BEFORE THE HEARING COMMISSIONERS

UNDER	the Resource Management Act of 1991
IN THE MATTER	of "Proposed Plan Change 5A (Lindis: Integrated Water Management)" to the Regional Plan: Water
BETWEEN	**OTAGO FISH & GAME COUNCIL**
AND	**OTAGO REGIONAL COUNCIL**

STATEMENT OF EVIDENCE OF RASMUS GABRIELSSON
ON BEHALF OF OTAGO FISH & GAME COUNCIL
1 March 2016

INTRODUCTION

1. My name is Rasmus Mikael Gabrielsson. I have a Bachelor of Science degree in ecology and a post graduate diploma in wildlife management, both from Otago University. I am also currently submitting my PhD thesis titled "Salmonid migration and recruitment patterns" for examination though Otago University.

2. I have worked professionally with issues relating to freshwater ecology and fish populations in New Zealand for eight years. Between 2008 and 2012 I was employed by Otago Fish and Game Council as a fish and game officer, and stationed in Cromwell. Since 2012 I have been employed as a freshwater ecologist by Cawthron Institute in Nelson. I am a member of the New Zealand Freshwater Sciences Society (NZFSS) and the American Fisheries Society (AFS).

3. My main areas of expertise are freshwater and fish ecology and recreational fisheries management. My research has advanced the use of chemical analysis to identify areas of high importance to freshwater fish populations, such as natal habitats and the spatial and temporal extent of migratory movements. I also have knowledge of the responses of fish populations to water abstraction and land use intensification, fish bioenergetics, instream habitat modelling and habitat suitability analyses. I have previously advised and presented evidence for regional hearings, mediation processes, as well as for a Special Tribunal for the Ministry for the Environment for the Kawarau Water Conservation Order.

4. I have conducted both my PhD research and other fisheries work and research projects in the upper Clutha catchment, and this included two studies of the trout population in the Lindis River. I am also a co-supervisor for Mr Morgan Trotter who is completing his MSc studying trout in the Lindis River. As such I have provided advice and assistance with study design, data processing and analysis to assess the impacts of water abstraction on juvenile trout movement and mortality during summer low flows.

5. I confirm I have read, and agree to comply with, the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note 2014. Other than where I specifically state I am relying on what I have been told by another person, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions I express in this statement of evidence.

SCOPE OF EVIDENCE

6. I have been asked by Otago Fish & Game Council to prepare evidence on the adequacy and effectiveness of Otago Regional Council's (ORC) proposed minimum flow for the Lindis River of 0.75 m^3/s (1 October – 30 May), measured at the Ardgour Road flow recorder.

7. My evidence includes:

a. The fishery values and the relative importance of the Lindis River for spawning and rearing of trout from Lake Dunstan and the Upper Clutha River;

b. The impacts of water abstraction and extreme low flow conditions on fish survival;

c. The hydrology of the lower Lindis River and the effect of surface to groundwater losses on residual river flows, habitat suitability, fish passage and survival;

d. The adequacy of the proposed minimum flow regime for sustaining fishery values;

e. Methods for assessing instream flow requirements, including hydraulic-habitat modelling and more recent methods such as net rate of energy intake (NREI) modelling, and their value for informing environmental flow regimes;

f. An assessment of nutrient levels, periphyton and cyanobacteria cover and water temperatures and consequences for instream life.

8. In preparing my evidence I have reviewed the following reports, statements of evidence and datasets:

a. Expert evidence by Mr Morgan Trotter (flows required to maintain the life-supporting capacity of the Lindis River);

b. Expert evidence by Mr Jens Rekker (hydrology evidence on surface and groundwater interactions along the lower Lindis River);

c. A study of the flow requirements for maintaining fish habitat in the Lindis River, prepared for Otago Regional Council by Jowett and Wilding (2003);

d. Several Otago Regional Council staff reports and data sets on the water quantity, quality and ecology of the Lindis catchment (see the reference section for details);

e. A review of the science supporting the proposed minimum flow regime for the Lindis River prepared by NIWA (Horrell 2014);

I also refer to peer-reviewed scientific articles as listed in the reference section, and national policy documents by the Ministry for the Environment such as the “National Policy Statement for Freshwater Management (NPSFW)”, “Flow guidelines for instream values” and the draft guidelines from the proposed “National Environmental Flow Standard (NES)”.

2. EXECUTIVE SUMMARY

Fishery values in the Lindis River

9. The Lindis River has a diverse fish fauna and several tributaries also support fragmented populations of native fish, of which the Clutha flathead galaxiid (*Galaxias sp. D* – nationally critical) and longfin eels have threatened conservation status.

10. The Lindis River supports significant trout spawning and nursery values, and provides an important contribution to the resilience of the nationally important recreational fishery in Lake Dunstan and the Upper Clutha River. The Lindis is estimated to provide spawning grounds for about 30% of Lake Dunstan’s migratory brown trout population.

11. The sports fish and gamebird management plan for Otago classifies the Lindis as a locally important trout fishery. However, adult trout habitat in the lower river has been severely degraded by water abstraction and the river no longer maintains a quality resident adult trout fishery.

Impacts of water abstraction and extreme low flow conditions on fish survival

12. Water abstraction causes extreme low flows (<16% of the naturalised 7-day mean annual low flow (MALF) at the Ardgour Road flow recorder) and loss of fish passage, which has been shown to result in the death of approximately 70% of the juvenile trout population within eight weeks.

Observations suggest smaller native fish (i.e. common and upland bullies) are likely to experience comparable levels of mortality.

13. Analysis indicates increased predation pressure, due to reduced habitat cover (i.e. loss of undercut banks and overhanging riparian vegetation), rather than adverse thermal or low dissolved oxygen stress, was the primary cause of juvenile trout mortality.

14. Comparisons with other studies show that the mortality rates experienced by juvenile trout in the Lindis, as a result of water abstraction and loss of fish passage, are at least two times higher than what would be expected under natural conditions.

Hydrology – losses of surface flows to groundwater

15. The lower Lindis River (below Cluden Stream) has a complex hydrology that is heavily influenced by water abstraction and losses of surface flow to groundwater during the summer low flow period.

16. Under the proposed minimum flow regime (0.75 m^3/s from October to May) losses to groundwater will result in most (over 70%) of the lower Lindis River having less flow than that measured at the flow recorder.

Adequacy of the proposed minimum flow

17. Otago Regional Council's (ORC) proposed minimum flow regime of 0.75 m^3/s is based on physical habitat surveys using the instream flow incremental methodology (IFIM), which indicated that juvenile trout habitat in the lower Lindis River declines sharply at flows below 0.75 m^3/s.

18. The proposed minimum flow represents a high degree of flow alteration in comparison to naturalised flow statistics. In other words it is 40% of the estimated naturalised 7-day mean annual low flow (MALF = 1.86 m^3/s), and less than the 1 in 50 year naturalised 7-day low flow.

19. Failure to account for losses to groundwater and differences in surface flows between the Ardgour Road flow recorder and the IFIM survey reach (located further downstream), which the proposed minimum flow was based upon, will result in over 70% of the lower Lindis having less flow than recommended for retaining sufficient suitable habitat to sustain juvenile brown

trout. Losses to groundwater also mean that the proposed minimum flow will not maintain suitable depths to provide adequate fish passage to the Clutha River, or for unhindered fish movement within all of the lower Lindis River.

20. Furthermore, recent research shows that recommendations from the most state-of-the-art method for assessing instream flow requirements, the drift-Net Rate of Energy Intake (NREI) model, would support a higher minimum flow and lower allocation limit for maintaining populations of drift feeding fish than proposed by traditional IFIM.

Water quality – consequences for instream life

21. Monitoring data shows that while the water quality in the upper Lindis River is generally very good, the lower catchment has high concentrations of total nitrogen (TN). Similarly while periphyton cover/biomass is low in the upper river, higher levels in the lower river indicate nutrient enrichment and low flows. The lower Lindis also has high levels of cyanobacteria (*Phormidium*), which is toxic to dogs and poses a risk to human health.

22. I expect that continued increases in TN concentration in the Lindis catchment, associated with ongoing agricultural intensification and heavy water abstraction, will result in adverse effects on macroinvertebrate communities.

Conclusion

23. It is my opinion that ORC's proposed minimum flow regime does not adequately provide for the flow requirements of fish and their invertebrate food resources.

24. In my opinion a minimum flow of 1.25 m^3/s (measured at the Ardgour Road flow recorder) would ensure all of the lower Lindis River achieves the minimum level of habitat retention recommended by physical habitat modelling; this equates to 67% of the naturalised MALF. I understand this is higher than the 1.0 m^3/s that Otago Fish and Game Council have recommended in their submission.

FISHERY VALUES IN THE LINDIS RIVER

25. The Lindis River has a diverse fish fauna and supports significant trout spawning and nursery values. Several tributaries also support fragmented populations of native fish, of which the Clutha flathead galaxiid (*Galaxias* sp. D – nationally critical) and longfin eels have threatened conservation status.

26. In the following paragraphs I first review adult trout fishery values, before more closely considering the Lindis River's role as a spawning and rearing area for migratory trout (paragraph 33 – 38).

27. The Lindis River is classified as a locally important recreational trout fishery[1]. However, fishery significance and importance rankings are primarily based on angler use. Hence, with the degraded nature of the fish habitat and fishery resulting from water abstraction there is limited use of the river by anglers. Adult trout habitat in the lower river in particular has been degraded, such that the river no longer maintains a quality resident adult trout fishery.

