Court File Reference: ENV-2018-CHC-38

BEFORE THE ENVIRONMENT COURT

I MUA I TE KOOTI TAIAO O AOTEAROA

UNDER	The Resource Management Act 1991 (RMA)
IN THE MATTER	Appeals under clause 14(1) of the First Schedule of the Act in relation to the Proposed Southland Water and Land Plan
BETWEEN	**MERIDIAN ENERGY LIMITED** **Appellants**
AND	**SOUTHLAND REGIONAL COUNCIL** **Respondent**

STATEMENT OF EVIDENCE OF Dr JOHN (JACK) McCONCHIE

FOR

MERIDIAN ENERGY LIMITED

29 July 2022

Topic B6 – Infrastructure

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(ENV-2018-CHC-47)

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(ENV-2018-CHC-49)

ROYAL FOREST AND BIRD PROTECTION SOCIETY OF NZ INC
(ENV-2018-CHC-50)

Appellants

AND **SOUTHLAND REGIONAL COUNCIL**

Respondent

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INTRODUCTION

1. My full name is Dr John (Jack) Allen McConchie. I am employed as the Technical Director (Hydrology & Geomorphology) by SLR Consulting (NZ). I have been engaged by Meridian Energy Ltd. (**Meridian**) to provide expert technical evidence relating to the hydrology of the Manapōuri Power Scheme (MPS) and its effects on the flow regime and turbidity of the Lower Waiau River.

QUALIFICATIONS AND EXPERIENCE

2. I have the following qualifications and relevant experience. I hold a Bachelor of Science degree with First Class Honours (from Victoria University of Wellington) and a PhD (also from Victoria University of Wellington).

3. I am a member of several professional and relevant associations including the:

   (a) New Zealand Hydrological Society;

   (b) American Geophysical Union;

   (c) New Zealand Geographical Society;

(d) Australia-New Zealand Geomorphology Group; and

(e) Environment Institute of Australia and New Zealand.

4. I am a certified RMA hearings' commissioner (2011-present). I have been an Independent Professional Adviser to Waka Kotahi NZ Transport Agency since 2011 and an Independent Natural Hazards' Expert for MBIE (Determinations).

5. I was the New Zealand Geographical Society representative on the Joint New Zealand Earth Science Societies' Working Group on Geopreservation. This Working Group produced the first geopreservation inventory; published as the New Zealand Landform Inventory.

6. Prior to the start of 2008, I was an Associate Professor at the School of Earth Sciences, Victoria University of Wellington. I taught undergraduate courses in hydrology and geomorphology, and a postgraduate course in hydrology, hydrogeology, and water resources.

7. For more than 40 years my research and professional experience has focused on various aspects of hydrology and geomorphology, including: slope and surface water hydrology (including water quality), hydrometric analysis, landscape evolution, and natural hazards. Within these fields I have edited one book. I have written, or co-authored, 10 book chapters and over 50 internationally refereed scientific publications.

8. I have extensive experience and knowledge of the hydrology of the MPS and its effect on the flow regime of the Lower Waiau River. For 13 years I led the team at WSP (Opus Consultants Ltd.) that maintained the Power Archive for Meridian. The Power Archive contains all the quality assured hydrometric and generation data relating to the MPS. These datasets have been collected, audited, processed, and stored in a manner consistent with industry best practice. This team also maintained the hydrometric data archives for Mercury Ltd. and Contact Energy Ltd.

9. I have considerable local experience having been heavily involved with the MPS and the hydrology of the Waiau catchment as described above. I also produced the last two independent audits of Meridian's compliance with all the various hydrology-related resource consent conditions for the MPS. I have traversed the Waiau catchment from Te Anau to Te Waewae Bay and visited all the various hydrometric sites discussed in this BoE.

10. I led a major investigation that monitored the causes of changes in turbidity of four major rivers on the Kāpiti and Horowhenua coast. The

study provided robust advice regarding resource consent conditions to mitigate the effects of the construction of the Peka Peka to Ōtaki Expressway.

11. Finally, I led a comprehensive investigation of the effects of flushing flows from Lake Moawhango each summer. These flows scour sediment and organic debris that is then transported and deposited downstream. These investigations led to the development of a 'smarter flushing flow regime' which achieves greater environmental outcomes while using the water resource more efficiently and effectively.

CODE OF CONDUCT

12. I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2014. I have complied with that note when preparing my written statement of evidence and will do so when I give oral evidence before the Environment Court.

13. The data, information, facts, and assumptions I have considered in forming my opinions are set out in my evidence to follow. The reasons for the opinions expressed are also set out in my evidence.

14. Unless I state otherwise, this evidence is within my knowledge and sphere of expertise. I have not omitted to consider any material facts known to me that might alter or detract from the opinions that I express.

PURPOSE AND SCOPE OF EVIDENCE

15. I have been asked by Meridian to provide evidence explaining how the Manapōuri Power Scheme (MPS) affects the Lower Waiau River. There are two principal hydrological factors that can be considered to understand how the MPS impacts the Lower Waiau River:
    (a) Changes to the flow regime, and
    (b) Changes to the suspended sediment, determined using its surrogate turbidity.

    These two aspects are therefore the focus of this Brief of Evidence (BoE).

16. The MPS has developed as a series of step changes over time so there have been five distinct development periods. An attempt is therefore made to the level possible given the constraints of the available data (variable lengths of the different phases and natural climatic variability), to

place changes to the flow regime at key locations in the Lower Waiau River during these development periods in the context of natural variability.

17. This BoE therefore provides a factual assessment of the effect of the MPS on the Waiau catchment, and particularly the Lower Waiau River. It identifies how these effects have changed over time and other potential drivers of change to the hydrology and turbidity of the Lower Waiau River.

18. In preparing this BoE, I have read the evidence prepared on behalf of Meridian by Dr Jennifer Purdie on the potential effects and implications of climate change and Dr Kristy Hogsden on freshwater ecology. I have also considered the evidence prepared by Mr Andrew Feierabend, both for this hearing and also an earlier statement dated 15 February 2019 which set out some basic hydrological information relating to the operation of the MPS. I have also read the evidence of Mr Hunt and Ms Whyte.

EXECUTIVE SUMMARY

19. The hydrology of the Waiau catchment is ultimately driven by precipitation, which is greatest in the mountains to the west of both Lakes Te Anau and Manapōuri. This rainfall pattern is reflected in corresponding runoff, with yields from the rivers and streams draining to the lakes being significantly higher than those lower down the Waiau catchment.

20. There is significant spatial and temporal variability in rainfall, however, some of which is buffered by the storage provided within Lakes Te Anau and Manapōuri.

21. Despite there being some large tributaries to the Lower Waiau River, only the outflows from the lakes, and flows in the main stem of the Waiau, Mararoa, Monowai, and Spey Rivers are monitored.

22. The MPS has modified flows in the Waiau catchment. Structures at the outlets from Lakes Te Anau and Manapōuri (downstream of the Waiau-Mararoa confluence) provide storage control and additional water respectively. Flow from the Mararoa River can be diverted into Lake Manapōuri under certain conditions. This means that the MPS has increased discharges both into and out of Lake Manapōuri. Discharge down the Lower Waiau River has been reduced both by the diversion of flow from the Mararoa River into Lake Manapōuri and the discharge of

water from Lake Manapōuri and the Waiau catchment to Deep Cove in Doubtful Sound.

23. While the MPS has no control over the inflows to Lake Te Anau, they are required to manage the water level of the lake, and therefore outflow, to comply with the Operating Guidelines for Levels of Lake Manapōuri and Te Anau (the Guidelines). Consequently, there are no significant differences between the inflows, outflows, and water levels of Lake Te Anau over the five development periods. Any extremes over each of the development periods are the result of natural climatic variability.

24. Prior to construction of the Mararoa weir in 1970, and the Manapōuri Lake Control (MLC) in 1976, inflow to Lake Manapōuri was solely from its own 'local' catchment and outflow from Lake Te Anau via the Upper Waiau River.

25. The diversion of the Mararoa River into Lake Manapōuri increased the lake's catchment area by ~25%, although the increase in inflow was less than 10% because of the lower rainfall (and therefore runoff) in the Mararoa catchment.

26. In 1996, consent conditions were imposed on the operational management of the MLC, including a requirement to provide minimum flows to the Lower Waiau River. Management of flows to the Lower Waiau River has been consistent for the past ~25-years and significant natural variability remains, particularly during higher flow events.

27. Prior to development of the MPS, the median outflow from Lake Manapōuri was 373m^3/s and all outflow from the lake was to the Lower Waiau River. However, since 1977, there has been a significant change to the total outflow regime. This is mainly attributed to the construction of the power station (with a machine discharge of up to 550m^3/s to Deep Cove), the Mararoa weir (1970), and then MLC (1976). The median discharge since 1996 has been about 17m^3/s.

28. Prior to the development of the MPS, the Mararoa River flowed freely into the Lower Waiau River. Now flow is diverted to help control the level of Lake Manapōuri for generation purposes. Flood flows and 'dirty water' continue past MLC into the Lower Waiau River as required by consent.

29. The median annual flow at the Sunnyside flow recorder on the Waiau River, 1km downstream of the Monowai Road bridge, is ~46m^3/s

(compared to ~17m^3/s below the MLC). That is, a significant proportion of the flow in the Waiau River at Sunnyside comes from tributaries downstream of the MLC.

30. The introduction of minimum flows in 1996 resulted in the median flows at Sunnyside increasing from ~33m^3/s to 46m^3/s. The lower quartile flow increased from 21m^3/s to 36m^3/s.

31. Floods from Lake Manapōuri and the Mararoa River are still discharged down the Lower Waiau River, although the annual flood maxima at Sunnyside are affected by the potential discharge of up to 550m^3/s through the Manapōuri Power Station to Deep Cove.

32. Flow was consistently lower during the 2003-2012 period compared to all other periods. This coincides with a period of lower rainfall and runoff in the catchment and therefore reduced spill past MLC.

33. Prior to development, flows were generally highest in April/May and November and lowest during summer and July. Since the MPS, peak flows are not as evident during April/May, and lower flows persist later in summer and winter.

34. The median flow in the Waiau River at Tuatapere is now about 74m^3/s (an increase from 46m^3/s at Sunnyside). Prior to the MPS it was ~328m^3/s. The lower quartile has decreased since the MPS from ~70m^3/s to ~51m^3/s and the upper quartile from 534m^3/s to145m^3/s.

35. The introduction of minimum flow requirements in 1996 resulted in minimum flows increasing from 8.6m^3/s to 28.5m^3/s.

36. Floods in the Lower Waiau River at Tuatapere are affected by the MPS in the same manner as upstream at Sunnyside. The number of large tributaries downstream of Sunnyside, however, tend to moderate and attenuate the flood hydrograph.

37. Prior to 1977, flow peaked in spring with lowest flows recorded in February and July. A similar pattern was still evident up until 2012. Since then, flows have peaked in May and November.

38. It is generally agreed that the Mararoa River is naturally high in suspended sediment, with additional sediment from human-induced changes in land use. The Mararoa River therefore has the potential to adversely affect the

water quality of the Lower Waiau River. This issue is exacerbated if ‘clean’ water is not discharged from Lake Manapōuri.

39. Condition 5 of the MLC operational consent requires that whenever the Mararoa River has a turbidity greater than 30 NTU a flow *“no less than the flow in the Mararoa River”* will be discharged through the structure. This is to prevent the flow of turbid water up the Waiau Arm to contaminate Lake Manapōuri.

40. The way this is operationalised by Meridian is that whenever turbidity in the Mararoa River exceeds 10 NTU, therefore a significant ‘margin of safety’, all the flow in the Mararoa River is spilled past MLC, together with an additional 5m^3/s from Lake Manapōuri. The discharge of ‘clean lake water’ prevents turbid water flowing up the Waiau Arm and dilutes the suspended sediment concentration i.e., turbidity, of the Mararoa water entering the Lower Waiau River.

41. The MPS generally discharges significantly more water past the MLC than the minimum specified. This is particularly the case during large inflow events when, although there is a degree of storage flexibility, Meridian must still comply with the Operating Guidelines and the spill and flood rules. When combined with the limit on the amount of water that can be used for generation, the balance has to go past the MLC and be discharged into the Lower Waiau River. Discharge from Lake Manapōuri and past the MLC therefore has a significant effect not only on diluting any suspended sediment (and turbidity) but in defining the shape and characteristics of the flow regime of the Lower Waiau River.

42. While the MPS can affect the flow regime, and the spill of lake water past the MLC ‘dilutes’ any suspended sediment to an extent, they have no ability to influence the actual supply of sediment that is entrained by the Mararoa River. The supply of sediment is a function of the underlying geology and resulting soils and land use activities within the catchment.

43. The Waiau Arm of Lake Manapōuri, upstream of the MLC, can also experience significant pulses of suspended sediment and elevated turbidity. While not as high or as frequent as in the Mararoa River, these local turbidity events require ‘flushing’ to prevent this ‘poor quality water’ from flowing into Lake Manapōuri. Again, the MPS does not cause these ‘turbidity events’, but mitigates any potential adverse effects on Lake

Manapōuri by 'flushing' the affected water, with 'clean lake water', into the Waiau River.

44. Turbidity varies down the Lower Waiau River in response to both increases in flow and the input of suspended sediment from various tributaries and land use activities. While the same general patterns in turbidity are present in both the Mararoa River and the Waiau River at Tuatapere, there are also distinct differences.

45. During the flood peaks, the turbidity in the Mararoa is higher but this is then diluted by spill from Lake Manapōuri over the MLC. Consequently, at times of high flow the turbidity recorded at Tuatapere is significantly lower than upstream. However, during periods of moderate flow the turbidity at Tuatapere is higher than upstream. Higher turbidity water is therefore entering the Waiau River downstream of MLC.

46. This increase in turbidity downstream of MLC is actually significantly greater than it might initially appear. This is because the turbidity of the tributaries entering the Waiau River has to also raise that of the cleaner water immediately below the MLC.

47. For approximately 5% of the time, turbidity in the Mararoa River is greater than that in the Waiau River at Tuatapere. However, for about 45% of the time, most likely during average or moderate flows, the turbidity at Tuatapere is greater than that in the Mararoa. For the remaining 50% of the time, during periods of low flow and therefore low turbidity, there is little difference between the sites.

48. Despite the relatively high degree of scatter in the data, the turbidity of the Waiau River at Tuatapere is about twice that recorded upstream at Sunnyside. Consequently, there must be a significant input of 'low quality' water between Sunnyside and Tuatapere that increases the turbidity and therefore reduces water quality to this degree.

49. Since the MLC is the lowest point in the catchment where the MPS can exercise any control or influence on water quality, any increases in turbidity downstream of MLC, including at Tuatapere, cannot be attributed to the way the MPS is operated.

BACKGROUND

Catchment Description

50. The hydrology of the Waiau catchment is ultimately driven by precipitation, which is greatest in the mountains to the west of both Lakes Te Anau and Manapōuri. This rainfall pattern is reflected in corresponding runoff, with yields from the rivers and streams draining to the lakes being significantly higher than in those tributaries lower down the Waiau catchment.

51. There are three major lakes in the Waiau catchment; Te Anau, Manapōuri, and Monowai (***Figure 1***). Lake Te Anau is the largest lake in the South Island, the second largest lake in New Zealand. Statistics for each of the three lakes are listed in ***Table 1***.

