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Review of Water Quality and Ecological Monitoring of the Taharua River

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EXECUTIVE SUMMARY

This report reviews water quality and ecological monitoring undertaken by Hawke's Bay Regional Council (HBRC) and Bioresearches Ltd. on the Taharua River to assess the effects of change in land use to intensive dairy farming, including spray irrigation of dairy shed effluent. In particular it comments on the adequacy of the monitoring and interpretation of results for assessing effects on trout. It provides suggestions on how to tailor HBRC's monitoring programme to better address potential impacts on the trout population that may be arising from dairy development. Interest in the latter arose after HBRC received comments from Poronui Station Ltd. that the trout fishery was declining – with fish becoming smaller – yet their interpretation of the monitoring results suggested the river was in good ecological health.

Key results from HBRC's and Bioresearches monitoring were:

- water clarity has declined over time, and also declined down the length of the Taharua River, although it is not often below HBRC's guideline of 1.6 m;
- nitrogen concentrations have increased over time to high levels – a matter of particular concern to HBRC;
- despite high nitrogen (and phosphorus) levels algal biomass in the Taharua River was well within current environmental guidelines and;
- ecosystem health of the Taharua River was considered good as evaluated by the macroinvertebrate community index (MCI).

The water clarity/turbidity guidelines used to interpret monitoring data from the Taharua River are, in our opinion, not stringent enough to assess effects on trout. This has lead to HBRC and Bioresearches underestimating the effects of temporal and spatial changes in water clarity/turbidity. Based on visual drift-feeding requirements of trout we suggest that a water clarity guideline of at least 3.75 m and preferably 4.75 m is appropriate, but this should depend on locality specific reference levels (i.e. natural levels in the absence of agricultural land use influence). Monitored water clarity in the Taharua River has frequently fallen below such levels. We recommend that the water clarity guidelines, and their turbidity equivalents, be revised upon peer review of our recommendations and the monitoring data reassessed against them.

Consideration should be given to installing a continuous turbidity meter in the Taharua River to capture episodic turbidity events in the monitoring record. Continuous turbidity/water clarity data would also allow effects to be interpreted with respect to frequency and duration (not just magnitude) and guidelines incorporating these features might be able to be developed, as has been done elsewhere for suspended sediment.

Daytime spot measurements of dissolved oxygen levels have mainly exceeded realistic guidelines for trout (>80% saturation) but these measurements have not been conducted at the critical time of the diel cycle (dawn). Continuous 24 h logging of oxygen and modelling of stream metabolism on one occasion (not part of the normal monitoring programmes) found oxygen saturation fell to 74% and

ecosystem respiration was particularly high, indicative of poor ecosystem heath. We recommend that in future, monitoring of oxygen levels should be undertaken by spot sampling at dawn or by continuous logging over a 24 h period. Value can be added to the latter by modelling stream metabolism (respiration and plant production rates).

Nitrate concentrations in the Taharua River have been exceeding levels that may be toxic to trout eggs. Total nitrogen levels have been high and although the levels recorded are not known to be toxic to trout and other aquatic life they are likely to be contributing to high ecosystem respiration rates. We recommend that in future the nitrogen monitoring data be interpreted with respect to 24 h oxygen monitoring data and stream metabolism modelling.

Although elevated nutrients (N and P) do not appear to be promoting proliferation of periphyton in the Taharua River (possibly because of mobile pumice sand), they may be doing so in the Mohaka River below the Taharua confluence. We recommend that nutrient and periphyton monitoring be extended into the Mohaka River.

We recommend that the monitoring programme be underpinned by a limiting factor analysis for trout taking into consideration key life history stages. In that context, in addition to the changes in interpretation of monitoring results suggested above, we recommend that the monitoring programme includes the following:

- a trout spawning survey to determine the distribution of spawning habitat;
- monitoring of stream bed siltation/sedimentation, including spawning gravel;
- a survey of riparian conditions, including sources of sediment influx;
- monitoring of trout abundance and growth – to verify whether potential effects indicated from monitoring water quality and habitat parameters are being realised in the trout population.

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1. INTRODUCTION

On 8 October 1999 consents were granted for two dairy conversions, including spray irrigation of wastes onto land, within the pumice-based Taharua River Catchment. The Taharua River supports a highly valued brown trout fishery and is a tributary of the Mohaka River which is nationally and internationally famous for the quality of its brown and rainbow trout fisheries. Poronui Station Ltd. owns land adjacent to the Taharua River and operates an internationally renowned fishing lodge, which is partly dependent on the fishing opportunities available in the Taharua and upper Mokaha rivers.