28. The estimated naturalised 7-day mean annual low flow (MALF) (without abstraction) in the lower Lindis is 1.86 m^3/s, which provides continuous fish passage to and from the Clutha River and moderate amounts of adult trout habitat[2]. Yet the measured 7-day summer low flow is only 0.26 m^3/s, or less than 15% of the naturalised low flow estimate[3]. Given the lack of flow in summer it is not surprising there are few adult trout in the lower half of the Lindis River.

29. Mr Trotter expects angling values and adult trout numbers to increase with the restoration of summer flows to a level approaching the naturalised MALF[4]. I agree on this point. The nearby upper Clutha River and Lake Dunstan (both classified as nationally important recreational fisheries) support substantial trout populations which would populate the Lindis if abstraction did not severely reduce the flows.

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[1] Otago Fish & Game Region Sports Fish and Game Management Plan (2015-2025).

[2] Jowett & Wilding 2003.

[3] ORC Science update 2016a.

[4] Trotter Evidence in Chief paragraph 84 and 85.

30. Hydraulic-habitat modelling[5] shows that available adult trout habitat continues to increase with flow up to around 4.0 m^3/s. Hence I conclude that under natural, or semi-natural flow conditions, the Lindis River would have every opportunity to be a well-stocked trout fishery fully comparable to other rivers of similar size offering good angling for both river resident and lake migratory trout.

31. Few records exist of what the angling quality was like in the Lindis before irrigation races began taking most of the surface flow. However, the Otago Witness newspaper did report on January 17th in 1906 that the Holden brothers spent a couple of days fishing on the Lindis River, and that they caught 21 trout, including a 5-pounder[6].

32. The upper Clutha region is a popular holiday destination, with three population centres (Wanaka, Cromwell and Queenstown) nearby, and popular with kiwi and overseas anglers. Angling pressure on available fishing waters is increasing so, in my opinion, the Lindis River would under natural flows be a valued trout fishery.

Trout spawning and rearing areas in the Upper Clutha catchment

33. Lake Dunstan ranks as the fourth most used lake/reservoir fishery in the South Island[7]. However, while the lake provides excellent trout feeding habitat and recreational angling opportunities, these values are dependent on the spawning and juvenile rearing areas that support its migratory trout populations.

34. The Lindis has long been considered to be an important recruitment source for trout in Lake Dunstan and the Upper Clutha River[8], and is estimated to be the spawning grounds for about 30% of Lake Dunstan's brown trout population (see Table 1 below).

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[5] Jowett & Wilding 2003.

[6] Papers Past, accessed 15 February, 2016.

[7] Unwin 2009.

[8] Turner 1985; Jellyman and Bonnett 1992 and Jellyman and Graynoth 1993.

35. Counts of redds (trout nests) have often been used for monitoring the spatial distribution of salmonid spawning. Spawning surveys / redd counts conducted by the Clutha Fisheries Trust and Otago Fish & Game provide evidence that on average about 30% of the observed spawning effort associated with Lake Dunstan's brown trout population occurs in the Lindis catchment (Table 1). Most of the spawning redds (over 70%) are observed in the lower 25 km of the Lindis catchment.

Table 1. Data on the proportional use of spawning areas across the Upper Clutha catchment based on redd counts during the 2009 – 2011 spawning seasons.

Location	Percentage observed spawning effort (± SD)		
	Mean (2009-2011)	Range	CV
Lindis River	31.7 (± 4.2)	26 – 36%	0.16
Clutha River	49.7 (± 4.8)	43 – 54%	0.12
Luggate Creek	5.0 (± 2.2)	3 – 8%	0.53
Lake Dunstan tributaries	9.7 (± 3.3)	6 – 14%	0.42
Kawarau River & tributaries	4.0 (± 0.8)	3 – 5%	0.25
In total	*100%*		

36. The most likely reason for the high proportional use of the Lindis by spawning trout is a combination of its close proximity to Lake Dunstan (less than 8 km away), an abundance of suitable spawning habitat, and natural flow regime during winter and spring. In comparison, flows in the Clutha River frequently vary by more than 100 m^3/s during the brown trout spawning and egg rearing period (May – Oct) as a result of hydro-power generation. Such a variable flow regime presents a high risk of egg mortality as redds in shallow areas and side channels are vulnerable to being either dewatered during low flows or scoured out by high flows.

37. Chemical markers in fish ear stones (otoliths) or eggs provide a powerful way to answer fundamental questions in fish ecology, conservation, and resource management because they can reveal recruitment sources and movement patterns (see Appendix for further details). My PhD research

focused on advancing and applying chemical analysis techniques to identify areas of high importance to freshwater fish populations, such as natal habitats and the spatial and temporal extent of migratory movements. As a part of this work I studied the role of the Lindis River as a recruitment source for Lake Dunstan's brown trout population.

38. Results show that migratory brown trout dominate the observed spawning activity in the lower 30 km of the Lindis River (see paragraph 35), but also to a lesser degree utilise headwater areas[9]. Reconstructed fish length at emigration from the Lindis River, based on chemical profiles of adults captured in Lake Dunstan, revealed juveniles remain in the Lindis River for about a year and typically emigrate at an average size of 120-140 mm.

39. The combination of the use of chemical analysis (Sr isotope ratios) in otoliths from adult trout captured in Lake Dunstan and eggs from spawning redds made it possible to clarify that while the Lindis River is drawing in a high proportion of Lake Dunstan's migratory spawners (i.e. about 30%) it currently returns fewer recruits than expected (11%). A subsequent study associated this discrepancy with fragmentation and loss of connectivity during low flows, which implicate water abstraction and a lack of fish passage as the cause of the Lindis River acting as a recruitment sink (see next section for details).

IMPACTS OF WATER ABSTRACTION AND EXTREME LOW FLOW CONDITIONS ON FISH SURVIVAL

40. Research conducted by Otago Fish & Game and the Cawthron Institute has revealed that juvenile trout survival and movements in the Lindis River are highly dependent on summer flow conditions[10]. To assess the impacts of water abstraction and low residual summer flows we studied juvenile trout survival in two reaches of the lower Lindis River using passive integrated transponder (PIT) tags (see evidence by Mr Trotter). Both reaches were disconnected from the rest of the river and each other by smaller drying reaches (less than 100 m in length). The lower study reach was 2 km long, and was located upstream of the SH8 road bridge (i.e. Lindis Crossing). It had a high level of low-flow stress with approximately 50% of the reach length

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[9] Gabrielsson 2016 - see Appendix.

[10] Trotter et al. 2016; Gabrielsson 2016.

drying up from the lower end but also became fragmented in several places as shallow riffles dewatered. The upper study reach was 1 km long, extending upstream from a few hundred meters below the Ardgour Road flow recorder. It had an intermediate level of low-flow stress with approximately 10% drying at the upper/lower end. The results from the two reaches reveal how flow is related to fish survival (Figure 1, Table 2 & 3).

41. Extreme low flows due to water abstraction and related loss of fish passage resulted on average in the death of more than 70% of the juvenile trout population within an eight-week period (Figure 1). The combined analysis of environmental conditions, physical habitat features and observations using motion cameras indicate that increased predation pressure, due to reduced habitat cover (i.e. loss of undercut banks and overhanging riparian vegetation), rather than adverse thermal or low dissolved oxygen stress was the primary cause of mortality. While not directly measured, observations suggest native fish (i.e. common and upland bullies) are likely to experience comparable levels of mortality.

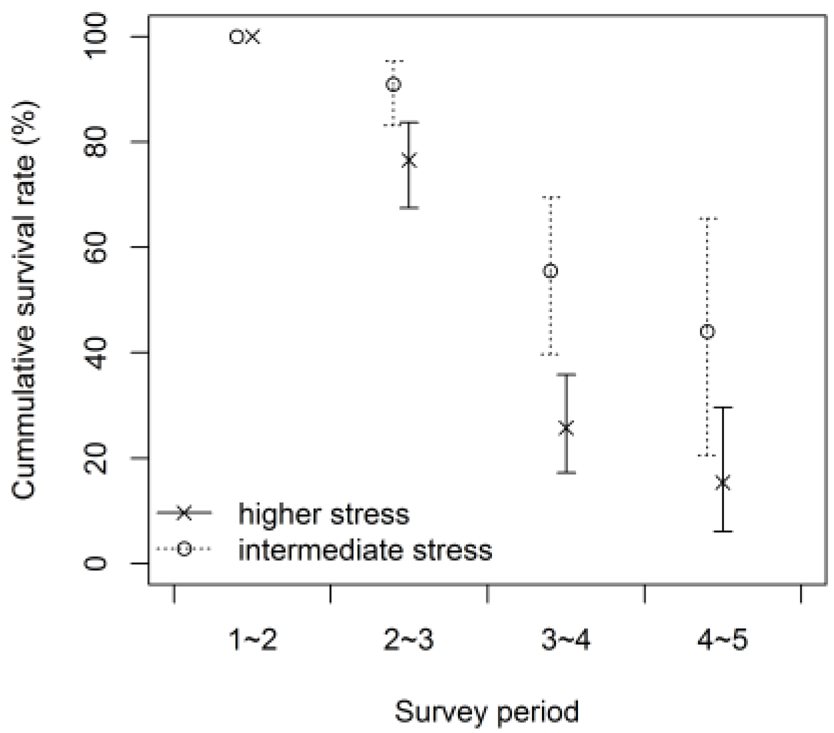

Figure 1. Total (cumulative) survival rate for juvenile brown trout in the lower Lindis River over the period 7 Jan – 6 March 2015 (i.e. 59 days), as predicted by the Cormack-Jolly-Seber model used to conduct a mark-recapture analysis. The intermediate stress reach had <10% dewatering at the upper/lower end, whereas the higher stress reach had 50% dewatering and habitat fragmentation in several places.

