Prepared for: Environmental Science and Policy Committee Briefing

Activity: Manuherekia River minimum flow setting process – Science summary

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Briefing Date: 22 August 2023

PURPOSE

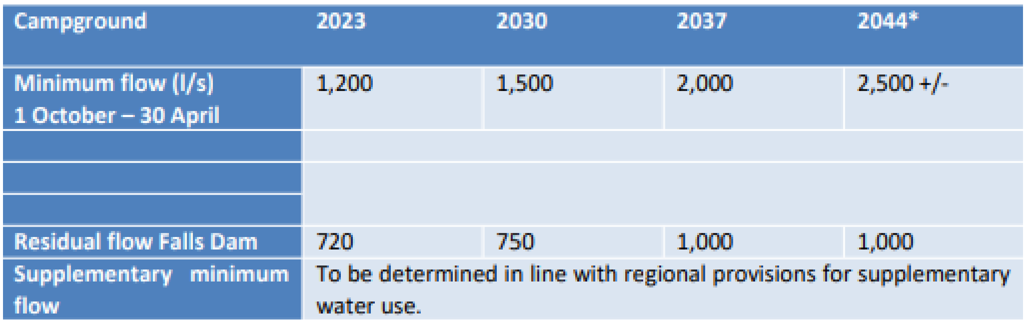
1. This report presents a summary of the combined results of a multi-year programme of work that will support the minimum flow setting process for the Manuherekia River catchment. The report includes hydrology and ecology information and outlines the consequence of both water abstraction and augmentation on the instream values of the Manuherekia catchment.

2. The purpose of this report is to inform councillors of the science inputs to the Manuherekia flow setting process.

EXECUTIVE SUMMARY

3. Developing minimum flows for the Manuherekia rohe has been underway since 2016. The Manuherekia rohe is water short at times and there are competing values, for the water. The effect of the competition is more observed during the summer months and during periods of low flows.

4. Otago Regional Council staff presented a minimum flow options paper to Council on 25th August 2021. At the time, staff recommended the following flow regime for the Manuherekia mainstem.



Campground	2023	2030	2037	2044*
Minimum flow (l/s) 1 October – 30 April	1,200	1,500	2,000	2,500 +/-
Residual flow Falls Dam	720	750	1,000	1,000
Supplementary minimum flow	To be determined in line with regional provisions for supplementary water use.			

5. Council resolved not to note a minimum flow number, nor the timeframes associated with shifting towards these numbers until additional science was obtained or finalised. Specifically, Council required the following tasks to be completed:
    - Manuherekia Catchment Hydrology Model to be peer reviewed.
    - The results of the Invertebrate Drift study to be clarified.
    - The Joint Hydrology Statement to be finalised.
    - The instream habitat modelling had been agreed to by the Manuherekia Technical Advisory Group.
    - Manuherekia Technical Advisory Group was to recommend a minimum flow, with ecological evidence which supports their recommended number.

6. Manuherekia Catchment Hydrology Model was documented and finalised and the peer review was completed. The reviewers noted that model was based on current state rather than a forecasting model. Overall, the reviewers stated that the model is fit for the purpose of understanding the flow and its allocation across the catchment and they did not specify any changes be made to the model or flow series i.e. they supported the flow time series produced by the model.

7. The field sampling of the Manuherekia invertebrate drift study was completed over two flow recessions. Ideally this should have been completed over a single flow recession. This coupled with influences of the role periphyton influencing invertebrate drift, and flow meters (attached to the sampling nets) not being calibrated to such low flows that were experienced at the sampling time led to concerns regarding the validity of the study.

8. After the reanalysis of the data, plus a comparison of the drift v flow of other rivers showed that the drift rate in the Manuherekia River is consistent with other rivers in New Zealand where they same study had been completed.
9. Manuherekia Technical Advisory Group, were to assess the potential ecological effects of the following seven minimum flow scenarios as measured at the Campground flow recorder:
   - 0.9 m^3/s
   - 1.2 m^3/s
   - 1.5 m^3/s
   - 1.7 m^3/s
   - 2.0 m^3/s
   - 2.5 m^3/s
   - 3.0 m^3/s

10. The Manuherekia catchment is one of the most complex catchments in New Zealand - water movement in and out of the catchment, within sub-catchments, and water storage makes it very difficult, if not impossible, to naturalise the flows. This challenge is multiplied by the fact that only water takes are metered meaning, it is common for stored water augmentation, discharge for conveyance and retake to occur largely unmetered.

11. Two hydrology models were used to determine the 7-day Mean Annual Low Flow (7-dMALF) in the Manuherekia River at Campground. Those two models are the Manuherekia Catchment Hydrology Model and TopNet/CHES. The results of both hydrological modelling studies suggested that natural (not naturalised) 7d-MALF at Campground was 4.0m^3/s with at least ±20% margin of error.

12. The Manuherekia catchment has a long history of intense environmental modification resulting from water management infrastructure – storage dams and races for irrigation. This modification has resulted in a situation where it is incredibly difficult to naturalise the flows. Therefore, despite all the

flow analysis in the Manuherekia catchment, the flows were never properly naturalised at a whole of catchment level. Several sub catchments were able to be naturalised. The closest we can assess the flows to natural is using the Manuherekia hydrology model "Falls Dam full, no irrigation" scenario.

13. Henderson (2023) noted when making the comparison of the two daily timeseries flow data (TopNet and Manuherekia catchment hydrology model) resulted in the Manuherekia catchment hydrology model was closer to 7d-MALF estimates. This reflects the use of flow data as input rather than rainfall.

14. In the absence of an exact number, and the knowledge that any additional hydrology study would not necessarily provide any additional certainty in the flow statistics, it is therefore considered that this is the best available hydrological information.

15. Using the timeseries output of Manuherekia Hydrology Model "Falls Dam full, no irrigation" the 7-d-MALF at Campground is estimated to be 4m^3/s ±20% (3.2m^3/s to 4.8m^3/s). Most of the attempts at naturalising MALF at Campground agree with this estimate.

16. Instream habitat models were used where available to make assessments of instream ecosystem health, and associated risk across the range of flow options.

17. For the Manuherekia - Ophir reach the risk assessment for macroinvertebrate indicated that a flow of 2.0 m^3/s provides a low risk for all but one of the modelled invertebrates, being caddisfly *Aoteapsyche*, which was considered to be at moderate risk (despite being one of the most abundant at this site under current conditions).

18. For the Manuherekia - Ophir reach the risk assessment for fish species and life history stages was very low risk for all fish species and life history stages at all flow scenarios.

19. For the Manuherekia – Ophir modelled reach the risk assessment for diatoms ranged from low risk to very high risk across the scenario range (Table 12). Flows higher than 2.0 m^3/s increase habitat availability. However, if the risk assessment revised by Olsen (memo 2023) taking into account the observed periphyton community composition at this site, this risk ranged from low/moderate at flows of less than 2m^3/s to low or very low at flows greater than 2m^3/s.

20. To maintain fish values in the Manuherekia – Galloway reach for fish species everything was low or very low risk when the minimum flow was 2.0 m^3/s or higher at Campground. indicates that when flows are >1.7m^3/s then the risk to instream values are either low or very low risk other than the caddis fly *Aoteapsyche* . (Aoteapsyche construct filter feeding nets which are attached to the streambed to trap drifting particulate food items, including algae and other invertebrates.). Long-term monitoring

shows that *Aoteapsyche* are often among the most abundant taxa at the Galloway site under the current flow management regime.

21. When considering the hydrological outputs, the likelihood of observing natural flows of 1.7m^3/s in the Manuherekia River was considered to be never, while flows of 2.0m^3/s are only likely to be observed an average of once every 25 years.

22. Instream habitat modelling indicates that there more diatom habitat is available at flows of 2.5m^3/s and above. However, real-world observations at the Galloway site between 2019 and 2023 show that the periphyton community is typically dominated by light brown thin films or medium mats, dominated by diatoms under the current flow regime.

23. The additional science and peer reviews have confirmed that the Manuherekia catchment hydrology model is fit for purpose. The results of this work have highlighted that there is a significant margin of error within the hydrology, however, due to the complexity of the catchment this is the best we consider we can achieve, and therefore represents the best available information.

24. To answer some of the complexities of the catchment, Otago Regional Council has designed a flow recorder network that in time will deliver a flow dataset that will allow flow naturalisation with less uncertainty than current modelling. In addition to this better water metering is required, particularly in regard to separating 'natural-run-of the-river' takes from stored water takes.

25. Instream habitat retention is comparing different flow scenarios against available habitat at 7d-MALF. Although there is a margin of error within 7d-MALF estimates for the Manuherekia, this figure has really remained the same over multiple studies over the past 20 years. The analysis of the instream habitat model used 4.0m^3/s at Campground to calculate percentage of habitat retention against the seven flow scenarios.

26. This modelling is the best available information and the results from this suggest that a flow at Campground of 2.0m^3/s at Campground would provide a low risk to invertebrates, fish, and periphyton.

27. Objective 2.1 (a) of the NPS-FM which states the first priority is to the health and well-being of water bodies and freshwater ecosystems. During the course of the TAG, Dr Richard Allibone presented the opinion that for a minimum flow to align with objective 2.1(a), the minimum should fall within the estimated natural low flow range. On that basis, then the minimum flow should be set at or above 2.5m^3/s.

Background – Catchment Context

28. The Manuherikia catchment lies in the centre of Otago, bounded on almost all sides by mountains and is known to be the most continental climate in New Zealand. The catchment is bounded by the Dunstan Mountains on the west, and Chain Hills and the Dunstan Range on the north-west, the Omarama Saddle from the north, Hawkdun Ranges from the north-east, the Rough Ridge, entering the Clutha River at the township of Alexandra.

29. The Manuherikia catchment includes two major depressions: the Manuherikia valley and the Ida valley, which are connected by the Poolburn Gorge. The Ida valley is drier than the Manuherekia valley and is prone to quite severe dry periods. The Manuherekia valley is aligned north-east to south-west. The upper northern catchment of the Manuherekia valley is divided into the Dunstan Creek catchment and the upper Manuherekia which are divided by the St Batham's Range which rises up to 2000 metres (Figure 1).

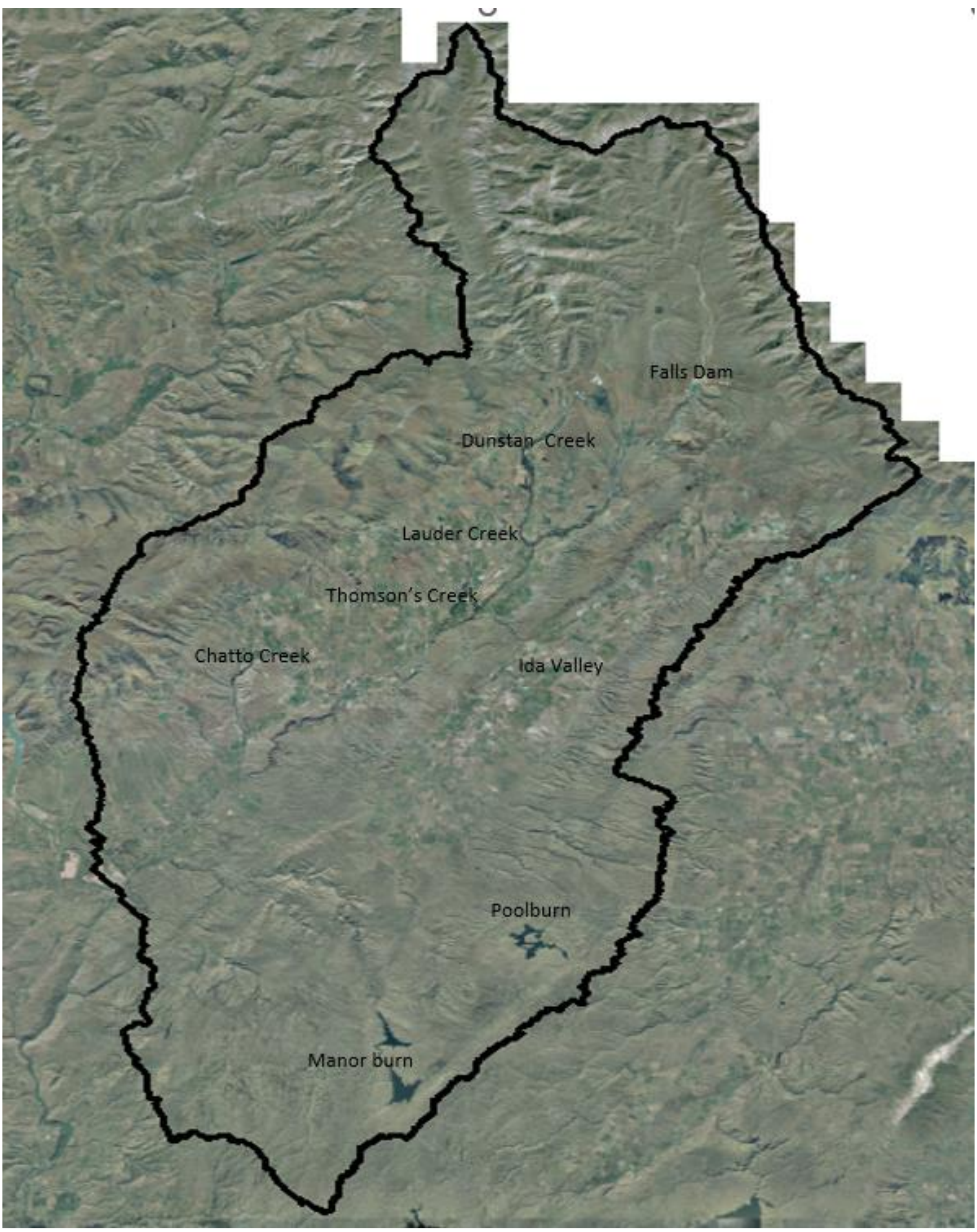


Figure 1 Satellite imagery of the Manuherekia Catchment

30. The Manuherekia catchment is considered to have the most continental type climate in the country. Cold winters and warm summers with high diurnal ranges prevail as a result of its location in Central Otago, away from the effect of the sea, and the surrounding mountains which shelter it from rain-bearing storms. The valley floor is classified as semi-arid as it receives between 350 mm and 500 mm of rainfall, while the hilly ranges, especially on the western and northern ranges, can receive up to

1100 mm of rainfall and more, as they pick up most south-westerly weather systems. Annual rainfall is estimated to reach 1500 mm near St Bathan’s Mountains. During summer, high intensity rainfall events, which can be localised to some sub-catchment areas and last for a short period, can result in shifting large quantities of debris including boulders. Moreover, thunderstorms can result in even heavier rainfall intensities. (ORC 2016).