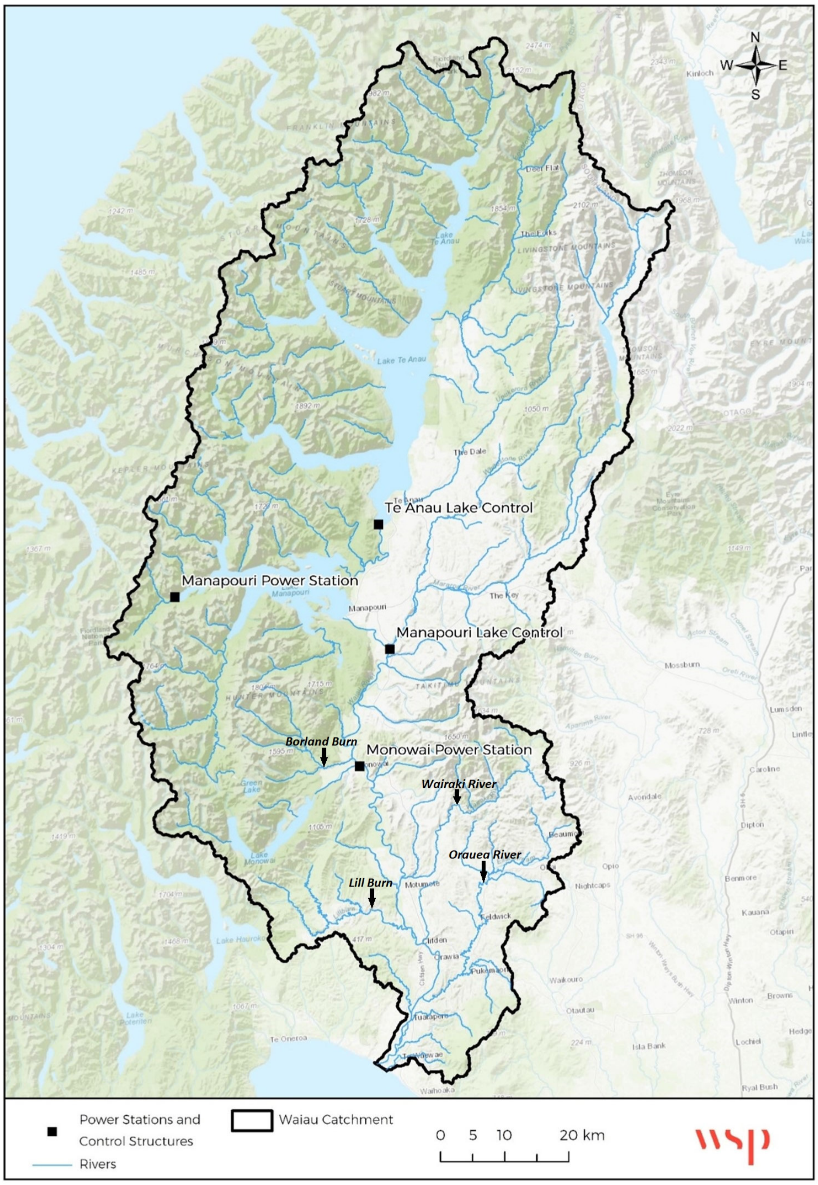

Figure 1 – Waiau River catchment with some of the larger tributaries labelled

Table 1 – Major lakes of the Waiau catchment

Lake	Catchment area (km^2)	Lake area (km^2)	Maximum depth (m)	Long axis (km)
Te Anau	3095	352	417	59.6
Manapōuri	4483*	142	444	28.3
Monowai	245	31	161	20.6

* Includes the catchment area of Te Anau which drains into Manapōuri.

52. At the most downstream flow gauging station (Tuatapere), the Waiau River has a natural catchment area of 8134km^2. Tuatapere is close to the sea (i.e., 11.3km) and the additional catchment area downstream is negligible from a hydrological perspective.

53. Despite there being some large tributaries to the Waiau River e.g., the Eglinton (575km^2), Grebe (365km^2), Lillburn (250km^2), Orauea (481km^2) and Wairaki Rivers (294km^2) only the outflows from the lakes, and flows in the main stem of the Waiau, Mararoa, Monowai, and Spey Rivers are monitored. The main Waiau River system is reasonably well monitored, and those data are the principal focus of this BoE.

54. There is a significant contrast in the catchment between the very wet upper western portion and the comparatively dry eastern and lower portion. A small sub-catchment at Lake Te Anau has an average annual rainfall of 7000 to 8000mm. A small sub-catchment near Tuatapere has an average rainfall of only 1000mm.

Hydrometric Data

55. This BoE uses hydrometric data obtained from the following agencies and/or hydrometric databases:
    (a) The Power Archive maintained by WSP on behalf of Meridian;
    (b) National Institute of Water and Atmospheric Research (NIWA); and
    (c) Environment Southland (ES).

56. Meridian's Power Archive holds many of the datasets relating to the MPS (e.g., lake levels, inflows, outflows, and machine discharges for Te Anau and Manapōuri, and flows and turbidity for the Mararoa and Waiau Rivers). These datasets are updated monthly using information collected by NIWA and Meridian. The data are peer-reviewed, and quality checked

before being added to the Power Archive. This provides long-term, quality assured datasets for detailed analysis

57. The various agencies follow New Zealand industry best practice guidelines for obtaining and maintaining hydrological data. Therefore, the data are assumed to be accurate and are considered the most appropriate to underpin the analyses provided in this BoE.

58. Although there is not a strong seasonal signature to the flow regime of the Waiau catchment, and limited snowfall affecting flow, a September water year has been adopted for the analyses (i.e., October-September). This avoids potentially splitting extended low flow periods over two calendar years.

MANAPŌURI POWER SCHEME

59. Prior to the MPS, flow from Lake Te Anau passed down the Upper Waiau River into Lake Manapōuri. Outflow from Lake Manapōuri was via the Lower Waiau River which flowed approximately 9km to the southeast before its confluence with the Mararoa River. The Lower Waiau River then flowed generally south, receiving inflow from various tributaries before discharging into Te Waewae Bay.

60. Gated control structures at the outlets from Lake Te Anau and Lake Manapōuri (downstream of the Mararoa River confluence) provide storage control and additional water respectively. Flow from the Mararoa River can be diverted into Lake Manapōuri under certain conditions. This means that the MPS has increased discharges both into and out of Lake Manapōuri (***Figure 2***).

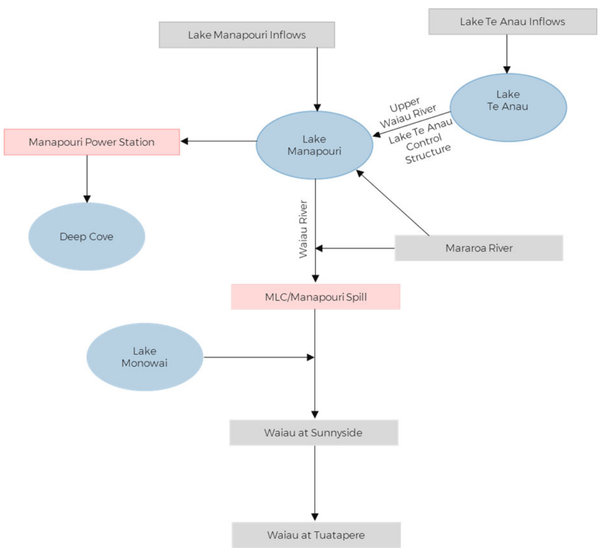

Figure 2 – Waiau catchment post-Manapōuri Power Scheme

61. Discharge down the Lower Waiau River has been reduced both by the diversion of flow from the Mararoa River into Lake Manapōuri and the discharge of water from Lake Manapōuri to Deep Cove (***Figure 2***).

Development Phases

62. The MPS has modified both the flows and flow paths upstream of the MLC which has affected the flow regime in the Lower Waiau River. However, the hydrological effect of the MPS has not been a single ‘step change’ but a series of ‘steps’, that correspond to the different stages in the development of the Scheme.

63. Consequently, the hydrology of the Waiau catchment is considered with respect to five development periods of the MPS. The five periods are:
   (a) Pre-development (up to 1 September 1977);
   (b) Development pre-minimum flow to the Lower Waiau River (1 September 1977 to 18 December 1996);
   (c) Development post-minimum flow to the Lower Waiau River (19 December 1996 to 22 May 2003);
   (d) Second tailrace tunnel to allow the consented discharge of 510m³/s (23 May 2003 to 22 October 2012); and
   (e) Post Manapōuri tailrace amended discharge of up to 550m³/s (23 October 2012 to date).

PRECIPITATION

64. Precipitation, predominantly in the form of rainfall, is the principal driver of the hydrology of the Waiau catchment. Rainfall exhibits strong spatial and temporal variability. While some of the effect of this natural variability on runoff is buffered by Lakes Te Anau and Manapōuri, it needs to be considered in assessing potential effects of the MPS. This is discussed in the evidence of Dr Jennifer Purdie.

Spatial Variability

65. Rainfall increases towards the west and north of the catchment, with the annual rainfall at Milford Sound and Manapōuri West Arm being much higher than at the other sites (***Figure 3***).

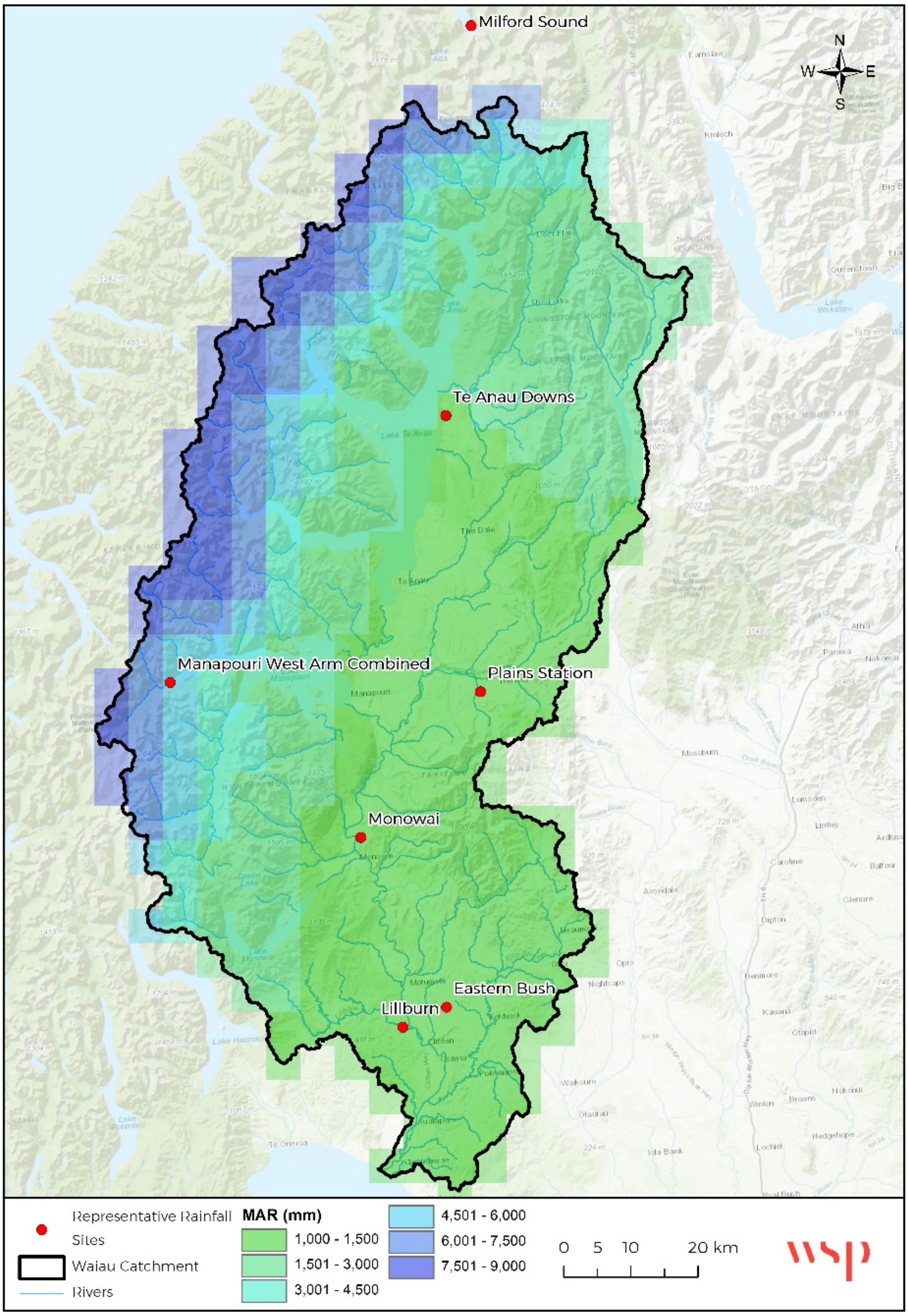

Figure 3 –Spatial distribution of mean annual rainfall in the Waiau catchment

66. The west of the Waiau catchment experiences the highest rainfall (and therefore runoff) because of its elevation and exposure to the dominant westerly, rain-bearing, weather systems. The orographic effect of these mountainous areas, however, creates a rain-shadow in the east of the catchment which experiences significantly less rainfall and runoff.

67. This spatial variability in rainfall therefore has a significant effect on the flow regimes of the rivers and streams in the Waiau catchment, and particularly the Lower Waiau River.

Temporal Variability

68. Summary statistics of the annual rainfall at seven gauges that have long term records during each development period are shown in ***Figure 4***. Rainfall tended to be higher on average during the 1977–1996 period, reducing to lower than average during the 2003–2012 development period, although there is some variability between sites.

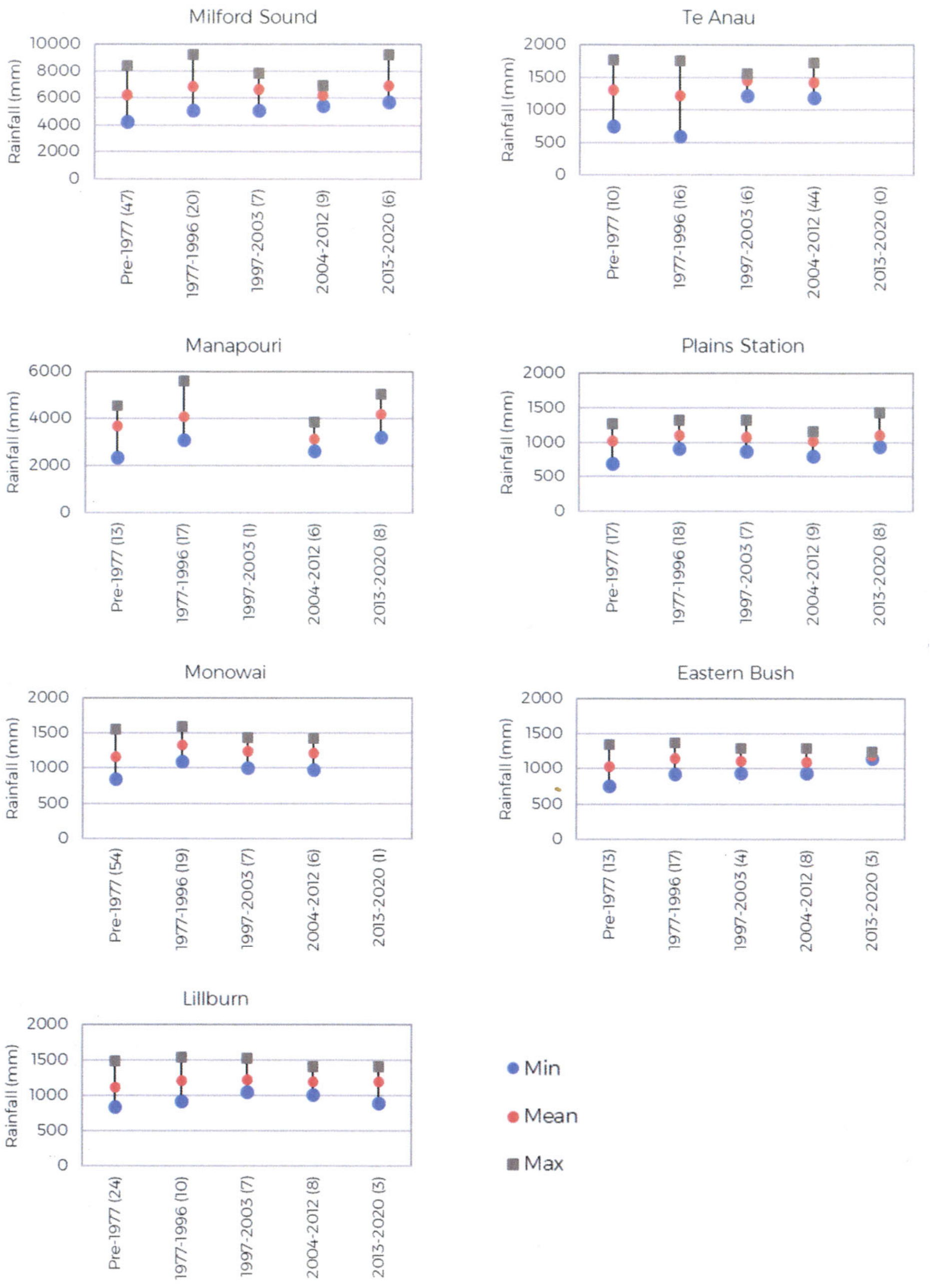

Figure 4 – Summary statistics of annual rainfall during each development period, including the number of years of record during that period

69. This temporal variability in rainfall also has a significant effect on the flow regimes of the rivers and streams in the Waiau catchment, and particularly the Lower Waiau River.

Recent Waiau Drought

70. As described above, despite the MPS affecting the water balance and flow regime of the Waiau catchment, the hydrology is still affected strongly by natural climatic variability.

71. For example, the Waiau catchment experienced a significant and prolonged drought and period of low flows from December 2021 until April 2022. This period of low flows was an entirely natural event.

72. This extended drought was actually two droughts interrupted by a moderate flow event on 2 February 2022. The first drought was from 30 December 2021 until 1 February 2022 (33 days) and the second from 6 February 2022 until 11 April 2022 (68 days).

73. Notable statistics relating to this extended period of low flows in the Waiau catchment include:

    (a) The rolling average three-month total Waiau inflow (Te Anau and Manapōuri) was the lowest on record.

    (b) Rolling average 1-month, 2-month, 3-month, 4-month, and 5-month local inflows to Lake Manapōuri were all the lowest on record.

    (c) Rolling average 1-month, 2-month and 3-month generations were the lowest since the second Manapōuri Tailrace (2012).