42. In the intermediate-stress reach, where the daily flow over the study period averaged 0.29 m^3/s (range 0.22–0.44 m^3/s) only 44% of the juvenile trout survived after the eight week study period (59 days) (Table 2 & 3). To put this in perspective, comparisons with another study show that the lowest mortality rates experienced by juvenile trout in the Lindis are still two times higher than natural levels. In the Rainy River, which is not impacted by water abstraction, show over 70% survival of juvenile brown trout over a nine month period[11]. The primary cause of mortality in that study was winter floods. Hence, the combined effects of abstraction and lack of fish passage subjects the juvenile trout population in the Lindis to a doubling of natural mortality rates over their first year.

Table 2. Cumulative survival rate for juvenile brown trout in each study reach of the Lindis River at the end of the study period (59 days). The intermediate stress reach had less than 10% dewatering at the upper/lower end, whereas the higher stress reach had 50% dewatering and habitat fragmentation in several places.

Habitat	**Survival**	**95% CI (range)**
Intermediate stress	44%	21 – 66%
Higher stress	15%	6 – 30%
Combined	22%	10 – 38%

Table 3. Details on the flow conditions at the downstream end of the intermediate stress zone over time during the 2015 PIT tagging study. The mean daily flow for the whole period was 0.29 m^3/s (range 0.22 – 0.44 m^3/s).

	Survey period			
	1 – 2	2 – 3	3 – 4	4 – 5
Mean daily flow (m^3/s)	0.36	0.25	0.29	0.30
Flow range (m^3/s)	0.30 – 0.44	0.22 – 0.31	0.25 – 0.37	0.24 – 0.36
Days since tagging	1 – 7	7 – 21	21 – 38	38 – 59

[11] Holmes et al. 2013; Hayes et al. 2010.

Fish passage and outmigration behaviour of juvenile trout

43. In general during their outmigration from nursery streams juvenile trout often form shoals, which is a strategy thought to reduce individual risk of predation[12]. The fish also often migrate downstream near the surface in the middle part of the river channel with the highest water velocities.

44. Initially outmigration mostly takes place at night and higher flows, which is another avoidance tactic against visual predators. However as water temperatures rise and nursery streams (habitat) shrinks, due to low flows, juveniles often begin migrating during daytime[13]. In the Lindis observations show daytime movements become increasingly common as dewatering and habitat fragmentation begin to first slow and finally hinder fish passage[14].

45. Much of the water taken from the lower Lindis is currently taken via unscreened irrigation races. At lower flows the lead arms in the main river channel that serve these takes block fish from migrating up or down the Lindis River. However at higher flows they also act to divert migrating fish away from the main river into irrigation races (Figure 2).

46. Research in Canterbury has shown that large numbers of juvenile salmonids (< 70 mm) can become diverted into unscreened irrigation races each year[15]. That study highlights the need to also carefully consider how water is abstracted from rivers, and that there is a large risk that lead arm structures and unscreened irrigation races will block fish passage and cause significant losses of outmigrating juveniles. This adds further adverse effects to fish populations that are already being impacted by water abstraction in the main river.

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[12] Jonsson & Jonsson 2011.

[13] Jonsson & Jonsson 2011.

[14] Personal observation, R. Gabrielsson.

[15] Unwin et al 2005.

A

B

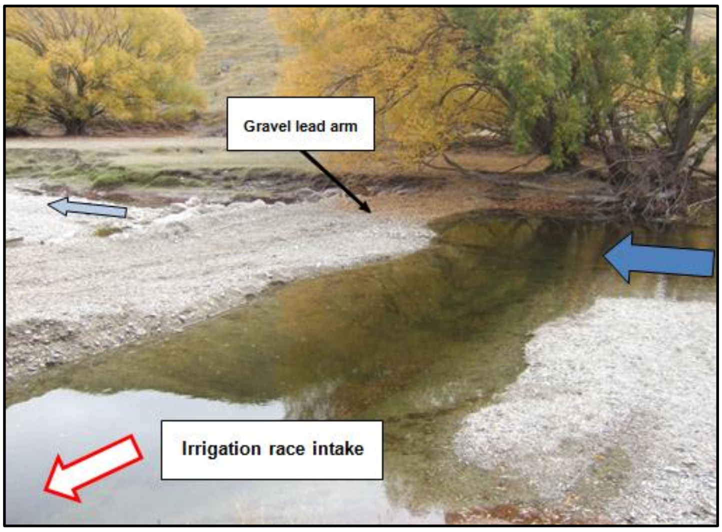

Figure 2. Aerial overview (A) and a close up (B) of the gravel lead arm of one of several unscreened irrigation races that completely or largely block fish migration in the lower Lindis River during summer low flows. The downstream direction of river flow in each picture is illustrated by blue arrows while water diversion is shown in red. Site photos were supplied by A. Horrell from the Clutha Fisheries Trust.

HYDROLOGY – LOSSES OF SURFACE FLOWS TO GROUNDWATER

47. In May–September, outside of the irrigation season, flow variability patterns at the upper and lower flow monitoring sites in the Lindis are very similar, but the lower site has a higher flow indicative of tributary contributions below the upper flow monitoring site. However, during the irrigation season the hydrology of the lower 25 km of the Lindis River (below Cluden Stream)

becomes heavily influenced by both water abstraction and surface and groundwater interactions[16].

48. The combination of large surface water takes and losses to groundwater result in large spatial variations in surface flow along the lower Lindis. This has implications for how effective a minimum flow set at the Ardgour Road flow recorder site will be at representing the state of flow, retention of suitable habitat for fish and preservation of fish passage throughout the lower Lindis River.

49. Monitoring by ORC has shown that when surface flows at the Ardgour Road flow recorder fall below 1.6 m^3/s surface flow at the Clutha River confluence (around 4.5 km downstream) can begin to diverge rapidly from those at the Ardgour Road recorder site[17]. The loss of surface flow to groundwater results in two long drying reaches (Figure 3).

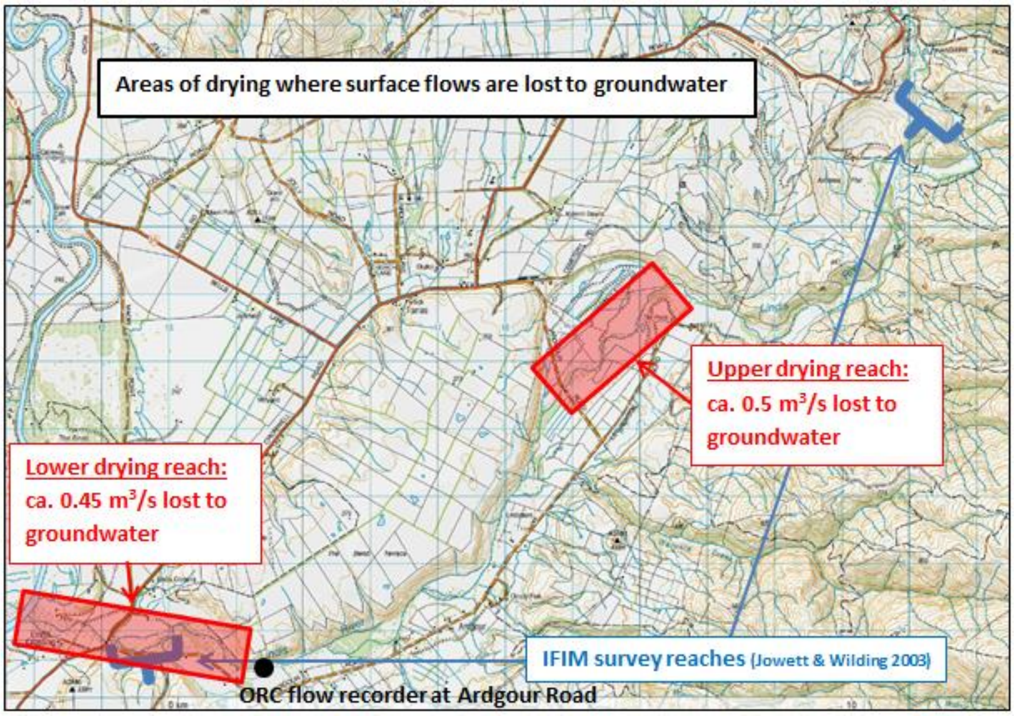

Figure 3. Illustration of where the upper and lower drying reaches are located in relation to the Instream Flow Incremental Methodology (IFIM) survey reaches and Otago Regional Council flow recorder at Ardgour Road.

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[16] ORC reports 2008, 2010 and 2016ab.

[17] ORC report 2008, 2010 & 2016ab.

