in the matter of: the Resource Management Act 1991

and

in the matter of: a number of applications to take and use water from the Upper Waitaki catchment

Brief of evidence of George Anthony Griffiths

Dated: 16 September 2009

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BRIEF OF EVIDENCE OF GEORGE ANTHONY GRIFFITHS

INTRODUCTION

1 My full name is George Anthony Griffiths.

2 I hold the academic qualifications of Bachelor of Science, Bachelor of Engineering (Hons – Civil) and Doctor of Philosophy (Civil – Sediment Transport) from Canterbury University.

3 I am a Scientist with the National Institute of Water & Atmospheric Research (NIWA), based in Christchurch. Previously I worked as an engineer or a scientist with the Ministry of Works and Development, the North Canterbury Catchment Board and Environment Canterbury. At Environment Canterbury, I held the position of Director of Investigations and Monitoring for some 11 years and became familiar with the general hydrology of the Waitaki Catchment during that time.

4 I have also been a reviewer for a number of international journals including, for example, the *Journal of Hydrology (Amsterdam), Journal of Hydraulic Engineering and Water Resources Research* for nearly 35 years.

5 I confirm that I have read the Environment Court's Code of Conduct for expert witnesses and this evidence has been prepared in accordance with that code. I agree to comply with the code's terms. In that regard, I confirm that the statements made in this evidence are within my area of expertise (unless I state otherwise) and I also confirm that I have not omitted to consider material facts which might alter the opinions stated in this evidence.

6 In preparing this evidence I have reviewed:

6.1 Water Audit of the Waitaki Catchment above Waitaki Dam (NIWA Client Report: CHC2005-049, 2004);

6.2 Mr Roddy Henderson's evidence, on climate variability and flow regimes to the Waitaki Catchment Water Allocation Board (WAB), 2005;

6.3 Mr Horace Freestone's evidence, regarding Waitaki Catchment Hydrology, to the WAB, 2005;

6.4 A draft list of mean flows based on measurements at primary sites in the Waitaki Catchment prepared by Environment Canterbury, 2009 as part of a draft Water Resources Report for the Waitaki Catchment. At this stage this Report is in the publishing process but the list of mean flows is not expected to change;

6.5 Cumulative Water Quality Effects of Nutrients from Agricultural Intensification in the Upper Waitaki Catchment: Summary Report – prepared for Russell McVeagh on behalf of Mackenzie Water Research Ltd for GHD, April, 2009;

6.6 Cumulative Water Quality Effects of Nutrients from Agricultural Intensification in the Upper Waitaki Catchment: Rivers and Lakes Report - prepared for Russell McVeagh on behalf of Mackenzie Water Research Ltd for GHD, April, 2009;

6.7 The Section 42A Reports of **Mr Stewart** and **Mr Heller**.

SCOPE OF EVIDENCE

7 In this evidence I outline:

7.1 The natural hydrology of the Upper Waitaki Catchment;

7.2 The hydro power development hydrology of the Upper Waitaki Catchment, including a discussion on the frequency and size of flow releases in the Tekapo River, Pukaki River, Upper Ohau River and Lower Ohau River; and

7.3 My comments on the mass balance assessment that has been completed by MWRL in the GHD Rivers and Lakes Report and the implications for the overall conclusions made regarding nutrient loads in the waterbodies of the Upper Waitaki Catchment.

NATURAL HYDROLOGY OF THE UPPER WAITAKI CATCHMENT

8 The main feature of the Upper Waitaki Catchment, in terms of both scenery and hydrology, is the presence of the main divide of the Southern Alps. This forms a continuous barrier ridge with an average height of around 2,500 metres across the northwest boundary of the catchment.

9 Lakes Tekapo (1951-1953) and Pukaki have both been raised by the building of dams or control structures. In the case of Lake Pukaki this has occurred twice; firstly between 1946 and 1957 and then again in 1979. Lake Ohau is also used as part of the Waitaki Power Scheme. Its outlet is controlled by a low level weir so its outflow is less controlled than Lake Tekapo and Pukaki.

