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# Manuherikia Valley: Detailed Hydrology

## Prepared for the Manuherikia Catchment Water Strategy Group

**Report C12040/3**

**July 2012**

AQUALINC RESEARCH LIMITED

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| **Quality Control** | | | |
|---|---|---|---|
| Client: | Manuherikia Catchment Water Strategy Group | | |
| Report reference: | Title: Manuherikia Valley: Detailed Hydrology | | No: 3 |
| Prepared by: | Peter Brown | | |
| Reviewed by: | Ian McIndoe | Approved for issue by: | Ian McIndoe |
| Date issued: | April 2012 | Project No: | C12119 |

| **Document History** | | | |
|---|---|---|---|
| Version: 1 | Status: DRAFT | Author: PB | Reviewer: IM |
| Date: 16-07-12 | Doc ID: Manuherikia_Hydrology_DRAFT | Typist: | Approver: IM |
| Version: 1.1 | Status: FINAL | Author: PB | Reviewer: IM |
| Date: 22-09-12 | Doc ID: Manuherikia_Hydrology_FINAL | Typist: | Approver: IM |



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# EXECUTIVE SUMMARY

Raising Falls Dam 6 m will allow for an additional 3,500 ha to be supplied above Ophir, provided existing and new irrigators accept the same level of reliability as they have a present. However if the priority is first to provide existing irrigators with high reliability, then no additional land could be supplied. Raising Falls Dam 15 m would allow an additional 6,000 ha to be supplied above Ophir, while providing high reliability for both new and existing irrigators. Raising Falls Dam 27 m would allow an additional 15,000 ha to be supplied above Ophir, while providing very high reliability for both new and existing irrigators. Irrigated area estimates include an allowance for increased Manuherikia main-stem minimum flows to off-set water quality risks associated with land use intensification. A greater area could be irrigated if a lower level of reliability, or lower minimum flows than we assumed, were acceptable.

**Irrigated Area Potential**

| Option | Irrigation reliability | New irrigated area (ha) | Minimum flow increase (l/s)* |
|---|---|---|---|
| Status quo. | Existing | 0 | |
| Raise Falls Dam 6 m | Existing | 3,500 | 300 |
| Raise Falls Dam 6 m | Good | 0 | 0 |
| Raise Falls Dam 15m | Good | 6000 | 500 |
| Raise Falls Dam 27m | V. Good | 15,000 | 1,000 |
| *Increase in Manuherikia main stem minimum flows | | | |

Raising Falls Dam will result in only modest increases in generation revenue; consequently the cost of raising the dam would need to be borne primarily by irrigators. Increases in power revenue should be sufficient to fund necessary power infrastructure upgrade costs, however it is unlikely power generation could contribute any significant amount to dam construction costs. In general, the value of water for power generation is an order of magnitude less than the value of water for irrigation.

**Power Generation Potential**

| Option | Average annual revenue | Increase in revenue |
|---|---|---|
| Status quo.<br>4 $m^3$/s turbine capacity | $690,000 | N/A |
| Raise Falls Dam 6 m & 3,500 ha of new irrigation.<br>4 $m^3$/s turbine capacity | $800,000 | $110,000 |
| Raise Falls Dam 6 m & no new irrigation.<br>4 $m^3$/s turbine capacity | $830,000 | $140,000 |
| Raise Falls Dam 15m & 6,000 ha of new irrigation.<br>6 $m^3$/s turbine capacity. | $1,300,000 | $610,000 |
| Raise Falls Dam 27m & 15,000ha of new irrigation.<br>6 $m^3$/s turbine capacity. | $1,360,000 | $670,000 |
| Raise Falls Dam 27m & no new irrigation.<br>6 $m^3$/s turbine capacity. | $1,780,000 | $1,090,000 |

A review of Falls Dam existing flood capacity supports previous conclusions the dam should be able to pass a major flood with a peak flow of 550 – 600 $m^3/s$. This capacity is in excess of a 1 in 500 year flood event, which is conservatively estimated to be 450 $m^3/s$. We cannot however exclude the possibility a more extreme Maximum Probable Flood event could exceed the dam's spillway capacity, resulting in the dam being overtopped.

# 1 Introduction

## 1.1 Project overview

The Manuherikia Catchment Water Strategy Group (MCWSG) was set up to develop and oversee the implementation of a water strategy for the catchment. The MCWSG has proposed that a project be undertaken in three sections to:

(i) Define the potential irrigation demand in the Manuherikia River catchment (land),
(ii) Provide an initial assessment of the water availability for meeting this demand (hydrology), and
(iii) Options to close the gap between supply and demand (options).

The project has been broken into two parts, Part A (Sections (i), (ii) and (iii a)) and Part B (Section (iii b)). Part A provides the initial big-picture information to understand the overall water resources in the catchment. Part B looks in more detail at specific options to progress water resources development. The MCWSG envisages that the project will provide information to help the community make informed decisions, leading to a comprehensive Manuherikia Catchment water strategy. Figure 1 provides an overview of the study.

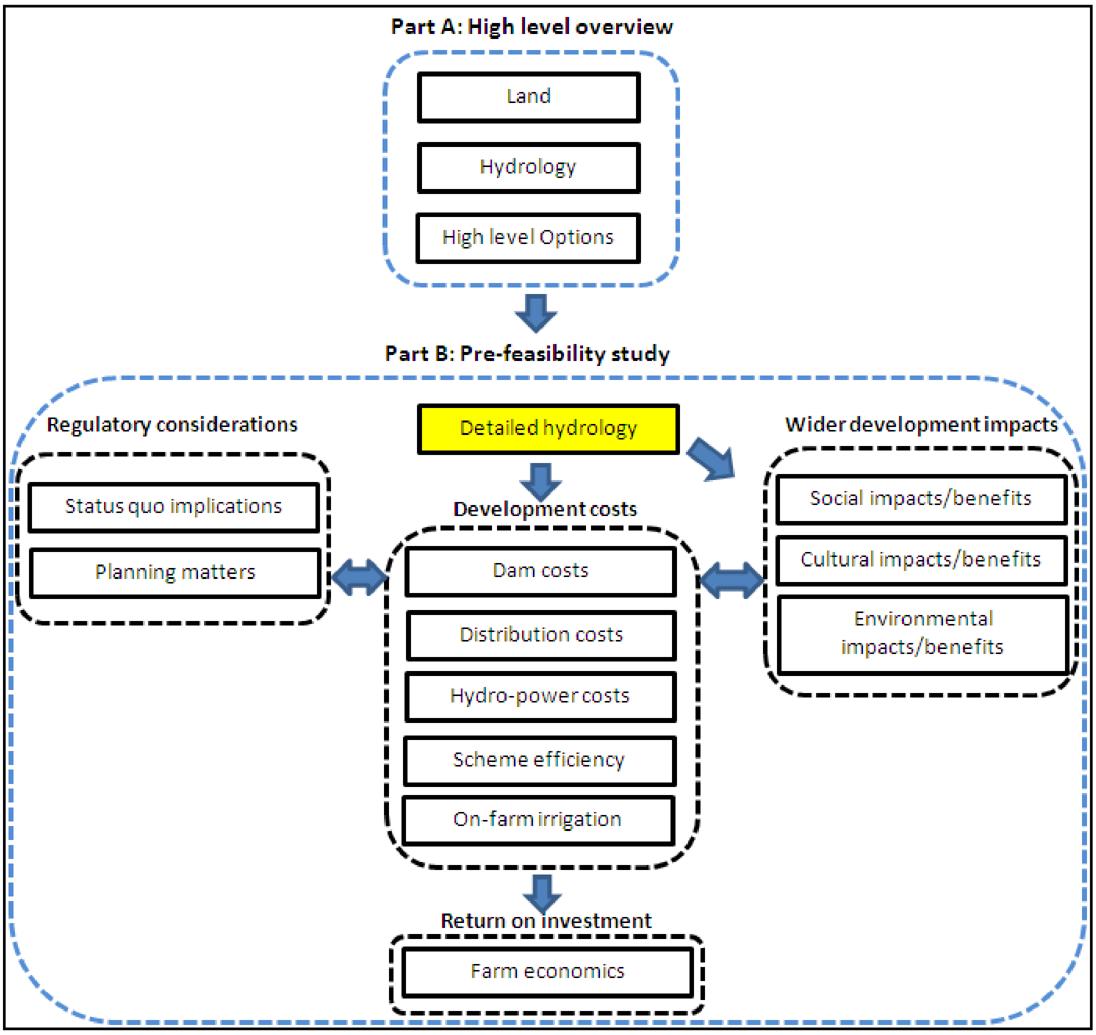



*Figure 1: Manuherikia Catchment Study overview*

This detailed hydrology report, builds on the Part A high level hydrology study. This report includes:

- Detailed Falls Dam storage daily timeseries modelling;
- Manuherikia Valley catchment modelling, including the impact of development options on river flows;
- Flood flow analysis; and
- Falls Dam power generation modelling.

A separate report will provide further details on the Manor Burn catchment hydrology, including Hope Creek, Little Valley Creek west, and Lower Manor Burn dam storage timeseries modelling.

This report should be read in conjunction with the Part A hydrology study. Results from this study will be used latter in the project in infrastructure design, and in environmental and cultural assessments.

## 1.2 Part A hydrology conclusions

The Part A hydrology study was a 'big-picture' view of the catchments water resources. Key conclusions from this study were:

The Manuherikia River has a mean naturalised flow at the Clutha River confluence of 18.5 $m^3$/s or 585 $Mm^3$/y. Irrigation reduces the flow by up to 8 $m^3$/s, although averaged over a year the reduction is about 2.7 $m^3$/s or 85 $Mm^3$/y. In dry years, irrigation abstraction can reduce flows at the confluence to below 1.0 $m^3$/s. Flows in the Manuherikia River are highest from June to November, and lowest in February and March.

Currently, about 25,000 ha of the Manuherikia catchment is irrigated. Of this 25,000 ha, only about 15,000 ha is fully irrigated. Water scarcity means the remaining 10,000 ha is only occasionally irrigated, in some cases as little as 2-3 times per year. The current area of irrigation is well short of the potential 60,000 ha of irrigable land identified in the Stage 1 study.

The Manuherikia Catchment is water-short in dry years. Water scarcity means it is unlikely the full 60,000 ha of irrigable land could be irrigated with water from the Catchment alone. The availability of reliable water rather than suitable land is the primary constraint on future irrigation development.

Total water allocated within the Manuherikia catchment is over 27 $m^3$/s and is several times in excess of the water available during low flow periods. Actual water use is closer to 8 $m^3$/s during periods of peak irrigation demand. Actual water use is much less than the consented allocation, because often the consented flow is unavailable. There is no remaining reliable run-of-river water. Therefore, any new irrigation water will need to come either from efficiency improvements, the Clutha River, or from new storage dams.

Improvements in irrigation efficiency will achieve only a modest increase in the irrigated area. Improvements in efficiency in the lower Manuherikia catchment below Ophir, would allow at most an additional 2,000 ha of irrigation. Above Ophir, any improvements in efficiency will not make additional water available for irrigation. The reason is because overall irrigation efficiency above Ophir at a catchment scale is already very high because any losses re-enter the Manuherikia River and are available for downstream use by the Manuherikia and Galloway irrigation schemes.

Existing dams provide about 36 $Mm^3$ of stored water per year. This is about 7% of the average annual flow of the Manuherikia River at the Manuherikia/Clutha confluence. The majority of usable storage is provided by the Falls, Pool Burn, and Upper Manor Burn dams. Usable storage in Falls Dam is limited by the dam's height. In contrast usable storage in the Pool Burn and Upper Manor Burn dams is primarily limited by inflows and raising these dams will not make more water available.

## 1.3 Study Funding and Contributors

This study has been made possible by the generosity of the following who have contributed by way of direct funding or by in-kind contributions. MCWSG are grateful for this support and wish to thank the following:

- Ministry of Primary Industries with funding via the Irrigation Acceleration Fund
- The Otago Regional Council
- The Central Otago District Council
- The Manuherikia Community

# 2 Manuherikia Valley Model

## 2.1 Overview

In our Stage 3a report (Aqualinc 2012c) raising Falls Dam was identified as the most promising option for making a large amount of new water available for irrigating the Upper Manuherikia Valley. In order to model the effect of raising Falls Dam we constructed a daily time step model of the Manuherikia Valley. We modelled the period from June 1973 to Map 2011, a period of 38 years. The model is illustrated in Figure 2.

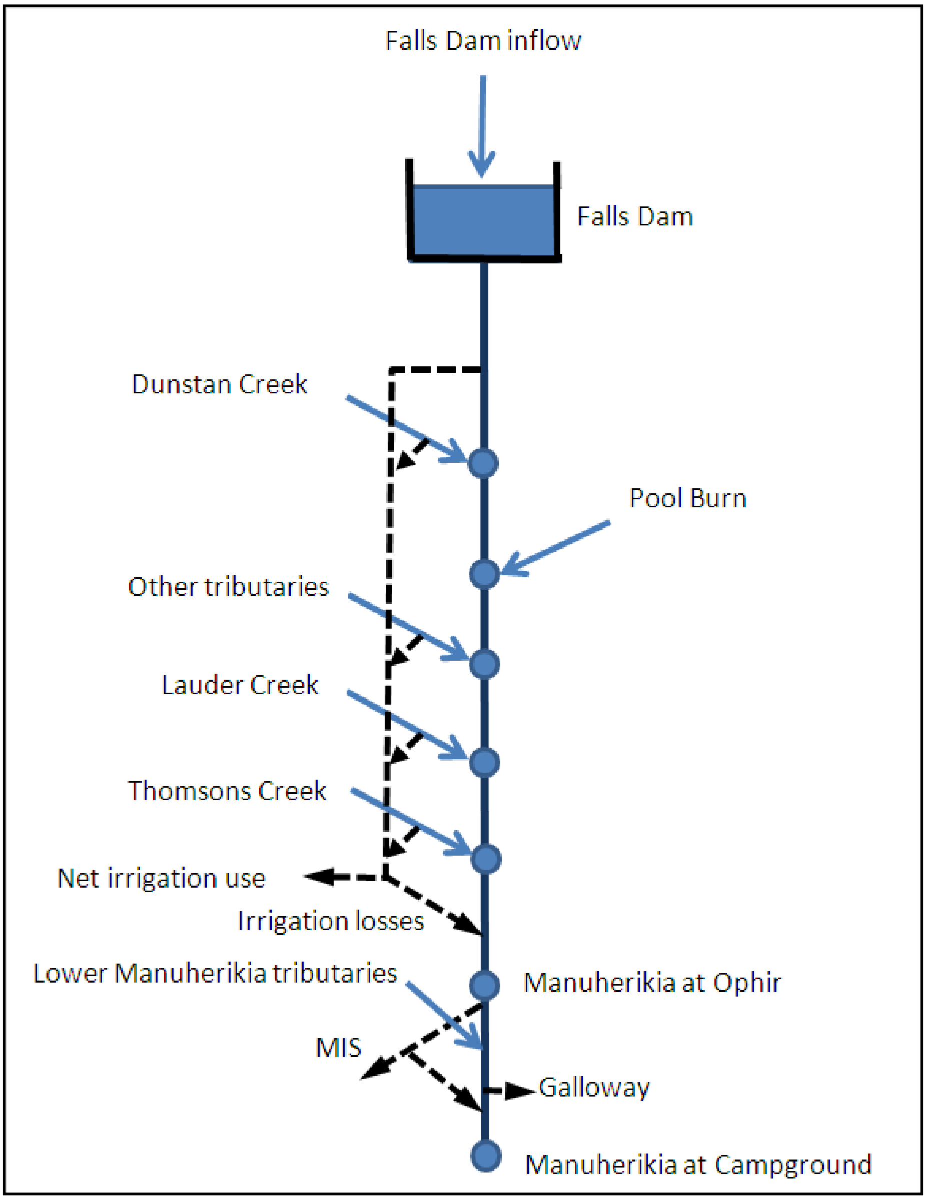



*Figure 2: Manuherikia Valley daily time-step model*

The best and longest flow record in the Manuherikia Catchment is on the Manuherikia River at Ophir. Near continuous flow records are available at this site from 1971 to the present. Flow accuracy at this site is good for both high and low flows. The difficulty with the Ophir flow record from a modelling perspective is that it is significantly affected by upstream irrigation abstraction and Falls Dam operations. In modelling we attempted to reconstruct what the flows in the Manuherikia tributaries would have been if there was no irrigation in the Upper Manuherikia Valley and if Falls Dam did not exist. We then added a model of how irrigation and Falls Dam may have affected these naturalised flows. The resulting reconstructed flows at Ophir were then compared with actual measured flows at Ophir. Overall, the modelled [reconstructed] flows showed a reasonable fit with measured flows at Ophir (see Figure 3 and Appendix F).

Our model assumes the amount of water taken by Mt Ida Race will not change significantly in the future. If additional water were taken from this race in the future, there would be a reduction in the water available in the Manuherikia Valley. This may have some impact on the potential irrigated area.

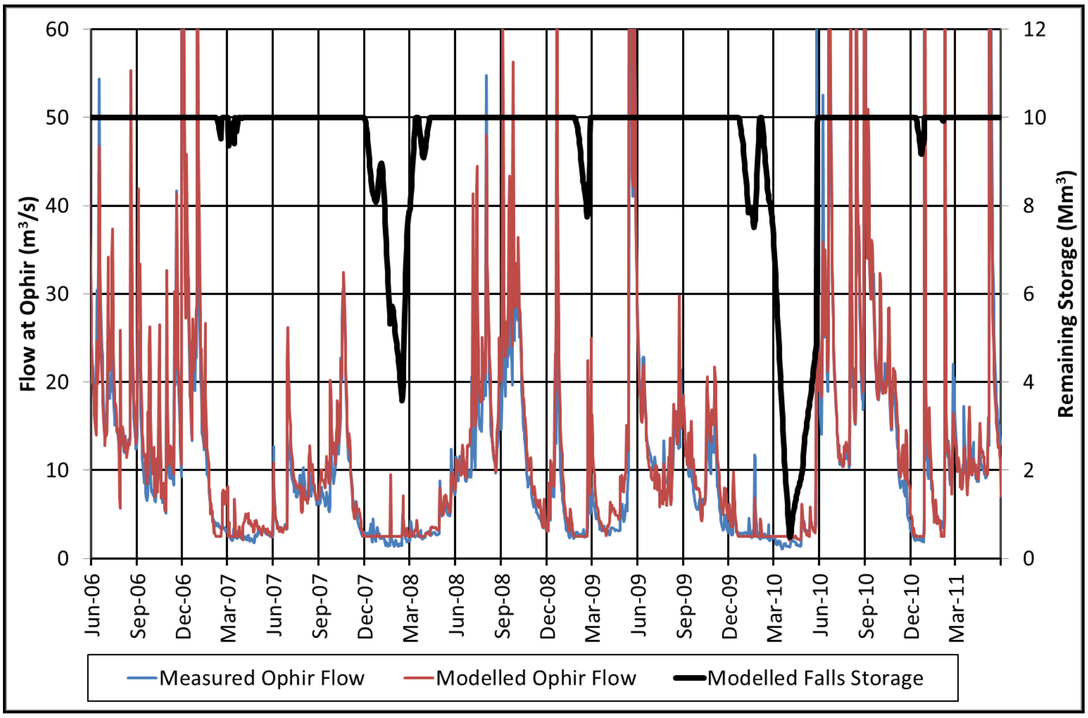



*Figure 3: Comparison between measured and modelled flows at Ophir*

## 2.2 Inflows

Our model included the following Manuherikia River tributaries:

- Manuherikia at Falls Dam;
- Dunstan Creek;
- Lauder Creek;
- Thomsons Creek;
- PoolBurn; and
- All other Upper Manuherikia Valley tributaries above Ophir.

Dunstan, Lauder, and Thomsons Creek inflows were modelled as naturalised flows. Naturalised flows were estimated from flow gauging sites located upstream of any major irrigation takes. Naturalised flow sites were:

- Dunstan Creek at Gorge;
- Lauder Creek at Cattle Yards; and
- Thomsons Creek at Diversion Weir.

Manuherikia at Falls Dam flows were estimated from records at Manuherikia downstream of Forks, and Manuherikia downstream of Falls (corrected for changes in Falls Dam storage). Flows were not completely naturalised, since they include the effects of the Mt Ida Water Race take.

PoolBurn flows were estimated from flow records at Cob Cottage, extended using correlation with flow records at Ophir. Flows were not naturalised, since they include the effects of the Ida Valley irrigation and the Upper Manor Burn and Pool Burn dams.

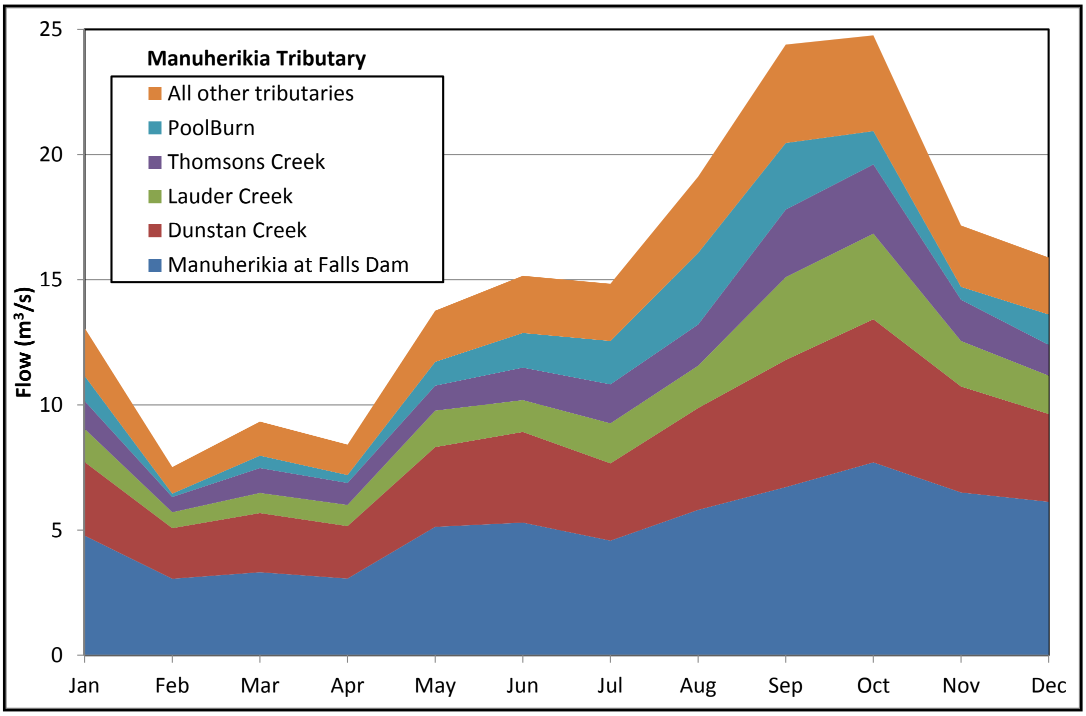



*Figure 4: Modelled average monthly flows at Ophir given no irrigation in the Upper Manuherikia Valley and no Falls Dam*

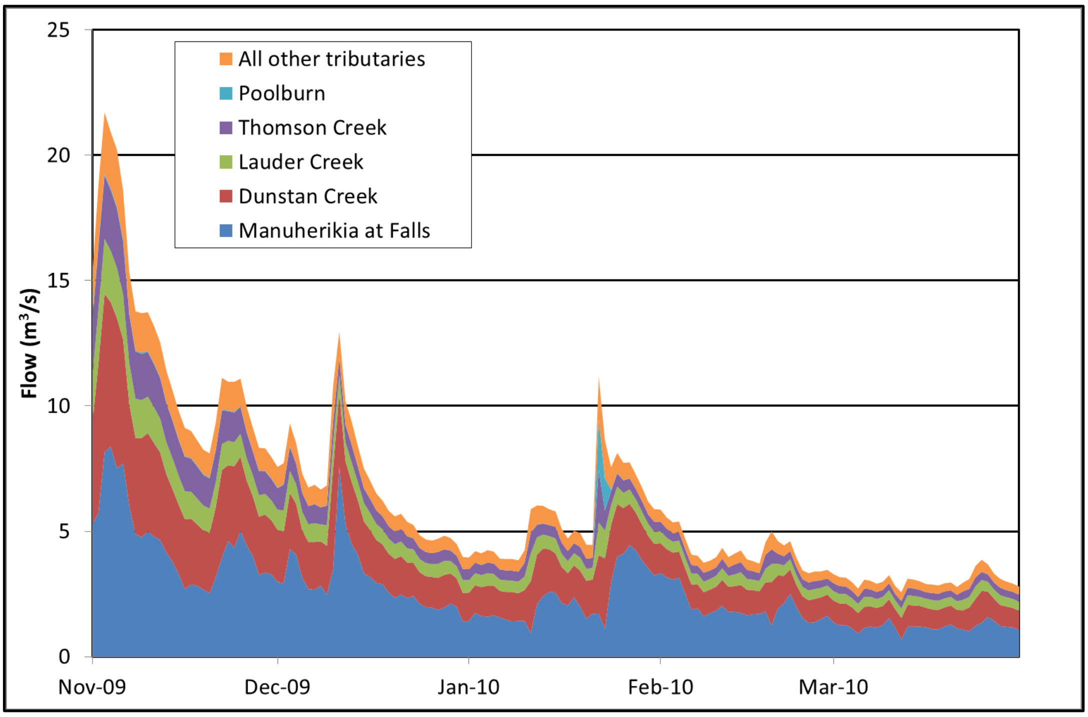



*Figure 5: Modelled flows at Ophir given no irrigation in the Upper Manuherikia Valley and no Falls Dam, during the dry summer of 2009/10*

Tributary flow records contained gaps in the data, and did not extend for the full period from 1973 to 2011. Flows at different recorder sites were correlated, to fill data gaps and extend records. Correlation relationships were calculated for each month to allow differences in seasonal trends at different sites to be maintained. Figure 6 illustrates how the seasonal flow profile for the different tributaries differs. Further details of how records were extended is provided in Appendix D.

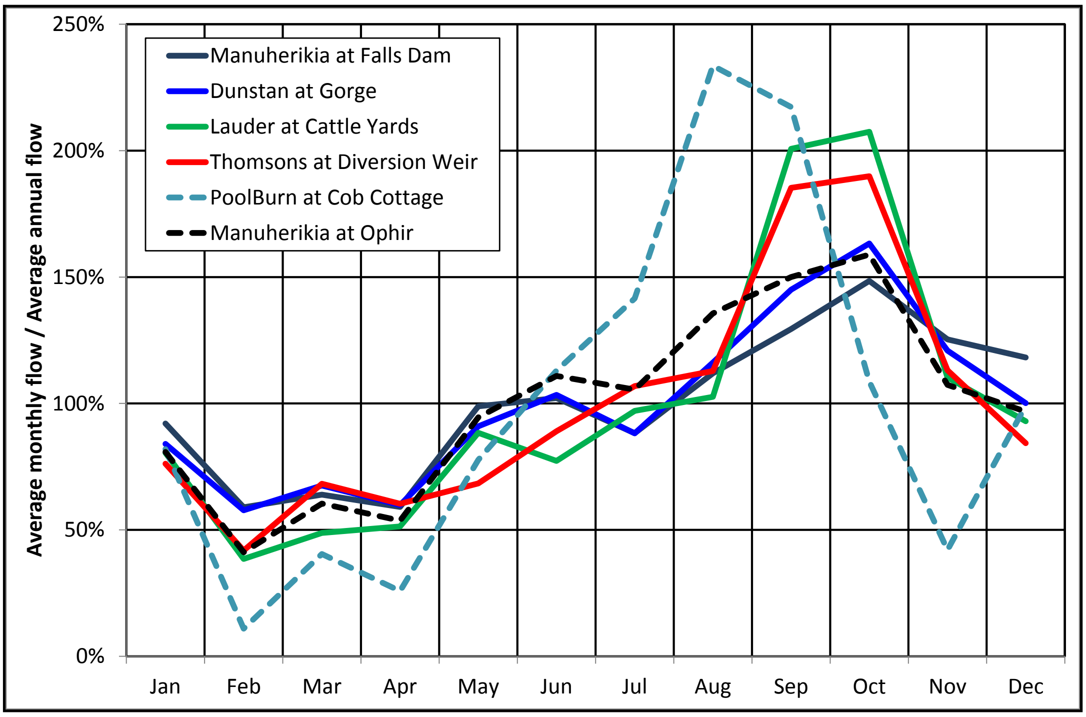



*Figure 6: Seasonal flow profile of Manuherikia River tributaries used in modelling*

## 2.3 Irrigation demand

Our model considered the irrigation water use above Ophir in a lumped manner. Our model did not consider individual irrigation takes or sub-catchment demands. The reason is because the lack of data and high degree of hydrological connection in the Upper Manuherikia Valley means a more detailed model is unlikely to result in more accurate results.

Upper Manuherikia Valley irrigation demand assumed Lauder Flats rainfall and Lauder evapotranspiration. We assumed 50% of the irrigated area was on light soils, and 50% was on medium soils. We modelled the equivalent area of full irrigation, which is the water required to fully irrigate and achieve close to 100% of the potential production. Irrigation demands are illustrated in Figure 7 and Figure 8.

For new irrigation, we assumed the net irrigation demand above Ophir was 80% of the gross irrigation demand, since most losses will re-enter the Manuherikia River before Ophir.

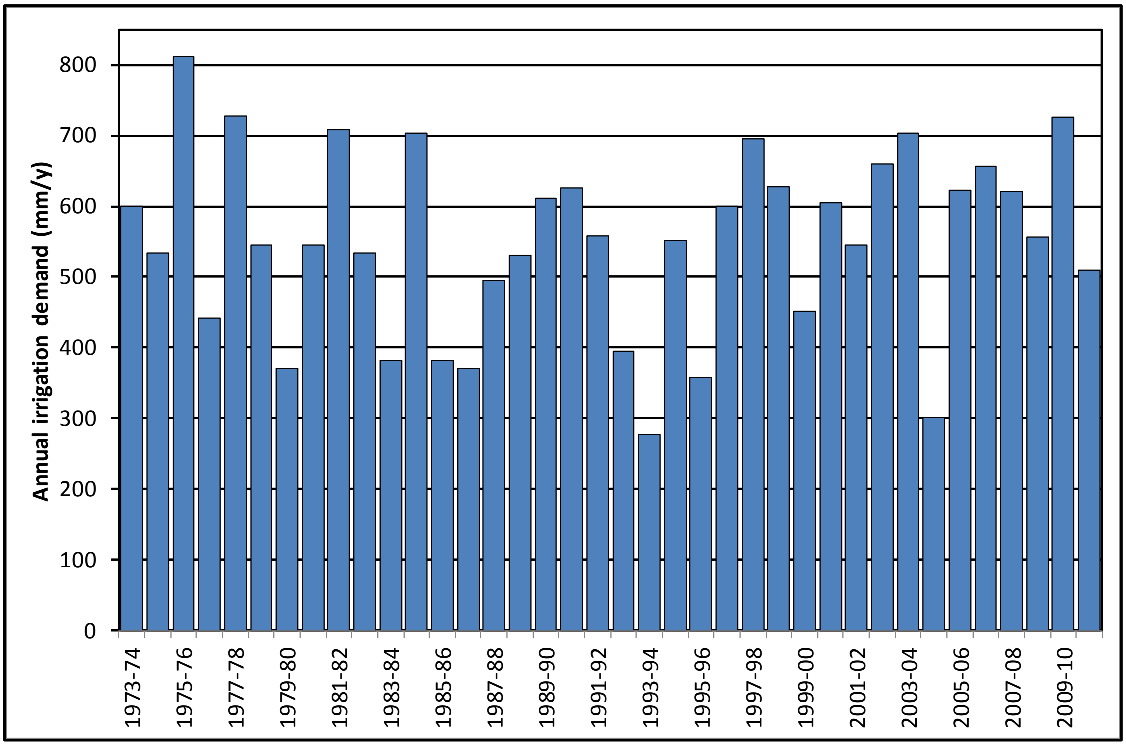



*Figure 7: Modelled annual irrigation demand in the Upper Manuherikia Valley*

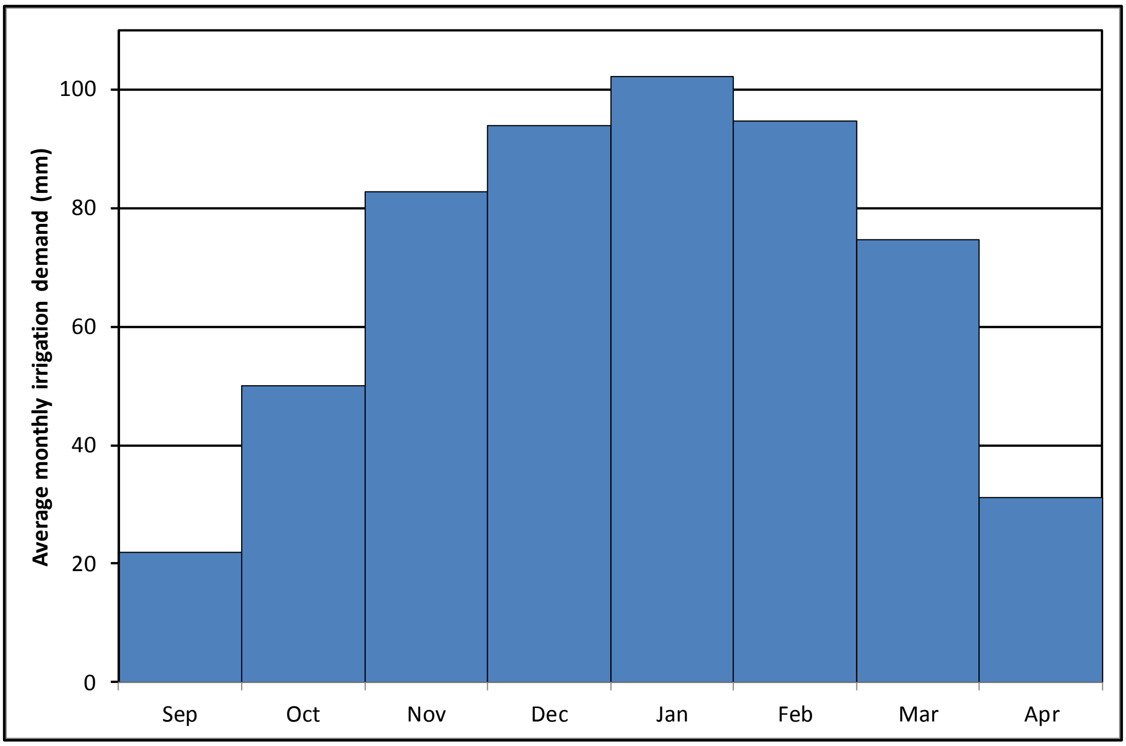



*Figure 8: Modelled average monthly irrigation demand in the Upper Manuherikia Valley*

Modelling assumed there was currently the equivalent of 8,000 ha of full irrigation in the Upper Manuherikia Valley. In practice water is spread much further, with a larger area (perhaps as much as 10,000 to 12,000 ha) being partially irrigated. From a modelling perspective, it makes little difference whether water is spread over a larger area or used to fully irrigate a smaller area, provided the combined gross and net irrigation water use is similar.