Monitoring data collected since 13 November 2001 suggests that dissolved nitrogen concentrations are increasing within the Taharua River and reports from Poronui Station indicate that the trout fishery is in decline – trout are thought to be smaller.

The present report was requested by Hawke's Bay Regional Council (HBRC) under Envirolink grant No. HBRC5. Its purpose is to peer review HBRC draft report EMI 0601, plan number 3828 '*Taharua River Water Quality and Instream Ecology November 01 to December 05*' (HBRC 2005) and provide recommendations as to how best to tailor HBRC's monitoring programme to address potential impacts on the trout population that may be arising from the dairy development. Additional data was available from monitoring undertaken by Bioresearches Ltd. for Poronui Station Ltd.

Although trout fisheries and fish habitat are often identified as critical instream values in regional plans throughout New Zealand, targeted monitoring of the effects of dairy farming, specific to trout (and salmon), have been largely overlooked by regional councils. In part this neglect has arisen because regional councils have assumed that the responsibility for monitoring lies with Fish and Game councils, whereas in fact both regional councils and Fish and Game councils share statutory responsibility in this regard. Moreover, Fish and Game councils do not have the financial or staffing resources to undertake such detailed monitoring which can include aspects of water quality, flow, instream and riparian ecology and trout population parameters (abundance, growth, condition).

If the joint initiative between the dairy industry and regional councils in the 'Dairy and Clean Streams Accord' is to be shown to be effective, then regional councils need to expand their stream monitoring programmes to include meaningful indicators of stream ecosystem health targeted at assessing effects on salmonids and other fishes. After all, a key goal of the accord is to have water that is suitable for fish. The present Envirolink initiative by Hawke's Bay Regional Council is a positive step in this direction.

2. REVIEW OF MONITORING

2.1. Aim

The aim of HBRC's Taharua River monitoring programme is to monitor the effects of the change in land use to intensive dairy farming, including spray irrigation of dairy shed effluent, on the surface water quality and instream benthic ecology of the Taharua River. In the context of the present Envirolink project there is interest in expanding the aim to include monitoring effects on the trout population.

2.2. Key results

The key results of HBRC's monitoring programme, which began in November 2001, as summarised in the draft report HBRC (2005), were:

- The Taharua River had comparatively good water clarity and displayed similar nutrient concentrations (with the exception of dissolved nitrogen) to other sites in the Mohaka River Catchment. However, water clarity declined significantly down the river – although it was often above the 1.6 m environmental guideline of the Hawke's Bay Regional Council Proposed Regional Resource Management Plan.
- The Taharua River had comparatively high dissolved nitrogen concentrations when compared to other sites in the Mohaka Catchment and these had increased over time. Oddly though, concentrations decreased down the Taharua, which was thought to be due to dilution in the lower reaches.
- The increasing trend in dissolved nitrogen (nitrate, DIN, total N) was thought to be due to land use intensification in the catchment, rather than the consented spray irrigation of dairy shed effluent per se.
- There was no trend in dissolved reactive phosphorus concentrations down the Taharua River, and levels recorded were not significantly different to other sites within the Mohaka Catchment. However, all sites in the Taharua regularly exceeded the 0.015 mg/l environmental guideline in the HBRC Proposed Regional Resource Management Plan.
- Faecal coliform concentrations were similar to other sites in the Mohaka Catchment and, with the exception of the Wairango site, were often within the environmental guideline (faecal coliforms <50/100 ml) for surface water quality from the Hawke's Bay Regional Council Proposed Resource Management Plan.
- Monitoring by Bioresearches was cited as indicating that algal biomass in the Taharua River was well within current environmental guidelines.
- The ecosystem health of the Taharua River was considered good as evaluated by the macroinvertebrate community index (MCI).