10 The middle portion of the Waitaki Valley consists of gorge and valley sections cut through the Benmore and Kirkliston Ranges to the north, and the St Mary's Range south of Otematata and Kurow. The hydro-electricity dams at Benmore, Aviemore and Waitaki utilised favourable sites within this more confined portion of the Waitaki Valley.

11 The main divide and upper catchments of Lakes Tekapo, Pukaki and Ohau receive more than 8,000 mm of rain per annum. Mt Cook Hermitage (1930-1999) has a mean annual rainfall of 4,195 mm. This decreases sharply to Braemar Station (1914-2001) with 892 mm, on the eastern side of Lake Pukaki. In a distance of 70 km, from the Hermitage to Grays Hills Station, the annual rainfall falls from 4,195 mm to 456 mm. The southern and eastern side of the Mackenzie Basin is the driest area of the Upper Waitaki Catchment.

12 Moving down the Waitaki Valley the annual rainfall increases from 467 mm at the Benmore Dam to 515 mm at the Waitaki Dam. Towards the coast the rainfall increases slightly as easterly and southerly storms are able to penetrate this area, giving Duntroon an annual rainfall of 548mm. Oamaru, on the coast, receives around 500 mm of rainfall per year.

13 By far the most important part of the Upper Waitaki Catchment in terms of rainfall input and river flows is the 10 km headwater zone immediately south east of the main divide, an area which receives in excess of 4 metres of annual rainfall.

14 Systematic recording of lake levels and outflows began in the 1920s, largely for hydro-generation development purposes. For example, recordings for Lake Tekapo began in 1925, Lake Pukaki in 1925, Lake Ohau in 1926 and at the Waitaki Dam site in 1924. Without these long records it would not be possible to have the good understanding of the Upper Waitaki Catchment hydrology that we have today.

15 The natural mean flow at the Waitaki Dam is 362 m^3/s (1931-2004). At this flow, the Waitaki River is New Zealand's fourth largest river by flow, behind the Clutha (570 m^3/s), Waiau (437 m^3/s) and the Buller (428 m^3/s). Although a large river, it is still only about 3.5% of the approximately 10,000 m^3/s which discharges to the sea from all New Zealand.

16 Another key feature of the hydrology of the Upper Waitaki Catchment River is that 289 m^3/s or 85% of the flow at the Benmore Power Station comes from Lakes Tekapo (81.3 m^3/s), Pukaki (127 m^3/s) and Ohau (80.5 m^3/s). These lakes, with their naturally modulated flows and ability to store water, greatly enhance the Waitaki Power Scheme. A natural flow tree has been produced as Annexure 1 to show how the river grows from the upper catchment to the Waitaki Power Station.

17 The strong pattern of seasonal flow variation is shown in Table 1.

Table 1 – Natural mean flows in Waitaki catchment 1931-2004(m^3/s)

Lake Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
L. Tekapo Inflows	120	107	92	82	68	53	43	45	54	83	106	126	81
L. Pukaki Natural Inflows	225	214	178	133	92	67	52	56	69	108	140	197	127
L. Ohau Inflows	111	96	85	80	70	55	43	46	60	92	111	125	81
Waitaki Dam Natural Inflows	527	485	418	362	293	245	199	216	261	370	449	253	362

18 There is a clear, high inflow period from October to March and a low inflow period from April to September. The high ice/snow component inflow for Lake Pukaki means the peak monthly flow is lagged in time (or delayed) by about a month compared with Lakes Tekapo and Ohau.

19 The clear seasonal pattern of inflows is particularly important to Lakes Tekapo and Pukaki because these lakes store water. Of note in that regard:

19.1 For Lake Tekapo 65% of the inflows occur between October and March (6 months) and only 35% between April and September (6 months);

19.2 For Lake Pukaki 71% of the inflows occur between November and April (6 months) and only 29% between May and October (6 months); and

19.3 The strong seasonal inflows means that storage capacity is very important.

20 The inflow-outflow patterns of Lake Tekapo illustrate the natural storage of this and other lakes. This is shown in Table 2.