50. During stable low flow periods ORC estimate the average loss rate in the lower and upper drying reaches to be about 0.45 and 0.50 m^3/s respectively (Figure 3)[18]. However the loss rate is also understood to be temporally variable and partially dependent on groundwater levels (see evidence by Mr Jens Rekker). Consequently, net losses ranging from 0.5-1.0 m^3/s have been measured in the lower drying reach between the Ardgour Road flow recorder and Clutha River confluence at times[19].

51. Large surface water takes located above or within these drying reaches will substantially exacerbate the effects of low summer flows on the habitat quality, fish passage and life supporting capacity in the lower Lindis River[20]. For example, Mr Trotter's study shows that reducing stream flows to < 0.45 m^3/s can have significant adverse effects on fish survival in the lower river[21] (see paragraph 41-42).

52. In my opinion, the effects of the complex hydrology and expected losses of surface flow to groundwater have not been adequately considered in the proposed minimum flow regime. Failure to consider this interaction has resulted in a contradictory situation where ORC accept recommendations by Jowett & Wilding (2003) that an environmental flow of 0.75 m^3/s is required to ensure sufficient juvenile trout habitat is preserved in the lower river. However, the proposed minimum flow makes no allowance for the fact that the Ardgour Road flow monitoring site is located at the end of a gaining reach, which makes it a poor representation of residual river flows over most (more than 70%) of the lower 15 kilometres of the Lindis River.

53. To visualise the effects of losses to groundwater I have modelled residual river flows for the lower 15 km of the Lindis River in Figure 4. This assessment was based on the quantified average loss rates of surface flow to groundwater in the upper and lower drying reaches measured by ORC, complemented by longitudinal flow profile gauging on the rate of recharge between Ardgour Road bridge and the flow recorder done by Cawthron Institute (February 2016).

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[18] ORC 2010 and 2016ab.

[19] ORC 2010 Figure 4.8.

[20] Aerial habitat surveys by CFT 2014 and 2015.

[21] Trotter et al. 2016.

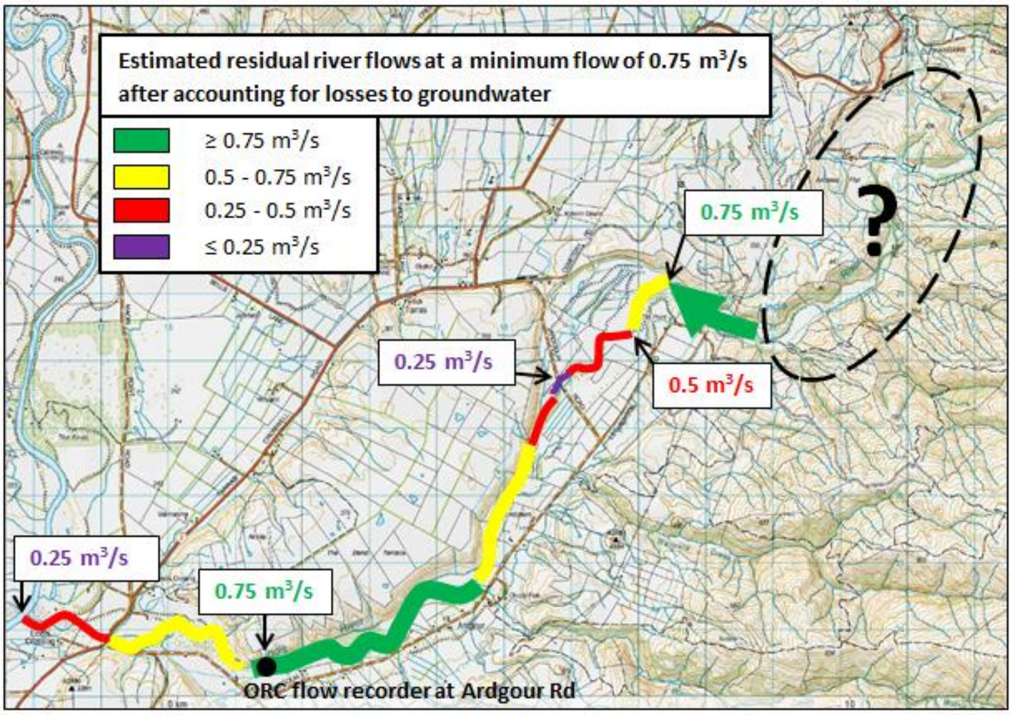

Figure 4. Illustration of where modelled surface flows along the lower Lindis River fall below the proposed minimum flow of 0.75 m^3/s measured at the Ardgour flow recorder. Based on data from Otago Regional Council regarding quantified loss rates to groundwater, and longitudinal flow profile gaugings undertaken by Cawthron Institute (February 2016).

54. While it is important to note that Figure 4 does not capture the influence of temporal variations in loss or recharge rates, it does provide an insight into how spatially-variable residual river flows are likely to be in the lower Lindis. Figure 4 shows ORC's proposed minimum flow of 0.75 m^3/s at the Ardgour Road flow recorder will result in large sections of the lower Lindis having significantly less surface flow than recommended by the IFIM study—i.e. over 70% of the lower Lindis River will have a surface flow of less than 0.75 m^3/s, and about 30% of the lower river a flow of less than 0.5 m^3/s (Figure 4).

55. Variations in surface flow influence how much of a river that provides adequate depth for fish passage. The contiguous (maximum connected) width in a riffle cross-section with the required minimum depth and velocity provides a precautionary measure of fish passage as it represents the widest uninterrupted section across a riffle that has suitable depth and velocity for fish passage.

56. While the most flow sensitive areas of the lower Lindis have not been surveyed (see Figure 3) the available data does provide some indications of

how fish passage changes with flow. I used the RHYHABSIM (River Hydraulic Habitat Simulation, Jowett Consulting) software package to model how changes in flow influence the contiguous amount of suitable water depth for fish passage, based on data collected from the lower Lindis IFIM survey reach[22]. Results show that the contiguous passage width with sufficient minimum water depth for fish passage for adult trout (over 20 cm depth) sharply as flows drop below 0.5 m^3/s (Figure 5).

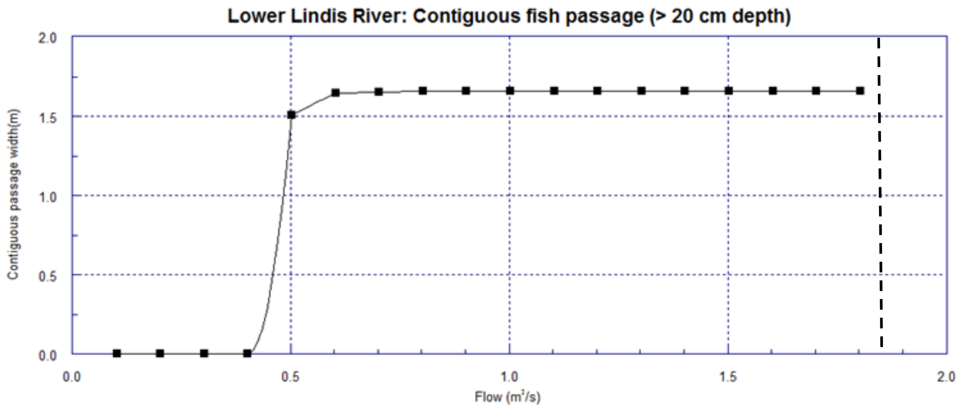

Figure 5. Relationship between flow and the availability of contiguous (maximum connected) fish passage for adult trout (> 20 cm depth) for riffle cross-sections in the lower Lindis River (based on RHYHABSIM data collected by Jowett & Wilding 2003). The dashed line indicates the mean annual low flow (MALF = 1.86 m^3/s).

57. When the spatial flow patterns in Figure 4 are considered together with flow related changes in fish passage from the river reach that has been surveyed (Figure 5) and trout survival estimates (paragraph 41–42) they collectively demonstrate the significant adverse effects that a lack of fish passage and prolonged exposure to low flows (less than 0.45 m^3/s in this specific reach) can cause.

58. I conclude that the proposed minimum flow of 0.75 m^3/s is not likely to prevent adverse effects on fish populations from water abstraction, because it fails to account for losses of surface flow to groundwater and ecosystem effects such as increased vulnerability to predation at very low flows when fish passage is restricted.

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[22] Jowett & Wilding 2003.

ADEQUACY OF THE PROPOSED MINIMUM FLOW REGIME

59. The Otago Regional Council have proposed the following minimum flow regime for the Lindis River:

> "From 1 October to 30 May:
>
> A minimum flow at the Ardgour flow recorder site of 0.75 m^3/s
>
> A primary allocation limit of 1.0 m^3/s
>
> From 1 June to 30 September:
>
> A minimum flow at the Ardgour Road recorder site of 1.6 m^3/s."

60. In the previous section of my evidence I pointed out that the proposed minimum flow regime fails to adequately account for losses to groundwater which results in large sections of the lower Lindis having a much lower flow than is measured at the flow recorder (see previous section). I also note that the proposed minimum flow regime also does not adequately provide for the needs of adult trout.

61. The proposed minimum flow between 1 October to 30 May appears to be based on IFIM habitat modelling by Jowett & Wilding (2003), which indicated that juvenile trout habitat in the lower Lindis River declines sharply below 0.75 m^3/s. However it is worth noting that they did not survey the most flow sensitive sections of the lower Lindis (see Figure 3 & 4). So the recommended minimum flow of 0.75 m^3/s is likely to be an underestimate of juvenile trout flow requirements.

