IN THE MATTER	of the Resource Management Act
AND	
IN THE MATTER	of Applications for Resource Consents to Take and Use Farm Irrigation Water in the Upper Waitaki Catchment of Lake Benmore
AND	
IN THE MATTER	of Stage One: Mackenzie Water Research Limited Submissions and Evidence on the Cumulative Nutrient Effects (and Mitigation thereof) of the Upper Waitaki Applications

Evidence of Brian Thomas Coffey

1.0 Introduction

Qualifications and general experience

1.01 My name is Brian Thomas Coffey. I am the Director of Brian T. Coffey and Associates Limited, and its chief scientist. I hold the degrees of Bachelor of Science, Master of Science with honours and Doctor of Philosophy in Botany from the University of Auckland.

1.02 I have had 15 years experience as a Government research scientist in New Zealand with national management and advisory responsibilities in the field of aquatic biology.

1.03 Since 1988, I have had 22 years applied experience as an independent consultant

- documenting resource inventories,
- assessing and monitoring the environmental effects of developments and
- preparing management plans

for freshwater, estuarine and marine sites in New Zealand. Examples of relevant stream evaluations I have conducted during the last ten years are attached as Appendix 1.

1.04 I am a member of the New Zealand Water and Wastewater Association and I am a past president of the New Zealand Limnological (freshwater sciences) Society.

Purpose and scope of evidence

1.05 The purpose of my evidence is to:

a) describe the existing aquatic environment in the catchment of Lake Benmore; and

b) assess the potential effects of predicted plant nutrient concentration increases provided by GHD Limited (2009C), on in-stream ecology and on Lake Benmore.

Involvement in Project

1.06 In 2007, I was retained by GHD Limited to participate in a desk top exercise to assess the aquatic ecological implications of modelling work being undertaken by that company to assess the current trophic status of surface and groundwaters in the Upper Waitaki catchment and to predict what the cumulative effect of changed nutrient loads to receiving waters would be as a result of changed land use, if current consent applications for additional irrigation schemes in the Mackenzie Basin were to be granted.

1.07 In April 2008, GHD Limited provided the opportunity for me to make a site visit with two of their field staff and collect data on instream community structure at 11 stream sites in the catchment of Lake Benmore (Coffey et. al., 2008).

1.08 Between August and September 2008, I collaborated with Drs. Melissa Robson (Senior Environmental Scientist, GHD Limited), Nimal Gamage (Senior Water Resources Engineer, GHD Limited) and Douglas Mzila (Senior Water Resources Engineer, GHD Limited) to prepare my report entitled "Predicted Limnological Responses to Calculated Changes in Nutrient Loads that would enter Surface Receiving Waters in the Upper Waitaki Basin due to Increased Irrigation" (Coffey, 2008).

1.09 In April 2009, following a review of Nodes at which GHD had calculated potential nutrient concentration changes I revisited the Study Area and to obtain a more comprehensive description of instream community structure at a total of 27 stream sampling sites in the catchment of Lake Benmore (Coffey, 2009). Eleven of these sites were in common (a repeat of) sites Melissa Anthony, Hannah Leckie and I described in April 2008 (Coffey et. al., 2008). A copy of this report is attached as Appendix 2.

1.10 On 22 July 2009, I attended an experts caucusing meeting at Environment Canterbury as a member of the GHD Water Quality Study Team.

Compliance with Expert Code of Conduct

1.11 I have read and agree to comply with the Code of Conduct for Expert Witnesses in the Environment Court. Except where I state that I am relying upon the specified evidence of another person, my evidence in this statement is within my area of expertise. I have endeavoured to be accurate and to cover all relevant matters relating to the topic on which I am giving evidence. I am not aware of any matters that might adversely affect my conclusions that I have not included. The assumptions on which my evidence is based are not, in my view, unlikely or unreasonable assumptions and, therefore, my evidence complies with Section 5.3 of the Environment Court's Code of Conduct for Expert Witnesses.

2.0 Background

2.1 An estimated 8,159 ha of land are currently irrigated in the Mackenzie Basin and consented irrigation areas that have yet to be irrigated amount to 3,367 hectares. (GHD, 2009C).

2.2 With an additional 25,000 ha of new irrigation consent applications, the total area of consented irrigation in the Mackenzie Basin could total 36,526 hectares.

2.3 The existing and proposed irrigation areas in the Mackenzie Basin are in the catchment of Lake Benmore, downstream of Lakes Tekapo, Pukaki and Ohau (GHD, 2009C).

2.4 Intensified land-use under irrigation typically results in the following changes:

- Increased plant nutrients from fertilisers and stock waste entering groundwater and surface waterways.
- Increased stocking rates that can lead to increased contamination of surface waterways with sediment (generally as suspended solids), micro-organisms (including pathogens), biological oxygen demand (organic matter that when aerobically decomposed in receiving waters can support heterotrophic slimes and reduce dissolved oxygen concentrations) and herbicide / pesticide residues.
- Intensified arable land-use that can also lead to increased contamination of surface waterways with sediment (generally as suspended solids) and herbicide / pesticide residues.
- Reduced residual flows in surface watercourses from which irrigation water has been abstracted.

2.5 My evidence addresses the potential instream ecological effects of increased plant nutrient concentrations in lakes and rivers that have been modelled by GHD Limited (2009C).

2.6 Increased plant nutrient concentration can have three potential effects in surface receiving waters.

a) In the case of stony / rock-bottomed stream / river channels that have perennial flow and that are not shaded with riparian cover, the most likely response to increased instream plant nutrient availability is increased periphyton (attached algal) biomass.

b) In the case of deep lakes such as Lake Benmore, the most significant response to increased plant nutrient availability is increased phytoplankton (suspended algal) biomass in the upper water column.

c) in the case of soft-bottomed streams / rivers and the littoral zone of lakes, waterweeds / lakeweeds may become more dense and problematic in moderately enriched or mesotrophic conditions.

2.7 Whilst, periphyton, phytoplankton and submerged macrophytes require a base concentration of plant nutrients for growth and healthy ecosystem function, an over-supply of plant nutrients to waterways (eutrophication) can have serious adverse effects on aquatic community structure and function due to the development of excessive plant production and biomass. It is necessary therefore, to identify “thresholds of concern” for nutrient concentration increases in waterways if the following nuisance conditions for periphyton, phytoplankton and lakeweeds are to be avoided.

2.8 “Nuisance” growths of periphyton in eutrophic streams and rivers has consequences for two types of values:

a) The effect on visual, aesthetic and recreation values is the increased period of time that the rivers would be degraded aesthetically, for swimming and for angling (see Table 1).

