BEFORE THE INDEPENDENT COMMISSIONERS

IN THE MATTER of the Resource Management Act 1991

AND

IN THE MATTER of Variation 2 (Hinds/Hekeao Plains Area) to the Canterbury Land and Water Regional Plan by the CANTERBURY REGIONAL COUNCIL

EVIDENCE IN CHIEF OF ADAM DOUGLAS CANNING ON BEHALF OF THE NEW ZEALAND FISH AND GAME COUNCIL

7 MAY 2015

ANDERSON LLOYD
LAWYERS
QUEENSTOWN

Solicitor: M Baker-Galloway
(maree.baker-galloway@andersonlloyd.co.nz)

Level 2,
13 Camp Street,
PO Box 201,
QUEENSTOWN 9348
DX ZP95010
Tel 03 450 0700
Fax 03 450 0799

QUALIFICATIONS AND EXPERIENCE

1 My full name is Adam Douglas Canning.

2 I am a Doctoral Researcher in Freshwater Ecology in the Institute of Agriculture and Environment – Ecology at Massey University. I have a Bachelor of Science with Honours – First class (Biological Sciences and Environmental Science).

3 I am a member of the Ecological Society of America, The International Association for Ecology (INTECOL), and the New Zealand Freshwater Sciences Society. I have presented research at conferences held in both New Zealand and the USA. I have refereed scientific manuscripts for three scientific journals.

4 My research is focussed on understanding community and ecosystem thresholds to ensure ecosystem health (life supporting capacity) of freshwater systems in New Zealand. I am very familiar with literature relating to ecological community stability, environmental thresholds, modelling thresholds, and nutrient and environmental determinants of New Zealand freshwater ecosystem health.

5 In preparing this evidence I have reviewed:

(a) Proposed Variation 2 to the Proposed Canterbury Land and Water Regional Plan – Section 13 Ashburton;

(b) Ashburton ZIP Addendum Hinds Plains Area March 2014;

(c) Golder Associates report to Canterbury Regional Council, Summary of Ecological Data for Hinds River Land and Water Planning;

(d) National Policy Statement for Freshwater Management 2014;

(e) Water quality (both physicochemical and biota), and hydrological data for the Canterbury Region as provided by the Canterbury Regional Council;

(f) Canterbury Regional Council's technical report, Hinds Plains Water Quality Modelling for the Limit Setting Process 2013;

(g) Canterbury Regional Council's technical report, Ecological Assessment of Scenarios and Mitigations for Hinds Catchment streams and waterways; and

(h) Hinds Plains Loads Calculations spreadsheet provided by Canterbury Regional Council.

6 I have read the Code of Conduct for Expert Witnesses in the Environment Court Practice Note. This evidence has been prepared in accordance with it and I agree to comply with it. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

SCOPE OF EVIDENCE

7 I have been asked by Fish and Game to prepare evidence on whether the Proposed Variation 2 to the Proposed Canterbury Land and Water Regional Plan – Section 13 Ashburton will safeguard life supporting capacity (ecosystem health) of the Hinds/Hekeao Plains Area Catchment rivers and streams.

8 This includes:

(a) A discussion of the current freshwater ecological state;

(b) The causes of ecosystem degradation;

(c) A review of Variation 2 and in particular proposed Freshwater outcomes/objectives, targets and limits;

(d) And to recommend appropriate limits to safeguard life supporting capacity (ecosystem health) in the Hinds/Hekeao Plains Area Catchment rivers and streams if appropriate.

EXECUTIVE SUMMARY

9 The principal driving factors of decreased freshwater ecosystem health include increased nutrient levels, loss of riparian habitats, altered and reduced flows, and increased suspended and deposited sediment. Ecosystem health has declined considerably over the last ten years from a predominantly health ecosystem to a largely unhealthy ecosystem in recent years that now ranks as one of the worst in the country.

10 The proposed objectives in Proposed Variation 2 are inadequate to safeguard life supporting capacity.

11 Instream habitat quality, water quantity, nutrients (nitrogen and phosphorus), suspended and deposited sediment and riparian margins all need to be managed appropriately to achieve ecosystem health. All of these factors interact together to determine ecosystem health thus all need to be managed.

12 In the Hinds Catchment, a twenty-fold reduction in in-stream DIN concentrations as well as extensive riparian buffers with natural vegetation are required to ensure ecosystem health.

13 Management should not be based on a single nutrient, rather a suite of metrics. Furthermore, limits for metrics need to be based on ecosystem health requirements as the starting point rather than working backwards from current land practices, which has no ecological basis whatsoever. Management of both DIN and DRP is recommended and limits should be set to maintain ecosystem health, not nitrogen toxicity or/and to suit current land use. Nutrients need to be managed to prevent excessive periphyton growth from suffocating invertebrates and fish if ecosystem health is to be restored.

14 Riparian buffer zones provide a range of benefits to freshwater communities including the reduction of in-stream nutrient concentrations, lowered fine suspended and deposited sediment, the exclusion of livestock, temperature control, flow variability control, maintaining natural habitat character, and providing a source of food for aquatic taxa.

TERMS AND DEFINITIONS

15 Throughout my text I use the words ‘life supporting capacity’ and ‘ecological health’ interchangeably. Although there may be some distinction between these in a planning and/or legal arena they are the same in an ecological context. Furthermore, I also use the term ‘adverse’ and ‘significant adverse’ effect interchangeably. Again while there may be differences in these terms within the planning and/or legal arena they are identical in an ecological context.

STREAM AND RIVER BIOLOGICAL COMMUNITIES

16 Within the flowing water ecosystems there is Periphyton, Detritus, Terrestrial Plant and Animal matter, Aquatic Invertebrates, and Fish. Periphyton (the coating of green or brown slime on rocks) and detritus (both in-stream and terrestrial derived plant matter, e.g., leaves) form the basis of the stream food web. Some periphyton is required as food for many aquatic invertebrates; however, too much algal growth can dramatically change the ecology and habitat conditions of a river. Aquatic invertebrates consume the periphyton and plant matter either directly (along with other organic sources) or by predating the smaller grazing invertebrates. Native and sport fish eat these invertebrates and some terrestrial inputs. All of the biological components of a river food web require the correct habitat and water quality conditions in order to maintain healthy populations and functioning ecosystems.

MANAGING THE FRESHWATER ECOLOGICAL COMMUNITIES TO MAINTAIN ECOLOGICAL HEALTH IN THE HINDS/HEKEAO PLAINS AREA CATCHMENT RIVERS

17 For freshwater communities to be stable in the long term, their constituents must exist in the right balance and have a suitable environment to allow this balance to be sustained. A change in a single constituent can alter the entire community composition as a result of trophic cascades and resource competition.