31. The first rights to take water from the Manuherekia were issued under mining legislation in the late 1860s for the purpose of gold mining. As gold mining became progressively uneconomic many of the rights to take water and associated conveyance infrastructure were used for irrigation as agriculture and horticulture ventures developed. (McKeague 2021).

32. The majority of the Manuherekia catchment consists of low producing grasslands, tussock, and high producing grassland. Otago Regional Councils’ land use map (2022) indicates that sheep and beef farming is the dominant land use and covers approximately 53% of the catchment with a further 25% is classified as mixed stock and sheep farming. An estimated 12% of the catchment is managed for conservation.

33. Agricultural water use in the Manuherekia catchment differs from mainly extensive orchard production near Alexandra and Clyde, to partially semi-extensive farming in the partially irrigated area, to very extensive run units where winter feed production is used for dairy support.

34. There are currently 213 water takes in the Manuherikia catchment, with the sum of all consented maximum rates of take (paper allocation) of 32 m^3 /s. It is important to note this figure is unlikely to reflect the actual rate of abstraction at any given time (Olsen 2016). The actual measured water is complicated as it is a mixture of both stored water and run of the river water and potential double-counting of water at multiple points of take.

35. Water take and use is dominated by several irrigation schemes in the Manuherekia catchment. These schemes move water around the catchment from one sub-catchment to another. The Ida Valley Scheme bring water into the catchment from the Taieri catchment during the winter/spring period. The Hawkdun Ida Scheme takes water from the Manuherekia catchment into the Taieri catchment. There are also several storage reservoirs that have been constructed to store water during winter, for use when there is high irrigation demand during the irrigation season.

There are six farmer cooperative irrigation companies in the catchment. These are:

- Omakau
- Manuherikia
- Galloway
- Blackstone Hill

- Hawkdun Ida Scheme
- Ida Valley

36. This network of storage and the races that connect them in the catchment has resulted in highly modified flows both by augmentation and abstraction. The most significant influence on the flow regime of the Manuherikia River itself is the augmentation of water from Falls Dam during the irrigation season in combination with the scheme off takes and their locations along the river.

37. Falls Dam is the only storage reservoir in the Manuherekia mainstem valley, located in the mid to upper reaches of the catchment. In comparison to other storage facilities found elsewhere in the country, Falls Dam is relatively small in size. Although small, the Dam plays a critical role in providing irrigation water, particularly by releasing flow during low flow periods that is then retaken.

38. Falls Dam was constructed in 1935 by the Public Works Department as part of the Omakau Irrigation Scheme. The dam is a rock-fill structure that is 34 m in height and with a storage capacity of about 10 million m^3. In 1955, the dam storage was increased to 11 million m^3 by raising the dam's height by 0.6m. The dam's outflow is controlled by a needle valve and a "morning glory" type spillway which operates almost continuously outside the season.

39. Falls Dam was sold to the local irrigators by the New Zealand Government in 1990 and at that stage became an asset of Omakau Irrigation Scheme. The Falls Dam Company was formed and represented four irrigation schemes. The shareholding for each scheme was based on the irrigated area as follows:

Omakau Irrigation Scheme	53%
Manuherekia irrigation Scheme	35%
Blackstone Hills	6%
Galloway Irrigation Scheme	6%

19. Due to the discharge infrastructure the ability to release water during low flows is restricted to an estimated 4 m^3/s.

20. Pioneer Generation installed a small hydroelectric station at Falls Dam in 2003 which uses water during the non-irrigation season as well as water discharged from the dam to supply irrigation schemes on the Manuherikia River (Ellis 2009).

21. The annual yield of the Manuherekia sub-catchment upstream of Falls Dam is 5.02 m^3/s or 158million m^3 /year. Thus, Falls Dam, at present, has a storage capacity of about 7% of the annual yield of its catchment area.

22. Manorburn Dam is a concrete arch dam, 27 metres above the stream bed and with a crest length of 118 metres. Its total storage is about 51 million m^3, covering an area of up to 7 million m^2. The dam was completed in 1914 as a part of a package to develop irrigation schemes for the Ida Valley.

40. Poolburn Dam is a concrete arch dam, 25 metres above stream bed and its crest length is 163 metres. Its storage is 26 million m^3, with a maximum reservoir area of about 4.5 million m^2. The Poolburn dam was completed in 1931 to increase the irrigation capacity of the Ida Valley irrigation scheme.

41. Moa Creek Diverting Weir is a 12.5 metre high and 61-metre-long arched dam. Its storage capacity is about 38,000 m^3, which is used for day-to-day regulation.

42. Poolburn Diverting Weir is a 11.25 metre high and 75.6-metre-long arched dam. Its storage capacity is about 59,000 m^3, which is used for day-to-day flow regulation.

43. The Lower Manorburn Dam is an arched dam with gravity abutments. The dam is about 16 metres above the stream bed, with a crest length of 115 metre. Its working storage is about 234,000m^3, although its total capacity is much higher. Its reservoir area is 283,000 m^2. The dam was built in 1934 as a relief work to provide more water storage for the irrigated command area in the Galloway Irrigation Scheme. Only the top meter is used for water storage.

44. West Eweburn Reservoir is situated in the Taieri/Taiari Catchment but receives water from the upper Manuherekia catchment. It is an earth fill dam, 21 metres above stream bed, with a crest length of 189 metres and a top width of 4.5 metres. The dam’s storage capacity is 2.4 million m^3.

45. The Idaburn Dam is 10.7 metres high above stream bed, and its crest is 34 metres long. Its storage capacity is about 210,000 m3 and it covers a maximum area of 81,000 m2. This small dam was built in 1931 to supply a 13 km long race with a 0.2 cumecs flow.

46. Blackstone Irrigation Company is the smallest of the six schemes (Consented to take 0.400m^3/s). It takes water from the Manuherekia River at Blackstone Hill. The water race traverses the slope of the Blackstone Hills over a total length of about 14 km.

47. Omakau Irrigation Company have multiple takes throughout the catchment but take water from the Manuherekia River above the township of Becks (consented to take 1.981 m^3/s). This race transports water crossing the Manuherekia River downstream to the confluence with Dunstan Creek then extends down to the Tiger Hills area.

48. Manuherekia Irrigation Co-operative Society take Manuherekia River water operating within the Ophir Gorge (consented to take 2.830 m^3/s). The 30km water race serves the lower Manuherekia Valley, ending its journey in the Waikerikeri Valley.

49. Galloway Irrigation Society operates a moderate take (consented to take 0.425 m^3/s) from the Manuherekia River above Galloway.

50. Hawkdun Ida Scheme extracts water from the sub-catchment bounded by the Hawkdun Range and the upper Manuherekia River and delivers it across the divide to the upper catchment of the Ida Valley, via the 100km long Mt Ida water race across the boundary of the Manuherekia catchment to Taieri/Taiari River Catchment, in the Eweburn area.

51. The Ida Valley scheme makes use of several old mining races, in addition to the storage of Poolburn and Manorburn.

Hydrology

52. Understanding the flow characteristics of a river is essential to identify how much water is needed to for river and ecosystem health, and how much is available for irrigation, drinking water, hydro–electric power generation, and recreational activities such as fishing.

53. Naturalising flows is a key component in understanding the effects of irrigation and augmentation on what should occur naturally. An understanding of the natural state enables an assessment on the effects of instream values as flows deviate from natural flows.

54. The Manuherekia catchment is a very challenging catchment for water resource assessment. Data collection of river flows has been intermittent at many sites, and most are affected by upstream water abstraction, diversion, augmentation, or water storage. There are approximately 600km of water races in the catchment, and three medium to large reservoirs - these being Falls Dam, Manorburn/ Greenland, and the Poolburn Reservoir. The water stored in these reservoirs' services over 28,000 ha of irrigated agriculture in the Manuherekia catchment.

55. In addition to these complexities, water is transported into and out of the Manuherekia catchment to and from the Taieri catchment. Water is also transported within the Manuherekia catchment and between sub-catchments. Water is either used immediately, stored in ponds for irrigation, or discharged into a receiving waterway to be taken by a downstream irrigators. These complexities often result in multiple accounting of water use.

Hydrology Studies

56. There have been several flow studies conducted within the Manuherekia catchment. Dating back at least as early as 1974 (Keller 1974). One of the more detailed early reports on the hydrology of the Manuherekia catchment by Otago Regional Council was 2002. This study reported on the "Water resources of the Manuherekia Catchment" with the findings estimating flows using specific yields during low flows which estimated the flow at Shakey Bridge to be 4239 L/s (Pg 23 ORC 2002)

57. More recently NIWA hydrologists Henderson /Duncan provided flow statistics that were incorporated into the "Management flows for aquatic ecosystems in the Manuherikia River and Dunstan Creek" (Olsen et al. 2017). This study indicated that 7d-MALF flow statistics were estimated to be 3,200l/s at Ophir and 3,900l/s at Campground. There were uncertainties within these figures with the estimated error of these figures of ± 20%. Thus, this analysis reported that 7d-MALF at Ophir lies between 2,600 and 3,800L/s and at Campground lies between 3,100 and 4,700L/s.

58. Otago Regional Council started minimum flow consultation with the wider Manuherekia community and stakeholders using the output of these hydrology results along with the instream habitat modelling results outlined within the "Management flows for aquatic ecosystems in the Manuherikia River and Dunstan Creek" (Olsen et al. 2017).

59. During these consultation events concerns were expressed about potential deficiencies within some of the presented information, including hydrology and the flow statistic 7d-MALF.

Hydrology Models

60. To fill the hydrology information gaps NIWA were commissioned (2017) and developed the Cumulative Hydrological Effects Simulator model, commonly referred to as CHES;which is NIWA's unique software. It estimates the net changes to the flow regime throughout a catchment due to multiple water use schemes. It also quantifies the consequences for both the overall availability and reliability of the water resource and the residual flows that determine the in-stream environmental effects.

61. TopNet model was used to input flow data into the CHES model: the integration of these two models allows for the simulation of effects with hydrological change. was NIWA's (Clark et al.2008),. It is a spatially semi-distributed, time-stepping model of water balance. It is driven by time-series of precipitation and evaporation, derived from temperature, and additional weather elements where available. TopNet simulates water storage in the snowpack, plant canopy, rooting zone, shallow subsurface, lakes and rivers. It produces time-series of modelled river flow (without consideration of water abstraction, impoundments, or discharges) throughout the modelled river network, as well as

evapotranspiration (derived from weather/climate input information), but the version used in this project does not adjust river flows for effects of irrigation/water take or water redistribution between catchments. TopNet has two major components, namely a basin module and a flow routing module.

62. CHES provides water resource managers with cost-effective, rapid, and flexible assessments of the cumulative effects of complex surface water allocation scenarios. It can also incorporate future climate change. CHES incorporates modelled river-flow time series for New Zealand's half-million reaches and includes user-specified abstraction and storage options. It calculates the effects of water use by combining numerical water routing with operating rules. For example, placing a dam into a catchment uses a digital elevation model to calculate reservoir geometry and storage dynamics.

63. The model combines TOPMODEL hydrological model concepts (Beven et al. 1995) with a kinematic wave channel routing algorithm (Goring 1994) and a simple temperature based empirical snow model (Clark et al. 2008). As a result, TopNet can be applied across a range of temporal and spatial scales over large watersheds using smaller sub-basins as model elements (Ibbitt and Woods 2002; Bandaragoda et al. 2004). Considerable effort has been made during the development of TopNet to ensure that the model has a strong physical basis and that the dominant rainfall-runoff dynamics are adequately represented in the model. TopNet model equations and information requirements are provided by Clark et al. (2008) and McMillan et al. (2013). The version of the model used in this project does not consider water transfers from river to river or water storage, nor does it model aquifer water balances.

64. At the start of this project, the assumption was made that simply adding water meter data back to the river flows at sites downstream of the take points would provide naturalised flow series at each flow recorder.

65. During the development of CHES, it highlighted the issue with the water take data, this manifested itself when adding the existing flows at Campground flow recorder with water take meters. This resulted in an estimated MALF of 9,500L/s at Campground which is not accurate and resulted in a rethink about the utility of the water meter data.

66. A rigorous investigation of each water take was undertaken with approximately 90 water takes having on site field inspections. The investigation assessed where and how the water was taken, where in relation to the take the water meter was, whether the water meter was measuring stored water and/or race water, whether the meter was picking up by-wash, or whether it was measuring water retake.

67. The change from the CHES model to the more simplistic GoldSim model, where water takes were aggregated within the catchment, was agreed to after an independent review completed by Sarah

Mager (Otago University), Roddy Henderson (NIWA) and Ian Lloyd (Davis Ogilvie). The GoldSim Model was titled the Manuherekia Hydrology Model.

