Natural Flow Relativities and Travel Times Between Water Level Recorder Sites on the Manuherikia River

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Flow and Volume Relativities Between Sites

General

There are six continuous water level and flow recorder sites on the main stem of the Manuherikia River. The sites include:

- Manuherikia Downstream of Forks (catchment area 174 km^2)
- Manuherikia at Falls Dam Downstream (catchment area 374 km^2)
- Manuherikia at Downstream Dunstan Creek Confluence (catchment area 539 km^2)
- Manuherikia at Ophir (catchment area 2145 km^2)
- Manuherikia at Chatto Creek u/s (catchment area 2193 km^2)
- Manuherikia at Campground (catchment area 3016 km^2)

The Manuherikia at Downstream Dunstan Creek confluence has only 18 months of record so will not be used in this analysis.

The Manuherikia at Chatto Creek u/s has close to 5 years of record but is a temporary site, only gauged over the summer season and has a maximum gauged flow of 12 cumecs. This raises questions over its ratings especially in the winter months which is the period of record being used in this analysis. As a result, this site will also not be used in the flow and volume relativities between sites.

Each of the other 4 sites has varying record length and two of the sites have been installed, removed, and reinstalled so the records have gaps in them. These are shown in Table 1. Also included in Table 1 are the lengths of the reaches between each site and the average slope in each reach. Because the Falls Dam records begin in 1999 and Campground starts in 2008, data at the Forks and Ophir sites were restricted to that during the period 1999 to present.

Except for the Manukerikia Downstream of Forks site, there is extensive modification of flows due to irrigation abstraction and winter power generation. Irrigation abstraction is mainly confined to the period September to April.

During winter, Pioneer Generation is permitted to release up to 4 cumecs from Falls Dam for power generation purposes further modifying the outflows from Falls Dam. Power generation during the irrigation season is from the water released from Falls Dam for irrigation purposes.

As a result of these modifications, natural flow conditions will occur only in the winter period 1 May to 31 August and for this analysis, the period is shortened to 10 May to 31 August. The extra 10 days allows the river to adjust to the cessation of irrigation in both the main stem and the tributaries. In addition, the data in this period is also reduced when comparisons are undertaken between the Falls Dam Downstream site and those immediately upstream and downstream of that site including Manuherikia Downstream of Forks and Manuherikia at Ophir because the flows from Falls Dam are only natural when the dam is full and spilling.

Table 1. Recorder Sites Information (various)

Manuherikia River Site	Catchment Area (km^2)	Record Length	Distance Between Sites (km)	Average Slope (m/km)
Forks	174	May 1975 to Dec 1993, Mar 1999 to Apr 2004, Sep 2008 to Sep 2010, Jun 2016 to Feb 2021	–	–
Falls Dam	371		11.7	10.7
Falls Dam d/s	374	Feb 1999 to Jun 2014, Jun 2019 to Dec 2020	2.2	15.6
D/S Dunstan Confluence	539	January 2019 to present	19.3	7.1
Ophir	2145	Feb 1971 to Aug 2021	23.6	4.2
Chatto Ck Confluence u/s	2193	Dec 2017 to Jan 2021	12.7	9.4
Campground	3016	Oct 2008 to Aug 2021	13.0	3.0

There were also restrictions on the data used due to questions over ratings because high flows were not gauged. For the Manuherikia Downstream of Forks, the highest gauging in the period of record between 1999 and the start of the recent record was 6.942 cumecs. This means that flows greater than 8 cumecs were excluded from the analysis. A gauging of 43.47 cumecs has been undertaken in the recent period of record but this is at a different site to the previous records, it cannot be retrospectively applied, and is therefore not valid for the previous records.

For the Manuherikia at Falls Dam Downstream site, the highest gauging was 36.775 cumecs. Therefore, any winter flows in excess of 38 cumecs will be excluded from this analysis.

At Ophir, the highest gauging was 98.86 cumecs so flows in excess of 100 cumecs will be excluded from the analysis.

At Campground, there are no restrictions since flows in the gauging tables exceed 400 cumecs.

Flow and Volume Relativities Between Sites

To determine the increase in flow between mainstem Manuherikia River sites, only natural data are used. This results in a significant reduction in data availability since only that data between 10 May and 31 August are available.