Table 1: Guidelines for maximum acceptable periphyton cover and biomass in gravel / cobble bed streams in relation to three main instream uses (Biggs, 2000)

Instream value/variable	Diatoms/cyanobacteria	Filamentous algae
Aesthetics/recreation (1 November - 30 April)		
Maximum cover of visible stream bed	60 % >0.3 cm thick	30 % >2 cm long
Maximum AFDM (g/m^2)	N/A	35
Maximum chlorophyll a (mg/m^2)	N/A	120
Benthic biodiversity		
Mean monthly chlorophyll a (mg/m^2)	15	15
Maximum chlorophyll a (mg/m^2)	50	50
Trout habitat and angling		
Maximum cover of whole stream bed	N/A	30 % >2 cm long
Maximum AFDM (g/m^2)	35	35
Maximum chlorophyll a (mg/m^2)	200	120

b) The ecological effects include:

- Increased periods of time that invertebrate populations (and food for fish), as well as spawning fish (e.g., trout), may be limited due to the smothering of habitat by periphyton.
- Possible increased periods of time that dissolved oxygen concentrations and pH fluctuate diurnally to an extent that is harmful to aquatic invertebrates and fish.

2.9 Similarly, “nuisance” growths of phytoplankton in lakes compromise visual, aesthetic and recreation values and can be toxic to both fish and humans. “Nuisance” growths of phytoplankton in deep lakes can be implicated in the depletion of dissolved oxygen in the deep lake basin during summer (hypolimnetic oxygen depletion) and the internal cycling of nutrients from the lakebed can lock a lake into a eutrophic condition despite attempts to manage nutrient inputs from the land catchment.

2.10 A combination of increased nutrient availability and the introduction of additional lakeweeds such as *Egeria densa* and / or *Ceratophyllum demersum* could also create issues with the increased likelihood of localised anoxia in the littoral zone, increased re-cycling rates for nutrients in the littoral zone of Lakes Ruataniwha and Benmore, and a greater quantity of dislodged waterweeds accumulating on intake screens at dams and water intake structures (Norton et. al. 2009). These are generally issues associated with a mesotrophic condition because when lakes become eutrophic (highly enriched with plant nutrients), phytoplankton communities can shade out (displace) submerged macrophyte communities that are rooted in the bed of the lake.

2.11 GHD (2009C) has modelled expected nutrient increases at particular nodes in the catchment of Lake Benmore in response to intensification of landuse following the development of nominated irrigation schemes. GHD (2009C) has also calculated the quantitative response of periphyton and phytoplankton biomass at these nodes to the nutrient concentration changes they had modelled. The purpose of my investigations and evidence is to consider and assess how these calculated changers in plant biomass would interact with other components of the aquatic community (including macroinvertebrates, fish, wildfowl and water quality).

3.0 Instream Communitiy Structure in Streams and Rivers

3.1 I investigated and subsequently described instream community structure at the 27 sampling sites shown in Figure 1 (Coffey et. al., 2008 and Coffey, 2009).

3.2 The purpose of these surveys was to benchmark the current ecological condition of streams that are potential receiving waters for the proposed irrigation schemes. The surveys were conducted in late summer following a period of dry weather conditions and relatively stable flows that would permit the accrual of periphyton biomass in hard-bottomed waterways.

3.3 Detailed methodology for describing habitat quality and for sampling, processing and reporting on periphyton (at hard-bottomed stream sites), macrophytes (at soft-bottomed stream sites), and aquatic macroinvertebrates (at all stream sites) has been provided by Coffey (2009). This report is attached as Appendix 2.

3.4 Each of the 12 “Nodes” shown in Figure 1 coincide with sites at which GHD (2009A and 2009C) have modelled nutrient concentration changes in relation to proposed irrigation schemes. I added the other 15 sampling sites shown in Figure 1 (as a combination of “control”, “upstream” and/or “reference” sites) to permit comment on the effect of existing landuse on water quality in these particular watercourses.

3.5 Areas of existing irrigation within the Study Area which could impact upon existing water quality are shown in Figure 2 and sub-catchment boundaries associated with the nominated Nodes are shown in Figure 3.

3.6 My summary comments on the ecological condition of the Nodes are set out in Table 2 but it is useful to first set out the geography of the Nodes and how they relate to Lake Benmore. Sub-catchment Nodes that discharge into the Northern (Haldon) Arm of Lake Benmore (see Figure 1) include the Twizel, Ohau (Ruataniwha), Tekapo and Stony Nodes. The Tekapo Node includes discharges from the Mary Burn and Grays Node while the Ohau (Ruataniwha) Node includes the discharge from the Wairepo Node.

Figure 1: Study Area within the catchment of Lake Benmore (after Coffey, 2009).