18 Various indices of community structure have been developed as biological measures of ecosystem health, such as the QMCI (Quantitative Macroinvertebrate Community Index). Freshwater communities are largely a product of their environment, that is, for species to persist then environmental conditions must be within their tolerance zones. As freshwater organisms are always present in the water they are sensitive to environmental disturbances that may otherwise go un-noticed if we relied simply on physicochemical spot samples. In the Hinds River, the QMCI at the SH1 monitoring site over the last decade shows a considerable decrease in ecosystem health from that of a reasonably healthy ecosystem to one that is very unhealthy (Fig. 1.). Furthermore, during 2012, the site ranked worse than 78% of state of environment monitoring sites around the country (data obtained from Northland Regional Council, Waikato Regional Council, Hawkes Bay Regional Council, Manawatu-Wanganui Regional Council, Taranaki Regional Council, Bay of Plenty Regional Council, Greater Wellington Regional Council, Tasman Regional Council, West Coast Regional Council, Canterbury Regional Council, Otago Regional Council, and Southland Regional Council). I support the proposition of having the QMCI as a biological measure of ecosystem health and consider the proposed values for QMCI in proposed Table 13(a) of proposed variation 2, as appropriate limits for ecosystem health. In addition to the QMCI, I propose that both the percentages of EPT (Ephemeroptera, Plecoptera and Tricoptera) taxa and abundance also be used as they have been shown to be sensitive to changes in metal and ammonia concentrations that have gone undetected by the QMCI (Clements, Brooks, Kashian and Zuellig 2008, Collier, Ilcock and Meredith 1998, Hickey and Clements 1998, Hickey and Golding 2002, Hickey and Martin 1999, Hogsden and Harding 2011, Winterbourn and McDiffett 1996).

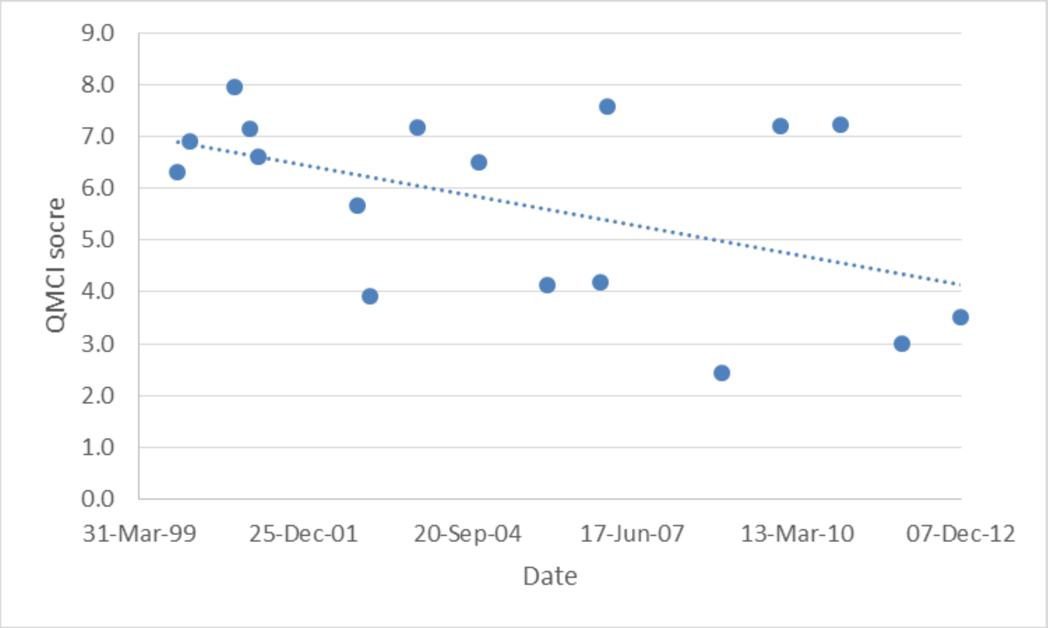

Figure 1. QMCI decreasing at the SH1 monitoring site at the Hinds River.

19 As we need to protect the entire freshwater community, I propose that fish also be monitored and that their communities attain a minimum IBI (the New Zealand Freshwater Fish Index of Biotic Integrity) of 40 (Joy and Death 2004), which should be incorporated into table 13(a). Fish require greater interstitial spaces than invertebrates and have different sensitivity thresholds than macroinvertebrates, therefore simply relying on the QMCI may not give an accurate depiction of the health of other trophic levels (Jowett and Davey 2007, Joy and Death 2004, Leathwick, Rowe, Richardson, Elith and Hastie 2005).

20 High turbidity and deposited sediment can drastically alter community composition. High turbidity can smother fish and invertebrates as well as make it difficult for them to find food (Lenat, Penrose and Eagleson 1981, Rowe and Dean 1998, Ryan 1991). Furthermore, native freshwater fish have been shown to exhibit preference for waterways with low turbidity and avoid those with high suspended sediment (Boubée, Dean, West and Barrier 1997). Fine deposited sediment reduces the space available for freshwater organisms to inhabit. The majority of New Zealand freshwater fish and organisms are benthic species and live in the interstitial spaces between substrate rocks (Jowett and Boustead 2001, Richardson and Jowett 2002, Suren and Jowett 2001). When high sediment loading occurs, the fine sediment

becomes deposited and fills the spaces between the rocks. Thus leaving little room for fish and invertebrates to live and be protected, consequently reducing the life supporting capacity of the stream and driving out taxa from these areas and many to local extinction (Burdon, McIntosh and Harding 2013, Harrison, Norris and Wilkinson 2007, Jowett and Boustead 2001, Lenat, Penrose and Eagleson 1981, Ramezani, Rennebeck, Closs and Matthaei 2014, Richardson and Jowett 2002, Ryan 1991, Suren and Jowett 2001, Wood and Armitage 1997).The originally proposed values for fine deposited sediment cover in table 13(a) of 20% for hill-fed upland sites and 50% for all other sites are far too high if life supporting capacity is the objective. The s42a officers report ECan has recommended changing them to 15% cover for the hill-fed Upper and Lower Hinds River and 20% for the drains, I support these recommendations and consider them suitable to protect ecosystem health (Burdon, McIntosh and Harding 2013). I also propose measuring suspended sediment using the black disk depth and turbidity, and propose suitable objectives in Table 1 (Boubée, Dean, West and Barrier 1997, Burdon, McIntosh and Harding 2013, Richardson and Jowett 2002, Rowe and Dean 1998).

21 Water temperature can also affect community composition as the freshwater organisms are ectotherms and their productivity rates will change with temperature. The productivity of a trout population will suffer as water temperature approaches and exceeds 19°C. Laboratory studies looking at the impacts of high temperatures on trout, have found that brown trout ceased feeding once temperatures climbed above 19°C and that they would die if temperatures climbed above 25°C for a sustained period (Elliott and Hurley 2003). Similarly, 50% of Deleatidium mayflies will die after 4 days in water at 22.6°C (Quinn, Steele, Hickey and Vickers 1994). Furthermore, Quinn and Hickey (1990) found that as temperatures surpassed 19°C that distributions of Ephemeroptera and Plecoptera taxa were restricted, thus drastically altering the community composition. Whilst the native fish species each have different preferred thermal ranges (Richardson, Boubée and West 1994), the Ephemeroptera and Plecoptera are important components of native fish diet and their absence could significantly reduce fish productivity (Hollows, Townsend and Collier 2002, Jellyman 1996, Jellyman 1989,

Main and Winterbourn 1987, McDowall, Main, West and Lyon 1996, Montori, Tierno De Figueroa and Santos 2006, Rowe, Konui and Christie 2002, West, Jowett and Richardson 2005). Trout embryos also have a narrow thermal range. The preferred range for brown trout spawning is 3-20°C, with an optimum temperature of 10°C, and for hatching a preferred range of 2-11°C with a maximum of 20°C (Death, 2002). To maintain life supporting capacity, I recommend that for all waterbodies that the maximum daily temperature during Summer (October to April inclusive) be reduced from 20°C to 19°C and during Winter (May to September inclusive) be reduced to 11°C.