    (d) The Upper Waiau River flow reached a minimum of $59m^3/s$ on 5 April 2022, the lowest flow since 1991.

    (e) The Spey River at West Arm of Lake Manapōuri indicated zero flow from 31-Mar-2022 to 5-Apr-2022.

74. Consequently, natural climatic variability remains a principal driver of variability in the flow regime of the Waiau catchment, particularly the extremes of the flow regime.

THE LAKES

75. The MPS has no effect on the inflow to Lake Te Anau or local inflow to Lake Manapōuri, although inflow to Manapōuri is augmented by flow diverted from the Mararoa catchment which is permitted by resource consent.

76. Although the Te Anau Lake Control (TLC) and Manapōuri Lake Control (MLC) were constructed in 1974 and 1976 respectively, the levels of these lakes must be managed within the Lake Operating Guidelines. These Guidelines are *"aimed to protect the existing patterns, ecological stability, and recreational values of their respective shorelines and to optimise the energy output of the Manapōuri Power Station."*[1]

77. Consequently, the levels of, inflows to, and outflows (***Table 2***) from Lake Te Anau over the various development periods have remained the same, apart from the effects of natural climatic variability.

Table 2 – Summary statistics for outflows from Lake Te Anau over the different development periods of the MPS (m³/s)

Period	Min	Max	Mean	Std Dev	L.Q.	Median	U.Q.	7-day LF
Pre 1977	53	916	266	107	189	247	325	58
1977 – 1996	21	1004	294	141	193	282	351	53
1996 – 2003	84	852	287	130	192	272	336	96
2003 – 2012	100	964	273	107	206	255	315	102
2012 – 2022	65	975	300	132	217	280	354	67

78. As mentioned, despite the construction of the MLC, Meridian must manage the level of Lake Manapōuri within the Guidelines. Consequently, there are no differences in the level of Lake Manapōuri over the different development periods.

79. Prior to construction of the Mararoa weir in 1970, and the MLC in 1976, inflow to Lake Manapōuri was solely from its own catchment and outflow from Lake Te Anau via the Upper Waiau River. With diversion of the Mararoa River into Lake Manapōuri following construction of the MLC, the catchment area was increased by 1220km².

80. Although diversion of the Mararoa River increased the Lake Manapōuri catchment area by ~25%, the increase in inflow was less than 10% because of the lower rainfall experienced in the Mararoa catchment. Also,

[1] Section 4A Manapōuri – Te Anau Development Act.

flood waters from the Mararoa River are not diverted into Lake Manapōuri following guideline rules introduced after 1996.

81. There was a significant change to the inflow regime of Lake Manapōuri following commissioning of the MPS, particularly the diversion of flows from the Mararoa (***Table 3***).

Table 3 – Summary statistics of inflows to Lake Manapōuri for each development period (m^3/s)

Period	Min	Max	Mean	Std Dev	L.Q.	Median	U.Q.	7-day Low flow
Pre-1977	5	3128	399	208	262	352	482	78
1977-1996	19.6	4299	459	257	308	404	504	89
1996-2003	19.2	2590	450	252	291	394	542	124
2003-2012	20.3	2678	423	212	293	379	499	134
2012-2020	11.7	2561	449	255	294	400	524	84

82. Prior to the MPS, the median inflow was 352m^3/s, with an interquartile range of 274m^3/s and standard variation 208m^3/s. Since 1977, the median inflow has increased to between 379m^3/s and 404m^3/s for subsequent development periods. This is attributed to the diversion of flows from the Mararoa River into Lake Manapōuri.

83. The large difference between the median and mean flows shows the influence of random large peak inflows.

OUTFLOWS FROM LAKE MANAPŌURI

84. Prior to the MPS, the only outflow from Lake Manapōuri was into the Lower Waiau River. However, now outflow from Lake Manapōuri is through both the Manapōuri Power Station and spill flow past the MLC to the Lower Waiau River. As explained, this 'spill' was originally 'natural', i.e., the natural outlet from Lake Manapōuri was to the Waiau River but this is now controlled by the MLC Gates.

Discharge to the Lower Waiau River

85. Water discharged from Lake Manapōuri to the Lower Waiau River combines with any flow in the Mararoa River that passes the MLC.

86. The MLC consists of four gates and is located just downstream of the confluence of the Mararoa and Waiau Rivers. It is designed to both divert water from the Mararoa River into Lake Manapōuri and to control outflow from the lake. Flow has been regulated by the structure since November

1976. In 1996, consent conditions were imposed on the operational management of the MLC; aimed at improving ecological, cultural, and recreational values of the Lower Waiau River. These conditions require seasonal fluctuations in minimum spill flows through the structure, and the recreational release of water at specific times (***Table 4***).

Table 4 – Consented minimum flows through the MLC

Period start	Period end	Minimum spill (m^3/s)
1 May	30 September	12
1 October	31 October	14
1 April	30 April	14
1 November	March 30	16

87. Flows past the MLC are shown in ***Figure 5***. The impacts of the minimum flow regimes from 1996 can be seen by the noticeable step-change in the minimum flows. Also apparent is the relatively consistent but random pattern of large flow events. This is because of the higher turbidity associated with these events and the need for the entire 'flood' to be passed to the Lower Waiau River.

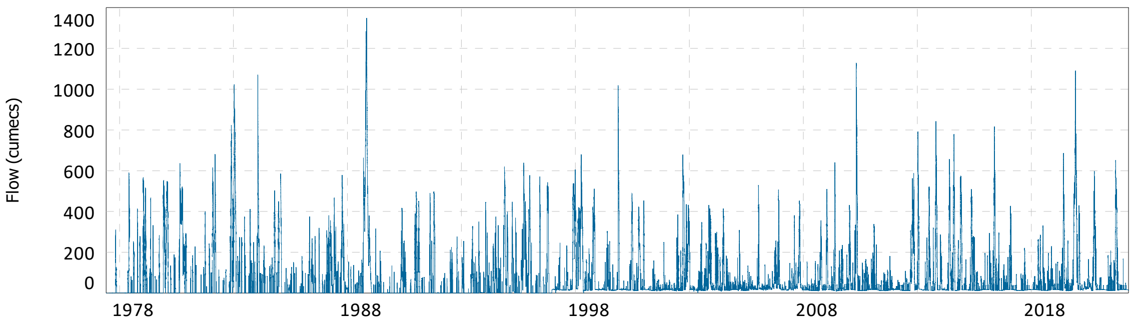

Figure 5 – Instantaneous discharge via MLC into the Lower Waiau River

88. Following commissioning of the MPS, the mean annual flow in the Mararoa River dropped from over 400m^3/s to an average of about 60m^3/s (***Figure 6***). During years with low rainfall in the Mararoa catchment, and few flood events, the mean annual flow has dropped to as low as about 10m^3/s. The characteristics of this flow regime, while intimately related to the MPS are also controlled by the climate and runoff in the catchment.

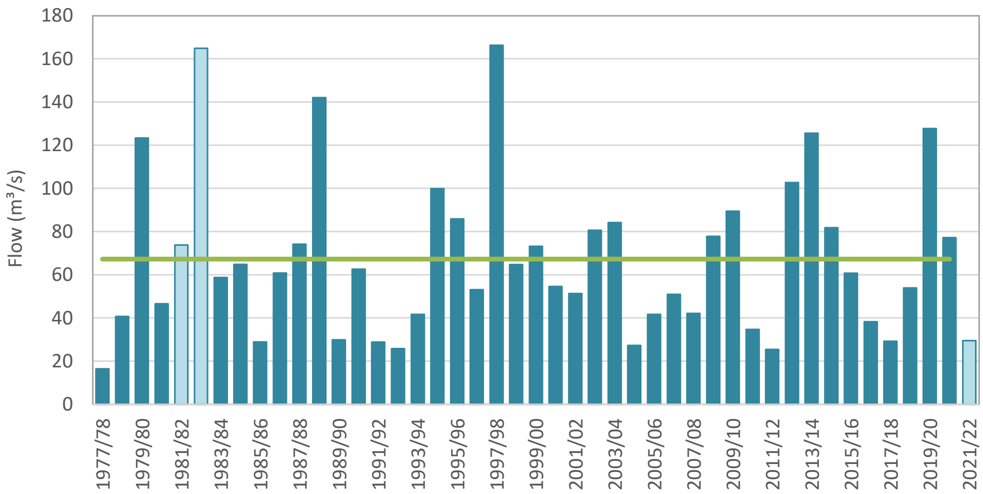

Figure 6 – Mean annual flow passed to the Lower Waiau River. Note: 2021-22 is only a partial year. The other highlighted years have gaps longer than 1 month.

89. Summary statistics for the discharge into the Lower Waiau River over the different development periods are provided in ***Table 5*** & ***Figure 7***.

Table 5 – Summary statistics for instantaneous discharge measured downstream of MCL over each development period (m³/s)

Period	Min	Max	Mean	Std Dev	L.Q.	Median	U.Q.	7-day LF
Pre 1977	77	1338	399	157	291	373	478	98.7
1977 – 1996	0.0	1349	67	144	0.3	0.6	66	0.0
1996 – 2003	0.1	1019	77	131	15	17	61	5.4
2003 – 2012	7.3	1129	54	94	15	17	48	10.3
2012 – 2022	9.7	1091	73	137	15	17	51	11.6

Note: The very low minimum and 7-day low flows relate to a short period of extremely low flows within the period of record. These are caused by authorized works on the gates and fish passage, gate control issues, retrospectively applied revised ratings etc.

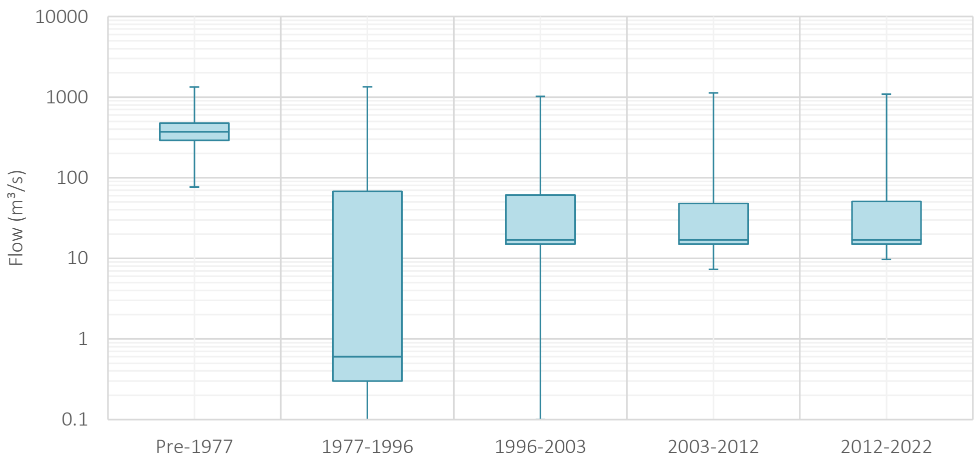

Figure 7 – Box and whisker plot of summary statistics for instantaneous discharge measured downstream of MLC over each development period (m³/s)

90. The diversion of Mararoa River flows into Lake Manapōuri, but more critically discharge through the power station to Deep Cove, have had a significant effect on nearly all metrics relating to the hydrology and flow regime of the Lower Waiau River below the MLC. Discharge to the Lower Waiau River dropped dramatically following the MPS. The only metric not affected is the maximum discharge during each of the development periods.

91. The mean and median flows below MLC decreased from ~400m³/s and 375m³/s respectively to ~70m³/s and 17m³/s. The various quartile and interquartile ranges were similarly affected (***Table 5*** & ***Figure 7***).

92. However, since 1996 and the implementation of the minimum flow regime there has been little change in the various hydrometric indices, except that caused by natural climatic variability (***Table 5*** & ***Figure 7***).

93. The effect of the changes to outflows through the MLC are shown in the flow distribution curves presented in ***Figure 8***. The reduction in flows over almost the entire distribution, at least the upper 55% of flows, with the MPS is obvious. Also, for 42% of the time there was no flow through the structure from 1977 to 1996 (i.e., before the introduction of a minimum flow regime). Also apparent from the distribution curves is the significant drop in high flows. Pre-1977, flows greater than 400m³/s occurred 18% of the time. Over subsequent periods, flows of this magnitude occur only 3-8% of the time. This is largely a result of discharge through the power station to Deep Cove.

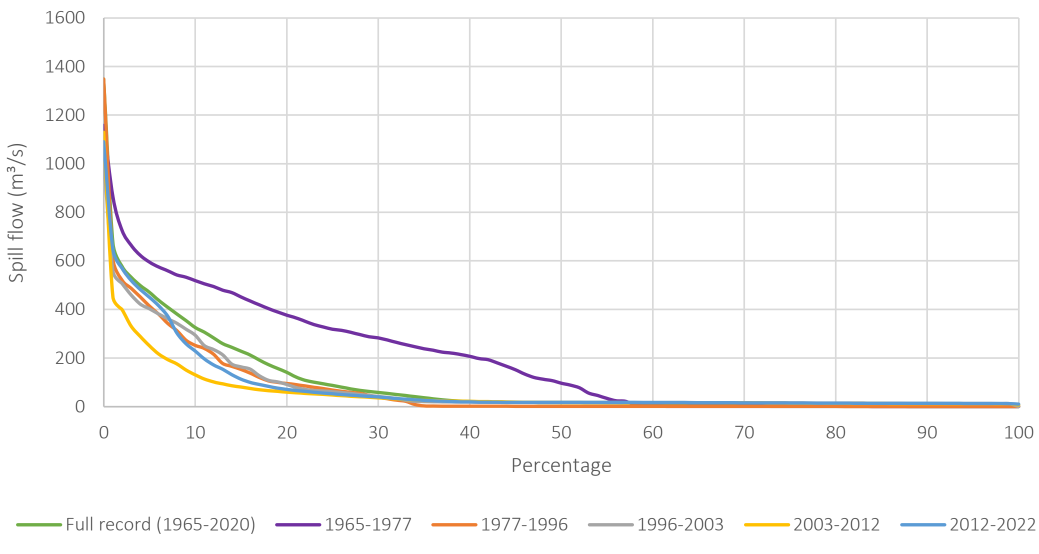

Figure 8 – Spill flows through the MLC over the five development periods and the entire record

94. While a considerable volume of water is now discharged to Deep Cove rather than to the Lower Waiau River, the effects of the MPS are mitigated by various actions. For example, flood flows in the Mararoa River are generally passed directly through the MLC to the Lower Waiau River. During larger inflow events, although Lake Manapōuri provides some storage, the Guidelines require that the level of the lake is managed to mimic what would be its natural behaviour. Consequently, greater, and more prolonged flows, relative to those in the Mararoa River, are passed to the Lower Waiau River. This is despite the fact that up to 550m³/s can be passed through the Manapōuri Power Station to Deep Cove. Spill past the MLC therefore adds significantly to the flow from the Mararoa River (***Figure 9***).

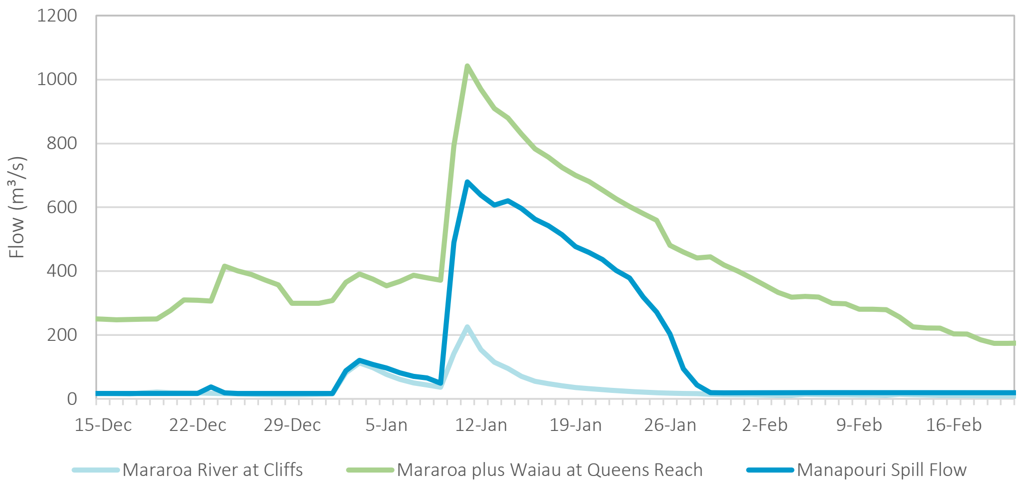

Figure 9 – Comparison of spill flow below MLC to the Mararoa River and the combined flows of the Mararoa River and Upper Waiau at Queens Reach: 15 December 2012–17 February 2013

95. Condition 5 of the MLC operational consent requires that whenever the water in the Mararoa River has a turbidity greater than 30 NTU (as recorded at Mararoa at Cliffs) a flow *"no less than the flow in the Mararoa River"* will be discharged through the MLC.