62. While instream habitat surveys using IFIM have been widely applied to set minimum flows throughout New Zealand, they have at times been contentious[23]. This is because while habitat suitability can strongly influence the distribution and abundance of fish in rivers, it is not the only influence. For example, the presence of suitable food resources or adequate river connectivity may be overlooked. In addition, habitat modelling predictions are

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[23] Hudson et al. 2003. A critique of IFIM.

sensitive to both the selection of survey reaches and the types of habitat suitability curves (HSC) used to make the assessment[24].

63. I have reviewed the HSC used by Jowett and Wilding and conclude that they do not include alternative, more flow-demanding curves available. The resulting predictions may, therefore, underestimate the flow requirements of juvenile trout habitat. However, the influence of not including a wider range of available HSC is likely to be far outweighed by ORC's decision to not account for the differences in the flows measured at the Ardgour Road flow recorder and the lower IFIM survey reach (located below the flow recorder upon which the 0.75 m^3/s minimum flow recommendation was based – see Figure 3).

64. Moreover, recent research by my Cawthron colleague Dr John Hayes suggests that traditional hydraulic-habitat modelling may underestimate the flow requirements of drift feeding trout. Dr Hayes and colleagues developed a new process-based model that accounts for the effects of flow change on the drifting invertebrate food that trout eat and the energetics of drift feeding by the trout[25]. A recent study on the Mataura River comparing the predictions of RHYHABSIM (the traditional hydraulic-habitat model used in the Lindis IFIM study) with the new drift-NREI model found that the NREI model predicted substantially higher adult trout flow requirements[26]. The NREI model predicted that feeding opportunities, growth and carrying capacity would keep increasing through the MALF and beyond into mid-range flows, whereas RHYHABSIM predicted habitat would be optimised below or just above the MALF, depending on the choice of habitat suitability curves used.

65. Dr Hayes' comparative modelling study highlights that assessing the flow needs of drift-feeding fish is more complex than has previously been recognised, and that the effects of flow on invertebrate drift also needs to be accounted for. The take-home message from the drift-NREI model is that more flow (over the low to mid-range) is better because it sustains more invertebrate transport which will provide better feeding opportunities for drift feeding trout. This in turn will translate to higher growth rates and stream

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[24] Jowett et al. 2008.

[25] Hayes et al. 2007.

[26] Hayes et al. in press.

carrying capacity for trout. The same principle applies to drift-feeding native fish, which include the Clutha flathead galaxiid and koaro.

66. While the Mataura predictions were for adult brown trout, the predictions of both the NREI and RHYHABSIM models scale with fish size in smaller rivers. That is, similar differences can be expected between the models for juvenile trout in the smaller Lindis River.

67. The predictions of the NREI model are supported by recent research overseas. A relevant example for the Lindis, a study on juvenile Atlantic salmon in a small Massachusetts river, showed that growth rate increased linearly through the low flow range into the mid-flow range in spring-summer-autumn (Figure 6)[27].

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[27] Armstrong and Nislow 2012.

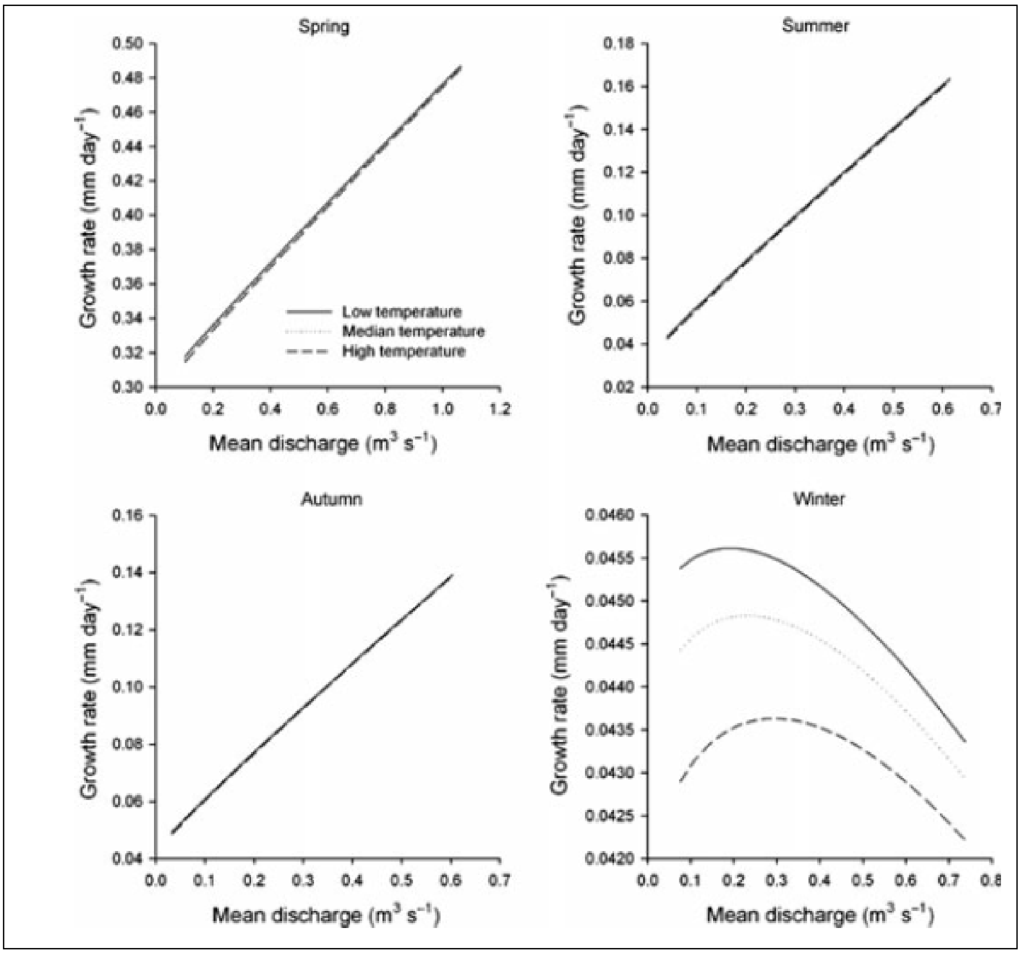

Figure 6. Relationships between the growth of juvenile Atlantic salmon and flow in four seasons in West Brook, Massachusetts, USA. Graphs are derived from coefficients relating mean stream discharge (over a seasonal sampling interval) to growth rate (over the same interval) in a 10-year study. Q95 for the stream was about 0.2 m^3/s ~ probably close to the MALF. From Armstrong and Nislow (2012).

68. In my opinion, although it is an improvement on the current situation, ORC's proposed minimum flow still represents a high degree of flow alteration compared to the naturalised flow. For example, 0.75 m^3/s represents 40% of the estimated naturalised MALF (1.86 m^3/s), and is also less than the 1 in 50 year 7-day low flow, which is estimated to be 0.8 m^3/s at the Lindis Peak flow recorder (Table 4).

Table 4. Low flow statistics for selected return periods in the Lindis catchment, based on data from Otago Regional Council[28].

Site	**Lowest recorded flow (m^3/s)**	**MALF (m^3/s)**	**Q7,5 (m^3/s)**	**Q7,10 (m^3/s)**	**Q7,20 (m^3/s)**	**Q7,50 (m^3/s)**
Lindis Peak (all year)	0.186	1.349	1.083	0.967	0.887	0.812
Lindis Peak (Oct - April)	0.608	1.616	1.078	0.961	0.883	0.808
Ardgour Rd (all year)	0.126	1.864*	**	**	**	**

* Estimated naturalised mean annual low flow (MALF), ** Insufficient data.

69. While selected return period flow statistics have not yet been calculated for the Ardgour Road flow recorder site, comparison of available MALF estimates can be made. This suggests that flows during a natural 1 in 50 year low flow event are likely to be very similar at both flow recorder or possibly slightly higher in the lower river (Table 4).

70. If fishery values associated with the Lindis River are to be protected from significant adverse effects of water abstraction the minimum flow needs to provide for fish passage within the lower river and to the Clutha River (see paragraphs 40, 42 and 57). Based on the information available regarding losses to groundwater, and habitat surveys conducted by the CFT[29], I am not convinced that the proposed October–May minimum flow of 0.75m^3/s will provide adequate fish passage to the Clutha River, or within all of the lower 25 km of the Lindis River (i.e. Cluden to the Clutha River confluence).

71. In my opinion, the degree of flow alteration proposed by the ORC does not protect instream values. As such it presents a high risk of adverse effects on fish and invertebrate habitat, fish growth rates and survival.

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[28] ORC reports 2008; 2016a.

[29] CFT 2014 and 2015 Aerial habitat surveys of the Lindis River during low flows.

72. To ensure that most (>80%) or all, of the lower Lindis River has a flow of 0.75 m^3/s would require a minimum flow of 1.0–1.25 m^3/s at the Ardgour Road flow recorder.

73. A minimum flow of 1.25 m^3/s at the Ardgour Road flow recorder represents 67% of the naturalised MALF (1.86 m^3/s), and is more closely aligned with the proposed NES for suitable environmental flows required to protect instream values while still allowing for out of stream use of water during the low flow season[30]. For rivers with a mean flow around 5 m^3/s the proposed NES recommends a minimum flow of either 80 % or 90 % of the 7-day MALF, and suggests a maximum allocation limit of 30 – 50 % of MALF. In the lower Lindis River this would equate to a minimum flow of 1.49 – 1.68 m^3/s, and a primary allocation of 0.56 – 0.93 m^3/s.