8,000 ha of full irrigation corresponds to an abstraction rate in summer of 4 $m^3/s$, which includes a 0.6 $m^3/s$ allowance for private water rights. In our Stage 2 report (Aqualinc 2012b) we previously estimated Omakau and Blackstone irrigation schemes have a combined summer abstraction rate of 3.4 $m^3/s$. Our modelled average annual net irrigation demand in the Upper Manuherikia Valley was 32 $Mm^3/y$. Given an average irrigation efficiency of 60%, this corresponds to a combined average annual abstraction of 54 $Mm^3$ per year.

Further details on irrigation demand modelling is provided in the Stage 1 report (Aqualinc 2012a).

Below Ophir, we assumed a seasonal demand profile for the Manuherikia Irrigation Scheme take as shown in Figure 9. Unlike the Upper Manuherikia Valley, we did not model how irrigation demands may change from year to year. The modelled demand corresponds to an annual water take of 39 $Mm^3$. This is about 10-20% higher than actual recorded water use.

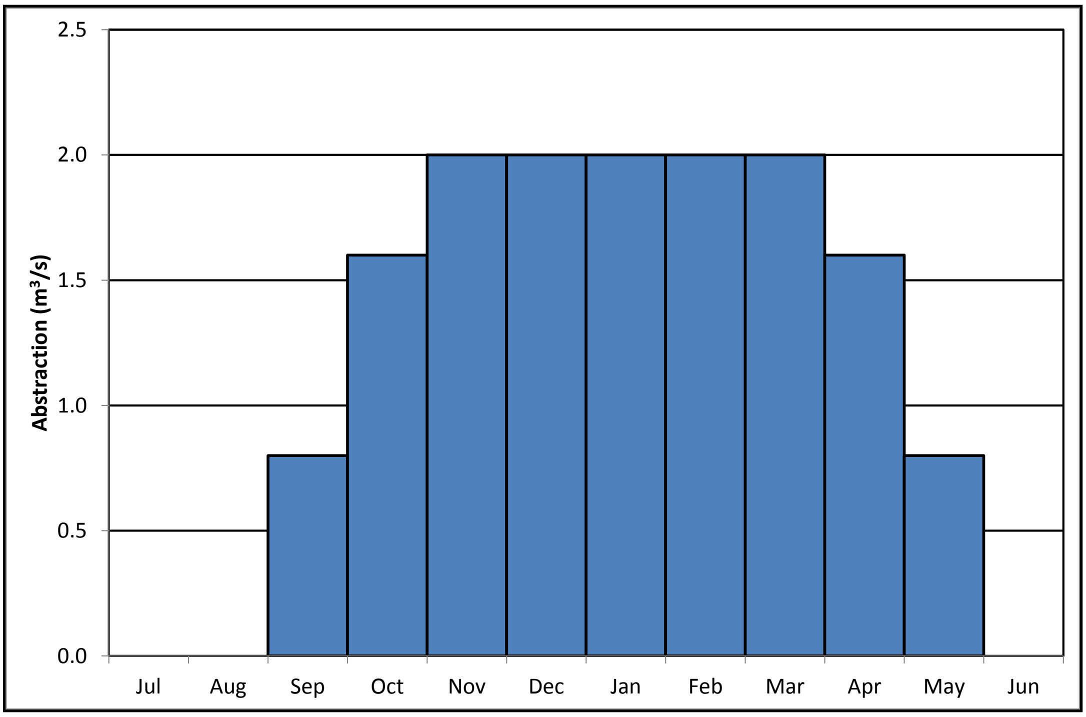



*Figure 9: Modelled Manuherikia Irrigation Scheme irrigation demand*

## 2.4 Residual flows

Currently, most water consents do not contain minimum flow or flow sharing conditions and consequently the amount of water available for abstraction can be up to the entire flow of a particular stream. Otago Regional Council are proposing to impose residual flow conditions on deemed permits when these are converted to RMA consents. Residual flow values have yet to be determined. Minimum flow assumptions used in modelling are given in Table 1.

*Table 1: Residual flows assumed in modelling*

| Location | New irrigation in Upper Manuherikia Valley (ha) | | | |
|---|---|---|---|---|
| | 0 | 3,500 | 6,000 | 15,000 |
| Manuherikia below Falls Dam | 500 l/s | 600 l/s | 1,000 l/s | 1,500 l/s |
| Manuherikia below Omakau intake | 300 l/s | 600 l/s | 800 l/s | 1,300 l/s |
| Manuherikia below MIS intake | 300 l/s | 600 l/s | 800 l/s | 1,300 l/s |
| Manuherikia at Camp Ground(1) | 1,000 l/s | 1,300 l/s | 1,500 l/s | 2,000 l/s |
| Dunstan Creek below Omakau intake | 250 l/s | 250 l/s | 250 l/s | 250 l/s |
| (1) Assumes flows at Camp ground are 500 l/s greater than the flow downstream of the Manuherikia Irrigation Scheme (MIS) take | | | | |

Because of the large amount of return flow in the catchment, and the small low flows, it is difficult to model minimum flows accurately. There is also a lack of historic monitoring of flows downstream of the major intakes. Lower Manuherikia minimum flows are particularly difficult to model. The relative increases in minimum flows should however be accurate.

In modelling, we assumed Manuherikia main-stem residual flows would be increase if there was an increase in the irrigated area. Raising residual flows would reduce water quality risks associated with land use intensification. Raising residual flows would also help off-set negative impacts associated with flows being at the minimum flow for longer periods of time.

## 2.5 Abstraction points

In the model the water available for abstraction in the Upper Manuherikia Valley was approximate as:

*Available Flow for abstraction= Flow below Falls dam –*
*Minimum flow downstream of Omakau Manuherikia intake +*
*Dunstan Creek at Gorge – 250 l/s +*
*Lauder Creek at Cattle Yards +*
*Thomsons Creek at Diversion Weir +*
*20% ×(other gains between Falls and Ophir)*

While this approximation is somewhat simplified, and may not account for individual irrigation takes dynamics, we expect it to be relatively conservative and representative of the catchment as a whole. Modelling water availability in greater detail is difficult due to the lack of data at most intakes.

## 2.6 Falls Dam storage

Raising Falls Dam would significant increase the amount of water available for irrigation. Storage capacity increases exponentially with increasing dam height (refer Figure 10). This exponential increase is due to the wide flat basin above the dam.

In modelling we considered four possible dam height scenarios; the status quo and raising the demand 6m, 15m, or 27 m. We have assumed that as the lake storage is increased, the minimum lake level would be increased to provide for fish habitat. Reserving 10% of the total lake storage for fish habitat may provide significant environmental and recreational enhancement, while only having a minor impact on the water available for irrigation.

*Table 2: Falls Dam storage scenarios*

| Scenario | Spillway crest height (m AMSL) | Total storage ($Mm^3$) | Minimum water level (m AMSL) | Usable storage ($Mm^3$) |
|---|---|---|---|---|
| Status quo | 561.4 | 10.3 | 547 | 10 |
| Raise dam 6 m | 567.4 | 21 | 549* | 20* |
| Raise dam 15 m | 577 | 48 | 556* | 43* |
| Raise dam 27 m | 588 | 100 | 561* | 90* |
| *Assumes 10% of any increase in Falls Dam storage is reserved for fish habitat | | | | |

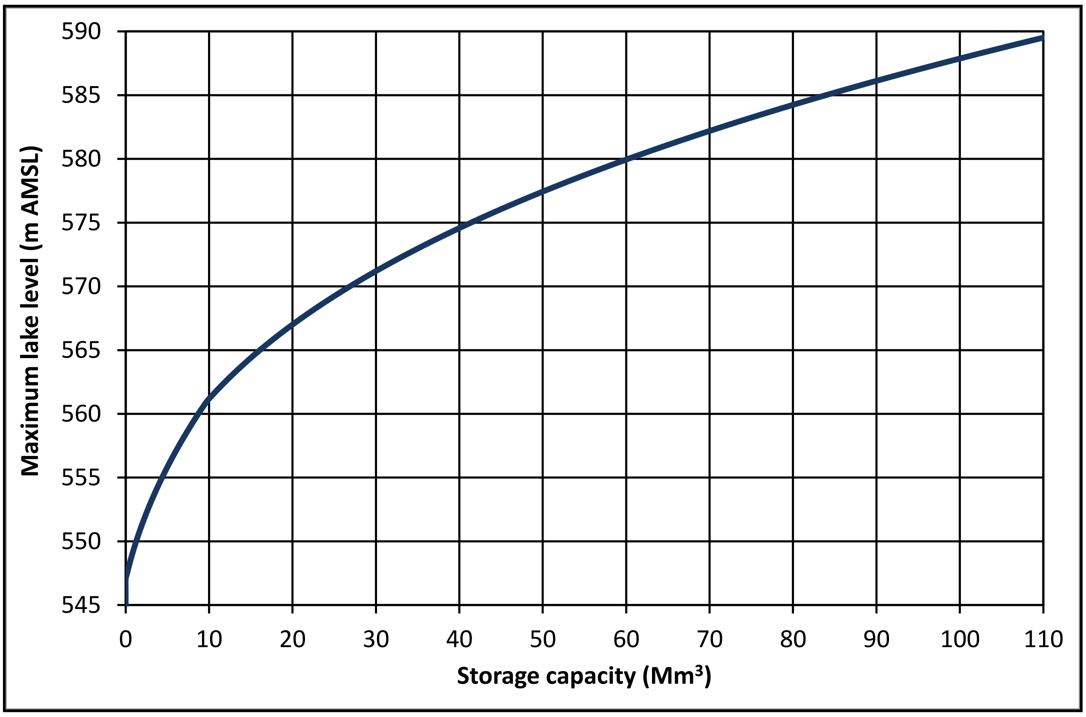



*Figure 10: Falls Dam stage – storage relationship*

In our model water from Falls Dam is released to ensure minimum flows and irrigation demands are met.

## 2.7 Falls Dam power generation

We approximated generation at Falls Dam as:

*Generation (kW) = Net generation head (m) × Generation flow ($m^3/s$) × Turbine efficiency × 9.81 $m/s^2$*
*Where:*
*Net generation head = Lake level – Downstream water level – Penstock losses*
*Generation flow = Min (Falls outflow, turbine flow capacity);*
*Turbine efficiency = 90%;*
*Downstream water level = 525.9 m; and*
*Penstock losses = 2.4 m.*

This relationship assumes turbine efficiencies are relatively constant. More detailed modelling of the system should include the relationship between turbine efficiency generation head and flow.

Generation revenue assumed the value of electricity depended only on the time of year. Monthly prices were based on Benmore wholesale prices for the period 2000 – 2009, scaled up to up to give an average annual price of $85/MWh.

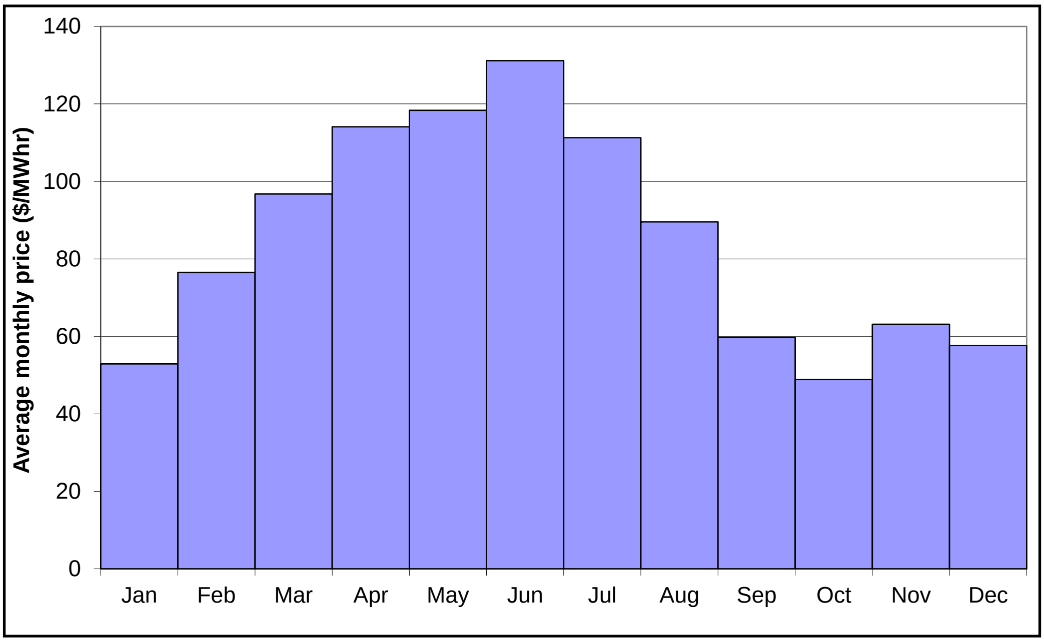



*Figure 11: Wholesale electricity price at Benmore from 2000 – 2009, scaled up to give an average annual price of $85/MWh*

## 2.8 Results

We modelled 5 scenarios:

(1) Status quo
(2) Raising Falls Dam 6 m, and expanding the irrigated area while providing only the existing level of reliability.
(3) Raising Falls Dam 6 m, with the priority of providing ‘high’ reliability to all irrigators.
(4) Raising Falls Dam 15 m and providing ‘high’ reliability to all irrigators.
(5) Raising Falls Dam 27 m and providing ‘very high’ reliability to all irrigators.

Results indicated that the major drought in 1998/99 was probably the driest season in the 38 years of simulation.

By ‘existing’ reliability we mean in the 38 seasons simulated, in 9 seasons Falls Dam would reach its minimum operating level and irrigators would be subject to fully restrictions. By ‘high’ reliability we mean in the 38 seasons simulated, in 1 season (1998/99) Falls Dam would reach its minimum operating level and irrigators would be subject to fully restrictions. By ‘very high’ reliability we mean for the full 38 seasons simulated irrigators were never subject to restriction.

Results indicated raising Falls Dam 6 m will allow for an additional 3,500 ha to be supplied above Ophir, provided existing and new irrigators accept the same level of reliability as they have a present. However if the priority is first to provide existing irrigators with high reliability, then no additional land could be supplied. Raising Falls Dam 15 m would allow an additional 6,000 ha to be supplied above Ophir, while providing high reliability for both new and existing irrigators. Raising Falls Dam 27 m would allow an additional 15,000 ha to be supplied above Ophir, while providing very high reliability for both new and existing irrigators. Irrigated area estimates include an allowance for increased Manuherikia main-stem minimum flows to off-set water quality risks associated with land use intensification. A greater area could be irrigated if a lower level of reliability, or lower minimum flows than we assumed, were acceptable. Modelling results are presented in Table 3 and Appendix F.

*Table 3: Upper Manuherikia modelling scenarios*

| Scenario | Falls Dam | New irrigated area (ha) | Years with restrictions[(1)] | Manuherikia min. flow (l/s) | | |
|---|---|---|---|---|---|---|
| | | | | Below Falls | Below Omakau intake | Below MIS intake |
| 1 | Status quo. | 0 | 9 in 38 | 500 | 500 | 500 |
| 2 | Raise 6m | 3,500 | 9 in 38 | 600 | 800 | 800 |
| 3 | Raise 6m | 0 | 1 in 38 | 500 | 500 | 500 |
| 4 | Raise 15m | 6,000 | 1 in 38 | 800 | 1,000 | 1,000 |
| 5 | Raise 27m | 15,000 | 0 in 38 | 1,500 | 1,500 | 1,500 |
| (1) Years when Falls Dam reaches the minimum operating level | | | | | | |

Power generation modelling indicated raising Falls Dam will result in only modest increases in generation revenue; consequently the cost of raising the dam would need to be borne primarily by irrigators. Increases in power revenue should be sufficient to fund necessary power infrastructure upgrade costs, however it is unlikely power generation could contribute any significant amount to dam construction costs. Results are presented in Table 4.

*Table 4: Generation potential*

| Scenario | Peak turbine flow ($m^3/s$) | Without control optimisation(1) | | With control optimisation(2) | |
|---|---|---|---|---|---|
| | | Average annual revenue | Increase in revenue | Average annual revenue | Increase in revenue |
| 1 | 4 | $680,000 | N/A | $690,000 | N/A |
| 2 | 4 | $760,000 | $80,000 | $800,000 | $110,000 |
| 3 | 4 | $780,000 | $100,000 | $830,000 | $140,000 |
| 4 | 6 | $1,150,000 | $470,000 | $1,300,000 | $610,000 |
| 5 | 6 | $1,250,000 | 570,000 | $1,360,000 | $670,000 |
| 5a(3) | 6 | N/A | | $1,780,000 | $1,090,000 |

(1) Assumes Falls Dam outflows are governed only by irrigation demand, and not generation considerations,
(2) Assumes Falls Dam outflows are optimised to ensure maximum generation revenue, but with priority given to irrigation demands and environmental flow requirements.
(3) As per scenario 5, but assuming there is no new irrigation with the increase in Falls Dam storage being used primarily to increase generation revenue.

Results from Scenario 1 indicates there is little opportunity at present to increase generation revenue by improving how Falls Dam is managed, because of the limited storage in Falls Dam, and the limited turbine capacity. Modelling indicated generation revenue would increase by a mere 1.5% given optimal dam control.

Results from Scenario 5a indicates that the power generation value of increased storage at Falls Dam is an order of magnitude less than the irrigation value of increased storage. If the dam were raised 27 m, to the full height of 60 m, and there was no increase in the irrigated area, the increase in power revenue would be only be above $1M. For comparison, the value of this water for irrigation is likely in the order of $500/ha/y, or $7.5M/y over 15,000 ha.

# 3 Falls Dam flood capacity

## 3.1 Flood flows

Major floods at Falls Dam are caused by high intensity rain events that generally last about 6 - 24 hours long. Major floods can occur at any time of the year, since snow melt is not a major factor. This is in contrast to major floods in the Clutha River, which generally occur in spring or early summer, when snow melt is a major factor.

Extreme flood flows at Falls Dam cannot be determined accurately due to a lack of rainfall and reliable high flow data above the dam. The flow recorder at Forks is not suitable for estimating flood flows because the site cannot be gauged during floods, and the bed of the river is mobile. There are no automatic rainfall recorders above Falls, which means high intensity rainfall cannot be accurately estimated. The water level recorder on Falls Dam has limited accuracy, and is of limited value for estimating spillway outflows.

Flow records from the flow recorder downstream of Falls Dam, installed in 1999, are of some value. The largest flow recorded at this site occurred on 17 March 2009, where flows peaked at an estimated 125 $m^3$/s. This is 35% of the flow recorded at Ophir during this event. We expect flood flow estimates are only moderately accurate, since the site has not been gauged in a major flood.

Accurate flood flow records are available at Ophir. Forty years of near continuous records are available at this site. The site has also been gauged during major flood events. Our upper bound estimate of the peak flow in a 1 in 500 year event is 940 $m^3$/s (refer Appendix B). This is similar to MWD's (1984) previous 1 in 500 year flood estimate of 900 $m^3$/s. MWD (1984) previously estimated peak flood flows at Falls Dam could be up to 50% of Ophir peak flows. This would indicate a 1 in 500 year flood at Falls Dam would be about 450 $m^3$/s. We expect this estimate to be conservative. However, in our opinion there is insufficient data at Falls to improve on MWD's original estimate.

Further information on how peak floods were estimated is given in Appendix B.

## 3.2 Existing flood capacity

Falls Dam has a “Morning Glory” or “Bell mouth” spillway. Water flows down through a tunnel beside the dam, rather than over the top of the dam.

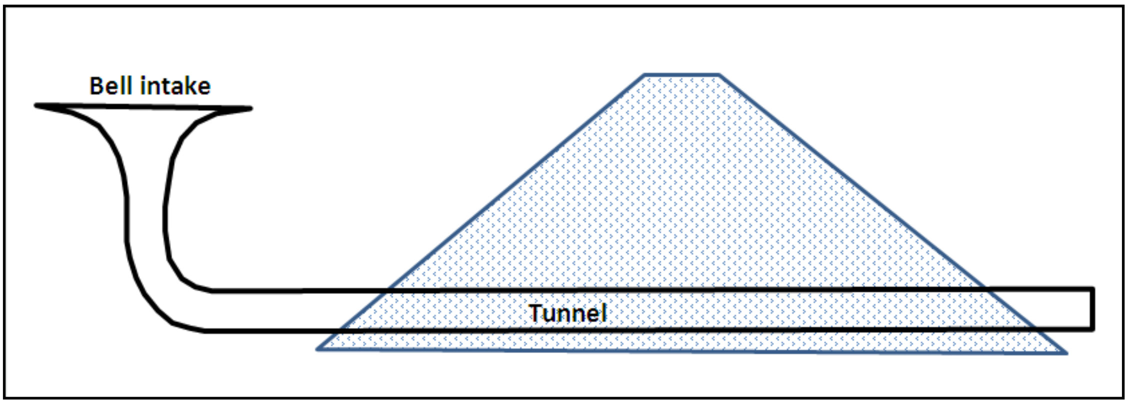



*Figure 12: Falls Dam bell intake spillway and tunnel*

In all but an extreme flood event, the spillway behaves like a conventional sharp crested weir spillway. All the other irrigation dams in the catchment have sharp crested weir spillways. Spillway flows are determined by the amount of water that can pass over the outer rim of the bell inlet, with flows increasing exponentially as the water depth increases.

In an extreme flood event, the spillway flow is limited by the capacity of the tunnel, rather than how much water can enter the bell intake. As the water level rises the spillway flow only marginally increases. This response is called “choked” flow. The spillway “chokes” at a flow of about 390 $m^3/s$, when the dam water level is 1.5 m above the spillway crest. Given the maximum possible water level of 3.5 m above the spillway crest, the spillway has a peak capacity of about 420 $m^3/s$ (±30$m^3/s$). Spillway capacity calculations are included in Appendix C.

In 1955 the rim of the spillway was raised 0.6 m, to increase lake storage by an additional 0.7 $Mm^3$. This should have only had a minor impact on the maximum flood the dam can pass.

For floods less than 390 $m^3/s$, at least 2 m freeboard should be maintained between the maximum water level and the dam crest. Under these circumstances the flood storage in the lake does little to attenuate flood peaks, since the spillway flow rate is almost the same as the lake inflow rate.

In an extreme flood event, where flows are greater than 390 $m^3/s$, lake storage plays an important role in attenuating the flood peak. We estimate lake storage should allow the dam to pass about a 550 - 600 $m^3/s$ flood peak, without over-topping. Our estimate is similar to MWD’s (1984) conclusion that the dam could pass a flood of about 585$m^3/s$ without overtopping.

The lack of reliable flood flow estimates for the dam means it is difficult to know whether or not the spillway could handle an extreme flood event. MWD (1984) previously concluded the dam should pass a 1 in 500 year flood event, but may not be able to pass a Probable Maximum Flood. From our analysis to date we cannot rule out the possibility an extreme flood would result in the dam being overtopped.

An accurate water level recorder on Falls Dam would allow for improved flood flow estimates in the future.


*Figure 13: Morning Glory spillway*

# 4 References

Aqualinc (2012a). "Manuherikia Catchment Study: Stage 1". Report prepared by Aqualinc Research Ltd for the Manuherikia Catchment Water Strategy Group. Report C12040/1. March 2012.

Aqualinc (2012b). "Manuherikia Catchment Study: Stage 2". Report prepared by Aqualinc Research Ltd for the Manuherikia Catchment Water Strategy Group. Report C12040/2. April 2012.

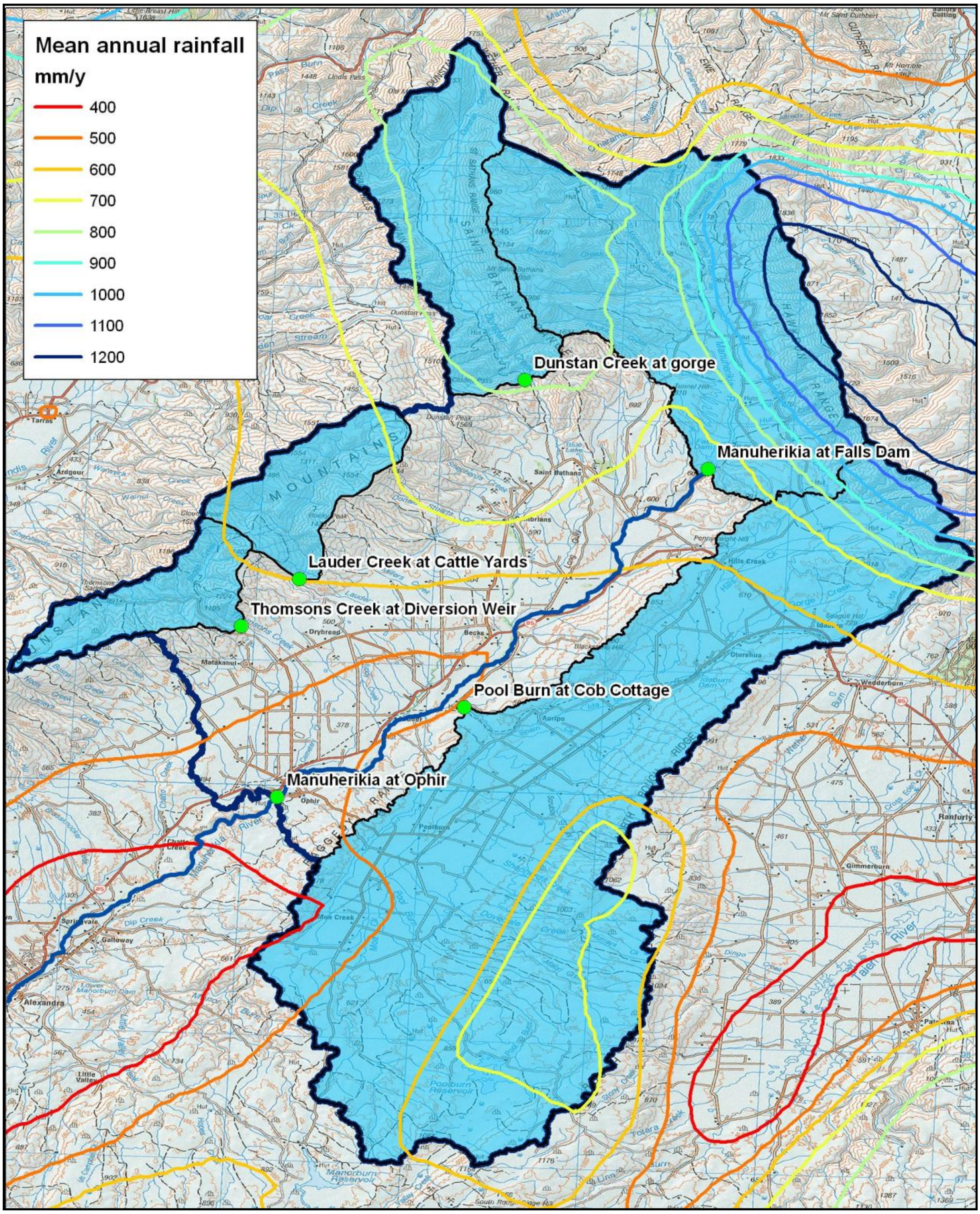
Aqualinc (2012c). "Manuherikia Catchment Study: Stage 3a". Report prepared by Aqualinc Research Ltd for the Manuherikia Catchment Water Strategy Group. Report C12040/3. June 2012.

MWD (1984). "Manuherikia River Falls Dam spillway capacity and design flood study". Unpublished.

MWD (1987). "Central Otago irrigation schemes flood damage report: 9-11 March 1987". Unpublished.