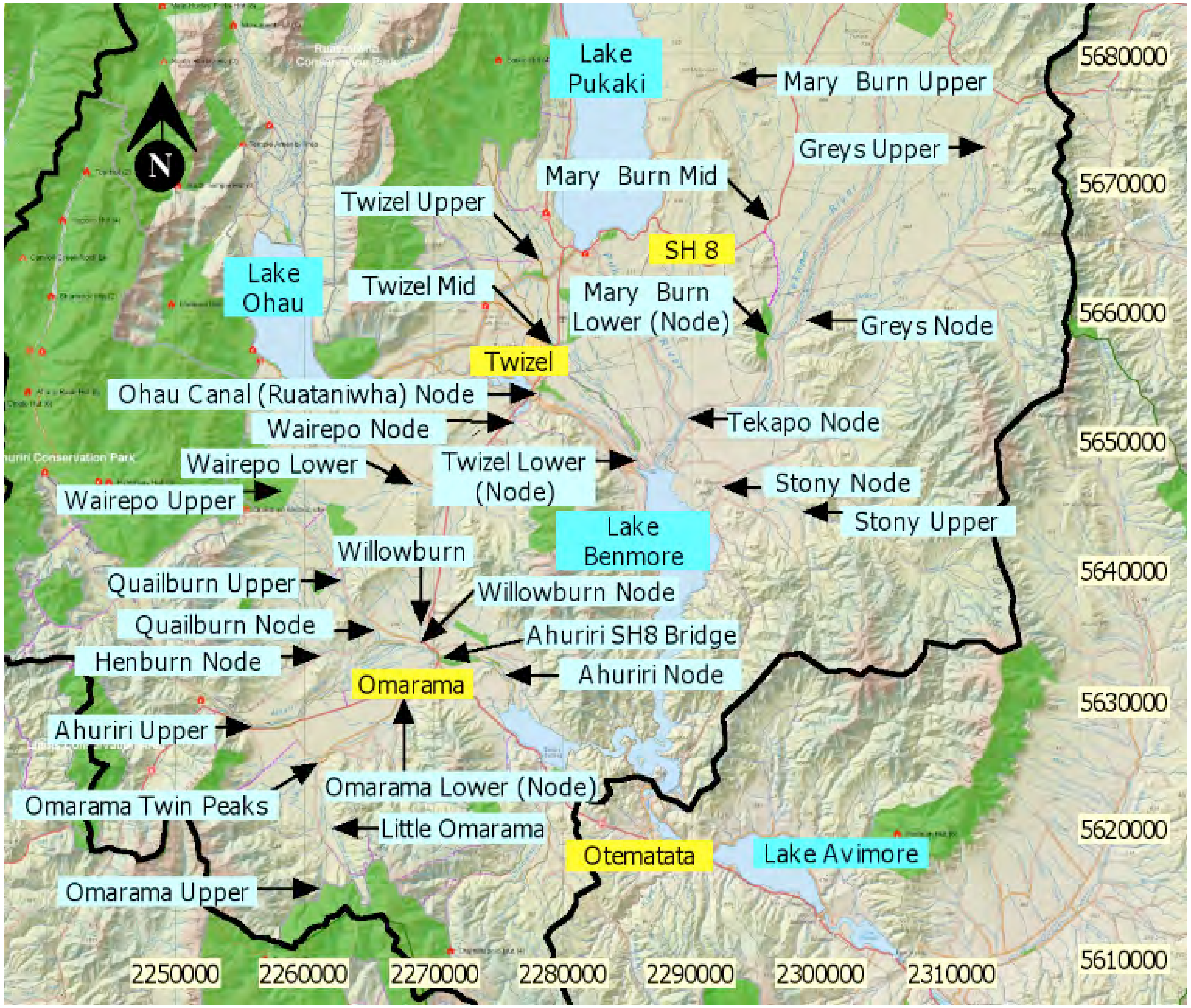

Figure 2: Study Area within the catchment of Lake Benmore showing existing Irrigation Schemes (after GHD, 2009C).

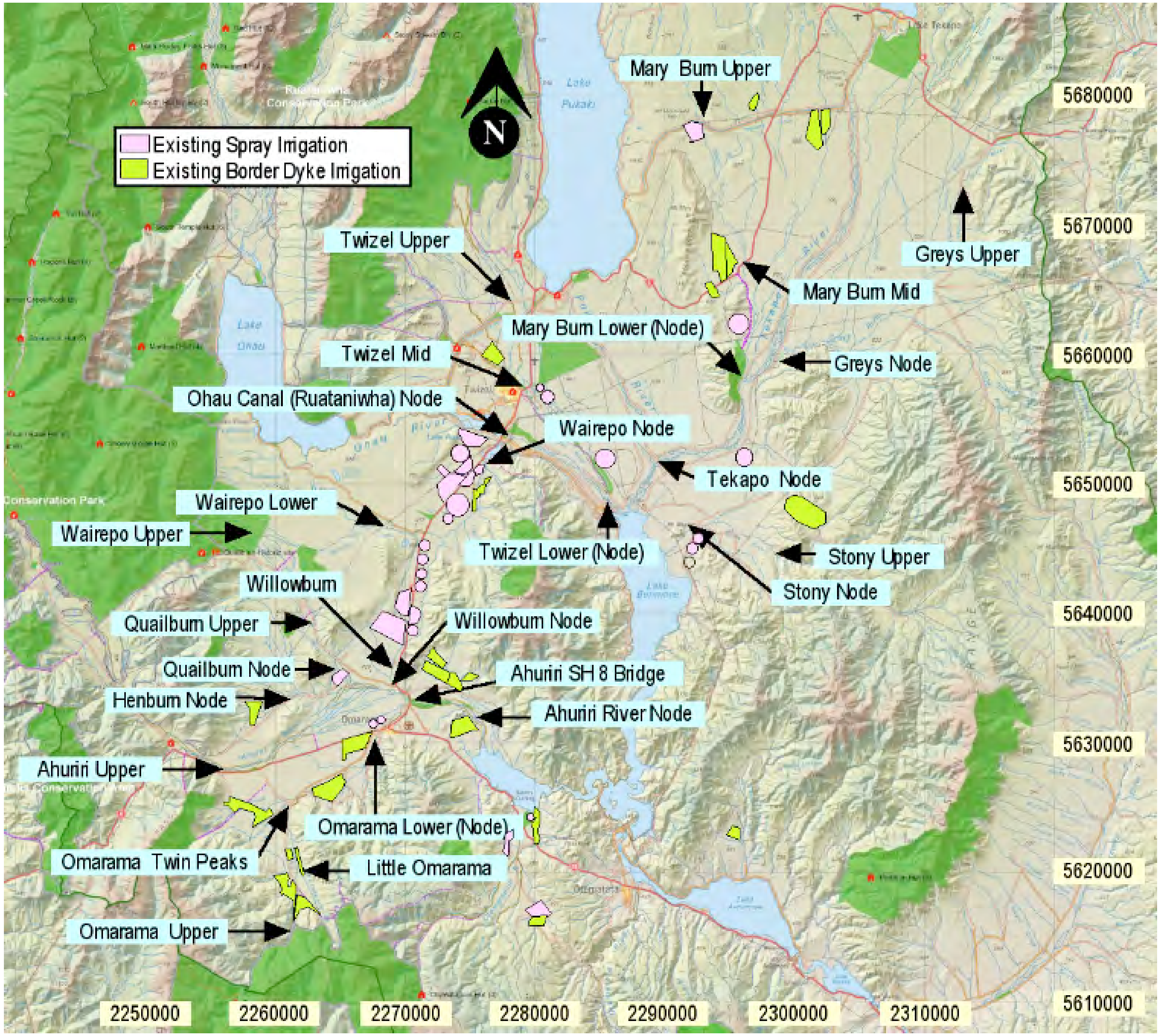

Figure 3: Sub-catchments boundaries within the Study Area upstream of Lake Benmore (after GHD, 2009C).