For analyses involving the Falls Dam Downstream site, the data used needed to be that when Falls Dam was full and spilling.

Relationship Between Manuherikia Downstream of Forks and Manuherikia Downstream of Falls Dam Sites

km

There is an area increase of 200 km^2 between the Forks (174 km^2) and Falls Dam (371 km^2) sites. Analysis of the data showed that flow contributions from upstream of the Forks site and the 200 km^2 area to the Falls Dam Downstream water level recorder are similar (see Table 2) with the Forks site contributing 49% of the total flow at the Falls Dam Downstream recorder and the remaining 200km^2 contributing 51%.

The analysis used 419 days of the 942 days available for the analysis. For the remaining 523 days, Falls Dam was not full which results in flows downstream of Falls Dam not being natural and, on a few occasions, daily flows exceeded their rating accuracy and were removed.

Note that the 419 days of flows at the Falls Dam Downstream site used here are natural but are modified by dam routing.

The linear relationship between daily mean flows at the two sites is usable but not great possibly due to flow modification because of the dam routing effects.

Table 2 summarises the results.

Relationship Between Manuherikia Downstream of Falls Dam and Manuherikia at Ophir Sites

Like the previous comparison, the daily flow data used was restricted to those days when Falls Dam was full and outflows from that site were natural.

The Manuherikia at Ophir site has an area almost 6 times larger than the Falls Dam site (Falls Dam 374 km^2 and Manuherikia at Ophir 2145 km^2) and includes the Ida Valley (about 806 km^2) which will occasionally have different weather and flow conditions to the area upstream of Falls Dam.

Based on daily mean flows and under natural conditions, flows passing through the Falls Dam Downstream site provide around 35% of the total flow measured at Ophir.

The analysis used 721 days of the 1721 days available for analysis. For the remaining 1000 days, either Falls Dam was not full and flows downstream of Falls dam were not natural or daily flows in the Manuherikia at Ophir exceeded 100 cumecs and were excluded as discussed earlier.

The linear relationship between daily mean flows at the two sites is not good possibly mainly due to the 83% catchment area increase. This increased catchment area includes both the Dunstan and Lauder Creeks catchments which may provide similar patterns of flows as the

Manuherikia upstream of Falls Dam but also includes the Ida Valley which may possibly provide quite a different input to Ophir flows than the other contributing catchment area.

Relationship Between Manuherikia at Ophir and Manuherikia at Campground

There is a 40% increase in catchment area between the Ophir and Campground sites but flow increases only about 20%. The flow increase would likely be higher if the full Manor Burn catchment was contributing to flows but the highest yielding 20% of the Manor Burn catchment is cut off at the Upper Manor Burn Dam site and only leakage from the main race is available from the 97.4 km Upper Manor Burn catchment.

The natural daily mean flow comparison shows that for all natural data (1346 days out of 1368 days available), the catchment upstream of Ophir contributes 81% of the flow measured at the Campground site.

For natural flows less than 10 cumecs, the flows at Ophir contribute about 87% of the Campground flows.

The linear relationship between the two sites is acceptable.

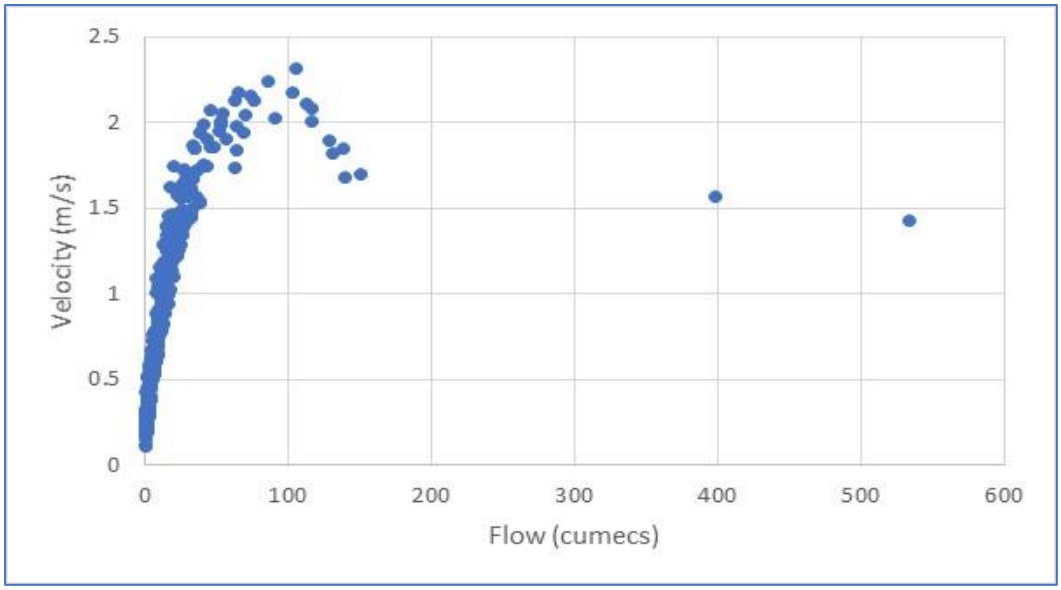
Table 2. Contributions of Upstream Sites to Downstream Sites