Monitoring by Bioresearches since December 1999 adds to this picture. Key findings of their monitoring were:

- Confirmation that water clarity declined downstream, but that it fell within the ANZECC (2000) guidelines. Water clarity ranged between 2.9 and 6.1 m at the upstream sites (PS3, PS4, PS5 – between Rere Falls to Wairango Station, Figure 1)[1] in 1999 and 2001. Lowest clarities were recorded in April 2001 (following rain); ranging from 0.87 to 1.05 (Bioresearches 2002).
- Turbidity levels were within the ANZECC guideline for upland rivers (4.1 NTU) at almost all sites and occasions. They have generally ranged from 0.19 to 2.21 NTU (the highest level in April 2002 following rain), but breached the ANZECC guideline at one site (PS2) in September 2000 (Bioresearches 2001d).
- Almost all measurements of suspended solids concentrations have fallen below the ANZECC (2000) guideline for the protection of aquatic life (6 g/m^3) (Bioresearches 2001a,b,c; 2002). The guideline was breached on one occasion at one site (PS2) in September 2001 (22 g/m^3) (Bioresearches 2001d).
- Confirmation of high nitrogen levels in the Taharua River, and that they decreased down the river.
- Confirmation that dissolved reactive phosphorus (DRP) levels exceeded the HBRC Proposed Regional Resource Management Plan's 0.015 mg/l guideline, but fell below the ANZECC (2000) guideline of 0.035 mg/l. However, contrary to the HBRC monitoring results concentrations of DRP and total phosphorus decreased down the river (recorded in December 1999, February and April 2000).
- Dissolved oxygen concentrations and saturation based on spot daytime sampling were not of ecological concern. They have generally been above or close to USEPA (1986) and ANZECC (2000) guidelines (Bioresearches 2002).
- Confirmation that faecal coliform concentrations were usually low but on occasions (when cattle were grazing near the river at Wairango Road Bridge (site PS5) in December 1999, and following rain in April 2002) high levels (≥260/100 ml and >2000/100 ml *E. coli* in December 1999 and April 2002, respectively) were recorded, exceeding the MfE and MoH (2003) alert level (260-550/100 ml) and action level (>550/100 ml) guidelines for contact recreation, respectively. The alert level was also breached at two sites (PS3 and PS5) in December 2000, and the <50/100ml environmental guideline in HBRC's Proposed Resource Management Plan was breached slightly more frequently.
- The increased nitrogen concentrations in the Taharua River have not been associated with increased periphyton growths nor related to poor macroinvertebrate communities.
- Algal biomass was generally low in terms of chlorophyll *a* and particularly low in terms of ash free dry weight (AFDW). Algal cover/biomass generally fell below the Mfe (1992) algal cover guideline for contact recreation (filamentous growths <40% cover, chlorophyll *a* ≤0.1 g/m^2, ≤40 g/m^2 AFDW), although the chlorophyll *a* guideline was

[1] PS5 and PS4 are equivalent to HBRC's Wairango Rd and Twin Culvert sites, respectively.

occasionally breached at one or two sites (PS5 – Wairango and PS2 – lower river in Poronui Station) (Bioresearches 2001a,b,c).

- Overall the water and biological communities of the Taharua River were considered to be of good quality, supporting diverse algal and macroinvertebrate communities, but with indications of nutrient enrichment, thought likely to be due to farming practices in the upper catchment (Bioresearches 2001a).

Interestingly, Bioresearches (2001a) baseline monitoring report showed that water clarity continued to decline down the Taharua River (lowest water clarity was recorded at site PS2 – well below the two recent dairy conversions, Figure 1). If decline in water clarity down the river is due to land use, as seems likely and is suggested in the Bioresearches and HBRC (2005) reports, then Poronui Station shares the blame with Perrott and Taharua Farms and Wairango Station. Recent logging operations may also be contributing to reduced water clarity in the Taharua (Eve Brown, Poronui Station Manager, pers. comm.).