22 Excessive periphyton growths are not only aesthetically unappealing, but they can also result in dramatic changes to the biological communities in rivers and streams. They lead to a change from mayfly, stonefly and caddisfly dominated communities to ones with worms, snails and midges that do not support the same abundance, biomass or diversity of fish that the former communities do. The periphyton can also build up to such a biomass that the lower layers start to rot. This can dramatically reduce the oxygen levels and change the pH of the water leading to significant adverse effects on many invertebrates and fish. Whilst oxygen concentration may be very high during the day time from high rates of photosynthesis, at night the lack of light prevents oxygen from being released into the water and oxygen levels can plummet to lethal levels (Dean and Richardson 1999, Franklin 2013). Thus many fish and invertebrate species are unable to survive, regardless of high oxygen concentrations that are recorded from daytime measurements, leading to differences in community composition. Surviving fish species would become stressed, susceptible to disease and develop poor condition as a result of undesirable dietary changes from alterations in macroinvertebrate community structure (Dean and Richardson 1999, Franklin 2013). It is for these reasons that I recommend dissolved oxygen sampling being conducted over at least a 24 hour period rather than spot sampling during the day time. The limits that are set in proposed Variation 2 should be upheld regardless of the time of day and not exceeded for any more than 1% of the time for a given period.

23 I do not deem the proposed dissolved oxygen limits in table 13(a) to be sufficient on their own, to sustain life supporting capacity. The proposed dissolved oxygen metric is measured in terms of percent saturation. The problem with this approach is that as water temperature increases, the amount of oxygen that can be held by the water decreases. Thus at high temperatures, high levels of saturation are easily met with low levels of absolute dissolved oxygen concentration. This will be most problematic during summer, when water temperature is high, flows are low, and periphyton growth is greatest (from typically low frequencies of scouring events). I therefore suggest the addition of an absolute dissolved oxygen concentration limit, Table 1. To maintain ecosystem health I suggest the values shown in Table 1 of my evidence of dissolved oxygen (mg/L), be included in table 13(a) as appropriate minimum absolute concentrations. The values will not only protect sensitive macroinvertebrates, they will also protect native fish species including inanga whitebait species (Dean and Richardson 1999, Franklin 2013, Landman, Van Den Heuvel and Ling 2005).

24 The amplitude of oxygen concentration fluctuation is a factor of periphyton biomass. The greater the periphyton biomass, the more oxygen there is produced during the day and the more decomposing biomass there is causing greater oxygen reductions at night (Biggs 2000, Welch, Jacoby, Horner and Seeley 1988, Welch, Quinn and Hickey 1992). I do not believe that proposed limits on chlorophyll a and filamentous algae (measures of periphyton biomass) are sufficiently low enough to prevent lethal or stressful levels of dissolved oxygen concentration. The values suggested are in line with those associated with eutrophic streams and high filamentous algae proliferation (Biggs and Price 1987, Welch, Jacoby, Horner and Seeley 1988, Welch, Quinn and Hickey 1992). I instead propose the values presented in Table 1 of my evidence, of 50mg/m^2 of chlorophyll a for the hill-fed upper and lower Hinds/Hekeao River area and 120mg/m^2 for the spring-fed plains as the limit which should be adopted in proposed variation 2 as they will prevent large proliferations from occurring and causing stressful oxygen depletion. The proposed variation 2 cyanobacteria levels in table 13(a) seem sensible to me and are also presented in Table 1 of my evidence (Wood, Hamilton, Paul, Safi and Williamson 2009).

25 Periphyton biomass is largely kept in check by the abundance of available resources, the amount of predation occurring, temperature, and the size and frequency of floods. Resources that limit periphyton growth are almost always shade and nutrients.

26 Maintaining the key elements of the hydrological regime of rivers and streams is also vitally important for protecting the ecological health of freshwater environments along with their geomorphology (physical form and structure). Decreased flow can mean more sediment being deposited, greater nutrient concentrations, less wetted habitat, greater temperatures, and more periphyton biomass. See the review by Dewson, James and Death (2007) for a comprehensive review of the ecological consequences of reducing flow. High flow events are important for scouring periphyton and keeping the standing stock low. Manipulations that cause lower flow variability than otherwise natural mean that periphyton may grow excessively and reduce ecosystem health. Flow variability also allows for runs, riffles and pools to all occur rather than a homogenous stretch, thus supports greater habitat for biota (Biggs, Nikora and Snelder 2005, Jowett and Duncan 1990).

Riparian Strips

27 Riparian buffer zones can range from a simple strip of vegetation from which livestock or other agricultural activities are excluded to a completely vegetated native forest riparian strip. The principal effect of the riparian buffer is to act as a barrier to nutrients, sediment, pathogens and other potential contaminants running off the land and to prevent it entering the waterway and consequently flowing downstream to lakes and estuaries. It will also stabilise stream banks and limit erosion and undercutting. The vegetation can also take up some of the nutrients. If a forested riparian zone exists this can also serve to limit light reaching the stream bed (which can also exacerbate periphyton growth) and water temperature (most aquatic animals have an upper threshold for survival which can be comparatively low, e.g., 19°C for stoneflies). In addition, riparian vegetation can also slow water movement from catchment to stream can prevent large pulses of water flows instream following high

rainfall (Anderson, Rutherfurd and Western 2006, Hupp and Osterkamp 1996, Naiman and Décamps 1997). Death and Collier (2010) found that streams with 40-60% upstream native riparian vegetation is likely to retain 80% of the biodiversity that would be found in pristine forest streams, and that those 80-90% native forest or scrub yields macroinvertebrate assemblages indicative of clean water.

28 The riparian buffer zone can also provide suitable habitat for the adult stages of many aquatic invertebrates (the in water life stage of many aquatic animals is the juvenile form with winged adults emerging from the water to mate and reproduce) (Collier and Smith 1997). Riparian buffer zones, particularly those with forested vegetation, are also important for providing instream habitat for native fish and trout by enhancing habitat diversity (e.g., overhanging branches, bank undercutting), creating pools and areas of day time and flood refuge. Grassy or forested river banks and lake shores also provide spawning habitat for Inanga and other Galaxias species, respectively. Terrestrial insects and mammals from riparian zones often form a major component of the diet for many native and sport fish at certain times of the year (Collier, Bury and Gibbs 2002, Jefferies 2000, Thompson and Townsend 2003). Furthermore, the addition of terrestrial matter into aquatic systems may stabilise the food webs by providing an alternative energy pathway should one become perturbed (Huxel and McCann 1998, Huxel, McCann and Polis 2002, Jefferies 2000, Takimoto, Iwata and Murakami 2002, Thompson and Townsend 2003). Thus riparian buffer zones also serve to maintain the proper ecological functioning of instream ecosystems.

29 Vegetated riparian buffer zones can shade streams thus limiting periphyton growth and lowering water temperature. Shade from riparian vegetation can slow periphyton growth by reducing photosynthesis and limiting the amount of energy available for growth. I liken this to building a house, a house with fewer builders will take longer to build than a house with many builders. Riparian shade can also prevent water temperatures from becoming too high. Quinn and others (1997) found that on average streams without riparian buffers (those in pasture) were 2.2°C warmer, had 30-fold higher periphyton biomass, and 11-fold

higher gross photosynthesis. However, riparian buffers need to be sufficiently long enough with enough shading to significantly lower temperature and control periphyton (Rutherford, Blackett, Blackett, Saito and Davies-Colley 1997, Storey and Cowley 1997).

