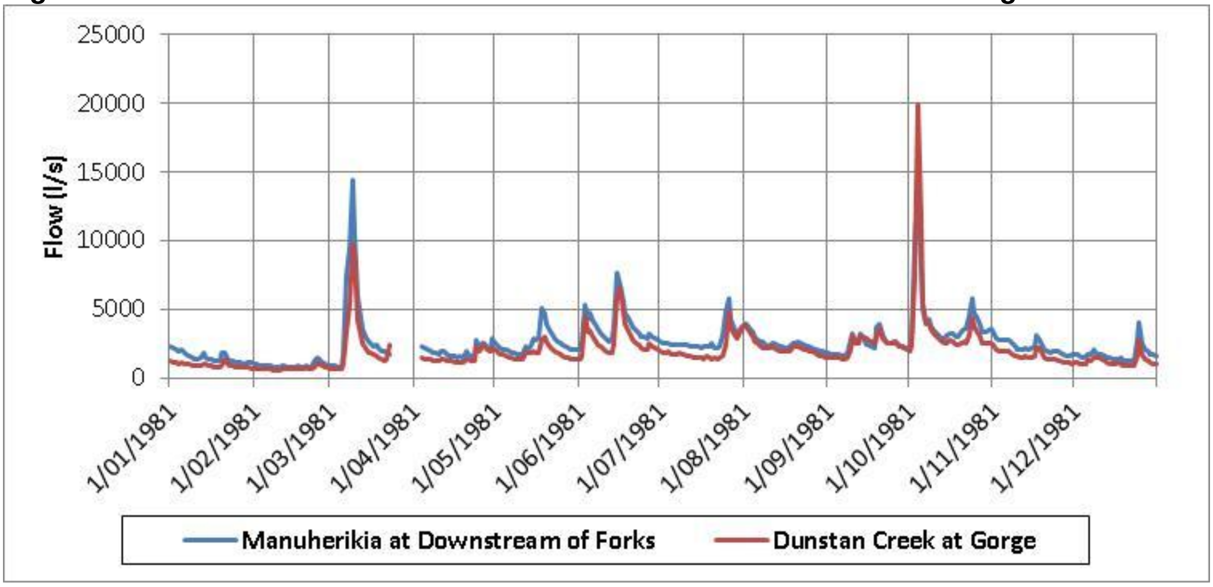
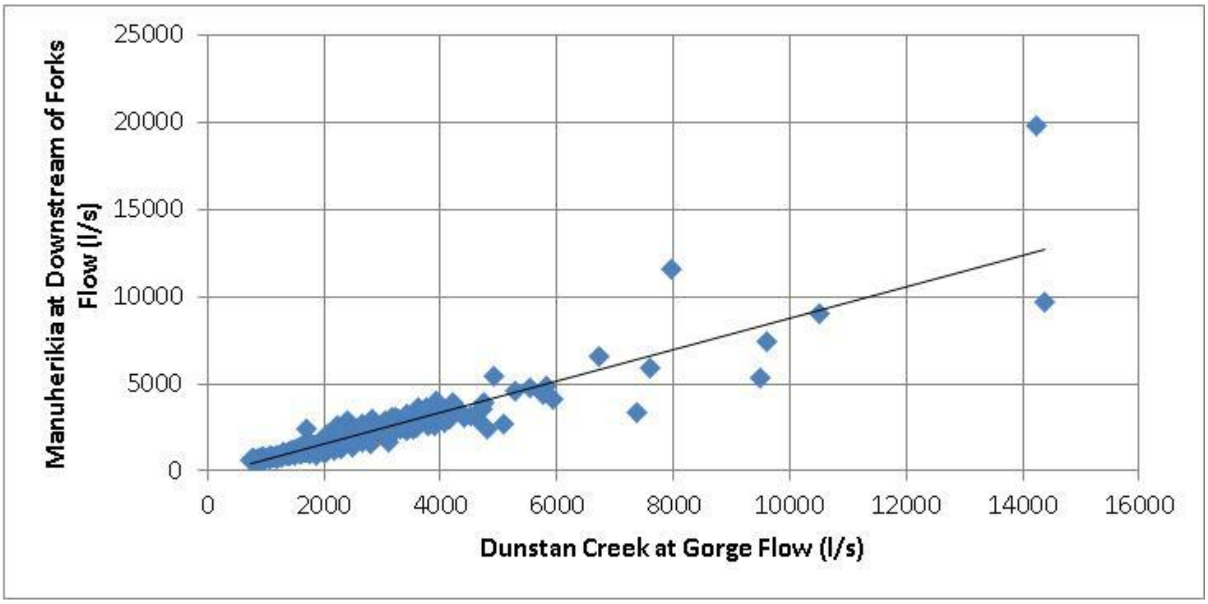


Figure 4. Manuherikia at Downstream of Forks and Dunstan Creek at Gorge Flow Correlation for 1981



A correlation of all the data pairs for the concurrent record for both sites produced the equation

Manuherikia at Downstream Forks = 1.3137*Dunstan Creek at Gorge + 73.6.

The relationship has an R^2 value of 0.855.

While this correlation is not the particularly good, it will be sufficient to fill the gaps in the Manuharikia at Downstream of Forks record. The likely reason for there not being a good correlation between these two sites is flow ratings at the two sites and whether or not some of the rating changes were picked up. Each time there was a rise in flow, the rating would change at either one or other or both of the sites and unless this rating change was picked up by the recording authority, then the two datasets would diverge and the correlation would change. Gaugings are generally done on a monthly basis but the attempted correlations showed that it was likely that in some months the ratings could change two or three times if there was several heavy rain events during the month. Figures 5 and 6 show examples of this.

Figure 5. Manuherikia and Dunstan Creek Flows July/August 1979

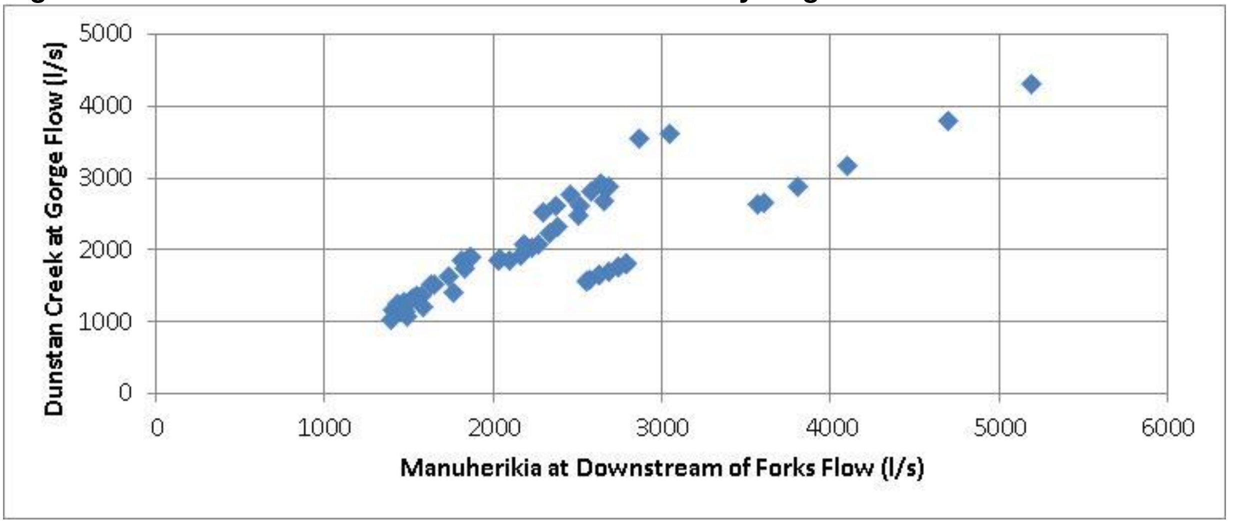
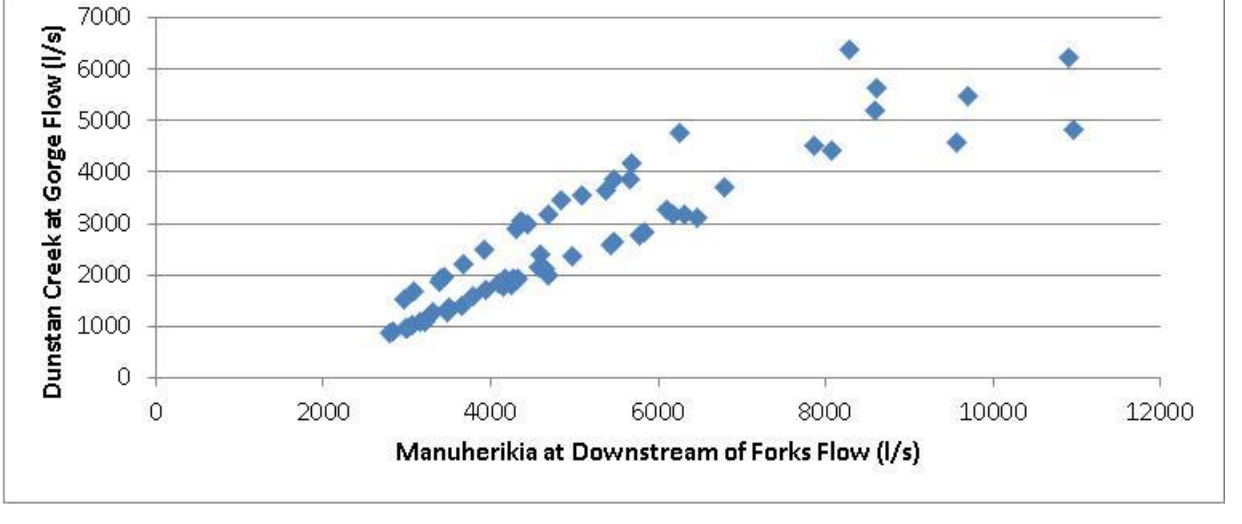