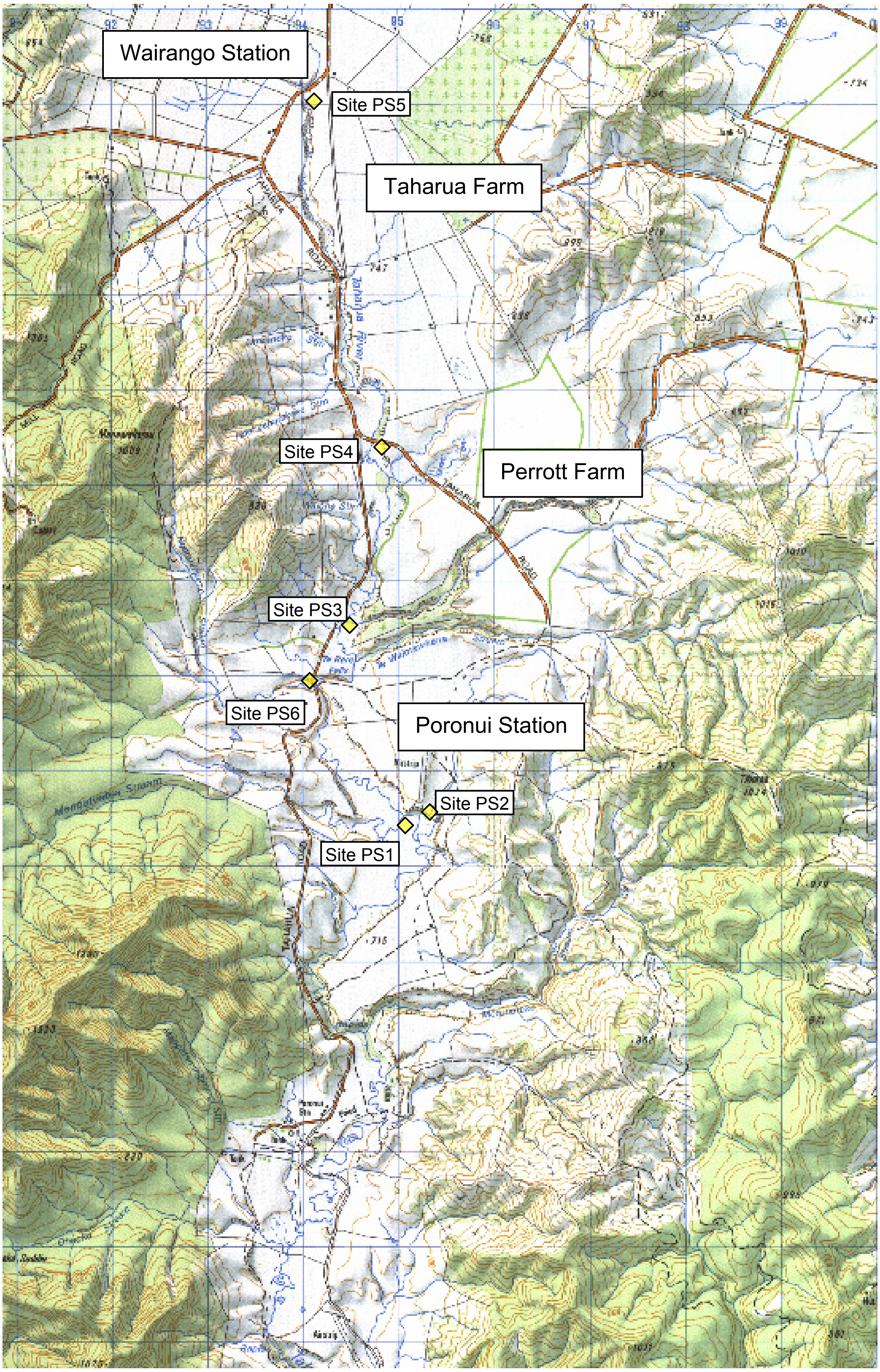

Figure 1. The Taharua catchment around Poronui Station, showing approximate locations of Bioresearches Ltd.'s sampling sites and approximate farm locations.

2.3. Adequacy and interpretation of monitoring results for detecting effects on trout

2.3.1. Dissolved oxygen

The dissolved oxygen requirements of salmonids are higher than for most other freshwater fishes (Dean & Richardson 1999). A minimum oxygen concentration of 5.0–5.5 mg/l can be tolerated by free swimming brown trout but should be at least 80% saturation (Mills 1971 cited in Elliott 1994). The incipient lethal level of dissolved oxygen concentration, for free swimming brown and rainbow trout, is about 3 mg/l (Raleigh et al. 1984, 1986). The oxygen requirements of salmonids increase with water temperature, due to increased metabolic rate (Elliott 1994). When water temperature exceeds 10°C, rainbow trout generally avoid water with dissolved oxygen concentrations <5 mg/l (May 1973). However, as oxygen concentration falls toward this level, the health, growth, reproduction, and survival of the fish may be jeopardised. Long term exposure to dissolved oxygen levels of even 6 mg/l can chronically impair the growth of salmon, by up to 20% depending on the water temperature (BCME 1997). Following the BCME (1997) guidelines, 8 mg/l is an appropriate long-term (e.g. 30 day mean) level for best protection of salmonids and other aquatic life.