30 A primary function of riparian buffer zones is absorbing nutrients before they enter the stream or river. The roots of the vegetation absorbs nutrients from water passing through soil from the mainland into the stream (Parkyn 2004, Parkyn, Davies-Colley, Halliday, Costley and Croker 2003). Smith (1989) found that even retiring 10-13m of pasture can remove up to 67% of nitrate and 55% of dissolve phosphorus surface flows flowing into small headwater streams. Where subsurface flow is dominant, pasture is much less effective at removing nutrients, however it was found that having forest cover instead of pasture with same buffer width does achieve a level of nutrient reduction similar to that by pasture when surface flows are dominant (Fennessy and Cronk 1997). Furthermore, a buffer zone of 20-30m of forested vegetation can remove almost all of the incoming nitrate (Fennessy and Cronk 1997, Parkyn 2004).

31 Riparian buffer zones can also reduce instream sediment loads by preventing the erosion of banks. The roots of the buffer zones, ground hugging vegetation, and decomposing leaf litter hold and protect soil during high rainfall and prevent the topsoil from being washed into the stream (Naiman and Décamps 1997, Parkyn 2004, Quinn and Stroud 2002). Smith (1989) found that in small headwater streams, simply retiring 10-13m of pasture reduced instream suspended sediment by up to 87%.

32 Livestock access to waterways results in the loss or destruction of the riparian buffer zone, significantly compromising its ecological function (Bagshaw and Policy 2002, Collins, McLeod, Hedley, Donnison, Close, Hanly, Horne, Ross, Davies-Colley, Bagshaw and Matthews 2007, Quinn, Williamson, Smith and Vickers 1992). Cattle and dairy cows, if given access to waterways, have a preference (in one study up to 50 times greater) for urinating and defecating directly into the waterway that will contribute to elevated levels of nitrogen and microbial contaminates

(Bagshaw 2002, Davies-Colley, Nagels, Smith, Young and Phillips 2004). Livestock (principally cattle, dairy cows and deer) trampling and wallowing can result in sediment deposition into streams, rivers and lakes. This can result in increased levels of deposited fine sediment with the direct detrimental ecological effects highlighted above. Phosphorous is also bound to the sediment and this can subsequently dissolve into the water and become available for periphyton growth. Finally livestock grazing will remove or degrade any riparian vegetation that might provide stream cover (to reduce light and temperature), stabilise banks, and provide habitat for aquatic and terrestrial invertebrates which are part of the aquatic food web (Bagshaw 2002, Collins, McLeod, Hedley, Donnison, Close, Hanly, Horne, Ross, Davies-Colley, Bagshaw and Matthews 2007, Quinn, Williamson, Smith and Vickers 1992, Williamson, Smith and Quinn 1992).

33 Proposed variation 2 aims to reduce nitrogen leaching from most farming land uses by 45% by 2035. The primary mechanisms for achieving this includes requirements for farming activities and farming enterprises to implement farm environment plans (schedule 7a), and Farm practices in accordance with Schedule 24a, along with requiring dairy and dairy support to reduce their nitrogen leaching by 45% and 25% respectively over time. While proposed Variation 2 requires cattle, pigs, and deer to be excluded from waterbodies and Schedule 24a includes some provisions for 3m setback from waterbodies in relation to winter grazing of intensively farmed stock and cultivation, I do not think the proposed plan adequately recognises nor provides for the establishment of vegetated riparian buffer zones which can significantly reduce nutrient discharges (overland flow and subsurface flow), and sediment and pathogen inputs to surface waterbodies. Given the significant benefit vegetation riparian margins have to protecting and enhancing ecosystem health and reducing the impacts of agriculture on freshwater environments, it is my opinion that further attention should be given to providing for and establishing vegetated riparian margins in the proposed plan.

34 To effectively manage the freshwater ecosystem health, I recommend that 80-90% of the streams and rivers within the catchment be fenced off

from livestock and covered with naturalised vegetation. Streams with a mean annual flow of 15-200L/s should have a 2-4m wide riparian strip either side of the stream, those with 200-500L/s should have a 5-7m wide riparian strip either side of the stream, with larger streams and rivers having a 10-30m riparian strip on either side, Table 1 (Collins, Mcleod, Hedley, Donnison, Close, Hanly, Horne, Ross, Davies-Colley and Bagshaw 2007, Death and Collier 2010, Naiman and Décamps 1997, Parkyn 2004, Quinn, Croker, Smith and Bellingham 2009, Smith 1989).

Nutrient management

35 For any organism to grow there must be sufficient nutrients available as nutrients are essential building blocks and without one an organism will not be able to be healthy or even grow at all. Whilst they may be essential, there can be too much of a good thing such that excessive nutrients can be detrimental to the life supporting capacity of freshwater ecosystems. High nutrient concentrations can impact freshwater taxa either by becoming toxic or by enabling competitive exclusion.

36 High levels of ammonia can be toxic to fish and invertebrates as a small rise can raise pH levels and damage gills and fins, thus making gas exchange and movement difficult, and if not reduced quickly it can fatal. Many experimental studies have found that New Zealand native freshwater species all differ considerably in their tolerance to ammonia and that many common taxa (such as *Deleatidium spp.*) are particularly sensitive to ammonia. Even concentrations as low as 0.1mg/L can be fatal with sufficient exposure (Hickey and Vickers 1994, Hickey, Golding, Martin and Croker 1999, Hickey and Martin 1999, Hickey and Vickers 1994, Richardson 1997). Furthermore, Richardson, Williams and Hickey (2001) experimentally found that native freshwater fish and shrimp actively avoid water flows with high ammonia concentration and seek those with lowest ammonia. Given these findings, I propose that ammonia concentrations at all locations be kept below 0.035mg/L (Hickey and Vickers 1994, Hickey, Golding, Martin and Croker 1999, Hickey and Vickers 1994, Quinn and Stroud 2002, Richardson 1997, Richardson, Williams and Hickey 2001). I also suggest that pH levels be

kept between 6.5 and 8.5 at all locations (Collier and Winterbourn 1987, Collier and Winterbourn 1990, Hogsden and Harding 2011, Winterbourn and McDiffett 1996). Furthermore, QMCI has been shown to be ineffective in responding to changes in ammonia, therefore I also suggest that %-EPT taxa and %EPT abundance also be measured and propose the limits in Table 1 be adopted (Hickey, Golding, Martin and Croker 1999, Hickey and Vickers 1994, Richardson 1997).

37 Nutrients also limit periphyton growth by capping the amount of growth that can occur. Once nutrients are no longer sufficiently available, periphyton growth ceases. Furthermore, the nutrients that are almost always limiting are either Dissolved Inorganic Nitrogen (DIN) or Dissolved Reactive Phosphorus (DRP). If either nutrient becomes limiting, then growth is also limited. Back to the analogy of building a house, having a limiting nutrient is like having no more bricks or mortar to continue building. However, unlike a house periphyton does not stop growing once the plan has been built, instead periphyton will continue growing until at least one resource becomes limiting (often Nitrogen or Phosphorus) or a flood scours the periphyton away. When the limiting nutrient is increased then periphyton biomass will continue to increase. High nutrient concentrations can allow periphyton to grow excessively, suffocate other wildlife (as discussed above) and cause competitive exclusion to occur. This is known as the Paradox of Enrichment. Therefore, it is recommended to manage instream nutrient concentrations for both nitrogen (DIN) and phosphorus (DRP) to prevent excessive periphyton growth from occurring.