# Appendix A: Falls Dam daily inflows

# Appendix B: Upper Manuherikia Valley tributary flows




Recorder sites where flow recorders were extended or used to extend other records

# Falls Dam inflows

RainEffects Falls Dam daily inflow timeseries, from 1976 to 2012, was extended back to 1973 using correlation with Dunstan Creek at Gorge flows. The correlation relationship was calculated for each month to allow differences in seasonal trends between the two sites to be maintained.

| Month | $x_1 =$ |
|---|---|
| Jan | $2.44\times x_2$ |
| Feb | $2.27\times x_2$ |
| Mar | $2.10\times x_2$ |
| Apr | $2.19\times x_2$ |
| May | $2.41\times x_2$ |
| Jun | $2.19\times x_2$ |
| Jul | $2.22\times x_2$ |
| Aug | $2.14\times x_2$ |
| Sep | $1.98\times x_2$ |
| Oct | $2.02\times x_2$ |
| Nov | $2.30\times x_2$ |
| Dec | $2.62\times x_2$ |

Where:
$x_1$ = RainEffects Falls Dam inflows
$x_2$ = Flow at Dunstan Creek at Gorge

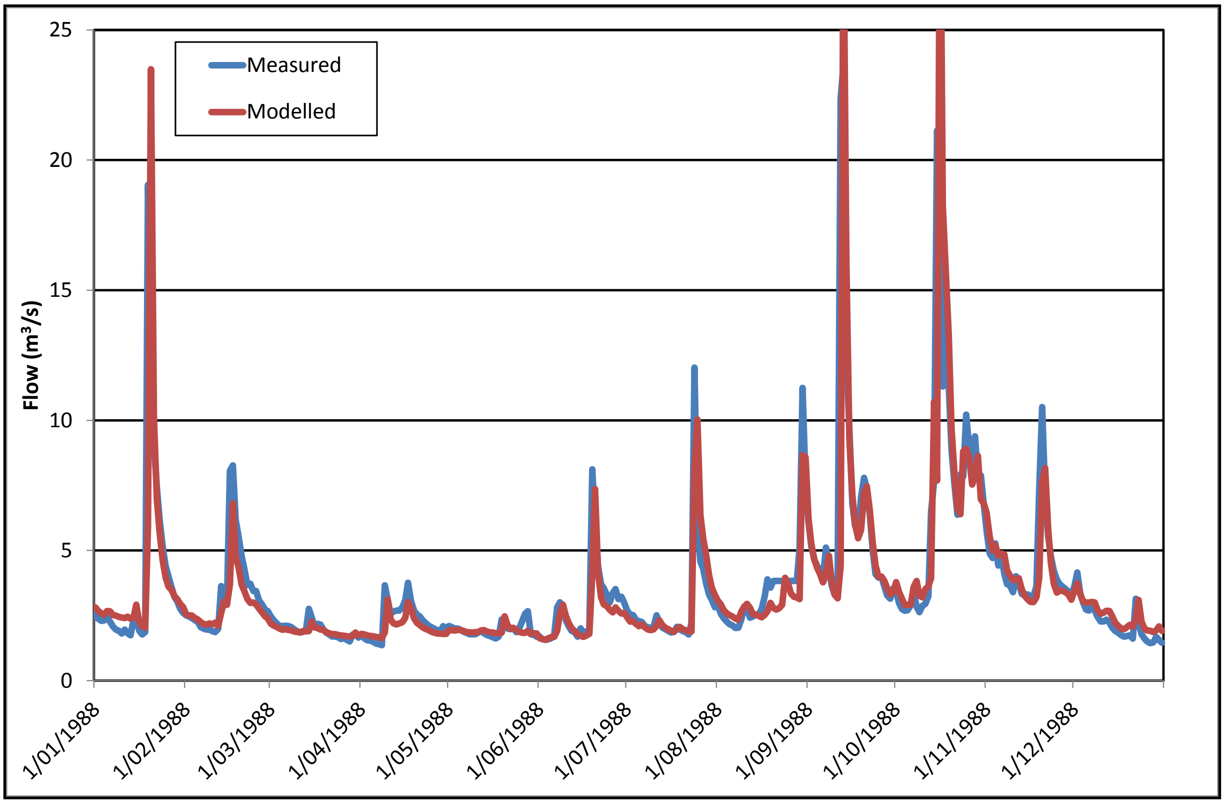



*Figure 14: 'Measured' vs. modelled Falls Dam inflows*

*Table 5: Falls Dam average monthly inflow ($m^3/s$)*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Ave.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | | | | 3.30 | 5.05 | 4.51 | 2.32 | 3.47 | 4.88 | 6.33 | 9.04 | 3.02 | **4.43** |
| 1974 | 1.72 | 5.41 | 3.61 | 3.31 | 3.90 | 3.13 | 3.83 | 4.07 | 5.96 | 7.84 | 6.31 | 3.60 | **4.38** |
| 1975 | 3.59 | 3.35 | 4.50 | 3.91 | 7.36 | 7.15 | 6.43 | 8.06 | 7.92 | 7.61 | 6.51 | 3.77 | **5.86** |
| 1976 | 2.96 | 2.09 | 1.23 | 1.05 | 3.43 | 4.89 | 5.03 | 4.23 | 4.91 | 7.23 | 7.56 | 16.25 | **5.09** |
| 1977 | 6.64 | 3.02 | 1.81 | 1.94 | 8.12 | 4.56 | 3.40 | 1.99 | 4.83 | 8.49 | 7.78 | 6.08 | **4.91** |
| 1978 | 3.89 | 1.61 | 1.17 | 1.82 | 6.36 | 3.96 | 4.45 | 7.76 | 12.29 | 11.65 | 7.31 | 7.13 | **5.81** |
| 1979 | 2.83 | 1.94 | 3.72 | 6.20 | 8.77 | 5.13 | 3.19 | 4.75 | 6.72 | 10.64 | 7.92 | 8.75 | **5.91** |
| 1980 | 11.43 | 4.76 | 4.88 | 6.23 | 6.52 | 9.89 | 4.34 | 9.46 | 5.93 | 8.16 | 8.08 | 5.47 | **7.10** |
| 1981 | 2.37 | 1.45 | 5.71 | 3.17 | 4.43 | 6.60 | 4.89 | 4.44 | 4.04 | 6.71 | 3.58 | 2.72 | **4.20** |
| 1982 | 2.21 | 1.77 | 1.32 | 2.74 | 6.79 | 4.10 | 2.94 | 3.39 | 5.44 | 8.19 | 15.09 | 9.81 | **5.33** |
| 1983 | 8.94 | 3.37 | 2.73 | 6.58 | 9.88 | 9.12 | 5.83 | 6.45 | 8.56 | 16.14 | 10.32 | 9.08 | **8.12** |
| 1984 | 7.04 | 4.28 | 7.42 | 3.39 | 4.40 | 2.94 | 3.96 | 4.84 | 4.06 | 8.60 | 5.75 | 9.41 | **5.53** |
| 1985 | 3.68 | 2.04 | 1.63 | 1.87 | 2.52 | 3.27 | 2.18 | 6.26 | 5.89 | 4.78 | 6.58 | 6.63 | **3.96** |
| 1986 | 3.59 | 4.04 | 8.95 | 3.43 | 2.99 | 6.68 | 4.87 | 4.77 | 5.79 | 8.26 | 7.87 | 5.60 | **5.58** |
| 1987 | 2.49 | 7.16 | 16.69 | 6.56 | 5.38 | 5.71 | 3.39 | 4.30 | 5.08 | 7.61 | 4.52 | 3.96 | **6.07** |
| 1988 | 3.94 | 3.40 | 1.96 | 2.29 | 1.95 | 2.81 | 2.87 | 3.49 | 6.48 | 7.21 | 4.45 | 2.22 | **3.58** |
| 1989 | 3.48 | 3.48 | 4.76 | 3.35 | 4.48 | 7.12 | 3.62 | 2.27 | 2.49 | 4.43 | 2.36 | 6.00 | **3.99** |
| 1990 | 4.29 | 2.16 | 1.93 | 2.08 | 6.37 | 3.86 | 3.68 | 3.59 | 2.71 | 6.60 | 4.63 | 2.81 | **3.74** |
| 1991 | 2.18 | 2.79 | 1.81 | 3.41 | 4.18 | 2.54 | 3.63 | 10.89 | 7.85 | 7.57 | 5.20 | 5.59 | **4.82** |
| 1992 | 3.51 | 1.70 | 1.17 | 1.33 | 2.82 | 2.91 | 3.55 | 3.81 | 5.21 | 9.13 | 13.29 | 5.76 | **4.52** |
| 1993 | 3.17 | 2.42 | 1.86 | 2.31 | 5.00 | 5.45 | 3.04 | 3.33 | 5.67 | 8.62 | 3.61 | 9.73 | **4.54** |
| 1994 | 16.01 | 4.29 | 5.48 | 3.71 | 4.52 | 6.79 | 14.42 | 11.25 | 10.47 | 8.32 | 13.42 | 3.51 | **8.55** |
| 1995 | 1.81 | 0.92 | 2.18 | 2.17 | 2.07 | 3.75 | 2.81 | 9.36 | 26.18 | 15.23 | 7.02 | 14.56 | **7.37** |
| 1996 | 6.26 | 3.97 | 3.77 | 7.36 | 8.97 | 6.47 | 3.78 | 3.40 | 5.28 | 8.62 | 3.84 | 3.11 | **5.41** |
| 1997 | 2.41 | 1.48 | 1.28 | 3.58 | 2.65 | 2.42 | 2.82 | 16.37 | 6.89 | 5.28 | 3.37 | 2.54 | **4.28** |
| 1998 | 1.51 | 1.18 | 2.32 | 3.12 | 2.64 | 5.41 | 11.55 | 10.22 | 8.28 | 10.70 | 5.20 | 2.49 | **5.42** |
| 1999 | 1.02 | 0.56 | 1.65 | 4.15 | 3.64 | 3.37 | 4.51 | 4.74 | 5.53 | 3.90 | 10.08 | 5.07 | **4.03** |
| 2000 | 13.69 | 7.86 | 2.65 | 3.35 | 6.24 | 16.97 | 8.10 | 6.21 | 13.89 | 10.04 | 4.99 | 4.17 | **8.16** |
| 2001 | 2.76 | 1.62 | 0.98 | 1.06 | 1.22 | 1.64 | 2.58 | 3.90 | 2.88 | 3.87 | 7.88 | 5.54 | **3.00** |
| 2002 | 10.79 | 3.39 | 1.65 | 1.50 | 2.54 | 3.80 | 4.43 | 3.73 | 5.69 | 3.95 | 6.89 | 5.90 | **4.53** |
| 2003 | 3.78 | 2.35 | 1.21 | 1.43 | 1.80 | 2.94 | 4.54 | 2.59 | 4.08 | 7.50 | 3.70 | 1.62 | **3.14** |
| 2004 | 1.77 | 6.35 | 7.71 | 2.67 | 4.70 | 5.73 | 3.99 | 5.03 | 5.62 | 6.21 | 7.31 | 11.51 | **5.72** |
| 2005 | 14.33 | 4.11 | 2.63 | 2.84 | 3.14 | 2.95 | 2.60 | 2.76 | 2.78 | 5.45 | 2.80 | 3.50 | **4.17** |
| 2006 | 2.43 | 1.57 | 1.39 | 2.91 | 12.50 | 7.51 | 6.52 | 5.68 | 5.57 | 4.57 | 7.68 | 15.88 | **6.23** |
| 2007 | 7.90 | 3.21 | 2.73 | 1.99 | 0.89 | 0.91 | 3.21 | 2.19 | 3.28 | 7.51 | 3.63 | 1.83 | **3.28** |
| 2008 | 1.42 | 2.83 | 2.10 | 1.39 | 3.36 | 5.16 | 7.31 | 6.70 | 10.64 | 6.88 | 3.53 | 6.90 | **4.86** |
| 2009 | 2.62 | 3.14 | 2.91 | 1.86 | 17.97 | 5.70 | 2.72 | 4.93 | 3.81 | 3.75 | 4.57 | 2.99 | **4.77** |
| 2010 | 2.29 | 1.99 | 1.19 | 1.27 | 5.26 | 12.70 | 4.36 | 13.62 | 9.79 | 7.76 | 5.94 | 5.34 | **5.97** |
| 2011 | 4.11 | 6.18 | 3.75 | 3.86 | 9.44 | 3.68 | 3.74 | 4.94 | 5.59 | 17.52 | 10.77 | 3.57 | **6.44** |
| **Ave.** | **4.76** | **3.14** | **3.33** | **3.09** | **5.24** | **5.24** | **4.50** | **5.72** | **6.64** | **7.92** | **6.68** | **5.98** | 5.20 |

Highlighted data was synthesised using correlation with Dunstan Creek at Gorge

## Dunstan Creek at Gorge

MWD and ORC maintained a flow recording site at Dunstan Creek at Gorge from September March 1973 to March 1994, and from March 2007 to September 2010. There are no abstractions of significance above this site, therefore measured flows are naturalised. This daily flow record was extended using correlation with RainEffects Falls Dam inflow timeseries. The correlation relationship was calculated for each month to allow differences in seasonal trends between the two sites to be maintained.

| Month | $x_1 =$ |
|---|---|
| Jan | $0.41\times x_2$ |
| Feb | $0.44\times x_2$ |
| Mar | $0.48\times x_2$ |
| Apr | $0.46\times x_2$ |
| May | $0.41\times x_2$ |
| Jun | $0.46\times x_2$ |
| Jul | $0.45\times x_2$ |
| Aug | $0.47\times x_2$ |
| Sep | $0.50\times x_2$ |
| Oct | $0.49\times x_2$ |
| Nov | $0.43\times x_2$ |
| Dec | $0.38\times x_2$ |

Where
$x_1$ = Flow at Dunstan Creek at Gorge
$x_2$ = RainEffects Falls Dam inflows

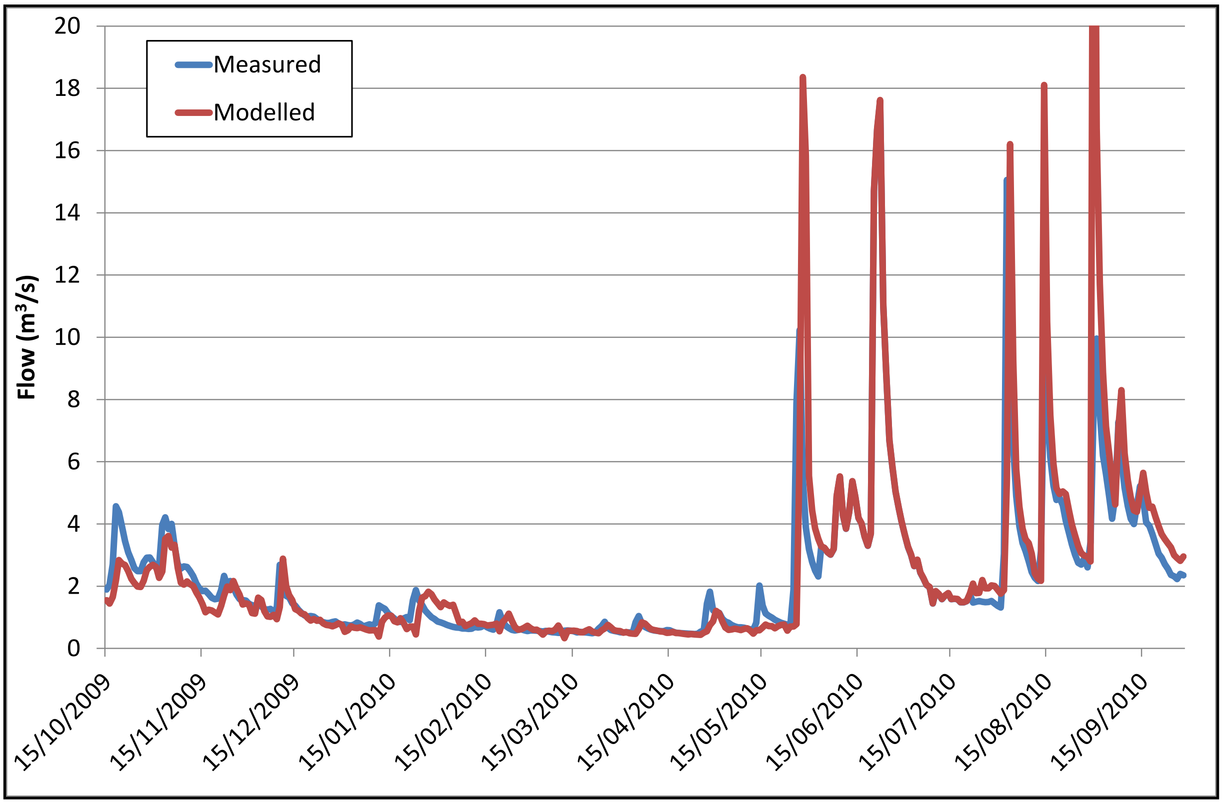



*Figure 15: Measured vs. modelled Dunstan Creek at Gorge flows*

*Table 6: Dunstan Creek average monthly flow at Gorge ($m^3/s$)*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Ave.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | | | | 1.51 | 2.09 | 2.06 | 1.04 | 1.62 | 2.46 | 3.13 | 3.92 | 1.15 | **2.01** |
| 1974 | 0.71 | 2.39 | 1.72 | 1.51 | 1.61 | 1.42 | 1.72 | 1.90 | 3.00 | 3.88 | 2.74 | 1.37 | **1.99** |
| 1975 | 1.47 | 1.48 | 2.14 | 1.78 | 2.99 | 2.94 | 2.74 | 4.11 | 4.59 | 3.90 | 2.45 | 1.14 | **2.65** |
| 1976 | 0.99 | 0.73 | 0.56 | 0.50 | 1.27 | 2.20 | 1.93 | 2.00 | 2.43 | 3.58 | 3.21 | 5.69 | **2.10** |
| 1977 | 2.64 | 1.36 | 0.85 | 0.87 | 3.53 | 2.08 | 1.54 | 1.10 | 2.38 | 4.95 | 3.61 | 1.91 | **2.24** |
| 1978 | 1.06 | 0.67 | 0.58 | 0.77 | 1.87 | 1.45 | 1.89 | 3.89 | 6.96 | 5.49 | 3.50 | 3.38 | **2.64** |
| 1979 | 1.27 | 1.04 | 2.02 | 3.77 | 4.70 | 3.36 | 1.74 | 2.26 | 3.63 | 5.14 | 4.14 | 4.75 | **3.16** |
| 1980 | 5.46 | 1.78 | 1.70 | 2.16 | 2.83 | 4.81 | 1.58 | 3.92 | 3.38 | 3.43 | 3.22 | 1.87 | **3.01** |
| 1981 | 0.94 | 0.70 | 2.55 | 1.53 | 1.78 | 2.84 | 2.01 | 2.26 | 2.31 | 3.94 | 1.62 | 1.20 | **1.98** |
| 1982 | 0.88 | 0.73 | 0.60 | 1.10 | 3.23 | 1.88 | 1.00 | 1.60 | 3.30 | 4.20 | 8.46 | 3.38 | **2.53** |
| 1983 | 3.83 | 1.29 | 0.95 | 2.84 | 4.68 | 5.22 | 3.48 | 2.96 | 3.77 | 7.30 | 3.24 | 2.85 | **3.55** |
| 1984 | 2.57 | 1.75 | 3.74 | 1.42 | 1.93 | 1.18 | 2.21 | 2.57 | 1.97 | 5.24 | 2.02 | 3.46 | **2.52** |
| 1985 | 1.58 | 0.86 | 0.71 | 0.84 | 1.05 | 1.55 | 0.96 | 2.68 | 2.67 | 2.27 | 2.80 | 2.09 | **1.67** |
| 1986 | 1.36 | 1.66 | 4.57 | 1.54 | 1.17 | 3.36 | 2.17 | 2.51 | 2.92 | 4.16 | 2.76 | 2.14 | **2.53** |
| 1987 | 1.02 | 3.28 | 8.59 | 3.44 | 2.48 | 2.45 | 1.52 | 2.22 | 2.35 | 2.85 | 1.65 | 1.49 | **2.78** |
| 1988 | 1.65 | 1.30 | 0.90 | 0.94 | 0.79 | 1.14 | 1.35 | 1.50 | 3.10 | 3.77 | 1.88 | 0.95 | **1.61** |
| 1989 | 1.67 | 2.01 | 1.66 | 1.40 | 1.94 | 2.93 | 2.05 | 1.05 | 1.20 | 2.49 | 1.18 | 2.16 | **1.81** |
| 1990 | 2.10 | 0.99 | 1.06 | 0.91 | 2.42 | 1.88 | 1.97 | 1.91 | 1.49 | 3.09 | 1.80 | 1.25 | **1.75** |
| 1991 | 0.89 | 0.96 | 0.81 | 1.46 | 1.51 | 0.81 | 1.14 | 5.18 | 3.93 | 3.72 | 2.54 | 2.13 | **2.10** |
| 1992 | 1.44 | 0.75 | 0.57 | 0.60 | 0.80 | 0.83 | 1.25 | 1.86 | 2.79 | 4.81 | 5.51 | 1.77 | **1.92** |
| 1993 | 1.07 | 0.88 | 0.75 | 1.06 | 1.54 | 2.26 | 1.25 | 1.57 | 2.84 | 4.07 | 1.60 | 3.96 | **1.91** |
| 1994 | 5.84 | 2.39 | 3.11 | 1.56 | 1.87 | 3.09 | 6.48 | 5.26 | 5.28 | 4.12 | 5.83 | 1.34 | **3.86** |
| 1995 | 0.74 | 0.41 | 1.04 | 0.99 | 0.86 | 1.71 | 1.26 | 4.37 | 13.20 | 7.54 | 3.05 | 5.55 | **3.40** |
| 1996 | 2.57 | 1.75 | 1.79 | 3.36 | 3.72 | 2.95 | 1.70 | 1.59 | 2.66 | 4.26 | 1.67 | 1.18 | **2.43** |
| 1997 | 0.99 | 0.65 | 0.61 | 1.63 | 1.10 | 1.10 | 1.27 | 7.64 | 3.47 | 2.61 | 1.46 | 0.97 | **1.97** |
| 1998 | 0.62 | 0.52 | 1.10 | 1.43 | 1.09 | 2.46 | 5.19 | 4.77 | 4.17 | 5.29 | 2.26 | 0.95 | **2.50** |
| 1999 | 0.42 | 0.25 | 0.78 | 1.89 | 1.51 | 1.54 | 2.03 | 2.21 | 2.79 | 1.93 | 4.38 | 1.93 | **1.81** |
| 2000 | 5.62 | 3.47 | 1.26 | 1.53 | 2.58 | 7.73 | 3.64 | 2.90 | 7.00 | 4.97 | 2.16 | 1.59 | **3.70** |
| 2001 | 1.13 | 0.71 | 0.47 | 0.48 | 0.51 | 0.75 | 1.16 | 1.82 | 1.45 | 1.92 | 3.42 | 2.11 | **1.33** |
| 2002 | 4.43 | 1.49 | 0.78 | 0.68 | 1.05 | 1.73 | 1.99 | 1.74 | 2.87 | 1.96 | 2.99 | 2.25 | **2.00** |
| 2003 | 1.55 | 1.04 | 0.57 | 0.65 | 0.75 | 1.34 | 2.04 | 1.21 | 2.06 | 3.71 | 1.61 | 0.62 | **1.43** |
| 2004 | 0.72 | 2.80 | 3.67 | 1.22 | 1.95 | 2.61 | 1.79 | 2.35 | 2.83 | 3.07 | 3.17 | 4.39 | **2.55** |
| 2005 | 5.88 | 1.81 | 1.25 | 1.30 | 1.30 | 1.35 | 1.17 | 1.29 | 1.40 | 2.70 | 1.22 | 1.33 | **1.84** |
| 2006 | 1.00 | 0.69 | 0.66 | 1.33 | 5.18 | 3.42 | 2.93 | 2.65 | 2.81 | 2.26 | 3.33 | 6.06 | **2.71** |
| 2007 | 3.24 | 1.41 | 1.06 | 0.69 | 0.68 | 1.17 | 1.66 | 1.42 | 1.58 | 3.13 | 1.56 | 0.83 | **1.54** |
| 2008 | 0.80 | 1.09 | 0.91 | 0.66 | 0.93 | 1.50 | 3.29 | 2.88 | 4.60 | 3.22 | 1.49 | 3.21 | **2.05** |
| 2009 | 1.35 | 2.07 | 1.67 | 1.14 | 7.57 | 2.60 | 1.22 | 2.30 | 1.92 | 2.24 | 2.33 | 1.21 | **2.31** |
| 2010 | 1.02 | 0.69 | 0.56 | 0.69 | 1.83 | 5.70 | 1.81 | 4.88 | 4.14 | 3.84 | 2.58 | 2.04 | **2.49** |
| 2011 | 1.69 | 2.72 | 1.78 | 1.76 | 3.91 | 1.68 | 1.68 | 2.31 | 2.82 | 8.67 | 4.67 | 1.36 | **2.92** |
| **Ave.** | **1.95** | **1.38** | **1.58** | **1.41** | **2.17** | **2.39** | **2.02** | **2.67** | **3.35** | **3.92** | **2.90** | **2.28** | 2.34 |

Highlighted data was synthesised using correlation with RainEffects Falls Dam inflows.

## Lauder Creek at Cattle Yards

ORC maintained a flow recording site at Lauder Creek at Cattle Yards from September 2008 to November 2010. There are no abstractions of significance above this site, therefore measured flows are naturalised. This daily flow record was extended using correlation with the Dunstan Creek at Gorge site. The correlation relationship was calculated for each month to allow differences in seasonal trends between the two sites to be maintained.

| Month | $x_1 =$ |
|---|---|
| Jan | $0.45 \times x_2$ |
| Feb | $0.31 \times x_2$ |
| Mar | $0.34 \times x_2$ |
| Apr | $0.40 \times x_2$ |
| May | $0.46 \times x_2$ |
| Jun | $0.35 \times x_2$ |
| Jul | $0.52 \times x_2$ |
| Aug | $0.42 \times x_2$ |
| Sep | $0.65 \times x_2$ |
| Oct | $0.60 \times x_2$ |
| Nov | $0.43 \times x_2$ |
| Dec | $0.44 \times x_2$ |

Where:
$x_1$ = Flow at Lauder Creek at Cattle Yards
$x_2$ = Flow Dunstan Creek at Gorge

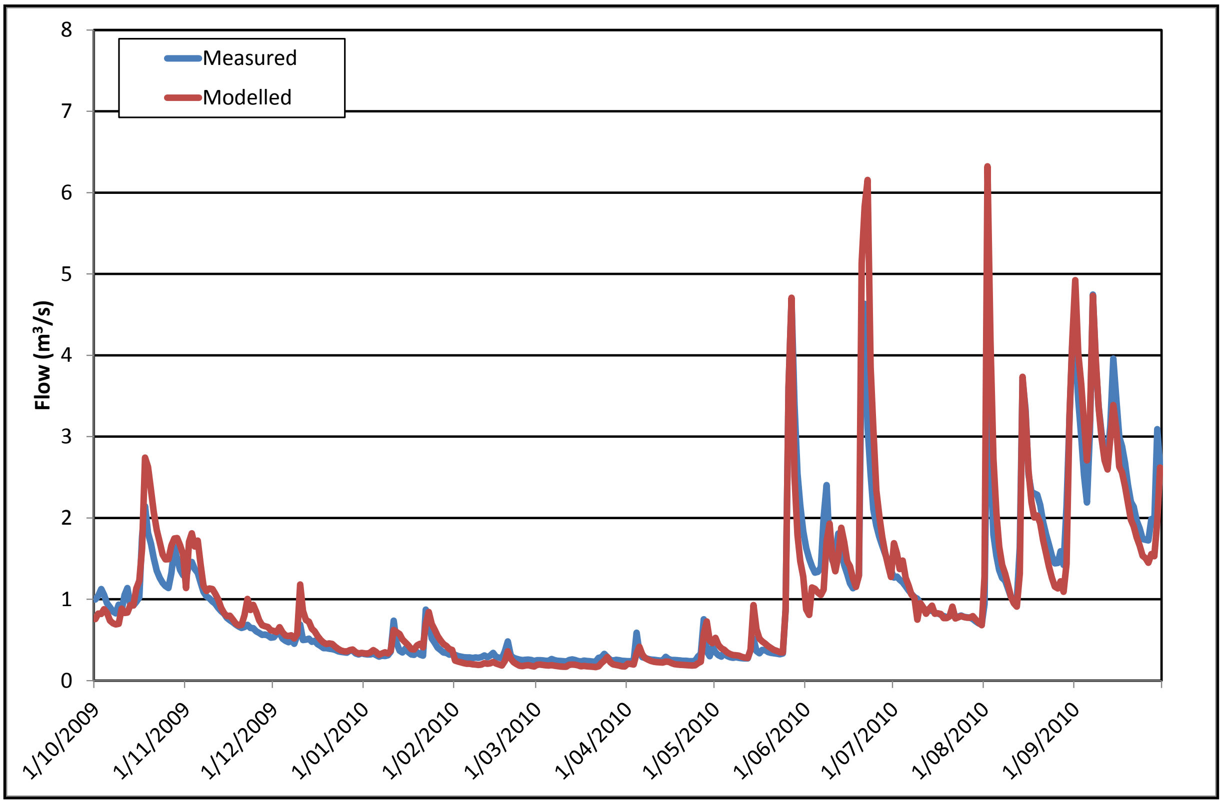



*Figure 16: Measured vs. modelled Dunstan Creek at Gorge flows*

*Table 7: Lauder Creek average monthly flow at Cattle Yard ($m^3/s$)*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Ave.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | | | | 0.61 | 0.96 | 0.72 | 0.54 | 0.67 | 1.60 | 1.87 | 1.68 | 0.50 | **0.96** |
| 1974 | 0.32 | 0.75 | 0.58 | 0.61 | 0.74 | 0.50 | 0.89 | 0.79 | 1.96 | 2.32 | 1.18 | 0.60 | **0.94** |
| 1975 | 0.67 | 0.46 | 0.73 | 0.72 | 1.37 | 1.03 | 1.42 | 1.71 | 2.99 | 2.33 | 1.05 | 0.50 | **1.25** |
| 1976 | 0.44 | 0.23 | 0.19 | 0.20 | 0.58 | 0.77 | 1.00 | 0.83 | 1.59 | 2.14 | 1.38 | 2.49 | **0.99** |
| 1977 | 1.19 | 0.43 | 0.29 | 0.35 | 1.61 | 0.73 | 0.80 | 0.46 | 1.55 | 2.96 | 1.55 | 0.83 | **1.07** |
| 1978 | 0.48 | 0.21 | 0.20 | 0.31 | 0.86 | 0.51 | 0.98 | 1.62 | 4.54 | 3.28 | 1.50 | 1.48 | **1.34** |
| 1979 | 0.57 | 0.33 | 0.69 | 1.52 | 2.15 | 1.18 | 0.90 | 0.94 | 2.37 | 3.07 | 1.78 | 2.07 | **1.47** |
| 1980 | 2.46 | 0.56 | 0.58 | 0.87 | 1.29 | 1.69 | 0.82 | 1.63 | 2.20 | 2.05 | 1.38 | 0.82 | **1.37** |
| 1981 | 0.42 | 0.22 | 0.87 | 0.62 | 0.81 | 1.00 | 1.04 | 0.94 | 1.50 | 2.36 | 0.70 | 0.52 | **0.92** |
| 1982 | 0.40 | 0.23 | 0.20 | 0.44 | 1.48 | 0.66 | 0.52 | 0.67 | 2.15 | 2.51 | 3.63 | 1.48 | **1.20** |
| 1983 | 1.73 | 0.41 | 0.32 | 1.15 | 2.14 | 1.83 | 1.80 | 1.23 | 2.45 | 4.37 | 1.39 | 1.24 | **1.68** |
| 1984 | 1.16 | 0.55 | 1.27 | 0.57 | 0.88 | 0.41 | 1.15 | 1.07 | 1.29 | 3.14 | 0.87 | 1.51 | **1.16** |
| 1985 | 0.71 | 0.27 | 0.24 | 0.34 | 0.48 | 0.55 | 0.50 | 1.11 | 1.74 | 1.36 | 1.20 | 0.91 | **0.79** |
| 1986 | 0.61 | 0.52 | 1.55 | 0.62 | 0.54 | 1.18 | 1.13 | 1.04 | 1.90 | 2.49 | 1.18 | 0.93 | **1.15** |
| 1987 | 0.46 | 1.03 | 2.92 | 1.39 | 1.13 | 0.86 | 0.79 | 0.92 | 1.53 | 1.71 | 0.71 | 0.65 | **1.18** |
| 1988 | 0.74 | 0.41 | 0.31 | 0.38 | 0.36 | 0.40 | 0.70 | 0.63 | 2.02 | 2.26 | 0.81 | 0.41 | **0.79** |
| 1989 | 0.75 | 0.63 | 0.56 | 0.57 | 0.89 | 1.03 | 1.06 | 0.44 | 0.78 | 1.49 | 0.51 | 0.94 | **0.81** |
| 1990 | 0.95 | 0.31 | 0.36 | 0.37 | 1.11 | 0.66 | 1.02 | 0.80 | 0.97 | 1.85 | 0.77 | 0.54 | **0.81** |
| 1991 | 0.40 | 0.30 | 0.28 | 0.59 | 0.69 | 0.28 | 0.59 | 2.15 | 2.56 | 2.23 | 1.09 | 0.93 | **1.01** |
| 1992 | 0.65 | 0.23 | 0.19 | 0.24 | 0.36 | 0.29 | 0.65 | 0.77 | 1.82 | 2.88 | 2.36 | 0.77 | **0.94** |
| 1993 | 0.48 | 0.28 | 0.25 | 0.43 | 0.71 | 0.79 | 0.65 | 0.65 | 1.85 | 2.44 | 0.68 | 1.73 | **0.92** |
| 1994 | 2.64 | 0.75 | 1.06 | 0.63 | 0.86 | 1.09 | 3.36 | 2.19 | 3.44 | 2.46 | 2.50 | 0.58 | **1.80** |
| 1995 | 0.34 | 0.13 | 0.35 | 0.40 | 0.39 | 0.60 | 0.66 | 1.82 | 8.60 | 4.51 | 1.31 | 2.43 | **1.80** |
| 1996 | 1.16 | 0.55 | 0.61 | 1.35 | 1.70 | 1.04 | 0.88 | 0.66 | 1.74 | 2.55 | 0.72 | 0.52 | **1.12** |
| 1997 | 0.45 | 0.20 | 0.21 | 0.66 | 0.50 | 0.39 | 0.66 | 3.18 | 2.26 | 1.56 | 0.63 | 0.42 | **0.93** |
| 1998 | 0.28 | 0.16 | 0.37 | 0.58 | 0.50 | 0.87 | 2.69 | 1.99 | 2.72 | 3.17 | 0.97 | 0.41 | **1.23** |
| 1999 | 0.19 | 0.08 | 0.27 | 0.76 | 0.69 | 0.54 | 1.05 | 0.92 | 1.82 | 1.15 | 1.88 | 0.84 | **0.85** |
| 2000 | 2.53 | 1.09 | 0.43 | 0.62 | 1.18 | 2.72 | 1.89 | 1.21 | 4.56 | 2.97 | 0.93 | 0.70 | **1.73** |
| 2001 | 0.51 | 0.22 | 0.16 | 0.20 | 0.23 | 0.26 | 0.60 | 0.76 | 0.95 | 1.15 | 1.47 | 0.92 | **0.62** |
| 2002 | 2.00 | 0.47 | 0.27 | 0.28 | 0.48 | 0.61 | 1.03 | 0.73 | 1.87 | 1.17 | 1.28 | 0.98 | **0.93** |
| 2003 | 0.70 | 0.33 | 0.20 | 0.26 | 0.34 | 0.47 | 1.06 | 0.50 | 1.34 | 2.22 | 0.69 | 0.27 | **0.70** |
| 2004 | 0.33 | 0.88 | 1.25 | 0.49 | 0.89 | 0.92 | 0.93 | 0.98 | 1.85 | 1.84 | 1.36 | 1.92 | **1.14** |
| 2005 | 2.65 | 0.57 | 0.42 | 0.52 | 0.60 | 0.47 | 0.61 | 0.54 | 0.91 | 1.61 | 0.52 | 0.58 | **0.84** |
| 2006 | 0.45 | 0.22 | 0.22 | 0.54 | 2.37 | 1.20 | 1.52 | 1.10 | 1.83 | 1.35 | 1.43 | 2.65 | **1.25** |
| 2007 | 1.46 | 0.44 | 0.36 | 0.28 | 0.31 | 0.41 | 0.86 | 0.59 | 1.03 | 1.87 | 0.67 | 0.36 | **0.73** |
| 2008 | 0.36 | 0.34 | 0.31 | 0.26 | 0.43 | 0.53 | 1.70 | 1.20 | 2.98 | 1.80 | 0.70 | 1.49 | **1.01** |
| 2009 | 0.68 | 0.57 | 0.51 | 0.44 | 3.43 | 1.09 | 0.67 | 1.01 | 1.18 | 1.22 | 0.87 | 0.45 | **1.01** |
| 2010 | 0.39 | 0.29 | 0.25 | 0.30 | 0.87 | 1.83 | 0.90 | 1.98 | 2.78 | 2.55 | 1.18 | 0.89 | **1.19** |
| 2011 | 0.76 | 0.86 | 0.61 | 0.71 | 1.79 | 0.59 | 0.87 | 0.96 | 1.84 | 5.19 | 2.01 | 0.60 | **1.40** |
| **Ave.** | **0.88** | **0.43** | **0.54** | **0.57** | **0.99** | **0.84** | **1.05** | **1.11** | **2.18** | **2.34** | **1.24** | **1.00** | **1.10** |