Figure 6. Manuherikia and Dunstan Creek Flows December/January 1983/84



The Lindis River at Lindis Peak was investigated to see if it would provide a better correlation with the Forks data. The Lindis River drains into the Clutha River in the Upper Clutha Valley so was not expected to give as good a correlation as the Dunstan Creek at Gorge site because it was likely to occasionally have weather systems affecting it that did not also affect the Manuherikia upstream of Falls Dam to the same extent. A graph of the 2 sites over the same time period shows that generally the flow pattern is the same but when studied closely, the relationship was not there. Figures 6 and 7 show the two sites graphed against each other. Further discussion of the relationship between these two sites is included in Section 3.5.

The Dunstan Creek relationship with the Manuherikia was better than that between the Manuherikia nd the Lindis so the Dunstan Creek correlation equation was used to generate flows that filled the gaps for that period. The gaps made up about 187 days of the total 6793 days of record (1975 – 1993) (about 2.8%) so how the gaps are filled even if they are not filled well will not affect the overall inflow series.

Using the continuous flow series for the Manuherikia Downstream of Forks and the two formulae in the previous section, a continuous inflow series for the period May 1975 to December 1993 can be calculated.

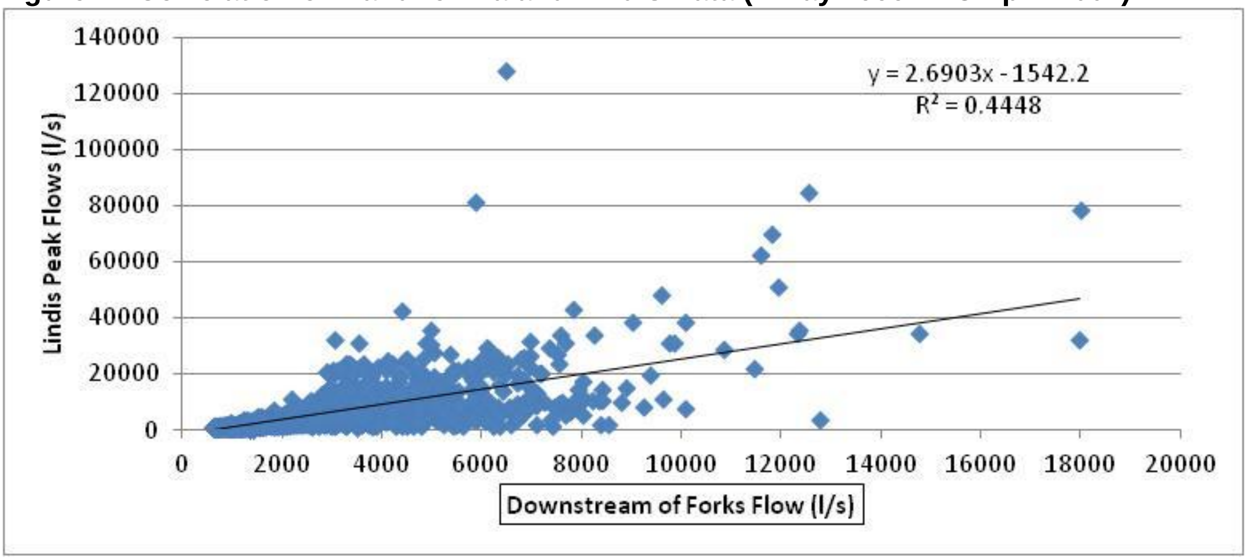
3.5 Falls Dam Inflows January 1994 – August 1999

This is the most difficult gap to fill. There were no recorders operating in the vicinity of Falls Dam, the upper Manuherikia Catchment or even in the adjoining Waitaki catchment that could be used to generate a record during this period.

The only record operating at the time which was in the vicinity of this catchment was the Lindis at Lindis Peak. As stated earlier, the Lindis River drains into the Clutha River in the Upper Clutha Valley. This record has been largely natural with few abstractions upstream so is the only option to fill the gap apart from some expensive modelling exercise which would also be a problem given the lack of basic information such as rainfall and temperature.

Correlation of the Lindis daily data with the Manuherikia at Downstream Forks data for both the early and later record failed. Figure 7 shows correlation of the shorter period of daily record from 1 May 1999 to 13 April 2004. The R^2 value shows that there is no correlation between the two sites. This analysis is representative of what the whole record looks like when attempting correlations between the two sites.

Figure 7. Correlation of Manuherikia and Lindis Data (1 May 1999 – 13 April 2004)



There has been a suggestion that non-linear regression should be tried on these data to see if there is any correlation. I don't believe that there is any point in spending the time and effort on this as the data are too inconsistent and no regression is likely to be able to give a good prediction given the inconsistency between flows at the two sites.

When flows for the two sites are plotted on a graph for comparison purposes, on a small scale the flow trends can look similar but when plotted on a larger scale, they can be similar at times but are divergent at other times. Figure 8 shows the 1983 year when on a small scale, flow trends were similar while Figure 9 shows the same year but on a larger scale and they were quite divergent at times. Note that these graphs have had the highest flows truncated to allow better definition of the lower flows for comparison.