Table 2– Lake Tekapo mean monthly inflows and outflows (1931 to 2004)

Lake Site	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Inflows (Natural)	120	107	92	82	68	53	43	45	54	83	106	126	81
Outflows (Natural)	122	105	97	90	74	72	75	69	57	60	79	95	81

21 Natural inflows are higher than natural outflows for 4 months of the year and for the rest of the year outflows are higher than inflows. As well as the average seasonal patterns in the lakes there is a lot of variation in annual inflows, that is from year to year.

22 The natural hydrology of the Upper Waitaki Catchment can be summarised as follows:

22.1 strongly seasonal;

22.2 has storage affecting when outflows occur; and

22.3 is highly variable from year to year.

HYDRO POWER DEVELOPMENT HYDROLOGY

23 An outline of the flow paths of the Waitaki Power Scheme is attached as Annexure 2 to my evidence. Details on the configuration of the Waitaki Power Scheme have already been provided in the evidence of **Ms Moss**.

24 The flow path for the Waitaki Power Scheme is much more complex than it was for the natural river. The Waitaki Power Station's mean historic flow for example is less than for the natural river because of water captured in storage during lake filling.

25 The commissioning of Waitaki Power Scheme took place between 1935 and 1985 (50 years), although the most significant period of commissioning was 1965 to 1985 (20 years).

26 Other key installations include the raising of Lake Pukaki in 1979 by the Pukaki High Dam, the installation of the George Scott Dam in association with the Tekapo A and Tekapo B Power Stations and the completion of the Ruataniwha Dam relative to the Ohau Power Stations.

27 The relevance of the commissioning of the various dams and power stations to the hydrology is that there was a progressive introduction of control from 1935 that is reflected in the hydrological records.

28 A significant factor is the control of Lake Tekapo (1951) and the raising of Lake Pukaki in 1979 by the Pukaki High Dam. These two features allow for the reduction of flood peaks in the lower catchment and the storage of inflows for redistribution over time.

Storage

29 The combined main operating range storage for Lakes Tekapo and Pukaki is as follows:

29.1 Lake Pukaki Storage - 25,402 cumec days (a cubic metre per second flowing for 24 hrs)

29.2 Lake Tekapo Storage - 7,792 cumec days ;

30 Because storage contained in Lakes Pukaki and Tekapo is 57% of the national hydro-electricity storage it is a key element in New Zealand's power resource.

31 Monthly mean lake levels for Lakes Tekapo and Pukaki are given in Table 3.

Table 3: Mean monthly levels (m) for Lakes Tekapo and Pukaki (1980-2009).

Lake	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Tekapo	709.1	709.1	709.0	708.9	708.6	708.3	707.5	706.4	705.9	706.5	707.3	708.2	707.9
Pukaki	529.1	530.5	530.5	530.0	529.1	528.4	527.4	526.0	524.5	524.0	524.7	526.4	527.5

River Systems

32 The Tekapo River, Pukaki River, Upper Ohau River and Lower Ohau River are the four sub-catchments of Lake Benmore that are hydrologically controlled by Meridian's consents for the operation of the Waitaki Power Scheme. I will discuss the hydrologically characteristics of each system as follows.

Tekapo River

33 The Tekapo River is 54 km long and flows from Lake Tekapo to Lake Benmore.

34 As outlined in the evidence of **Mr Turner**, Meridian is not required to provide a minimum flow or flushing flows down the Tekapo River under its consents. As a result, the first significant flow contribution to the river comes from the Fork Stream (3.3 m^3/s) and by the time the river reaches Lakes Benmore the mean flow is 9.5 m^3/s. Table 4 below outlines the key flow characteristics of the Tekapo River over its length.