68. The Manuherekia Catchment Hydrology Model produces output data (Figure 2) at the following river nodes:
    - Manuherekia main-stem
    - Below Falls Dam,
    - Below Omakau Irrigation Scheme intake
    - Below Dunstan Creek confluence
    - At Ophir,
    - Campground

    Tributaries
    - Dunstan Creek
    - Lauder Creek
    - Thomson's Creek
    - Chatto Creek

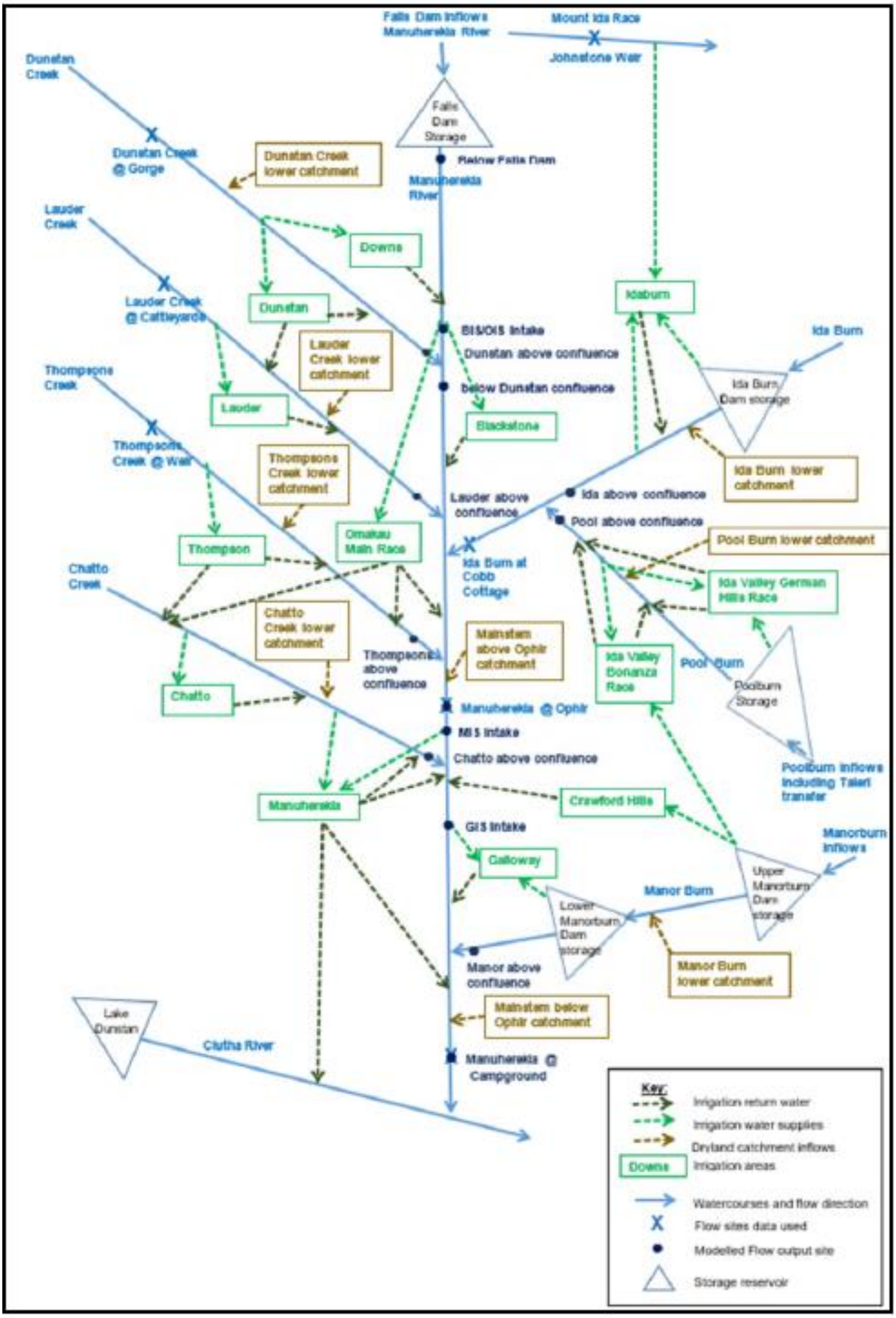


Figure 2 Manuherekia Catchment Hydrology Model – Model Logic Diagram for the Manuherekia Catchment Hydrology Model

69. The GoldSim model was owned by Manuherikia River Limited, after consultation between the Otago Regional Council and Manuherekia River Limited there was agreement signed to use and build on the original GoldSim hydrology model.

70. Ian Lloyd of Davis Ogilvie was contracted to produce a hydrology model for the Manuherekia catchment. To assist in producing the model a hydrology group was formed, with each member of the group charged in providing different inputs. The members and the tasks allocated were as follows;

Dave Stewart Raineffects – Assessment of flow gauging data

NIWA – Roddy Henderson, Christian Zammit and James Griffiths

- Rainfall Sensitivity and Climate Change
- Providing peer review of the Manuherekia Hydrology model
- Analysis of Manuherekia River flow data timeseries

Sarah Mager – University of Otago

- Comparison of the CHES and earlier Manuherekia hydrology models using the GoldSim platform
- Assisting with gauging analysis
- Peer review of the Manuherekia Hydrology model

Peter Brown – PZB Consulting

- Pasture production modelling

Matt Hickey – Water Resources Management

- Technical input

Roger Williams – Omakau Irrigation

- Technical input – an understanding of Manuherekia catchment and water movement and irrigation within the catchment

Xiaofeng Lu, Pete Stevenson and Pete Ravenscroft

- Supporting the group by providing data

71. The Manuherekia Hydrology Model calculates the volume of water required for each irrigation take based on the following four variables:

    a. The area irrigated.

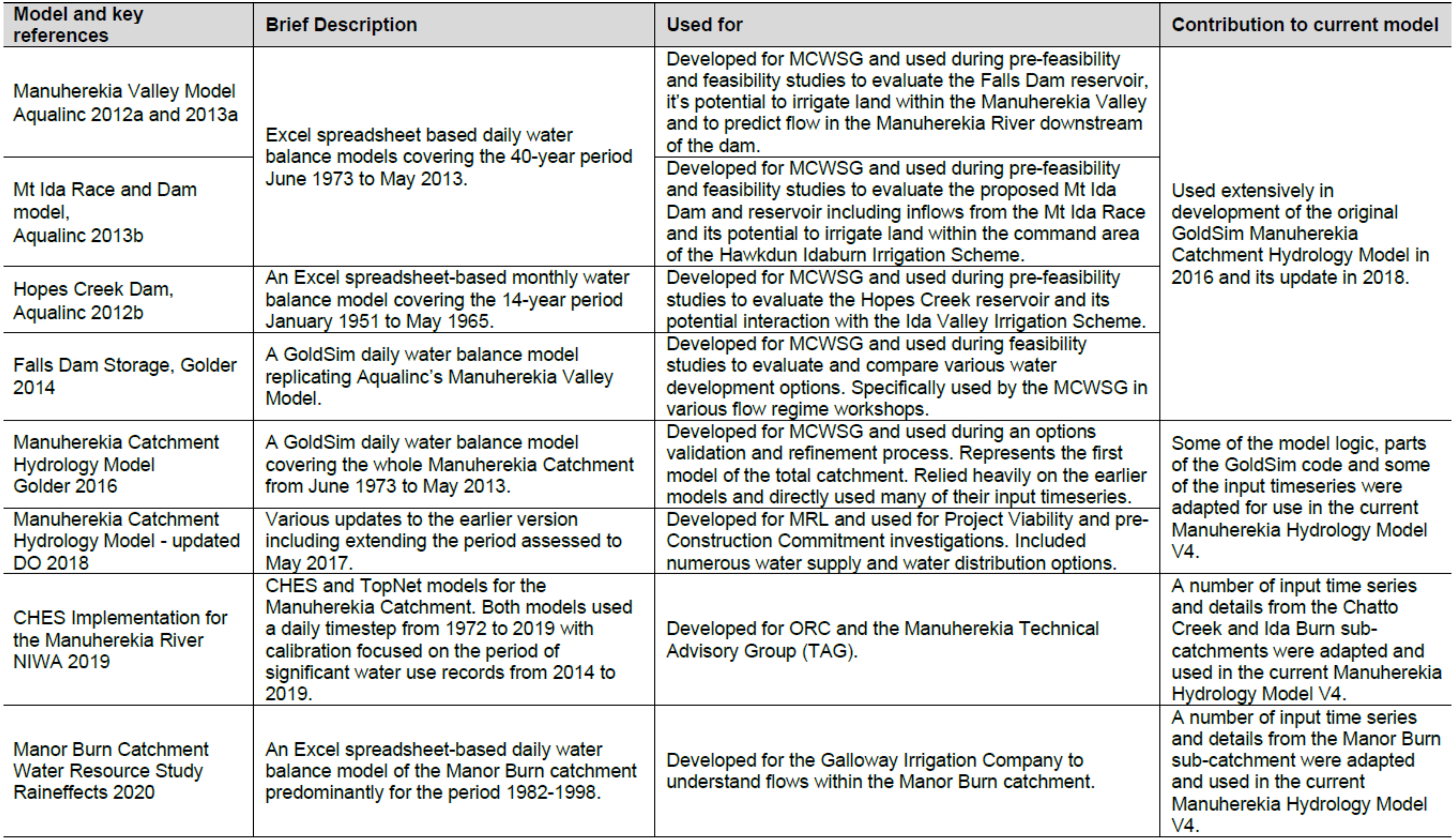
b. The irrigation type namely either a representative spray irrigation system or a representative of a flood irrigation system.
c. The location of the irrigation relative to three zones: Above Ophir, Below Ophir and the Ida Valley
d. Six daily irrigation timeseries which have been developed using a soil moisture and irrigation demand model that considers climate data, properties of the irrigated soils and representative irrigation regimes for both flood and spray irrigation in each of the three zones. The irrigation regimes do not include seasonal limits or allocations. The Ida Valley Irrigation Scheme is based on a seasonal allocation which is determined from storage volume available at the start of the season.

72. The model then compares the water available at the take point against the irrigation water requirements to determine how much water is actually taken. The model's predicted take has been calibrated/verified against measured take data for the years when water take data is available. This is predominantly from the 2008 -2009 irrigation season onwards.

73. The final version of the Manuherekia Catchment Hydrology Model was finalised September 2022, and known as Manuherekia Hydrology Model V4. The Manuherekia Catchment Hydrology Model is a daily water balance model of the catchment from 1 June 1973 to 31 May 2020. (Davis Ogilvie 2022)

74. The Manuherekia Catchment Hydrology Model builds on earlier hydrology models. These earlier hydrological investigations (Table 1) in the Manuherekia Catchment included the TopNet / CHES model developed by NIWA for ORC and various Excel and GoldSim models prepared for MCWSG and MRL by Aqualinc Research Limited (Aqualinc), Golder Associates (NZ) Ltd (Golder) and Davis Ogilvie.

Table 1 summaries the earlier models and how they have contributed to development of the current Manuherekia Hydrology (Davis Ogilvie 20022 Pg11)



Model and key references	Brief Description	Used for	Contribution to current model
Manuherekia Valley Model Aqualinc 2012a and 2013a	Excel spreadsheet based daily water balance models covering the 40-year period June 1973 to May 2013.	Developed for MCWSG and used during pre-feasibility and feasibility studies to evaluate the Falls Dam reservoir, it's potential to irrigate land within the Manuherekia Valley and to predict flow in the Manuherekia River downstream of the dam.	Used extensively in development of the original GoldSim Manuherekia Catchment Hydrology Model in 2016 and its update in 2018.
Mt Ida Race and Dam model, Aqualinc 2013b		Developed for MCWSG and used during pre-feasibility and feasibility studies to evaluate the proposed Mt Ida Dam and reservoir including inflows from the Mt Ida Race and its potential to irrigate land within the command area of the Hawkdun Idaburn Irrigation Scheme.	
Hopes Creek Dam, Aqualinc 2012b	An Excel spreadsheet-based monthly water balance model covering the 14-year period January 1951 to May 1965.	Developed for MCWSG and used during pre-feasibility studies to evaluate the Hopes Creek reservoir and its potential interaction with the Ida Valley Irrigation Scheme.	
Falls Dam Storage, Golder 2014	A GoldSim daily water balance model replicating Aqualinc's Manuherekia Valley Model.	Developed for MCWSG and used during feasibility studies to evaluate and compare various water development options. Specifically used by the MCWSG in various flow regime workshops.	
Manuherekia Catchment Hydrology Model Golder 2016	A GoldSim daily water balance model covering the whole Manuherekia Catchment from June 1973 to May 2013.	Developed for MCWSG and used during an options validation and refinement process. Represents the first model of the total catchment. Relied heavily on the earlier models and directly used many of their input timeseries.	Some of the model logic, parts of the GoldSim code and some of the input timeseries were adapted for use in the current Manuherekia Hydrology Model V4.
Manuherekia Catchment Hydrology Model - updated DO 2018	Various updates to the earlier version including extending the period assessed to May 2017.	Developed for MRL and used for Project Viability and pre-Construction Commitment investigations. Included numerous water supply and water distribution options.	
CHES Implementation for the Manuherekia River NIWA 2019	CHES and TopNet models for the Manuherekia Catchment. Both models used a daily timestep from 1972 to 2019 with calibration focused on the period of significant water use records from 2014 to 2019.	Developed for ORC and the Manuherekia Technical Advisory Group (TAG).	A number of input time series and details from the Chatto Creek and Ida Burn sub-catchments were adapted and used in the current Manuherekia Hydrology Model V4.
Manor Burn Catchment Water Resource Study Raineffects 2020	An Excel spreadsheet-based daily water balance model of the Manor Burn catchment predominantly for the period 1982-1998.	Developed for the Galloway Irrigation Company to understand flows within the Manor Burn catchment.	A number of input time series and details from the Manor Burn sub-catchment were adapted and used in the current Manuherekia Hydrology Model V4.

75. To achieve the minimum flows scenarios at Campground each of the major tributaries are required to contribute towards meeting the Campground minimum flow. Table 2 provides what would be required from each tributary using pro-rata basis.

Table2: Pro rata flows in the tributaries at the different flow scenarios at Campground. (Source; Manuherekia Catchment Hydrology model)

Campground flow (m^3/s)	Dunstan Creek	Lauder Creek	Thomson's Creek	Chatto Creek
0.9	0	0	0	0
1.2	410	130	70	70
1.5	510	160	80	90
1.7	580	180	90	100
2.0	680	210	110	120
2.5	850	260	140	150
3.0	1020	320	170	180

76. Documentation of the Manuherekia Catchment Hydrology Model was finalised with the peer review being completed by Sarah Mager (Otago University) and James Griffiths (NIWA).

77. The outcomes of the peer review indicate that "….*the model is fit for the purpose of understanding the flow and its allocation across the catchment and we do not specify any changes be made to the model or flow series i.e., we support the flow time series produced by the model"* (Mager, S and Griffiths, J 2022)

Model Comparison

78. A further requirement of the project was for the hydrologists to come to an agreed position on the hydrology of the Manuherekia catchment. The draft Joint Hydrology Statement was considered at the hydrology group workshop on the 10th of May 2023, where concern was raised that the ecology technical advisory group may be using the timeseries data incorrectly i.e., treating the timeseries data as naturalised flows.

79. It was agreed that Roddy Henderson from NIWA would undertake comparison analysis of the flow timeseries data from the Manuherekia Catchment hydrology model and TopNet models for estimated natural flow conditions. A comparison of dry year and a wet year were included, with flows assessed at Campground, Ophir, and Dunstan Creek at Gorge.

80. TopNet flow timeseries data was generated as part of the development of the CHES model and the timeseries data from the Manuherekia Catchment Hydrology model for the "Full Dams no irrigation" was used.

81. Both the TopNet and GoldSim models were calibrated/optimised for low flow behaviour. Thus, the first comparison is between estimates of the 7-day mean annual low flow (MALF), a useful reference flow for dry periods. Table 2 below shows estimates for the calibration/validation period (2014–2018) and the longer record now available (1974 to 2020).

82. Time series data from the GoldSim model for the "Full Dams no irrigation" scenario at the three sites were provided by Ian Lloyd of Davis Ogilvie, and TopNet time series by Dr Christian Zammit of NIWA. Additionally, simulated natural flows at Campground and Ophir from the 2019 NIWA report[4], and recorded flows at the two Dunstan Gorge sites (provided by ORC), were used.