The ANZECC (2000) guidelines recommend greater than 90% oxygen saturation for the protection of aquatic life, but may be unrealistic. The USEPA (1986) minimum dissolved oxygen concentration guideline for protection of all life stages of salmonids is 8.0 g/m^3. In our opinion, the >80% saturation guideline suggested in ANZECC (1992) should provide adequate protection to trout, so long as water temperatures are maintained within the tolerance range of trout. The incipient lethal temperature for brown trout increases with acclimation to a plateau at 24.7°C (Elliott 1994), and slightly higher for rainbow trout (26.2°C), but behavioural disturbances can be expected at temperatures less than the incipient lethal temperature for both species (e.g. brown trout cease feeding at temperatures above 19°C). Lower temperatures are required during winter and spring for successful incubation of trout eggs, with suitable temperatures less than about 11°C being commonly cited in the literature (Hay et al. 2006). The weight per volume of dissolved oxygen required to achieve 80% saturation does not fall below 6 mg/l until temperatures of >30°C, which is well into the lethal temperature range for trout. Also, 80% saturation is approximately equivalent to the 9 mg/l guideline (suggested in BCME 1997) for protection of eggs and fry in the substrate at 11°C, and is more conservative at lower temperatures.

Oxygen levels in the Taharua River, based on spot daytime sampling recorded by Bioresearches, have been close to, or above, 90% saturation levels on most occasions (Bioresearches 2001a, 2002). However, spot daytime sampling does not address diel variation in oxygen levels. Lowest oxygen levels usually occur at dawn. Spot sampling should be conducted at this critical time, or oxygen should be continuously recorded over a 24 hour period.

Continuous 24 hour logging of dissolved oxygen levels has been conducted on one occasion in the Taharua River, and dropped to 74% saturation at night (R. Young, Cawthron, pers.

comm.). This is slightly below the ANZECC (1992) guideline (80% saturation), and flags the need for ongoing monitoring. In the same study stream metabolism was modelled and the estimated ecosystem respiration rate in the Taharua was particularly high (14.7 $gO_2/m^2/day$), and indicative of poor ecosystem health (Young et al. 2006). However, the authors cautioned that not enough was known about pumice bed streams to judge whether this was indeed due to poor ecosystem health or local geology.

2.3.2. Nitrogen

Elevated nitrogen is the other main water quality change that has occurred in the Taharua catchment. There are three ways in which elevated levels of nitrogen can potentially impact on trout; 1) direct toxic effects, 2) in combination with organic matter it may promote higher river respiration rates thereby reducing nocturnal dissolved oxygen levels, 3) indirect effects via algal proliferation altering pH (potentially to harmful levels, >pH 9) and benthic invertebrate communities (trout food).

Direct toxic effects

With respect to direct toxic effects, ammoniacal nitrogen is usually of most concern with the disposal of dairy shed wastes. Salmonids are very sensitive to ammonia – more so than native fish and aquatic macroinvertebrates (Richardson 1997). Toxic concentrations of un-ionised ammonia reported for 96 h tests are 0.08–1.09 mg/l for salmonids (USEPA 1985). There is evidence that trout eggs and alevins (larvae) are sensitive to ammonia. A report into the toxicity of ammonia produced by the United States Environmental Protection Agency (USEPA 1999) cites two studies into the lethal effects of ammonia on salmonid eggs and alevins. They both found that high ammonia concentrations produced increased mortality, with one study reporting that survival was reduced by 67% at a total ammonia nitrogen concentration of 2.55 mg/l. However, the effects of ammonia are dependent on pH and while this testing was carried out at a pH of 7.52, this concentration would be equivalent to 1.44 mg/l at pH 8 (USEPA 1999). Ammonia concentrations monitored in the Taharua River by HBRC and Bioresearches have been well below these levels. However, both of the studies cited by the USEPA also found that long-term exposure reduced the concentration required to cause 50% mortality, as did reduction in the time from fertilisation to first exposure to ammonia.

HBRC's un-ionised ammonia guideline (0.1 mg/l) is based on the ANZECC (2000) water quality guidelines and concentrations recorded in the Taharua are usually below this.

There is very little published information on the toxicity of other species of nitrogen to fishes – which perhaps indicates this is not a major issue. However, we have found reference to one study that suggests nitrate might be of some concern. This study was cited in a document produced by the State of California Regional Water Quality Control Board (SCRWQCB 2004), investigated the toxic effects of nitrate. It concluded that steelhead trout eggs suffered a statistically significant higher rate of mortality when subjected to nitrate concentrations above 1.1 mg/l. Nitrate concentrations in the Taharua River have exceeded this level, and have exceeded the maximum concentration found in Close & Davies-Colley's (1990) survey of 96 New Zealand rivers (HBRC 2005; Bioresearches 2001a, 2002). However, the SCRWQCB report noted that there was some doubt as to the reliability of the experiment in which the 1.1 mg/l nitrate threshold was found, so further investigation may be warranted.