96. The way this is operationalised by the MPS, is that whenever turbidity in the Mararoa River exceeds 10 NTU (so a significant margin of 'safety'), all the flow in the Mararoa is passed by the MLC, together with an additional 5m³/s of water from Lake Manapōuri. This additional 5m³/s water, because it is low turbidity 'lake water', acts to dilute the suspended sediment and reduce the turbidity of the Mararoa water that is passed to the Lower Waiau River. This action affects both the volume of water that is diverted from the Mararoa River into Lake Manapōuri and the turbidity of water passed to the Lower Waiau River.

97. Since turbidity is primarily caused by high flows, the relationship between flood flows observed in the Mararoa River and flows through the MLC is shown in ***Figure 10***.

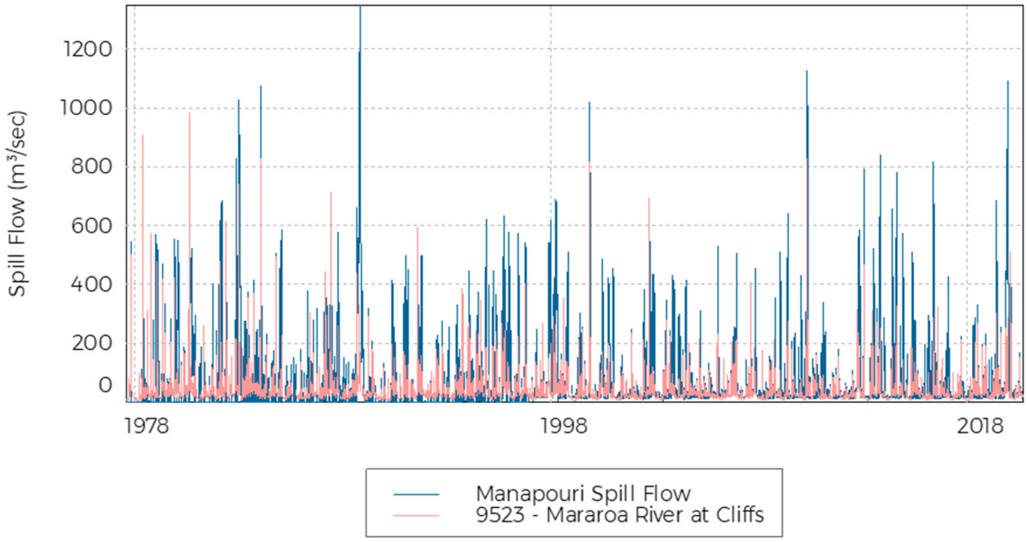

Figure 10 – Flows in Waiau River below the MLC as a result of floods in the Mararoa River

98. Seasonal variation in baseflow, as required by Condition 2 of the consent, is highlighted in ***Figure 11***, i.e., there is a greater 'release' of water from the MLC as flows in the Mararoa River decrease over the drier months. This ensures that a significant baseflow is maintained in the Lower Waiau River as required by the condition.

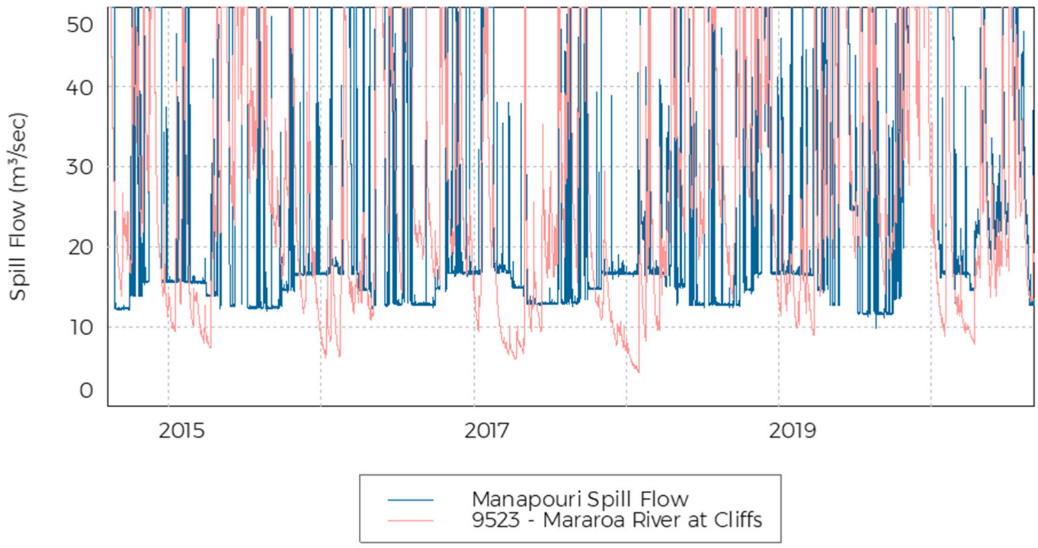

Figure 11 – Seasonal variation in minimum flows through the MLC (2015-2020)

MARAROA RIVER

99. The Waiau catchment can be separated into a series of reaches or sub-catchments. Broadly speaking, water flows from north to south, with the head of the Lake Te Anau catchment at the northern end and Tuatapere to the south.

100. The sub-catchments for which there are flow records are Lake Te Anau, Lake Manapōuri, the Mararoa River, Lake Monowai, the Waiau River catchment above Sunnyside, and the Waiau catchment above Tuatapere (***Figure 12***).

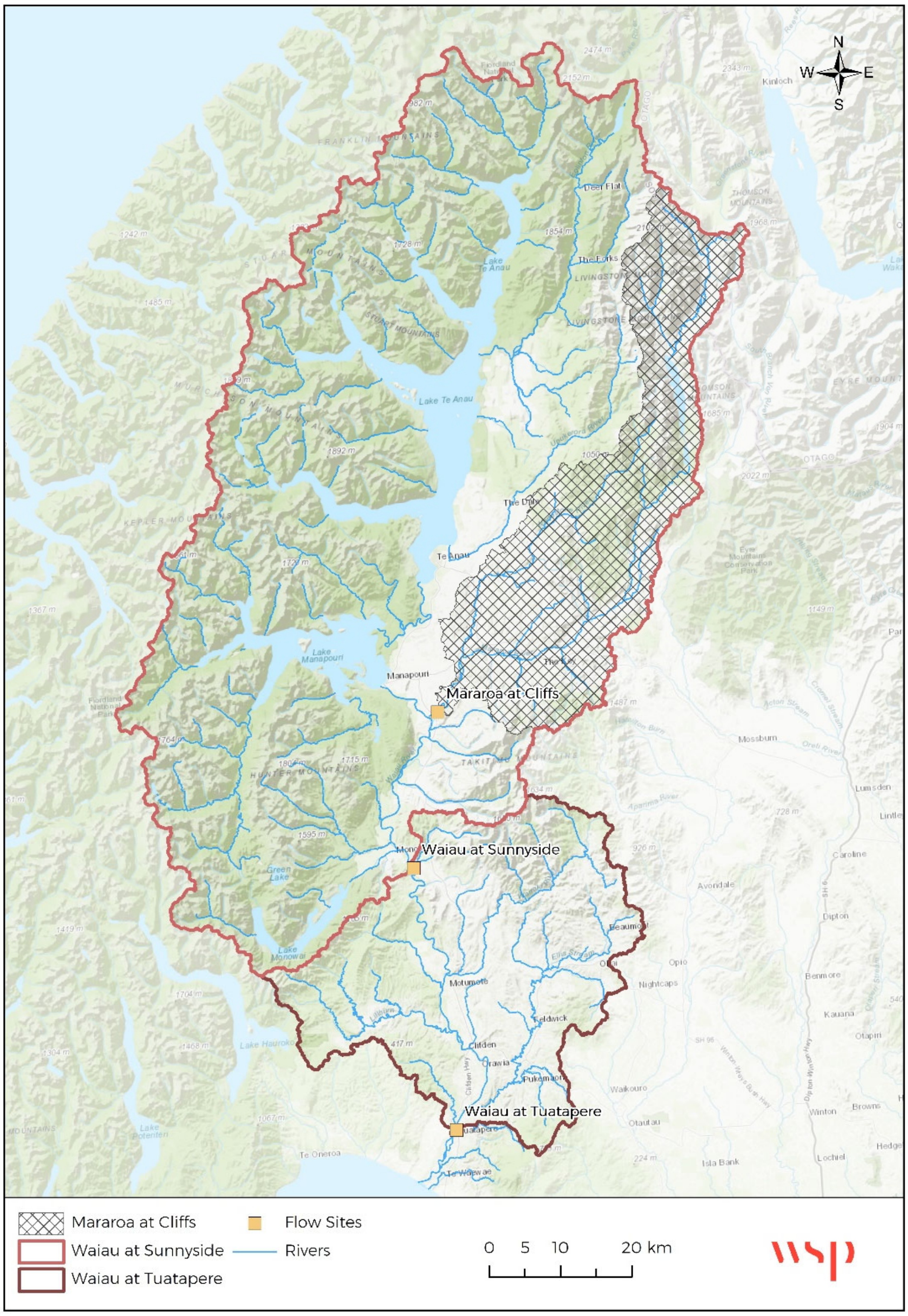

Figure 12 – Sub-catchments of the Waiau River and streamflow gauging locations

101. Prior to construction of the Mararoa weir, and then the MLC, the Mararoa River flowed naturally into the Lower Waiau River about 8km downstream of Lake Manapōuri.

102. Since the MPS, the MLC at the confluence of the two rivers is used to control the level of Lake Manapōuri for compliance with the Lake Operating Guidelines while providing both for hydro-electric generation flows and required flows into the Lower Waiau River.

103. Since the streamflow record for the Mararoa at Cliffs begins in 1975, there are no continuous flow data available for this catchment prior to the MPS (***Figure 13***). It should be noted that the MPS has no effect on the flows recorded in the Mararoa River. The flow regime is essentially natural.

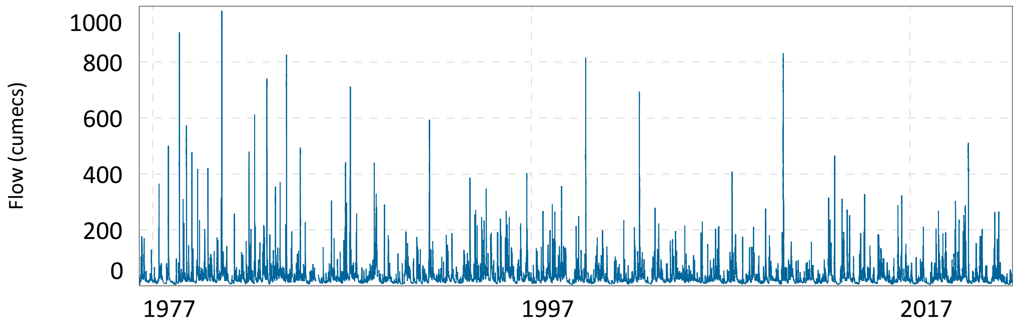

Figure 13 – Flow record for Mararoa at Cliffs (1975-2022)

104. Summary statistics for the Mararoa at Cliffs flow record over the different development periods are provided in ***Table 6*** & ***Figure 14***. As expected for a natural flow regime, there is little difference in the flow regimes over the different development periods. Any variation is a response to variations in rainfall.

Table 6 – Summary statistics for the mean annual flow (m³/s) in the Mararoa River at Cliffs over the different development periods of the MPS

Period	Min	Max	Mean	Std Dev	L.Q.	Median	U.Q.	7-day LF
Pre 1977	-	-	-	-	-	-	-	-
1977 – 1996	4.2	983	36	36	17	26	42	4.5
1996 – 2003	4.7	815	32	33	14	22	38	4.9
2003 – 2012	5.8	831	29	27	15	23	35	6.4
2012 – 2022	4.2	511	31	29	14	22	36	4.6

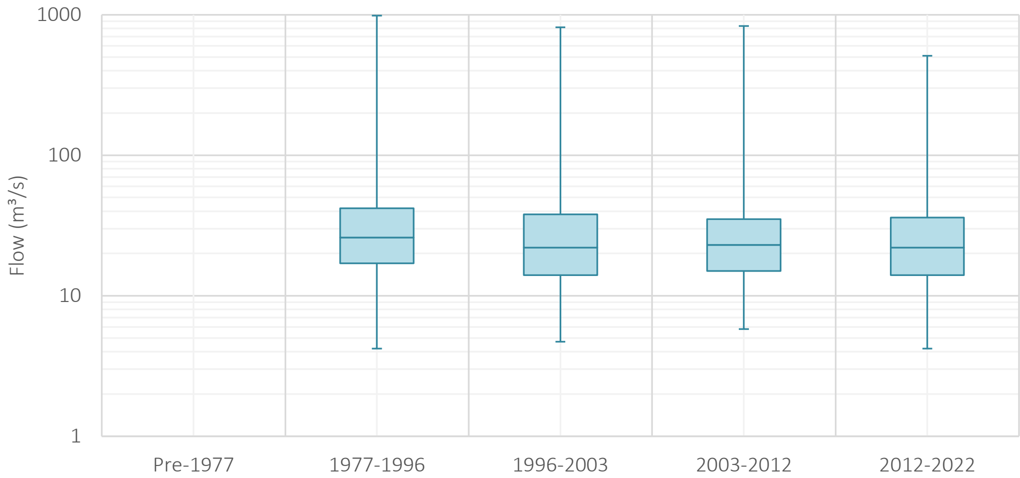

Figure 14 – Box and whisker plot of summary statistics for the flow in the Mararoa River at Cliffs over the different development periods

WAIAU RIVER AT SUNNYSIDE

105. The catchment area upstream of the flow recorder on the Waiau River at Sunnyside is 6616km² of which 823km² (12.5%) is below the MLC. The flow recorder has operated since 10 February 1972 (***Figure 15***). Consequently, there are limited data available from which to infer the flow regime of the Waiau River at this location prior to commissioning of the MPS.

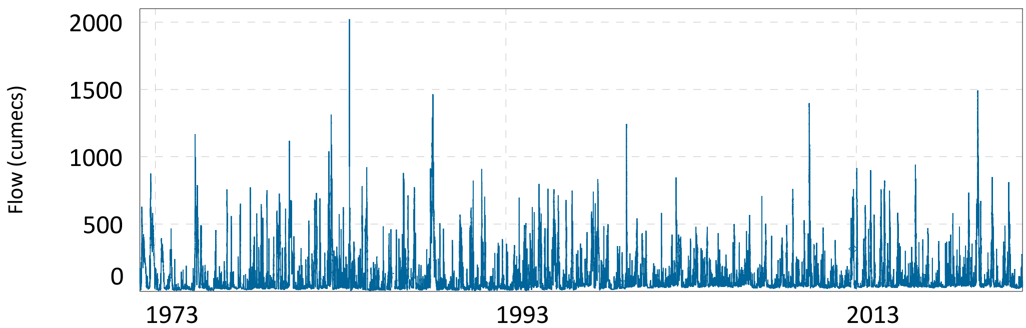

Figure 15 – Flow record for Waiau at Sunnyside (1972-2022)

106. Floods from Lake Manapōuri and the Mararoa River are still discharged down the Lower Waiau River, although the annual flood maxima at Sunnyside are affected by the potential discharge of up to 550m³/s through the Manapōuri Power Station to Deep Cove.

107. Minimum flows at Sunnyside have been affected significantly by the MPS. Flows through the MLC have been regulated since 1976, and a suite of minimum seasonal flows was set in 1996. The effect of the addition of these minimum flow requirements can be seen in the low flow record of

Waiau at Sunnyside, with almost a tripling of the annual minimum flows from 8.4m³/s to 22.9m³/s (***Figure 16)***.

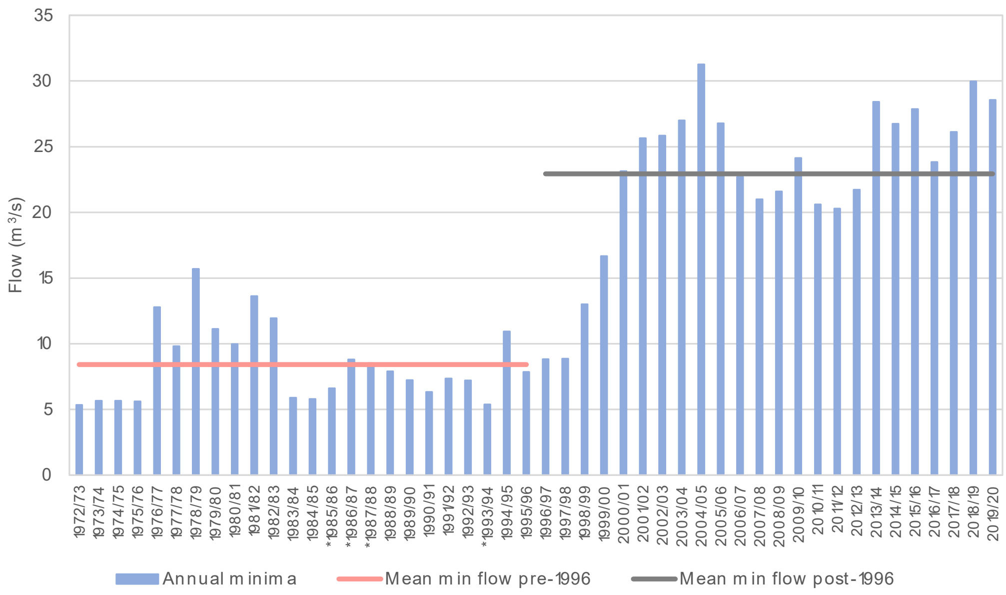

Figure 16 – Annual minimum flow recorded in the Waiau River at Sunnyside

108. Annual mean flows and the long-term mean are shown in ***Figure 17***. The considerable variation in the annual mean flow is the result of the spilling of augmented flood flows from the Mararoa River past the MLC. These flows lead to a flashy more natural system downstream of the control structure.