Highlighted data was synthesised using correlation with Dunstan Creek at Gorge

## Thomsons Creek at Diversion Weir

ORC set up a flow recording site at Thomsons Creek at Diversion Weir in September 2008. This site is still operating. There are no abstractions of significance above this site, therefore measured flows are naturalised. This daily flow record was extended using correlation with the Dunstan Creek at Gorge site. The correlation relationship was calculated for each month to allow differences in seasonal trends between the two sites to be maintained.

| Month | $x_1 =$ |
|---|---|
| Jan | $0.28 \times x_2$ |
| Feb | $0.23 \times x_2$ |
| Mar | $0.32 \times x_2$ |
| Apr | $0.32 \times x_2$ |
| May | $0.24 \times x_2$ |
| Jun | $0.27 \times x_2$ |
| Jul | $0.38 \times x_2$ |
| Aug | $0.30 \times x_2$ |
| Sep | $0.40 \times x_2$ |
| Oct | $0.36 \times x_2$ |
| Nov | $0.29 \times x_2$ |
| Dec | $0.26 \times x_2$ |

Where:
$x_1$ = Thomsons Creek at Diversion Weir
$x_2$ = Dunstan Creek at Gorge

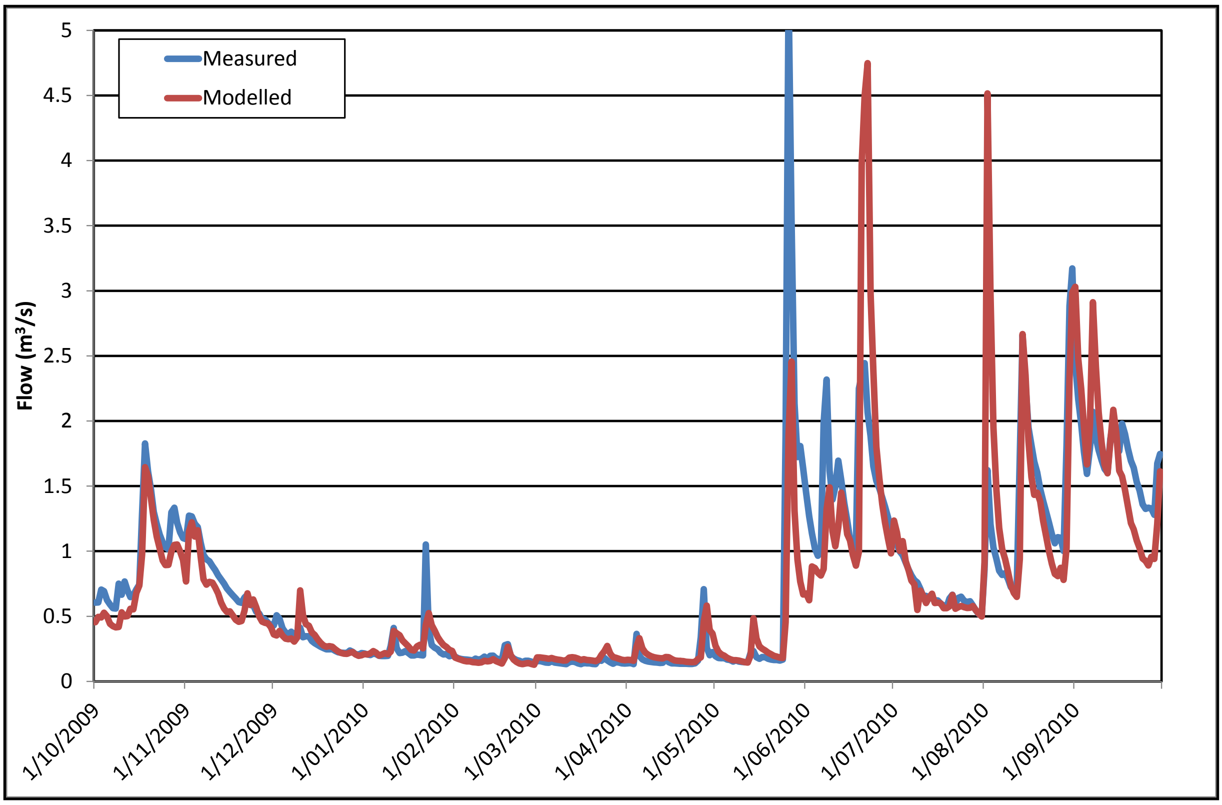



*Figure 17: Measured vs. modelled Thomsons Creek at Diversion Weir flows*

*Table 8: Thomsons Creek average monthly flow at Diversion Weir ($m^3/s$)*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Ave.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | | | | 0.48 | 0.50 | 0.55 | 0.39 | 0.49 | 0.98 | 1.14 | 1.14 | 0.30 | **0.63** |
| 1974 | 0.20 | 0.54 | 0.55 | 0.48 | 0.38 | 0.38 | 0.65 | 0.58 | 1.20 | 1.41 | 0.80 | 0.36 | **0.63** |
| 1975 | 0.42 | 0.34 | 0.68 | 0.56 | 0.71 | 0.79 | 1.04 | 1.24 | 1.83 | 1.41 | 0.71 | 0.30 | **0.84** |
| 1976 | 0.28 | 0.17 | 0.18 | 0.16 | 0.30 | 0.59 | 0.73 | 0.61 | 0.97 | 1.30 | 0.94 | 1.49 | **0.64** |
| 1977 | 0.75 | 0.31 | 0.27 | 0.28 | 0.84 | 0.56 | 0.58 | 0.33 | 0.95 | 1.80 | 1.05 | 0.50 | **0.69** |
| 1978 | 0.30 | 0.15 | 0.18 | 0.24 | 0.44 | 0.39 | 0.71 | 1.18 | 2.78 | 1.99 | 1.02 | 0.89 | **0.86** |
| 1979 | 0.36 | 0.24 | 0.64 | 1.19 | 1.12 | 0.90 | 0.66 | 0.68 | 1.45 | 1.86 | 1.21 | 1.25 | **0.97** |
| 1980 | 1.54 | 0.40 | 0.54 | 0.68 | 0.67 | 1.29 | 0.60 | 1.19 | 1.35 | 1.24 | 0.94 | 0.49 | **0.91** |
| 1981 | 0.26 | 0.16 | 0.81 | 0.48 | 0.42 | 0.76 | 0.76 | 0.68 | 0.92 | 1.43 | 0.47 | 0.32 | **0.63** |
| 1982 | 0.25 | 0.17 | 0.19 | 0.35 | 0.77 | 0.50 | 0.38 | 0.48 | 1.32 | 1.52 | 2.47 | 0.89 | **0.77** |
| 1983 | 1.08 | 0.29 | 0.30 | 0.90 | 1.11 | 1.40 | 1.31 | 0.90 | 1.50 | 2.65 | 0.95 | 0.75 | **1.10** |
| 1984 | 0.73 | 0.40 | 1.19 | 0.45 | 0.46 | 0.32 | 0.84 | 0.78 | 0.79 | 1.90 | 0.59 | 0.91 | **0.78** |
| 1985 | 0.45 | 0.20 | 0.23 | 0.27 | 0.25 | 0.42 | 0.36 | 0.81 | 1.06 | 0.82 | 0.82 | 0.55 | **0.52** |
| 1986 | 0.38 | 0.38 | 1.46 | 0.49 | 0.28 | 0.90 | 0.82 | 0.76 | 1.16 | 1.51 | 0.81 | 0.56 | **0.79** |
| 1987 | 0.29 | 0.74 | 2.73 | 1.09 | 0.59 | 0.66 | 0.57 | 0.67 | 0.94 | 1.03 | 0.48 | 0.39 | **0.85** |
| 1988 | 0.47 | 0.30 | 0.29 | 0.30 | 0.19 | 0.31 | 0.51 | 0.46 | 1.24 | 1.37 | 0.55 | 0.25 | **0.52** |
| 1989 | 0.47 | 0.45 | 0.53 | 0.44 | 0.46 | 0.79 | 0.78 | 0.32 | 0.48 | 0.90 | 0.34 | 0.57 | **0.55** |
| 1990 | 0.59 | 0.23 | 0.34 | 0.29 | 0.57 | 0.50 | 0.75 | 0.58 | 0.60 | 1.12 | 0.52 | 0.33 | **0.54** |
| 1991 | 0.25 | 0.22 | 0.26 | 0.46 | 0.36 | 0.22 | 0.43 | 1.57 | 1.57 | 1.35 | 0.74 | 0.56 | **0.67** |
| 1992 | 0.41 | 0.17 | 0.18 | 0.19 | 0.19 | 0.22 | 0.47 | 0.56 | 1.11 | 1.75 | 1.61 | 0.47 | **0.61** |
| 1993 | 0.30 | 0.20 | 0.24 | 0.33 | 0.37 | 0.61 | 0.47 | 0.48 | 1.13 | 1.48 | 0.47 | 1.04 | **0.60** |
| 1994 | 1.65 | 0.54 | 0.99 | 0.49 | 0.45 | 0.83 | 2.45 | 1.59 | 2.10 | 1.49 | 1.70 | 0.35 | **1.23** |
| 1995 | 0.21 | 0.09 | 0.33 | 0.31 | 0.20 | 0.46 | 0.48 | 1.32 | 5.26 | 2.73 | 0.89 | 1.46 | **1.15** |
| 1996 | 0.72 | 0.40 | 0.57 | 1.06 | 0.88 | 0.79 | 0.64 | 0.48 | 1.06 | 1.55 | 0.49 | 0.31 | **0.75** |
| 1997 | 0.28 | 0.15 | 0.19 | 0.52 | 0.26 | 0.30 | 0.48 | 2.32 | 1.38 | 0.95 | 0.43 | 0.25 | **0.63** |
| 1998 | 0.17 | 0.12 | 0.35 | 0.45 | 0.26 | 0.66 | 1.96 | 1.45 | 1.66 | 1.92 | 0.66 | 0.25 | **0.83** |
| 1999 | 0.12 | 0.06 | 0.25 | 0.60 | 0.36 | 0.41 | 0.77 | 0.67 | 1.11 | 0.70 | 1.28 | 0.51 | **0.57** |
| 2000 | 1.58 | 0.79 | 0.40 | 0.48 | 0.61 | 2.08 | 1.38 | 0.88 | 2.79 | 1.80 | 0.63 | 0.42 | **1.15** |
| 2001 | 0.32 | 0.16 | 0.15 | 0.15 | 0.12 | 0.20 | 0.44 | 0.55 | 0.58 | 0.69 | 1.00 | 0.55 | **0.41** |
| 2002 | 1.25 | 0.34 | 0.25 | 0.22 | 0.25 | 0.46 | 0.75 | 0.53 | 1.14 | 0.71 | 0.87 | 0.59 | **0.62** |
| 2003 | 0.44 | 0.24 | 0.18 | 0.21 | 0.18 | 0.36 | 0.77 | 0.37 | 0.82 | 1.35 | 0.47 | 0.16 | **0.46** |
| 2004 | 0.20 | 0.63 | 1.17 | 0.39 | 0.46 | 0.70 | 0.68 | 0.71 | 1.13 | 1.11 | 0.93 | 1.15 | **0.77** |
| 2005 | 1.66 | 0.41 | 0.40 | 0.41 | 0.31 | 0.36 | 0.44 | 0.39 | 0.56 | 0.98 | 0.35 | 0.35 | **0.55** |
| 2006 | 0.28 | 0.16 | 0.21 | 0.42 | 1.23 | 0.92 | 1.11 | 0.80 | 1.12 | 0.82 | 0.97 | 1.59 | **0.81** |
| 2007 | 0.91 | 0.32 | 0.34 | 0.22 | 0.16 | 0.31 | 0.63 | 0.43 | 0.63 | 1.13 | 0.46 | 0.22 | **0.48** |
| 2008 | 0.23 | 0.25 | 0.29 | 0.21 | 0.22 | 0.40 | 1.24 | 0.87 | 1.72 | 1.10 | 0.45 | 1.04 | **0.67** |
| 2009 | 0.48 | 0.42 | 0.37 | 0.28 | 1.27 | 0.71 | 0.45 | 0.77 | 0.80 | 0.96 | 0.78 | 0.31 | **0.63** |
| 2010 | 0.26 | 0.18 | 0.15 | 0.19 | 0.72 | 1.52 | 0.70 | 1.40 | 1.73 | 1.32 | 0.64 | 0.35 | **0.76** |
| 2011 | 0.41 | 0.65 | 0.76 | 0.67 | 1.18 | 0.46 | 0.64 | 0.70 | 1.12 | 3.14 | 1.36 | 0.36 | **0.96** |
| **Ave.** | **0.55** | **0.31** | **0.50** | **0.45** | **0.52** | **0.64** | **0.76** | **0.81** | **1.33** | **1.42** | **0.85** | **0.60** | 0.73 |

Highlighted data was synthesised using correlation with Dunstan Creek at Gorge

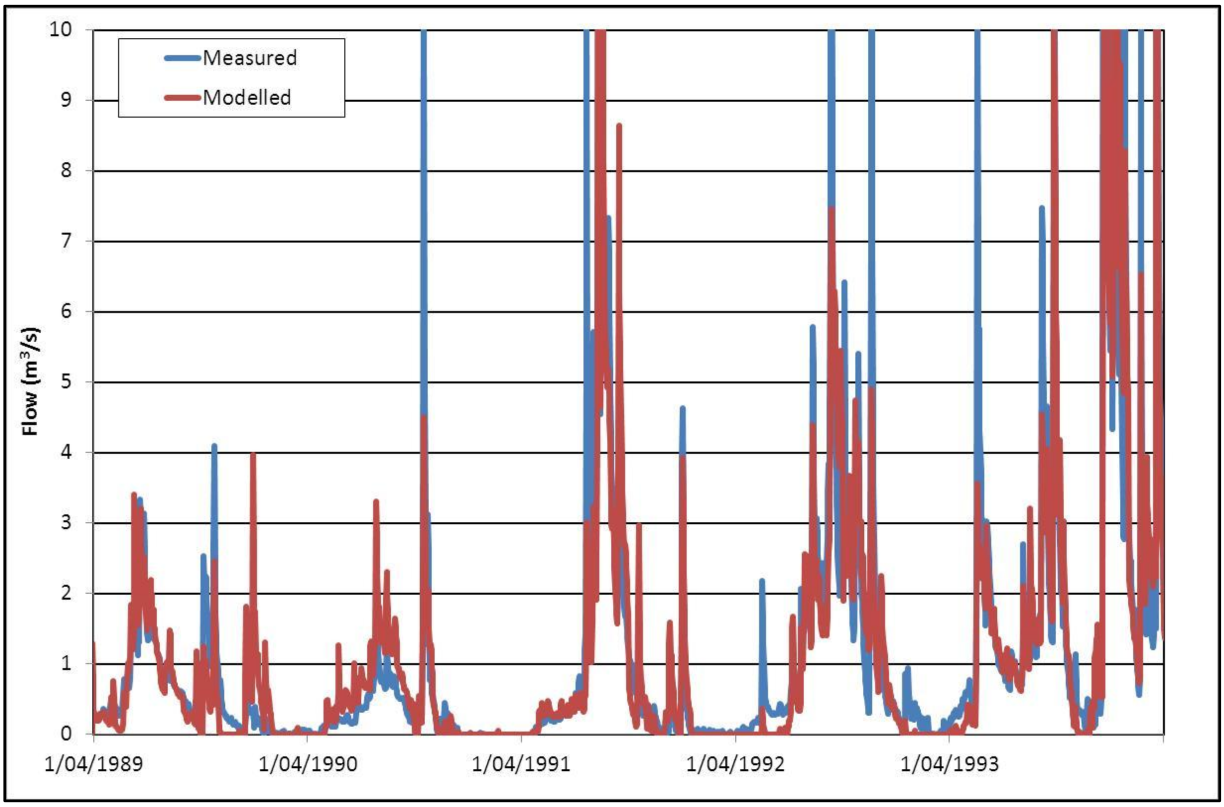
## Poolburn at Cob Cottage

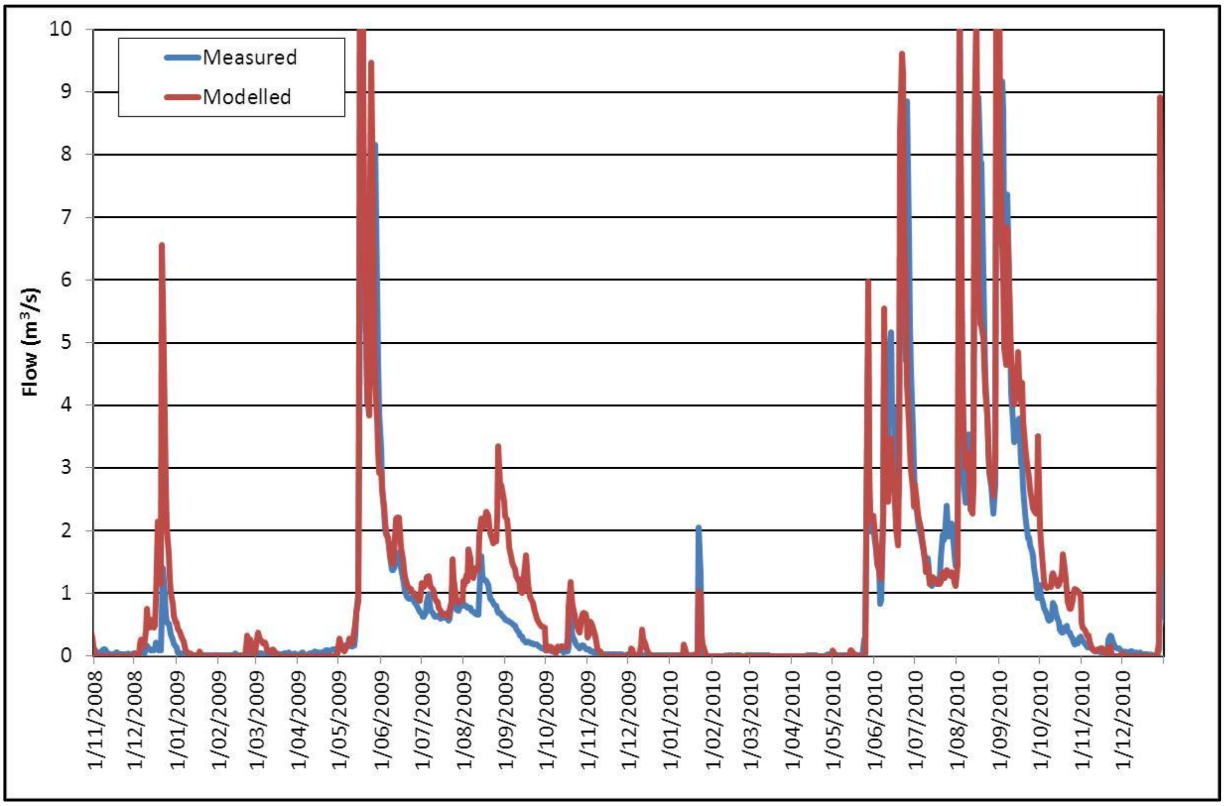
ORC set up a flow recording site at Pool Burn at Cob Cottage in March 1989. This site is still operating. The Manor Burn and Pool Burn dams, together with irrigation in the Ida Valley means the measured flow has been significantly altered from it's natural state.

This daily flow record was extended using correlation with the Manuherikia at Ophir site. The correlation relationship was calculated for each month to allow differences in seasonal trends between the two sites to be maintained.

| Month | $x_1 =$ |
|---|---|
| Jan | $x_2 \times 0.118 - 0.35$ |
| Feb | $x_2 \times 0.064 - 0.35$ |
| Mar | $x_2 \times 0.092 - 0.35$ |
| Apr | $x_2 \times 0.076 - 0.35$ |
| May | $x_2 \times 0.102 - 0.35$ |
| Jun | $x_2 \times 0.112 - 0.35$ |
| Jul | $x_2 \times 0.141 - 0.35$ |
| Aug | $x_2 \times 0.173 - 0.35$ |
| Sep | $x_2 \times 0.146 - 0.35$ |
| Oct | $x_2 \times 0.076 - 0.35$ |
| Nov | $x_2 \times 0.053 - 0.35$ |
| Dec | $x_2 \times 0.115 - 0.35$ |

Where:
$x_1$ = Poolburn at Cob Cottage
$x_2$ = Manuherikia at Ophir


Measured
Modelled
Flow (m³/s)
10
9
8
7
6
5
4
3
2
1
0
1/04/1989
1/04/1990
1/04/1991
1/04/1992
1/04/1993


Measured
Modelled
Flow (m³/s)
10
9
8
7
6
5
4
3
2
1
0
1/11/2008
1/12/2008
1/01/2009
1/02/2009
1/03/2009
1/04/2009
1/05/2009
1/06/2009
1/07/2009
1/08/2009
1/09/2009
1/10/2009
1/11/2009
1/12/2009
1/01/2010
1/02/2010
1/03/2010
1/04/2010
1/05/2010
1/06/2010
1/07/2010
1/08/2010
1/09/2010
1/10/2010
1/11/2010
1/12/2010

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Ave.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1972 | | | | | | 1.60 | 3.58 | 2.58 | 5.32 | 1.82 | 0.39 | 0.21 | **2.21** |
| 1973 | 0.02 | 0.00 | 0.00 | 0.11 | 0.60 | 0.71 | 0.40 | 1.99 | 3.19 | 0.84 | 1.32 | 0.03 | **0.77** |
| 1974 | 0.00 | 0.05 | 0.22 | 0.41 | 0.69 | 0.91 | 1.58 | 6.14 | 4.00 | 2.36 | 0.39 | 0.05 | **1.41** |
| 1975 | 0.08 | 0.02 | 0.44 | 1.07 | 1.40 | 1.43 | 1.99 | 5.30 | 3.36 | 1.02 | 0.39 | 0.07 | **1.39** |
| 1976 | 0.01 | 0.00 | 0.00 | 0.00 | 0.16 | 1.16 | 1.95 | 3.13 | 2.88 | 1.59 | 0.57 | 5.08 | **1.39** |
| 1977 | 2.44 | 0.01 | 0.00 | 0.02 | 1.66 | 1.34 | 1.44 | 0.81 | 1.83 | 1.42 | 0.34 | 0.40 | **0.98** |
| 1978 | 0.26 | 0.00 | 0.00 | 0.01 | 0.59 | 1.05 | 2.00 | 5.93 | 8.12 | 3.51 | 0.70 | 1.84 | **2.01** |
| 1979 | 0.49 | 0.00 | 0.37 | 0.87 | 1.78 | 1.48 | 1.12 | 2.62 | 3.11 | 2.63 | 0.70 | 2.10 | **1.45** |
| 1980 | 2.80 | 0.24 | 0.29 | 0.74 | 3.23 | 5.55 | 4.56 | 9.37 | 3.42 | 1.14 | 0.57 | 0.72 | **2.73** |
| 1981 | 0.03 | 0.00 | 0.52 | 0.29 | 0.45 | 1.09 | 2.31 | 3.68 | 1.79 | 0.84 | 0.02 | 0.05 | **0.93** |
| 1982 | 0.02 | 0.00 | 0.00 | 0.01 | 0.97 | 1.25 | 0.69 | 1.71 | 3.06 | 1.84 | 2.42 | 3.43 | **1.29** |
| 1983 | 3.00 | 0.03 | 0.33 | 1.45 | 3.54 | 3.69 | 5.11 | 5.26 | 4.25 | 4.01 | 1.26 | 2.00 | **2.85** |
| 1984 | 1.13 | 0.13 | 1.37 | 0.21 | 0.75 | 0.53 | 1.79 | 3.24 | 1.50 | 1.40 | 0.15 | 0.89 | **1.10** |
| 1985 | 0.09 | 0.00 | 0.00 | 0.00 | 0.01 | 0.09 | 0.20 | 2.30 | 2.80 | 0.27 | 0.28 | 0.98 | **0.59** |
| 1986 | 0.20 | 0.21 | 2.63 | 1.32 | 1.83 | 2.72 | 3.11 | 4.01 | 2.46 | 1.42 | 0.33 | 0.86 | **1.77** |
| 1987 | 0.02 | 0.35 | 5.78 | 0.90 | 1.47 | 1.76 | 2.28 | 2.46 | 2.86 | 2.09 | 0.20 | 0.23 | **1.71** |
| 1988 | 0.49 | 0.20 | 0.03 | 0.05 | 0.25 | 0.70 | 0.97 | 1.73 | 2.23 | 0.85 | 0.09 | 0.05 | **0.64** |
| 1989 | 0.32 | 0.03 | 0.15 | 0.30 | 0.47 | 1.72 | 1.27 | 0.71 | 0.37 | 1.55 | 0.30 | 0.20 | **0.62** |
| 1990 | 0.13 | 0.01 | 0.04 | 0.03 | 0.17 | 0.25 | 0.75 | 0.81 | 0.37 | 1.73 | 0.24 | 0.05 | **0.39** |
| 1991 | 0.00 | 0.00 | 0.00 | 0.03 | 0.22 | 0.33 | 1.70 | 5.54 | 2.61 | 0.60 | 0.17 | 0.37 | **0.97** |
| 1992 | 0.47 | 0.03 | 0.02 | 0.05 | 0.48 | 0.33 | 1.02 | 2.41 | 4.39 | 2.94 | 2.55 | 0.61 | **1.28** |
| 1993 | 0.37 | 0.16 | 0.05 | 0.35 | 2.25 | 1.61 | 0.87 | 1.31 | 4.12 | 1.55 | 0.33 | 7.63 | **1.73** |
| 1994 | 8.83 | 2.29 | 4.74 | 1.59 | 0.84 | 1.47 | 4.52 | 3.01 | 2.09 | 0.69 | 1.09 | 0.36 | **2.64** |
| 1995 | 0.00 | 0.00 | 0.05 | 0.00 | 0.16 | 1.28 | 1.59 | 2.90 | 7.57 | 4.12 | 1.20 | 5.79 | **2.07** |
| 1996 | 2.54 | 0.15 | 0.46 | 0.54 | 1.64 | 2.54 | 1.38 | 1.53 | 0.97 | 0.56 | 0.23 | 0.68 | **1.11** |
| 1997 | 1.86 | 0.13 | 0.25 | 0.62 | 0.88 | 0.82 | 1.51 | 4.28 | 1.81 | 0.67 | 0.02 | 0.09 | **1.09** |
| 1998 | 0.07 | 0.00 | 0.00 | 0.00 | 0.10 | 0.46 | 2.03 | 1.69 | 1.89 | 1.43 | 0.16 | 0.01 | **0.66** |
| 1999 | 0.00 | 0.00 | 0.00 | 0.06 | 0.11 | 0.55 | 1.78 | 1.99 | 1.81 | 0.18 | 1.31 | 1.23 | **0.76** |
| 2000 | 3.43 | 0.71 | 0.11 | 0.32 | 1.62 | 4.01 | 2.96 | 3.59 | 5.78 | 1.43 | 0.09 | 0.32 | **2.03** |
| 2001 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.12 | 0.43 | 1.44 | 0.74 | 0.17 | 0.42 | 0.94 | **0.37** |
| 2002 | 2.33 | 0.02 | 0.00 | 0.04 | 0.15 | 1.03 | 2.00 | 1.96 | 2.15 | 0.28 | 0.25 | 0.75 | **0.92** |
| 2003 | 0.24 | 0.00 | 0.00 | 0.00 | 0.02 | 0.17 | 1.16 | 0.82 | 1.12 | 1.07 | 0.02 | 0.00 | **0.39** |
| 2004 | 0.03 | 0.07 | 0.74 | 0.00 | 0.60 | 1.27 | 1.16 | 2.00 | 1.72 | 0.87 | 0.58 | 3.61 | **1.06** |
| 2005 | 4.50 | 0.21 | 0.18 | 0.23 | 0.49 | 0.55 | 0.65 | 0.80 | 0.44 | 0.47 | 0.00 | 0.21 | **0.74** |
| 2006 | 0.16 | 0.00 | 0.00 | 0.31 | 2.45 | 2.31 | 2.11 | 2.34 | 1.59 | 0.30 | 0.62 | 4.00 | **1.36** |
| 2007 | 1.48 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 | 0.90 | 0.98 | 0.80 | 0.98 | 0.04 | 0.01 | **0.45** |
| 2008 | 0.01 | 0.00 | 0.00 | 0.00 | 0.32 | 0.77 | 2.08 | 2.87 | 3.63 | 1.04 | 0.05 | 0.25 | **0.92** |
| 2009 | 0.02 | 0.02 | 0.03 | 0.06 | 3.21 | 1.41 | 0.73 | 0.86 | 0.31 | 0.15 | 0.04 | 0.01 | **0.58** |
| 2010 | 0.11 | 0.00 | 0.00 | 0.00 | 0.53 | 3.96 | 1.69 | 5.10 | 3.88 | 0.52 | 0.14 | 0.22 | **1.35** |
| 2011 | 0.20 | 1.05 | 0.88 | 0.72 | 3.07 | | | | | | | | **1.19** |
| **Ave.** | **0.98** | **0.16** | **0.50** | **0.33** | **1.00** | **1.39** | **1.78** | **2.85** | **2.73** | **1.34** | **0.51** | **1.19** | **1.22** |

# Appendix C: Manuherikia Valley model

Manuherikia River flow at Ophir was modelled as:
*Flow at Ophir = Falls Dam inflow + Δ(Falls Dam storage) + Dunstan Creek + Lauder Creek + Thomsons Creek + Pool Burn + Other tributaries – Net irrigation use*

Where:
Dunstan Creek [at Beatties Rd] = 1.5 × Dunstan Creek at Gorge (Aqualinc 2012b)