Table 4: Mean flow profile of the Tekapo River (Source: Page 15 of Mr Freestone's WAB Evidence)

Node	Site	Distance (km)	Mean flow (m^3/s)	95%-exceeded flow (m^3/s)
1	Lake George Scott outlet	3.5	0.0	0.0
2	u/s Fork Stream	6.6	0.1	0.1
3	d/s Fork Stream	6.8	3.3	1.3
4	u/s Grays River	34.6	4.0	1.5
5	d/s Grays River	34.8	7.0	3.8
6	u/s Mary Burn	36.7	7.1	3.8
7	d/s Mary Burn	36.9	9.1	4.5
8	u/s Pukaki River	50.0	9.3	4.6
9	d/s Pukaki River	50.2	9.4	4.6
-	Lake Benmore	54.1	9.5	4.7

35 For the period 1 February 1978 to 31 December 2008, the maximum spill flow down the Tekapo River was 280 m^3/s. The mean spill flow was 9.21 m^3/s. The average number of spill events down the river per year was 1.5, but only 0.5 in the period 2000-2008. Spill events can last from one to eight weeks.

Pukaki River

36 The Pukaki River is 17 km long from Lake Pukaki to its confluence with the Tekapo River.

37 **Mr Turner** has already outlined in his evidence that Meridian's consents for the damming of Lake Pukaki do not require it to provide a minimum flow or flushing flows down the Pukaki River. As a result, most flow releases down the river are either for recreational purposes or as a result of the level for the lake exceeding the consented limits.

38 For the period 1 January 1979 to 31 December 2008, the maximum spill flow down the Pukaki River was 1070 m^3/s. The mean spill flow was 19.1 m^3/s. The average number of spill events down the river per year was 1.2, but only 0.3 for the period 2000 to 2008. Spill events can last from one to eight weeks.

Upper Ohau River

39 The Upper Ohau River extends from the outlet of Lake Ohau to Lake Ruataniwha. Of the four river systems identified in Paragraph 31 of my evidence, it is the only one that Meridian is required to release a minimum flow down.

40 The required minimum flow down the Upper Ohau River is 8 m^3/s between May and October and 12 m^3/s between November and April. However, the mean flow down the Upper Ohau River is 12.8 m^3/s.

41 For the period 8 September 1992 to 31 December 2008, the maximum spill flow was 467 m^3/s. The mean spill flow down the river was 12.8 m^3/s. The average number of spill events per year was 1.5.

Lower Ohau River

42 The Lower Ohau River is the section of river from the Ruataniwha Dam to Lake Benmore. The Lower Ohau River effectively runs parallel to the Ohau B – C Canal and there is a spillway from the canal for the purpose of accommodating emergency or outage events at the Ohau B and C Power Stations. The river is 12 km long and its major tributary is the Twizel River (mean flow = 4.6 m^3/s), which discharges into the Lower Ohau River approximately 2 km from its confluence with Lake Benmore.

43 As with the Tekapo and Pukaki Rivers, Meridian is not required by its consents to provide a minimum or flushing flow down the Lower Ohau River.

44 Spill events are extremely rare. Available data do not allow characterisation of the spill flow regime.

45 The Ahuriri River catchment arises near the Man Divide and flows into Lake Benmore, a distance of some 80 km. The mean flow that it contributes to Lake Benmore is 30 m^3/s.

MWRL MASS BALANCE

46 Section 5.1 (Hydrology) of the GHD Rivers and Lakes Report (August 2009) presents material on rainfall distribution and potential evapotranspiration within the Upper Waitaki Catchment, a mass balance for the catchment, mean flows for key tributaries, FRE3 and gains and losses. Section 5.3 (Rivers and Streams) deals with nutrient transport for nitrogen and phosphorous.

47 My comments in this section of my evidence largely relate to what I perceive as shortcomings in Section 5.1.

48 An initial major difficulty in understanding the GHD Report is the different way the Upper Waitaki Catchment has been partitioned for hydrological analysis from that used in previous work by Mr Freestone and Mr Henderson during the WAB hearings. This means that one's ability to compare flow values at various locations with those estimated previously is severely limited. Specifically, the GHD Report adopts a node system shown in Figure 2 (p. 12). While satisfactory as an approach in theory, it suffers from the practical comparison problem mentioned. To overcome this problem it would be necessary, as details are not given in the GHD Report, to recalculate flow values at the GHD nodes from flow records; and as part of that process check the values calculated by Mr Freestone and Mr Henderson at the locations listed by them. I am not aware of any analysis which suggests that the mass balance obtained by Mr Freestone and Mr Henderson is in error.