WATER QUALITY – CONSEQUENCES FOR INSTREAM LIFE

74. In this section I review the status and trends of water quality in the Lindis catchment. My assessments are based on monitoring data collected by ORC available either in technical reports or on LAWA[31], complemented with data collected by Mr Trotter / CFT for his study of juvenile trout movement and survival in the Lindis River.

Water quality

75. Otago Regional Council monitoring shows that the water quality in the upper Lindis River (Lindis Peak) is generally very good, but the lower catchment has high concentrations of total nitrogen (TN)[32]. ORC reports also note that the deterioration in water quality in the lower catchment coincides with the location of the major surface water takes.

76. Water quality degradation (particularly elevated TN) has also occurred in the lower Lindis River over the last ten years (ORC, 2015; LAWA, accessed 29th January 2016), which is consistent with upward nitrogen trends

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[30] Ministry for the Environment 2008.

[31] Land, Air, Water Aotearoa (LAWA) http://www.lawa.org.nz/

[32] ORC Water Quality Report 2016b.

associated with agricultural intensification, throughout New Zealand[33]. In addition, ORC monitoring also show that water quality attributes (TN, TP and DRP) in two tributaries of the lower Lindis River are generally worse than most mainstem sites monitored. This is particularly noteworthy as one of the monitored tributaries was Cluden Stream, which is an important spawning and nursery area for both brown and rainbow trout, and provides a refuge for resident native fish populations in its reaches[34].

77. Resent research at Cawthron investigating nutrient effects on stream ecosystems using a regional data set[35] has shown through multiple lines of evidence that even small increases in nitrogen concentrations above background levels have strong effects on macroinvertebrate communities, *Phormidium* cover and ecosystem functioning. For example, the Macroinvertebrate Community Index (MCI) and % EPT[36] taxa index declined at median TN values in the range 0.22-0.55 mg/L.

78. Figure 7 compares TN concentrations in the Lindis catchment (lower river sites are marked by a red line) against the range where MCI and % EPT taxa have been shown to correlate with increases in median TN values (0.22-0.55 mg/L[37]). This highlights the sensitivity of macroinvertebrate communities in the lower Lindis River to further eutrophication as a result of additional agricultural intensification.

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[33] Ministry for the Environment & Statistics New Zealand, 2015.

[34] Gabrielsson 2016; ORC 2008.

[35] Wagenhoff et al. (in review).

[36] EPT = Ephemeroptera (Mayfly), Plecoptera (Stonefly) and Trichoptera (Caddisfly) index. These drift-prone taxa, important as fish food, are known to be sensitive to water quality degradation and related periphyton proliferation, and to fine sediment deposition.

[37] Wagenhoff et al. (in review).

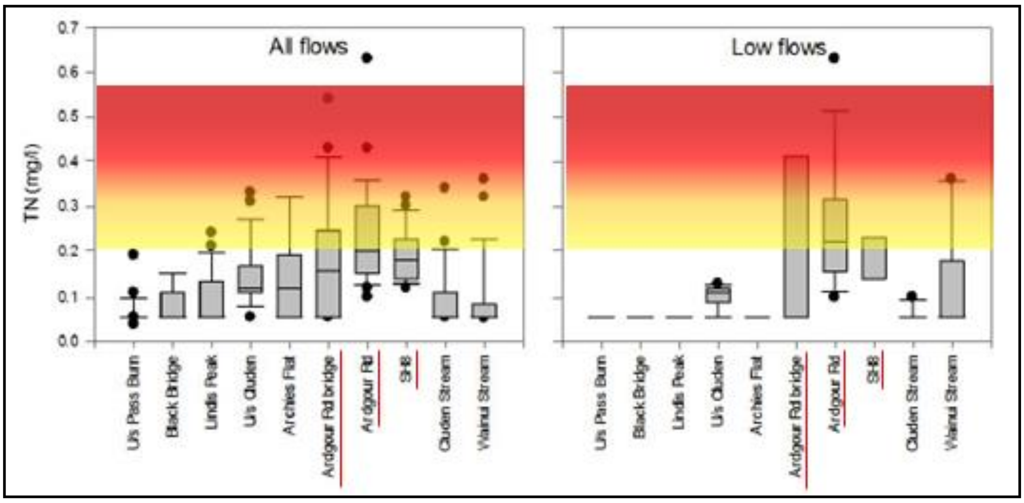

Figure 7. Indicative illustration of how TN concentrations in the Lindis River (data from ORC, 2015) compare against the range where declines in MCI and % EPT taxa have been shown to correlate with increases in median TN values (0.22-0.55 mg/L[38]), highlighting the sensitivity of macroinvertebrate communities in the lower Lindis River to both low flow conditions and further eutrophication. The colour contour band indicates increasing adverse effect from white through yellow to red.

79. I recently co-authored a study that investigated the responses of native and introduced fish populations to farming intensity and water abstraction in the nearby Manuherikia catchment[39]. It showed TN and fine sediment levels were closely related to farming intensity, and juvenile trout density was negatively related to both TN and fine sediment cover/depth. This adds to the growing body of evidence that highlights the need to consider multiple stressors, with low flow, water quality and fine sediment interacting to adversely affect stream ecosystems[40].

80. I conclude that continued increases in TN concentration in the Lindis catchment, associated with ongoing agricultural intensification and heavy water abstraction, will result in adverse effects on juvenile trout and macroinvertebrate communities.

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[38] Wagenhoff et al. (in review).

[39] Lange et al. 2013.

[40] Matthaei et al, 2010; Piggott et al. 2015.

Periphyton

81. Otago Regional Council monitoring data show low periphyton cover and biomass in the upper Lindis River, indicative of low nutrient levels, but higher levels in the lower Lindis River, indicating nutrient enrichment[41]. Additionally cyanobacteria (*Phormidium*), which is toxic to dogs and poses a risk to human health, was the most abundant periphyton taxon identified in the lower Lindis River in both 2011 and 2014[42].

82. Recent research at Cawthron provides evidence that cyanobacteria blooms respond positively to long stable flow conditions and increasing levels of nitrogen (DIN > 0.2 mg/L) and fine sediment[43]. However cyanobacteria blooms also occur in rivers with low DIN concentrations under stable flow conditions.

83. The Cawthron research has also found that cyanobacteria can be highly toxic to the common New Zealand mayfly (*Deletidium*)[44], which is an important prey for both native and introduced fish. Thus, together these findings imply that nutrient enrichment and fine sediment deposition, combined with prolonged low and stable river flows, contribute to the increasing rates of toxic cyanobacteria blooms across the nation in recent years.

84. Evidence provided by Mr Trotter shows that total periphyton cover in the lower Lindis River frequently exceeds the standards within the Otago Regional Plan: Water and provisional national standerds for long filamentous algae (30%) and diatoms/cyanobacteria (60%)[45], and in some cases even exceeds 90% cover (Figure 8). Nuisance periphyton growth can compromise stream-related values, including fish and their invertebrate food, and angling. The invertebrate community can change, becoming dominated by small non drifting invertebrates that are less preferred by trout as prey, which reduces fish feeding opportunities and growth rates.

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[41] ORC Water Quality report 2016b.

[42] ORC Water Quality report 2016b.

[43] Wood et al. 2014.

[44] Bridge 2013; Champeau et al. 2013.

[45] Biggs 2000.

Figure 8. Examples of high levels of green filamentous algae and didymo mats smothering large sections of the lower Lindis River. Photos taken by A. Horrell (Clutha Fisheries Trust) on 6 March 2015 downstream of the Ardgour Road flow recorder after approximately 60 days of accrual at an average flow of 0.3 m^3/s (range 0.22 – 0.44 m^3/s).

85. A study on relationships between invertebrate drift, benthic invertebrates, and periphyton indicated that a smaller percentage of the benthic invertebrates entered the drift at sites with higher periphyton biomass. The

proportion of large drifting prey (*Ephemeroptera*, *Plecoptera*, *Trichoptera* (EPT)), favoured by drift feeding trout can decline[46]. Finally, there is a strong tendency for bits/clumps of periphyton to detach from the bottom as biomass increases. This will result in drifting debris that reduces the drift foraging efficiency / ability of salmonids to detect and capture prey[47].

86. So in summary while thick periphyton cover can support diverse and abundant invertebrate communities, they may in fact no longer benefit fish. It is therefore my opinion that the high levels of periphyton growth observed in the Lindis highlight the importance of considering both the water quantity and water quality required for sustaining minimum flow objectives and values associated with ecosystem health, fish conservation and contact recreation activities, such as swimming and fishing.

Water temperature

87. It has been suggested the suitability of the lowest 1.5 km of the Lindis River (i.e. from Lindis Crossing to the Clutha confluence) for trout is likely to be limited during warmer months (December–March) due to high water temperatures[48]. While I agree this is currently the case I do not believe there is any compelling evidence to suggest this would be the case under natural flow conditions, or with a suitable environmental flow that both retains an adequate level of suitable trout habitat for most (more than 70%) of the lower river, and provides adequate fish passage to the Clutha River (i.e. a minimum of 10 – 15 cm water depth across shallow riffles).