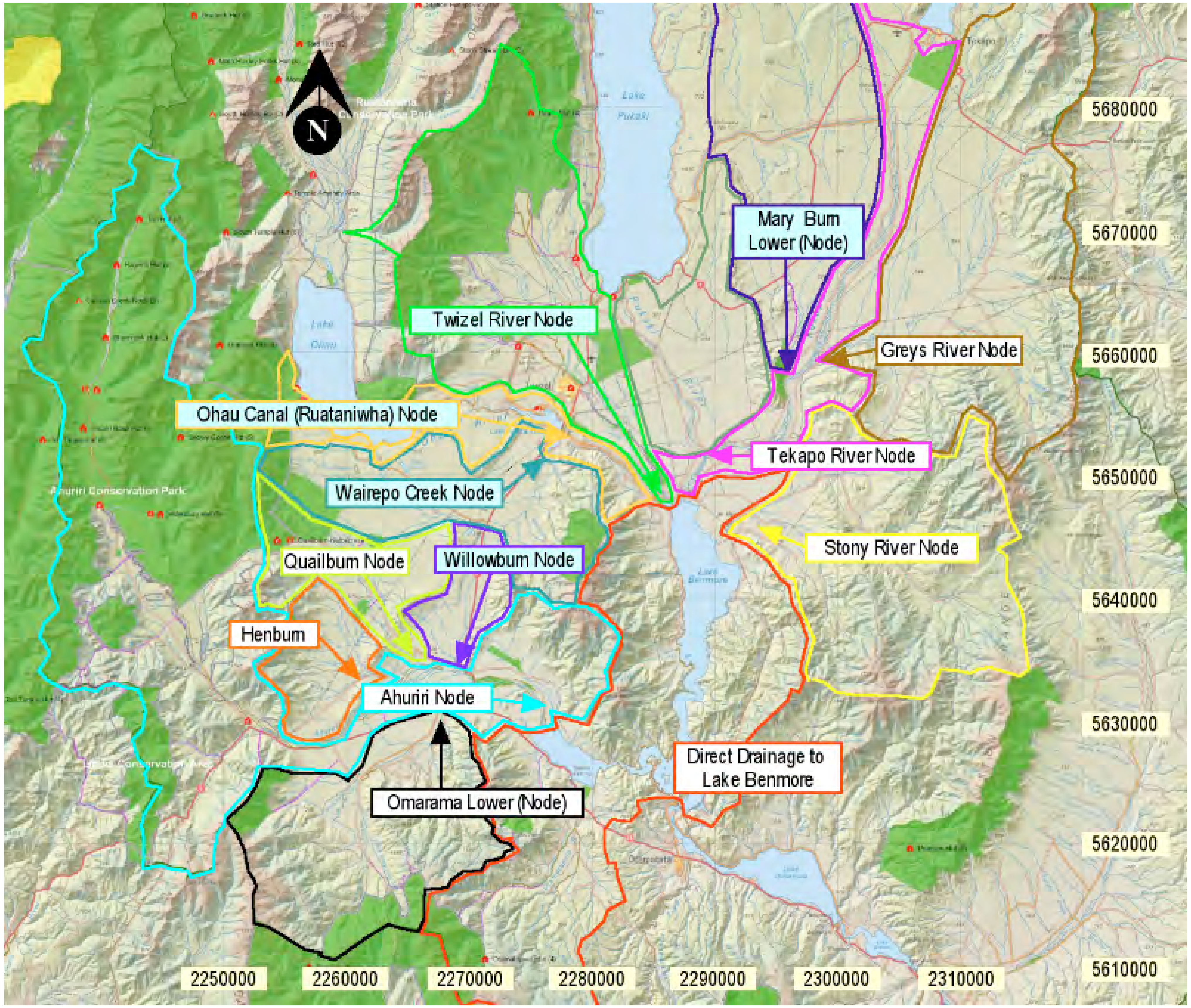

Table 2: Summary Comments on Instream Community Structure / Ecological Condition at the Nodes shown in Figures 1, 2 and 3 (see Appendix 2).

Site	Physical Habitat	Existing Irrigation	Periphyton	Macroinverterbrate	Other comments
Twizel	Physical habitat at the three hard-bottomed sampling sites in the Twizel sub-catchment was compromised by a lack of riparian cover at Sampling Site Twizel Upper.	There was no existing irrigation (see Figure 2) upstream of Sampling Site Twizel Upper, but there was some existing irrigation between Sampling Sites Twizel Upper and Twizel Middle and then additional existing irrigation between Sampling Sites Twizel Middle and Twizel Lower (Node).	Periphyton communities had a low cover and low biomass indicating a short accrual period or nutrient limitation to periphyton growth.	The structure of aquatic macroinvertebrate communities indicated instream habitat quality at Sampling Site Twizel Upper was very good, instream habitat quality at Sampling Site Twizel Middle was borderline between good and very good, and instream habitat quality at Sampling Site Twizel Lower (Node) was fair. Coffey et al. (2008) also found the downstream sampling site in the Twizel River was degraded in terms of instream habitat quality relative to the upstream sampling site.	There was evidence of recent instream channel disturbance at Sampling Site Twizel Lower as of April 2009 due to machines removing gravel and shingle from the river.
Tekapo		There was some existing irrigation upstream of the Tekapo Node that was downstream of the discharge to the Tekapo River from both the Grays River Node and the Mary Burn Lower (Node).	A “nuisance” condition of periphyton (see Table under 2.7 a) was present at the Tekapo River Node and periphyton taxa present at this site are generally associated with relatively high available nutrient concentration in rivers and streams.	The structure of aquatic macroinvertebrate communities indicated instream habitat quality at Sampling Site Tekapo Node was variously good, fair or moderate.	
Mary Burn	Physical habitat at the three hard-bottomed sampling sites in the Mary Burn sub-catchment was highest at Sampling Site Mary Burn Lower (Node) because of improved riparian cover at that site.	There was no existing irrigation upstream of Sampling Site Mary Burn Upper, but there was some existing irrigation between Sampling Sites Mary Burn Upper and Mary Burn Middle and then additional existing irrigation between Sampling Sites Mary Burn Middle and Mary Burn Lower (Node).	Periphyton cover and biomass indicated a progressive increase in available plant nutrients moving downstream from Sampling Sites Mary Burn Upper to Sampling Site Mary Burn Lower (Node) where “nuisance” growths of periphyton were present.	The structure of aquatic macroinvertebrate communities indicated instream habitat quality available for macroinvertebrates reduced from very good at Sampling Site Mary Burn Upper to fair at both Mary Burn Middle and Mary Burn Lower (Node).	
Henburn		There was a small area of existing irrigation upstream of the soft-bottomed Henburn Node, while this Node was colonized by aquatic macrophytes.		The structure of aquatic macroinvertebrate communities indicated that the instream habitat quality available for macroinvertebrates was fair to moderate.	
Grays River	The physical habitat at the two sampling sites in the Grays River sub-catchment were quite different, with the compromised score for Sampling Site Greys Upper reflecting a soft-bottomed sampling site dominated by macrophytes where water was emerging from a dry upstream river bed.		Periphyton cover and periphyton biomass constituted a “nuisance” condition at the downstream Sampling Site Greys Node in the absence of any irrigation in this sub-catchment (see Figure 2).	The structure of aquatic macroinvertebrate communities indicated instream habitat quality available for macroinvertebrates was poor at Sampling Site Grays Upper and fair at Sampling Site Grays Node.	In this instance, instream habitat differences between Sampling Sites Greys Upper and Grays Node were more likely to reflect differences in physical habitat quality rather than land use.
Stony River	A reduced physical habitat score at Sampling Site Stony Node compared to Stony Upper reflected increased periphyton and macrophyte cover at the downstream node.	There was a moderate amount of existing irrigation in the Stony River sub-catchment between Sampling Sites Stony Upper and Stony Node.		The structure of aquatic macroinvertebrate communities indicated instream habitat quality available for macroinvertebrates was fair at both sites and a reduction of instream habitat quality at Sampling Site Stony Node was considered to be relatively minor.	