Figure 8. Manuherikia Downstream of Forks and Lindis at Lindis Peak Flows - 1987

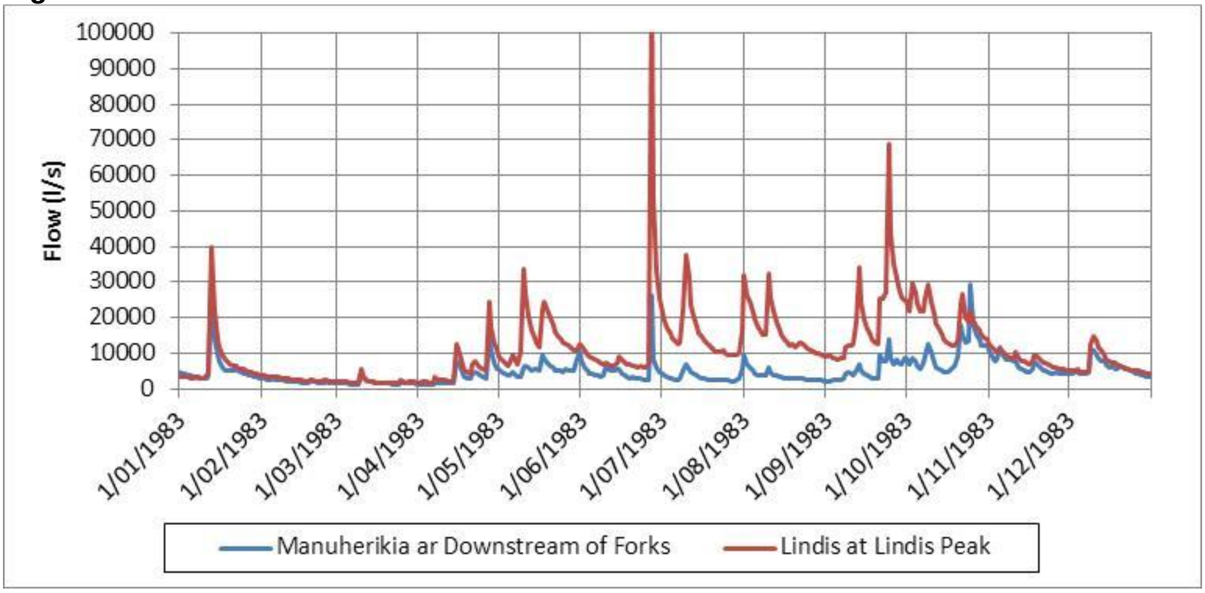


Figure 9. Manuherikia Downstream of Forks and Lindis at Lindis Peak Flows-1983

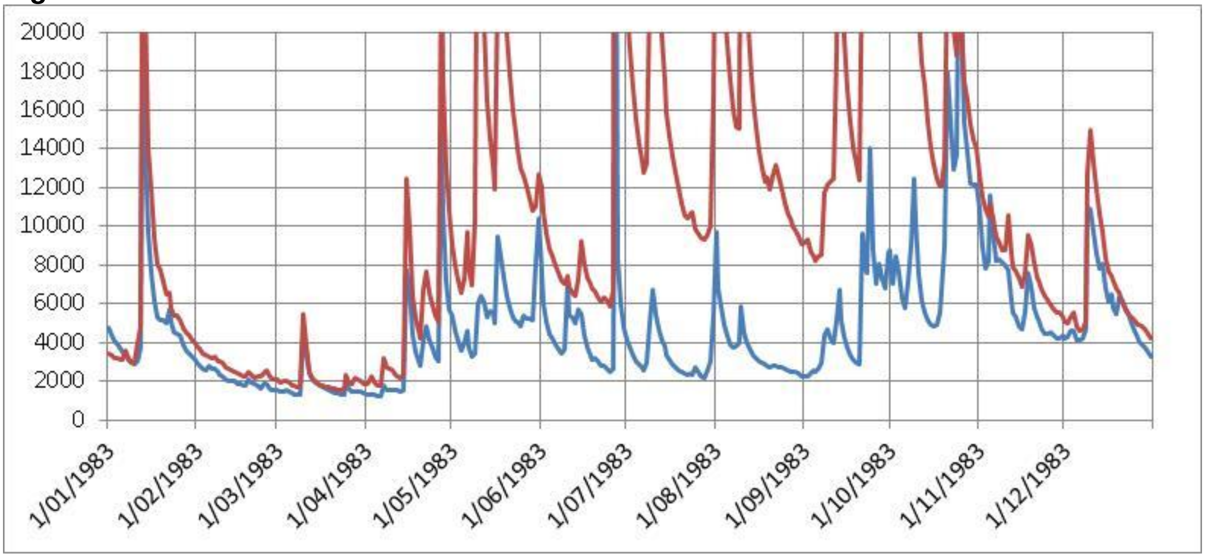
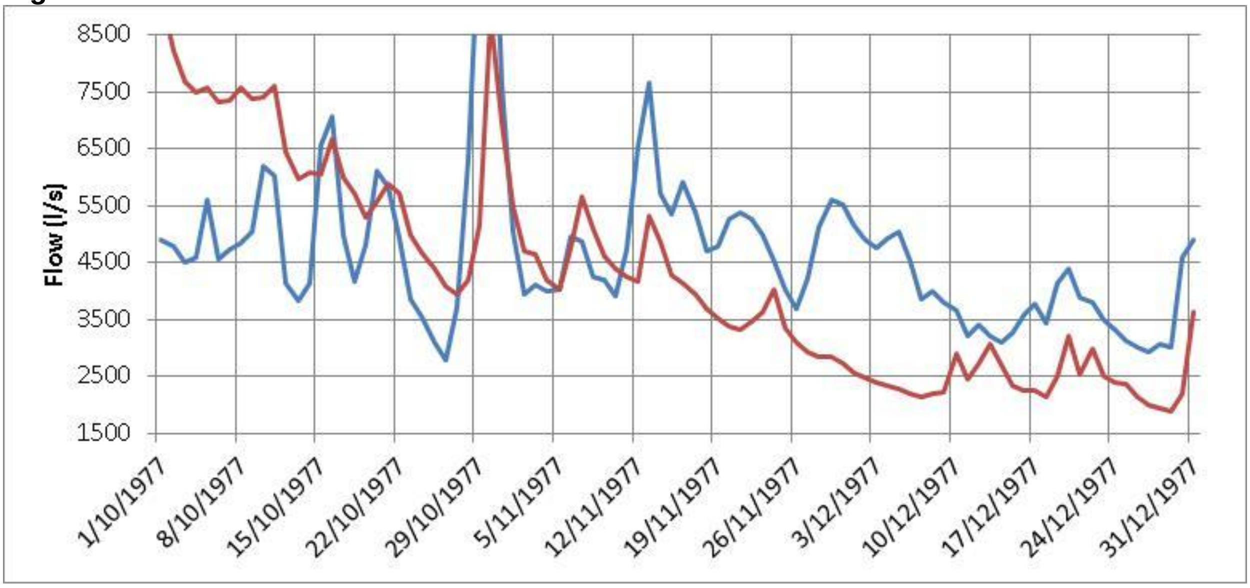


Figure 10 shows a 3 month flow period on a large scale and when viewed in this detail, while overall trends are similar for most of the time, in detail there is considerable difference between flows at the two sites and the differences are not consistent.

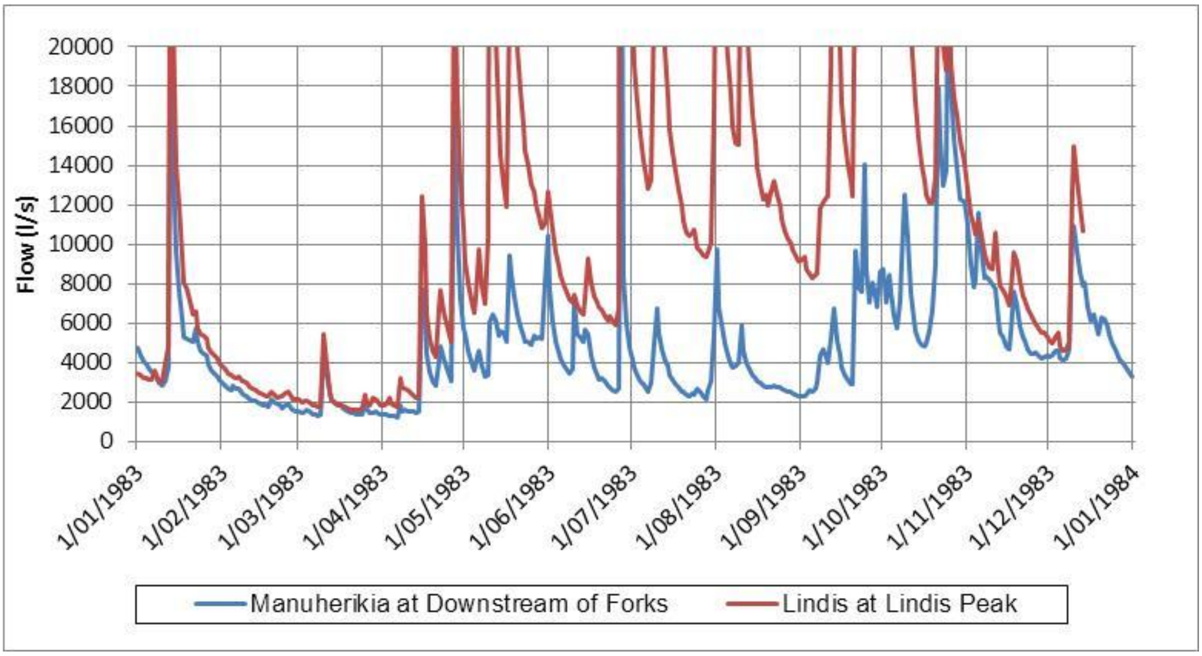
Figure 10. Manuherikia Downstream of Forks and Lindis at Lindis Peak Flows-1977