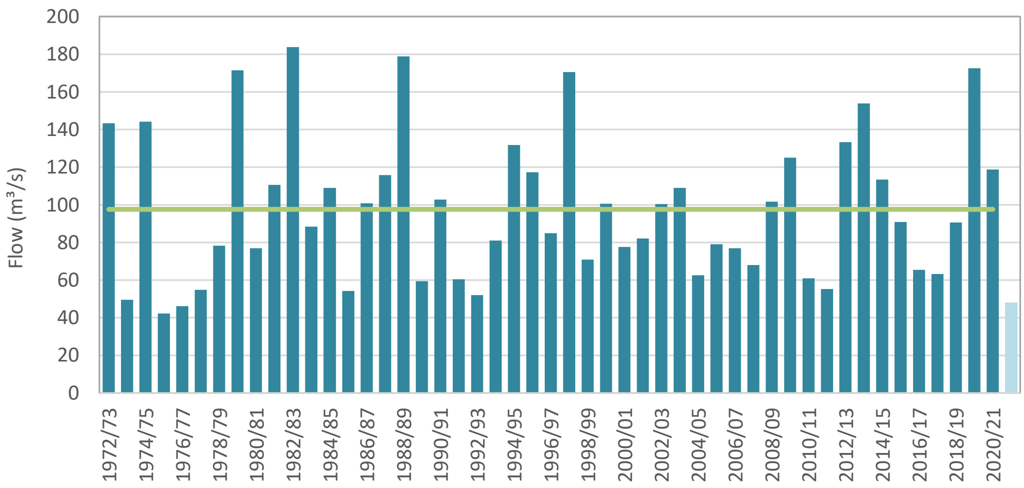

Figure 17 – Mean annual flow in the Waiau River at Sunnyside and the long-term mean. Note: 2021-22 is only a partial year

Waiau River at Sunnyside Over Development Periods

109. Summary flow statistics for the Waiau River at Sunnyside over the different development periods are shown in ***Table 7*** & ***Figure 18***. Since 1996, the median flow has been significantly higher than during the two

previous periods (up to 1996). Instantaneous minimum flows were 5.3m³/s and 5.4m³/s over the first two periods, compared to 8.9m³/s once minimum flow restrictions were applied in 1996. Minimum flows have not fallen below 20m³/s since 2003. The only significant change over the different development periods is the effect of the increased minimum flows. This is shown by the contraction of the 'boxes' in ***Figure 18***.

Table 7 – Summary statistics for instantaneous discharge measured in the Waiau River at Sunnyside (m³/s)

Period	Min	Max	Mean	Std Dev	L.Q.	Median	U.Q.	7-day LF
Pre 1977	5.3	1167	97	151	18	29	91	8.4
1977 – 1996	5.4	2021	102	160	21	33	106	7.3
1996 – 2003	8.9	1243	97	122	32	45	93	14
2003 – 2012	20.3	1398	84	99	36	47	87	21.8
2012 – 2022	20.4	1493	105	149	36	46	87	22.7

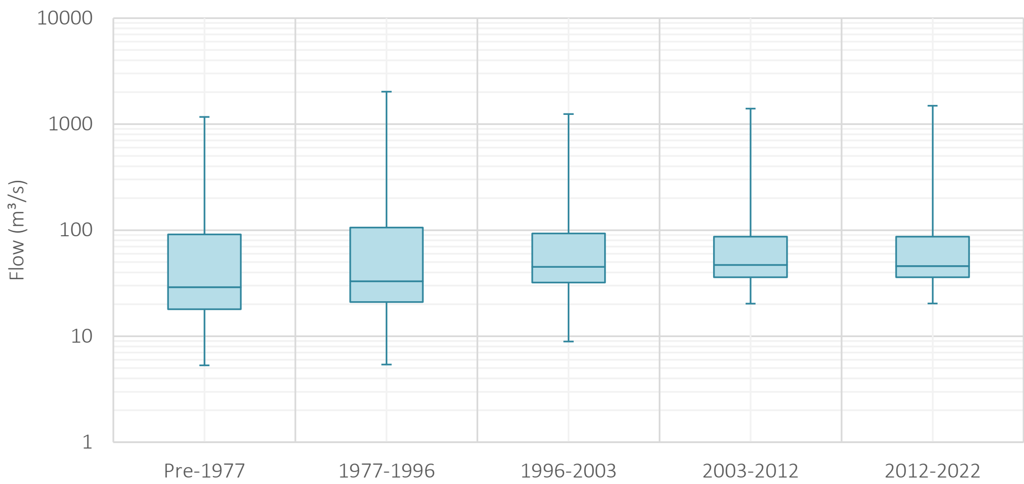

Figure 18 – Box and whisker plot of summary statistics for instantaneous discharge measured in the Waiau River at Sunnyside (m³/s)

110. Flow distribution curves comparing each development period and the full record for Sunnyside are shown in ***Figure 19***. Flows are strongly influenced by the magnitude, frequency, and duration of floods in the upper catchment resulting from spill over the MLC. This is shown by the large difference between the mean (98m³/s) and median (41m³/s) flows. Flows less than 300m³/s occur 91% of the time.

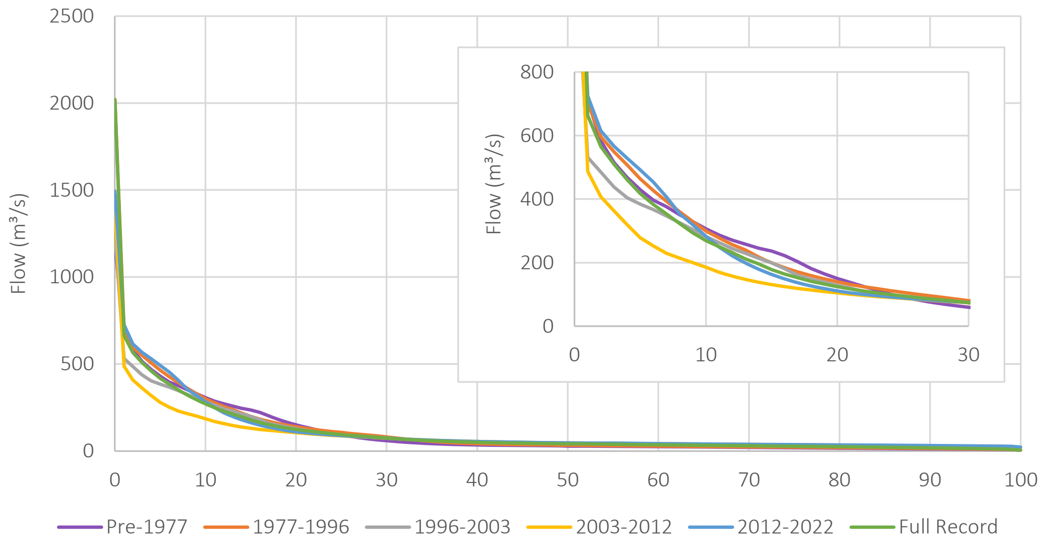

Figure 19 – Waiau River at Sunnyside flow distribution curves (1972-2022). The flow distribution curve for the full record is compared against the flow distribution for each of the development periods

111. The largest differences in the flow regimes occur over the top 25% of flows, particularly during the 2003-2012 period. Flow was consistently lower during this period because of lower rainfall and runoff, therefore reductions in spill.

WAIAU RIVER AT TUATAPERE

112. The catchment area of the Waiau River at Tuatapere is 8134km². Of this, 2341km² (25%) is downstream of the MLC with 1518km² (16%) downstream of Sunnyside. This catchment downstream of Sunnyside includes the Wairaki (approximately 300km²), Orauea (475km²) and Lill Burn (245km²) sub-catchments.

113. A flow recorder has operated on the Waiau River at Tuatapere since late July 1964, five years before water was first diverted out of both the Mararoa River and Lake Manapōuri to Deep Cove (***Figure 20***).

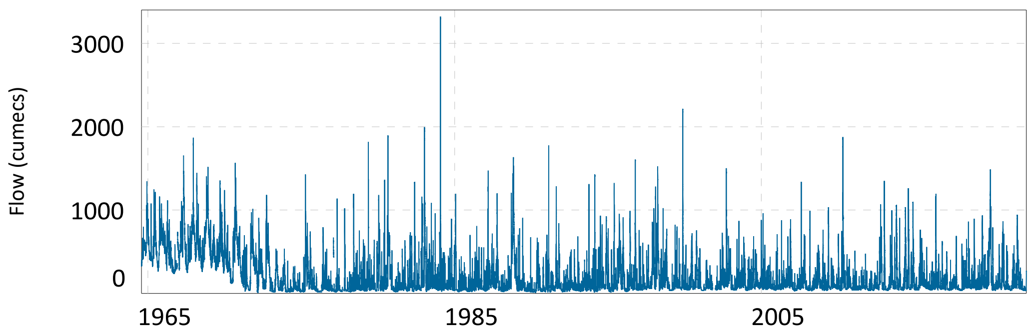

Figure 20 – Flow record for Waiau at Tuatapere (1964-2022).

114. Floods from Lake Manapōuri and the Mararoa River are still discharged down the Lower Waiau River, although the annual flood maxima at Tuatapere may be reduced by up to a maximum of 550m³/s because of discharge through the Manapōuri Power Station.

115. The largest flow recorded in the Waiau River at Tuatapere was 3320m³/s, on 27 January 1984. This was approximately 64% larger than upstream at Sunnyside. A flow of this magnitude or greater has an Average Recurrence Interval of approximately 370 years i.e., it was an extreme event.

116. Flows through the MLC have been regulated since 1976, with minimum flows since 1996. The effect of the minimum flow restrictions has been a doubling of the minimum flows, from 15.8m³/s to 32.1m³/s (***Figure 21***).

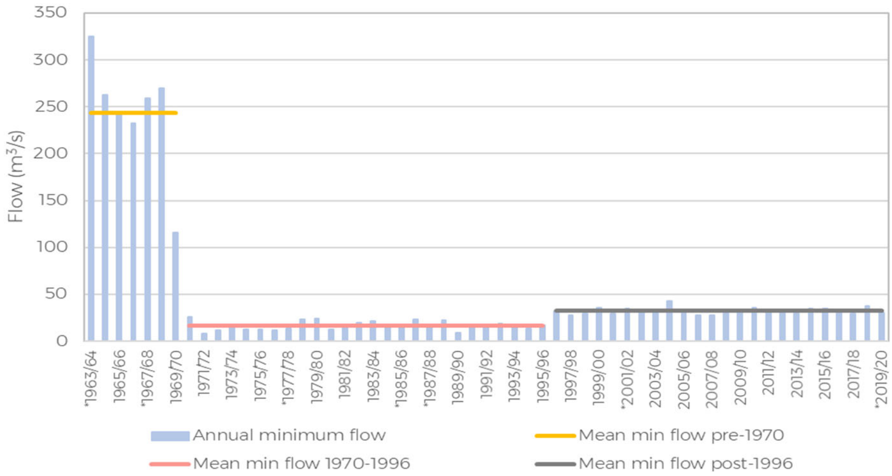

Figure 21 – Annual minimum flow recorded in the Waiau River at Tuatapere

117. Annual mean flows, and the long-term mean since 1972/73, are shown in ***Figure 22***.

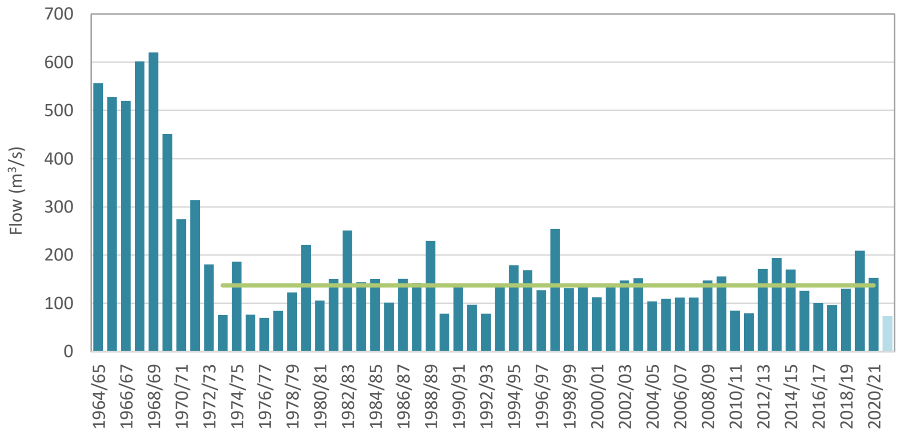

Figure 22 – Mean annual flow in the Waiau River at Tuatapere and the long-term mean.
Note: 22021-22 is only a partial year

118. Considerable variation in the annual mean flow occurs in the Waiau River at Tuatapere. As upstream at Sunnyside, this is the result of the spilling of augmented flood flows from the Mararoa River and Lake Manapōuri over the MLC. It is also affected by rainfall in the local catchment which may be distinctly different to that in the headwaters.

119. The effect of the MPS on the mean annual flow is obvious, with a significant difference before and after about 1970. Since about 1972, the variation in mean annual flows, is also controlled by climatic and runoff variability within the Waiau catchment.

Waiau River at Tuatapere Over Development Periods

120. Summary flow statistics for the Waiau at Tuatapere over the different development periods are shown in ***Table 8*** & ***Figure 23***. Since 1996, the median flow has been significantly higher than during the two previous periods (up to 1996). Instantaneous minimum flows were ~8.5m³/s over the first two periods, compared to ~27.5m³/s once minimum flow restrictions were applied in 1996.

Table 8 – Summary statistics for instantaneous discharge measured in the Waiau River at Tuatapere (m³/s)

Period	Min	Max	Mean	Std Dev	L.Q.	Median	U.Q.	7-day LF
Pre 1977	8.4	1867	346	282	70	328	534	14
1977 – 1996	8.6	3320	145	185	41	66	170	10.1
1996 – 2003	27.6	2215	149	169	53	76	159	30.4
2003 – 2012	27.3	1875	120	125	53	77	132	28.6
2012 – 2022	28.5	1485	144	171	51	74	145	31.1

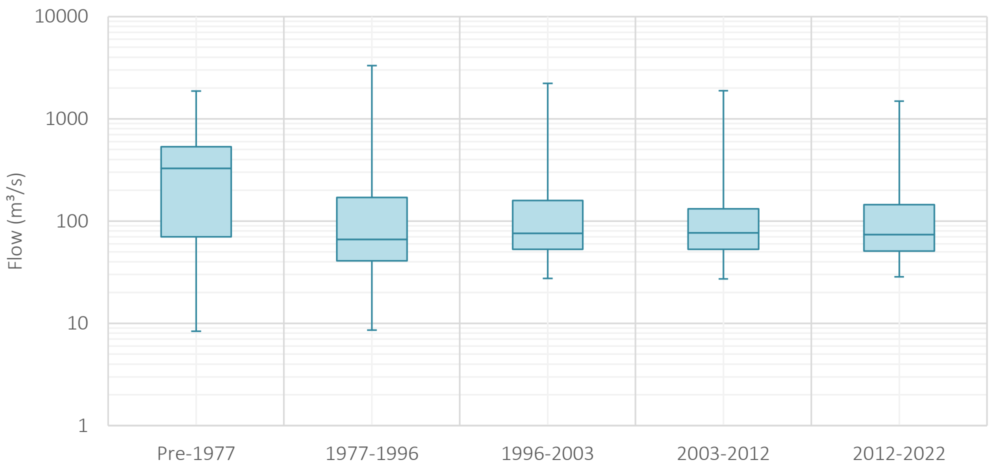

Figure 23 – Box and whisker plot of summary statistics for instantaneous discharge measured in the Waiau River at Tuatapere (m³/s)

121. Since 1996, all the various metrics have been very similar for each of the development periods (***Figure 23***). Any variation is likely the result of climatic variability and the effect of local tributary flows.