Site	Physical Habitat	Existing Irrigation	Periphyton	Macroinverterbrate	Other comments
Wairepo Creek	Sampling Site Wairepo Node had better riparian cover than the two upstream sampling sites and physical habitat quality was higher at Sampling Site Wairepo Lower relative to Wairepo Upper because of better riparian vegetation and the reduced embeddedness of gravels.	There was no existing irrigation upstream of hard-bottomed Sampling Site Wairepo Upper or Wairepo Lower. However, there was extensive existing irrigation between Sampling Sites Wairepo Lower and the soft-bottomed Wairepo Node.	There was an increase in average periphyton cover and biomass between Sampling Sites Wairepo Upper and Wairepo Lower but both cover and biomass were relatively low.	The structure of aquatic macroinvertebrate communities indicated Sampling Site Wairepo Upper supported very good instream habitat quality, Wairepo Lower supported fair instream habitat quality and Wairepo Node supported poor instream habitat quality.	There was a marked reduction of flow in the Wairepo Creek between Sampling Sites Wairepo Lower and Wairepo Node at the time of this survey (06 April, 2009). This was likely to reflect draw off of surface waters for irrigation or the loss of surface water to ground water in the downstream reach of the Wairepo Creek. Table 21 of GHD (2009B) shows flows tend to reduce from Wairepo Upper to Wairepo Lower due to a loss of surface water to groundwater in this reach and flows frequently reduce to zero at the Ohau Road Bridge over the Wairepo Creek. However, Figure 7 of GHD (2009B) shows groundwater recharging surface waters in the lower reach of Wairepo Creek.
Quailburn		There was no existing irrigation in the Quailburn sub-catchment and reduced physical habitat quality at Sampling Site Quailburn Node relative to Quailburn Upper reflected reduced riparian cover and increased periphyton cover at the downstream sampling site.	There was an increase in average periphyton cover and biomass between Sampling Sites Quailburn Upper and Quailburn Node with both cover and biomass constituting a “nuisance” condition at the downstream site.	Sampling Site Quailburn Upper supported very good instream habitat quality on the basis of macroinvertebrate community structure. Sampling Site Quailburn Node supported good instream habitat quality on the basis of macroinvertebrate community structure. It appeared therefore, that nuisance growths of periphyton at the downstream sampling site were a reasonably recent development.	
Willowburn	Physical habitat quality was higher at the downstream Willowburn Node site due to improved riparian vegetation cover along the stream bank.	Both Sampling Sites Willowburn and Willowburn Node were soft-bottomed sites and there was extensive existing irrigation in the Willowburn sub-catchment that extended into the headwaters of the sub-catchment		Aquatic macroinvertebrate community structure indicated poor instream habitat quality at both sampling sites.	
Omarama Stream	The lowest physical habitat score recorded in the Omarama sub-catchment was at Sampling Site Omarama Twin Peaks and reflected a lack of suitable substrate for aquatic macroinvertebrates at this soft-bottomed site. There was a trend of reducing physical habitat scores at hard-bottomed sampling sites in the Omarama sub-catchment due to a combination of changes in substrate type and increased plant cover. Lower (Node) was a hard-bottomed site.	Sampling Site Little Omarama and Omarama Upper were hard-bottomed sites upstream of any existing irrigation. Sampling Site Omarama Twin Peaks was a soft-bottomed site and Omarama There was irrigation schemes between Sampling Sites Omarama Upper and Omarama Twin Peaks and additional irrigation between Sampling Sites Omarama Twin Peaks and Omarama Lower (Node).	The lowest average periphyton cover and biomass in the Omarama sub-catchment was recorded in the Little Omarama Stream. Localised “nuisance” growths of periphyton occurred along the shallow margins of the riverbed at Sampling Site Omarama Lower (Node).	Aquatic macroinvertebrate community structure indicated a reduction from very good instream habitat quality at hard-bottomed Sampling Sites Omarama Upper and Little Omarama to good at hard-bottomed Sampling Site Omarama Lower (Node). Instream habitat quality on the basis of macroinvertebrate community structure was fair to poor at Sampling Site Omarama Twin Peaks.	

Site	Physical Habitat	Existing Irrigation	Periphyton	Macroinverterbrate	Other comments
Ahuriri River	The lowest physical habitat score was recorded at Sampling Site Ahuriri Upper due to a higher cover of periphyton at that site and a lack of riparian zone vegetation. Stones and gravels at Sampling Site Ahuriri Node were more embedded than at Sampling Site Ahuriri SH8 Bridge and accounted for the marginally lower physical habitat score at Sampling Site Ahuriri Node.	Sampling Site Ahuriri Upper was a hard-bottomed site upstream of any irrigation or any sub-catchment discharges that included irrigation schemes. Sampling Site Ahuriri SH 8 Road Bridge was a hard-bottomed site downstream of the Omarama, Henburn, Quailburn and Willowburn Nodes and downstream of some existing irrigation between Sampling Sites Ahuriri Upper and Ahuriri SH 8 Road Bridge. Sampling Site Ahuriri Node was also a hard-bottomed site and there was existing irrigation in the Ahuriri sub-catchment between Sampling Sites Ahuriri SH 8 Road Bridge and Ahuriri Node.	Average periphyton cover and biomass at the three Ahuriri River sampling sites were below a threshold of concern. However, there was a very dense periphyton cover dominated by the pest diatom *Didymosphenia geminata* ("Didymo") in a narrow zone along both banks of the river at Sampling Site Ahuriri Upper.	Macroinvertebrate community structure indicated a trend of reducing instream habitat quality from good to fair moving downstream from Sampling Site Ahuriri Upper to Ahuriri Node.	

3.7 The Ahuriri sub-catchment Node discharges into the Ahuriri Arm of Lake Benmore and it includes discharges from the Henburn, Quailburn, Willowburn and Omarama Nodes (see Figure 1).

3.8 Existing landuse in the catchment of Lake Benmore is already having an impact on water quality in streams and rivers and in the Ahuriri Arm of Lake Benmore.

3.9 Instream habitat quality was degraded in the lower reaches of the Twizel River, Mary Burn, Stony River, Wairepo Creek, Quailburn and Omarama Creek relative to upstream sites (Coffey, 2009).

3.10 Nuisance growths of periphyton were present in the downstream reaches of the Tekapo River and Grays River and poor instream habitat quality was present in the downstream reaches of the Willowburn and Henburn sub-catchments as of April 2009 (Coffey, 2009).

4.0 Other Ecosystem Values of Waterbodies in the Catchment of Lake Benmore

4.1 Daly (2004) has provided a desktop review of instream ecosystem values for Canterbury Rivers and Lakes. He considered seven sub-catchments upstream of Lake Benmore and two sub-catchments downstream of Lake Benmore in the Waitaki Valley. Noteworthy instream values for those sub-catchments in the Study Area (see Figure 3) are summarised in Appendix 3 (after Daly, 2004). This study complements my assessment of the instream community structure and helps provide a full assessment and description of the existing aquatic environment in the catchment of Lake Benmore.

4.2 Some of the values for rare and / or endangered taxa inhabiting river floodplains and river terraces might be considered “out-of-stream” rather than “instream” values, but these habitats are partially or substantially flooded by river water at times of the year.

4.3 It is unlikely that predicted changes in the trophic status of river water would adversely impact on taxa in these habitats.

4.4 However, a reduced frequency / period of inundation of such habitats as a result of the abstraction of irrigation water from surface watercources, and / or additional loads of:

- suspended solids;
- microorganisms (including pathogens);
- biological oxygen demand; and /or
- pesticide residues;

that may be generated from intensified landuse would have the potential to adversely impact on such habitats and the taxa they support.

4.5 The waterways within the Study Area shown in Figure 1 support a range of rare and endangered native plants, native insects, native waterfowl and fish. Many of these water courses also support a highly valued sport fishery and there are three commercial salmon farms in hydro canals in the Mackenzie Basin.

4.6 Any further significant deterioration of water quality within the Study Area would therefore be of concern.

5.0 Calculated Response of Periphyton Biomass to Modelled Irrigation Induced Increases in Available Plant Nutrients

5.1 An increased concentration of plant nutrients in hard-bottomed stream and rivers would affect other instream users by causing a change in the cover and / or biomass of periphyton.