Table 3: 7-day MALF Natural Flow estimates, in cumecs (m³/s).

Location	**Dunstan Creek Gorge**	**Ophir**	**Campground**
7-day MALF 2014 – 2018			
GoldSim	0.65	3.0	3.6
TopNet	0.31	2.7	3.4
NIWA 2019		2.9	3.5
[1]Simulated Natural		3.1	3.9
7-day MALF 1974 – 2020			
GoldSim	0.67	3.4	4.0
TopNet	0.49	4.5	5.5
NIWA 2019		4.1	5.1
[1]Simulated Natural	0.67		
Booker & Woods	0.65	3.1	3.9

Table 3. Mean Natural Flow estimates, in cumecs (m³/s).

Location	**Dunstan Creek Gorge**	**Ophir**	**Campground**
Mean flow 2014 – 2018			
GoldSim	2.6	15.2	18.7
TopNet	2.3	16.9	20.7
NIWA 2019		22.5	27.1
[1]Simulated Natural		15.9	19.5
Mean flow 1974 -2020			
GoldSim	2.4	13.6	17.3
TopNet	2.9	20.3	24.8
NIWA 2019		26.1	30.8

[1]Simulated Natural	2.2		
Booker & Woods	2.0	15.9	22.3

[1] “Simulated Natural” refers to estimates derived from measured plus water data as described in the 2019 NIWA report. Henderson RD, Zammit, CL, Griffiths J. 2019. CHES Implementation for the Manuherekia River, Otago

83. Henderson (2023) noted to assess the potential impact of climate change on future water resource availability, the current Manuherekia catchment hydrology model would not be appropriate as it is dependent on historical flow data (current climate), and its irrigation demand assumptions would need modification.

84. Henderson (2023) also confirmed the uncertainty and the warranted caution that was highlighted in the Joint hydrology Statement about the use of output timeseries data from Manuherekia catchment hydrology model as the ‘natural’ flow. He also supported the uncertainty by at least ±20% variation of 7-day MALF statistic.

85. In the conclusion section of the NIWA report it states the statistics of mean flow and low flow from the described model time series are substantially the same as those reported in the Joint Hydrology Statement. In general, the Manuherekia catchment hydrology model is closer than the TopNet model to the 7-day MALF estimates of Natural Flow derived from other sources, such as the national model and the Simulated Natural flow series. This reflects the use of flow data as input rather than rainfall. (NIWA, Henderson 2023).

Additional Hydrology Studies

86. During the development period of the hydrology models, additional flow studies were completed, primarily focusing on the larger tributaries that are sourced from Dunstan Mountains which are – Chatto Creek, Lauder Creek, Thomson’s Creek, and Dunstan Creek.

87. There has been a noticeable increase in the number of flow recorders installed throughout the catchment from seven to 16. This network will improve confidence in future hydrology assessments in the Manuherekia Catchment.

88. The flow recorders provided actual data, which has allowed for more of an appreciation on how the behaviour flows in the river. The recorders have highlighted pinch points in the river, particularly flows at the downstream end of the gorge between Ophir and Chatto Creek. The data they provided also highlighted that a single minimum flow number at the bottom of the catchment did not necessarily provide protection throughout the river. Therefore, other management tools such as allocation, residual flows, and flow sharing will need to be considered alongside any minimum flow settings.

89. A Thomson's Creek catchment hydrology study resulted in confirmation the creek dries naturally from approximately 1km upstream of Glassford Road and downstream to Mawhinney Road. Water abstraction for irrigation does exacerbate the issue by extending the length of the drying reach. (Raineffects 2022)

90. The Lauder Creek catchment study confirmed that surface flows in the reach between Omakau Irrigation Scheme take and upstream of Glassford would dry naturally, disconnecting once every three years. Water takes exacerbated this situation causing disconnection of low flow more frequently.

91. The objective of the Chatto Creek study was different than Lauder and Thomson's Creek, with the objective to determine flow behaviour. Multiple longitudinal gauging runs were undertaken, plus an upgrade and ongoing maintenance of the flow recorder in Neds Creek were completed.

92. The Dunstan Creek study was a combination of longitudinal gauging and the installation of three flow recorders, two permanent at Beattie Rd and the Gorge plus a temporary flow recorder at the confluence. The temporary flow recorder was installed to understand the flow relationship between the Beattie flow recorder and observed flows at the confluence with the Manuherekia River. The results explained the influence of Woolshed Creek and recharge from groundwater.

Hydrology Findings

93. There is high degree of hydrological alteration relative to natural state due to the effects of water storage, augmentation, and abstraction. An example of this is that the river demonstrates a retrograde flow profile, with flow reducing as it moves downstream, compared to a natural operating where system where flows would normally increase as the river flows down the catchment (Figure 3).

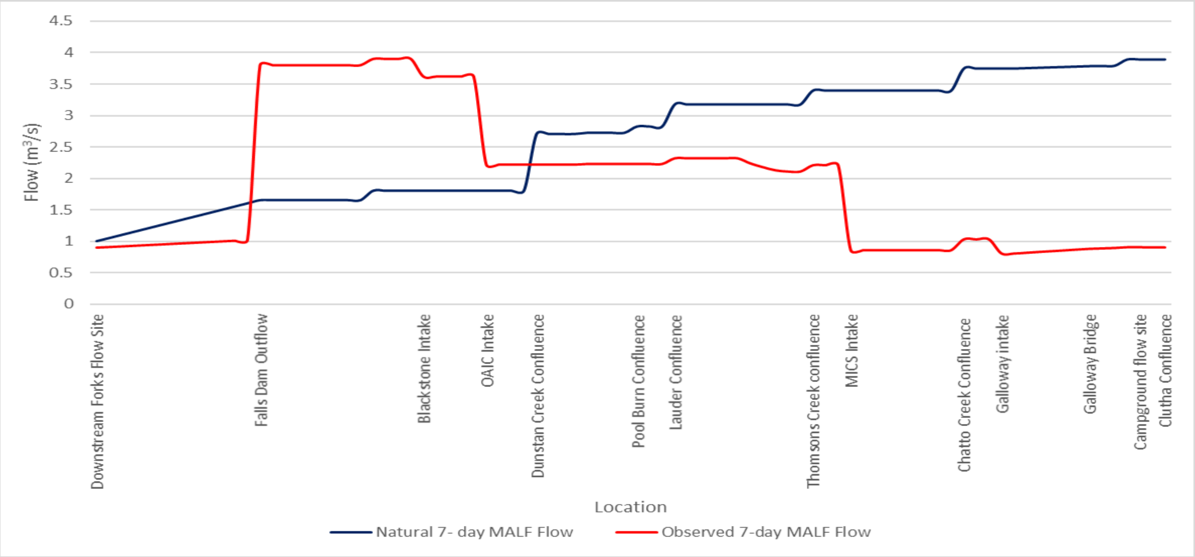


Figure 3 Longitudinal flows expected under the natural 7-day MALF and observed 7-Day MALF (Graph Hickey, M. 2020)

94. During low flow periods the augmentation of flow released from Falls Dam has been 'picked-up' by Omakau Irrigation Scheme at Becks. From this location downstream there is limited to no benefit from Falls Dam water.

95. The estimated natural frequency of the seven minimum flow scenarios occurring at Campground was analysed, using the 47 years of daily timeseries flow output data generated by Manuherekia Catchment Hydrology Model, then using the 7-day moving average value flow statistic as well as using BOC-Lake TopNet. The frequency of these flows occurring were:

Table 4 Percent of time estimated naturalised flow is less than range of minimums set at Campground.

From 1974 -2020		
Campground minimum flow (m^3/s)	Manuherekia Catchment Hydrology Model	BOC -Lake TopNet
0.9	Never	Never
1.2	Never	Never
1.5	Never	0.04%
1.7	Never	0.13%
2.0	Never	0.41%
2.5	0.16%[1]	0.86%
3.0	1.04%[2]	1.63%

[1] Estimated to once / 24.8 years [2] Once every 4.8years

From 2015 -2019		
Campground minimum flow (m^3/s)	Manuherekia Catchment Hydrology Model	BOC -Lake TopNet
0.9	Never	Never
1.2	Never	Never
1.5	Never	Never
1.7	Never	Never
2.0	Never	0.82%
2.5	0.33%	3.10%
3.0	1.44	4.86%

96. Assessments of climate change impacts on the hydrological regime in the Manuherekia catchment was carried out by using climate change projections to drive a calibrated hydrological model, TopNet. Modelling considered four climate change scenarios over the period 1971-2060. Analysis was carried using 20-years periods overlapping each other by ten years, spanning from 2006 to 2060 (e.g. analysis carried out over the period 2030-2050 to represent changes into the 2040s) to represent the dynamic aspect of the climate. Key results are as follows:

    - High flows are expected to increase by over 5% by 2050;

  - Median and mean flows are expected to slightly increase up to 5% by 2050;

97. Low flows and Mean Annual Low Flow calculated over a running 7-day period (7-day MALF) are expected to slightly increase up to 5% by 2020 before decreasing back to their historical level by 2050, except in the Manuherekia headwaters (above Falls Dam) where periods of low flow are expected to decrease by up to 5%.

98. Seasonally, mean, and median discharge over Winter-Spring and Autumn are expected to increase with warming across the Manuherekia catchment, while mean and median discharge during Summer is expected to decrease from the 2020s onward.

99. Low flows during the irrigation season (taken from September to March) are expected to increase in Spring, while decreasing in Summer. This behaviour is spatially variable as Summer low flows are expected to increase by the 2020s and decrease to their historical simulated levels by the 2050s for Ida Burn, while Spring flows at Falls Dam are projected to increase up to the 2020s before reducing to their historical simulated level by the 2050s.

100. Median number of consecutive days below hindcast 7-day MALF is not expected to change with warming, while the maximum number of events of five consecutive days is expected to increase by up to 10 occurrences. If 7-day MALF is used as a water consent threshold, this would point towards a shift in the distribution of periods where water consent will be restricted with restriction being less often but potentially lasting longer.

101. Analysis of the Wilcoxon Signed Rank test1 indicates that across the Manuherekia catchment changes in discharge are extremely likely to be associated with climate change effects (95% confidence level) for a majority of the overlapping time periods analysed over the period 2006 to 2060.

Available hydrology reports produced as part of Otago Regional Council flow study.

Stewart, D. 2021. *Comparison of Dunstan Creek at Beattie Road 100m Downstream and Dunstan Creek at Manuherikia Confluence*. ORC internal report
Stewart, D. 2022. *Thomson's Creek Hydrology Report*. ORC internal report
Stewart, D. 2021. *Lauder Creek Hydrology Report*. ORC internal report
Stewart, D. 2021. *Natural Flow Relativities and Travel Times Between Water Level Recorder Sites on the Manuherikia River.* ORC internal report
Stewart, D. Mager, S. 2020. *Review of discharge gauging data for the Manuherekia catchment*.
Zammit, C. 2020**.** *Potential climate change impacts on streamflow in the Manuherekia catchment.*

Zammit, C 2020. *Manuherekia Rainfall Sensitivity.*

Brown, P. 2020. *Manuherekia Hydrology: Report 1*

Lloyd, I. 2023. *Manuherekia Catchment Hydrology – Joint Expert Statement (Draft)*

Lloyd, I. 2019. Memo, *Manuherekia Catchment hydrology model comparison – initial review of the Manuherekia Catchment GoldSim model.*

Lloyd, I. *2022.* Manuherekia Catchment Hydrology Model Report

Lloyd, I. 2018. *Manuherekia Catchment Hydrological Model – Update Report. Report prepared for Manuherekia River Limited, reference number 180904.37308, dated 13 September 2018.*

Lloyd, I. 2020. *Manuherekia Catchment GoldSim model – scoping document – revised draft. A memorandum prepared for the ORC and the Manuherekia Hydrology Group dated 6 July 2020.*

Lloyd, I., 2021a. *Manuherekia Hydrology model – Calibration Memorandum – Final Draft. A memorandum prepared for the ORC and the Manuherekia Hydrology Group dated 21 May 2021.*

Lloyd, I. 2021b. *Manuherekia Hydrology model – Ecology Memorandum – Final Draft. A memorandum prepared for the ORC and the Manuherekia Technical Advisory Group dated 21 May 2021.*

Lloyd, I. 2021c. *Manuherekia Hydrology model – Scenario Memorandum – Final Draft. A memorandum prepared by Davis Ogilvie for the ORC dated 21 May 2021.*

Henderson, R.2019**.** *CHES Implementation for the Manuherekia River, Otago. A report prepared for the Manuherekia Technical Advisory Group and ORC dated November 2019.*

Henderson, R. 2023**.** *Analysis of Manuherekia River flow data timeseries*

Mager, S and Griffiths, J. 2022. *Review of the Manuherekia Hydrology Model. A report prepared by Sarah Mager (University of Otago) and James Griffiths (NIWA) for ORC*

ECOLOGY

Instream Habitat Modelling

102. Instream habitat assessment has been conducted for three reaches of the Manuherekia River and for one reach in Dunstan Creek. Chatto Creek has two reaches assessed using previous models generated in 2004, which were used recently in the AEE for Chatto Creek water take consent renewal application. Both Lauder and Thomsons Creeks have two reaches modelled respectively which, were conducted by Manuherekia Catchment Limited.

103. Instream habitat modelling can be used to consider the effects of changes in flow on instream values, such as physical habitat, water temperature, water quality and sediment processes. The strength of

instream habitat modelling lies in its ability to quantify the loss of habitat caused by changes in the flow regime, which helps to evaluate alternative flow proposals.

104. Habitat modelling does not take several other factors into consideration, including the disturbance and mortality caused by flooding as well as biological interactions (such as predation), which can have a significant influence on the distribution of aquatic species.

105. Instream habitat modelling requires detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat methods is that if there is no suitable physical habitat for a given species, then they cannot exist.

106. However, if there is physical habitat available for that species, then it may or may not be present in a survey reach, depending on other factors not directly related to flow, or to flow-related factors, which have operated in the past (e.g. floods). In other words, habitat methods can be used to set the outer envelope of suitable living conditions for the target biota (Jowett 2005).

107. Instream habitat is expressed as Reach Area Weighted Suitability (RAWS), a measure of the total area of suitable habitat per metre of stream length. It is expressed as square metres per metre (m^2/m). Another metric, the reach-averaged Combined Suitability Index (CSI) is a measure of the average habitat quality provided at a particular flow. CSI is useful when considering the effects of changes in flow regime on periphyton where it is not the overall population response that is of interest (such as for fish), but rather the percentage cover across the riverbed (such as periphyton).