122. Flow distribution curves for the Waiau River at Tuatapere over the various development periods are shown in ***Figure 24***. The mean flow recorded at Tuatapere over the period from July 1964 to 1969 was 560m³/s, and the median flow was 520m³/s. By contrast the mean and median flows at Tuatapere from 1973 to 2022 were 137m³/s and 70m³/s respectively. The mean flow (especially since control) is influenced by the frequency, magnitude and duration of floods which are random events. Flow is less than 137m³/s for 72% of the time. As at Sunnyside further upstream, the flow regime over the 2003-2012 development period had generally lower flows. This was a response to a period of lower rainfall and reductions in spill.

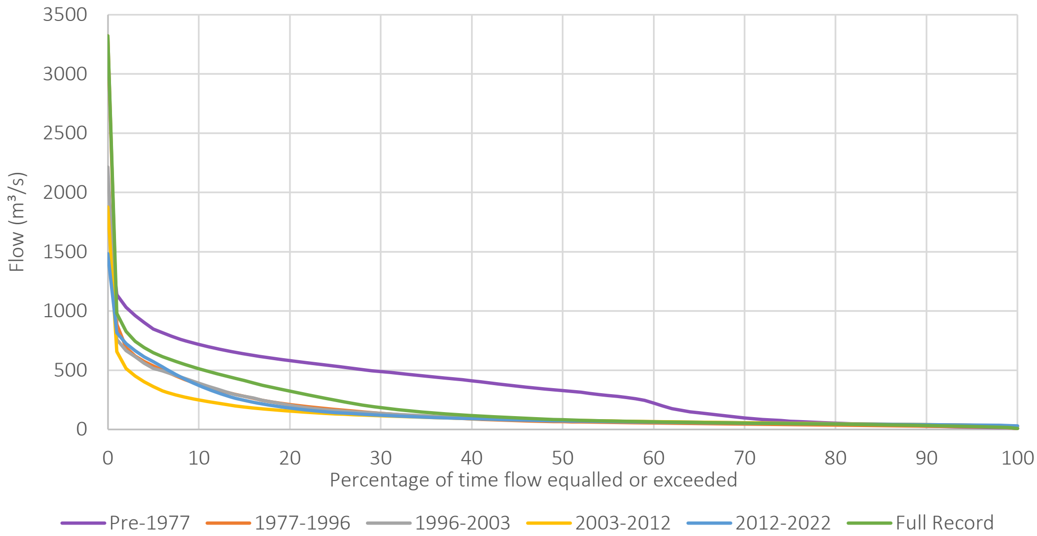

Figure 24 – Waiau River at Tuatapere flow distribution curves (1964-2022). The flow distribution curve for the full record is compared against the flow distribution for each of the development periods

123. Prior to 1977, flow peaked in spring with lowest flows recorded in February and July. A similar pattern is still evident up until 2012. Since then, flows have peaked in May and November.

Effect of the MPS on Flows

124. As discussed, despite affecting both inflows to and outflows from Lake Manapōuri, the MPS still affects the flow regime of the Lower Waiau River. This is most noticeable during periods of high inflows to Lake Manapōuri and floods in the Mararoa River (***Figure 25***).

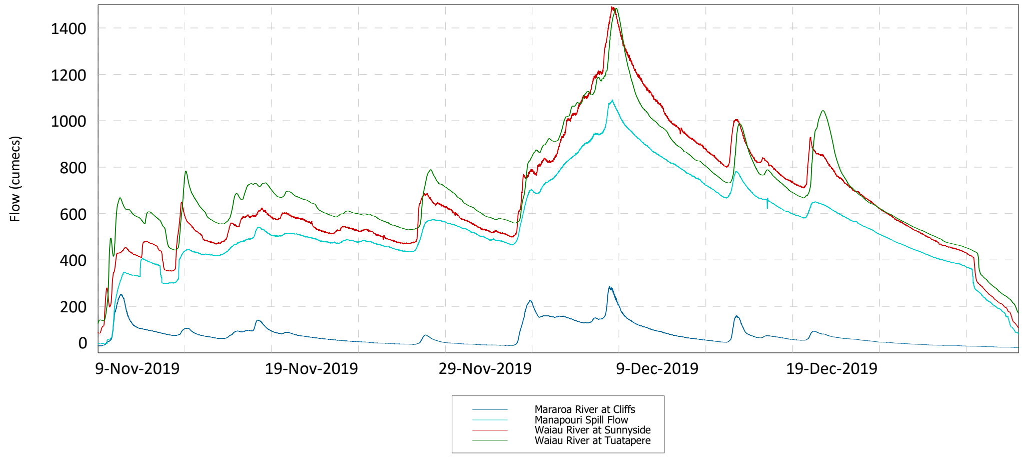

Figure 25 – Flows at three locations in the Lower Waiau River during the large flood/inflow event of November 2019

125. To manage the level of Lake Manapōuri within the 'Guidelines', a significant amount of spill is required past MLC and into the Lower Waiau River. This spill is in addition to the discharge through the power station that can be up to 550m³/s. This spill, while mimicking the flood hydrograph of the Mararoa River, because of its volume largely defines the shape and characteristics of the flood wave passed down the Lower Waiau (***Figure 25***).

126. While the majority of the flood peak and volume in the Lower Waiau River is controlled by the spill, there is an incremental gain in flow between the MLC and Sunnyside and then between Sunnyside and Tuatapere (***Figure 25)***.

127. While spill past MLC tends to control the flood regime in the Lower Waiau River, local tributary flows dominate during periods when only the minimum flow is passing the MLC (***Figure 26***). While the minimum flow past MLC provides baseflow to the Lower Waiau River, local tributary flows provide the majority of the flow and the characteristics of the hydrograph.

128. The flow at Sunnyside is approximately twice that released past the MLC. The effect of local rainstorms on runoff from the tributaries is apparent in the random flood hydrographs of various magnitudes and durations. There is a lag between the flood peaks at Sunnyside and at Tuatapere because of the distance between the two sites and the time it takes the flood wave to move downstream. During periods of sustained low flow, the effect of discharge from the Monowai Power Station is also apparent (***Figure 26).***

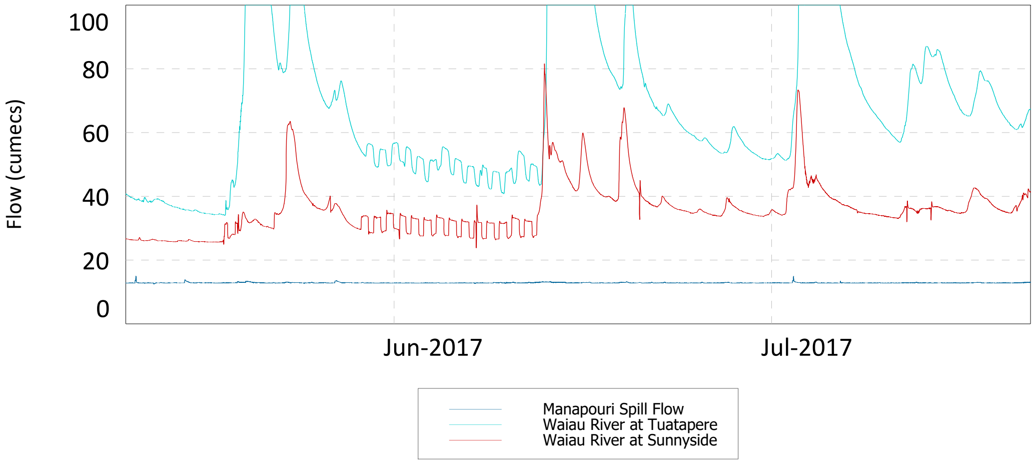

Figure 26 – Flows at three locations on the Lower Waiau River while a minimum flow of ~14m³/s is maintained past MLC from 10 May to 21 July 2013

129. The same patterns of response are also apparent when the minimum flow is maintained at about 16m³/s (***Figure 27***).

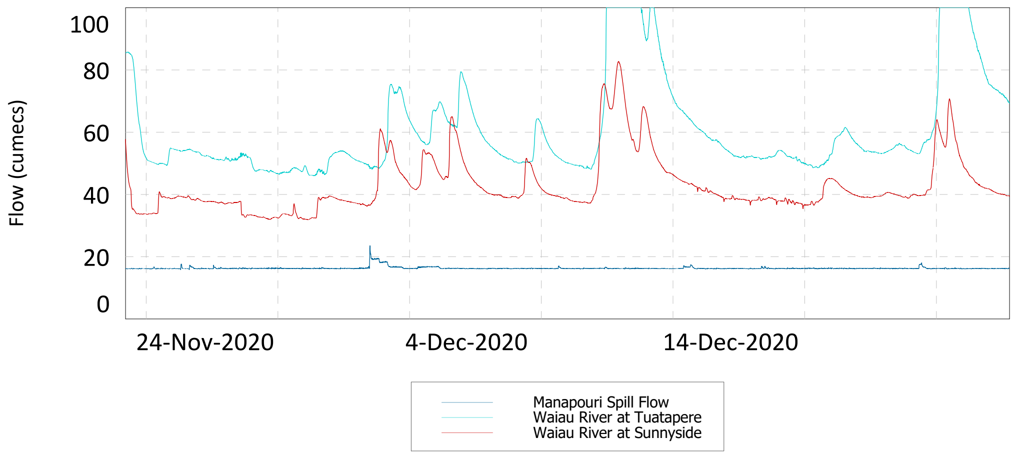

Figure 27 – Flows at three locations on the Lower Waiau River while a minimum flow of ~16m³/s is maintained past MLC from 23 November to 26 December 2020

130. Consequently, flow past the MLC tends to dominate the flow regime of the Lower Waiau River during higher flow events. However, local inflows from the various tributaries downstream of the MLC control the flow regime during periods of lower flow.

TURBIDITY

131. Suspended sediment, and its associated effects on the optical properties of water, are important parameters affecting both water quality and in-stream ecology. These parameters are discussed in the evidence of Dr Kristy Hogsden on freshwater ecology. While the effects of these parameters are not discussed below, the collection of these data and their relationship to the flow regime of the Waiau River are reviewed.

132. There is generally a strong relationship between suspended sediment concentration and turbidity, at least within a particular stream or water course. However, because it has been easier to measure turbidity than suspended sediment, turbidity has generally been the metric used when assessing these parameters.

133. Turbidity is widely used as a water quality indicator and to infer the mass of suspended sediment transported through riverine systems. Equipment for monitoring turbidity is inexpensive, readily available, and can be easily deployed to record continuous measurements. However, using turbidity as a surrogate for suspended sediment concentration is frequently confounded by the composition of the suspended material and the size and shape of the sediment.[2]

134. Turbidity is usually measured in NTU or FTU; there is a 1:1 relationship between the two measures. The NTU or FTU increases as the concentration of suspended sediment increases and the water becomes more opaque. However, it is important to place the turbidity of the Mararoa River, particularly the consented threshold of 30 NTU, in context. Therefore, ***Figure 28*** shows that a turbidity limit of 30 NTU, and certainly 10 NTU, is relatively 'clear' water.

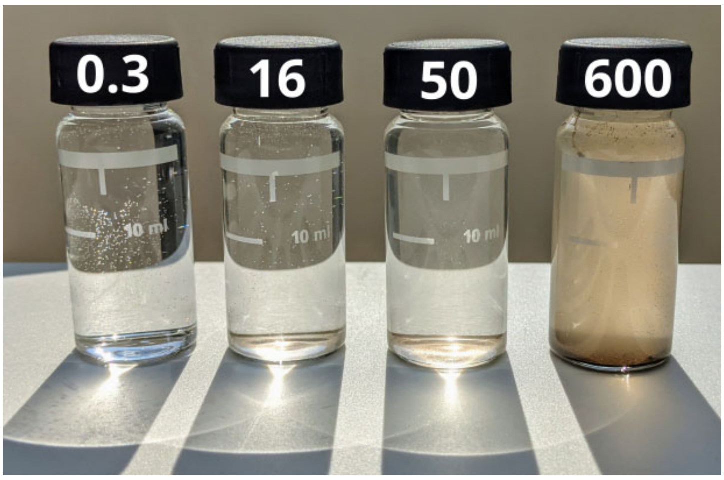

Figure 28 – The clarity of water with different NTU over the range of relevance to Condition 5 of consent 96022

135. Turbidity data has been collected by Meridian and Environment Southland at various sites in the Waiau catchment (***Table 9***). The principal purpose of the turbidity data collected by Meridian relates to Condition 5 of consent 96022. This condition requires that:

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2 Bright, C.E.; Horton, S.L. & Mager, S.M. (2020): Clarifying the waters: the use of turbidity for suspended sediment monitoring in New Zealand. Journal of Hydrology (NZ) 59(2): 83-99.

Whenever water in the Mararoa River has a turbidity greater than 30 NTU at the site referred to in Condition 7, the Consent Holder shall discharge from lake control structure a flow no less than the flow in the Mararoa River measured at the same time.

Table 9 – Mararoa River, Lake Manapōuri and Lower Waiau River turbidity data

Location	Time series	Record	Resolution and comments
Data collected by Meridian			
Mararoa at Cliffs		31-Mar-2000 to 2-Dec-2019	Range to 100 NTU Unit replaced and relocated to Mararoa at Weir Rd Bridge
Mararoa at Weir Rd Bridge		6-Nov-2019 on	NTU full range
Waiau at Manapōuri Channel		31-Mar-2000 on	Range to 100 NTU
Data collected by Southland Regional Council			
Waiau at Tuatapere:	10-minute (FTU) Monthly sampling (NTU)	19 May 2016 on From 2009 on	10-minute data. Data to April-2018 “patchy” Also, longer term monthly water quality sampling including turbidity (from 2009). Dataset not continuous.
Waiau at Sunnyside:	Monthly sampling (NTU)	From 2000 on	Longer term monthly water quality sampling including turbidity from 2000. Dataset not continuous.

Continuous Turbidity Data

136. The turbidity data collected by Meridian from the Mararoa River at Cliffs (***Figure 29***) and the Waiau Arm of Lake Manapōuri (***Figure 30***) focus on a very narrow range, from 0-100 NTU. This is because Condition 5 requires the monitoring of the turbidity only above or below the threshold of 30 NTU. The narrow range over which turbidity is measured means that the turbidity of ‘dirty water’ is not measured.

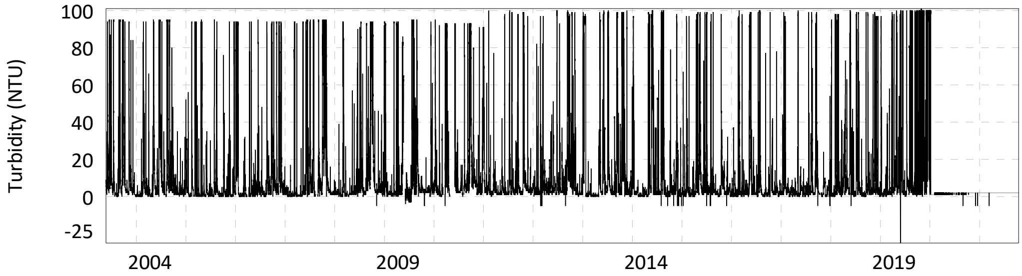

Figure 29 – Turbidity in the Mararoa at Cliffs since 2000

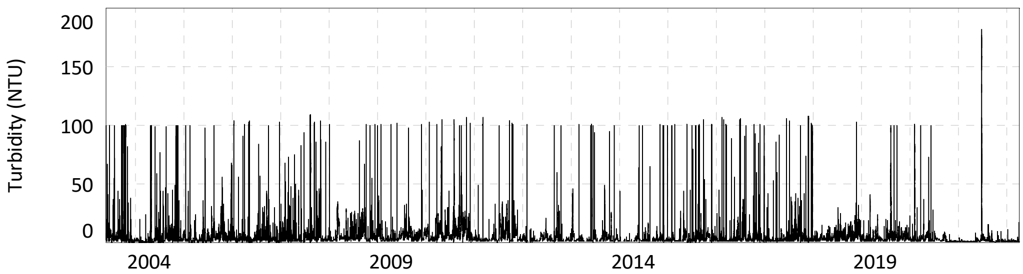

Figure 30 – Turbidity in the Waiau Arm of Lake Manapōuri since 2003

137. Problems were experienced with Meridian's turbidity sensor installed in the Mararoa River at Cliffs from about 2020 (***Figure 29***). However, Environment Southland had previously installed a TriOS OPUS spectral sensor to measure a range of environmental parameters on the Mararoa River at the Weir Road Bridge (***Figure 31***). This sensor, because of the different focus of these data, records turbidity over a much wider range than recorded by those sensors operated by Meridian. This record has measured turbidity up to 1000 NTU on fresh flows of up to 500m³/s.