Manuherikia Reach	Mean Flow (cumecs)		Contribution (%)
Forks to Falls Dam d/s	Forks	Falls Dam d/s	
	3.00	6.09	49
Falls Dam d/s to Ophir	Falls Dam d/s	Ophir	
	7.63	2.11	35
Ophir to Campground	Ophir	Campground	
	17.92	22.04	81

Travel Time Between Recorder Sites

Travel times between sites depends to a large extent on the volume of flow, slope of the channel (Table 1) and the roughness of the channel bed as flows increase. Constrictions such as flows entering a gorge can cause water velocities to slow if the flows are very high and pooling occurs at the top end of the gorge. This appears to be the situation with the Manuherikia at Ophir site. Figure 1 shows velocity plotted against measured flow at the Ophir recorder site. When flows reach greater than 110 cumecs at Ophir, average velocities at the gauging site begin to slow presumably because the gorge immediately downstream of the Daniel O'Connell Bridge causes some pooling of the water trying to enter the Gorge at such high flows.

Figure 1. Manuherikia River Velocity vs Flow at Ophir



In the Manuherikia, slopes between recorder sites can vary considerably as shown in Table 1. Slopes within reaches also vary as is the case for the total reach Ophir to Campground (see Table 3). In Table 3, Ophir is at an elevation of 300m above mean sea level (amsl) and Campground is at 140m amsl.

Table 3. Varying Slopes in the Reach Ophir to Campground

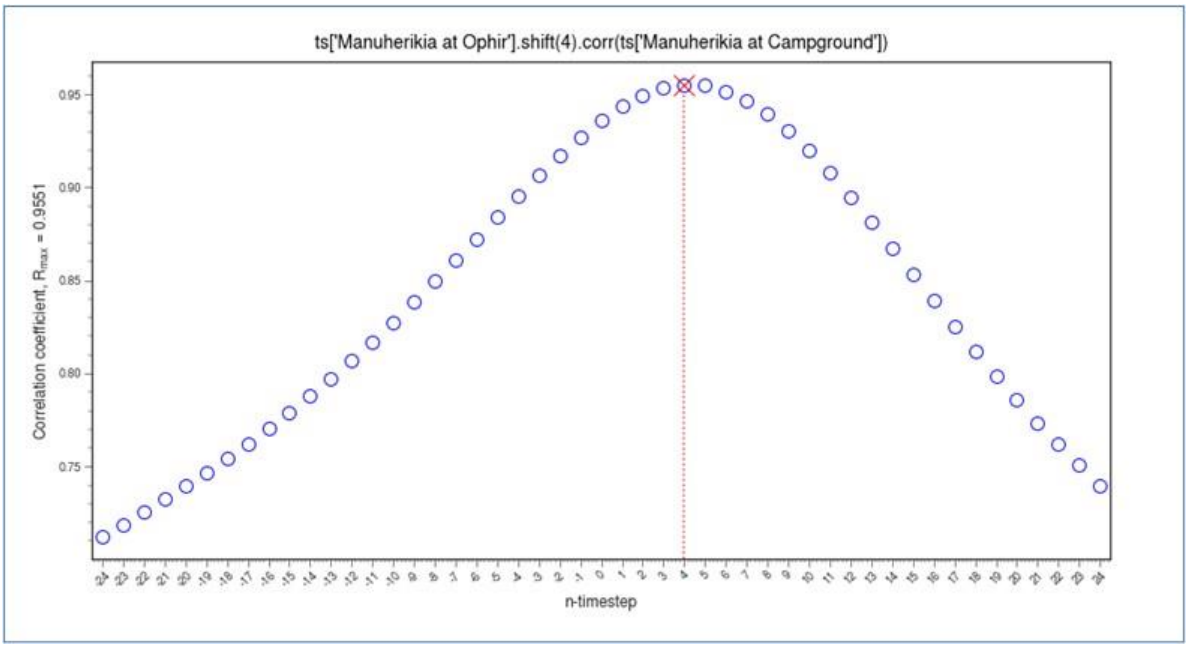
Elevation Change (metres above mean sea level)		Reach Distance (km)	Slope (m/km)
Ophir	300 – 280	2.3	8.7
	280 – 260	1.9	10.5
	260 – 240	1.5	13.3
	240 – 220	0.8	25.0
	220 – 200	1.8	11.1
	200 – 180	2.5	8.0
	180 – 160	6.4	3.1
	160 – 138 Campground	8.5	2.4