Lauder Creek [at Rail Trail] = 1.5 × Lauder Creek at Cattle Yards (Aqualinc 2012b)

Thomsons Creek [at SH85] = 2.0 ×Thomsons Creek at Diversion Weir (Aqualinc 2012b)

Pool Burn = Pool Burn at Cob Cottage

Other Tributaries = 0.4 × Dunstan Creek at Gorge +
0.5 × Lauder Creek at Cattle Yards +
0.3 × Pool Burn at Cob Cottage

Net irrigation use [above Ophir] = Irrigation abstraction – irrigation losses

Falls Dam releases used the following logic

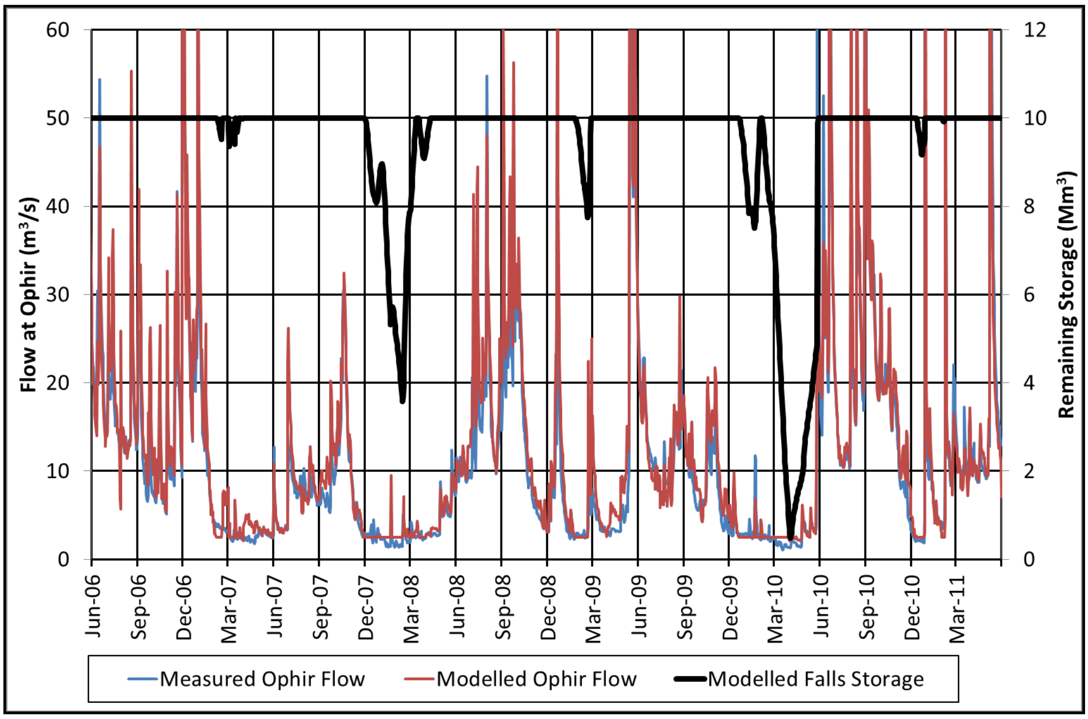
Falls outflow = max(Demand shortfall, Ophir shortfall, Min. flow below dam)

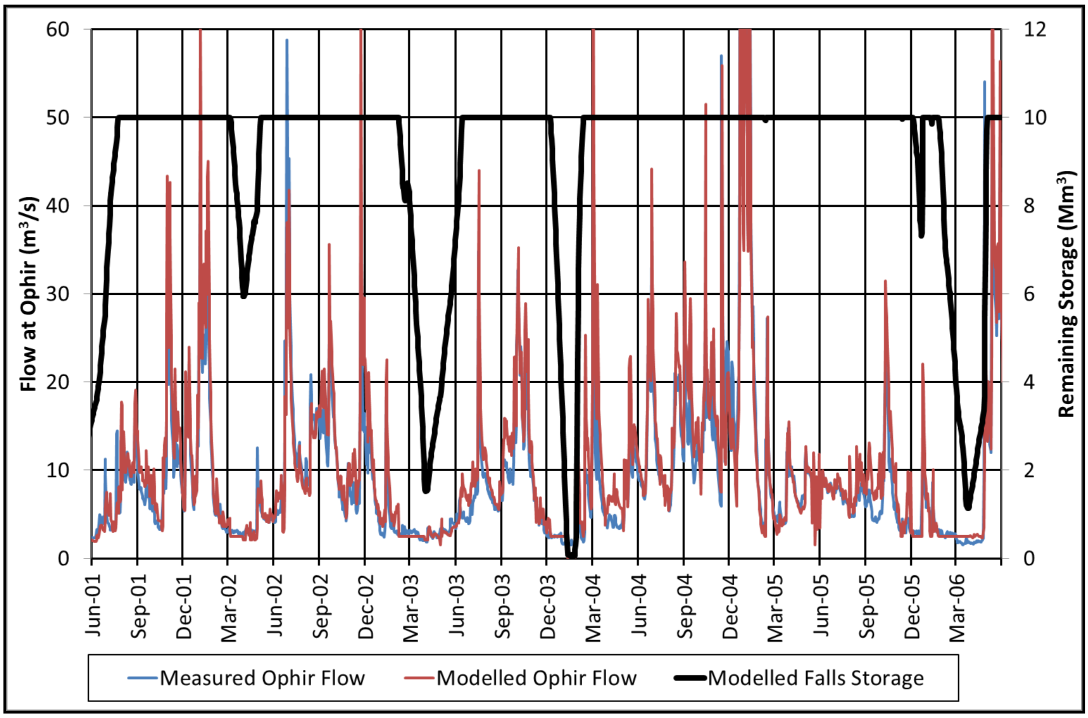
Demand_Shortfall = Irrigation abstraction - Available Flow [other than Falls outflow] + Minimum flow below Omakau intake

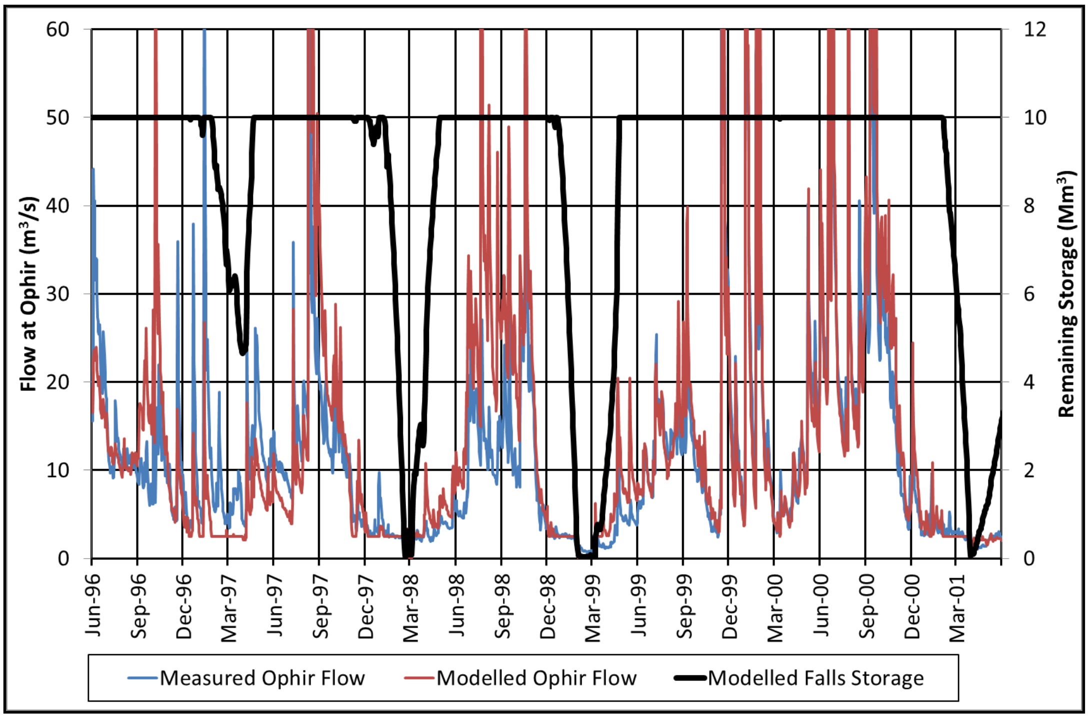
Available Flow = Dunstan Creek at Gorge – 300 l/s [minimum flow] +
Lauder Creek at Cattle Yards +
Thomsons Creek at Diversion Weir +
20% ×(other gains between Falls and Ophir)

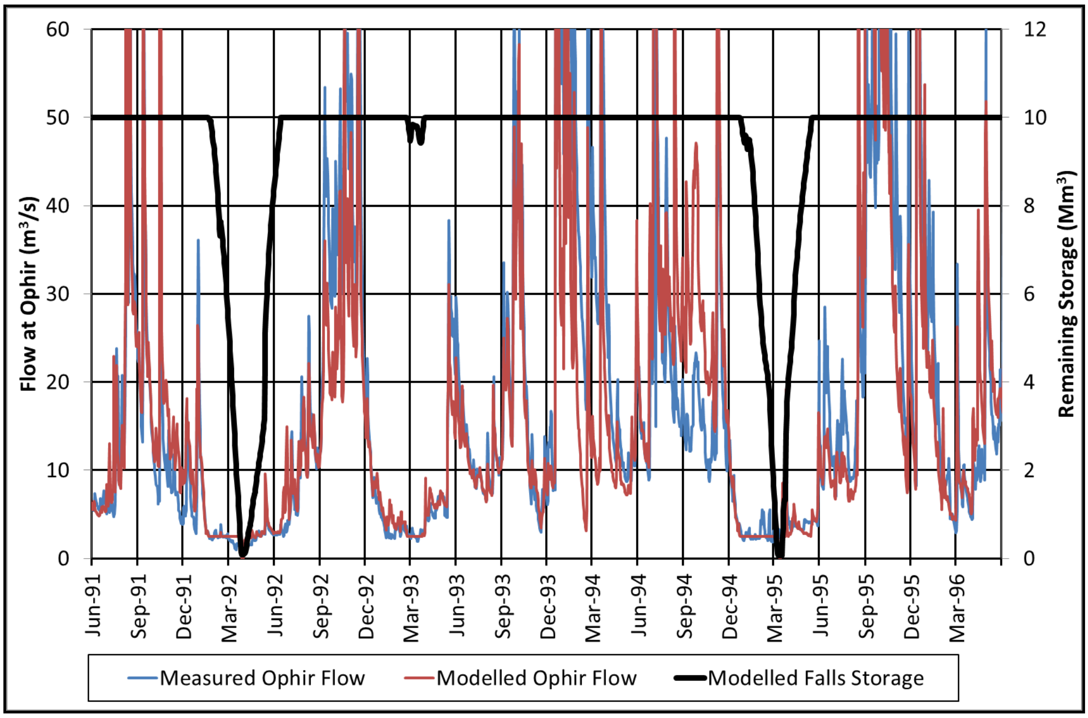
Ophir shortfall = Net irrigation use above Ophir + Gross irrigation demand below Ophir + Min. flow below MIS take – Inflow from Falls to Ophir [excluding Falls Outflow]

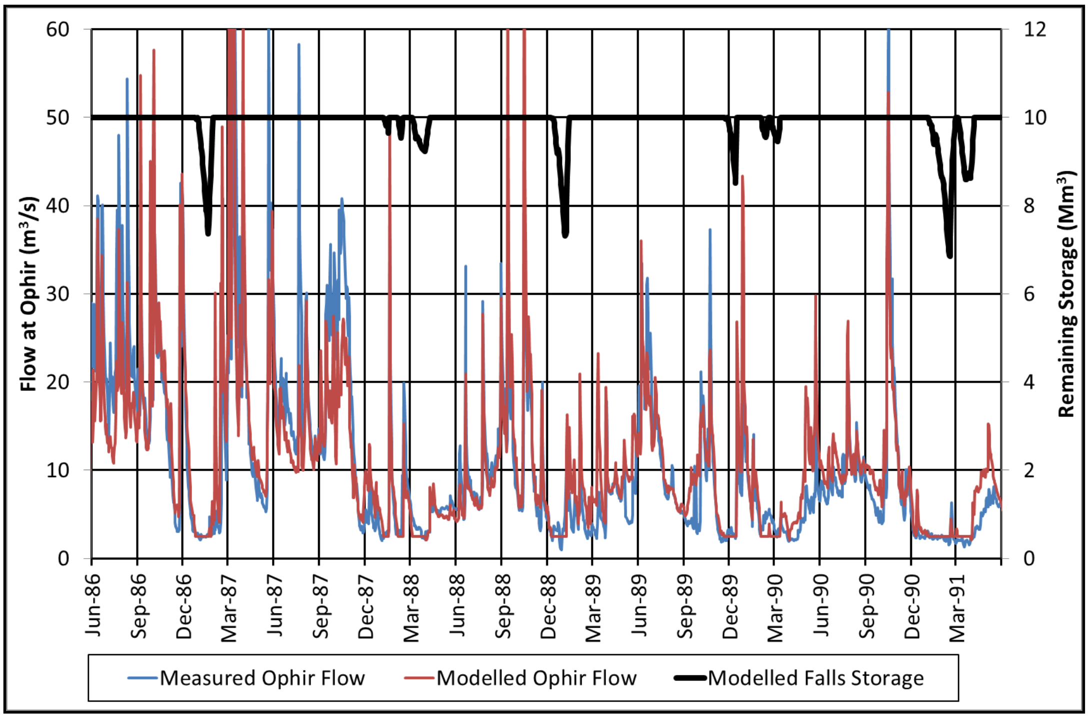
# Appendix D: Manuherikia Valley model – status quo



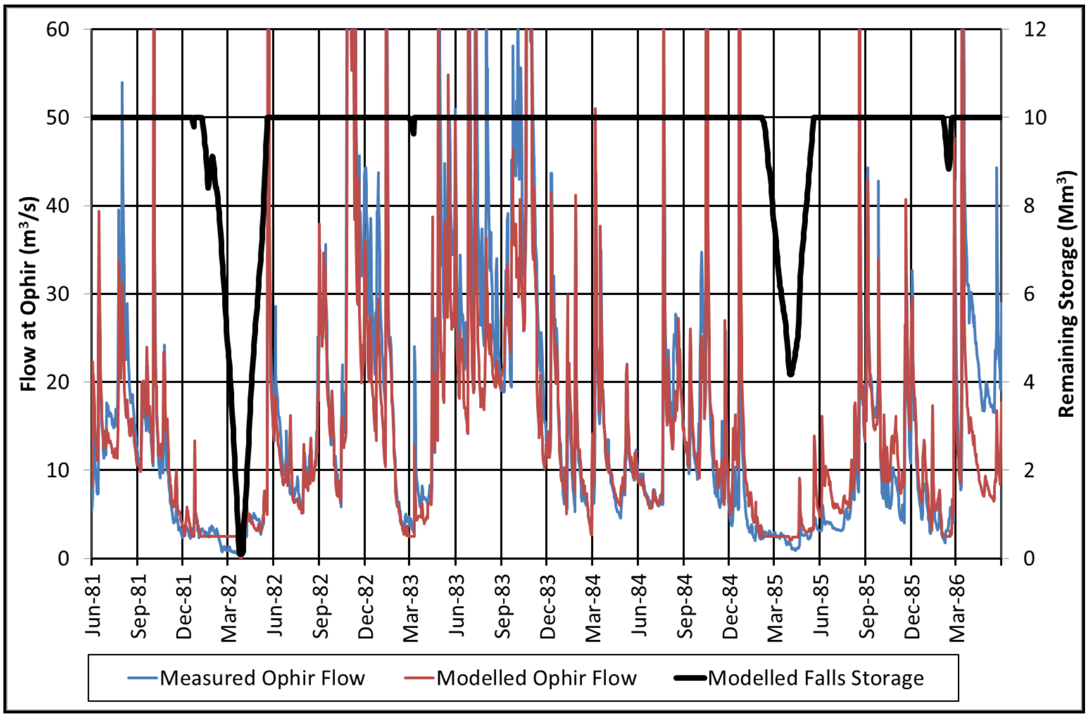




Flow at Ophir (m³/s)
Remaining Storage (Mm³)
Jun-96
Sep-96
Dec-96
Mar-97
Jun-97
Sep-97
Dec-97
Mar-98
Jun-98
Sep-98
Dec-98
Mar-99
Jun-99
Sep-99
Dec-99
Mar-00
Jun-00
Sep-00
Dec-00
Mar-01
Measured Ophir Flow
Modelled Ophir Flow
Modelled Falls Storage

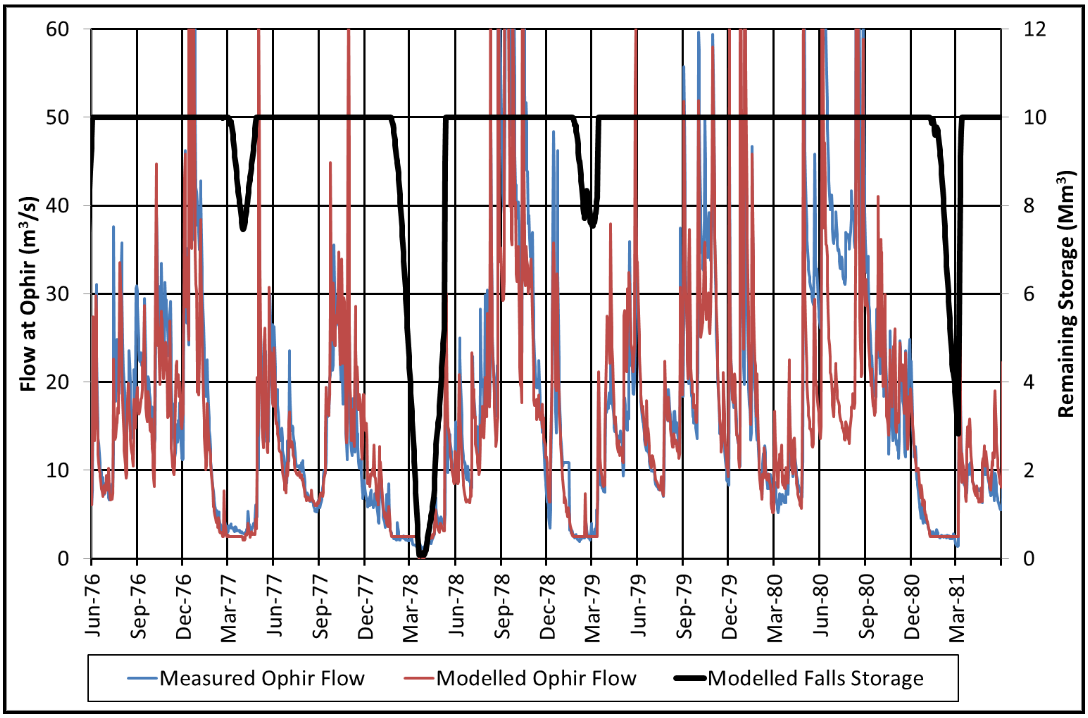

Flow at Ophir (m³/s)
Remaining Storage (Mm³)
Jun-91
Sep-91
Dec-91
Mar-92
Jun-92
Sep-92
Dec-92
Mar-93
Jun-93
Sep-93
Dec-93
Mar-94
Jun-94
Sep-94
Dec-94
Mar-95
Jun-95
Sep-95
Dec-95
Mar-96
Measured Ophir Flow
Modelled Ophir Flow
Modelled Falls Storage



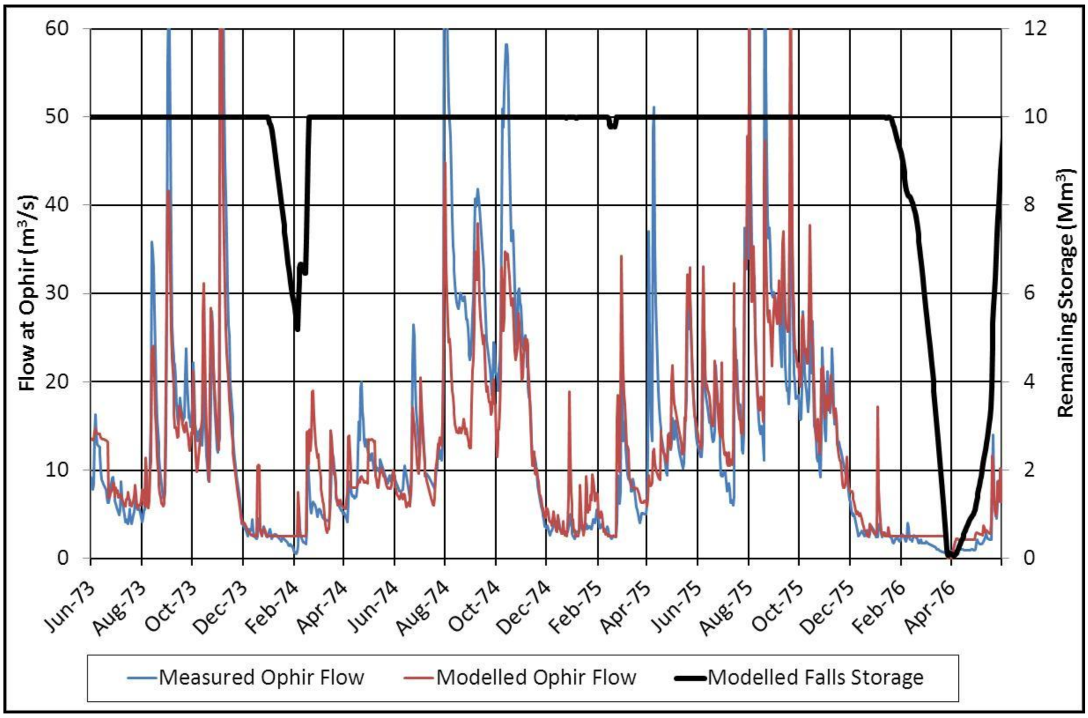
Flow at Ophir (m³/s)
Remaining Storage (Mm³)
60
50
40
30
20
10
0
12
10
8
6
4
2
0
Jun-86
Sep-86
Dec-86
Mar-87
Jun-87
Sep-87
Dec-87
Mar-88
Jun-88
Sep-88
Dec-88
Mar-89
Jun-89
Sep-89
Dec-89
Mar-90
Jun-90
Sep-90
Dec-90
Mar-91
Measured Ophir Flow
Modelled Ophir Flow
Modelled Falls Storage

Flow at Ophir (m³/s)
Remaining Storage (Mm³)
60
50
40
30
20
10
0
12
10
8
6
4
2
0
Jun-81
Sep-81
Dec-81
Mar-82
Jun-82
Sep-82
Dec-82
Mar-83
Jun-83
Sep-83
Dec-83
Mar-84
Jun-84
Sep-84
Dec-84
Mar-85
Jun-85
Sep-85
Dec-85
Mar-86
Measured Ophir Flow
Modelled Ophir Flow
Modelled Falls Storage



Flow at Ophir (m³/s)
Remaining Storage (Mm³)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
Jun-76
Sep-76
Dec-76
Mar-77
Jun-77
Sep-77
Dec-77
Mar-78
Jun-78
Sep-78
Dec-78
Mar-79
Jun-79
Sep-79
Dec-79
Mar-80
Jun-80
Sep-80
Dec-80
Mar-81
Measured Ophir Flow
Modelled Ophir Flow
Modelled Falls Storage

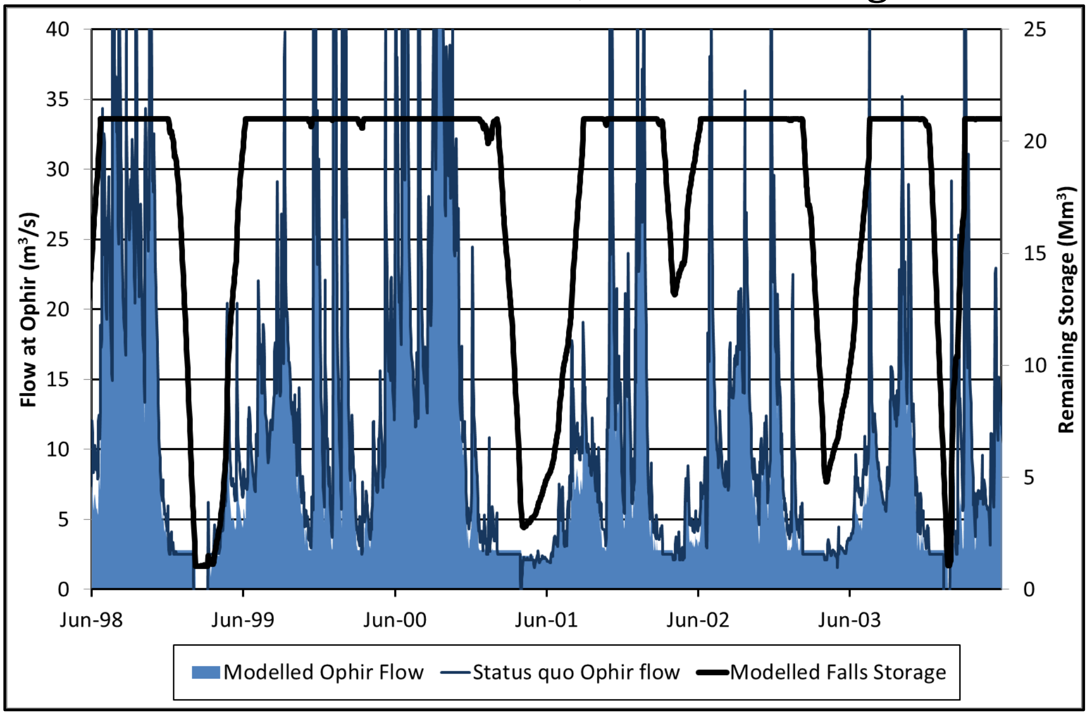



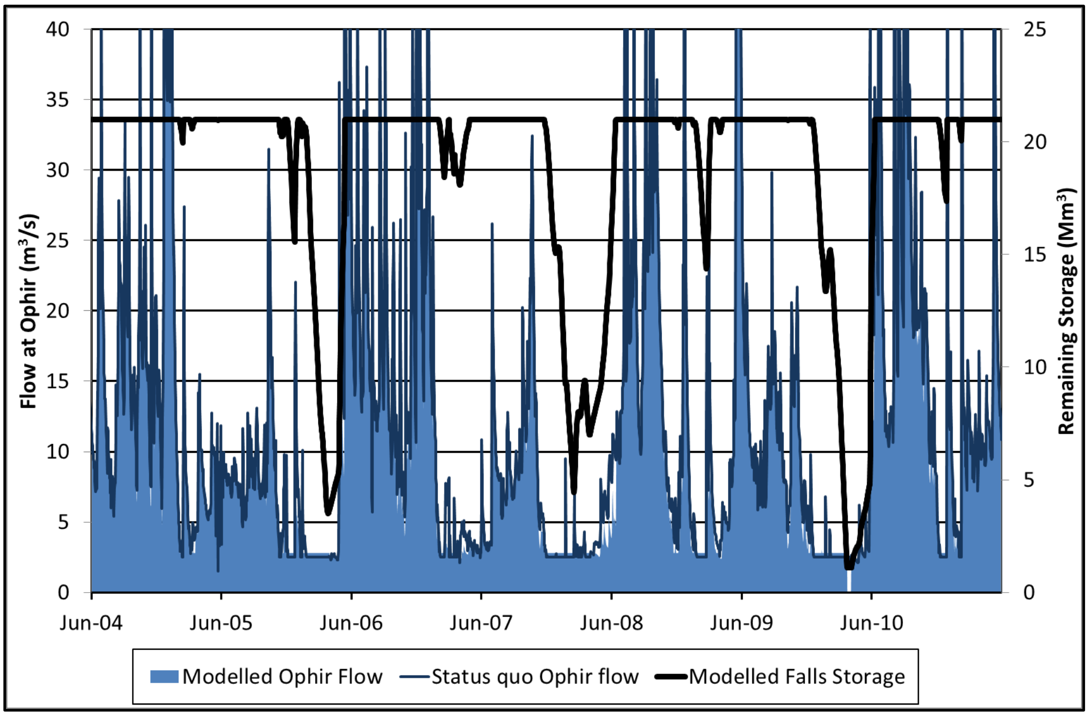
Flow at Ophir (m³/s)
Remaining Storage (Mm³)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
Jun-73
Aug-73
Oct-73
Dec-73
Feb-74
Apr-74
Jun-74
Aug-74
Oct-74
Dec-74
Feb-75
Apr-75
Jun-75
Aug-75
Oct-75
Dec-75
Feb-76
Apr-76
Measured Ophir Flow
Modelled Ophir Flow
Modelled Falls Storage

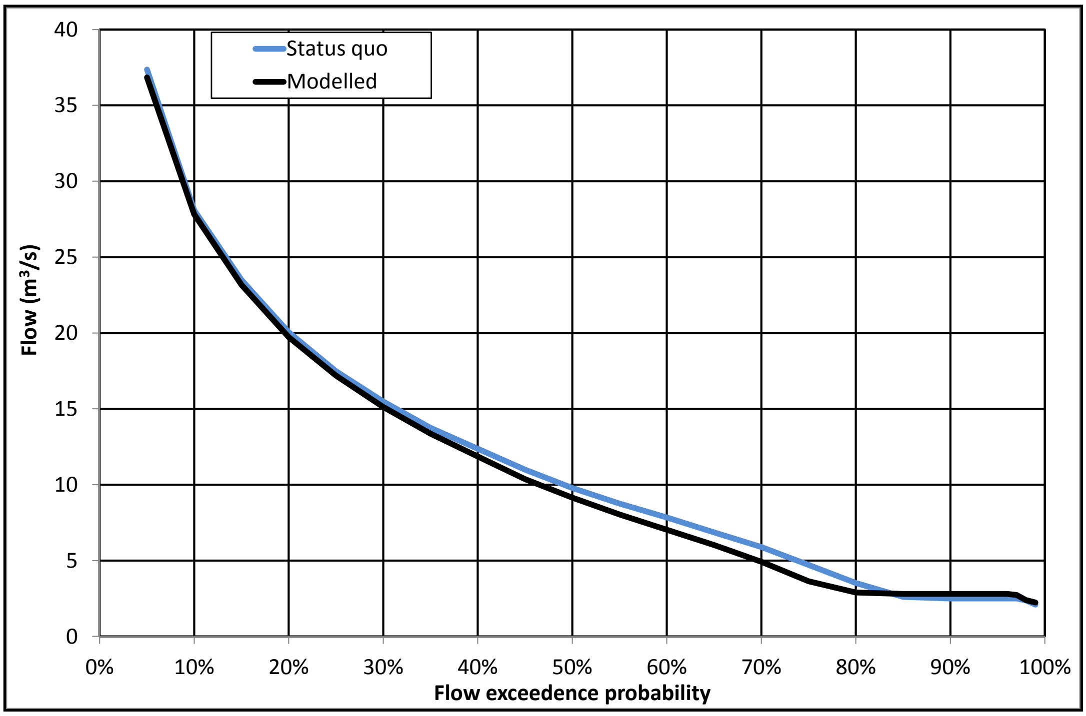
# Appendix E: Manuherikia Valley model – Scenarios

| Scenario | Falls Dam | New irrigated area (ha) | Years with restrictions | Manuherikia min. flow (l/s) | | |
|---|---|---|---|---|---|---|
| | | | | Below Falls | Below Omakau intake | Below MIS intake |
| 1 | Status quo. | 0 | 9 in 38 | 500 | 500 | 500 |
| 2 | Raise 6m | 3,500 | 9 in 38 | 600 | 800 | 800 |
| 3 | Raise 6m | 0 | 1 in 38 | 500 | 500 | 500 |
| 4 | Raise 15m | 6,000 | 1 in 38 | 800 | 1,000 | 1,000 |
| 5 | Raise 25m | 15,000 | 0 in 38 | 1,500 | 1,500 | 1,500 |