38 Variation 2 plan proposes to put limits on Nitrogen losses from farming activities to attain a Nitrogen toxicity instream target. Whilst placing limits on Nitrogen loss on land has its merits, the value should be derived by determining the in-stream concentration needed for ecosystem health, not toxicity, and then working out on-land load limits needed to meet the desired in-stream concentration and loading. Setting on-land loads without considering the desired in-stream concentration required to provide for ecosystem health is likely to mean that the freshwater outcomes/ objectives set in table 13(a) especially in regards to macroinvertebrate community health as set by QMCI will not be attained.

Land limits should be used as a management tool to attain the desired in-stream nutrient concentrations needed for ecosystem health and to achieve the freshwater outcomes/objectives set in table 13(a).

39 When setting in-stream nutrient concentration limits, both Dissolved Inorganic Nitrogen (DIN) and Dissolved Reactive Phosphorus (DRP) need to have limits. Thus I do not support the current proposal to only manage Nitrogen to toxicity limits. As discussed above, it is prudent to manage both nutrients. Managing only one nutrient is fraught with risk as flow, temperature, pH and nutrient fluxes can easily switch a DRP limited stream to a DIN limited stream, and vice versa (Briand 1983, Wilcock, Biggs, Death, Hickey, Larned and Quinn 2007), furthermore, different algae species thrive in and are composed of different N:P ratios (Biggs 1990, Biggs and Price 1987, Milner 1953). Therefore managing only nitrogen is unlikely to yield ecosystem health. Furthermore, two recent reviews of an extensive array of studies (237 and 382 studies, respectively) have found Redfield ratios (the molar N:P ratio) are not accurate for determining nutrient limitation, thus managing via the use of Redfield ratios or by managing a single species is not recommended (Francoeur 2001, Keck and Lepori 2012).

40 Macroinvertebrate communities are influenced by many factors and their prediction typically requires using multifactorial modelling. Nutrients are a few of the various potential determinants of macroinvertebrate community structure, along with shade, upstream vegetation, substrate size, flow variability. We can use models to indicate what nutrient concentrations are predicted to achieve a desired level of ecosystem health (as indicated by the QMCI). I modelled data collected by Environment Canterbury from 350 macroinvertebrate sampling occasions across Canterbury during Summer between 2008 and 2014; physicochemical field data (the means of each metric for the three months prior to QMCI sampling were used), and a wide range of physical and chemical metrics obtained from the FENZ (Leathwick, West, Gerbeaux, Kelly, Robertson, Brown, Chadderton and Ausseil 2010) GIS database for each macroinvertebrate sampling site. See Table 2 for a complete list of metrics used in the model and the mean and standard deviations of values across all sampling occasions. Using

WEKA (Hall, Frank, Holmes, Pfahringer, Reutemann and Witten 2009), I applied Additive Regression (Stochastic Gradient Boosting) to model QMCI in response to all of the metrics presented in Table 2 as well as the sampling date. The model cross-validated (k-fold=10) and had a correlation coefficient of 0.74. I used this model to predict the DIN concentrations needed to achieve the proposed QMCI values for each management unit. Using FENZ geodatabase I obtained mean site specific environmental data (mean is from five randomly selected sites) for each of the three management units, with all other data set to the mean regional values, the model was then used to predict the DIN required to achieve the QMCI for each management unit. Given the findings of this model, as well as relevant literature on other nutrient-biota models and experiments, I suggest that to support a QMCI=6 in both the hill-fed upland and lower Hinds/Hekeao River Area Catchment that DIN be kept between 0.1-0.3mg/L and DRP be kept below 0.0004mg/L, and that to support a QMCI=5 in the spring-fed plains that DIN be kept between 0.5-0.7mg/L and DRP below 0.006mg/L (Biggs 2000, Clapcott, Goodwin, Young and Kelly 2014, Hickey, Golding, Martin and Croker 1999, Wagenhoff, Townsend and Matthaei 2012, Wagenhoff, Townsend, Phillips and Matthaei 2011).

41 The proposed on-land nitrogen loads is highly likely to result in in-stream nutrient concentrations that are far too high to support a healthy freshwater ecosystem, or achieve the OMCI freshwater outcomes/objectives set in table 13(a). The proposed nitrogen load target (to be met by 2035) for the Lower Hinds/Hekeao Plains Area is 3400 tonnes/year, according to the Hinds Plains Loads Calculations spreadsheet provided by Canterbury Regional Council, yields a groundwater concentration (without MAR) of 9.3mg/L under the Good Management Practice scenario. Using the same groundwater to in-stream concentration conversion factor of 0.6 from Scott (2013) the mean annual in-stream concentration would be 5.6mg/L, this is 10-fold higher than the concentrations I recommend to support ecosystem health. This is also higher than the average instream DIN concentration between June 2012 and June 2014 of 4.1mg/L at the Hinds River SH1 sampling site, and 4-fold higher than the mean value for all sampling occasions across the entire Canterbury region for that same period of

1.1mg/L, and ten times higher that national average over 2012 of 0.41mg/L (data obtained from Northland Regional Council, Waikato Regional Council, Hawkes Bay Regional Council, Manawatu-Wanganui Regional Council, Taranaki Regional Council, Bay of Plenty Regional Council, Greater Wellington Regional Council, Tasman Regional Council, West Coast Regional Council, Canterbury Regional Council, Otago Regional Council, and Southland Regional Council). Thus the proposed loadings, as calculated from Nitrogen leaching as modelled by OVERSEER would result in further declining ecosystem health, rather than improving the health of the Hinds/Hekeao catchment waterbodies. To give a potential indicator of on-land nitrogen loads required to meet the ecosystem health upper DIN limits I suggest of 0.5mg/L, I first converted the suggested in-stream concentration to shallow groundwater concentration. Then using the exact same model Scott (2013) used and the spreadsheet she provided, I replaced the shallow groundwater concentration with the value suggested and calculated back to determine an on-land nitrogen leaching load of 303 tonnes/year. Thus further reinforcing that setting limits based on on-land practices rather than ecosystem requirements can, and is likely to, mean loads are set which are detrimental to sustaining freshwater ecosystem health.

42 Furthermore, given that there is sometimes considerable lag between on-land nutrient leaching reaching waterways such that it may take many years before in-stream water quality increases, and water quality may get worse before it gets better. Therefore, I recommend that water quality limits are meet as soon as possible and that riparian buffer retirement and planting occurs with pace to buffer the in-stream environment from high nutrient loads from land.

CONCLUSIONS

43 Ecosystem health has reduced considerably in the Hinds/Hekeao Rivers Plains Area catchment over the last ten years to an extremely degraded state that ranks as one of the worst in the country. Current mean and median nitrate levels are approximately four times the region's average and 20 times the region's median.

44 A suite of environmental limits have been recommended. These include limits on sediment, nutrient concentrations, temperature, oxygen, periphyton biomass, and freshwater community health indices.

45 A ten to twenty fold reduction in nitrogen loading from current and proposed levels is recommended to support ecosystem health.

46 Managing a single nutrient and setting nitrogen loads based on on-land practices rather than in-stream water quality required to sustain freshwater life supporting capacity has been discredited. Management of both DIN and DRP is recommended and limits should be set to maintain ecosystem health, not nitrogen toxicity or/and to suit current land use.

47 Extensive riparian retirement and planting is recommended to ensure ecosystem health is maintained.

Adam Douglas Canning
Freshwater Ecologist
7th of May 2015

REFERENCES

Anderson, B. G., et al. 2006. An analysis of the influence of riparian vegetation on the propagation of flood waves. - Environmental Modelling & Software 21: 1290-1296.