49 In addition, there is no consideration given as to the standard errors of the various estimates. Because estimates are given, it is essential to have a measure of how reliable they are likely to be: this information is provided by standard errors.

50 Table 7 of the GHD Rivers and Lakes Report identifies the mean annual flow values in millions of cubic metres (Mm^3) for the sub-catchment nodes that have been identified. The figures presented for the Ahuriri River Node at Benmore and the Mary Burn Node appear reasonable. However, I consider in comparison with the work of Mr Freestone and Environment Canterbury that the figure presented for the Stony River Node is too low (should be 54 Mm^3 instead of 34.27 Mm^3), while the figure for the Tekapo Node is not high enough. In this respect, it should be 280 Mm^3 instead of 216.6 Mm^3. I do not know what length of record was used by GHD in making their estimates but I do not believe the difference can be explained by this reason. I have not been unable to verify any of the other numbers presented for the other nodes in Table 7.

51 Figure 8 (p.27) of the GHD Rivers and Lakes Report presents a mass balance for Lake Benmore. The mass balance gives a lake evaporation value of 77.9 Mm^3 (or about 1.10 m). I consider this to be an error when compared with previous estimates of approximately 0.63 m by Tait and Woods (2007, Journal of Hydrometeorology 8:430-438) and unchallenged by GHD. It appears that rain on the lake, a basic component of any water balance, is omitted in Figure 8 of the GHD Rivers and Lakes Report. In the overall water balance the contribution of the difference between the evaporation figures and the omission of rain on the lake are small. However, this omission, which is of the first importance in terms of the theory or principle, reduces my confidence in the mass balance estimates given in Figures 8 to 11 of the GHD Rivers and Lakes Report.

52 In addition, the mass balance prepared by GHD does not make any mention of spill releases from Lakes Tekapo, Pukaki or Ruataniwha. While clarification from MWRL on the treatment of spills was requested, no response was provided at the

time of writing this evidence. It also does not consider the small amount of flow abstraction for irrigation and other uses.

53 In Annexure 2 of my evidence spills total to approximately 30 m^3/s or 1200 Mm^3 which is a significant part of the total water balance at Lake Benmore of 10,721 Mm^3 (Figure 8 of the GHD Rivers and Lakes Report). Both spills and abstractions are a fundamental part of a mass balance. Their omission further reduces confidence in the mass balance estimates of the GHD Rivers and Lakes Report.

54 The flow from the Ohau C Tailrace and upstream catchment (8,223.4 Mm^3) and the total surface outflow (10,723.3 Mm^3) are consistent with earlier work by Mr Freestone.

55 Another value able to be checked is the inflow to Ahuriri Arm, given in Figure 11 (p. 28) as 38.9 m^3/s. Previous estimates by H. Freestone give a value of 30 m^3/s. The reason for this difference is not discussed in the GHD report, and reduces confidence in the mass balance calculations.

56 FRE3, or the mean number of events per year that exceed three times the median flow, have I believe been estimated correctly in Table 8 (p. 31) of the GHD Rivers and Lakes Report as there is a sufficient length of record at the reference sites to make estimation reasonably precise. This point is relevant to the evidence of **Dr Snelder**.

57 The period of record or the reference period for the mass balance is not specified. I consider the need for this information to be critical in order to determine the robustness of the mass balance because the Interdecadal Pacific Oscillation (a recognised, broadscale influence on New Zealand climate) is known to alter mean flow values in the eastern South Island by up to 15% (McKerchar and Henderson, 2003, Hydrological Sciences Journal 48(4): 637-654). It is not possible to assess the impact of this omission on future mean flows without carrying out a detailed mass balance for the upper Waitaki. However it was found by McKerchar and Henderson (2003) that the period 1978-1999 was one of higher flows compared with the period 1947-1977 and 2000-2002. One can expect then, that for the next decade or so, mean flows will be lower but up to 15% than those estimated using, for the most part, the record from 1978-1999.