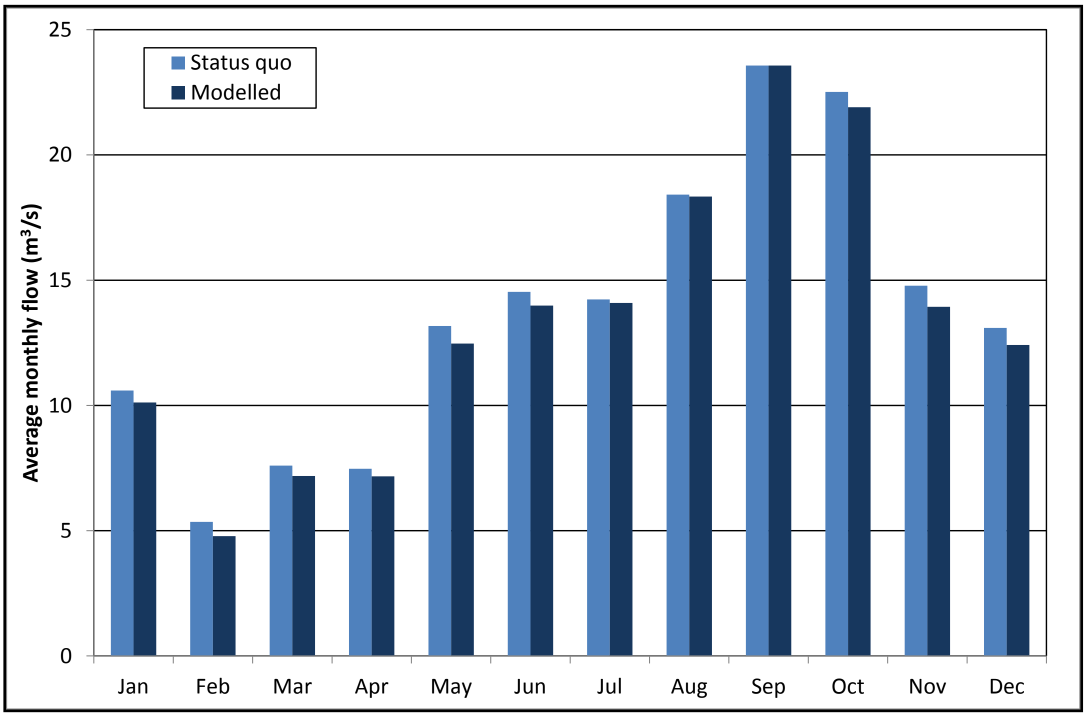
# Scenario 2 – Raise Falls 6m & 3,500 ha new irrigation



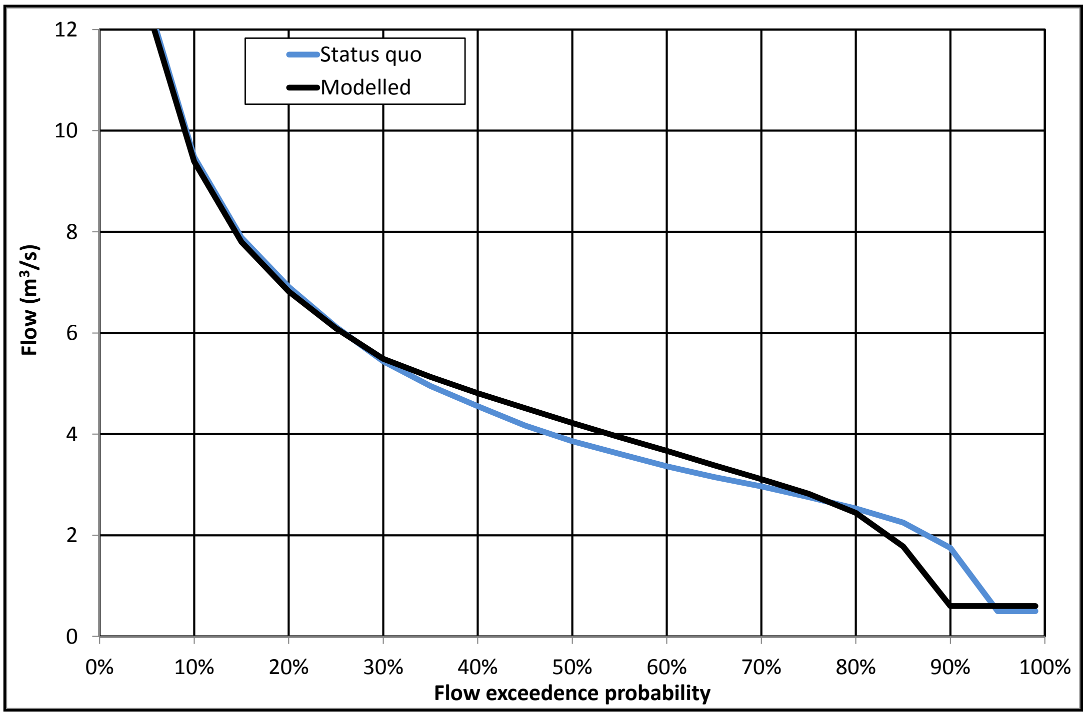





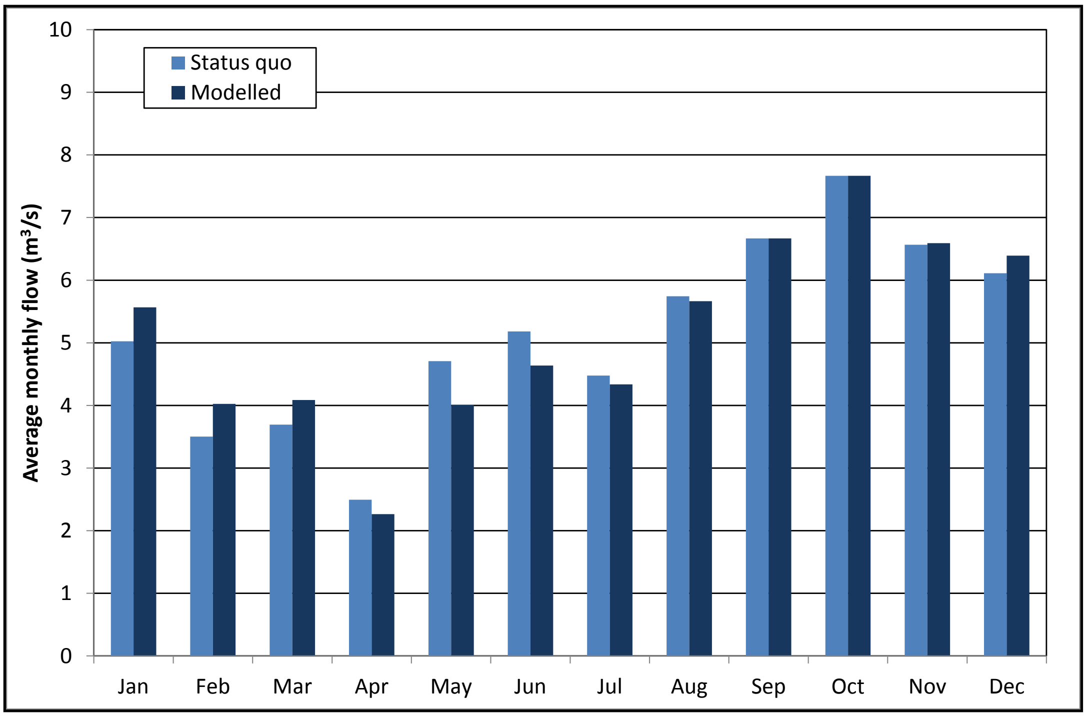

Manuherikia at Ophir – flow duration curve



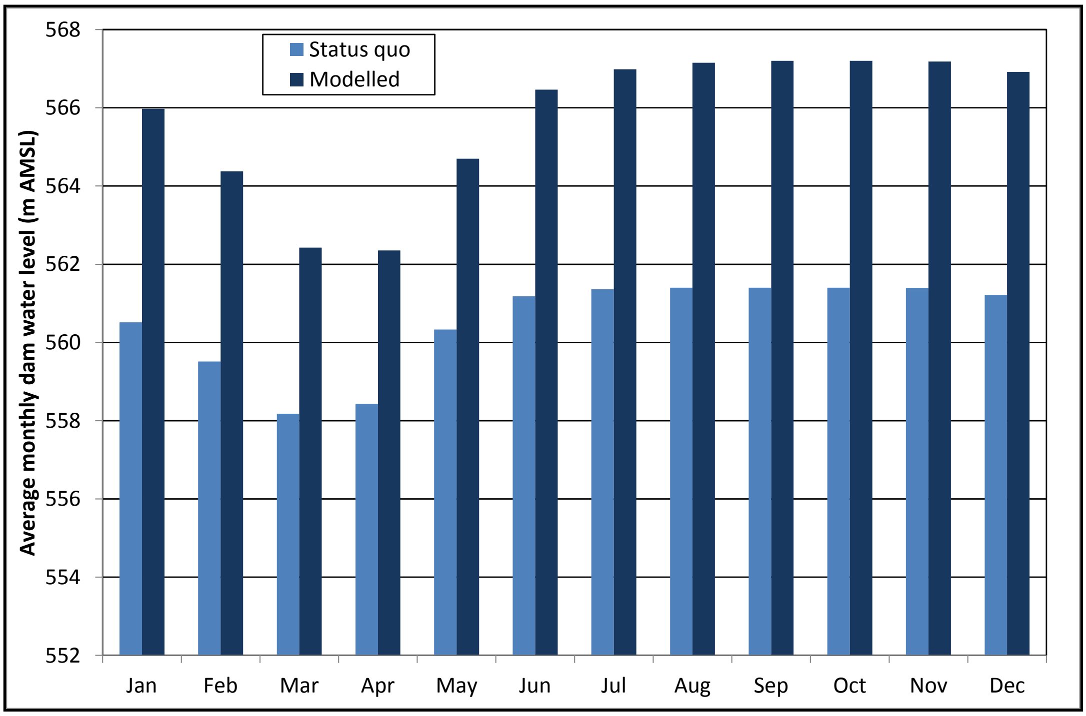

Manuherikia at Ophir – seasonal flow profile



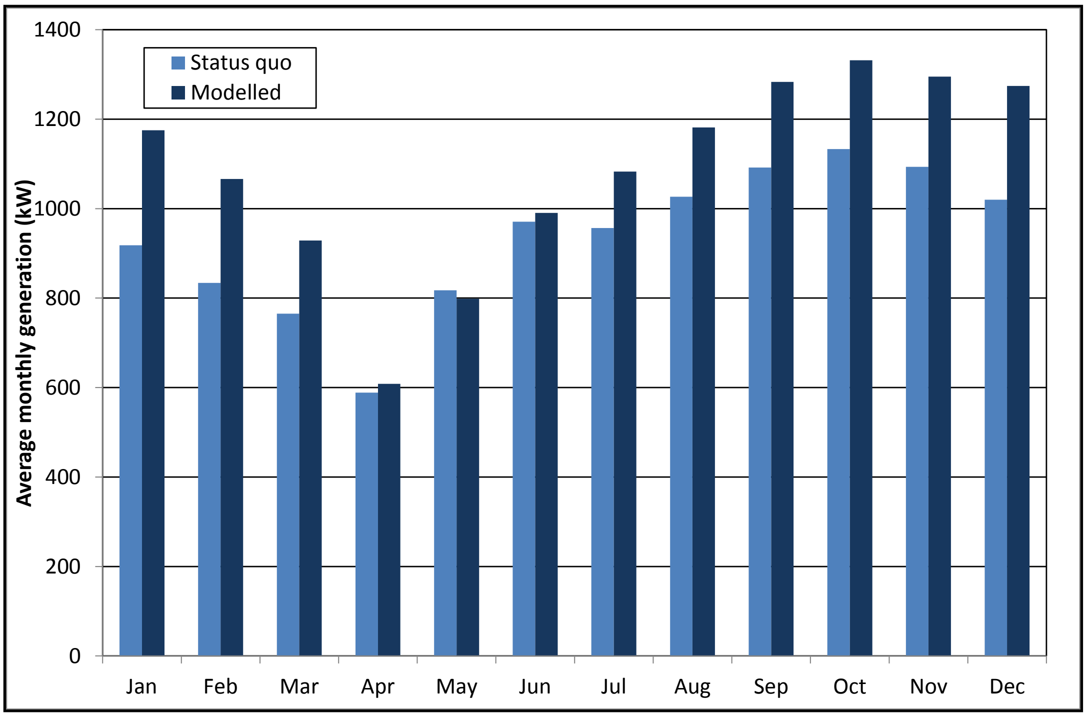

Manuherikia downstream of Falls Dam – flow duration curve




Manuherikia downstream of Falls Dam – seasonal flow profile

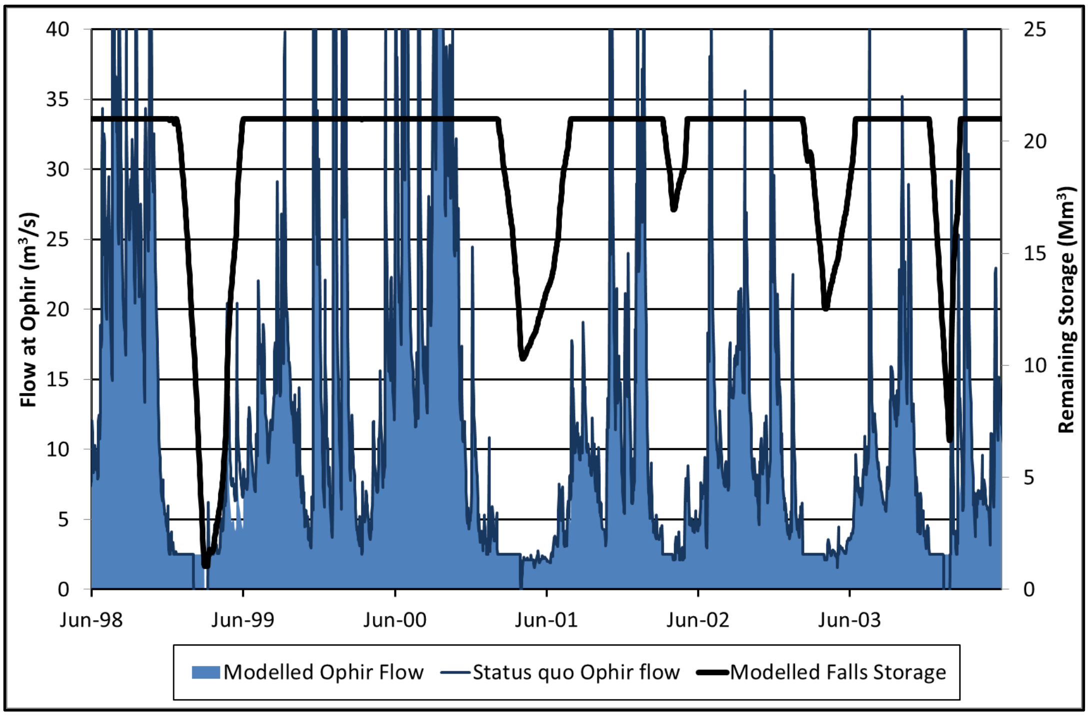


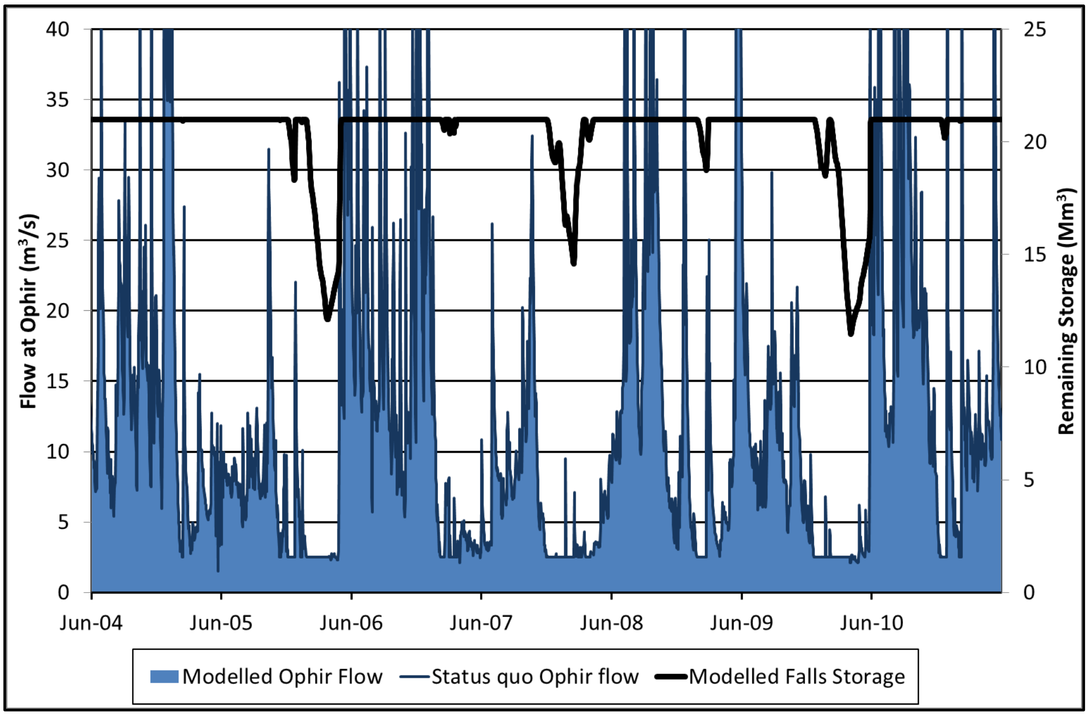

Falls Dam seasonal water level profile

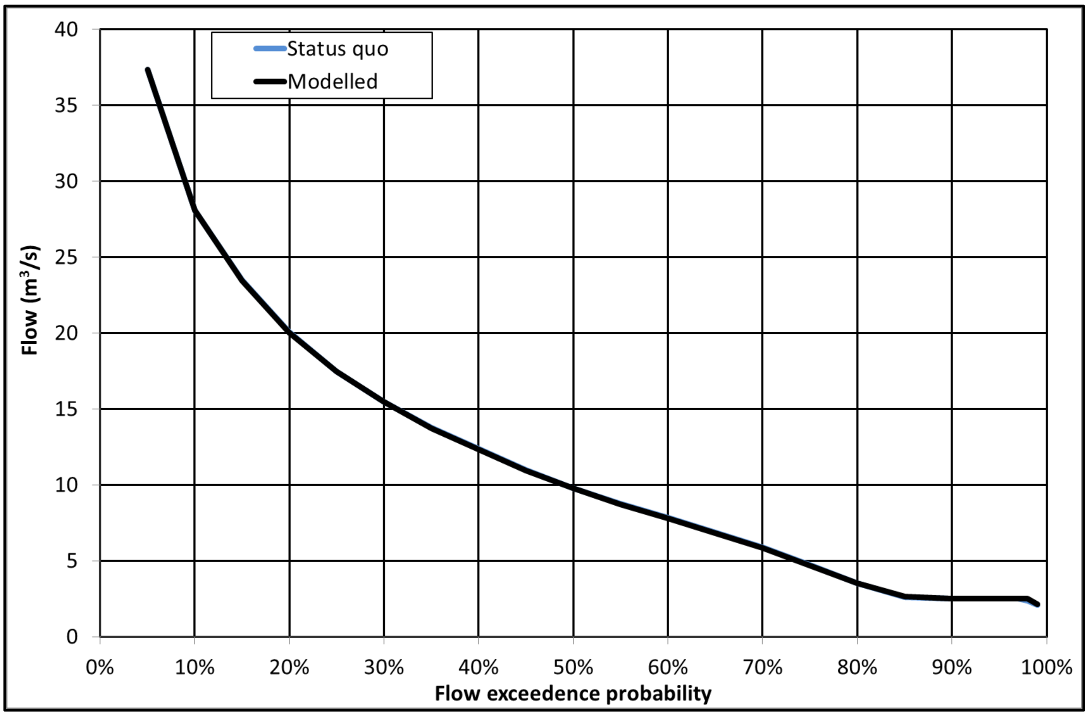



Falls Dam seasonal generation profile (4cu turbine capacity)

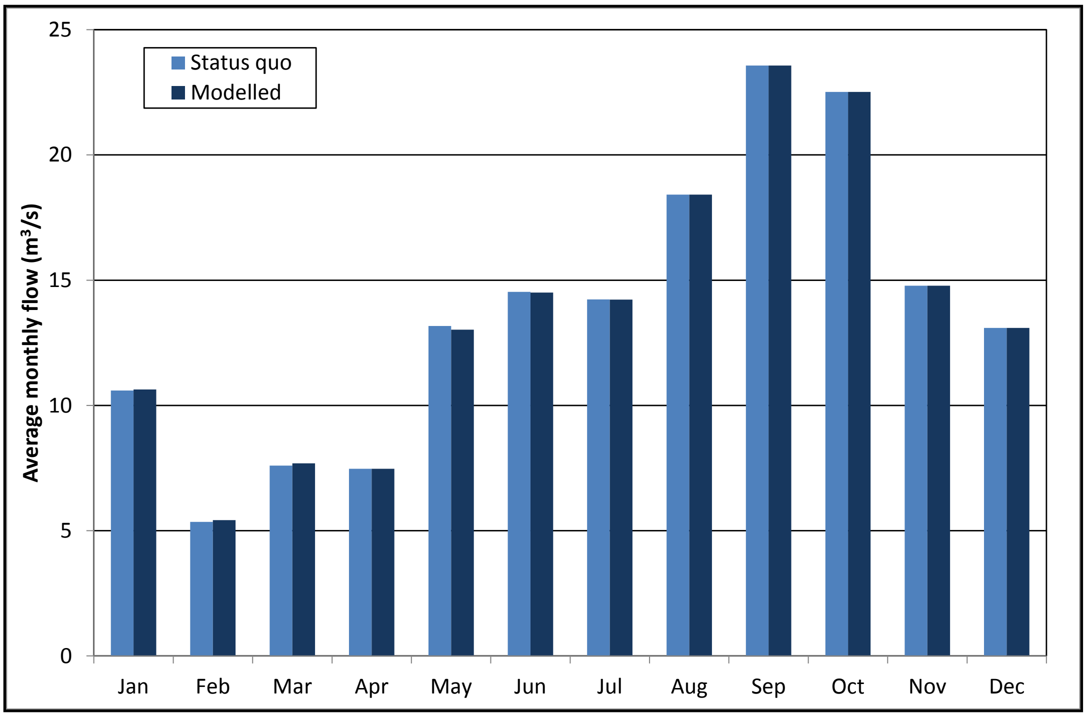
# Scenario 3: Raise Falls 6m & no new irrigation