Inspection of the complete record comparisons between these two sites shows the following:

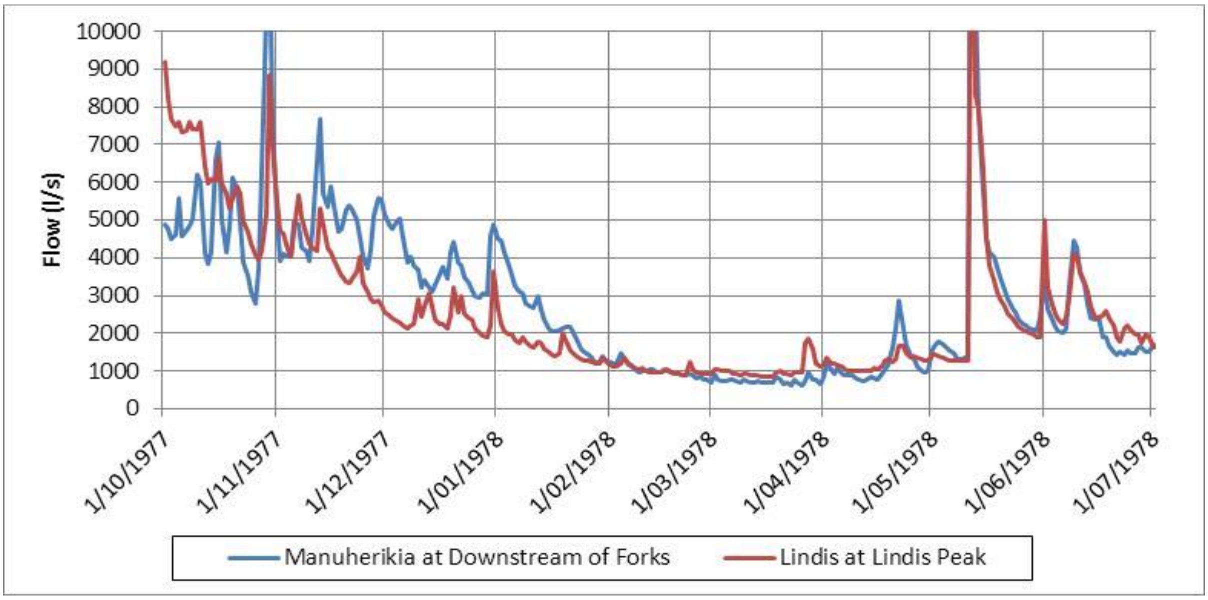
- Generally the occasional high daily flows occur on the same day at both sites. Sometimes the Lindis Peak average daily flow will be a day later but mostly they occur on the same day so it appears attenuation at higher flows in the larger Lindis catchment is not an issue.
- The graphs show inconsistent differences between the two sites data at similar flows. Figure 11 shows the 1983 year.   The data show that in 1983 a flow of 4560 l/s at the Forks site compares to a flow of 5952 l/s or 25781 l/s at the Lindis Peak site (yellow circles on Figure 11) and a flow of 3750 l/s at Forks is compared to 4848 l/s, 17084 l/s and 19140 l/s at the Lindis peak site (magenta circles on Figure 11). Note that the high flows have been truncated so that the details at the lower flows can be seen.

Figure 11. Manuherikia Downstream of Forks and Lindis at Lindis Peak Flows-1983



- Occasionally the Manuherikia Downstream of Forks flows are higher than the Lindis at Lindis Peak for more than a few weeks. While it would not be unusual for the Manuherijkia at Downstream of Forks to have higher flows than the Lindis at Lindis Peak on occasions, such higher flows are very unlikely to persist for many days. The Lindis Peak catchment is three times as large as that for the Manuherikia at Downstream of Forks (542 km^2 for Lindis at Lindis Peak and 174 km^2 for Manuherikia at Downstream of Forks) so the likely explanation for this sort of difference is a rating change at one or other of the sites. Given the much greater instability of the Forks site compared to the Lindis Peak site, then the rating change is most likely to be at the Forks site. Figure 12 shows a prolonged period when the Forks flows were higher than the Lindis Peak flows.

Figure 12. Manuherikia at d/s Forks Flows Greater Than Lindis at Lindis Peak Flows



- In most years, there is a wide difference between flows at the two sites in the winter/spring months. Sometimes the large differences occur from the beginning of May and sometimes they occur for most of the year. In other years such as 2001, there is very little difference between the flows at the two sites throughout the year.

The lack of correlation between the two sites is probably due to two main reasons. Firstly because of its location, the Lindis Catchment is likely to occasionally have weather systems affecting it that do not also affect the Manuherikia upstream of Falls Dam to the same extent and therefore there could be times when flows increase in the Lindis but not in the Manuherikia for example. The Lindis catchment is likiely to be affected by vigourous storms crossing from the west and providing very heavy rain around the southern lakes and extending as far as the Lindis whereas such storms are unlikely to produce much rain in the Manuherikia catchment. The opposite could also occur where the Manuherikia is affected more by a storm than the Lindis.

The second reason will again be the rating changes at the two sites, when these changes are picked up and how high and low the highest and lowest gaugings are to allow good definition of the rating at higher and lower stages. It is noted that the early record does have some higher stage gaugings which should assist with the rating at higher flows (in excess of 40 m^3/s). Given that there is no other flow information available, the Lindis data needs to be used.

A comparison of flows was undertaken to see if there was any similarity and trends between mean flows at Lindis Peak and d/s Forks sites. The data at both the Lindis Peak and Forks sites was divided into 5 year blocks and the mean flows for each site compared. Table 1 shows the mean flows and their relationship for each 5 year period.

Table 1 Five Year Period Mean Flow Comparison

Period	Mean Flow (l/s)		Percent Manuherikia Compared to Lindis
	Manuherikia at Forks	Lindis at Lindis Peak	
1979 – 1983	3723	8291	45
1984 – 1988	3038	6652	46
1989 – 1993	2630	4683	56
1999 – 2003	2704	6048	45

The table shows that generally the flows at the Manuherikia site are around 45% of those at the Lindis site. However the 1989 – 1993 period shows a significant difference to the other periods so there is no consistency there.

The record period was then investigated on an annual basis with a comparison of mean flows as above. Table 2 shows the results.

Table 2 Annual Mean Flow Comparison

Period	Mean Flow (l/s)		Percent Manuherikia Compared to Lindis
	Manuherikia at Forks	Lindis at Lindis Peak	
1979	3586	7118	50
1980	4318	11938	36
1981	2535	5722	44
1982	3259	5538	59
1983	4921	11145	44
1984	3496	8577	41
1985	2408	5774	42
1986	3409	5926	58
1987	3723	7929	47
1988	2187	5246	42
1989	2426	3560	68
1990	2266	4764	48
1991	2932	5868	50
1992	2778	4256	65
1993	2752	4987	55
1999	2508	6265	40
2000	4308	11361	38
2001	2166	2655	82
2002	2590	5865	44
2003	1945	4081	48

A review of the data in the table shows there is no real trends or consistency from year to year.