108. The Galloway model reach extends from Shaky Bridge upstream to the Chatto Creek confluence. The Omakau reach extends from the upstream end of Ophir Gorge to Lauder Creek excluding the Lauder Gorge. The Blackstone reach extends downstream from the Blackstone irrigation take to the upstream of the Dunstan Creek confluence. All reaches are dominated by run and riffle habitat and pool habitat is rare.

109. A risk assessment process was conducted using the physical habitat predictions from the SEFA models to assess the risk presented by the changes in predicted habitat available to periphyton, macroinvertebrates and fish in the Manuherekia. This assessment used the following five categories:

   a. Very high risk – loss of more than 50% of predicted habitat at naturalised 7dMALF
   b. High risk -loss of between 40 – 50% of predicted habitat at naturalised 7dMALF
   c. Moderate risk- loss of between 30-40 % of predicted habitat at naturalised 7dMALF
   d. Low risk -loss of between 20-30 % of predicted habitat at naturalised 7dMALF
   e. Very low risk – loss of between 0-20% of predicted habitat at naturalised 7dMALF

110. Risk assessment for periphyton differed from the fish and macroinvertebrates because four taxa are undesired algal taxa where risk is based on avoiding increasing occurrence. For the desired taxa diatoms, the risk was assessed on the loss of diatom habitat when compared to the full dam no irrigation scenario.

111. The risk assessment analysis was conducted at each of the sites SEFA model and hydrology information of the scenario flows was available:

- Galloway-Campground
- Ophir
- Chatto Creek (fish only)
- Thomsons Creek (fish only)
- Lauder Creek (fish only)
- Dunstan Creek (fish only)

112. The Blackstone SEFA model requires minimum flow scenario flows before it can be added to this risk assessment.

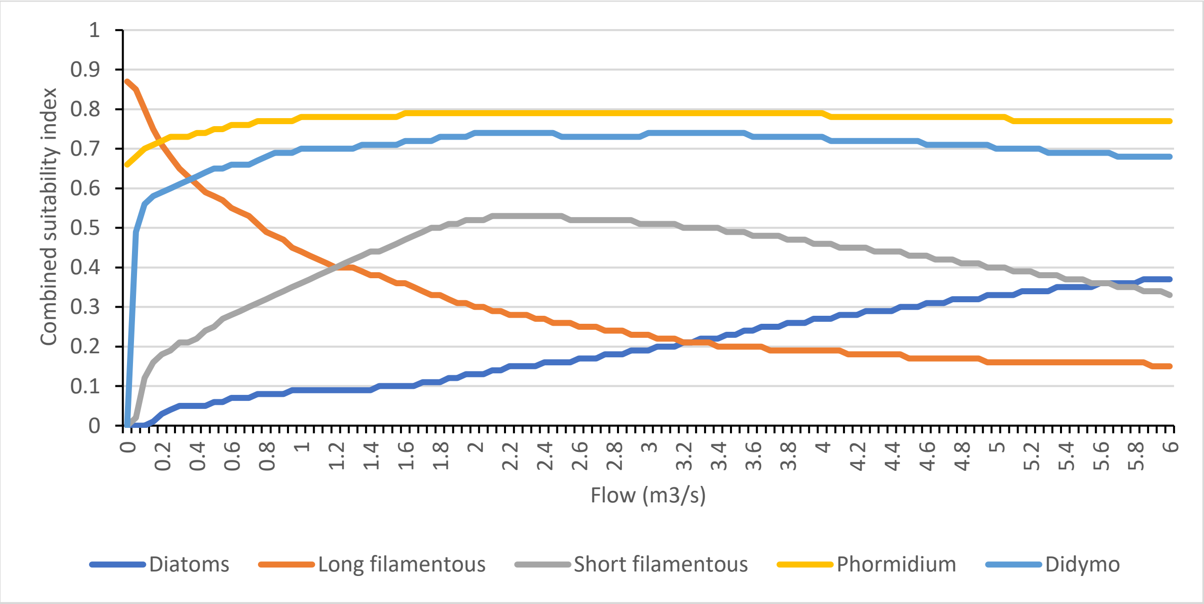


Figure 4 Changes in modelled habitat suitability with flow for algal taxa at Blackstone

113. The habitat for diatoms increases as flow increases with the rate of habitat increase increasing between 2 and 6 m^{3}/s (Figure 4). Habitat for *Phoridium* and didymo increases rapidly from 0 to 0.5 m^{3}/s and then the rate of increases slows and nearly plateaus at and above 2 m^{3}/s. Long filamentous algae habitat peaks at very low flows (0.1 m^{3}/s) and declines as flow increases above this low flow. Habitat for short filamentous algae rises slowly and peaks at 2.8 m^{3}/s before gradually declining as flow increases further.

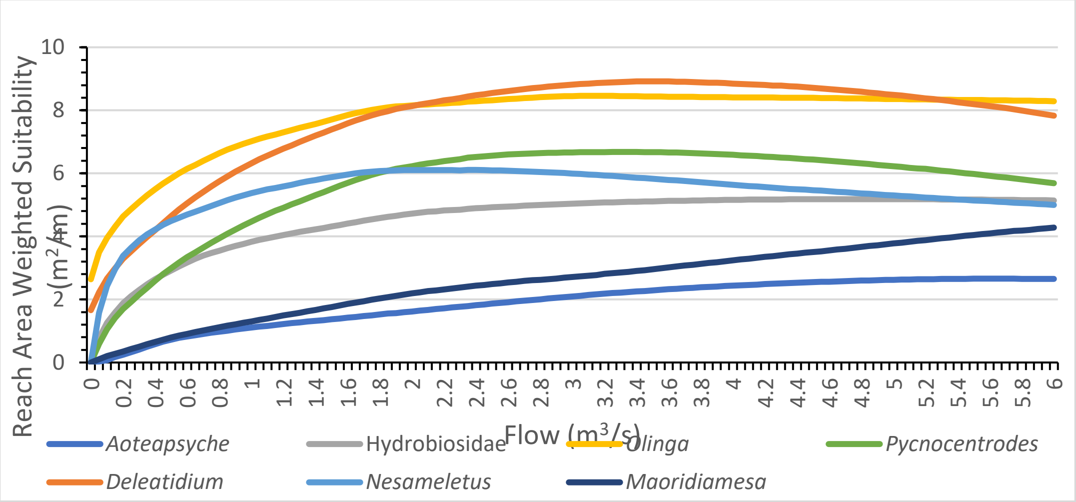


Figure 5 Changes in modelled habitat with flow for macroinvertebrate taxa at Blackstone

114. Macroinvertebrates show two trends at the Blackstone reach (Figure 5). Habitat for *Aoteapsyche* and *Maoridiamesa* increase as flow increases throughout the flow range modelled. The other five taxa have rapid increases in habitat from 0 m^3/s to 0.5 m^3/s and then the rate at which habitat increases slows and for *Nesameletus* it declines slowly once the flow exceeds 2 m^3/s.

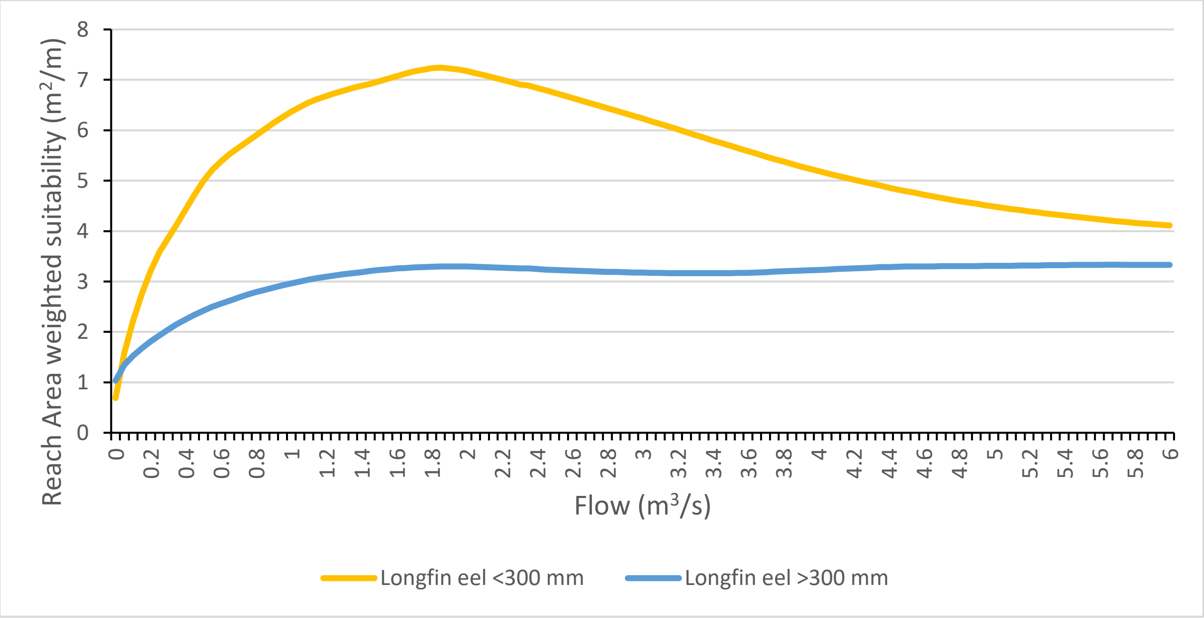


Figure 6 Changes in modelled habitat with flow for longfin eels at Blackstone

115. The habitat for small longfin eel peaks when flow reaches 1.9 m^3/s in the Blackstone reach (Figure 6). The habitat then declines, and the rate of decline reduces as flow increases. At 6 m^3/s the decline in habitat nearly stops. For large longfin eel habitat rises from 0 m^3/s to 1.9 m^3/s. As flow increase over 2 m^3/s the large longfin eel habitat is stable.

116. For the Campground Galloway reach the risk assessment for fish species and life history stages ranged from Very low risk to high risk across the scenarios and species (Table 5). For fish species everything was low or very low risk when the minimum flow was 2.0 m^3/s or higher.

Table 5: Fish risk assessment for Campground Galloway reach.

Flow Scenario Campground m^3/s	Species				
	Lamprey	**Upland bully**	**Roundhead galaxias juv/adult**	**Longfin eel < 300 mm/ >300 mm**	**Trout fry/juvenile / adult**
0.900	VLR*	VLR	VLR / VLR	MR / VLR	VLR / VLR/ HR
1.1	VLR	VLR	VLR / VLR	MR / VLR	VLR / VLR/ HR
1200/0.08	VLR	VLR	VLR / VLR	MR / VLR	VLR / VLR / HR
1500/0.09	VLR	VLR	VLR / VLR	LR / VLR	VLR / VLR / MR
1700/0.1	VLR	VLR	VLR / VLR	LR / VLR	VLR / VLR / MR
2000/0.12	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / LR
2500/0.14	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / VLR
3000/0.16	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / VLR

*Risk assessment abbreviations: VLR- very low risk; LR – low risk; MR moderate risk; HR – high risk; VHR – very high risk

117. For the Campground Galloway reach the risk assessment for macroinvertebrate species ranged from Very low risk to very high risk across the scenarios and species (Table 6). For macroinvertebrate species everything was low or very low risk when the minimum flow was 3.0 m^3/s or higher. A minimum flow of 2.0 m^3/s was required for the risk assessment for all species to exceed very high risk (less than 50 % habitat loss).

Table 6: Invertebrate Risk Campground Galloway reach.

Scenario	**7dMALF**	***Aoteapsyche***	***Deleatidium***	***Hydrobiosidae***	***Pycnocentrodes***	**Food producing**	**Benthic invertebrate**
Full Dam no irrigation	4.040	100	100	100	100	100	100
Estimated existing	0.860	24	67	62	65	52	53
0.900	1.130	30	73	68	74	63	60
1.100	1.270	33	76	70	78	68	63
1.200	1.340	35	78	71	80	70	65
1.500	1.610	42	82	75	85	76	70
1.700	1.790	47	85	78	88	79	73
2.000	2.060	54	88	81	92	84	77
2.500	2.520	65	93	87	96	90	84
3.000	2.970	77	96	91	98	95	89
RISK ASSESSMENT							

Full Dam no irrigation	4.040	Natural	Natural	Natural	Natural	Natural	Natural
Estimated existing	0.860	High	Moderate	Moderate	Moderate	High/Mod	High/Mod
0.900	1.130	VHR	LR/MR	MR	LR/MR	MR	HR/MR
1.100	1.270	VHR	LR/MR	LR/MR	LR	MR	MR
1.200	1.340	VHR	LR/MR	LR/MR	LR	MR	MR
1.500	1.610	VHR	LR	LR/MR	VLR	LR	MR
1.700	1.790	VHR	VLR	LR/MR	VLR	LR	LR/MR
2.000	2.060	HR/MR	VLR	VLR	VLR	VLR	LR/MR
2.500	2.520	MR	VLR	VLR	VLR	VLR	VLR
3.000	2.970	LR/MR	VLR	VLR	VLR	VLR	VLR

*Risk assessment abbreviations: VLR- very low risk; LR – low risk; MR moderate risk; HR – high risk; VHR – very high risk

118. Periphyton monitoring in the Campground at Galloway between 2019 and 2023 has found that cover is typically dominated by thin diatom films and cover by filamentous algae is typically low and rarely exceeds 30% cover. Thus, any minimum flow that is higher than the status quo (0.9 m^3/s) is expected to increase suitability for diatoms and short filamentous algae and will reduce suitability for long filamentous algae (Table 7). Habitat suitability for benthic cyanobacteria and Didymo is not expected to be affected much by flow (Table 7). Thus, periphyton cover in the Campground is expected to continue to be dominated by thin films and medium diatom mats (Table 7). The risk of proliferation of long filamentous algae is expected to decline with increasing minimum flows up to approximately 3 m^3/s (**Error! Reference source not found.** 7), although observations of the periphyton community in the Campground at Galloway suggests that proliferations of long filamentous algae are relatively infrequent at this site under the status quo conditions (Olsen memo 2023).

119. Instream habitat modelling operates at a reach scale, whereas actual environmental monitoring operates at site scale the direct comparison of these two data sets should be treated with caution.

Table 7. Habitat quality (CSI) retention for periphyton classes in the Manuherekia at Galloway and risk assessment based on instream habitat modelling and observations.