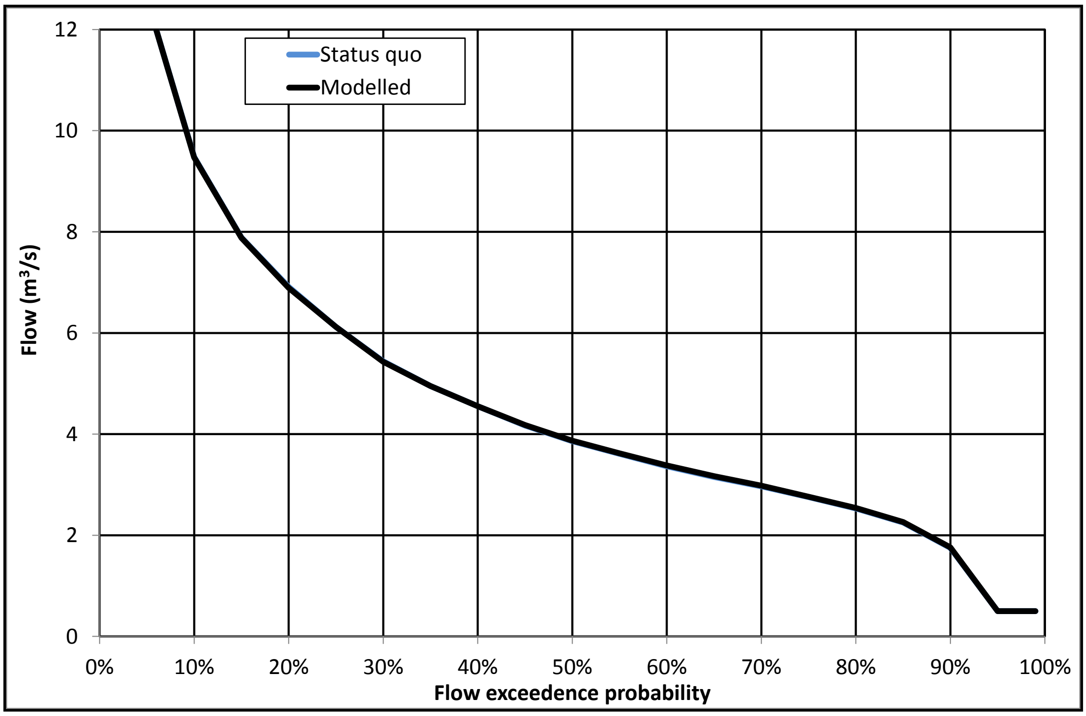





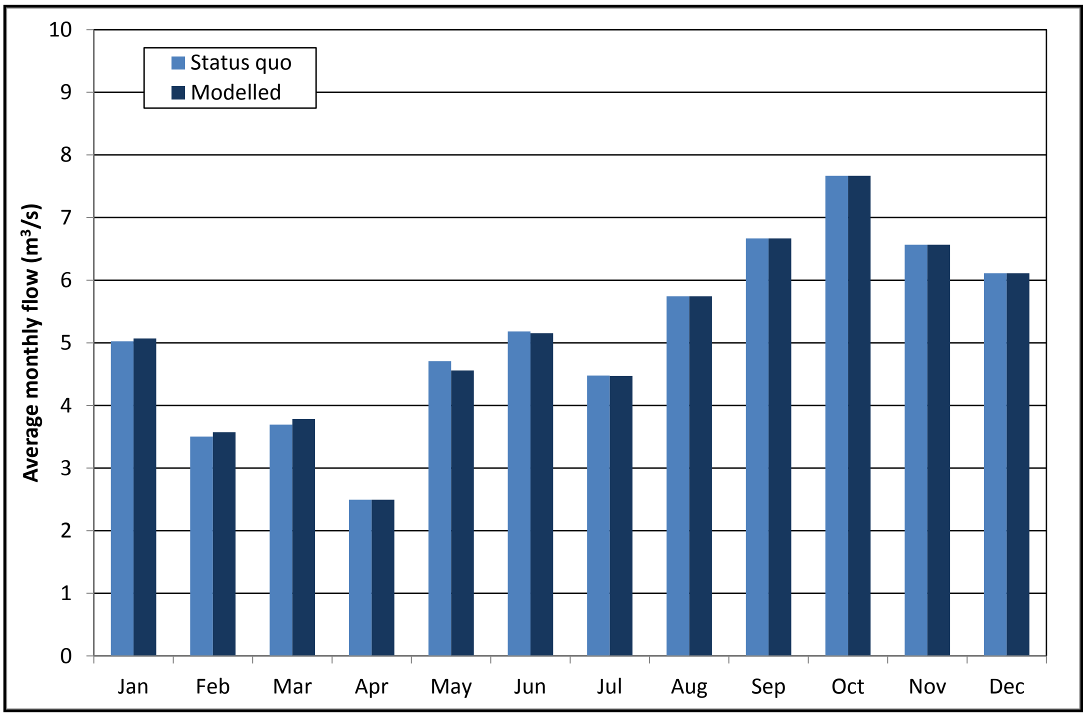

Manuherikia at Ophir – flow duration curve



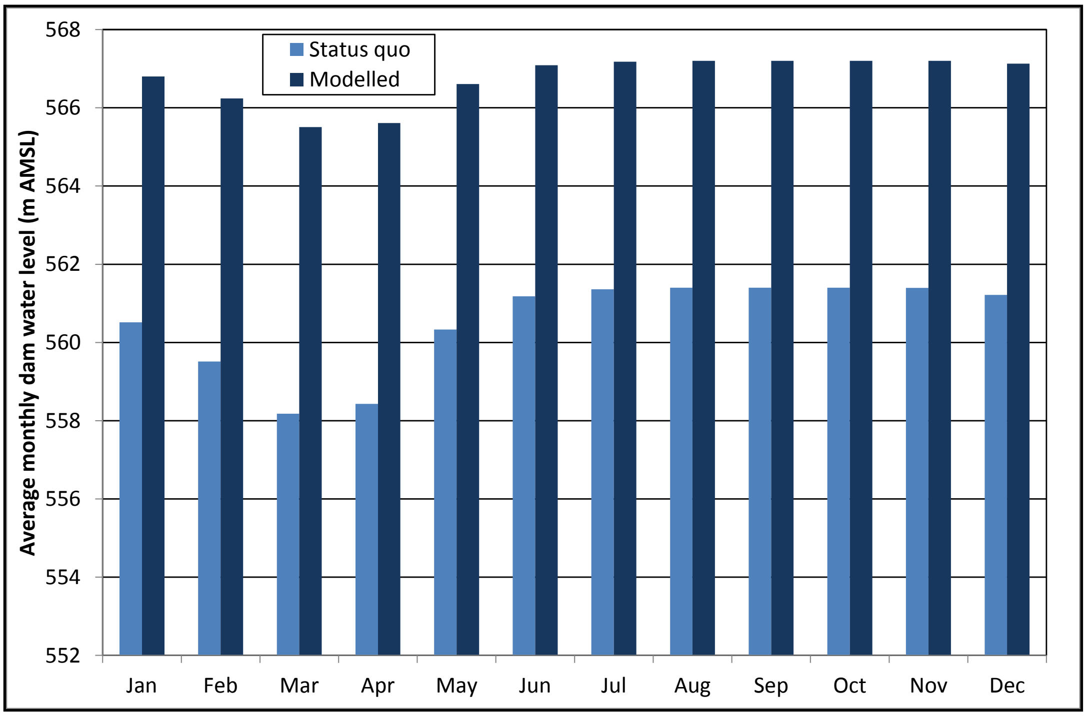

Manuherikia at Ophir – seasonal flow profile



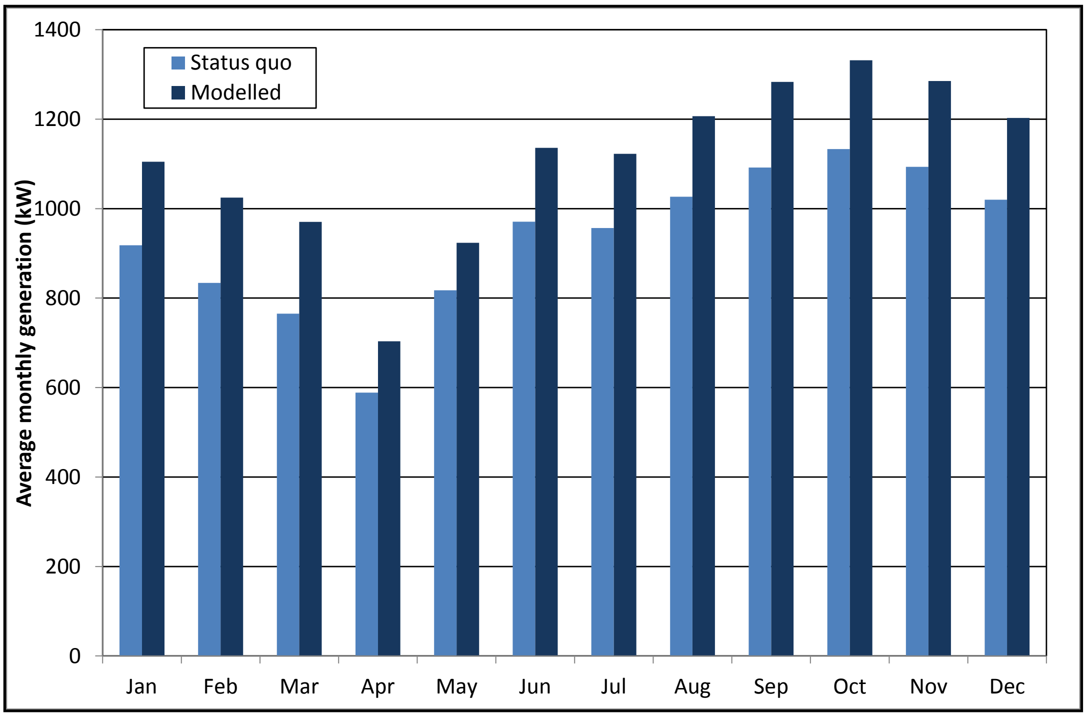

Manuherikia downstream of Falls Dam – flow duration curve




Manuherikia downstream of Falls Dam – seasonal flow profile

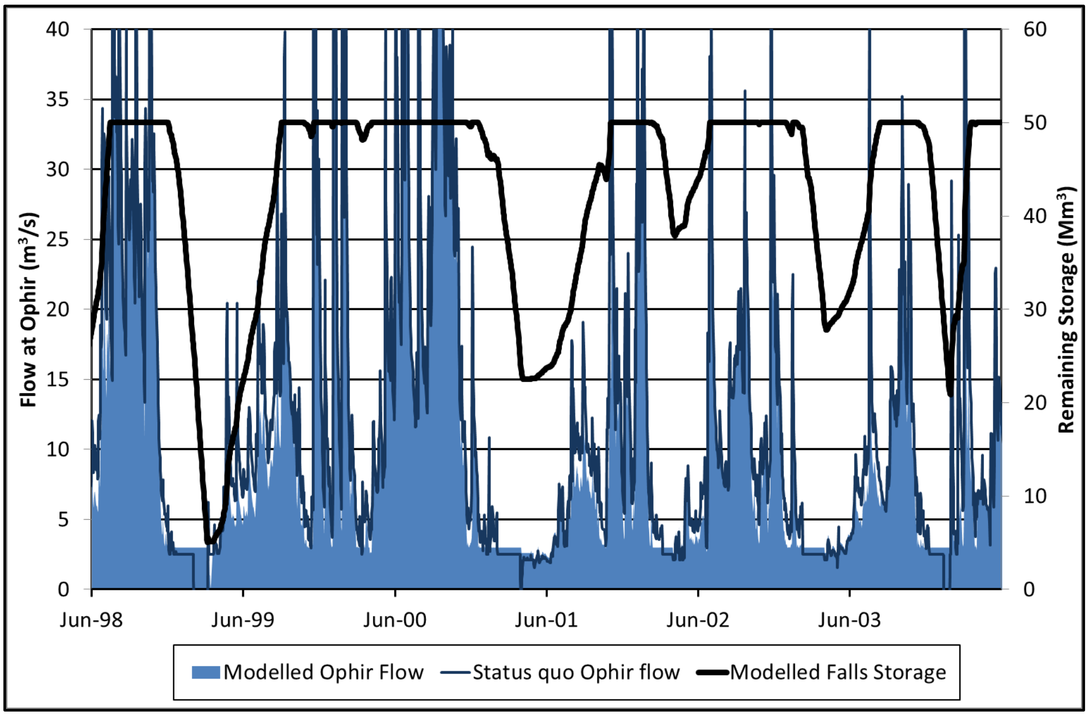


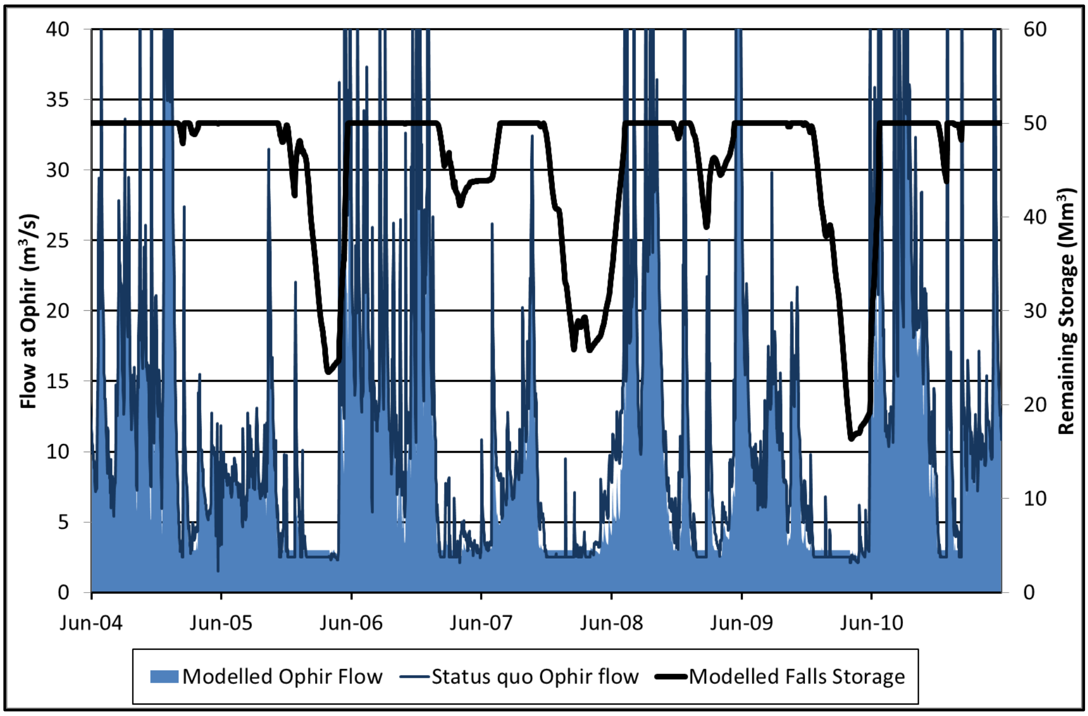

Falls Dam seasonal water level profile

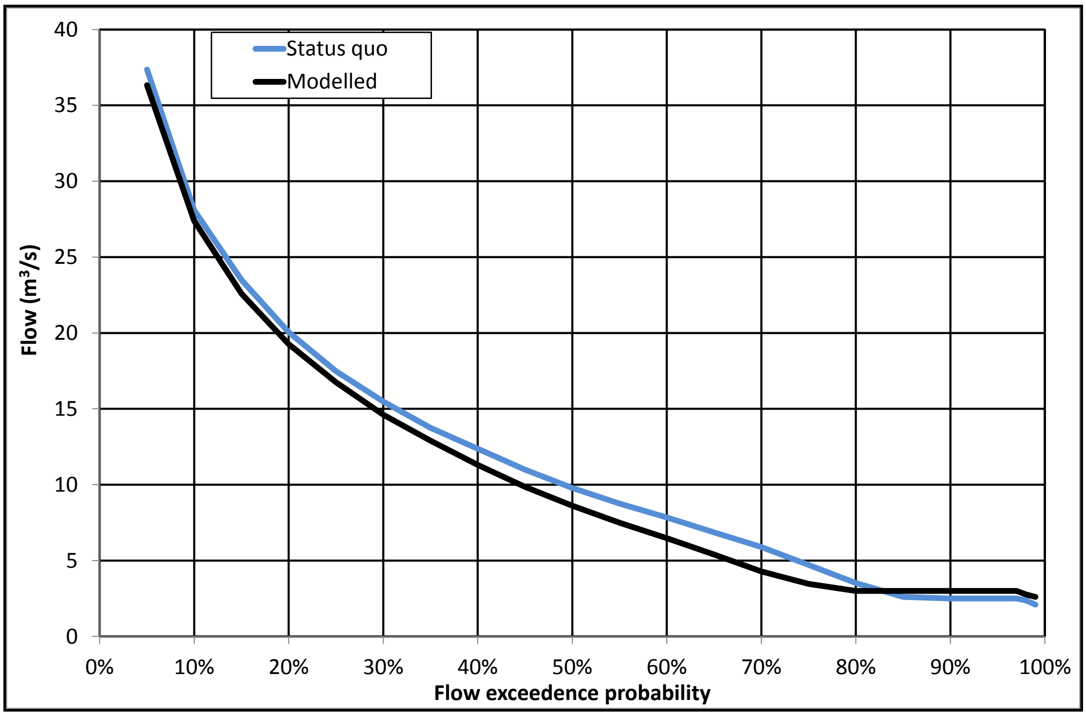



Falls Dam seasonal generation profile (4cu turbine capacity)

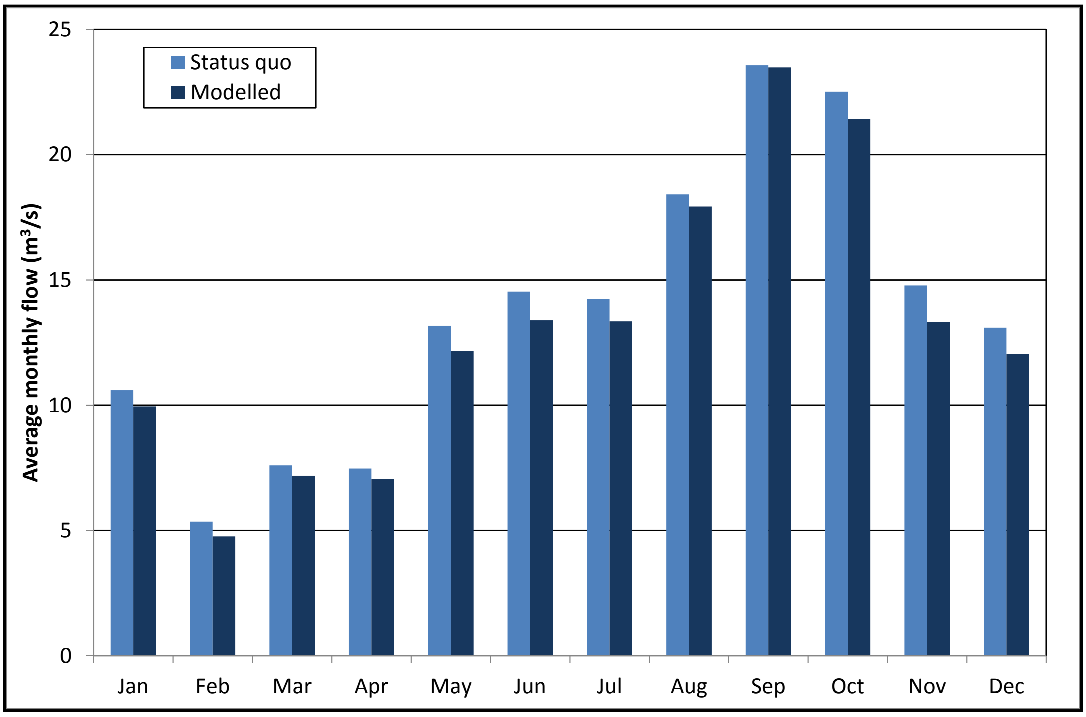
# Scenario 4: Raise Falls 15m & 6,000 ha new irrigation



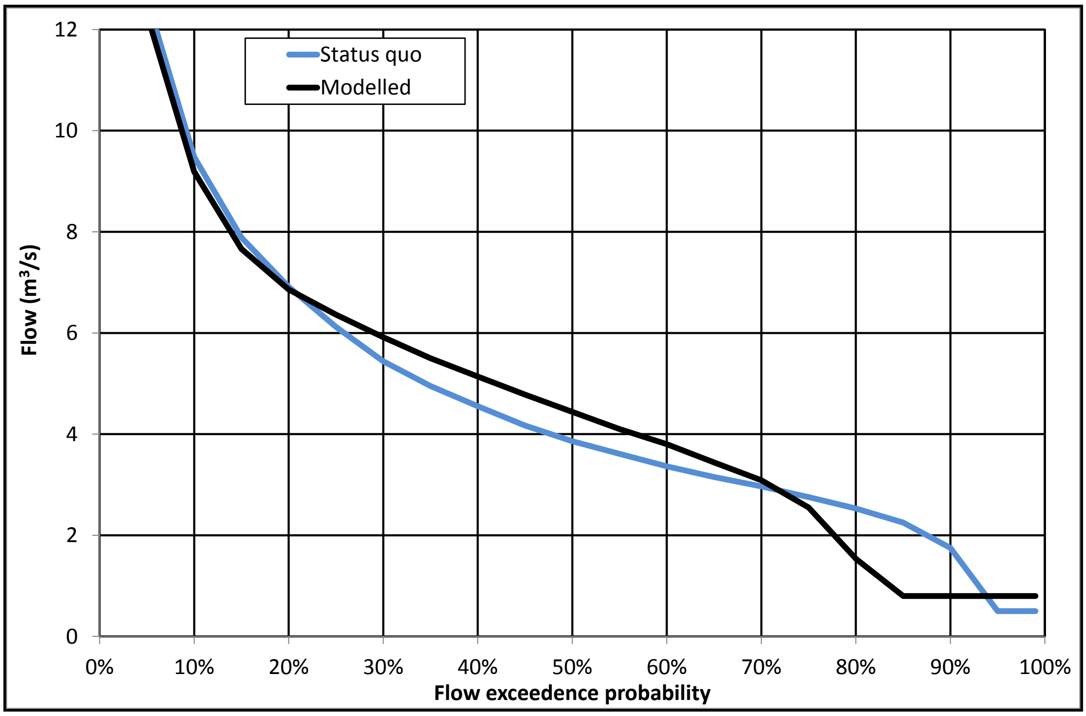





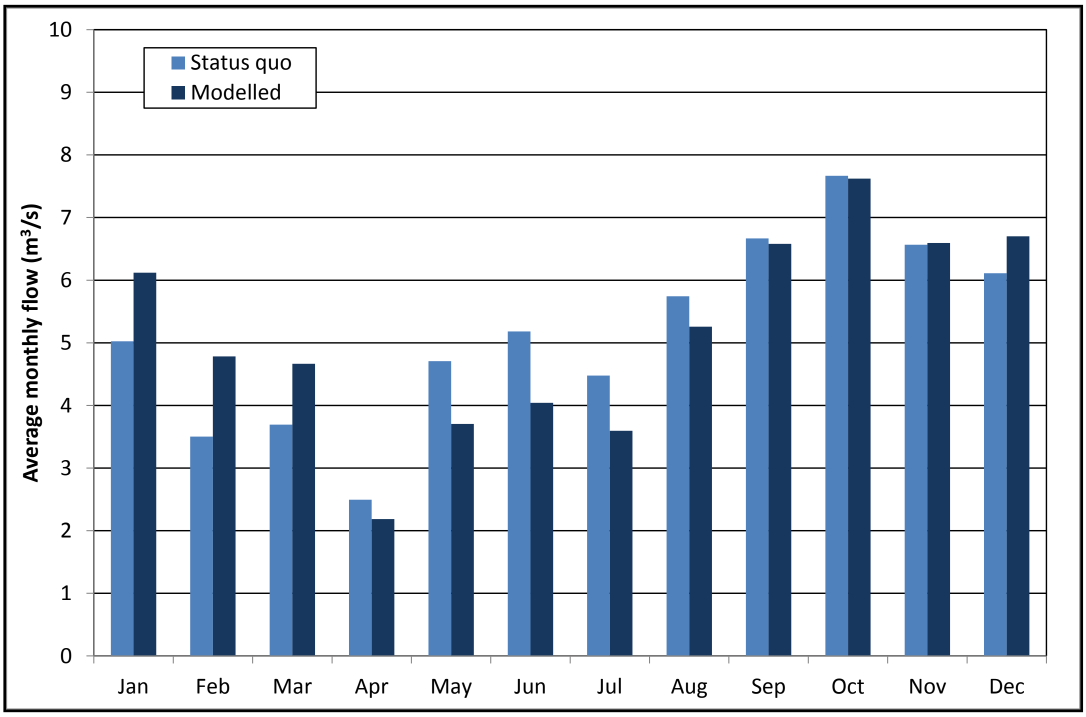

Manuherikia at Ophir – flow duration curve



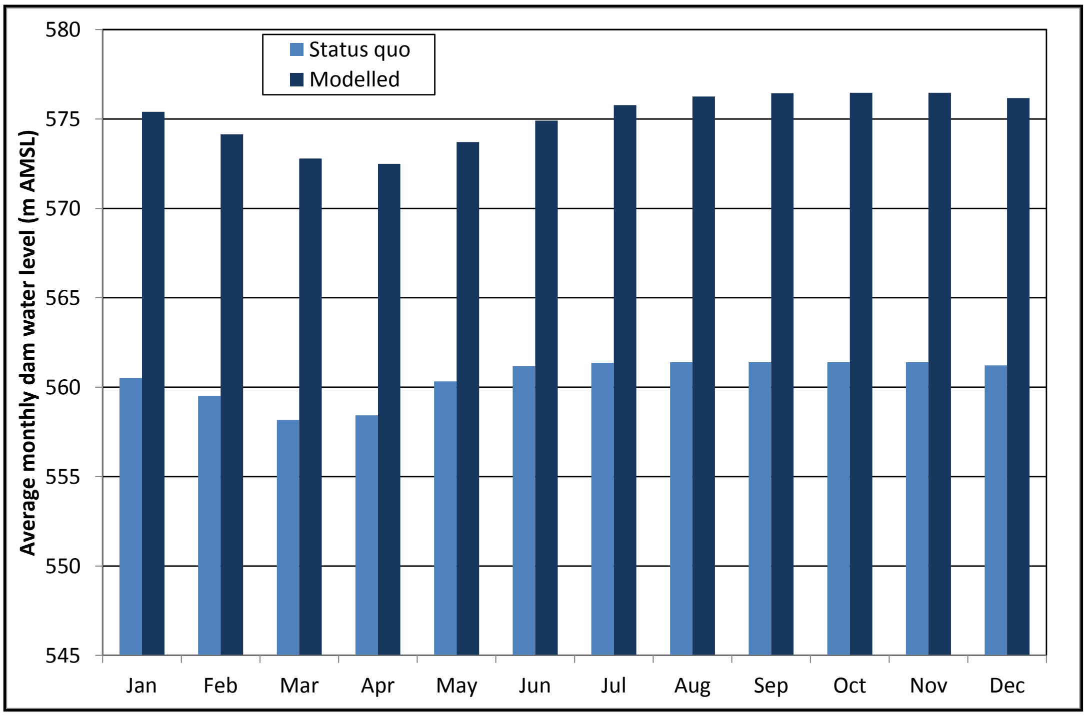

Manuherikia at Ophir – seasonal flow profile



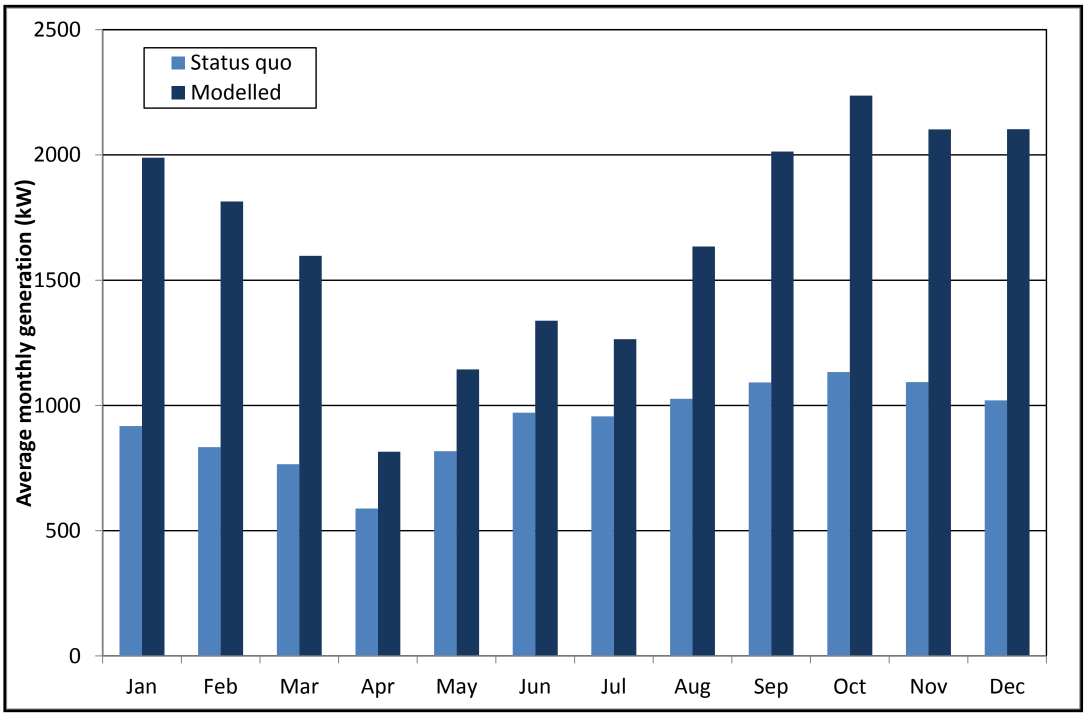

Manuherikia downstream of Falls Dam – flow duration curve




Manuherikia downstream of Falls Dam – seasonal flow profile

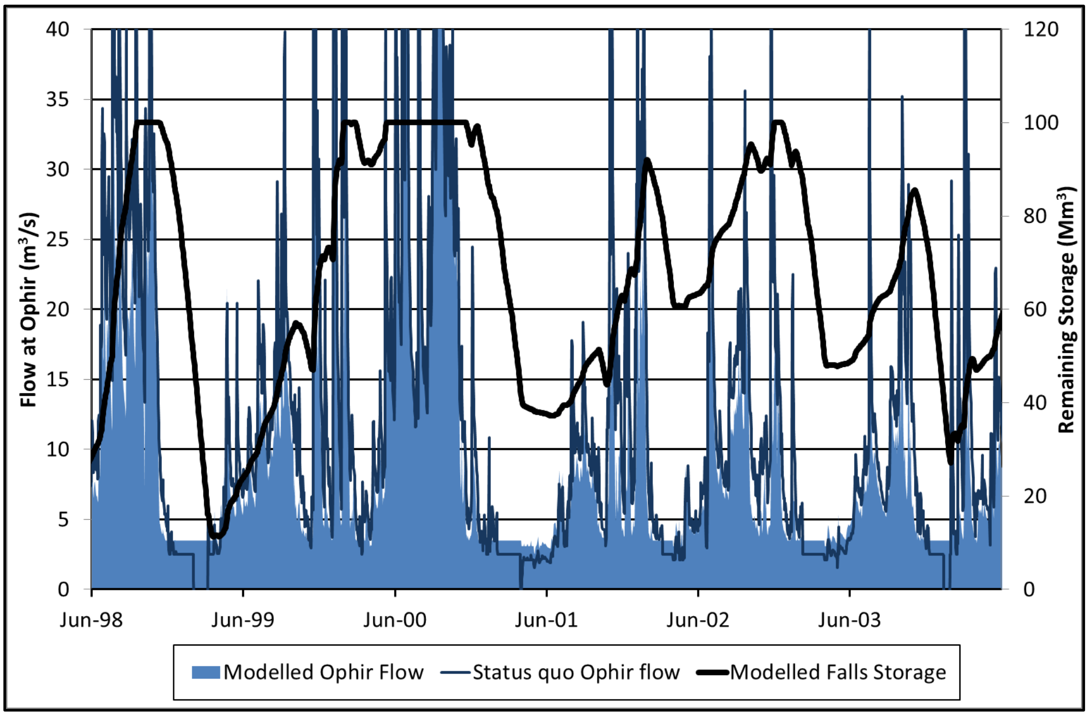


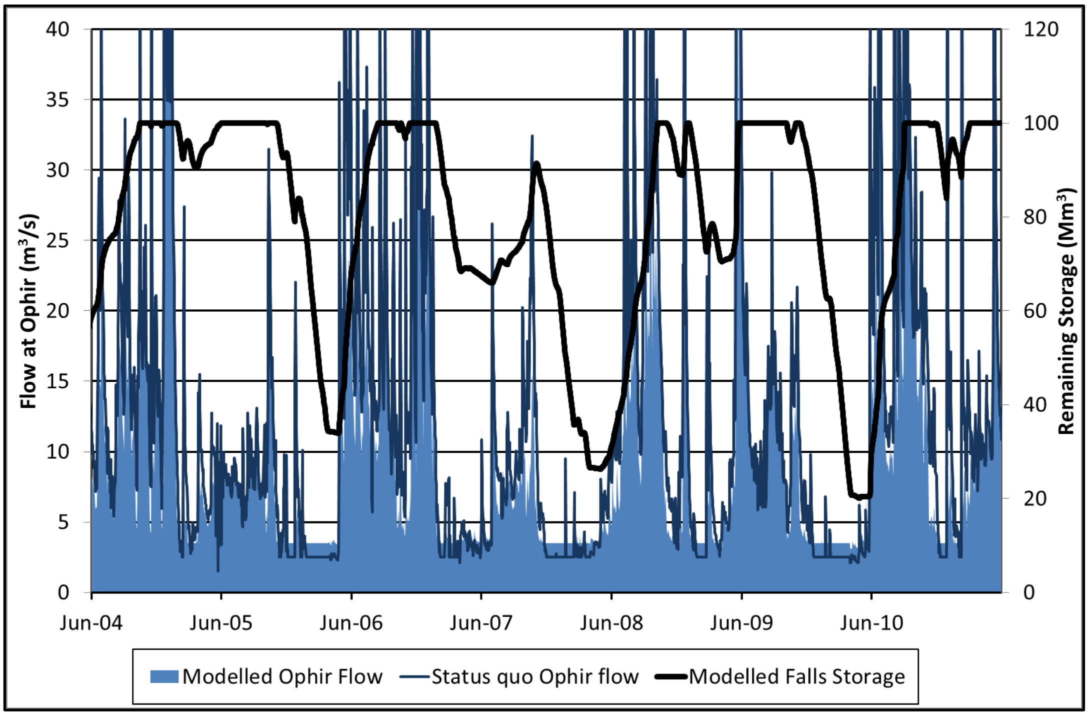

Falls Dam seasonal water level profile

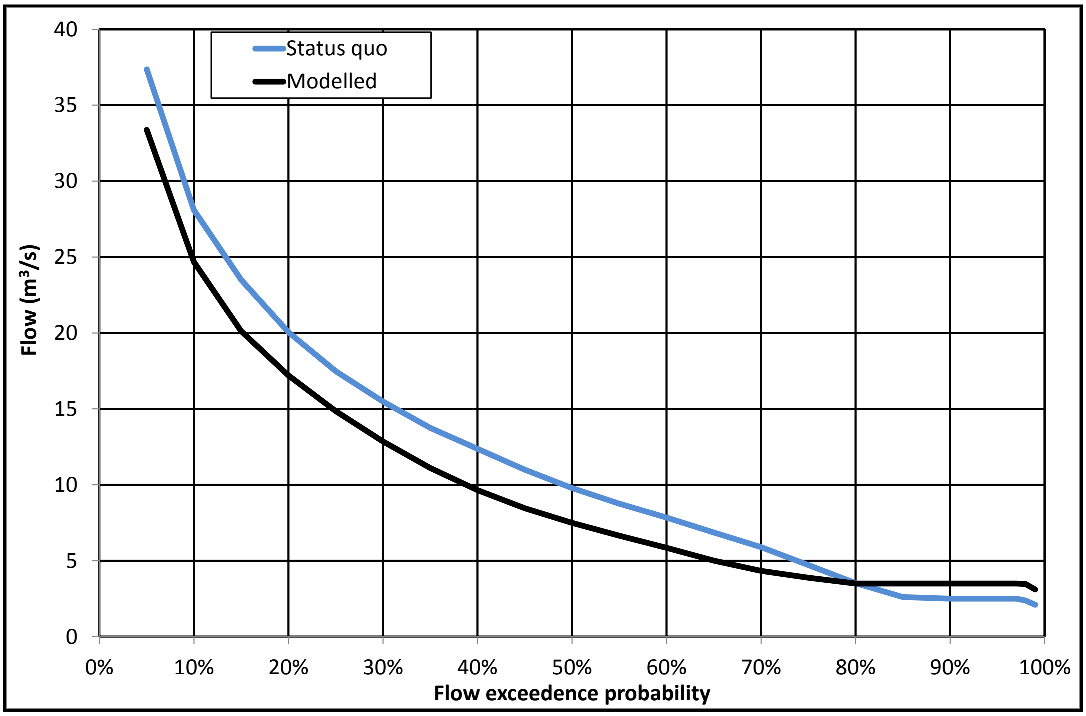



Falls Dam seasonal generation profile (6cu turbine capacity)

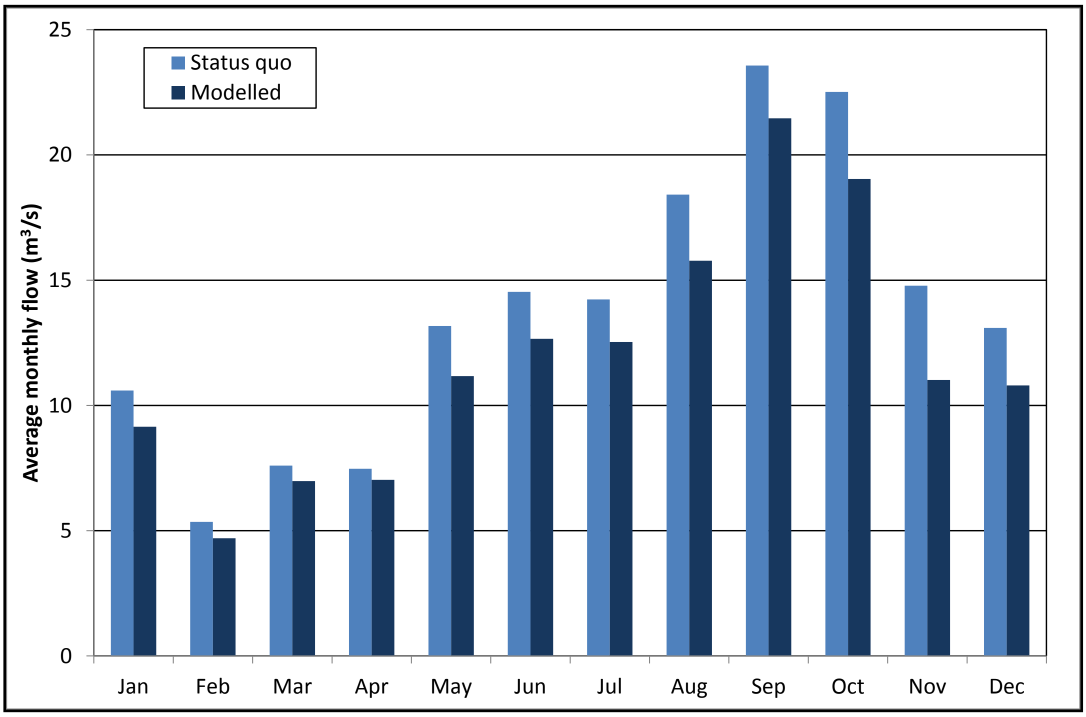
# Scenario 5: Raise Falls 25m & 15,000 ha new irrigation



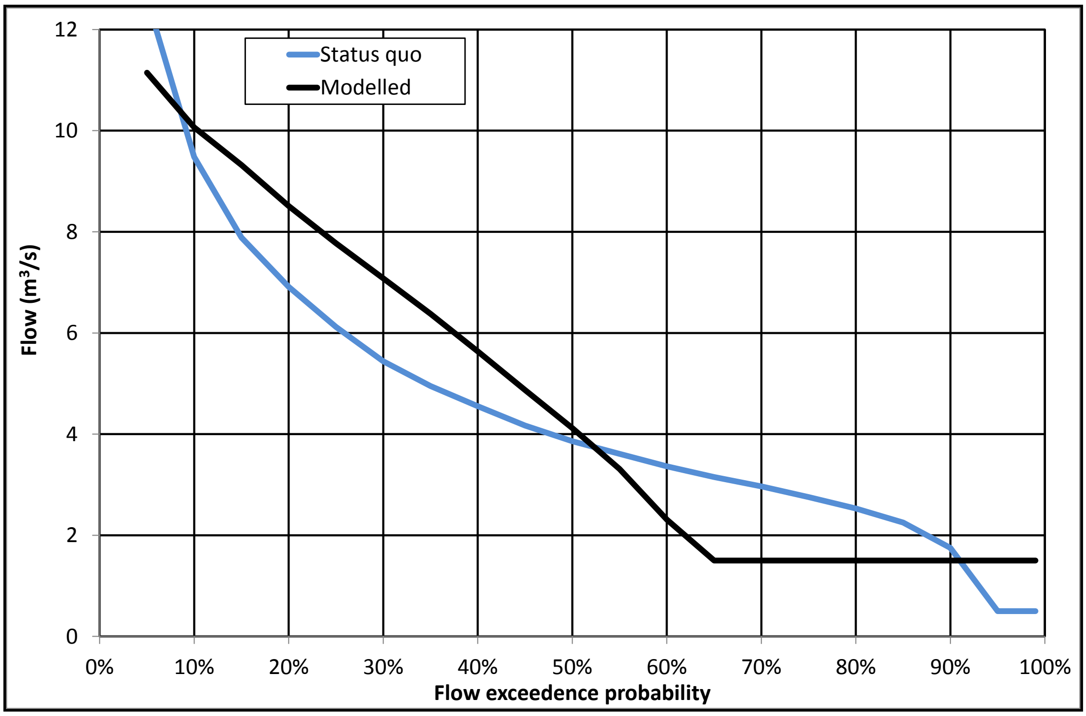





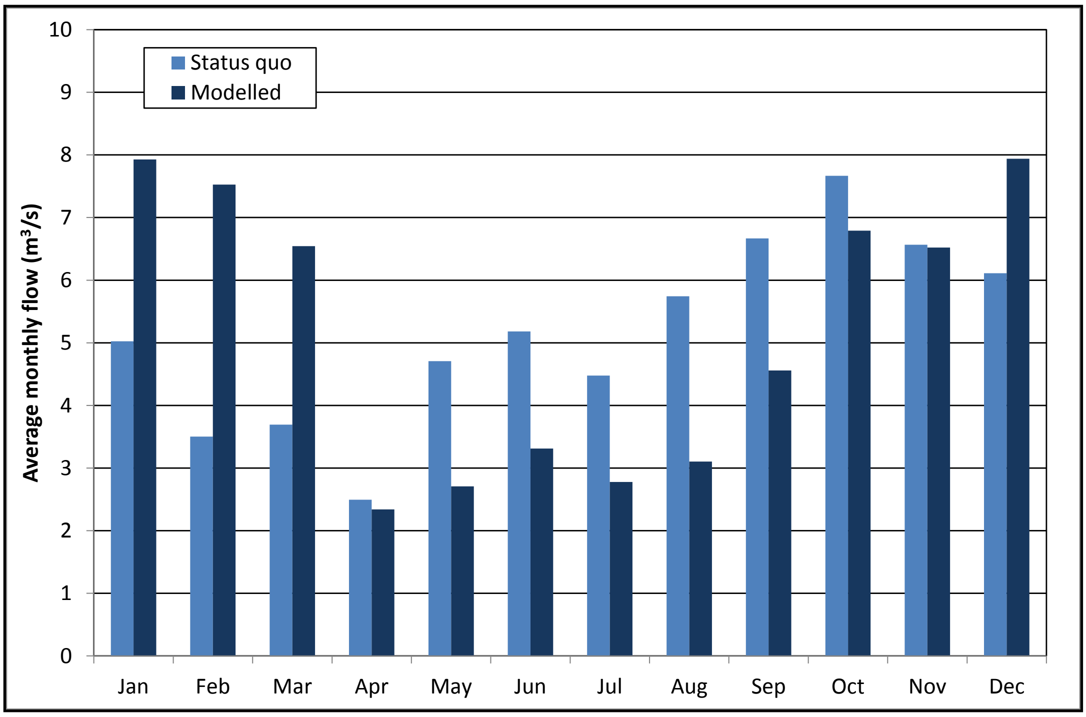
Manuherikia at Ophir – flow duration curve