A review of the isohyetal map of the two areas shows that maximum annual average rainfall in the Manuherikia is about 1250mm, same as the Lindis. The difference between the two catchment areas is that the Manuherikia has much more area subject to these higher annual rainfalls than does the Lindis so the Manuherikia at Downstream of Forks will have a higher specific discharge (litres per second per square kilometre) than the Lindis at Lindis Peak Note that the catchment areas for the two sites are 174 km^2 for the Manuherikia at Downstream Forks and 542 km^2 for Lindis at Lindis Peak so the catchment area for the Manuherikia is about 32% of that of the Lindis.

The discussion in this section to here shows that there is no conventional way to fill the gap from 1994 to 1999 in the Manuherikia at Downstream of Forks record. What is needed is a daily flow record that would have variability from day to day and generally follow the trend of the Lindis at Lindis Peak but will also retain the general statistics of the existing Downstream of Forks record.

A correlation between the two sites can be found if the data are carefully selected but usually nothing more than about 30 consecutive days will be usable before the flows begin to diverge. There are many sections of data like this in the record but usually the equations relating one dataset to the other are different on every occasion.

The daily data for both sites for the concurrent periods of record were compared with the result being a relationship of

Manuherikia at Downstream of Forks = 0.5285*Lindis at Lindis Peak – 227

with an R^2 value of 0.4358

It is recognised that this is a poor correlation but using it will provide a record that will have variability, will have the same trend in flows as does the Lindis at Lindis Peak and will retain the flow statistics of the Manuherikia at Downstream of Forks.

The gap from 1994 to 1998 inclusive will be filled using this relationship

A complete daily Falls Dam Inflow record from 29 July 1975 to 8 March 2012 is available in electronic form on an excel spreadsheet. A hardcopy of the daily flows is included in Appendix 1 of this report.

The statistics from this record which are based on daily mean flows are included in Table 3.

Table 3. Flow Statistics for Falls Dam Inflows (l/s)

Mean	Median	MALF		Specific Discharge ($l/s/km^2$)	Max	Min
		1-day.	7-Day			
5252	3870	1110	1362	30	92227	257

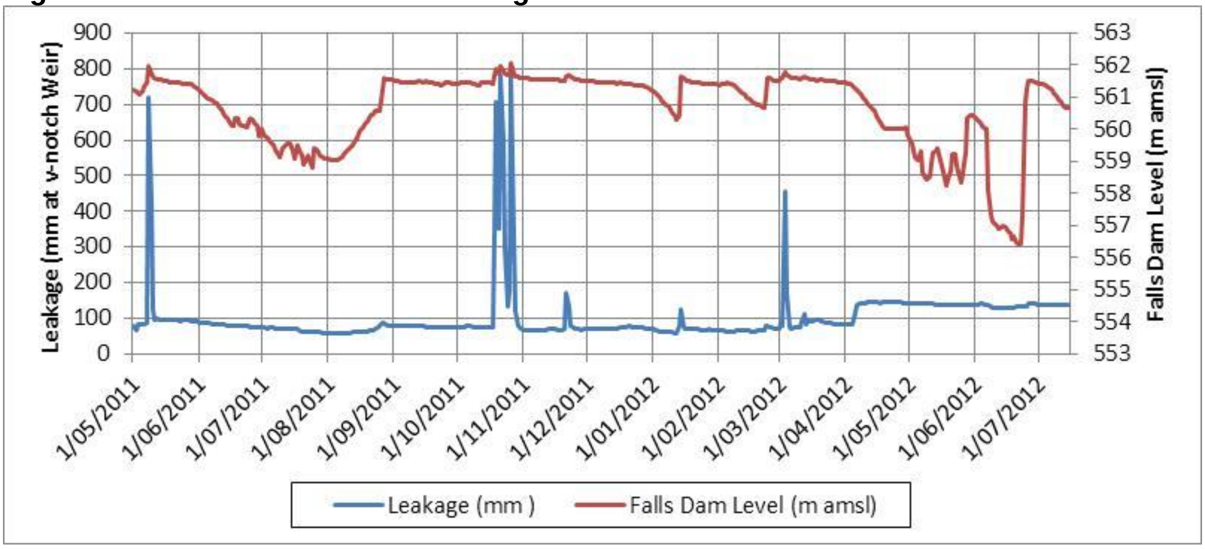
4. Current losses

4.1 Seepage

Current seepage from Falls Dam is measured on a weekly basis. A V-notch weir has been installed where all seepage passes through and Pioneer Generation take a weekly water level reading on it. Using the theoretical rating for the V-notch weir, a weekly record should be able to be derived.

From discussion with Robert Miller of Pioneer Generation, the amount of seepage is related to the water level in Falls Dam. Pioneer Generation provided a year of daily data showing the current lake level and the seepage measurement through the v-notch weir as a level. Inspection of these data showed that they are very inconsistent. The data period covered was from 1 May 2011 to 15 July 2012 and Figure 13 shows these data plotted on a graph.

Figure 13. Falls Dam Level vs Leakage Measurement



An estimate of leakage is that it is in the order of 20 l/s. This is a very small amount of water and has no effect on the hydrological calculations for this report both because it is so small and because it is not important in this case since all outflows are measured at the Manuherikia Downstream of Falls Dam site and are therefore included in the inflow calculations.

4.2 Evaporation

There are no measurements of evaporation from the lake created by Falls Dam. There are a number of ways of calculating lake evaporation but most of them rely on measured data such as wind speed, saturated vapour pressure in the air and at the water surface, net radiation, air temperature and several other measured meteorological elements. None of these data are available for the Falls Dam area.

Lake evaporation can be estimated from pan evaporation data but a review of available pan evaporation data shows that there was only one site where such data was recorded in the Manuherikia Valley and that was a site near Lauder. This site was operational between March 1982 and May 1986. A review of the data from this site shows that there were many gaps in the record especially in the winter months. Because there are so many gaps in the winter months, the average monthly evaporation is based on only 2 values so the pattern and total needs to be compared with other sites to ensure the monthly evaporation values are not excessive. Average monthly pan evaporation data were calculated for all sites which were likely to be relevant and which may provide a relevant longer dataset than that for Lauder. Table 4 provides the monthly average data for these sites including an estimate for Falls Dam and Figure 14 shows these values plotted on a graph.

Table 4. Monthly Pan Evaporation Data for Various Sites

	Elevation (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Tara Hills	488	201	162	113	66	33	14	14	36	68	120	162	190	1179
Lauder	370	194	143	113	67	35	19	12	37	75	117	158	152	1122
Clyde Dam	160	203	162	117	68	35	13	14	35	67	121	160	193	1242
Cromwell	213	227	182	142	79	44	21	24	46	92	144	181	220	1430
Northburn	210	227	173	130	78	43	21	19	45	92	140	187	214	1369
Bendigo	200	236	187	144	87	47	23	23	52	98	144	192	220	1454
Queensbury	277	237	178	132	77	40	20	20	43	91	137	181	217	1372
Falls Dam	570	141	113	79	46	23	10	10	25	48	84	113	133	825