Bagshaw, C. S. 2002. Factors influencing direct deposition of cattle faecal material in riparian zones. MAF Technical Paper

Bagshaw, C. S. and Policy, M. 2002. Factors influencing direct deposition of cattle faecal material in riparian zones. - Ministry of Agriculture and Forestry.

Biggs, B. J. 1990. Periphyton communities and their environments in New Zealand rivers. - New Zealand journal of marine and freshwater research 24: 367-386.

Biggs, B. J. 2000. Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. - Journal of the North American Benthological Society 19: 17-31.

Biggs, B. J. F., et al. 2005. Linking scales of flow variability to lotic ecosystem structure and function. - River Research and Applications 21: 283-298.

Biggs, B. J. F. and Price, G. M. 1987. A survey of filamentous algal proliferations in New Zealand rivers. - New Zealand journal of marine and freshwater research 21: 175-191.

Boubée, J. A. T., et al. 1997. Avoidance of suspended sediment by the juvenile migratory stage of six New Zealand native fish species. - New Zealand journal of marine and freshwater research 31: 61-69.

Briand, F. 1983. Environmental control of food web structure. - Ecology: 253-263.

Burdon, F. J., et al. 2013. Habitat loss drives threshold response of benthic invertebrate communities to deposited sediment in agricultural streams. - Ecological Applications 23: 1036-1047.

Clapcott, J. E., et al. 2014. A multimetric approach for predicting the ecological integrity of New Zealand streams. - Knowl. Managt. Aquatic Ecosyst.: 03.

Clements, W. H., et al. 2008. Changes in dissolved organic material determine exposure of stream benthic communities to UV-B radiation and heavy metals: implications for climate change. - Global Change Biology 14: 2201-2214.

Collier, K. J., et al. 2002. A stable isotope study of linkages between stream and terrestrial food webs through spider predation. - Freshwater Biology 47: 1651-1659.

Collier, K. J., et al. 1998. Influence of substrate type and physico- chemical conditions on macroinvertebrate faunas and biotic indices of some lowland Waikato, New Zealand, streams. - New Zealand journal of marine and freshwater research 32: 1-19.

Collier, K. J. and Smith, B. J. 1997. Dispersal of adult caddisflies (Trichoptera) into forests alongside three New Zealand streams. - Hydrobiologia 361: 53-65.

Collier, K. J. and Winterbourn, M. J. 1987. Faunal and chemical dynamics of some acid and alkaline New Zealand streams. - Freshwater Biology 18: 227-240.

Collier, K. J. and Winterbourn, M. J. 1990. Population dynamics and feeding of mayfly larvae in some acid and alkaline New Zealand streams. - Freshwater Biology 23: 181-189.

Collins, R., et al. 2007. Best management practices to mitigate faecal contamination by livestock of New Zealand waters. - New Zealand Journal of Agricultural Research 50: 267-278.

Collins, R., et al. 2007. Best management practices to mitigate faecal contamination by livestock of New Zealand waters. - New Zealand Journal of Agricultural Research 50: 267-278.

Davies- Colley, R. J., et al. 2004. Water quality impact of a dairy cow herd crossing a stream. - New Zealand journal of marine and freshwater research 38: 569-576.

Dean, T. L. and Richardson, J. 1999. Responses of seven species of native freshwater fish and a shrimp to low levels of dissolved oxygen. - New Zealand journal of marine and freshwater research 33: 99-106.

Death, R. G. and Collier, K. J. 2010. Measuring stream macroinvertebrate responses to gradients of vegetation cover: when is enough enough? - Freshwater Biology 55: 1447-1464.

Dewson, Z. S., et al. 2007. A review of the consequences of decreased flow for instream habitat and macroinvertebrates. - Journal of the North American Benthological Society 26: 401-415.

Elliott, J. and Hurley, M. 2003. Variation in the temperature preference and growth rate of individual fish reconciles differences between two growth models. - Freshwater Biology 48: 1793-1798.

Fennessy, M. S. and Cronk, J. K. 1997. The effectiveness and restoration potential of riparian ecotones for the management of nonpoint source pollution, particularly nitrate. - Critical Reviews in Environmental Science and Technology 27: 285-317.

Francoeur, S. N. 2001. Meta-analysis of lotic nutrient amendment experiments: detecting and quantifying subtle responses. - Journal of the North American Benthological Society 20: 358-368.

Franklin, P. A. 2013. Dissolved oxygen criteria for freshwater fish in New Zealand: a revised approach. - New Zealand journal of marine and freshwater research 48: 112-126.

Hall, M., et al. 2009. The WEKA data mining software: an update. - ACM SIGKDD Explorations Newsletter 11: 10-18.

Harrison, E. T., et al. 2007. The impact of fine sediment accumulation on benthic macroinvertebrates: implications for river management. Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference. - Charles Sturt University: Thurgoona, New South Wales, pp. 139-144.

Hickey, C. and Vickers, M. 1994. Toxicity of ammonia to nine native New Zealand freshwater invertebrate species. - Arch. Environ. Contam. Toxicol. 26: 292-298.

Hickey, C. W. and Clements, W. H. 1998. Effects of heavy metals on benthic macroinvertebrate communities in New Zealand streams. - Environmental Toxicology and Chemistry 17: 2338-2346.

Hickey, C. W. and Golding, L. A. 2002. Response of macroinvertebrates to copper and zinc in a stream mesocosm. - Environmental Toxicology and Chemistry 21: 1854-1863.

Hickey, C. W., et al. 1999. Chronic Toxicity of Ammonia to New Zealand Freshwater Invertebrates: A Mesocosm Study. - Arch. Environ. Contam. Toxicol. 37: 338-351.

Hickey, C. W. and Martin, M. L. 1999. Chronic Toxicity of Ammonia to the Freshwater Bivalve Sphaerium novaezelandiae. - Arch. Environ. Contam. Toxicol. 36: 38-46.

Hickey, C. W. and Vickers, M. L. 1994. Toxicity of ammonia to nine native New Zealand freshwater invertebrate species. - Arch. Environ. Contam. Toxicol. 26: 292-298.

Hogsden, K. L. and Harding, J. S. 2011. Consequences of acid mine drainage for the structure and function of benthic stream communities: a review. - Freshwater Science 31: 108-120.

Hollows, J. W., et al. 2002. Diet of the crayfish Paranephrops zealandicus in bush and pasture streams: insights from stable isotopes and stomach analysis. - New Zealand Journal of Marine and Freshwater Research 36: 129-142.

Hupp, C. R. and Osterkamp, W. 1996. Riparian vegetation and fluvial geomorphic processes. - Geomorphology 14: 277-295.

Huxel, G. R. and McCann, K. 1998. Food web stability: the influence of trophic flows across habitats. - The American Naturalist 152: 460-469.

Huxel, G. R., et al. 2002. Effects of partitioning allochthonous and autochthonous resources on food web stability. - Ecological Research 17: 419-432.

Jefferies, R. L. 2000. Allochthonous inputs: integrating population changes and food-web dynamics. - Trends in ecology & evolution 15: 19-22.

Jellyman, D. 1996. Diet of longfinned eels, Anguilla dieffenbachii, in Lake Rotoiti, Nelson Lakes, New Zealand. - New Zealand Journal of Marine and Freshwater Research 30: 365-369.

Jellyman, D. J. 1989. Diet of two species of freshwater eel (Anguilla spp.) in Lake Pounui, New Zealand. - New Zealand journal of marine and freshwater research 23: 1-10.