Two methods for calculating velocities between sections were used. The first was a computer analysis, and the second used observations from Roger Williams of the Omakau Area Irrigation Company and flow velocities from flow gaugings at the various gauging sites.

Computer Analysis

Xiaofeng Lu (Otago Regional Council) undertook analyses using all data points at each site and correlating them in pairs against each other. The analysis involved various lags in flows between upstream and downstream sites. The result was a bell-shaped curve for each set of correlations with the best R^2 correlations between the two sites at the apex of the curve. Figure 2 shows an example.

Figure 2. Example of Computer Output



The results of this analysis are included in Table 4. Note that correlations involving the Falls Dam Downstream recorders will correlate well only when the dam is full, and any flood peaks will pass through the storage. The peaks will be modified on what initially entered the dam. Table 4 shows a range of values because it is not possible to be precise as can be seen in Figure 2. The values either side of the chosen time are very similar to the one chosen. The size of the flood channel slope and bed roughness will vary and as a result, so too will the travel times be depending on the magnitude of the flood.

Table 4. Calculated Travel Times for High Flows in the Manuherikia River.

Manuherikia Site	Lag Time from Manuherikia d/s Forks (hours)	Lag Time Between Sites (hours)	Distance Between Sites (km)	Average Slope Between Sites (m/km)	Average Velocity Between Sites (m/s)
d/s Forks	–	–	–	–	–
Falls Dam d/s	5 – 7	5 – 7	16.6	7.1	0.92 – 0.66
Ophir	10 – 12	5 – 7	42.9	4.7	2.38 – 1.70
Chatto Ck u/s	11 – 13	1 – 3	12.7	9.4	3.53 – 1.18
Campground	13 – 15	2 – 4	13.0	3.1	1.81 – 0.90

Generally, the velocities in Table 4 are acceptable but the velocity of 3.6m/s for the 1-hour travel time between the Ophir and Chatto Creek u/s sites is questionable. Velocities of that magnitude would be very unusual.

Low Flow Velocities Analysis

Information provided by Roger Williams (Omakau Area Irrigation Scheme) is contained in an email dated 6 October 2021 which summarises the analysis he undertook to calculate the travel times from Falls Dam to the Campground site. He states:

"*During normal operations, a release from Falls Dam takes 13 hours to Ophir flow site. This is the initial increase and it takes two hours for the full release to arrive. Another 13 hours to get to Campground, plus two hours to get the full flow. So 26 hours from Falls Dam to Campground plus two hours to get full flow."*

Table 5 shows the results of the analysis carried out by Roger Williams. The measurements were made from the Otago Regional Council's recorder sites, the flow at the Campground site was about 1 cumec at the time of the release, and the release was around the maximum of 4 cumecs.