Figure 14. Monthly Evaporation for Various Sites

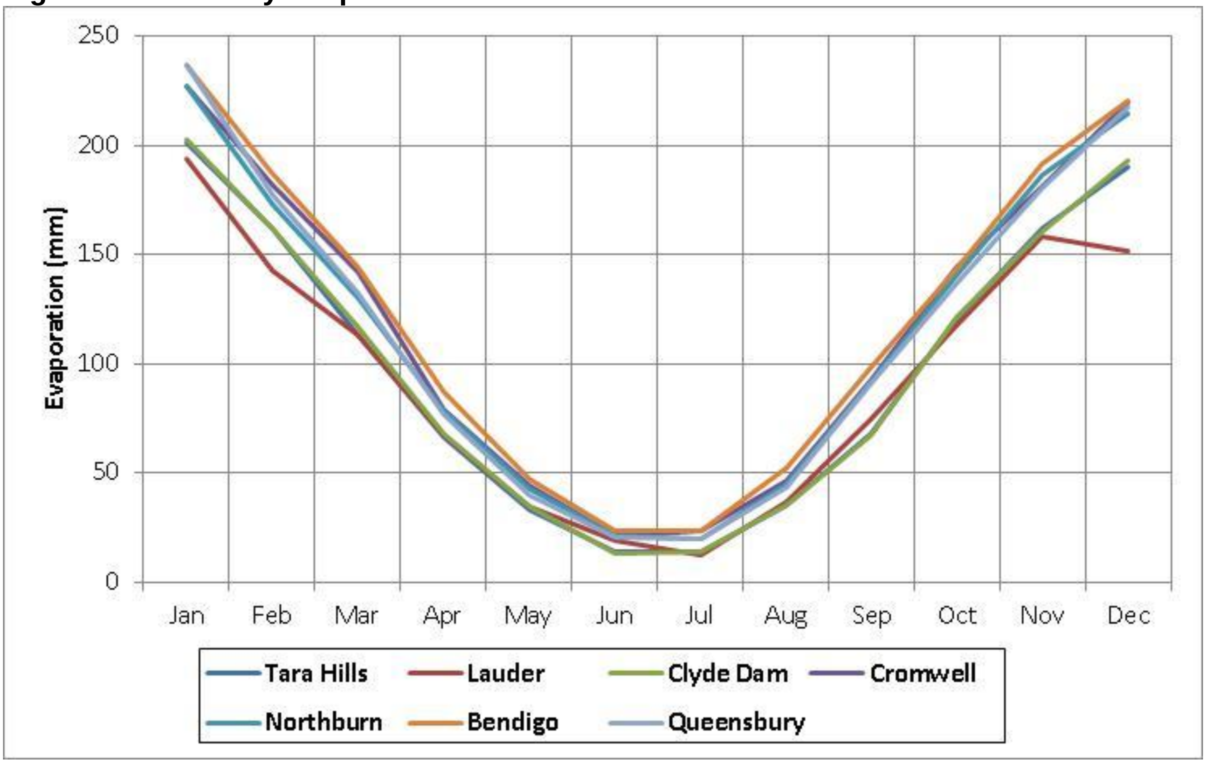


Table 4 and Figure 14 show that the Lauder pattern of evaporation is consistent with the other sites except for the month of December and that the average annual evaporation is the lowest of all the measured sites listed in Table 4. This table also lists the elevation of all the sites used and Lauder is at a higher elevation that the rest except Tara Hills. Note that the Tara Hills data are for a sunken pan while the others are all raised pan evaporation. It is stated that sunken pan evaporation provides a better representation of lake evaporation than does the raised pan evaporation. Elevation is important because the higher the site, the lower the average annual temperature and by default, the lower the annual evaporation. Falls Dam is situated at an elevation of 570m which is some 230m higher that the Lauder site and about 100m higher than the Tara Hills site, so average annual temperatures and evaporation are likely to be less than those at Lauder.

Figure 14 shows the seven pan evaporation datasets in graphical form. The Tara Hills and Lauder data are very similar except in December. The value for Lauder for December is less than that in November and clearly this is unlikely to be the real situation. Given the closeness of the data and the shape of the curve in Figure 14, the Tara Hills data will be used in the estimation of evaporation losses from lake behind Falls Dam.

When calculating lake evaporation from pan evaporation data, the literature generally states that lake evaporation is about 70-75% of raised pan evaporation and about 80% of sunken pan evaporation. In the case of Falls Dam, because the Lauder data and Tara Hills data are very similar, the Tara Hills data will be used in preference because it has a more reliable value for December. Because the Falls Dam site is 230m higher than Lauder, some further adjustment could be made to the data. Using standard air temperature lapse rates, it would appear that average temperatures at Falls Dam are likely to be about 1.5^{o}C lower than those at Lauder. For the purposes of this exercise, it is probably better to use only the 70% reduction factor and that is likely to result in a conservative estimate of evaporation losses. Annual evaporation at Falls Dam is estimated to be 70% of 1179mm which is 825mm.

Using the pattern of pan evaporation at Tara Hills, an estimate of monthly evaporation from the lake behind Falls Dam can be calculated and this is also included in Table 4.

The possible volume of water lost from the Falls Dam Lake through evaporation can be calculated using the Table 4 estimates and the area of the lake which depends on the lake level. The higher the lake, the greater the area, and therefore the greater the evaporation loss. Table 5 shows the calculated current and potential future losses due to evaporation from Falls Dam assuming the lake remained at that constant level throughout the year. It shows that there could be an almost 70% increase in losses through evaporation with increasing lake area under the maximum proposed lake level. Note that lake area is calculated to increase from 134.4ha at 561.5m, to 166.8ha at 564.5m (24% increase) to 189.6ha at 566.5m (41% increase), to 225.5ha at 569.5m (68% increase). The median lake level is 561.41m. Using the formulae that provide the data in Table 4, the annual loss from evaporation is about 1,102,000 m^3 which equates to about 0.7% of the average annual calculated surface water inflow. However losses will generally be negated by the input of rainfall directly onto the lake area. Average annual rainfall onto the lake formed by Falls Dam is estimated to be around 750mm and is therefore close to the estimated evaporation loss.

In the current inflow series analysis, the data used (lake levels, downstream flows) already include the losses of seepage and evaporation. The lake level and downstream flow measurements are the results after these evaporation and seepage losses and after the input of rainfall throughout the year. Given the likely errors involved in all these calculations and estimates, the losses from increased evaporation due to lake area increasing are likely to be small so no adjustment to the series is necessary and any increase to the lake area and therefore evaporation is likely to be offset by rainfall.

Table 5. Calculated Evaporation Losses for Falls Dam for Various Dam Levels (m^3) and Increase on Calculated Current Losses

Falls Level (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	%age Increase
568.5	300667	241668	168919	99187	49748	20377	20649	53141	101663	179847	241517	283827	1760634	59
567.5	283797	228108	159441	93622	46957	19234	19490	50159	95959	169755	227965	267902	1661846	50
566.5	267241	214802	150140	88160	44218	18112	18353	47233	90361	159853	214667	252274	1564901	41
565.5	251007	201753	141020	82805	41532	17012	17238	44364	84872	150142	201627	236949	1469840	32
564.5	235102	188969	132084	77558	38900	15934	16146	41553	79494	140629	188851	221935	1376705	24
563.5	219534	176456	123338	72422	36324	14879	15077	38801	74230	131317	176346	207239	1285543	16
562.5	204312	164221	114786	67400	33805	13847	14031	36111	69083	122211	164118	192869	1196402	8
561.5	189444	152270	106432	62495	31345	12839	13010	33483	64056	113317	152174	178833	1109337	0
560.5	174939	140612	98284	57711	28945	11856	12014	30920	59152	104642	140524	165142	1024405	
559.5	160810	129255	90346	53050	26608	10899	11044	28422	54374	96190	129174	151804	941667	
558.5	147067	118209	82625	48516	24334	9967	10100	25993	49727	87970	118135	138830	861191	
557.5	133723	107483	75128	44114	22126	9063	9184	23635	45215	79988	107416	126234	783052	
556.5	120792	97090	67863	39848	19986	8186	8296	21349	40843	72253	97029	114027	707331	
555.5	108290	87040	60839	35724	17918	7339	7437	19140	36616	64774	86986	102225	634119	
554.5	96233	77349	54065	31746	15923	6522	6609	17009	32539	57562	77301	90843	563516	
553.5	84641	68032	47552	27922	14005	5736	5813	14960	28619	50629	67989	79900	495636	
552.5	73536	59106	41314	24259	12167	4984	5050	12997	24864	43986	59069	69417	430608	
551.5	62943	50592	35363	20764	10415	4266	4323	11125	21283	37650	50561	59418	368582	
550.5	52893	42514	29716	17449	8752	3585	3633	9349	17885	31639	42488	49931	309730	
549.5	43420	34900	24394	14324	7184	2943	2982	7674	14682	25972	34878	40989	254259	
548.5	34568	27785	19421	11404	5720	2343	2374	6110	11688	20677	27767	32632	202420	
547.5	26389	21210	14826	8705	4366	1788	1812	4664	8923	15785	21197	24911	154525	
546.5	18953	15234	10648	6252	3136	1284	1302	3350	6408	11337	15224	17891	110982	
545.5	12355	9931	6941	4076	2044	837	849	2184	4178	7390	9925	11663	72350	
544.5	6740	5418	3787	2224	1115	457	463	1191	2279	4032	5414	6363	39469	
543.5	2360	1897	1326	779	391	160	162	417	798	1412	1896	2228	13822	
542.5	0	0	0	0	0	0	0	0	0	0	0	0	0	

4.3 Mt Ida Water Race Abstractions

There was some discussion of this race in the previous Raineffects Ltd report prepared for Pioneer Generation Ltd in 2002.