88. The daily mean water temperature is in general relatively insensitive to flow, and more directly affected by climate and shading. However, flow changes as a result of abstraction can affect the amplitude of daily temperature fluctuations. During warm periods when water temperatures approach or exceed thermal tolerance levels in some locations river reaches that are influenced by groundwater recharge can provide cool-water refuges

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[46] Shearer et al. 2003.

[47] O'Brien and Showalter 1993.

[48] ORC Science update 2016a.

for fish, and other aquatic life[49]. However this requires that fish passage remains unhindered.

89. The optimal temperature for growth of brown trout is dependent on the energy content of available food[50]. For example the optimal temperature for growth of brown trout fed an invertebrate diet is approximately 14°C, but increases to 17°C if trout are fed a fish diet[51]. Growth of brown trout ceases at about 23°C, however fish take food in warmer water than the upper limit for growth[52].

90. Monitoring at several sites in the lower Lindis River between Lindis Crossing and Ardgour Road Bridge (a section that represents approximately 70% of the lower 15 km) show that daily maximum water temperature generally stays below 20ºC[53]. Comparisons of water temperatures measured above Cluden Stream (above most water takes) and Ardgour Road flow recorder (after major takes) also show similar patterns, highlighting that large sections of the lower river are buffered by inputs from groundwater recharges. However as surface flows are reduced by first abstraction between Cluden and Ardgour Road flow recorder, and then by losses to groundwater below the Ardgour Road large increase in daily amplitude become apparent near the confluence with the Clutha River (see Figure 9).

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[49] Nielsen et al. 1994; Torgersen et al. 1999; Olsen and Young 2009.

[50] Elliot and Hurley 1999.

[51] Elliott & Hurley 1998; 1999; 2000.

[52] Jonsson & Jonsson 2011.

[53] ORC 2016ab, Trotter et al 2016, Gabrielsson 2016.

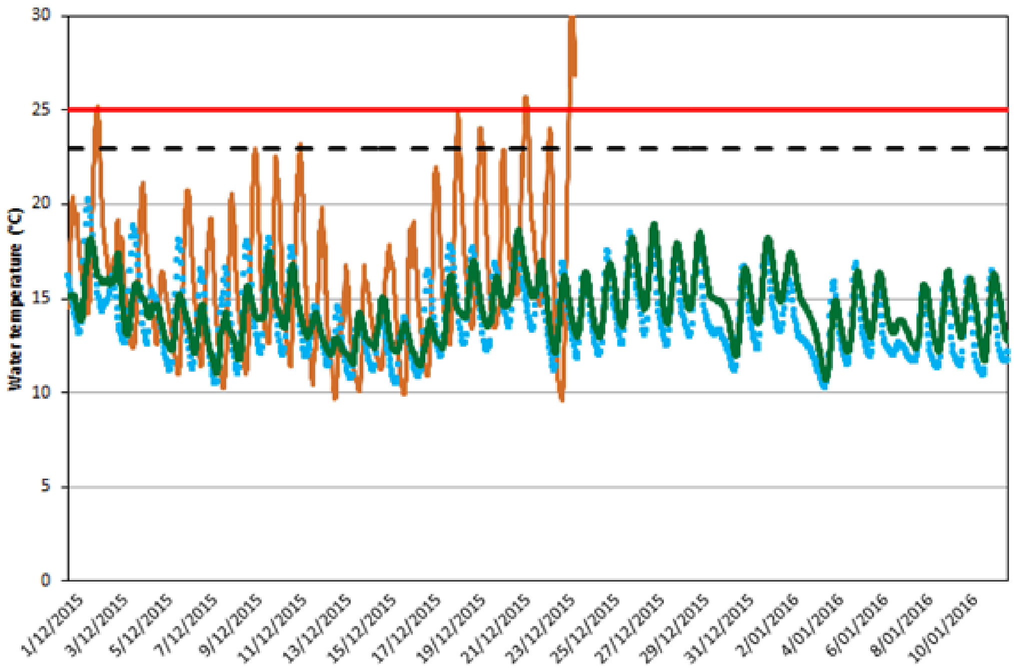

Figure 9. Comparison of the water temperature in the Lindis River at Cluden (green line), the Ardgour Road flow recorder (blue dots), and near the confluence with the Clutha River (orange line). The temperature at which brown trout growth stops (23°C black dashed line) and the incipient lethal temperature which 50% of brown trout can tolerate for prolonged periods, usually 7 days (25°C red line) are also shown.

CONCLUSION

91. Many factors determine the health of a river ecosystem and its fish populations. These include discharge (flow), the physical structure of both the instream channel and riparian zone, water quality, and the presence of barriers to fish passage/migration.

92. Nutrient levels in the lower Lindis River are approaching or at levels where research has shown changes in the MCI occur. Hence I expect that continued increases in TN concentration in the Lindis catchment, associated with ongoing agricultural intensification and heavy water abstraction, will result in adverse effects on juvenile trout and macroinvertebrate communities.

93. Otago Regional Council's proposed minimum flow of 0.75 m^3/s measured at the Ardgour Road flow recorder does not account for the interactions between surface and groundwater along the lower Lindis River. Consequently it does not maintain a residual river flow of 0.75m^3/s or provide for the required level of habitat retention recommended by Jowett & Wilding (2003) for sustaining instream fish values in most (>70%) of the lower Lindis River.

94. Recent research show that high levels of water abstraction resulting in surface flows less than 0.45 m^3/s can have significant adverse effects on fish survival in the lower Lindis River. Given the proposed minimum flow will result in approximately 30% of the lower Lindis having a flow < 0.5m^3/s it will, in my opinion, not be enough to prevent significant adverse effects on the life supporting capacity of the lower Lindis River.

95. If all sections of the lower Lindis River are to have a continuous surface flow at or greater than 0.75 m^3/s, then in my opinion, a minimum flow of 1.25 m^3/s at the Ardgour flow recorder is required.

Rasmus Gabrielsson

14 March 2016

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APPENDIX

Appendix 1.1: Clutha Fisheries Trust observations, 15 March 2014.

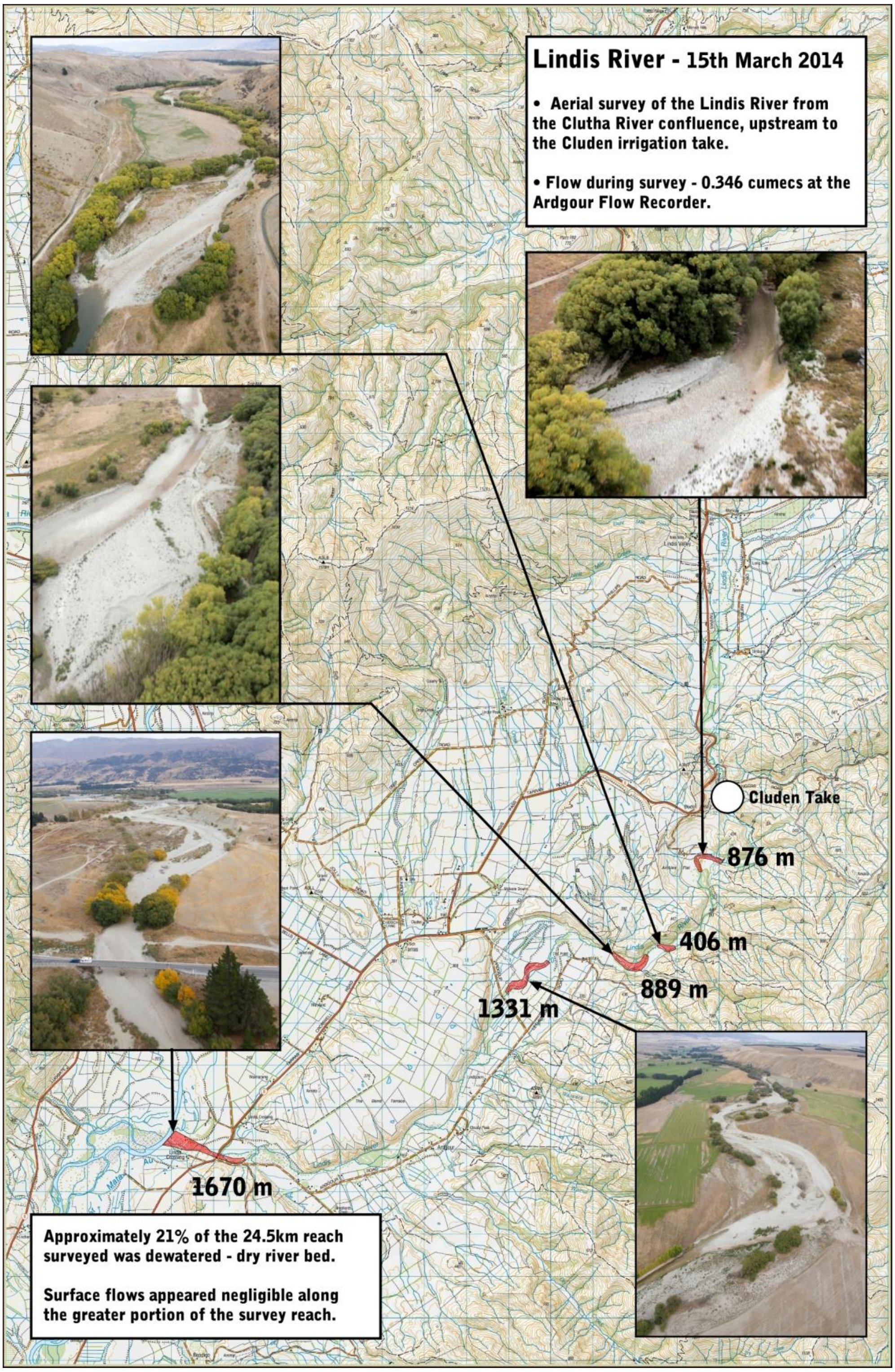

Figure A2. Aerial habitat survey conducted by the Clutha Fisheries Trust 15 March 2014 showing the influence of losses of surface flow to the groundwater aquifer along the lower Lindis River.