Table 5. Travel Times and Velocities Ophir to Campground

River Sites	Time for Arrival of Initial Increase (hours)	Time for Full Release to Arrive (hours)	Average Velocity in the Reach (m/s)	
			First Arrival	Full Release
Falls Dam d/s to Ophir	13 Hours	15 Hours	0.92	0.79
Falls Dam d/s to Campground	26 hours	28 hours	0.73	0.68
Ophir to Campground	13 Hours	15 hours	0.55	0.48

The travel times in Table 5 were compared to average velocities for flows gauged at the various recorder sites down the river. The average velocities at these sites will be, at best, indicative only for the full reach between each site. Gaugings are undertaken in a section in the reach which is best suitable for laminar flow and a riverbed cross-section that is not too rough. These sections may not be typical of the reach upstream of the gauging section so average velocities of the gaugings are indicative only.

In addition, an average gauging velocity is the average over the whole cross-section including water at either edge of the cross-section where it can be very shallow and slow moving. So, a gauging's average velocity may underestimate travel times through river reaches depending on how representative the gauging section is of the rest of the upstream reach.

Gaugings show that at 5 cumecs, the average velocity at the Falls Dam Downsteam site is about 0.32 m/s, at Ophir about 0.55 m/s, at Chatto Creek u/s site about 0.50 m/s and at Campground, about 0.55 m/s.

The average gauged velocities are about or less than the calculated velocities from Roger Williams analysis. The velocity at the Ophir site is significantly less than that calculated by Mr Williams but analysis of the slope in the reach from Falls Dam Downstream to Ophir shows that the slope varies considerably (see Table 6). The reach immediately upstream of Ophir has the least slope and this is likely the reason average gauging velocities are much lower.

Table 6. Slope in the Reach Falls Dam d/s to Ophir

Elevation Difference (m)	Reach Length (km)	Slope (m/km)
500 – 480	2.6	6.9
480 – 460	2.9	6.9
460 – 440	3.4	5.9
440 – 420	3.1	6.4
420 – 400	4.7	4.3
400 – 380	2.6	7.7
380 – 360	4.4	4.5
360 – 340	3.6	5.6
340 – 320	2.5	8.0
320 – 300	10.0	2.0

Summary and Results

In determining flow contributions from upstream catchment areas to downstream water level and flow measuring sites, concurrent records needed to be identified and only the winter period (defined here as 10 May to 31 August) data could be used as all records outside of that period were likely to be affected by irrigation abstraction. In addition, calculations involving the Manuherikia at Falls Dam Downstream site had a further restriction on available data and only those data when Falls Dam was full and spilling could be used.

The results were that:

- the catchment area upstream of the Manuherikia Downstream of Forks site contributes about 49% of the flow measured at the Manuherikia at Falls Dam Downstream recorder site:
- the catchment area upstream of the Manuherikia at Falls Dam Downstream recorder site contributes about 35% of the flow measured at the Manuherikia at Ophir site recorder site:
- and the Manuherikia at Ophir recorder site contributes about 81% of the flow recorded at the Manuherikia at Campground recorder site.

Travel times between water level recorder sites depend mainly on the volume of flow, channel slope and bed roughness. Generally, the greater the flow, the greater the velocity between recorder sites.

A computer analysis of flood peaks showed the lag time between flood peaks at the following sites:

- between 5 and 7 hours from the Manuherikia Downstream of Forks to Manuherikia at Falls Dam Downstream sites (average velocity 0.92 – 0.66m/s):
- between 5 and 7 hours from the Manuherikia at Falls Dam Downstream to the Manuherikia at Ophir sites (average velocity 2.38 – 1.70m/s):
- between 1 and 3 hours between the Manuherikia at Ophir and Manuherikia at Chatto Creek Confluence u/s sites (average velocity 3.53 – 1.18m/s):
- Between 2 and 4 hours between the Manuherikia at Chatto Creek Confluence u/s to Manuherikia at Campground sites (average velocity 1.81 – 0.90m/s).

For low flows, reliance was made on timing of a release of 4 cumecs measured at the Manuherikia at Falls Dam Downstream site to reach Manuherikia at Ophir and subsequently Manuherikia at Campground sites with some supporting information from average flow velocities at the individual gauging sites. The results showed that with an initial 1 cumec flow at the Manuherikia at Campground site, a 4 cumec release from Falls Dam and measured at the Falls Dam Downstream site could take:

- between 13 and 15 hours to reach the Manuherikia at Ophir site (average velocity 0.92 – 0.79 m/s):
- and between 26 and 28 hours to reach the Manuherikia at Campground site (average velocity 0.73 – 0.68m/s).

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