Jowett, I. G. and Boustead, N. C. 2001. Effects of substrate and sedimentation on the abundance of upland bullies (Gobiomorphus breviceps). - New Zealand journal of marine and freshwater research 35: 605-613.

Jowett, I. G. and Davey, A. J. 2007. A comparison of composite habitat suitability indices and generalized additive models of invertebrate abundance and fish presence–habitat availability. - Transactions of the American Fisheries Society 136: 428-444.

Jowett, I. G. and Duncan, M. J. 1990. Flow variability in New Zealand rivers and its relationship to in- stream habitat and biota. - New Zealand journal of marine and freshwater research 24: 305-317.

Joy, M. K. and Death, R. G. 2004. Application of the Index of Biotic Integrity Methodology to New Zealand Freshwater Fish Communities. - Environmental management 34: 415-428.

Keck, F. and Lepori, F. 2012. Can we predict nutrient limitation in streams and rivers? - Freshwater Biology 57: 1410-1421.

Landman, M. J., et al. 2005. Relative sensitivities of common freshwater fish and invertebrates to acute hypoxia. - New Zealand journal of marine and freshwater research 39: 1061-1067.

Leathwick, J. R., et al. 2005. Using multivariate adaptive regression splines to predict the distributions of New Zealand's freshwater diadromous fish. - Freshwater Biology 50: 2034-2052.

Leathwick, J. R., et al. 2010. Freshwater Ecosystems of New Zealand (FENZ) Geodatabase -Department of Conservation.

Lenat, D. R., et al. 1981. Variable effects of sediment addition on stream benthos. - Hydrobiologia 79: 187-194.

Main, M. and Winterbourn, M. 1987. Diet and feeding of koaro (Galaxias brevipinnis) in forested, South Westland streams. - Mauri ora 14: 77-86.

McDowall, R., et al. 1996. Terrestrial and benthic foods in the diet of the shortjawed kokopu, Galaxias postvectis Clarke (Teleostei: Galaxiidae). - New Zealand journal of marine and freshwater research 30: 257-269.

Milner, H. W. 1953. The chemical composition of algae. - Carnegie Inst. Wash. Publ 600: 285-302.

Montori, A., et al. 2006. The Diet of the Brown Trout Salmo trutta (L.) during the Reproductive Period: Size- Related and Sexual Effects. - International review of Hydrobiology 91: 438-450.

Naiman, R. J. and Décamps, H. 1997. The ecology of interfaces: riparian zones. - Annual review of Ecology and Systematics: 621-658.

Parkyn, S. 2004. Review of riparian buffer zone effectiveness. - Ministry of Agriculture and Forestry.

Parkyn, S. M., et al. 2003. Planted Riparian Buffer Zones in New Zealand: Do They Live Up to Expectations? - Restoration Ecology 11: 436-447.

Quinn, J. M., et al. 1997. Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill- country streams. - New Zealand journal of marine and freshwater research 31: 579-597.

Quinn, J. M., et al. 2009. Integrated catchment management effects on flow, habitat, instream vegetation and macroinvertebrates in Waikato, New Zealand, hill- country streams. - New Zealand journal of marine and freshwater research 43: 775-802.

Quinn, J. M. and Hickey, C. W. 1990. Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. - New Zealand journal of marine and freshwater research 24: 387-409.

Quinn, J. M., et al. 1994. Upper thermal tolerances of twelve New Zealand stream invertebrate species. - New Zealand journal of marine and freshwater research 28: 391-397.

Quinn, J. M. and Stroud, M. J. 2002. Water quality and sediment and nutrient export from New Zealand hill- land catchments of contrasting land use. - New Zealand journal of marine and freshwater research 36: 409-429.

Quinn, J. M., et al. 1992. Effects of riparian grazing and channelisation on streams in Southland, New Zealand. 2. Benthic invertebrates. - New Zealand journal of marine and freshwater research 26: 259-273.

Ramezani, J., et al. 2014. Effects of fine sediment addition and removal on stream invertebrates and fish: a reach- scale experiment. - Freshwater Biology 59: 2584-2604.

Richardson, J. 1997. Acute ammonia toxicity for eight New Zealand indigenous freshwater species. - New Zealand journal of marine and freshwater research 31: 185-190.

Richardson, J., et al. 1994. Thermal tolerance and preference of some native New Zealand freshwater fish. - New Zealand journal of marine and freshwater research 28: 399-407.

Richardson, J. and Jowett, I. G. 2002. Effects of sediment on fish communities in East Cape streams, North Island, New Zealand. - New Zealand journal of marine and freshwater research 36: 431-442.

Richardson, J., et al. 2001. Avoidance behaviour of freshwater fish and shrimp exposed to ammonia and low dissolved oxygen separately and in combination. - New Zealand journal of marine and freshwater research 35: 625-633.

Rowe, D., et al. 2002. Population structure, distribution, reproduction, diet, and relative abundance of koaro (Galaxias brevipinnis) in a New Zealand lake. - Journal of the Royal Society of New Zealand 32: 275-291.

Rowe, D. K. and Dean, T. L. 1998. Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. - New Zealand journal of marine and freshwater research 32: 21-29.

Rutherford, J. C., et al. 1997. Predicting the effects of shade on water temperature in small streams. - New Zealand journal of marine and freshwater research 31: 707-721.

Ryan, P. A. 1991. Environmental effects of sediment on New Zealand streams: A review. - New Zealand journal of marine and freshwater research 25: 207-221.

Scott, L. 2013. Hinds Plains water quality modelling for the limit setting process. - Canterbury Regional Council.

Smith, C. M. 1989. Riparian pasture retirement effects on sediment, phosphorus, and nitrogen in channellised surface run- off from pastures. - New Zealand journal of marine and freshwater research 23: 139-146.

Storey, R. and Cowley, D. 1997. Recovery of three New Zealand rural streams as they pass through native forest remnants. - Hydrobiologia 353: 63-76.

Suren, A. M. and Jowett, I. G. 2001. Effects of deposited sediment on invertebrate drift: An experimental study. - New Zealand journal of marine and freshwater research 35: 725-737.

Takimoto, G., et al. 2002. Seasonal subsidy stabilizes food web dynamics: balance in a heterogeneous landscape. - Ecological Research 17: 433-439.

Thompson, R. and Townsend, C. 2003. Impacts on stream food webs of native and exotic forest: an intercontinental comparison. - Ecology 84: 145-161.

Wagenhoff, A., et al. 2012. Macroinvertebrate responses along broad stressor gradients of deposited fine sediment and dissolved nutrients: a stream mesocosm experiment. - Journal of Applied Ecology 49: 892-902.

Wagenhoff, A., et al. 2011. Subsidy- stress and multiple- stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers. - Freshwater Biology 56: 1916-1936.

Welch, E. B., et al. 1988. Nuisance biomass levels of periphytic algae in streams. - Hydrobiologia 157: 161-168.

Welch, E. B., et al. 1992. Periphyton biomass related to point-source nutrient enrichment in seven New Zealand streams. - Water Research 26: 669-675.

West, D. W., et al. 2005. Growth, diet, movement, and abundance of adult banded kokopu (Galaxias fasciatus) in five Coromandel, New Zealand streams. - New Zealand Journal of Marine and Freshwater Research 39: 915-929.

Wilcock, R. J., et al. 2007. Limiting nutrients for controlling undesirable periphyton growth. - National Institute of Water & Atmospheric Research.