5.2 A change in benthic invertebrate community structure with increasing periphyton biomass has been a common observation in New Zealand streams (Towns, 1981; Quinn and Hickey, 1990; Quinn et al, 1996, 1997a, b). In particular, a shift from faunas typifying "clean waters" to those typically found in organically degraded conditions has been widely observed as a function of enrichment (Quinn and Hickey, 1990). For example, the mayfly *Deleatidium* favours relatively "clean" rock surfaces, whereas orthoclad chironomids prefer thick periphyton mats into which they burrow (Winterbourn, 1986; Quinn et al, 1996). These general changes in invertebrate community composition with increasing enrichment can be demonstrated clearly with invertebrate data from the streams of varying trophic status (Biggs, 2002).

5.3 Therefore, by modelling changes in periphyton biomass (in relation to available nutrient supply), associated changes in macroinvertrebrate community structure and instream habitat quality can also be predicted.

5.4 GHD Limited provided estimates of pre and post in-river concentrations of soluble inorganic nitrogen (SIN) and soluble reactive phosphorus (SRP) at selected nodes in the catchment of Lake Benmore. River flood frequency was also provided by GHD Limited at these nodes using FRE3 (the mean number of flood events per year that exceed three times the median flow) estimated from daily mean flow records, using a 7-day filter period.

5.5 Published relationships between nutrient concentrations, the frequency of river flood events and periphyton biomass in New Zealand rivers (Biggs, 2000), were then used to predict average annual maximum benthic algae biomass (as chlorophyll a in mg m^{-2}) at each assessment node for the before and after additional irrigation scenarios (Coffey, 2008 and GHD Limited, 2009A and 2009C).

5.6 These relationships justifiably assume that:

- algal biomass in gravel bed rivers is a function of the counteracting processes of resource supply (required for growth) and biomass loss,
- growth rate is determined primarily by nutrient supply and light,
- biomass loss is determined by hydrological disturbance (i.e., velocity increase and substrate movement during flood flows) and invertebrate grazing.

5.7 However, Meredith and Hayward (2002) have also established that excessive periphyton growths have not been as prevalent as predicted by the eutrophication status of Canterbury rivers in general.

5.8 GHD (2009C) have calculated that under Scenario 2 (a total of 36,526 ha irrigation assuming developed soils and no mitigation) annual average maximum periphyton biomass would increase by less than 25% greater in the Stony River, Greys River, Mary Burn, Twizel River, Henburn, Omarama Stream sub-catchments. Sub-catchments with a greater than predicted 25 % increase in annual average maximum periphyton biomass under Scenario 2 were Willowburn, Tekapo River, Ahuriri River, Quailburn and the Wairepo Creek.

5.9 GHD (2009C) have calculated that under Scenario 4 (a total of 36,526 ha irrigation assuming highly developed soils and no mitigation) annual average maximum periphyton biomass would be increased by more than 25 percent at all sub-catchment nodes except the Hen Burn (where no proposed irrigation is allocated) and Stony River.

5.10 In the case of the Tekapo, Mary Burn, Grays, Stony and Quailburn Nodes (see Figure 1), these predicted increases in annual average maximum periphyton biomass relate to existing "nuisance" growths of periphyton at these sites.

5.11 The approach of using annual average maximum periphyton biomass (measured as the concentration of chlorophyl a per unit area) could be further refined once additional data are available for soluble inorganic nitrogen (SIN) and soluble reactive phosphorus

(SRP) at selected nodes in the catchment of Lake Benmore. The number of analyses for SIN and SRP at the various nodes vary from:

- Willow Burn Node: 41 recent samples.
- Wairepo Creek Node: 32 - 33 recent samples.
- Quail Burn Node: 13 recent samples.
- Greys Node: 8 samples taken since 2007.
- Mary Burn Node: 8 samples taken since 2007.
- Omarama Node: 7 recent, 2 historical samples.
- Stony Node: 8 samples since 2004.
- Hen Burn Node: Five recent samples.
- Twizel Node: 4 samples.
- Ohau (Ruataniwha) Node: 4 recent samples.
- Tekapo Node: 3 samples.

5.12 Ideally, any further water quality sampling should be events based in terms of dry and wet weather events and stream flow.

5.13 Moreover, flushing rate (FRE3) needs to be established for the Greys River, Stony River, Wairepo Creek, and Tekapo River to verify periphyton biomass estimations (GHD, 2009C).

6.0 Calculated Response of Phytoplankton Biomass to Modelled Irrigation Induced Changes in Available Plant Nutrients

6.1 An increased concentration of plant nutrients in Lakes Ruataniwha or Benmore would affect other instream users by causing an increase in the biomass and a change in the composition of phytoplankton.

6.2 These changes then determine changes in other members of the community such as the zooplankton, weed bed fauna, benthic invertebrates and fish, together with changes in contact recreation value, amenity value and nuisance growths to hydro-generation.

6.3 Table 3 provides a summary description of lake characteristics in relation to seven trophic states proposed by Burns et. al. (1999).

6.4 Production conditions for phytoplankton in the Ahuriri Arm of Lake Benmore appear to be better than in the Northern or Haldon Arm of the lake due to (Norton et. al., 2009):

- an absence of glacial till that imposes light limitation on phytoplankton growth in the Haldon Arm during spring and early summer,
- a longer residence time of water in the Ahuriri Arm of the lake due to lower inflows, and
- a lack of summer / autumn thermal stratification in the Ahuriri Arm of the lake.

6.5 On the assumption there is no internal cycling of nutrients in Lake Benmore, it is possible therefore to calculate an existing nutrient budget for the lake and to nominate a maximum increase in nitrogen and phosphorous load from the intensification of landuse in the catchment of Lake Benmore that could be tolerated without compromising a particular trophic state that is considered acceptable for the lake.

6.6 This has been done by both GHD Limited (2009A and 2009C) and by Norton et. al. (2009). The next step is to identify the degree of change in the trophic status of Lake Benmore (if any) that can be defended on environmental grounds.

Table 3: Trophic Characteristics of Lake Types proposed by Burns et. al (1999).