IMPLICATIONS OF MASS BALANCE ON NUTRIENT CONCENTRATION AND LOAD ASSESSMENT

58 The main importance of the hydrology and in particular the estimation of mean flows is to calculate nitrogen and phosphorous concentrations and loads.

59 It is implied in Section 5.3 (p. 34 et seq.), from the description of the nutrient sampling programme and no mention of flows other than the mean flows, that nutrient loads at a site for both nitrogen and phosphorus were calculated by simply multiplying mean flow by mean concentration. This is a rudimentary and unreliable approach and is a fundamental error with potentially large consequences for the reliability of nutrient loads. The reason is that the relationships between nitrogen concentration and flow, and phosphorus

concentration and flow, are non linear so that simply multiplying mean values together gives biased estimates of loads. To avoid the introduction of significant error as a consequence of this rudimentary approach, an attempt should have been made to establish a rating between nitrogen and phosphorus concentrations and flow at key sites; and to integrate that rating over the flow record in order to compute the load for the period of flow record. The ratings are also needed to predict concentrations at values other than the mean flows. The suggested nutrient sampling regime that should be used to establish such ratings is described in the evidence of **Dr Snelder** and **Ms Sutherland**.

60 Alternatively, automatic water sampling devices are readily available and have been used for decades to help establish concentration ratings. I would recommend that a sampling programme be undertaken at approximately three key sites for preferably a year to establish both nitrogen and phosphorus ratings.

61 Because of the flawed methodology mentioned in Paragraph 59 and doubt about mass balance flow volumes I believe the estimation of existing nutrient loads to the lakes and concentrations in the streams and rivers presented in the Reports are quite uncertain and should not be relied upon in subsequent inferences and calculations, such as setting a cap for nutrients. It is likely there will be a mix of under and overestimation of nutrient loads. In the case of phosphorus, for example, estimation of the mean concentration by GHD is based on samples from low flows whereas most of the nutrient load is carried by flows about five times mean flow. Consequently phosphorus loads could easily be underestimated by 50% or more. But a thoroughgoing analysis is required to quantify this.

RESPONSE TO SECTION 42A REPORTS

62 I have reviewed the Section 42A Report of **Mr Stewart** (Report 2B-Hydrology and Part 1B-Hydrology) and am in general agreement with the details he presents and conclusions he reaches.

63 With regard to the report by **Mr Heller** (Report 4A-Hydrology and Hydrogeology), I do not agree with the methodology used to calculate Nitrogen loads in Appendix A which involves multiplication of mean flows by mean concentrations to estimate Nitrogen loads. This is the same methodology used in the GHD Rivers and Lakes Report. My objections to the methodology are described in Paragraph 59 of my evidence.

RECOMMENDATIONS

64 I recommend that:

64.1 A mass balance be calculated for a specified future time period which takes account of all the input, output and storage variables of a catchment water balance. Standard errors of estimate should be given and allowance made for the effects of the Inter Decadal Oscillation. Where flow estimates differ from those of earlier scientific work, reasons for the differences should be given.

64.2 A sampling programme should be undertaken at three key sites for a period of at least 12 months to establish concentration ratings for nitrogen and phosphorus as functions of water discharge.

CONCLUSIONS

65 Because of the lack of information on data and methodology I am unable to confirm whether the entire mass balance for Lake Benmore has been computed correctly. A number of estimates provide in the Report vary, in places markedly, from earlier work. Much more detail needs to be provided about how values of mean annual flows and volumes were arrived at together with estimates of errors and the reference period for the mass balance before these values can be accepted with confidence.

66 The method used to calculate total nutrient loads of nitrogen and phosphorus delivered to Lake Benmore is flawed. The unreliability of the load estimates is further increased by uncertainty about mean annual flows and volumes. Further sampling of nitrogen and phosphorous concentrations at key sites is required to allow robust estimation of both concentrations in rivers and canals and nutrient loads. Consequently, conclusions based on load values given in the Report should be regarded as speculative.