Since that report was prepared, some measurement of water abstracted by this race for use in the Ida Valley and Maniototo Basin has been undertaken. The record is not long (3.5 years) but is the first set of reliable recent records that can be used in assessing the Mt Ida Race abstraction from the upper Manuherikia catchment.

The recently granted water permits for this scheme allow abstraction for irrigation to occur between 15 September and 30 April every season. This water is also used for stockwater and stockwater abstraction can continue into May.

Table 6 shows the mean monthly abstraction for the available periods of record.

Table 6. Average Mt Ida Race Abstractions–Measured and Estimated in 2002 (l/s)

Season	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2007/08	314.9	669.6	490.0	356.4	342.0	470.1	397.0	205.4	0
2008/09	80.0	422.8	577.9	485.3	274.9	321.6	488.5	364.8	0
2009/10	430.6	583.3	548.7	389.6	369.1	252.1	141.9	160.6	141.5
2010/11	0.0	379.6	670.3	525.9	533.8	547.5			0
Average	206.4	513.8	571.7	439.3	380.0	397.8	342.4	243.6	35.4
2002 Report	0.0	127.0	416.0	386.0	286.0	271.0	293.0	65.0	

The Mt Ida Race abstraction is a loss of water for Falls Dam but this has been the case from when Falls Dam was first constructed and as a result, these losses are automatically incorporated into the inflow series which has been derived.

The main change that has occurred with the Mt Ida Race is that it has steadily been upgraded over the last 20 years or so. Mr Keith Campbell of Hawkdun-Idaburn Irrigation Scheme, believes that the upgrading of the race has had no real impact on volumes abstracted as there is a maximum flow that can be abstracted and the race upgrade has not changed available volumes. He also believes that since the Department of Conservation took over much of the higher Manuherikia catchment area, flows “hold on” for longer. He believes the regeneration into tussock land is helping to sustain flows for longer in summer than used to occur.

It would seem logical if the races are less porous, then more water may be transported out of the Manuherikia Catchment when the race is not full than in the past.

Whatever the actual abstraction is, the potential increase in abstraction and therefore loss to Falls Dam cannot be quantified as there are no reliable records to allow comparison of abstraction 20-30 years ago with current abstraction. In the Raineffects 2002 report, an estimate of average monthly abstraction was provided. Table 6 shows this estimate which can be compared with the current monthly measured average abstraction.

In the past, leakage from the race meant that much of the water captured by it leaked back into the Manuherikia River and subsequently Falls Dam either through surface or subsurface flow. The reduction in leakage has undoubtedly meant that more water is taken from this catchment with a consequent reduction in inflows to Falls Dam. The only records available cover the brief period 2007-2011 which means abstractions of 20 years or so ago cannot be compared with current abstractions to try to determine the increased loss. The mean abstraction rate from the available records is 348 l/s. If it is assumed that reduction of losses have resulted in a 10% increase in abstraction, then an estimated extra 32 l/s will be lost from Falls Dam inflows. This equates to a volume of 755000 cubic metres per season which is about 0.5% of the calculated average annual inflow into Falls Dam. The current average annual abstraction is 8,210,000m^3.

It is likely that the current abstraction rate will continue in the future and is a loss to Falls Dam that is generally already accounted for in the current calculated daily inflow series.

5. Future losses

5.1 Seepage

Any new dam built is likely to be better sealed against seepage than the current dam which was built in 1935. Future seepage for planning purposes could probably use the existing data and this would likely provide a conservative estimate of dam seepage.

5.2 Evaporation Losses

As discussed in the previous section, the current lake level and downstream of dam flow measurements automatically incorporate evaporation losses but a new higher dam will result in a greater lake surface area when levels rise higher than they can currently do. Future analysis using these large lake areas may need to include the extra evaporation losses and computer models may need to ensure that only the extended area is used along with the appropriate monthly loss. While the inflow data are available on a daily basis, the evaporation data will, of necessity, be a monthly average and will be the same for every year of record. However given that rainfall in the area is about equivalent to the calculated evaporation from the lake, then evaporation is basically negated by the rainfall which falls directly onto the lake and there seems little point in complicating any future analyses with evaporation calculations.

6. Climate Change

6.1 General

The following discussion is generally a summary and interpretation of information provided by the Ministry for the Environment (MFE) on their website. There are two key references used and these are detailed at the end of this report. In these reports the changes expected are provided over two time scales, one being from 1990 to 2040 and the other from 1990 to 2090. In this report I will look only at the predicted changes to climate for the long term period 1990 – 2090.

The information provided by MFE is of necessity quite broad scale and needs to be interpreted for the Manuherikia Valley. It also is expressed mainly in terms of averages and on short time scales the changes may not be apparent.

6.2 Increasing Westerly Wind Frequency

New Zealand lies in the westerly wind belt and is subject to weather systems mostly travelling from west to east across or south of the country. The key change expected due to climate change is that there will be an overall increase in westerly quarter wind frequency. By season, there is expected to be a significant increase in westerlies in winter and spring and a decrease in frequency in summer and autumn.

Changes to southerly quarter wind frequency is not so marked but there is a predicted decrease in these winds in summer, autumn and winter with no change in spring.

6.3 Temperatures

In the 100 year period 1990 – 2090, there is expected to be an overall increase in mean daily temperature of 2^{o}C. The prediction is New Zealand-wide and there is little difference on a regional basis. For daily temperature extremes including frosts and hot days, it states there should be fewer cold temperatures and frosts and more high temperature episodes.

6.4 Rainfall

The increased frequency of westerly quarter winds is likely to result in an overall increase in rainfall in the Manuherikia Valley although on a 4 part scale of confidence (very confident, confident, moderate confidence, low confidence), NIWA ranks this prediction as moderate confidence.

The annual rainfall in the Manuherikia Valley is predicted to increase between 7.5% and 10%. By season, there is an increase of 5-10% in spring, an increase of 2.5 – 7.5% in summer, an increase of 0 - 5% in autumn and an increase of 10-15% in winter.

With regards to extreme rainfalls (likely flood-producing rainfall events), there is moderate confidence that there will be heavier and/or more frequent extreme rainfalls especially where annual mean rainfalls are predicted to increase.

With respect to snowfall, it is predicted that the duration of seasonal snow lying will shorten and there is likely to be a rise in the snowline. While they state there is likely to be a decrease in snowfall events, they have only low confidence in this prediction. The importance of snow in an irrigation system that has a large storage facility is decreased as the snowmelt can be captured whenever it occurs. In Central Otago, snowmelt tends to maintain flows in streams until about November. If snow-cover is reduced, then the melt is likely be less than current and to occur earlier which means streams may not be sustained into November.

6.5 Current Signs of Climate Change

A review of mean temperatures on an annual basis and annual rainfall totals at a number of sites was undertaken for data collection sites in the Otago, Southland and South Canterbury regions.

6.5.1 Temperatures

For temperatures, a period of at least 25 to 30 years of data was required to try to detect if there was any trends in mean annual temperatures. When it came to choosing sites for this review, there were many sites that could not be used due to gaps in the record. In many instances, the gaps were too great and the sites were rejected.