Parameter	Trophic Status of Lake						
	Ultramicrotrophic	Microtrophic	Oligotrophic	Mesotrophic	Eutrophic	Supertrophic	Hypertrophic
Water Clarity	Clear Visually appealing	Clear Visually appealing	Clear Visually appealing	Clear tending green (variable appeal	Turbid green visually unappealing	Turbid green visually unappealing	Turbid green visually unappealing
Visual Phyto-plankton	No risk of green colour	No risk of green colour	Very low risk of green colour	Moderate risk	High risk of sustained phytoplankton blooms	Sustained phytoplankton blooms	Sustained phytoplankton blooms
Periphyton on bed & margins	Low	Low moderate	Low moderate	moderate	Low moderate	Low	Low
Macrophyte beds	Healthy	Healthy	Healthy	Increased Stress. Potential shift to phytoplankton dominated system	High risk of collapse. Likely phytoplankton dominated system	High risk of collapse. Likely phytoplankton dominated system	High risk of collapse. Likely phytoplankton dominated system
Toxic algal blooms	No risk	No risk	No risk	Some risk	High risk	High risk	High risk
Invertebrate & fish communities	Healthy	Healthy	Healthy	Increased productivity	Shifts in composition	Shifts in composition	Shifts in composition
Biodiversity Value	Moderate	High	High	Good	Compromised	Compromised	Compromised
Contact Recreation Value	Very High	Very High	High	Good	Poor	Poor	Poor
Amenity Value	Very High	Very High	High	Good	Poor	Poor	Poor
Nuisance growths to Hydro-generation	Very low risk	Very low risk	Low risk	Moderate risk	High risk	High risk	High risk

7.0 Thresholds of Instream Effects

7.1 Increased irrigation in the Mackenzie Basin is expected to result in increased intensification of land use and a greater leaching / loss of plant available nutrient to receiving waters. These increased nutrient loads would enter Lake Benmore in a combination of surface and ground water discharges.

7.2 Given the proposed increase in the area of irrigation, GHD Limited have modelled the likely magnitude of changes in nutrient concentrations / loads passing selected Nodes in representative streams and rivers in the catchment of Lake Benmore and the increase of nutrient loads entering Lake Benmore itself.

7.3 Potential responses (increases) of annual average maximum periphyton biomass have been calculated for selected Nodes in representative streams and rivers within the catchment of lake Benmore.

7.4 GHD Limited (2009A and 2009C) have calculated that the proposed increase in the area of irrigation has the potential to shift the trophic status of the Ahuriri Arm of Lake Benmore from its current oligotrophic to a mesotrophic state and / or shift the trophic status of the Northern Arm of Lake Benmore from its current ultra-microtrophic to a microtrophic state. An independent study by NIWA has also calculated the additional nutrient loads that would result in a shift in the trophic status of Lake Benmore (Norton et. al., 2009).

7.5 The Water Quality Study team considered what degree of change in the trophic status of waters in the catchment of Lake Benmore, and in Lake Benmore itself, might be justified on environmental grounds.

7.6 The merit of an agreed, not to be exceeded, threshold of eutrophication effects that could be tolerated in response to increased irrigation is that this could then be managed by nominated, not to be exceeded, nutrient concentrations and loads at specified sub-catchment Nodes and in Lake Benmore itself.

7.7 Clearly the extent of permissible irrigation schemes in any given sub-catchment of Lake Benmore would then be a factor of how effectively nutrient losses from irrigated land could be reduced with available mitigation measures.

7.8 I considered that a change of trophic status in the Ahuriri Arm of Lake Benmore, from its current oligotrophic to a mesotrophic state would be significant and undesirable for aquatic habitat quality within and downstream of Lake Benmore (Coffey, 2008).

7.9 Following discussions and the seeking of alternative opinions, GHD Limited (2009A and 2009C) adopted my recommendation that nutrient loads should be managed to ensure the trophic state of the Ahuriri Arm of Lake Benmore did not become mesotrophic but remained in an oligotrophic state.

7.10 I recommended that this target should be met for both nitrogen and phosphorus (Coffey, 2008), as there is the possibility of either nutrient becoming limiting for phytoplankton growth in the future. My recommendation was adopted by GHD (2009C) and Norton et. al. (2009) subsequently established with nutrient bioassay studies that phytoplankton in Lake Benmore was co-limited by both nitrogen and phosphorous.

7.11 In effect therefore, if this trophic threshold of effects is adopted, effective mitigation measures would be required to reduce expected (unmitigated) nutrient losses from the area of land it is proposed to irrigate in the Ahuriri catchment of Lake Benmore.

7.12 I consider that a change of trophic status in the Northern or Haldon Arm of the lake from an ultra-microtrophic to a microtrophic state would not be significant and undesirable for aquatic habitat quality within and downstream of Lake Benmore (Coffey, 2008). This view is supported by reference to Table 1 (under 6.2) where the only changes would be that the potential for periphyton on the bed and margins of the lake would increase from low to low moderate and the biodiversity value would improve from moderate to high because of the very low productivity of an ultra-microtrophic lake.

7.13 In terms of a not to be exceeded threshold for increased periphyton growth, I considered that a 25% increase in the annual average maximum periphyton biomass at any nominated stream / river node in the catchment of Lake Benmore could be considered a minor effect relative to current conditions (Coffey, 2008).

7.14 As explained in Sections 2.6 and 2.7, periphyton was the appropriate indicator to use because it is dominant plant type in rivers and streams and plants respond to a change in available nutrient concentrations. Animals do not respond to changes in nutrient concentrations unless changes in nitrogen forms such as ammonia for example are high enough to be toxic to aquatic animals. A change in the carrying capacity or biomass of periphyton can then affect the type and abundance of aquatic animals that occur in streams or rivers.

7.15 The reasons I considered a 25% increase in annual average maximum periphyton biomass would not result in other than a minor effect relative to current conditions were:

- a 25% increase in annual mean maximum periphyton biomass at most Nodes would not create a “nuisance” condition from a “non-nuisance” condition,
- periphyton biomass already exceeds a “nuisance” during those times of the year when annual mean maximum periphyton biomass forms,

- “nuisance” growths already comprises instream conditions for aquatic animals,
- current annual average maximum periphyton biomass may not yet have responded to existing land use effects and may increase with time even if there are no changes to current land use, and
- a 25 % increase of existing “nuisance” periphyton growths would probably not be noticeable to a casual observer.

7.16 If Ministry for the Environment Guidelines (Biggs 2000) or Environment Canterbury Proposed Water Quality Guidelines (Environment Canterbury 2004) were adopted, no further increase in nutrients would be permitted as these periphyton thresholds are generally exceeded in streams and smaller rivers in the Mackenzie Basin.

7.17 As these guidelines are already compromised in many non-irrigated areas in the Mackenzie Basin, it could be argued they are unrealistic and not relevant in this situation. However, many streams and smaller rivers in the Mackenzie Basin are in a highly modified state. I consider an overall increase in instream habitat quality and a reduction of current periphyton proliferations would be associated with the establishment of functional riparian zones along these watercourses.

7.18 Again, following discussions and the seeking of alternative opinions, GHD Limited (2009A and 2009C) adopted the recommendation that increased nutrient concentrations associated with increased irrigation at any given stream / river Node should be less than that calculated to result in a 25% increase in mean annual maximum periphyton biomass.

7.19 This recommendation was reviewed by Dr. Greg Ryder who correctly highlighted that the invasive diatom Didymo (*Didymosphenia geminata*) appears to be capable of forming nuisance growths in very low nutrient concentrations and that this criteria should only therefore apply to periphyton communities that did not include Didymo.

7.20 In my view, if Didymo was to invade any or all of the nominated Nodes, the criteria would be best to default to monitored nutrient concentrations rather than measured periphyton responses. That is, in the presence of Didymo, “*increased nutrient concentrations associated with increased irrigation at any given stream / river Node should be less than that calculated to result in a 25% increase in mean annual maximum non-Didymo periphyton biomass*”.