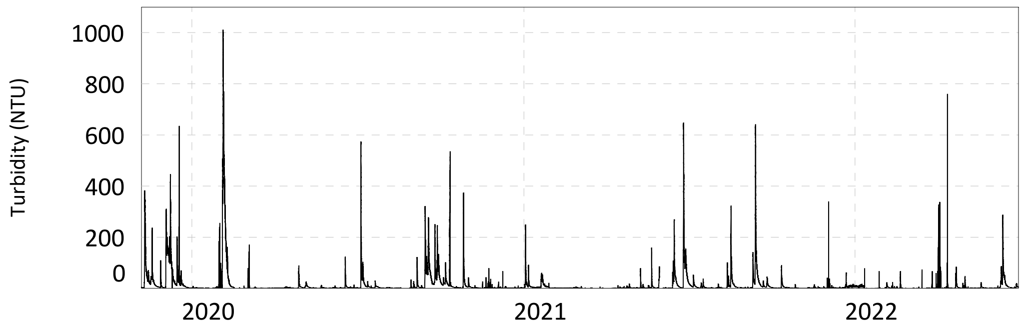

Figure 31 – Turbidity in the Mararoa at Weir Road Bridge since 2019.

138. Environment Southland has also been recording turbidity in the Waiau River at Tuatapere since 2016, although data quality was poor until 2018 (***Figure 32***).

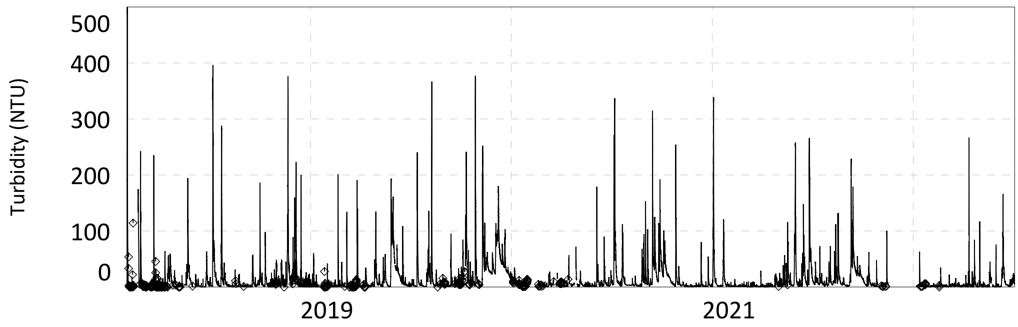

Figure 32 – Turbidity in the Waiau at Tuatapere since 2018.

Relationship Between Flow and Turbidity

139. Despite the potential issues when monitoring turbidity in natural rivers and streams, there is generally a good relationship between changes in flow and turbidity (***Figure 33***). As expected, increasing flow is associated with increasing turbidity, at least once the entrainment threshold for suspended sediment has been exceeded.

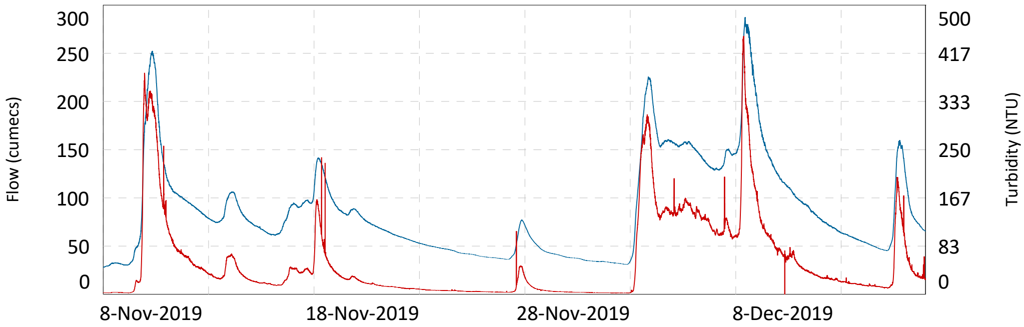

Figure 33 – Mararoa River at Cliffs flow (blue trace, m^3/s, left axis) and Mararoa at Weir Road Bridge turbidity (red trace, NTU, right axis)

140. It is important to recognise that the supply and type of material available for entrainment, thereby increasing suspended sediment and turbidity, can affect any relationship between flow and turbidity. Suspended sediment and turbidity can only increase as a function of flow if sufficient material is available for entrainment.

141. While the MPS, through the use of spill past the MLC, dilutes any suspended sediment and turbidity of water passing down the Mararoa River, they have no effect on the supply of material that is entrained. The supply of sediment is a function of the underlying geology and resulting soils, and land use activities within the catchment.

142. The Waiau Arm of Lake Manapōuri, upstream of the MLC, can also experience pulses of suspended sediment and elevated turbidity (***Figure 34***). While not as high or as frequent as in the Mararoa River, the local

turbidity effects result in the MPS using 'flushing flows' to prevent this 'poor quality water' from flowing into Lake Manapōuri. Again, the MPS does not cause these 'turbidity events', which are likely the result of land use activities along the 8km Waiau Arm. However, the MPS does mitigate any potential adverse effects of these events on Lake Manapōuri by 'flushing' and diluting the affected water into the Waiau River.

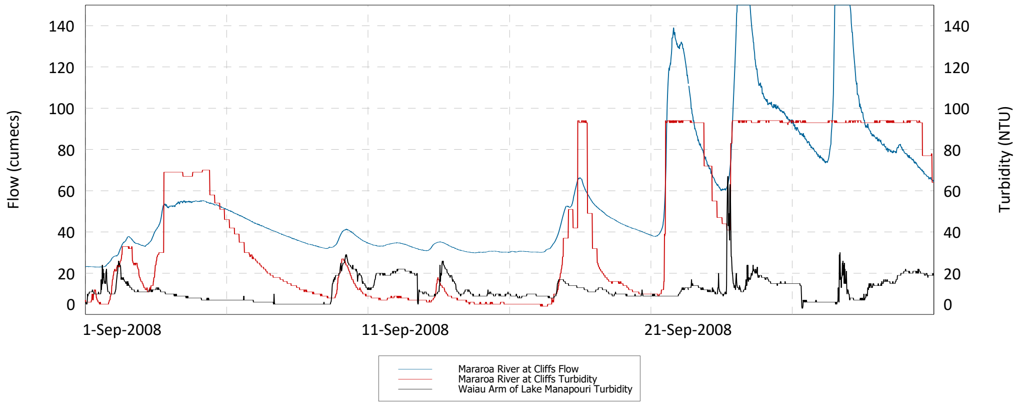

Figure 34 – Flow (blue trace) and turbidity (red trace) in the Mararoa River at Cliffs and turbidity in the Waiau Arm of Lake Manapōuri (black trace) over September 2008

143. As discussed, while there is a general relationship between flow and turbidity, there is considerable scatter about any trend. This is a function of both the instrumentation used to measure turbidity and those factors that affect the suspended sediment concentration and the resulting turbidity.

144. ***Figure 35*** shows the general relationship between flow in the Mararoa River at Cliffs and turbidity recorded just upstream at the Weir Road Bridge. While turbidity increases with discharge (flow) there is significant variability. This is despite using 1-hr averages to remove some of the 'noise' from the data. For example, a flow of 100m³/s can be associated with turbidity that ranges from 40 to 400 NTU. The variability appears to be much greater at lower flows and turbidity. This is likely a function of the accuracy and resolution of the turbidity sensors and that relatively small changes in suspended material, either its size or composition, can have a proportionately greater effect on turbidity. It is also apparent that the same 'loop rating' described earlier affects the relationship. Turbidity is greater for a particular flow on the rising limb of the hydrograph than for the same flow on the falling limb.

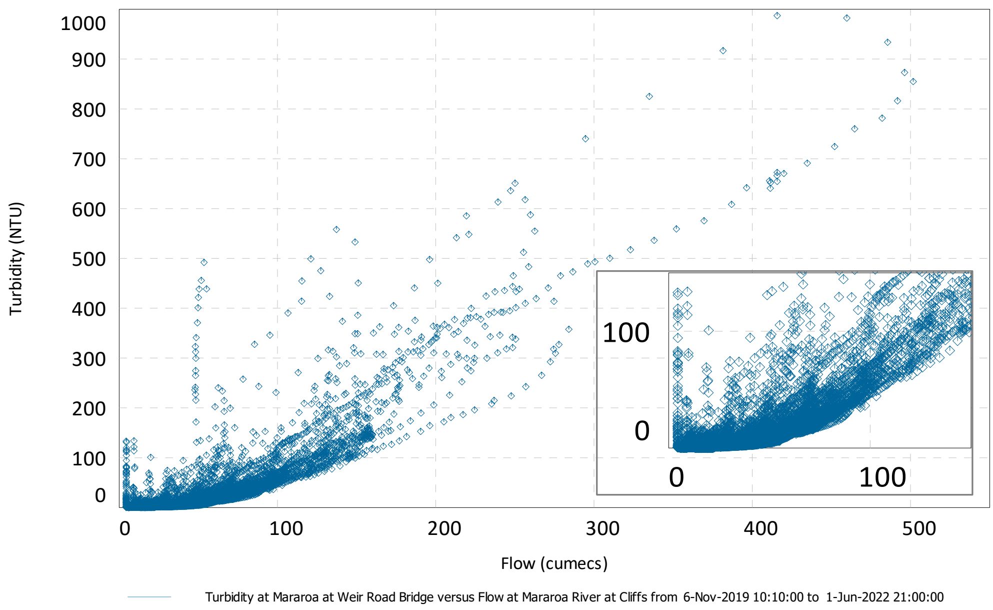

Figure 35 – Mararoa at Weir Road Bridge turbidity plotted against Mararoa at Cliffs Flow (November 2019 to June 2022). Average 1-hour data used in the analysis. Inset graph is the same data with higher resolution scale

145. Turbidity varies down the Waiau River in response to both increases in flow and the input of sediment from the various tributaries and land use activities.

146. While the same general patterns in turbidity are reflected at both the Mararoa River at Weir Road Bridge and the Waiau River at Tuatapere, there are also distinct differences (***Figure 36***).

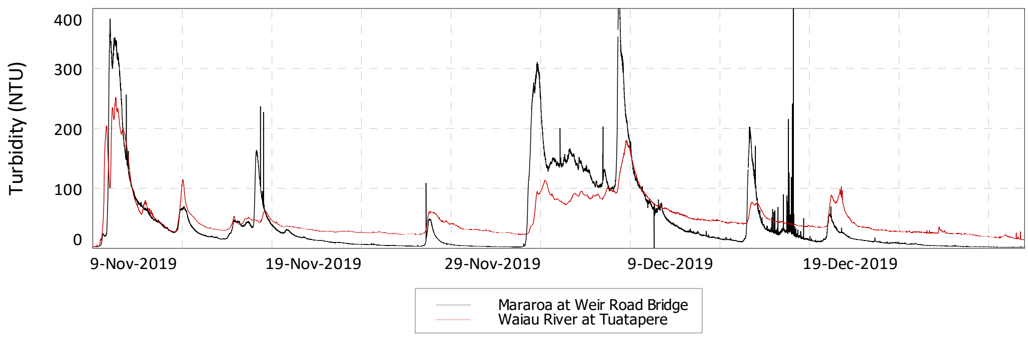

Figure 36 – Mararoa at Weir Road Bridge and Waiau River at Tuatapere measured turbidity for the large November 2019 flood event

147. During floods, the turbidity of the Mararoa River is higher but this is then diluted by spill flow over the MLC. Consequently, turbidity recorded at Tuatapere is significantly lower than upstream. However, during periods of relatively low flow, the turbidity at Tuatapere is higher than in the Mararoa River. More highly turbid water is therefore being added to the Waiau River downstream of where the MPS is exercising any control over flow.

148. This increase in turbidity at times of lower flows indicates that at these times, when the inflows from tributaries to the Lower Waiau River are relatively small, the turbidity of these tributaries must be high because they have the effect of reducing the quality (in turbidity terms) of the much greater flows from upstream. This pattern of behaviour was consistent for all the periods analysed (***Figure 37*** & ***Figure 38***).

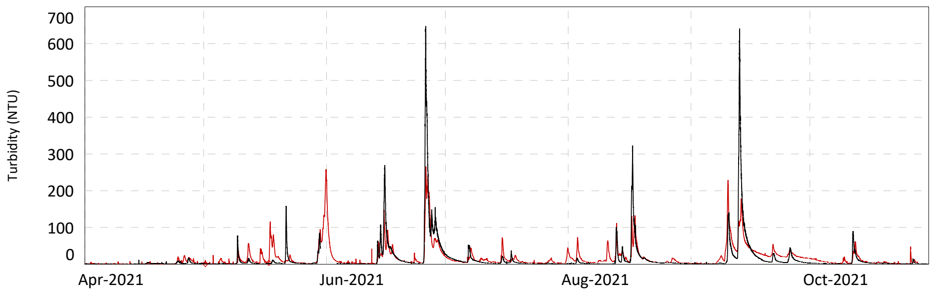

Figure 37 – Turbidity at Mararoa at Weir Road Bridge (black trace) and Waiau at Tuatapere (red trace) for several months during 2021

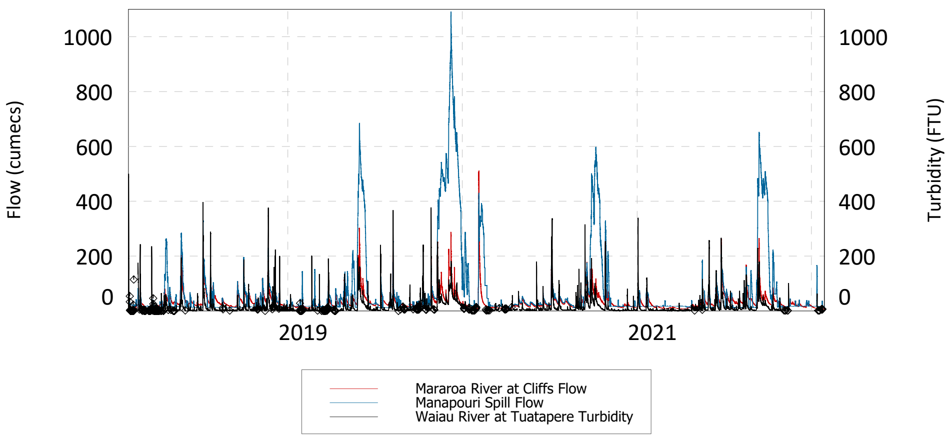

Figure 38 – Lake Manapōuri spill flow (blue trace), Mararoa at Cliffs flow (red trace) and Waiau at Tuatapere turbidity (black trace). Period February 2018 to January 2022

Effect of MPS on Turbidity

149. It is generally agreed that the waters of the Mararoa River are naturally high in sediment, with some additional contribution from human induced changes in land use and land cover. The Mararoa River therefore has the potential to have a significant effect on the quality of the Lower Waiau River in the absence of discharge of 'clean' water from Lake Manapōuri. However, measures are taken by Meridian to mitigate the potential adverse effects of the MPS on turbidity in the Lower Waiau River.

150. Condition 5 of the MLC operational consent requires that whenever the water in the Mararoa River has a turbidity greater than 30 NTU (as

recorded at Mararoa at Cliffs) a flow *“no less than the flow in the Mararoa River”* will be discharged through the structure.

151. As discussed, the way this is operationalised by the MPS is that whenever turbidity in the Maroroa exceeds 10 NTU (so a significant margin of ‘safety’), all the flow in the Mararoa River is passed by the MLC, together with an addition 5m³/s of water from Lake Manapōuri. This water, because it is ‘lake water’, dilutes the suspended sediment i.e., turbidity, in the Mararoa River that is passed to the Lower Waiau River. This ‘process’ therefore affects both the volume of water that is diverted from the Mararoa River into Lake Manapōuri and the volume and turbidity of water passed to the Lower Waiau.

152. Water from Lake Manapōuri is therefore used to ‘dilute’ the suspended sediment concentration i.e., turbidity of the Waiau River downstream of MLC. During periods of high inflows to Lake Manapōuri and flows in the Mararoa River, when turbidity is generally higher, dilution can be significant (***Figure 39*** & ***Figure 40***).