Appendix 1.2:

USING CHEMICAL ANALYSIS TO TRACK FISH MOVEMENT AND IDENTIFY IMPORTANT RECRUTIMENT AREAS

Chemical markers in fish ear stones (otoliths) or eggs (roe) provide a powerful way to answer fundamental questions in fish ecology, conservation, and resource management. The approach capitalises on detectable differences in the water chemistry between different rivers, which is the result of unique variations in the bedrock and geology of each catchment.

From the moment fish fry emerge from the redd and begins to feed that rivers distinctive water chemistry will begin to create permanent chemical marks in their otoliths that are characteristic of that stream environment / catchments geology and water chemistry. These chemical “fingerprints” make it possible to retrospectively determine the birth place (natal origin) of individual adult fish. Once a comprehensive baseline map of the chemical fingerprints for each river in a region / stream network has been established it is then possible to quantify the actual recruitment contribution that any particular stream makes to a fish population of interest.

Strontium (Sr) isotope ratios ($^{87}Sr/^{86}Sr$) have proven to be particular useful chemical markers for tracing fish movements globally because they often remain stable over time and show no evidence of biological fractionation, which ensures Sr isotope values in otoliths and other body tissues are typically the same as ambient stream waters (Kennedy et al., 2000, 2002; Walther and Thorrold, 2008). Sr isotope ratios are also particularly diverse in New Zealand, often changing considerably at very small spatial scales (<10km). For example in the upper Clutha catchment tributaries like the Lindis River have a very different chemical signature to the Clutha River and Lake Dunstan.

The chemical composition of trout eggs has also been found to match the chemistry of the maternal rearing habitat (Waite et al., 2008; Gabrielsson et al., 2012). This makes it possible to accurately separate the spawning locations of migratory and river resident trout across large catchment areas, by simply sampling eggs from spawning redds.

For my PhD I collaborated with chemical experts to develop and accurately measure the chemical content (strontium isotope ratio) of trout eggs buried in spawning nests (redds) in order to separate the spawning locations of migratory and resident trout. I applied this technique to the Lindis River, while studying the brown trout population in Lake Dunstan and the upper Clutha River.

My research has shown that the strontium isotope ratio in eggs from lake rearing and river resident trout provide a powerful marker for separating lake and river resident spawning effort in spawning streams like the Lindis River. Results show that migratory spawners dominate in the lower river, but also to a lesser degree utilise headwater areas (Figure A2 and A3).

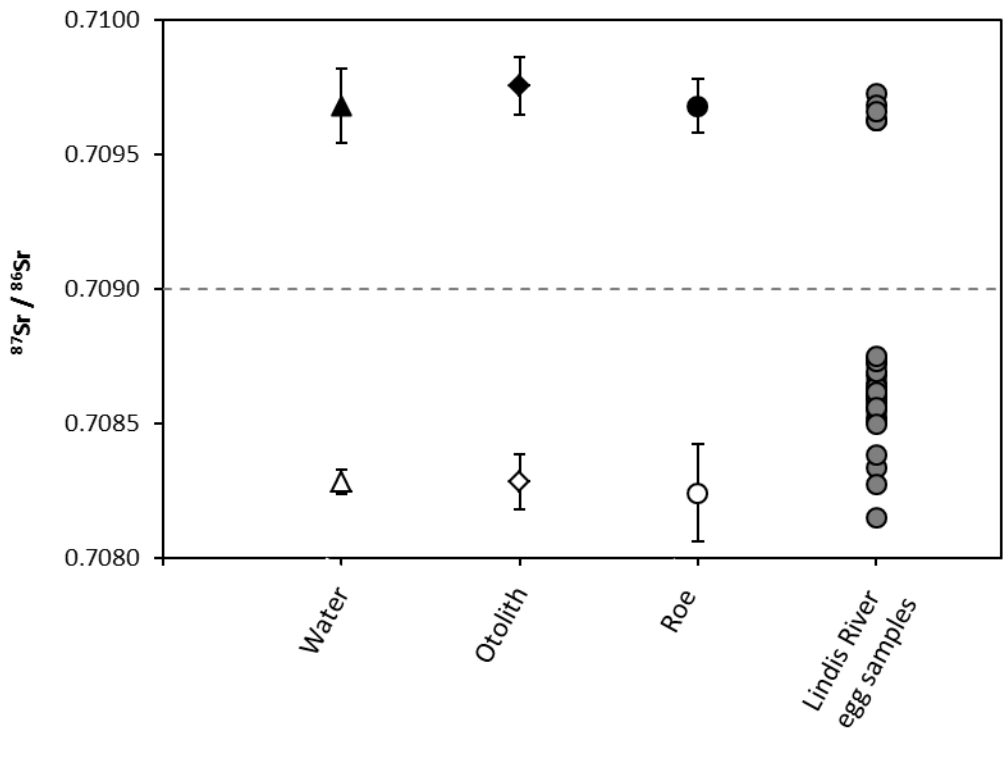

Figure A2. Scatter plot showing mean $^{87}Sr/^{86}Sr$ ratios in brown trout egg samples (N = 31) collected from spawning redds in the Lindis River (grey circles), along with chemical reference signatures from water samples, brown trout otoliths and roe (unfertilised eggs). Reference samples were collected from ripe female brown trout captured in Lake Dunstan (open symbols) or the upper Lindis River (closed symbols). Error bars are ± 2 SD, while the dashed line illustrates the estimated threshold between resident and migratory brown trout egg Sr signatures, based on *K*-means cluster analysis.

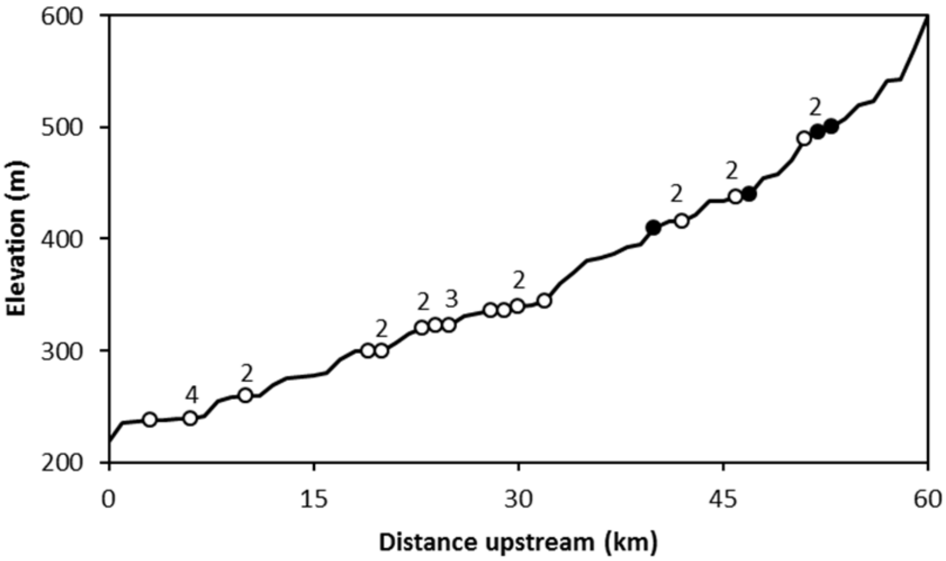

Figure X. Elevation profile for the Lindis River, as it leaves the Clutha River, illustrating that chemical analysis of eggs from spawning nests (redds) reveal migratory brown trout (white dots, $^{87}Sr/^{86}Sr$ <0.7090) dominate the spawning activity observed in the first 30km of the Lindis River. Spawning efforts in the upper catchment is more varied but eventually becomes dominated by river resident brown trout (black dots, $^{87}Sr/^{86}Sr$ > 0.7090) Numbers indicate places where >1 redds were sampled at a single location.

When the results from spawning surveys and chemical analysis of eggs from spawning redds are combined with $^{87}Sr/^{86}Sr$ analysis of otoliths from adult brown trout it can be used to determine what proportional recruitment contribution spawning streams make to the adult trout population in a lake. Consequently, by combining the use of Sr isotope analysis in otoliths from adult trout captured in Lake Dunstan and eggs from redds it has been possible to clarify that while the Lindis River is drawing in a high proportion of Lake Dunstan's migratory spawners (i.e. about 30%) it currently returns fewer recruits than expected (11%)[54].

This approach provided an opportunity to improve our understanding of the relationship between human activities such as water extraction and the creation of sink habitats. Subsequent examination associated this discrepancy with fragmentation and loss of connectivity during low flows[55], implicating water extraction practices for causing the Lindis River to act as a recruitment sink. Thus, taken together, this study highlights the need for holistic instream effects assessments of water extraction practices at the watershed rather than sub-catchment scale, in order to minimise negative effects of anthropogenic impacts on recruitment dynamics of migratory fish.

[54] Gabrielsson 2016

[55] Trotter et al. 2016