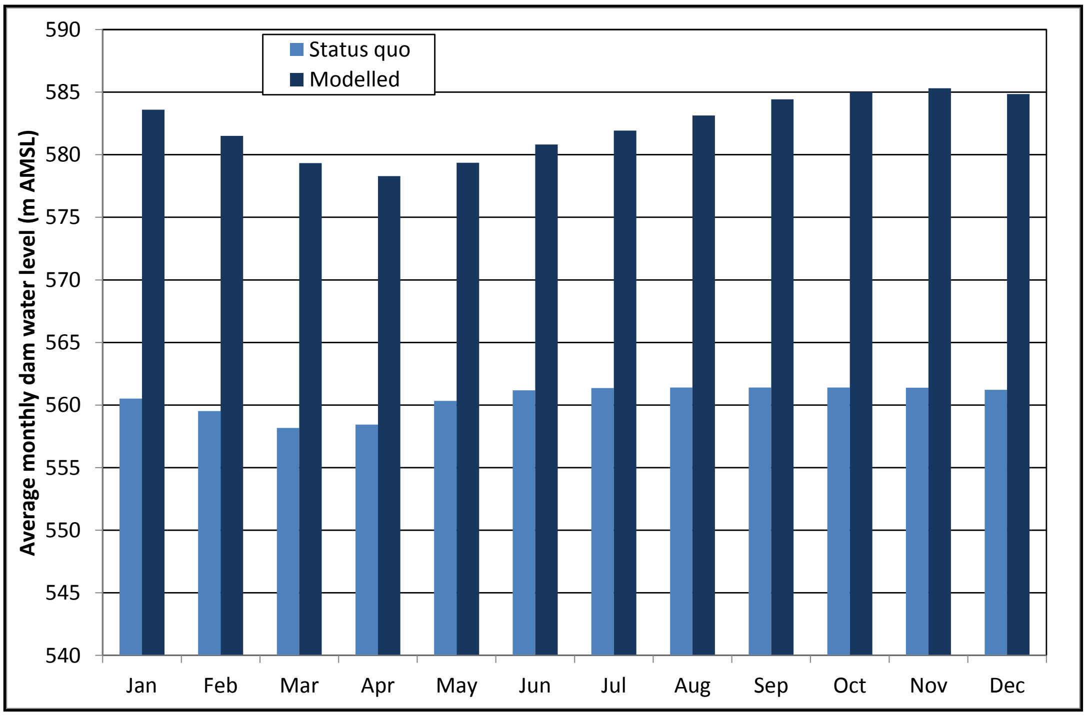
Manuherikia at Ophir – seasonal flow profile



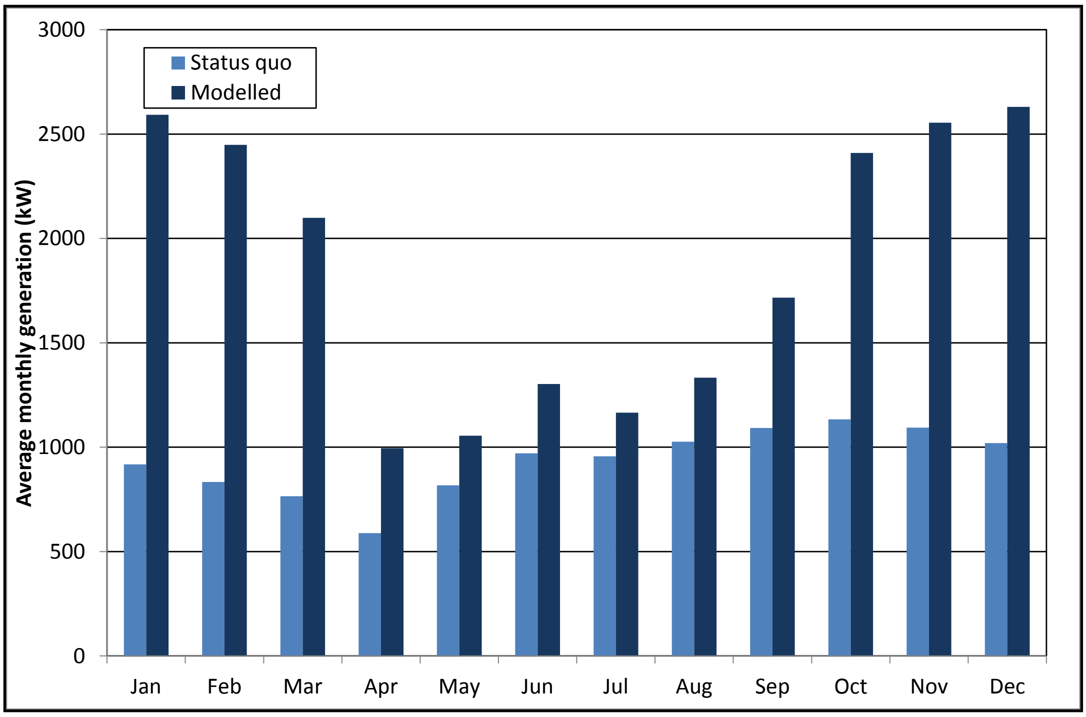

Manuherikia downstream of Falls Dam – flow duration curve




Manuherikia downstream of Falls Dam – seasonal flow profile




Falls Dam seasonal water level profile




Falls Dam seasonal generation profile (4cu turbine capacity)

# Appendix F: Flood flows

Flow records for the Manuherikia River are described below.

*Table 9: Manuherikia catchment flow recorder sites*

| Site | Catchment area ($km^2$) | Highest gauged flow ($m^3/s$) | Record length | |
|---|---|---|---|---|
| | | | Start and end | Years |
| Manuherikia d/s of Forks | 174 | 6 | 1976 – 2010 | 21 (excluding gaps) |
| Manuherikia d/s of Falls | 365 | 36 | 1999 – 2012 | 12 |
| Manuherikia at Ophir | 2036 | 535 | 1971 - 2012 | 40 |

The flow recorder downstream of Forks is not suitable for estimating flood flows because the site cannot be gauged during floods, and the bed of the river is mobile.

Flow records from the flow recorder downstream of Falls Dam are of some value. This recorder lacks high flow gaugings, and the site is only moderately stable. Flood estimates are expected to have moderate accuracy. The largest flow recorded at this site occurred on 17 Marcy 2009, where a flow of 124 $m^3/s$ was recorded. Indicatively, this peak flood estimate could have an accuracy of ±25%. The flow recorded at Ophir during this event was 355 $m^3/s$; 2.9 times the flow downstream of Falls.

Accurate flood flow records are available at Ophir. Forty years of near continuous records are available at this site. The site has also been gauged during major flood events. Flood estimates are given below.

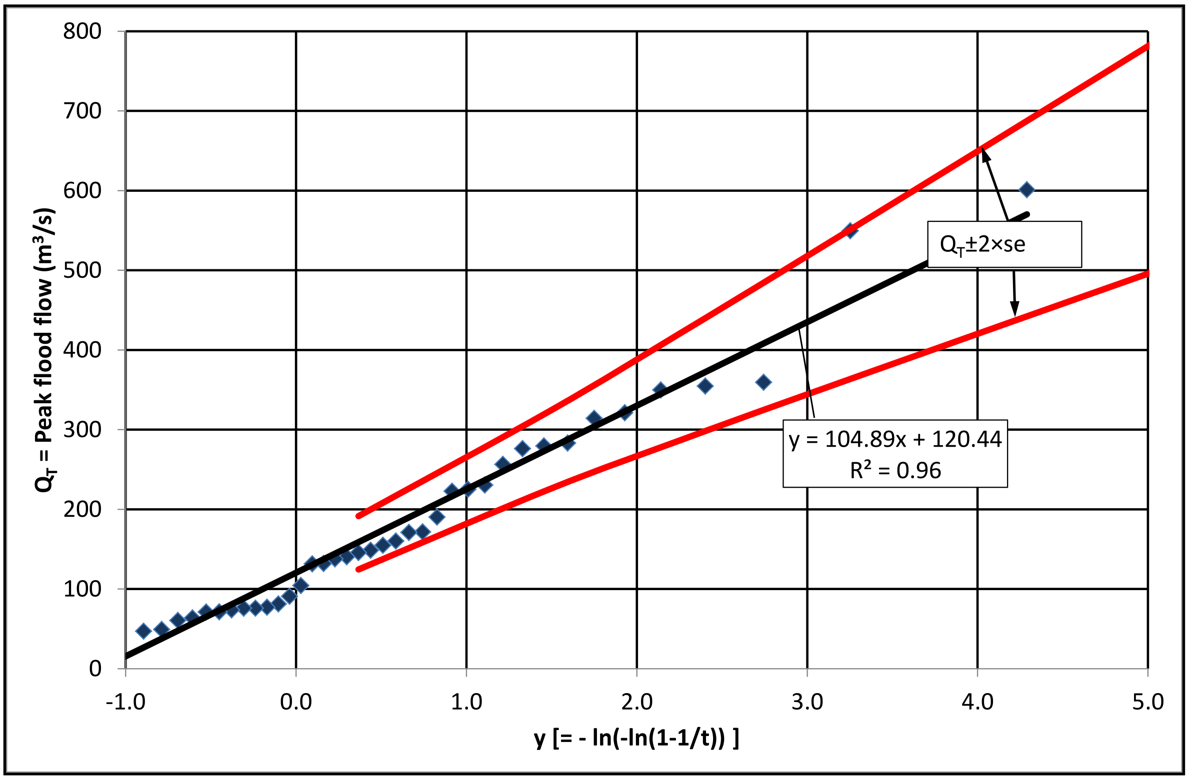
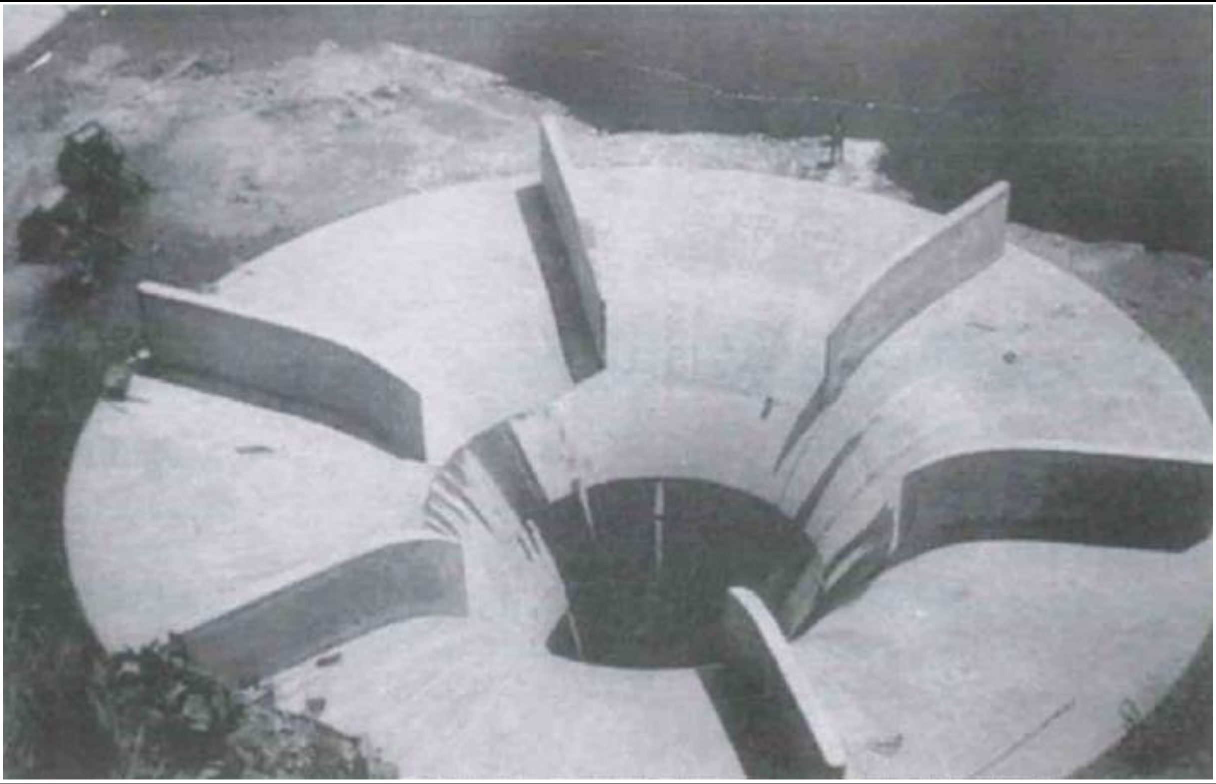



*Figure 18: Manuherikia at Ophir annual maxima, plotted on Gumbel probability paper*

*Figure 19: Estimated Manuherikia at Ophir peak flood flows*

| AEP | Return period (yr) | Peak flow ($m^3/s$) |
|---|---|---|
| 0.2 | 5 | 280±50 |
| 0.1 | 10 | 350±70 |
| 0.05 | 20 | 430±90 |
| 0.01 | 100 | 600±130 |
| 0.002 | 500 | 760±180 |
| 0.001 | 1000 | 840±200 |

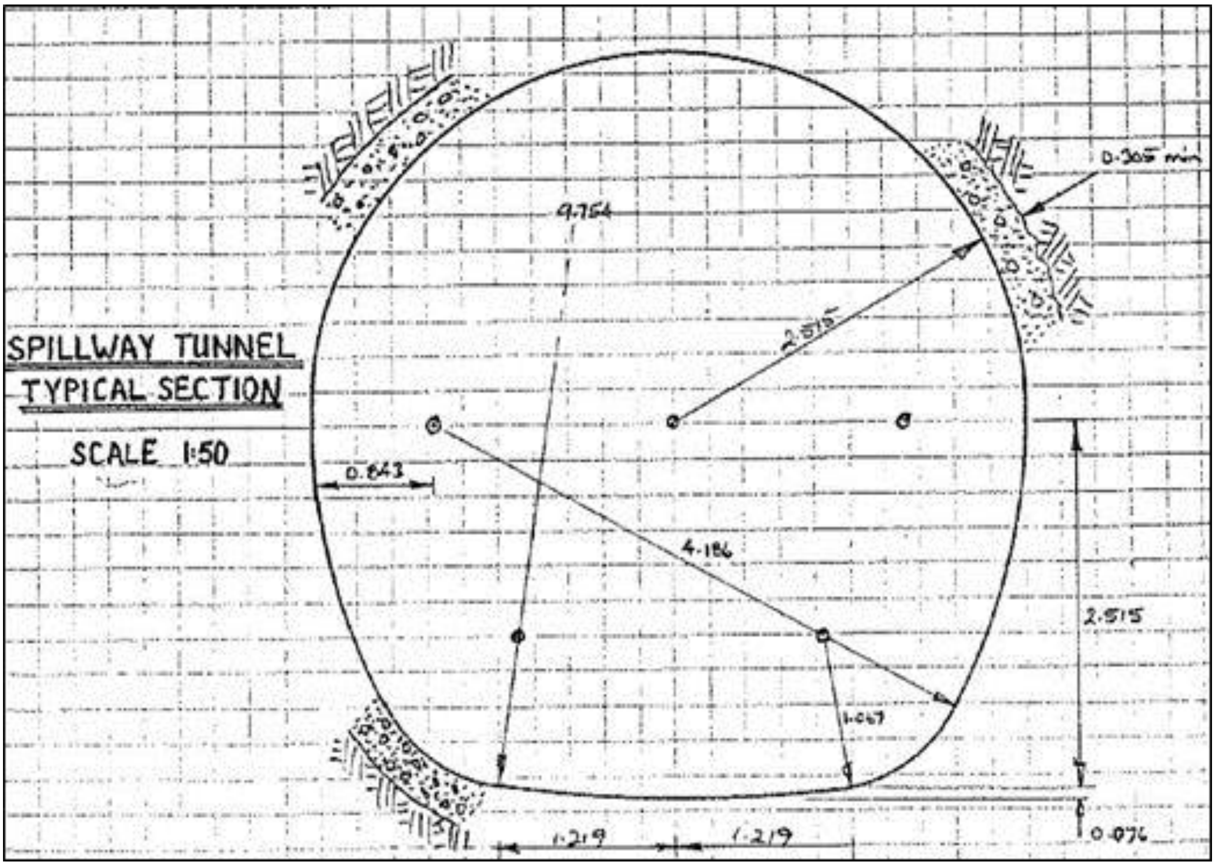
# Appendix G: Falls Dam flood capacity



Original spillway without raised rim (source: Ellis 2009)


Current spillway with raised rim

Spillway response in the flood of 9 – 11 March 1987 (source: MWD 1987)



Tunnel profile (source: MWD 1985)

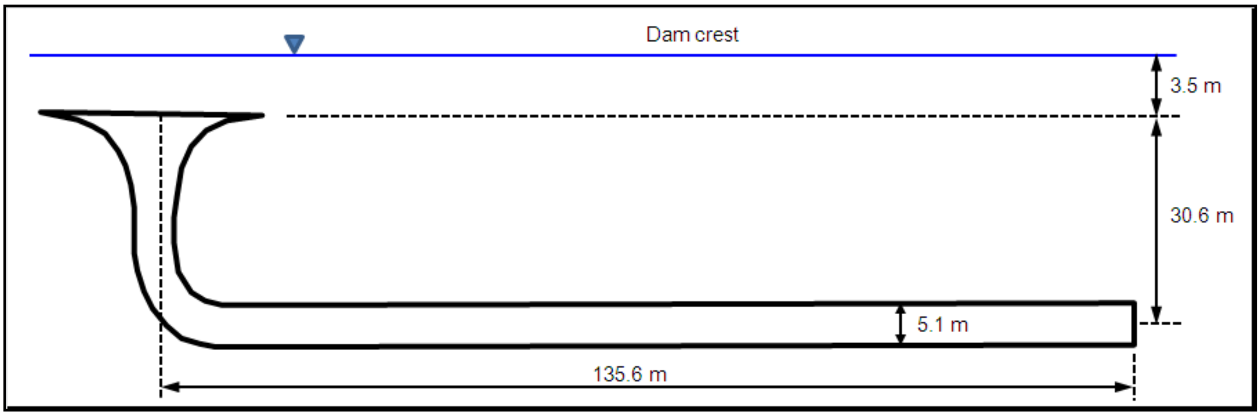
**Maximum discharge flow**

When the water level is 1.5 m above the spillway crest, flows are controlled by the downstream pipe capacity, and not by the inlet. Peak spillway discharge is:

$$Q = A\sqrt{\frac{\Delta h\, 2g}{\left(1 + K_e + K_{Lb} + f\,\frac{L}{D}\right)}}$$

Where

| | | |
|---|---|---|
| D | 5.1 | Effective tunnel diameter (m) |
| L | 155 | Effective tunnel length (m) |
| ε | 3.0 | Concrete roughness (mm) (estimated range: 1.5 – 5) |
| ε/d | 0.0006 | Relative roughness |
| Re | $1\times10^8$ | Reynolds No. (=VD/*v*) |
| *f* | 0.017 | Tunnel friction loss (estimated range: 0.015 - 0.019) |
| *f* L/d | 0.52 | Straight tunnel loss coefficient |
| $K_e$ | 0.03 | Entrance loss coefficient (estimated range: 0.03 - 0.05) |
| $K_{Lb}$ | 0.25 | 90° bend loss coefficient (estimated range 0.23 – 0.27) |
| Δh | 34.1 | Height from the dam crest to the centre of the pipe outlet |
| g | 9.81 | Gravity ($m^2/s$) |
| V | 19.3 | Pipe outlet water velocity (m/s) |
| A | 21.8 | Tunnel cross-section area ($m^2$) |
| **Q** | **421** | **Spillway discharge ($m^3/s$). Estimated accuracy: ±8%** |




Because flow is controlled by the downstream pipe, the raising of the outer rim of the spillway by 0.6 m in 1955 should not have had an impact on the peak discharge capacity. Raising the weir would however have affected the discharge relationship when the water level is less than 1.5 m above the spillway crest.

**Inlet controlled discharge flow**

When the water level is less than 1.5 m, spillway discharge is controlled by the bell inlet. The discharge for a circulate weir is given by:

$$Q = C(2\pi R)h^{3/2}$$

Where

Q = discharge (cfs)

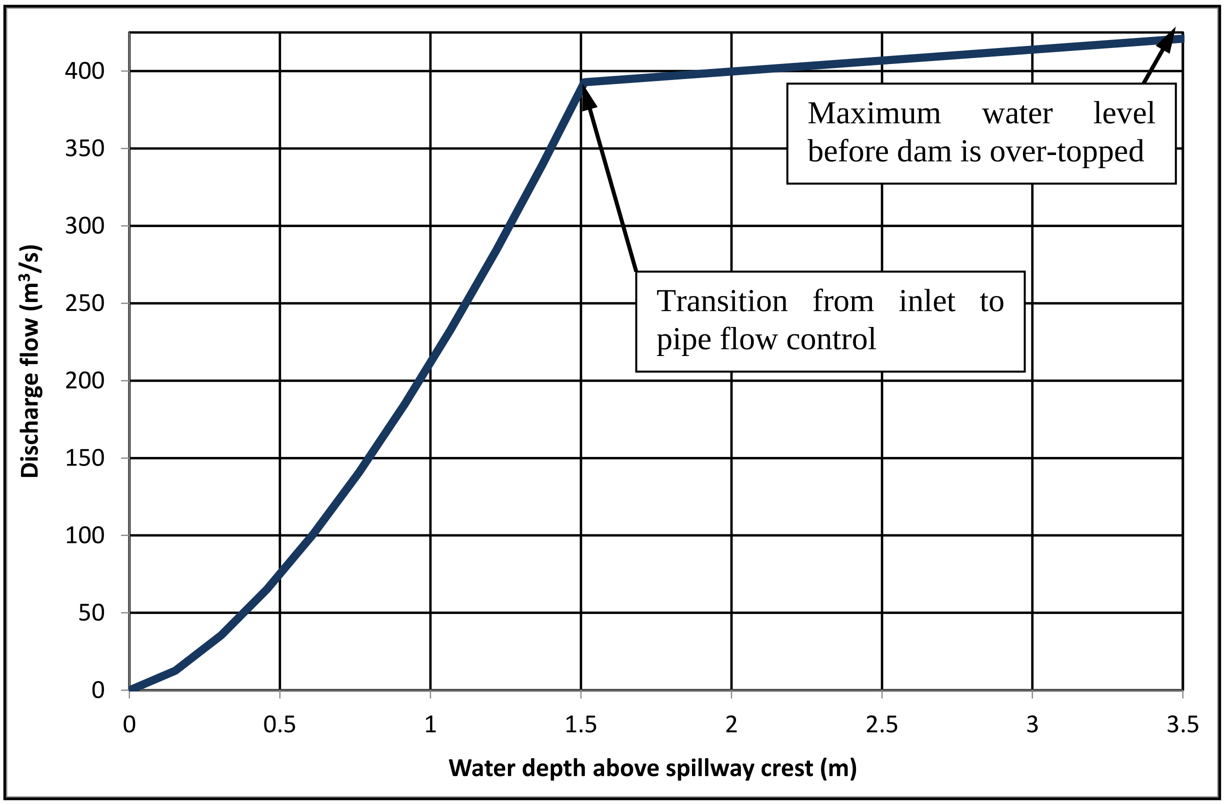
C = discharge coefficient (~4.0 for h <1.5 m)

R = Bell crest radius (50ft)

h = Water depth above above crest (ft)

Source: US Army Corps of Engineers: Sheets 140-1 to 140-1/8 "Morning Glory Spillways". http://chl.erdc.usace.army.mil/Media/2/7/9/100-c.pdf

Because h/R is small, the response is essentially the same as a linear sharp crested weir.

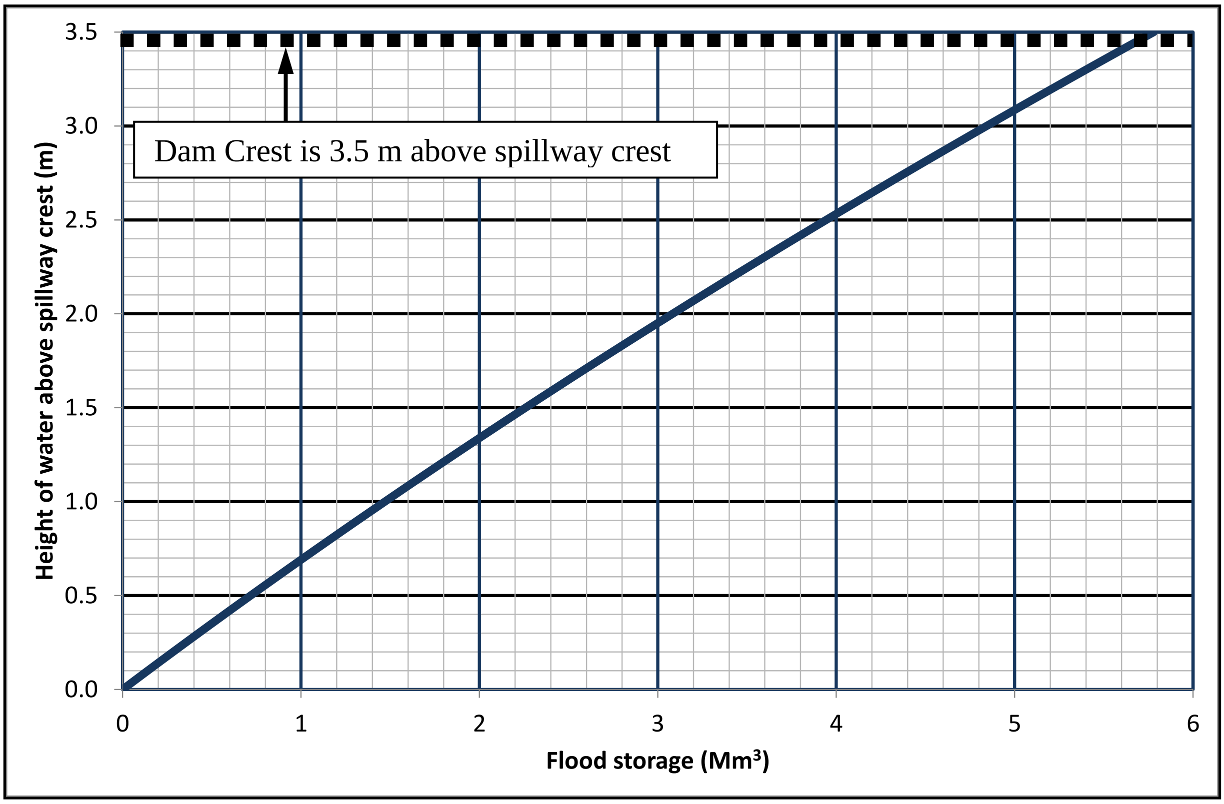



Relationship between Falls Dam water depth and spillway discharge

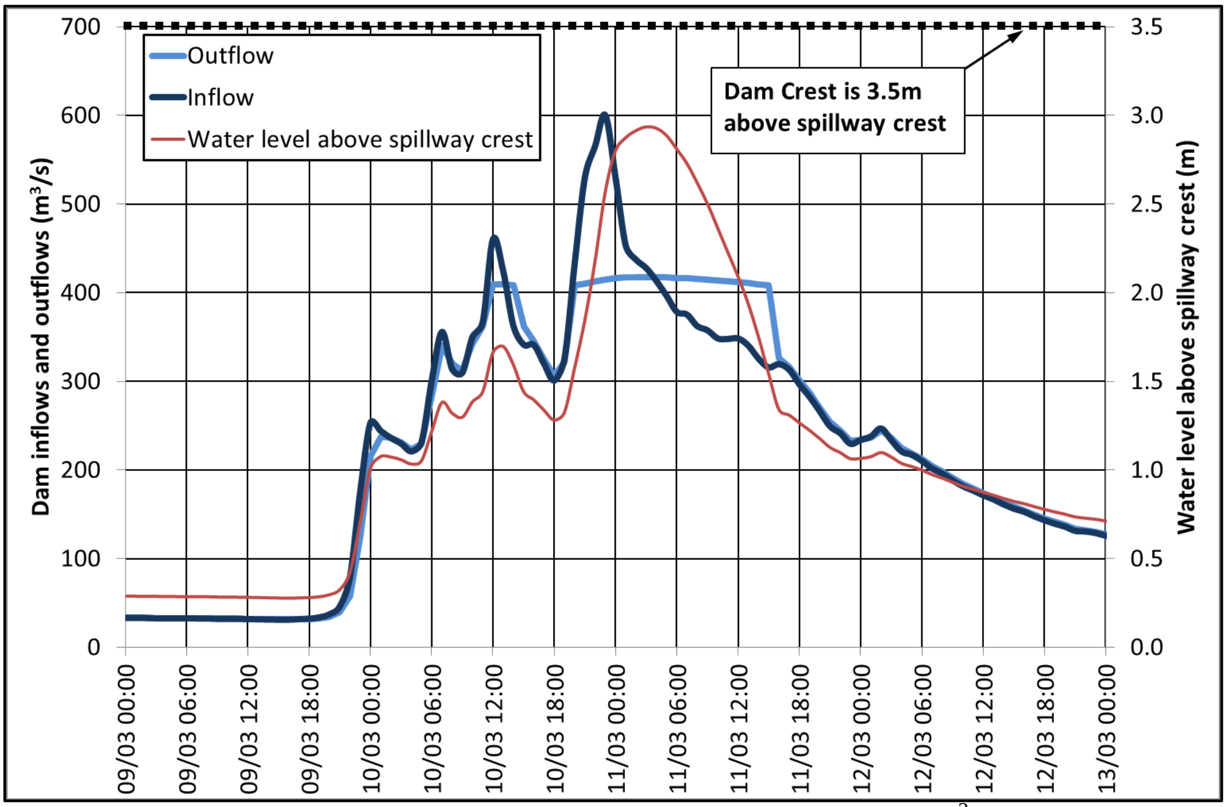
**Flood storage**

For floods less than 390 $m^3$/s, there would be at least 2 m freeboard below the dam crest. Under these circumstances the storage in the lake does little to attenuate flood peaks, since the spillway flow rate will be almost the same as the lake inflow rate.

In an extreme flood event, where flows are greater than 390 $m^3$/s, lake storage plays an important role in attenuating the flood peak. We estimate lake storage should allow the dam could pass about a 600 $m^3$/s (±50 $m^3$/s) flood event, without over-topping.




Falls Dam flood storage




Falls Dam flood routing for the March 1987 flood event, when 550 $m^3/s$ was recorded at Ophir. Flood flows have been scaled up to give a flood peak Falls Dam inflow of 600 $m^3/s$.