Monitoring

7.21 I consider a precautionary approach is warranted when setting such "not to be exceeded" thresholds and support recommendations that both nutrient concentrations and algal biomass should be monitored at all sites nominated by GHD Limited (2009C). I agree with the sampling sites recommended in Figure 15 of the Water Quality Summary Report produced by GHD (2009C) A copy of this Figure is included as Attachment 1 of my evidence. However, with reference to Table 20 of GHD Limited (2009C) that details the recommended monitoring programme for the Upper Waitaki Catchment, I would recommend dissolved oxygen, suspended solids, biological oxygen demand and faecal coliforms are included in the surface water sampling programme for all sub-catchment nodes shown in Figure 15 of GHD (2009C). A copy of Table 20 from GHD Limited (2009C) is included as Attachment 2 of my evidence.

7.22 In terms of ecological monitoring in lakes, I recommend that the description of parameters to be measured in Table 20 of GHD Limited (2009C) should read benthic invertebrates, macrophytes and plankton and that annual monitoring should be conducted in early autumn of each year.

7.23 In terms of ecological monitoring of stream and river nodes in Table 20 of GHD Limited (2009C), I recommend the parameters to be described should be periphyton, macrophytes and macroinvertebrates and that these annual surveys should be conducted during low flow summer conditions.

7.24 Contingency plans should be in place to respond to any trends in monitoring data that indicate the trophic status of the Ahuriri Arm of Lake Benmore is likely to shift over the oligotrophic / mesotrophic boundary following the commissioning of additional irrigation schemes in the catchment of the Ahuriri Arm of Lake Benmore. A bottom line response to nutrient loads being exceeded at a particular sampling node would be to reduce or cease irrigation in the sub-catchment of that node.

7.25 However, I concur with the approach advocated in the evidence of Craig McKibbin and John Kyle. It is important to have a number of ‘tiers’ to work through prior to such action needing to be taken. The type of conditions recommended would be consistent with:

> *“When measurements of X, Y and Z at [node] exceed Q, R and S, then consent holders [list all that are relevant] in the [name] sub catchment shall do A, B and C, until such time as the threshold levels of Q, R and S are no longer exceeded at [node]”.*

7.26 This should ensure that as measurements of X, Y and Z get progressively worse the actions to be taken (A, B and C) become more comprehensive to address the environmental impact. This should commit the consent holder to take action when measurements of X, Y and Z are only starting to show signs of environmental deterioration. Should the consent holder take no action and the impact worsens, the mitigation measures get tougher and ultimately the irrigation of the land will have to cease.

7.27 In my opinion, it is also important to clearly identify who would be responsible for “off-farm” monitoring and implementing the adaptive management approach that is proposed. I understand that Mackenzie Irrigation Company would adopt the “off farm” monitoring role and that Environment Canterbury would manage the adaptive management approach that is proposed.

8.0 Conclusions

8.1 Existing landuse in the catchment of Lake Benmore is already having an impact on water quality in streams and rivers and in the Ahuriri Arm of Lake Benmore. Instream habitat quality was degraded in the lower reaches of the Twizel River, Mary Burn, Stony River, Wairepo Creek, Quailburn and Omarama Creek relative to upstream sites (Coffey, 2009). Nuisance growths of periphyton were present in the downstream reaches of the Tekapo River and Grays River and poor instream habitat quality was present in the downstream reaches of the Willowburn and Henburn sub-catchments as of April 2009 (Coffey, 2009).

8.2 The waterways within the Study Area shown in Figure 2 support a range of rare and endangered native plants, native insects, native waterfowl and fish. Many of these water courses also support a highly valued sport fishery and there are commercial salmon farms in the hydro canals.

8.3 Therefore any further significant deterioration of water quality within the Study Area would be of concern.

8.4 However, in terms of the trophic status of these watercourses, I consider that a 25% increase in average annual maximum periphyton biomass at the downstream sampling nodes shown in Figure 15 of GHD Limited (2009C) would constitute a minor effect on overall instream habitat quality. The reason for this opinion is summarised in 7.15.

8.5 GHD Limited (2009C) have modelled increased nutrient losses to waterways associated with the proposed increase in irrigated land in the Mackenzie Basin where a total of 36,526 ha of developed soils would be under irrigation without mitigation. This scenario (Scenario 2) would increase annual average maximum periphyton biomass by less than 25% in the Stony River, Greys River, Mary Burn, Twizel River, Henburn, Omarama Stream sub-catchments.

8.6 However, annual average maximum periphyton biomass in the Willowburn, Tekapo River, Ahuriri River, Quailburn and the Wairepo Creek sub-catchment would increase by more than 25% under Scenario 2 and hence mitigation will be required to reduce nutrient losses at these sampling nodes.

8.7 GHD Limited (2009C) have also modelled increased nutrient losses to waterways associated with the proposed increase in irrigated land in the Mackenzie Basin where a total of 36,526 ha of highly developed soils would be under irrigation without mitigation (Scenario 4). This scenario would increase annual average maximum periphyton biomass by more than 25 percent at all sub-catchment nodes except the Hen Burn (where no proposed irrigation is allocated) and Stony River.

8.8 Therefore, once soils have reached a steady state in terms of their ability to immobilse nitrogen (the highly developed scenario), mitigation will also be required to reduce nutrient losses at Greys River, Mary Burn, Twizel River, Henburn, Omarama Stream sub-catchments.

8.9 GHD Limited (2009A and 2009C) have calculated that the proposed increase in the current area of irrigation has the potential to shift the trophic status of the Ahuriri Arm of Lake Benmore from its current oligotrophic to a mesotrophic state and / or shift the trophic status of the Northern Arm of Lake Benmore from its current ultra-microtrophic to a microtrophic state. An independent study by NIWA has also calculated the additional nutrient loads that would result in a shift in the trophic status of Lake Benmore (Norton et. al., 2009).

8.10 I consider that a change of trophic status in the Ahuriri Arm of Lake Benmore, from its current oligotrophic to a mesotrophic state would be significant and undesirable for aquatic habitat quality within and downstream of Lake Benmore.

8.11 GHD Limited (2009A and 2009C) have adopted my recommendation that nutrient loads should be managed to ensure the trophic state of the Ahuriri Arm of Lake Benmore does not become mesotrophic but remains in an oligotrophic state.

8.12 In effect therefore, if this trophic threshold of effects is adopted, effective mitigation measures would be required to reduce expected (unmitigated) nutrient losses from the area of land it is proposed to irrigate in the Ahuriri catchment of Lake Benmore.

8.13 I consider a precautionary approach is warranted when setting such not to be exceeded thresholds and support recommendations that both nutrient concentrations and algal biomass should be monitored at all sites nominated by GHD Limited (2009C).

8.14 Contingency plans should be in place to respond to any trends in monitoring data that indicate the trophic status of the Ahuriri Arm of Lake Benmore is likely to shift over the oligotrophic / mesotrophic boundary following the commissioning of additional irrigation schemes in the catchment of the Ahuriri Arm of Lake Benmore (see Sections 7.20 to 7.26).

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