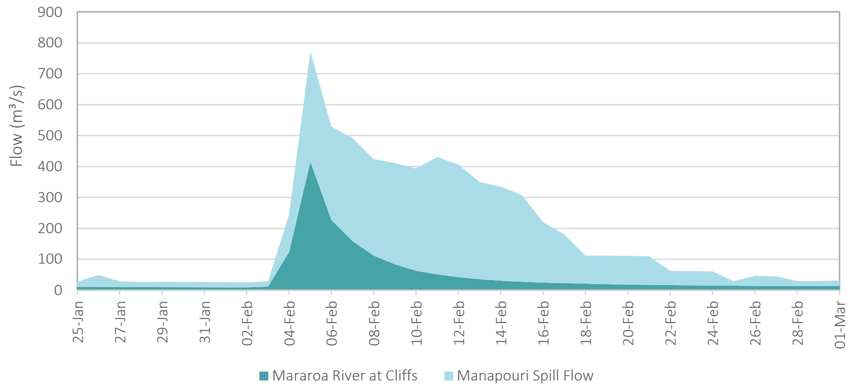

Figure 39 – Comparison of the flow in the Mararoa River and downstream of MLC showing the 'dilution' of turbidity by 'clean' water discharged from Lake Manapōuri (25 January-1 March 2020)

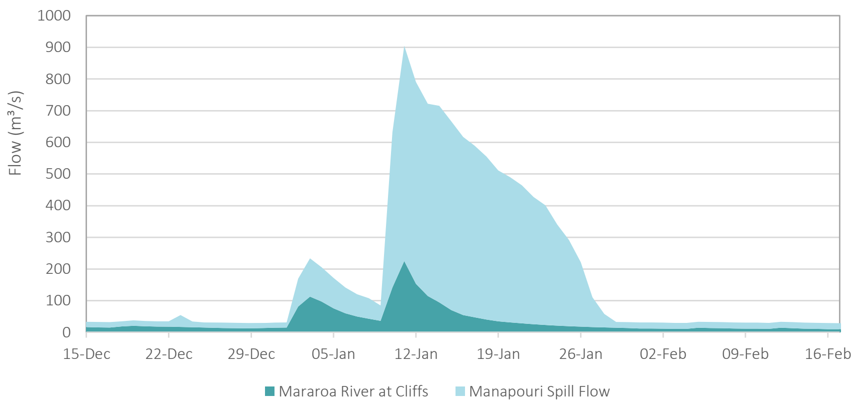

Figure 40 – Comparison of the flow in the Mararoa River and downstream of MLC showing the 'dilution' of turbidity by 'clean' water discharged from Lake Manapōuri (15 December 2012–17 February 2013)

153. The effect of spill flow past the MLC on reducing suspended sediment concentration and turbidity, however, is not only related to high inflow events to Lake Manapōuri.

154. ***Figure 41*** shows all events when the turbidity of the Mararoa River exceeded 30 NTU since November 2019. Dilution of turbid water from the Mararoa River occurs by the addition of water from Lake Manapōuri on all occasions, generally by at least 50% but most often by up to 100%.

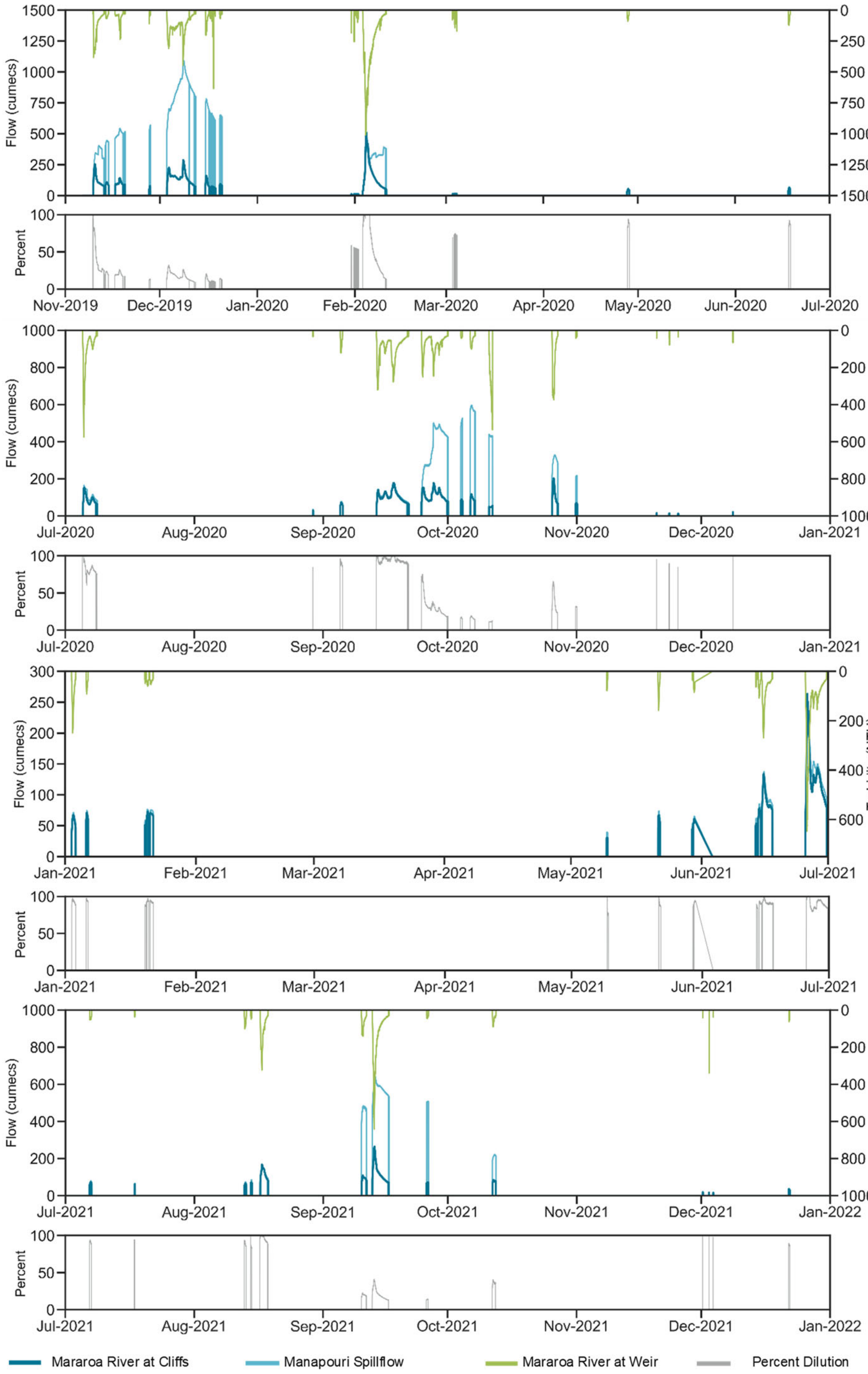

Figure 41 – Relationship between flow and turbidity in the Mararoa River, spill past the MLC and the percent dilution

155. The effect of spill from Lake Manapōuri diluting the suspended sediment concentration (turbidity), and locally high inputs of suspended sediment in the lower river, is highlighted in ***Figure 42***. For approximately 5% of the time, turbidity in the Mararoa River is greater than that in the Waiau River at Tuatapere. However, for about 45% of the time, most likely during average or moderate flows and when there are local rainstorms, the turbidity at Tuatapere is greater than that of the Mararoa River. For the remaining 50% of the time, most likely during periods of low flow, there is little difference between the sites, with both locations having low turbidity.

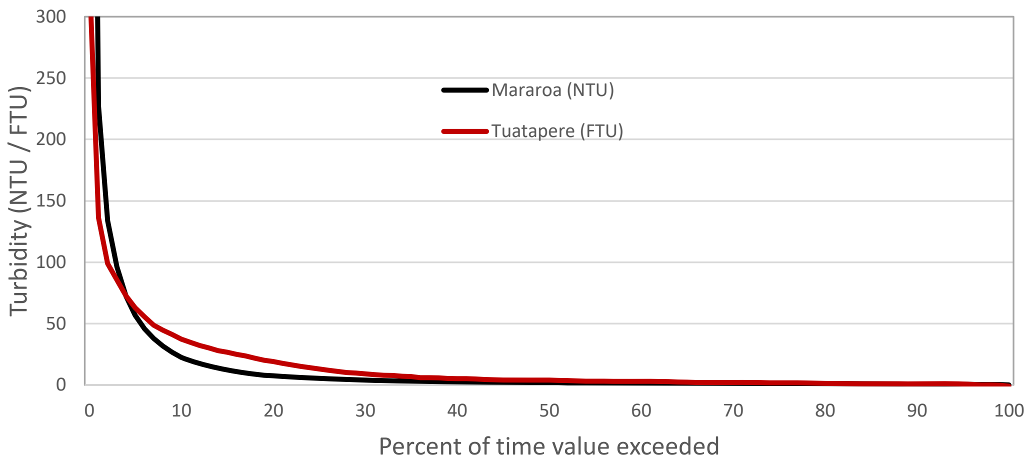

Figure 42 – Cumulative distribution of the Mararoa at Weir Road Bridge and Waiau at Tuatapere turbidity records. Hourly average data for the period from 6 November 2019 to 30 June 2022

Turbidity of the Lower Waiau River

156. Environment Southland collects monthly 'spot readings' of turbidity in the Waiau River at both Sunnyside and Tuatapere (***Figure 43***). These data are essentially discrete, one-off samples. The data indicate that turbidity in the Waiau at Tuatapere is higher than upstream at Sunnyside, although all the measurements are relatively low.

157. To provide greater resolution, only those data from the three sites from October 2018 through to May 2022 are shown in ***Figure 44***.

158. In general, the turbidity in the Mararoa River and in the Waiau River at Sunnyside are very similar. This is despite the fact that the turbidity of the Mararoa has been diluted by water spilled from Lake Manapōuri through the MLC. Consequently, the tributaries that enter the Waiau River downstream of MLC must have significantly higher turbidity than the Waiau River downstream of MLC. The suspended sediment load and resulting turbidity of these tributaries must be sufficiently high to increase

the overall turbidity of the total flow despite their relatively small contribution to flow.

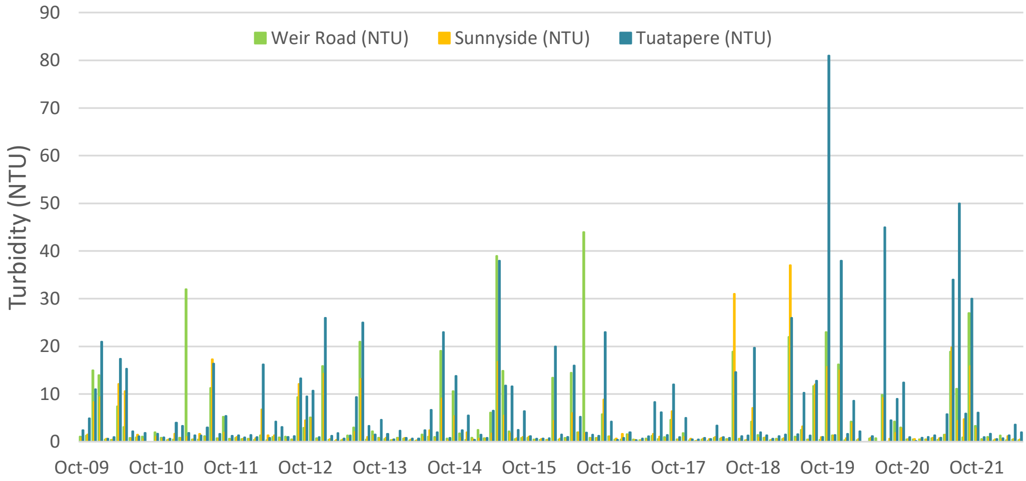

Figure 43 – Approximate monthly, "same day" turbidity values for Mararoa at Weir Road and the Waiau River at Sunnyside and Tuatapere from October 2009 to May 2022 (Environment Southland)

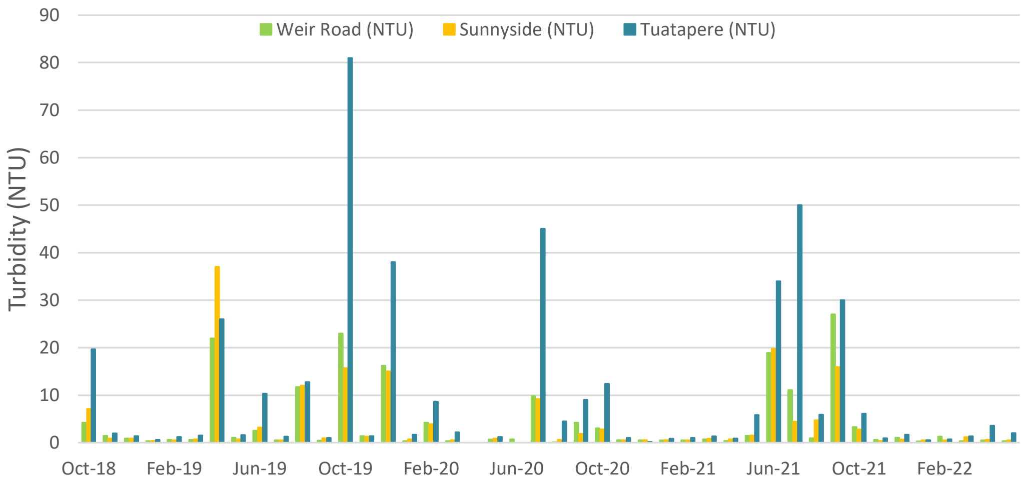

Figure 44 – Approximate monthly, "same day" turbidity values for Mararoa at Weir Road and the Waiau River at Sunnyside and Tuatapere from October 2018 to May 2022

159. The effect of the tributary inputs of sediment between Sunnyside and Tuatapere is even more significant, with the turbidity of the total flow increasing significantly between these two locations. This is despite the relatively small difference in runoff over this reach. The MPS has no effect on this pattern of behaviour or water quality.

160. The effect of high suspended sediment/turbid tributary water on the suspended sediment concentration and turbidity in the Lower Waiau River between Sunnyside and Tuatapere described above is highlighted in ***Figure 45***.

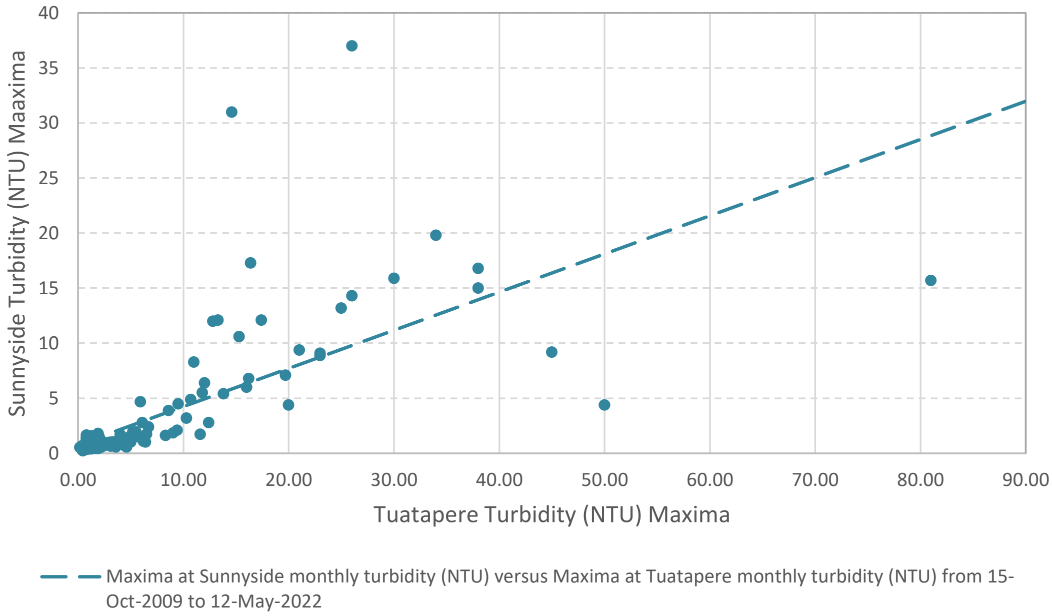

Figure 45 – Sunnyside turbidity plotted against Waiau at Tuatapere turbidity. Same day readings values from 2009

161. Despite the relatively high degree of scatter in the data, the turbidity of the Waiau River at Tuatapere is about twice that recorded upstream at Sunnyside. Consequently, there must be a significant input of 'low quality' water between Sunnyside and Tuatapere that increases the turbidity to this degree.

CONCLUSIONS

162. The hydrology and flow regime of the Waiau catchment has been affected by the MPS since the scheme was commissioned in 1977 i.e., approximately 45 years. Since 1996 and the introduction of a minimum flow regime for the Lower Waiau River, the effects of the MPS have been relatively consistent. The effects of natural variability in climate, rainfall, and consequently runoff, however, continue to affect the flow regime of the Lower Waiau River.

163. The MPS has its greatest effect on the flow regime of the Lower Waiau River over the mid-range. Its effects are relatively small over both extremely large and low flows, when the flow regime adopts more 'natural' characteristics.

164. The MPS has been operated in a consistent manner since about 1996, with variability about 'average conditions' now largely the result of natural fluctuations in rainfall and runoff. The scheme is operated in a way to

minimise and mitigate adverse effects on Lakes Te Anau and Manapōuri and the flow regime of the Lower Waiau River.

165. Occasional high suspended sediment and turbidity in the Mararoa River, and the Lower Waiau River, has been a persistent issue, as it is in many rivers and streams.

166. The MPS manages spill from Lake Manapōuri to mitigate (via dilution) the effects of high turbidity events in the Mararoa River, both on the water quality of the lake and the Lower Waiau River. Management of spill past the MLC and its effects on turbidity and the flow regime of the Lower Waiau River has not changed since 1996 i.e., about 30-years.

167. The significant changes (increases) in turbidity that are seen in the Lower Waiau River downstream of the MLC (and particularly between Sunnyside and Tuatapere) cannot, because of the source of sediment and hydrology be attributed logically to the MPS. Once the water passes the MLC, the MPS can exercise no influence or control. Any increases in turbidity below MLC must therefore be from other sources.

Dr John (Jack) Allen McConchie
29 July 2022