Dated: 16 September 2009

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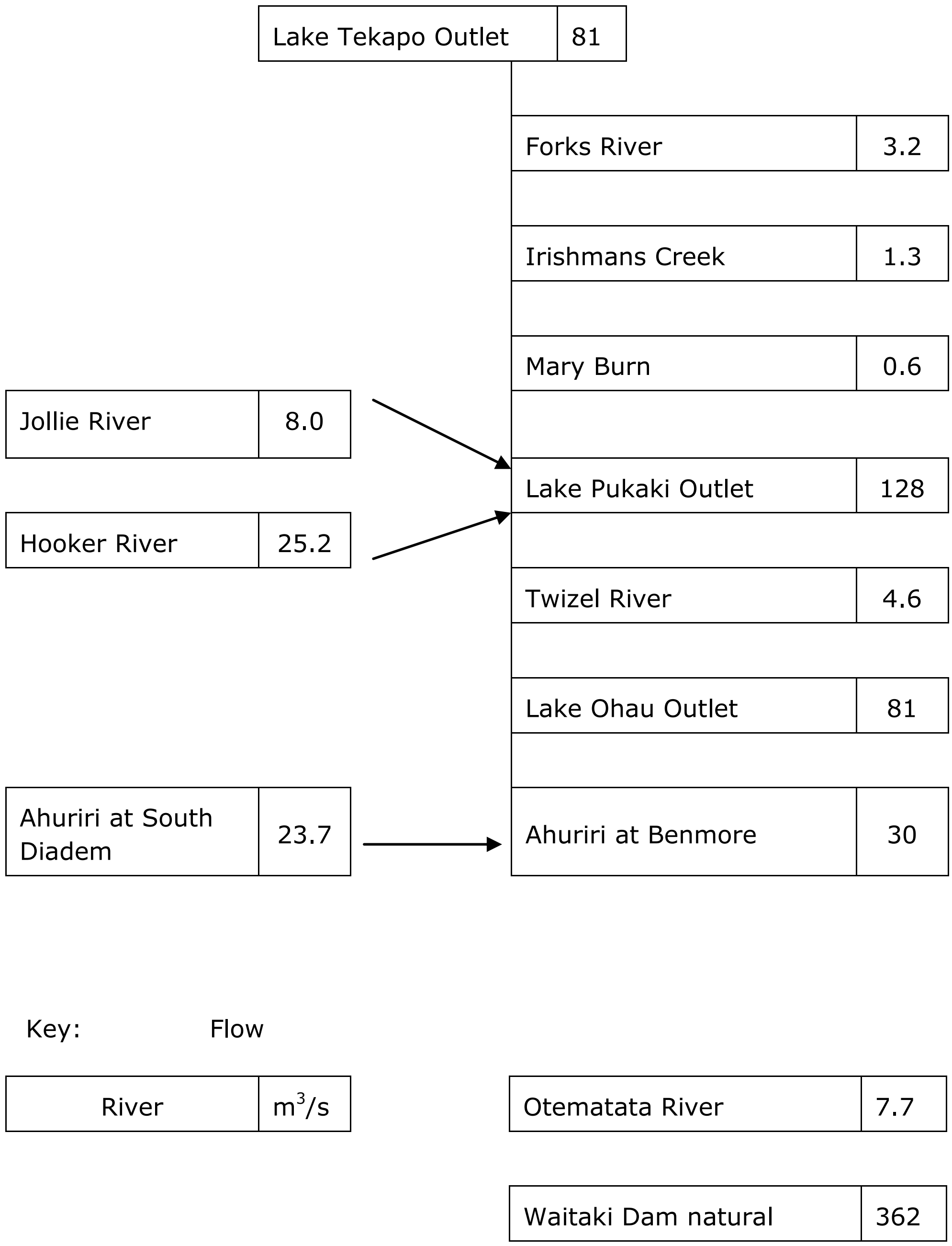
George Griffiths

Attachment 1 Natural Mean Tributary Flows in the Waitaki Catchment (1931 – 2004). All flows are in m^3/s. Flows for sites with records shorter than 1931-2004 are for the full record.



Attachment 2 Mean Flows in the Waitaki Catchment (1931 – 2004). All flows are in m³/s. Flows for sites with records shorter than 1931-2004 are for the full record.