An issue with temperature is the urban heat island effect. This is where the site is initially situated in a sparsely populated area and the temperature at the thermometer is the same as the rural surrounds and is not affected by any concrete, paved or other surfaces that store heat and release it later especially at night. Townships such as Alexandra and Queenstown are typical of areas where recordings have been undertaken for many years when there was little development but the current townships are hugely expanded on the initial towns and bear little resemblance to what they were 40 – 50 years ago. The urban heat island effect can result in a rising temperature trend even though the surrounding rural areas show no such trend. However it was assumed that if temperature change was already occurring, it should be occurring over the Otago, Canterbury and Southland regions and so sites outside of Central Otago were also used. An issue with these data at a few sites is that the site location has changed even though the site name remains the same and this can impact on temperatures. This is especially the case with Alexandra and Milford Sound. Table 6 provides the list of sites where data was able to be analysed and indicates the general trend showing in the data.

In Table 6, there are three sites which have significantly different increases compared to the other 5 sites with an increasing trend. Of these, both Queenstown and Queenstown Airport are likely to be affected by the urban heat island effect so their trends are highly questionable and should not be used. For the Milford Sound site, there was a site location change in 1990. Prior to 1990, the trend at this site was decreasing but since the site location changed, the trend is increasing. Therefore there is a question over this site and given its inconsistency with all the other sites, little weight should be given to the trend at this site.

If those three sites were not included in the analysis, Table 7 shows that most of the increases are within the margin of error of temperature measurement. There are three sites where there is no trend, 5 sites where there is a small increase and 5 sites where there is a small decrease. My conclusion from this is that currently there is no significant increasing or decreasing trend in temperature in the Southland, Otago, and South Canterbury area at present.

Table 7. Temperature Trends at Various Sites

Site	Record Period	Temperature from Trendline		Increasing/ Decreasing	Change in 30 years
		1980	2010		
Clyde	1980-2010	10.8	10.8	Neither	0
Lumsden	1982-2010	9.6	9.6	Neither	0
Queenstown Aero	1980-2010	9.4	10.0	Increasing	+0.6
Queenstown	1980-2010	10.6	11.4	Increasing	+0.8
Musselburgh	1980-2010	11.0	11.1	Increasing	+0.1
Dn Airport	1980-2010	10.1	10.4	Increasing	+0.3
Palmerston	1980-2010	10.4	10.2	Decreasing	-0.2
Ettrick	1985-2010	10.4	10.3	Decreasing	-0.1
Winchmore	1980-2010	11.0	11.3	Increasing	+0.3
Ashburton	1980-2010	11.7	11.7	Neither	0
Tiwai Pt.	1980-2010	10.7	10.6	Decreasing	-0.1
Ingill Aero	1980-2010	9.9	10.1	Increasing	+0.2
Milford Snd.	1980-2010	10.0	10.6	Increasing	+0.6
Tekapo	1980-2010	8.8	8.7	Decreasing	-0.1
Orari	1980-2010	10.8	10.7	Decreasing	-0.1

6.5.2 Rainfall

There are complications with analysing rainfall over the past 30 years and these are the Interdecadal Pacific Oscillation (IPO) and the Southern Oscillation Index (SOI). The IPO and SOI indices do not appear to have a significant impact on temperatures but they do on rainfall.

Records show that western areas were about 10% wetter in the period 1978 to 1999 but in periods both prior and post this approximately 20 year period, these areas were drier. The IPO was in a drier phase from 1945 to 1978 and from 2000 to present. The wetter phase was from 1979 to 1999.

Because the IPO brought increased rainfall in the west during the period 1978-1999, the initial analysis on rainfall covered a 40 year period 1970-2010 so that there would be about 20 years when the IPO was causing heavier falls and 20 years in the drier phase. The analysis was also undertaken on the 30 year period 1980-2010 and trends in the data noted. Table 7 shows the results of this brief analysis. In Table 8, the sites have been grouped so that all the most western sites are together (Tiwai Point and Invercargill Airport are included in this group because their changes appear similar to those western sites), with the other two groups being the sites in the centre of the country, and those near the east coast.

Table 8. Rainfall Trends at Various Sites for Various Periods

Site	Record Period	Rainfall from Trendline		Change in 40 years	Record Period	Rainfall from Trendline		Change in 30 years
		1970	2010			1980	2010	
Milford	1970-2010	6630	6634	+4	1980-2010	7066	6384	-680
Earnslaw	1970-2010	1486	1622	+136	1980-2010	1680	1528	-152
Makarora	1970-2010	2369	2416	+47	1980-2010	2616	2282	-334
Glenfinnan	1970-2010	2021	2143	+122	1980-2010	2258	2026	-232
Queenstown	1970-2010	855	940	+85	1980-2010	968	885	-83
Arthurs Pt.	1970-2010	893	989	+96	1980-2010	988	949	-39
Tekapo	1970-2010	592	576	-16	1980-2010	652	539	-113
Inv. Aero	1970-2010	1071	1169	+98	1980-2010	1166	1130	-36
Tiwai Pt.	1970-2010	1100	1128	+28	1980-2010	1164	1096	-68
Matakanui	1970-2010	558	516	-42	1980-2010	607	479	-128
Lindis Xing	1970-2010	478	522	+44	1980-2010	5121	502	-19
Bannockburn	1972-2010	441	470	+29	1980-2010	502	439	-63
Alexandra	1970-2010	374	364	-10	1980-2010	414	338	-76
Ranfurly	1970-2010	430	437	+7	1980-2010	443	434	-9
Middlemarch	1970-2010	525	474	-49	1980-2010	532	462	-70
Maungatua	1971-2010	758	807	+49	1980-2010	763	813	+50
Musselburgh	1970-2010	867	666	-201	1980-2010	841	650	-191
Dn. Aero	1970-2010	711	618	-93	1980-2010	714	601	-113
Palmerston	1970-2010	663	602	-61	1980-2010	644	603	-41
Winchmore	1970-2010	726	732	+6	1980-2010	689	745	+56
Orari	1970-2010	748	627	-121	1980-2010	728	612	-116

The first conclusion from these groupings is that sites in the east with the exception of Winchmore show no real change in trend over both periods analysed. Middlemarch, Musselburgh, Dunedin Airport, Palmerston and Orari maintained a general downwards trend, Maungatua (only a few kilometres away from Dunedin Airport) maintained a slight upwards trend and Winchmore also showed an upwards trend.

For those sites in the centre of the island, Ranfurly generally showed no trend but the others either changed from a slight positive trend for the longer record to a slight negative trend for the shorter record (Lindis Crossing, Bannockburn),or a slight negative trend to an increasing negative trend (Matakanui, Alexandra, Tekapo).

For the more western and most southern sites, all sites had a positive or no trend with the longer period of record and a negative trend with the shorter period of record, although Milford Sound had no real trend in the longer period.

From the brief rainfall analysis, there is no real sign of an increasing rainfall trend as predicted by the climate change scenario for the Manuherikia Valley area.

6.6 Possible Future Impacts of Climate Change

The key elements of climate change that could impact on irrigation in Central Otago is temperature and rainfall. The previous discussion shows that currently there are no signs of climate change neither in temperature nor rainfall. However, the predictions are for a 2^{o}C rise in temperature and a 5-10% increase in rainfall.

With regard to temperature, the prediction is that winter has the greatest warming and spring the least, but the range is from1.8 – 2.2^{o}C over all seasons. From this information, it appears the region which can already be quite hot during the irrigation season is likely to get hotter resulting in a greater irrigation requirement by 2090 if this average climate change scenario occurs.

An increase in temperature should result in an increase in evaporation from the lake surface. However this is likely to be offset by the predicted increase in rainfall for the area so the overall effect on evaporation from the lake is likely to be negligible..

Rainfall is expected to increase between 7.5 – 10% on an annual basis with the greatest increases in winter (10 – 15%) and spring (5 – 10%) and autumn with the lease increase (0 – 5%). The possible increase in temperature causing a greater irrigation requirement may be offset to some extent by the increased summer rainfall. Autumn average irrigation demands are likely to stay the same.

The winter and spring increases in rainfall are likely to assist with filling irrigation storages over this period giving better reliability to schemes where storage has occasionally failed. It could also allow for more storage to be constructed which could allow increase in area to be irrigated. However, it should be noted that the discussion on rainfall in the previous section shows that this increase could be off-set at times by the SOI and IPO and any proposed increase in storage capacity would need to take this into account.