Scenario	7dMALF	Diatoms	Long filamentous	Short filamentous	Phomidium	Didymo
Full Dam no irrigation	4.040	100	100	100	100	100
Estimated existing	0.860	26	171	75	96	112
0.900	1.130	31	153	87	97	111
1.100	1.270	35	147	94	97	110
1.200	1.340	38	145	97	97	110
1.500	1.610	43	137	106	98	108
1.700	1.790	46	132	109	99	106
2.000	2.060	50	123	110	99	104

2.500	2.520	64	110	111	100	104
3.000	2.970	76	103	108	100	103
RISK ASSESSMENT						
Full Dam no irrigation	4.040	Natural	Natural	Natural	Natural	Natural
Estimated existing	0.860	VHR*[1]	VHR†*	VLR	VLR	VLR
0.900	1.130	VHR*[1]	VHR†*	VLR	VLR	VLR
1.100	1.270	VHR*[1]	MR	VLR	VLR	VLR
1.200	1.340	VHR*[1]	MR	VLR	VLR	VLR
1.500	1.610	VHR*[1]	MR	VLR	VLR	VLR
1.700	1.790	VHR*[1]	MR	VLR	VLR	VLR
2.000	2.060	VHR*[1]	MR	VLR	VLR	VLR
2.500	2.520	VHR*[1]	LR	VLR	VLR	VLR
3.000	2.970	LR*	LR	VLR	VLR	VLR

[1] Current community usually dominated by thin to medium diatom mats. Analysis indicates higher flows favour these communities, so dominance expected to continue or increase with higher minimum flows i.e. >900 l/s.

† Proliferation by long filamentous algae at this site is uncommon. Analysis indicates higher flows are less favourable for these communities, so rare occurrence of long filamentous blooms is expected to continue to be low or decrease with higher minimum flows.

120. For the Campground Galloway reach the risk assessment for diatoms ranged from low risk to very high risk across the scenario range based on habitat modelling alone (Table 7).

121. Periphyton monitoring in the Manuherekia at Galloway between 2019 and 2023 has found that cover is typically dominated by thin diatom films. Over this period, cover by filamentous algae was typically low and rarely exceeded 30% cover. This data is inconsistent with the predictions of the instream habitat model, likely because the model only considers 3 factors (depth, velocity, substrate). Actual monitoring reflects real-world conditions including accrual times, water quality, water temperature, invertebrate grazing, all of which are important factors for periphyton (Biggs 2000).

122. Olsen (memo 2023) proposed a revised risk assessment incorporating the results of these observations from 2019-2023 into the risk assessment (Table 8).

Table 8. Revised risk assessment for periphyton at Manuherekia at Galloway proposed by Olsen (memo 2023).

RISK ASSESSMENT						
		Diatoms	**Long filamentous**	**Short filamentous**	**Phomidium**	**Didymo**
Full Dam no irrigation	4.040	Natural	Natural	Natural	Natural	Natural
Estimated existing	0.860	LR-MR*[1]	MR†*	LR	LR	LR
0.900	1.130	LR-MR*[1]	MR†*	LR	LR	LR
1.100	1.270	LR-MR*[1]	LR-MR	LR	LR	LR
1.200	1.340	LR-MR*[1]	LR-MR	LR	LR	LR
1.500	1.610	LR-MR*[1]	LR-MR	LR	LR	LR
1.700	1.790	LR-MR*[1]	LR-MR	LR	LR	LR

2.000	2.060	LR-MR*[1]	LR-MR	LR	LR	LR
2.500	2.520	LR-MR*[1]	LR	LR	LR	LR
3.000	2.970	LR*	LR	LR	LR	LR

123. For the Campground -Galloway reach to have all species and life history stages in the low risk (70% or more habitat retained) the minimum flow needs to be 2.0 m^3/s and to have all species in the very low risk (80% or more habitat retained) the minimum flow needs to be 2.5 m^3/s.

124. For the Manuherekia at Ophir reach the risk assessment for fish species and life history stages very low risk for all fish species and life history stages at all flows.

Table 8: Risk result table for the Manuherekia River at Ophir fish habitat.

Flow Scenario /Ophir	Species				
	Lamprey	Upland bully	Roundhead galaxias juv/adult	Longfin eel < 300 mm/ >300 mm	Trout fry/juvenile / adult
900/1.98	VLR*	VLR	VLR / VLR	VLR / VLR	VLR / VLR/ VLR
1100/2.02	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR/ VLR
1200/2.07	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / VLR
1500/2.16	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / VLR
1700/2.24	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / VLR
2000/2.31	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / VLR
2500/2.58	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / VLR
3000/2.81	VLR	VLR	VLR / VLR	VLR / VLR	VLR / VLR / VLR

125. For the Ophir reach the risk assessment for macroinvertebrate species ranged from very low risk to high risk across the scenarios and species (Table 9). For macroinvertebrate species everything was low or very low risk when the minimum flow was 2.5 m^3/s or higher. A minimum flow of 3.0 m^3/s was required for the risk assessment for all species to achieve a very low risk score.

Table 9 Habitat (RAWS) retention for common macroinvertebrate taxa in the Manuherekia at Ophir and risk assessment based on instream habitat modelling and observations.

Scenario	7dMALF	*Aoteapsyche*	*Deleatidium*	*Hydrobiosidae*	*Pycnocentrodes*	Food producing	Benthic invertebrate
Full Dam no irrigation	3.400	100	100	100	100	100	100
Estimated existing	1.78	39	86	85	90	74	77
0.900	2.02	51	90	89	95	83	83
1.100	2.090	54	91	90	96	85	84

1.200	2.130	55	91	90	96	85	84
1.500	2.250	60	93	92	98	88	87
1.700	2.340	63	94	93	99	89	89
2.000	2.460	67	95	94	99	91	90
2.500	2.720	77	97	96	100	95	93
3.000	2.980	86	98	98	101	97	96
RISK ASSESSMENT							
Full Dam no irrigation	3.400	Natural	Natural	Natural	Natural	Natural	Natural
Estimated existing	2.020	High	Low	Low	Low	Low/Mod	Low/Mod
0.900	1.780	HR/MR	VLR	VLR	VLR	LR	LR
1.100	2.090	HR/MR	VLR	VLR	VLR	VLR	VLR
1.200	2.130	HR/MR	VLR	VLR	VLR	VLR	VLR
1.500	2.250	HR/MR	VLR	VLR	VLR	VLR	VLR
1.700	2.340	MR	VLR	VLR	VLR	VLR	VLR
2.000	2.460	MR	VLR	VLR	VLR	VLR	VLR
2.500	2.720	LR/MR	VLR	VLR	VLR	VLR	VLR
3.000	2.980	LR	VLR	VLR	VLR	VLR	LVR

126. For Ophir reach the risk assessment for diatoms ranged from low risk to very high risk across the scenario range based on the instream habitat model alone (Table 10).

Table 10: Habitat quality (CSI) retention for periphyton classes in the Manuherekia at Ophir and risk assessment based on instream habitat modelling and observations.

Scenario	7dMALF	Diatoms	Long filamentous	Short filamentous	Phomidium	Didymo
Full Dam no irrigation	3.400	100	100	100	100	100
Estimated existing	2.020	28	181	89	98	104
0.900	1.780	45	156	102	99	104
1.100	2.090	48	152	103	99	104
1.200	2.130	51	149	104	99	104
1.500	2.250	58	143	107	100	104
1.700	2.340	64	138	108	100	103
2.000	2.460	70	133	109	100	103
2.500	2.720	80	120	109	100	102
3.000	2.980	87	112	107	100	102
RISK ASSESSMENT						
Full Dam no irrigation	3.400	Natural	Natural	Natural	Natural	Natural
Estimated existing	2.020	LR/MR*	MR†	VLR	VLR	VLR
0.900	1.780	VHR*	HR†	LR	VLR	VLR
1.100	2.090	VHR*	HR†	VLR	VLR	VLR
1.200	2.130	VHR*	MR	VLR	VLR	VLR

1.500	2.250	VHR*	MR	VLR	VLR	VLR
1.700	2.340	VHR*	MR	VLR	VLR	VLR
2.000	2.460	LR*	MR	VLR	VLR	VLR
2.500	2.720	VLR*	MR	VLR	VLR	VLR
3.000	2.980	VLR*	LR	VLR	VLR	VLR

127. Monthly observations of periphyton cover at the Manuherekia at Ophir between 2019 and 2023 found that periphyton was consistently dominated by thin light brown films, medium or thick light brown mats (Olsen memo 2023). Short and/or long filamentous algae have been present on occasion and were among the most abundant periphyton types at this site on approximately 20% of occasions but did not exceed 30% cover on any of the 33 sampling occasions over this period (Olsen memo 2023). As for the Galloway site, these observations are inconsistent with the predictions of the instream habitat model and for the same reasons. Olsen (memo 2023) proposed a revised risk assessment incorporating the results of the real-world observations from 2019-2023 into the risk assessment (Table 11).

Table 11 Revised risk assessment for periphyton at Manuherekia at Galloway proposed by Olsen (memo 2023).

RISK ASSESSMENT	7dMALF	Diatoms	Long filamentous	Short filamentous	Phomidium	Didymo
Full Dam no irrigation	3.400	Natural	Natural	Natural	Natural	Natural
Estimated existing	2.020	Low/mod*	Moderate†	Low	Low	Low
0.900	1.780	Low/mod*	Moderate†	Low	Low	Low
1.100	2.090	Low/mod*	Moderate†	Low	Low	Low
1.200	2.130	Low/mod*	Low/mod	Low	Low	Low
1.500	2.250	Low/mod*	Low/mod	Low	Low	Low
1.700	2.340	Low/mod*	Low/mod	Low	Low	Low
2.000	2.460	Low*	Low/mod	Low	Low	Low
2.500	2.720	Very low*	Low/mod	Low	Low	Low
3.000	2.980	Very low*	Low	Low	Low	Low

128. At Galloway the physical habitat parameters, average water depth and average river width increase rapidly from 0 m3/s to 0.15 m3/s (Figure 7). After the initial rise water depth increases only slowly as flow increases to 6 m3/s and average river depth from a flow of 2 m3/s to 6 m3/s only increases from 30 cm to less than 40 cm with this increase in flow. However, average river width and average water velocity increase more rapidly as flow increases and this leads to the riverine habitat subject to higher water velocities. Organisms that prefer low water velocities will find the reach becomes less suitable. The rarity of pool habitat and the small increase in water depth also limits organisms that prefer deep water throughout the flow range.

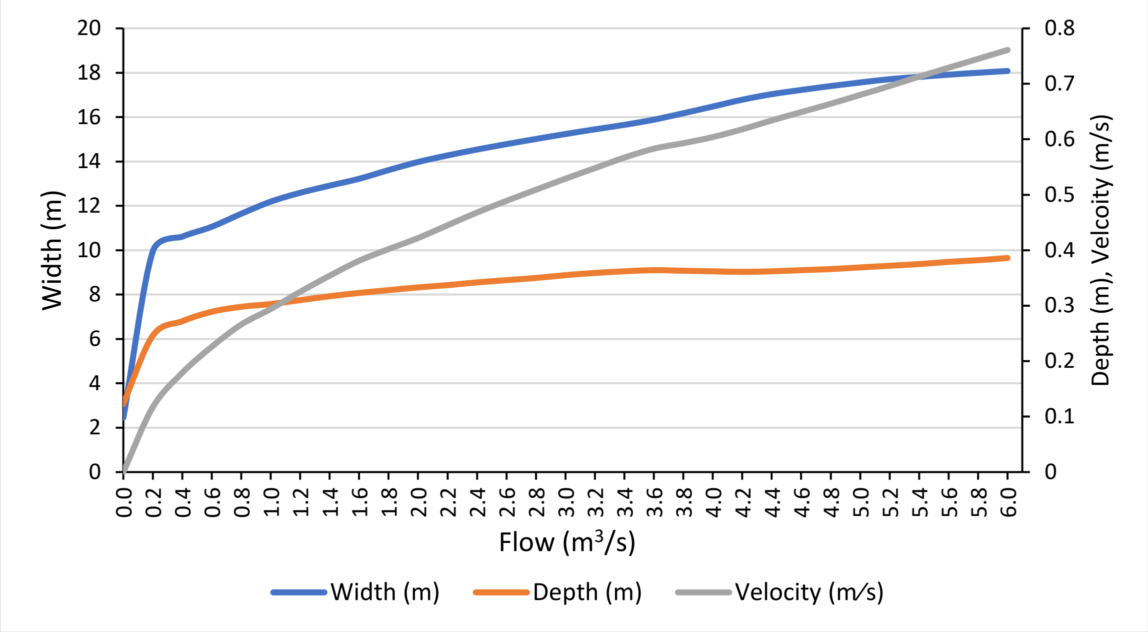


Figure 7: Changes in average width, depth, and water velocity with flow at Galloway.

129. At the Manuherekia – at Ophir reach the physical habitat parameters, average water depth and average river width increase rapidly from 0 m^3/s to 0.5 m^3/s (Figure 8). Once the flow exceeds 0.5 m^3/s the rate of river width and water depth increase slows. Average water velocity has a steady rate of increase throughout the 0 m^3/s to 6 m^3/s flow range, indicating the increase in flow is being accommodated by the increase in water velocity rather than an increase in stream width or depth.

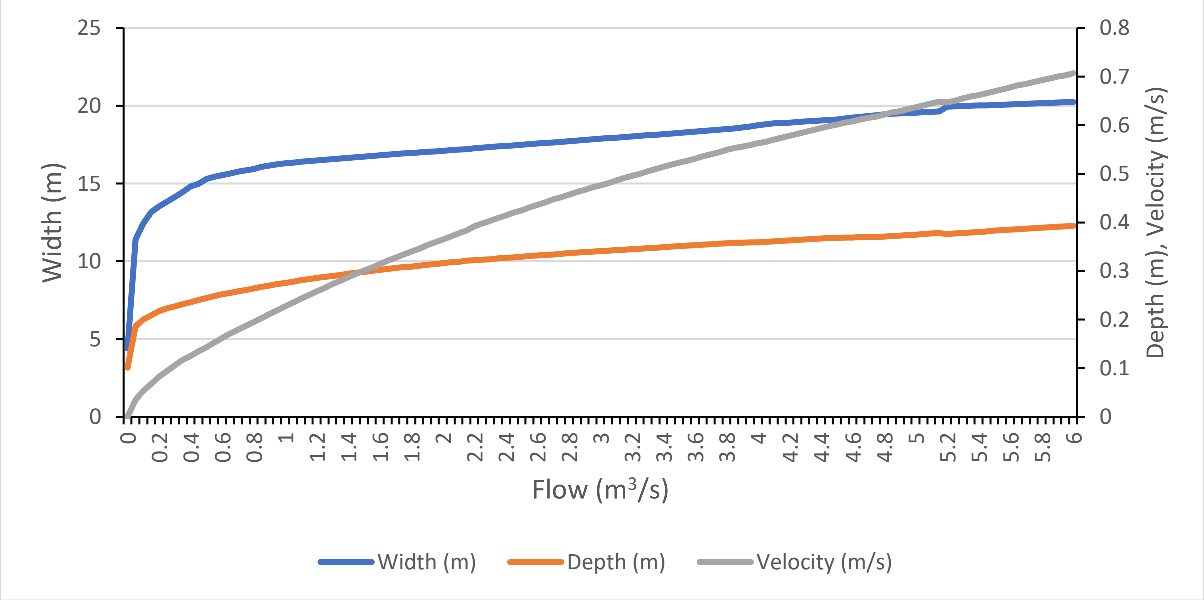


Figure 8: Changes in width, depth, and water velocity with flow at Manuherekia at Ophir.