Williamson, R. B., et al. 1992. Effects of riparian grazing and channelisation on streams in Southland, New Zealand. 1. Channel form and stability. - New Zealand journal of marine and freshwater research 26: 241-258.

Winterbourn, M. and McDiffett, W. F. 1996. Benthic faunas of streams of low pH but contrasting water chemistry in New Zealand. - Hydrobiologia 341: 101-111.

Wood, P. J. and Armitage, P. D. 1997. Biological effects of fine sediment in the lotic environment. - Environmental management 21: 203-217.

Wood, S. A., et al. 2009. New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters Interim Guidelines. - Ministry for the Environment and Ministry for Health.

Table 1. Proposed limits to ensure the safeguarding of ecosystem health within Hinds/Hekeao River Catchment Area.

Metric	**Hill-fed Upper Hinds/Hekeao River Catchment**	**Hill-fed Lower Hinds/Hekeao River Catchment**	**Spring-fed plains**
QMCI (minimum score)	**6**	**6**	**5**
%EPT-taxa (minimum score)	**70**	**70**	**50**
%EPT-abundance (minimum score)	**70**	**70**	**50**
Minimum Fish-IBI score	**40**	**40**	**40**
Dissolved oxygen (%) [minimum daily saturation]	**90**	**90**	**70**
Dissolved oxygen (mg/L) [minimum daily concentration]	**8**	**8**	**7**
Temperature [daily maximum] (°C) to apply from October to April inclusive	**19**	**19**	**19**
Temperature [daily maximum] (°C) to apply from May to September inclusive	**11**	**11**	**11**
Maximum Dissolved Inorganic Nitrogen (mg/L)	**0.3-0.5**	**0.3-0.5**	**0.5-0.7**
Maximum Dissolved Reactive Phosphorus (mg/L)	**0.0004**	**0.0004**	**0.006**
Maximum Ammonia (mg/L)	**0.035**	**0.035**	**0.035**
Emergent macrophytes [maximum cover of bed] (%)	**30**	**30**	**30**
Total macrophytes [maximum cover of bed] (%)	**50**	**50**	**50**
Maximum chlorophyll a biomass (mg/m^2)	**50**	**50**	**120**
Filamentous algae >20mm [Maximum bed cover] (%)	**10**	**10**	**20**
Cyanobacteria [maximum bed cover] (%)	**15**	**15**	**20**
Fine deposited sediment <2mm diameter [maximum bed cover] (%)	**15**	**15**	**20**

Minimum clarity black disc (m)	4	4	3
Maximum turbidity (NTU)	5	5	10
Maximum E coli cfu/100mL	100	100	260
Allowed pH range [no greater than 0.5 change]	6.5-8.5	6.5-8.5	6.5-8.5
Minimum proportion (%) of reach protected by fenced and native vegetation riparian buffer zone. Buffer is 2-4m wide when MALF= 15-200L/s, 5-7m when MALF=200-500L/s, and 10-30m when MALF>500L/s.	90	90	80

Table 2. Mean environmental metrics for 350 stream/river macroinvertebrate Summer sampling occasions across the Canterbury region between 2008 and 2014. SD=standard deviation. Data obtained from the Canterbury Regional Council and FENZ Geodatabase.

Metric	**Mean**	**SD**
QMCI	**4.936035**	**1.629449**
AmmoniaNitrogen	**0.0221**	**0.049345**
logammonia	**-1.87119**	**0.326522**
NitrateandNitriteNitrogen	**1.24646**	**2.08939**
lognitrate	**-0.56716**	**0.896963**
TotalNitrogen	**1.410866**	**2.161265**
logN	**-0.31338**	**0.669054**
DissolvedReactivePhosphorus	**0.027247**	**0.105127**
logdrp	**-2.14046**	**0.595348**
TotalPhosphorus	**0.045743**	**0.126013**
logP	**-1.72279**	**0.479601**
DissolvedOrganicCarbon	**1.929282**	**1.863054**
Conductivity	**14.67277**	**8.072807**
pH	**7.675371**	**0.378004**
TotalSuspendedSolids	**10.14257**	**54.3186**
Turbidity	**4.386619**	**11.84695**
Blackdiscclarity	**2.876239**	**2.138991**
DissolvedOxygen	**10.9032**	**7.698165**
DissolvedOxygensaturation	**96.72431**	**15.35045**
WaterTemperature	**12.93971**	**2.821275**
Ecoli	**543.6143**	**735.3479**
Cyanobacterialmat	**1.417391**	**5.635076**
Didymo	**0.140351**	**0.515426**
Periphytonthickmats	**6.020761**	**13.30838**
Periphytonlongfilament	**5.258591**	**12.77359**
Periphytontotalcover	**55.96564**	**33.36422**
Ephiphyticperiphyton	**2**	**6.366495**
Macrophytesemergent	**4.07931**	**7.445576**
Macrophytessubmerged	**13.5**	**22.79266**
lnmacro	**1.226524**	**1.618631**

Sedimentation	**15.29199**	**21.78166**
CoordX1	**1514033**	**82945.88**
CoordY1	**5154944**	**82958.6**
Catchmentorder	**3.605505**	**0.994016**
Character	**1**	**0**
DSAvgSlope	**0.397994**	**0.954716**
DSDist2Coast	**35.28689**	**47.25444**
DwnStmDam	**0.007898**	**0.043666**
ExtentHa	**3429.318**	**4058.18**
FishEffect	**0.164203**	**0.104166**
Impervious	**0.034257**	**0.044592**
IndustEffect	**0**	**0**
LakeDSPolyID	**15361.05**	**16659.8**
LogNConc	**0.348132**	**0.503577**
tCover	**0.135257**	**0.198813**
tiolProtCumArea	**70.71989**	**22.55086**
tiolProtRank	**18679.39**	**5345.249**
tiolRank	**18038.95**	**5904.077**
PressureSum	**0.466781**	**0.106479**
ReachHab	**3.79**	**0.427477**
ReachSed	**3.089142**	**0.841984**
RegiolCumArea	**58.352**	**30.08022**
RegiolRank	**1153.498**	**722.0899**
RiverDSPolyID	**9998.716**	**12020.39**
RiverProtectness	**0.095539**	**0.095197**
logriverprot	**-2.94631**	**1.162154**
SegCluesLogN	**0.348131**	**0.503577**
SegCluesN	**4.583976**	**7.00376**
SegFlow	**4.670431**	**14.3353**
SegFlow4th	**1.044464**	**0.167881**
SegFlowVariability	**0.115611**	**0.107342**
SegHisShade	**0.759514**	**0.105611**
SegJairT	**16.25686**	**0.751043**
SegLowFlow	**0.582799**	**4.422838**
SegMinTNorm	**-0.66325**	**1.300057**
SegRiptive	**16.66**	**26.89919**

SegSlope	**1.206086**	**2.162656**
SegSlopeSqrt	**1.383856**	**0.540242**
SpatialProtection	**0.031283**	**0.082237**
USCalcium	**1.699343**	**0.383804**
lncalc	**0.500964**	**0.251055**
USDam	**0.048571**	**0.215278**
USGlacier	**6.69E-05**	**0.00072**
USHardness	**2.913319**	**0.760789**
USIndigFor	**0.020913**	**0.098472**
USLake	**8.57E-05**	**0.000923**
UStive	**0.296143**	**0.339096**
USPasture	**0.669**	**0.341089**
USPeat	**0**	**0**
USPhosphorus	**3.478171**	**0.447007**
USWetland	**0.000177**	**0.001045**