130. At the Manuherekia Blackstone reach, the hydraulic component of instream habitat modelling made predictions about how water depth, channel width and water velocity will change with changes in flow (Figure 9). The most notable pattern is that there is a gradual decline in channel width, depth, and water velocity with declining flows down to 0.5 m^3/s, below which width and velocity drop rapidly.

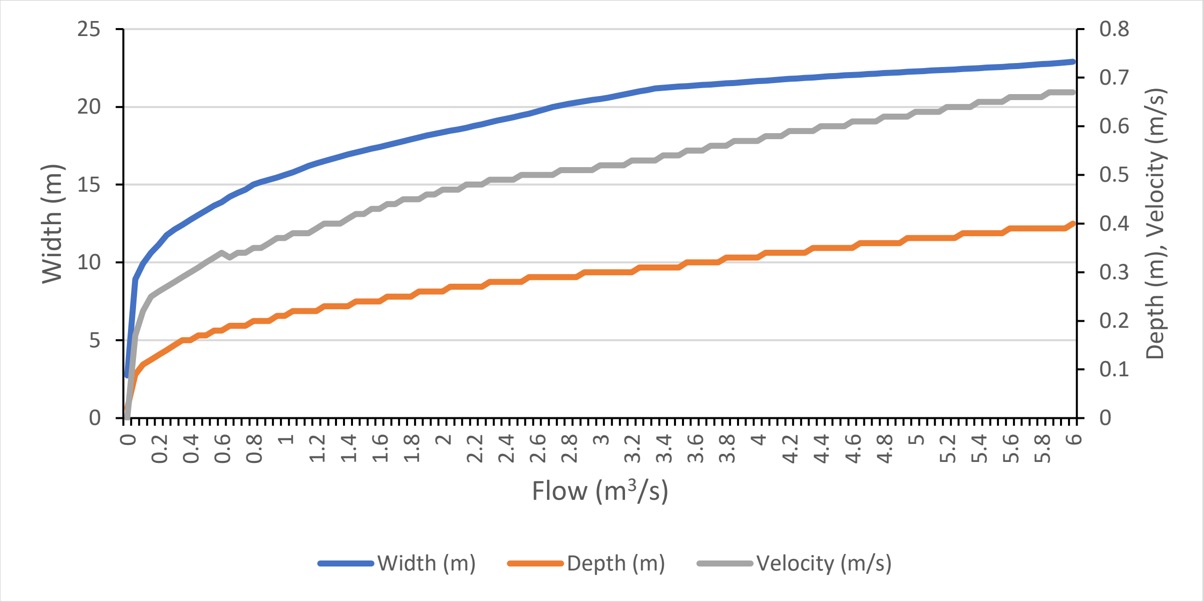


Figure 9: Changes in width, depth, and water velocity with flow at Blackstone.

Invertebrate Drift Study

131. The invertebrate drift studies main aim was to obtain empirical evidence for whether the concentration and flux (rate) of drifting invertebrates declines with flow reduction. Understanding whether drift concentration and rate declines with flow reduction is relevant to assessing the effects of flow abstraction on dispersal of invertebrates as well as food supply for drift-feeding fishes, such as introduced trout and some native galaxiids.

132. The benthic invertebrate stock of variable flow rivers is continually changing as a result of floods resetting the stock to lower biomass, followed by biomass accrual and community change during the following flow recessions. Drift concentrations and rates will vary in response, i.e. drift concentrations should increase in response to increasing benthic density and biomass. It is important not to conflate this natural variation in benthic-drift dynamics with the influence of flow, and flow alteration, on drift.

133. Benthic aquatic invertebrates enter the water column and begin drifting via passive or active mechanisms. Passive drift occurs when invertebrates are accidentally entrained into the water column by near-bed shear stress (related to water velocity and turbulence). Particle transport theory and process-based transport modelling predicts that the concentration and flux of fine particles (including invertebrates) should decline with flow reduction.

134. However, the empirical evidence for drift concentration declining with flow reduction is equivocal; some studies from drift sampling in New Zealand and overseas rivers are supportive, others are not. This is not surprising given that active (behavioural) drift can obscure the signal of flow-related passive drift. Invertebrates enter the drift actively (i.e. volitionally) for various reasons, including to find more suitable habitat, escape predators, and emerge (to complete their lifecycles). Very low flows can cause invertebrates to actively drift to escape desiccation and to find more suitable faster flowing habitat. Active drift can be highly variable in space and time, usually peaking at dusk and to a lesser extent at dawn. For this reason, it makes sense to sample drift during daylight hours when attempting to isolate the influence of flow on passive, background, drift. Nevertheless, pulses of active drift may occur due to emergence at any period in the day or in response to declining habitat quality.

135. The field component of collecting drift samples was conducted at 15 locations (3 locations on each 5 cross sections) below Chatto Creek on six sampling occasions in November 2019. Ideally sampling would occur over a single flow recession. However, floods after the second sampling occasion delayed further sampling until January 2020 resulting in the field sampling being completed over two separate flow recessions.

136. Concerns were raised regarding the influences on the levels of periphyton on the invertebrate drift as well as developing a drift relationship over the two separate flow recessions. (Olsen & Hickey)

137. Cawthron Institute responded to these concerns with “Drift concentration (no./m^3) and rate (no./s) can be influenced by benthic density; a higher benthic stock giving rise to more drifting invertebrates (Shearer et al. 2003; Weber et al. 2014). Ideally then, if benthic density varies significantly among drift sampling occasions, drift concentration or rate ought to be standardised by benthic density”.

138. The revised analysis demonstrated that benthic invertebrate density did vary significantly between the two-flow recessions, increasing from the first to second recession. This resulted in Cawthron standardising the drift rate accordingly.

139. The revised conclusion that drift rate declined from about the MALF (~ 4 m^3/s) to low flows is consistent with previous studies undertaken by Cawthron on New Zealand rivers which have shown drift concentration and rate declining over lower mid-range flows to low flows.

140. The drift sampling data set was compromised by the interruption by floods, in addition it was further compromised by low water velocities over a low flow range sampled during the second flow recession, lower than the calibration range of the drift sampler current sampler meters.

141. Because of the challenges identified above, the Manuherekia Technical Advisory Group requested further analysis of invertebrate drift -flow data, specifically to compare drift rate-flow relationships from other rivers with those established from the Manuherekia River.

142. Cawthron Institute responded with the conclusion”…..the drift -flow relationship results from other drivers confirm the observed relationship of drift declining with flow reduction in the lower Manuherekia River.”

143. The empirical relationships from the other rivers, and drift transport model predictions, help resolve the uncertainties in the Manuherekia drift-rate dataset and indicate that the relationship between passive drift rate and flow in the Manuherekia should decline in a smooth curvilinear fashion down through the MALF (~ 4m³/s) towards zero at zero flow.

144. Manuherekia Technical Advisory Group categorised the Risk to invertebrate drift, (Table 11) which was confirmed by Dr John Hayes (Cawthron Institute) as a sensible risk classification.

Table 11. **Risk result table for the Manuherekia River for invertebrate drift relationship to flow.**

Risk Level	Invertebrate Drift
Very High risk	< 1m³/s
High Risk	1 – 2m³/s
Moderate	2 – 2.5m³/s
Low Risk	2.5 – 3m³/s
VLR- very low risk	> 3m³/s

Consideration of the natural flow regime

145. Objective 2.1 (a) of the NPS-FM which states the first priority is to the health and well-being of water bodies and freshwater ecosystems. During the course of the TAG, Dr Richard Allibone presented the opinion that for a minimum flow to align with objective 2.1(a), the minimum should fall within the estimated natural low flow range.

146. Table 12 shows analysis taken from the Manuherekia Hydrology Model and the CHES/Topnet Model. The table outlines the percentage of time the modelled natural flow would have been below each minimum flow option.

147. In the conclusion section of the NIWA report it states the statistics of mean flow and low flow from the described model time series are substantially the same as those reported in the Joint Hydrology Statement. In general, the Manuherekia catchment hydrology model is closer than the TopNet model to the 7-day MALF estimates of Natural Flow derived from other sources such as the BOC – Lake TopNet Model (NIWA, Henderson 2023).

148. Using the Manuherekia Hydrology Model, for the 1974 – 2020 period, it was likely that flows were never observed at and below 2.0m³/s. The analysis showed a flow of 2.5 m³/s would occur 0.16% of the time, and a flow of 3.0m³/s occurred 1.04% of the time over the analysis period.

149. Return period statistics were also calculated- 2.5 m³/s was estimated to occur 1 in every 24.8 years, and 3.0m³/s at 1 in every 4.8 years.

Table 12 Percent of time estimated naturalised flow is less than range of minimums set at Campground.

From 1974 -2020		
Campground minimum flow (m³/s)	Manuherekia Catchment Hydrology Model	BOC -Lake TopNet
0.9	Never	Never
1.2	Never	Never
1.5	Never	0.04%
1.7	Never	0.13%
2.0	Never	0.41%
2.5	0.16%[1]	0.86%
3.0	1.04%[2]	1.63%

[1] Estimated to once / 24.8 years [2] Once every 4.8years

Other Ecological information

150. The catchment supports important habitat for indigenous biodiversity in some of the tributaries and the braided mainstem above Falls Dam. Indigenous freshwater species include bullies, nationally threatened galaxias, and at-risk species of longfin eel (tuna) and koura/crayfish. Non-migratory galaxias species are endemic to the area and highly valued. The catchment vegetation supports a diverse invertebrate community, as well as significant lizard species, including Scree Skinks (nationally vulnerable) and Green Skinks (at risk). The braided upper mainstem, along with streams, ponds and reservoirs throughout the catchment provide nesting and foraging habitat for a diverse array of birdlife, including at-risk or vulnerable birds such as banded dotterels, wrybill, black-fronted tern, pied stilt, and oyster catchers.

151. Although not critical to initial minimum flow setting, further studies are required to manage threatened freshwater values appropriately. This information would be useful when addressing allocation and any future potential residual flow consent condition.

152. Nine native fish species in addition to koura/freshwater crayfish (Paranephrops zealandicus) have been recorded in the Manuherekia catchment. Native fish include three non-migratory galaxiids, koaro, two bully species (upland and common bully), and longfin eels. Of these, koaro longfin eels and koura, are listed as “at risk, declining” in the most recent threat classification publications.

153. There are three threatened non-migratory galaxiids: Alpine galaxias "Manuherekia" (Nationally Endangered) is only known from a single location from a 12km reach of the Manuherekia River approximately a kilometre upstream from Falls Dam, the fisherman huts to the Forks flow recorder. How pressures such as surface flows influence habitat and the galaxiid dispersal and overall distribution is unknown. Also unknown is the potential detrimental effects from the predation and competition from salmonids. The reach of the upper Manuherekia River that the Alpine galaxias occupies is also the same reach that salmonids utilise for spawning. A study design to assess the freshwater values of this upper reach is currently being designed. The study will include the changes in the number of braids in relation to flows, the habitat (flow) requirements for the braided river birds (wrybill, tern, and banded dotterel), wetlands and springs.

154. The decline of the Central Otago roundhead galaxias, throughout the Manuherekia catchment has been well documented. Population fragments still persist but their overall area occupancy continues to shrink under pressure from trout predation and competition. Actions such as the Thomson's Creek galaxiid management programme is critical to the long-term persistence of this species within the Manuherekia catchment. If the management of flows is being considered within a Central Otago roundhead galaxias population, then care and management tasks (i.e. fish passage barriers, trout removal) will need to be considered alongside.

155. The Clutha flathead galaxias is present in waterways associated with the Manorburn / Poolburn area. In the Manuherekia catchment this galaxiid is found at reasonably high altitudes, where the gradient of streams tends to be steep, and thereby restricting salmonid movement which has provided some security.

156. Nineteen species of birds have been recorded in the Manuherekia catchment, 16 of which are native (Olsen et al. 2017). The upper Manuherekia River and the mid to lower reaches provide two quite distinct types of habitat. The upper reaches are a braided river system, whereas the mid to lower sections are willow-lined and confined to a single thread. Excessive broom and gorse growth on the gravel beaches of the streambed are considered to influence the availability of river bird habitat.

157. The upper reaches (upstream of Falls Dam) provides ideal habitat for wading birds and, banded dotterel, pied stilts, South Island oyster catcher as well as the occasional wrybill which have all been observed in this upper reach of the river (Ravenscroft 2014). Black fronted terns have also been recorded from braided river habitats upstream of Falls Dam (O'Donnell & Hoare 2011, Wildland Consultants Ltd 2014). The habitat/flow requirements for these birds in the upstream reach of Falls Dam will form part of the study (Refer Paragraph 120).

158. Black–backed gulls, little shags and black shags, pied stilt, and the South Island oyster catchers are present in the reach of river downstream of Falls Dam. There is a nesting colony of Black-backed gulls immediately downstream of the dilapidated bridge in the upper reaches.

Available ecology produced as part of Otago Regional Council Manuherekia study.

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Duncan, M. Bind, J 2016 *Instream habitat, and minimum flow requirements in the Manuherikia River* (NIWA).

Hayes, J. Shearer K, Casanovas P. 2021 *The relationship between invertebrate drift and flow in the Manuherikia River: revised analysis and implications for setting minimum flow and allocation limits. Nelson: Cawthorn Institute. Report 3574A. Prepared for Otago Regional Council, Aukaha, and Otago Fish and Game.*

Hayes, J. Shearer K. 2021. *Response to review of Cawthorn reports presenting invertebrate drift relationships for the lower Manuherekia River. Nelson: Cawthron Institute. Cawthron Advice letter 2179.*

Hayes, J. Shearer K. 2023. *Response to review of Cawthorn reports presenting invertebrate drift relationships for the lower Manuherekia River. Nelson: Cawthron Institute. Cawthron Advice letter 2319*.

Hickey ,M. Olsen, D. 2020 *Assessment of Environmental Effects of water abstraction from the Chatto Creek catchment*

Hickey ,M. Olsen, D. 2020 *Assessment of Environmental Effects for water abstraction from Manuherikia River from the Falls Dam to the confluence with the Clutha / Mata Au.*

Hickey ,M. Olsen, D. 2020 *Assessment of Environmental Effects of water abstraction from Thomsons catchment*.

Hickey ,M. Olsen, D. 2020 *Assessment of Environmental Effects of water abstraction from Thomsons catchment*.

Hickey ,M. Olsen, D. 2020 *Assessment of Environmental Effects of water abstraction from the Lauder catchment*.

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McKeague, S. 2021 *Manuherikia Catchment Group Incorporated. Overview of Proposed Catchment Management Approach. McKeague Consulting*

Olsen, D. 2021 *Review of Cawthron reports presenting invertebrate drift relationships for the lower Manuherekia River*

Olsen, D. 2023 Periphyton and macroinvertebrate communities of the Manuherekia River.

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MANUHEREKIA TECHNICAL ADVISORY GROUP

159. The Manuherekia Technical Advisory Group (TAG) comprised eight members who represented the following stakeholders: Aukaha, Otago Fish and Game, Department of Conservation, Otago Regional Council, Omakau Irrigation company and Otago water users' group. The original group was formed in early 2019. The Terms of Reference were signed sometime later.

160. During the four-year period that TAG was meeting, there were multiple member changes, resulting in a total of sixteen individuals being a part of TAG over its history. A combination of membership changes and the delay in receiving hydrology information, had a flow on effect in that there was need to brief new members and update existing members.

161. The TAG reviewed ecological reports, made comments, asked questions of the authors, and made recommendations on where further work was required. They also advised on process, and assisted the attribute assessment that was carried out in this this report.

162. It had been intended that TAG would make a final recommendation, however it became clear that agreement was unlikely to be reached, especially within the timeframes of the Land and Water Regional Plan Development. Ultimately therefore what is available to Council is not a final minimum flow recommendation from TAG but a staff recommendation that takes into account the groups extensive input into developing the scientific information.

FURTHER AREAS FOR CONSIDERATION:

163. This report, and TAG's work to inform it, focused on minimum flow setting at Campground. Minimum flow regimes are one tool for managing water abstraction and some of the consequential ecological stressors. Minimum flow regimes are typically paired with allocation regimes, residual flows and flow sharing regimes. To be effective these regimes must be underpinned by appropriate measurement to enable water accounting. This section outlines future work that would need to occur to deliver robust management of water resources in the Manuherekia.

Water Accounting:

164. Accounting for water use, transfer, discharge of stored water and retake is fundamental to appropriately account for water use. Hydrologists who have worked in the Manuherekia catchment agree that the catchments hydrology is complex. This complexity is impossible to overcome without appropriate measurement of water take, discharge and retake. Current metering practice focuses on capturing predominantly water take data. Of particular importance in the Manuherekia is determining the relative quantities of run of river and stored water that is available to take which is mostly unmeasured currently.

165. Measuring irrigation water discharge (to the river and irrigated areas), and retake will enable ORC, water users and the community to have informed conversations about appropriate allocation, water use efficiency, hydrological studies, and future minimum flow reviews in the future. This is not unique to the Manuherekia Catchment and additional metering should be implemented where take, augmentation and retake occurs.

Allocation:

166. Allocation regimes serve to ensure an appropriate amount of water take is appropriately distributed both geographically and across the hydrograph. Allocation is typically provided in blocks to serve this purpose. Paper primary allocation in the Manuherekia is currently 32m3/s. (Based on adding up all the consent face values) while the best estimate of realised take is 9m3/s, including stored water.

167. The allocation structure in the Manuherekia has not been reviewed and originates from the original deemed permit system. The allocation structure is not optimised to align with a minimum flow regime, and a shift to a significantly higher minimum flow before reviewing allocation would likely result in negative impacts on the river ecosystem due to sustained flatlining of the hydrograph.

168. Ideally the geographical spread of allocation should match flow availability.

169. Allocation would ideally be broken into blocks that are released to water users as the available flow rises. This enables river flows to rise and fall naturally as weather and other seasonal hydrological processes such as snow melt occur.

170. Allocation in the Manuherekia originates for the deemed permit system and is not optimised to align with a minimum flow regime. Extensive paper allocation still exists and is expected to reduce as reconsenting addresses actual use and flow requirements for efficient irrigation.

171. A robust allocation review would likely be more successful with sufficient data. Improving water accounting therefore should occur before an allocation review.

Flow Rationing:

172. All water users should be subject to allocation and minimum flow regimes. This is not currently the case in the Manuherekia. Flow ratioing is triggered among Falls Dam shareholder associated irrigators as the level of Falls Dam drops. Some water users are not beneficiaries of Falls Dam and make their own decisions about water use at different flow stages and are subject to their own consent requirements.

173. Implementing a system to manage flow rationing across the Manuherekia catchment will be important to ensure all water users are collectively organised to manage their water take such that the river is not compromised, and any system is equitable for water users.

Residual flows:

174. Residual flows apply at the point of take and dictate the amount of water that must be left in the water body after the take. Residuals are an important part of flow management. Residual flow should be reviewed systematically alongside allocation and flow rationing.

Staged Implementation:

175. Transitioning the river from the current management regime to a higher minimum flow should be implemented over an appropriate period of time. The Manuherekia River ecology is currently characterised by species that have adapted to a highly modified river habitat characterised by reduced flows. This includes pockets of Nationally Threatened non-migratory galaxiids.

176. Increasing the minimum flow substantially should be done with a degree of caution – as higher flows potentially allow for greater range for species like trout, resulting in greater predation on already threatened aquatic species. Programmes to manage fish passage should be implemented prior to lifting the minimum flow substantially.

CONCLUSION

177. The Manuherekia catchment has a long history of intense environmental modification resulting from water management infrastructure – storage dams and races for irrigation. This modification has resulted in a situation where it is incredibly difficult to naturalise the flows. Therefore, despite all the flow analysis in the Manuherekia catchment, the flows were never properly naturalised at a whole of catchment level. Several sub catchments were able to be naturalised. The closest we can assess the flows to natural is using the Manuherekia hydrology model "Falls Dam full, no irrigation" scenario.

178. Henderson (2023) noted when making the comparison of the two daily timeseries flow data (TopNet and Manuherekia catchment hydrology model) resulted in the Manuherekia catchment hydrology model was closer to 7d-MALF estimates. This reflects the use of flow data as input rather than rainfall.

179. In the absence of an exact number, and the knowledge that any additional hydrology study would not necessarily provide any additional certainty in the flow statistics, it is therefore considered that this is the best available hydrological information.

180. Using the timeseries output of Manuherekia Hydrology Model "Falls Dam full, no irrigation" the 7-d-MALF at Campground is estimated to be $4m^3/s$ ±20% ($3.2m^3/s$ to $4.8m^3/s$). Most of the attempts at naturalising MALF at Campground agree with this estimate.

181. The NPS – FM 2020 – Objective 2.1 outlines the objective of the National Policy Statement to ensure that natural and physical resources are managed in a way that prioritises:
    (a) First, the health and well-being of waterbodies and freshwater ecosystems
    (b) Second, the health needs of people (such as drinking water)
    (c) Third, the ability of people and communities to provide for their soil, economic, and cultural well-being, now and in the future.

182. To fulfil Objective 2.1 of the NPS-FM the needs of the Manuherekia River need to be considered first. Applying this objective to the risk factor to instream values then the risk should be "Low Risk (LR) or Very Low Risk (VLR)". (Refer to risk tables: 5,6,7,8,9,10).

183. The Blackstone reach is augmented from released flows from Falls Dam. The increase of flows above natural flows can reduce habitat suitability for indigenous fish species. However, whether these fish species have ever occupied this reach or still do is uncertain.

184. At the time of writing, the seven-scenario flow data for Blackstone modelled reach wasn’t available. This prevents the comparison of habitat retention across the seven scenarios.

Table 13 Risk result table to habitat for instream values Manuherekia River at Ophir

Taxa	% habitat at 0.9m^3/s	% habitat at 1.2 m^3/s	% habitat at 1.5m^3/s	% habitat at 1.7 m^3/s	% habitat at 2.0 m^3/s	% habitat at 2.5m^3/s	% habitat at 3.0m^3/s
Phormidium	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Didymo	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Long filamentous algae	**HR**	**HR**	**MR**	**MR**	**MR**	**MR**	**VLR**
Short filamentous algae	**LR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Diatoms	**VHR**	**VHR**	**VHR**	**VHR**	**HR**	**VLR**	**VLR**
Lamprey	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Upland bully	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Central Otago roundhead galaxias	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Longfin eel <300mm	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Longfin eel >300mm	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Trout fry	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Trout juvenile	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Trout adult	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Aoteapsyche (Caddis fly)	**HR/MR**	**HR/MR**	**HR/MR**	**MR**	**MR**	**LR/MR**	**LR**
Deleatidium (mayfly)	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Hydrobiosidae (caddisfly)	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**
Pycnacentrodes (caddisfly)	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**	**VLR**

185. For the Manuherekia - Ophir reach the risk assessment for macroinvertebrate indicated that a flow of 2.0 m3/s provides a low risk for all but one of the modelled invertebrates, being caddisfly Aoteapsyche, which was considered to be at moderate risk (despite being one of the most abundant at this site under current conditions).

186. For the Manuherekia - Ophir reach the risk assessment for fish species and life history stages was very low risk for all fish species and life history stages at all flow scenarios.

187. Manuherekia – Ophir modelled reach the risk assessment for diatoms ranged from low risk to very high risk across the scenario range (Table 12). Flows higher than 2.0 m^3/s increase habitat availability. However, if the risk assessment revised by Olsen (memo 2023) taking into account the observed

periphyton community composition at this site, this risk ranged from low/moderate at flows of less than 2m3/s to low or very low at flows greater than 2m3/s.

188. To maintain fish values in the Manuherekia – Galloway reach for fish species everything was low or very low risk when the minimum flow was 2.0 m3/s or higher at Campground. (Table 5).

Table 14 Risk result table to habitat for instream values Manuherekia River at Campground – Galloway.

	Risk to habitat at 0.9m^3/s	**Risk to habitat at 1.2 m^3/s**	**Risk to habitat at 1.5m^3/s**	**Risk to habitat at 1.7 m^3/s**	**Risk to habitat at 2.0 m^3/s**	**Risk to habitat at 2.5m^3/s**	**Risk to habitat at 3.0m^3/s**
Phormidium	VLR	VLR	VLR	VLR	VLR	VLR	VLR
Didymo	VLR	VLR	VLR	VLR	VLR	VLR	LR
Long filamentous algae	HR	HR	MR	MR	MR	LR	LR
Short filamentous algae	VLR	VLR	VLR	VLR	VLR	VLR	VLR
Diatoms	VHR*	VHR*	VHR*	VHR*	VHR*	VHR*	LR
Lamprey	VLR	VLR	VLR	VLR	VLR	VLR	VLR
Upland bully	VLR	VLR	VLR	VLR	VLR	VLR	VLR
Central Otago roundhead galaxias	VLR	VLR	VLR	VLR	VLR	VLR	VLR
Longfin eel <300mm	MR	MR	MR	LR	LR	VLR	VLR
Longfin eel >300mm	VLR	VLR	VLR	VLR	VLR	VLR	VLR
Trout fry	VLR	VLR	VLR	VLR	VLR	VLR	VLR
Trout juvenile	VLR	VLR	VLR	VLR	VLR	VLR	VLR
Trout adult	HR	HR	MR	MR	LR	VLR	VLR
Aoteapsyche (Caddis fly)	VHR	VHR	VHR	VHR	HR/MR	MR	LR/MR
Deleatidium (mayfly)	LR/MR	LR/MR	LR	VLR	VLR	VLR	VLR
Hydrobiosidae (caddisfly)	MR	LR/MR	LR/MR	LR/MR	VLR	VLR	VLR
Pycnacentrodes (caddisfly)	LR/MR	LR	VLR	VLR	VLR	VLR	VLR
Invertebrate rate/flow	VHR	HR	HR	HR	LR	LR	VLR

* Instream habitat modelling indicates the level of risk in the Campground – Galloway reach, however actual monitoring results might be inconsistent with these results.

189. Table 13 indicates that when flows are >1.7m^3/s then the risk to instream values are either low or very low risk other than the caddis fly Aoteapsyche . (Aoteapsyche construct filter feeding nets which are attached to the streambed to trap drifting particulate food items, including algae and other

invertebrates.). Long-term monitoring shows that Aoteapsyche are often among the most abundant taxa at the Galloway site under the current flow management regime.

190. When considering the hydrological outputs, the likelihood of observing natural flows of 1.7m^3/s in the Manuherekia River was considered to be never, while flows of 2.0m^3/s are only likely to be observed an average of once every 25 years.

191. Instream habitat modelling indicates that there more diatom habitat is available at flows of 2.5m^3/s and above. However, real-world observations at the Galloway site between 2019 and 2023 show that the periphyton community is typically dominated by light brown thin films or medium mats, dominated by diatoms under the current flow regime.

192. The additional science and peer reviews have confirmed that the Manuherekia catchment hydrology model is fit for purpose. The results of this work have highlighted that there is a significant margin of error within the hydrology, however, due to the complexity of the catchment this is the best we consider we can achieve, and therefore represents the best available information.

193. To answer some of the complexities of the catchment, Otago Regional Council has designed a flow recorder network that in time will deliver a flow dataset that will allow flow naturalisation with less uncertainty than current modelling. In addition to this better water metering is required, particularly in regard to separating ‘natural-run-of the-river’ takes from stored water takes.

194. Instream habitat retention is comparing different flow scenarios against available habitat at 7d-MALF. Although there is a margin of error within 7d-MALF estimates for the Manuherekia, this figure has really remained the same over multiple studies over the past 20 years. The analysis of the instream habitat model used 4.0m^3/s at Campground to calculate percentage of habitat retention against the seven flow scenarios.

195. This modelling is the best available information and the results from this suggest that a flow at Campground of 2.0m^3/s at Campground would provide a low risk to invertebrates, fish, and periphyton.

196. If we adopt the principle set out in paragraph 145 in relation to interpretation of Objective 2.1 (a) of the NPS-FM, which states the first priority is the health and well-being of water bodies and freshwater ecosystems, then any minimum flow regime should fall within the estimated natural low flow range. On that basis, then flow should be at or above 2.5m^3/s.