Elevated river respiration rate

Preliminary results of river metabolism studies indicate that respiration rates are high in the Taharua River (Young et al. 2006). This may be caused by high inputs of organic matter and nutrients (N and P), or might be related to the extensive hyporheic zones (i.e. the zone of surface water influence within the substrate) which are a feature of pumice bed streams. Stream metabolic rates are typically closely correlated with nutrient levels. The high organic load in streams, which occurs with dairy farming, must be processed instream, mainly within the hyporheic zone. This breakdown of organic matter can be limited by nitrogen in the same manner as occurs in garden compost heaps. Addition of nitrogen stimulates the breakdown process and increases respiration rates and associated oxygen demand. This results in oxygen depletion at night when oxygen production from photosynthetic activity of algae shuts down. High stream respiration rates increase the risk that nocturnal levels of oxygen will fall below the critical requirements of trout and other aquatic life. Trout are particularly sensitive to oxygen depletion.

The above discussion may be helpful for interpretation of monitoring results for nitrogen in the Taharua River. Interpretation of this parameter is best undertaken in conjunction with oxygen monitoring, preferably continuous 24 hour oxygen records within the context of stream metabolism modelling.

Promotion of periphyton proliferation

Notwithstanding the above cautions on ammonia and river respiration rates, the main concern over nitrogen in aquatic ecosystems is usually with the stimulatory effect of this nutrient on algae. The ANZECC (2000) guidelines recommend trigger levels of nitrate (and/or nitrite) nitrogen and total nitrogen of 0.167 g/m^3 and 0.295 g/m^3, respectively, for the prevention of adverse effects due to nutrients in upland rivers. This matter is addressed further in the next section. HBRC's and Bioresearches monitoring has shown that these levels are being exceeded in the Taharua River.

2.3.3. *Periphyton/algae*

While the total nitrogen (and nitrate) concentrations recorded in the Taharua River have been exceeding ANZECC nutrient guidelines, Bioresearches monitoring has indicated periphyton proliferation is not a major problem. Algal biomass estimates made by Bioresearches were interpreted with respect to Mfe's (1992) guidelines. More up to date guidelines are available (MfE 2000a). Algal biomass, as measured by chlorophyll *a*, recorded by Bioresearches (2001a,b,c) (0.030-0.133 g/m^2 chlorophyll *a*) has occasionally exceeded MfE's (2000a) periphyton guidelines for benthic biodiversity (0.05 g/m^2 chlorophyll *a*). However, these estimates and those for ash free dry weight (<1.4 g/m^2) are well below the MfE guidelines for trout habitat and angling (0.2 g/m^2 chlorophyll *a*; 35 g/m^2 ash free dry weight).

Biggs (MfE 2000a) recommended that an appropriate total nitrogen concentration to match the above periphyton guideline for trout fisheries is 0.295 g/m^3 (i.e. the same as the ANZECC 2000 guideline). However, Biggs' (MfE 2000a) guidelines for trout fisheries may need to be revised in the future in light of improved understanding of the inter-relationships between periphyton, invertebrate drift and trout growth and abundance. Although high densities of invertebrates (potential trout food) may be associated with high algal biomass, there is evidence that these invertebrates may not be as readily available to drift feeding trout (Shearer et al. 2003). While the periphyton guidelines for trout fisheries suggested in MfE (2000a) may be sufficient to protect fisheries values in lowland rivers it is likely that algal biomass and cover at these levels would be seen as a significant reduction in the "pristine" natural character of many headwater fisheries. Headwater rivers generally have thin diatom films. In these rivers, the guideline proposed by MfE (2000a) to protect benthic biodiversity values (rather than fisheries values) (0.02 g/m^3 soluble inorganic nitrogen) would provide better protection for trout habitat, benthic invertebrate (food producing) habitat and aesthetic values. However, with respect to the Taharua this may be of only academic interest because on the basis of Bioresearches monitoring results significant periphyton proliferation does not appear to have been occurring at nitrogen levels well above this level. The reasons for this have not been determined but it may be related to the unstable pumice sand substrate, and associated sand-blasting of stable bed elements.

Although elevated nutrients (N and P) do not appear to be promoting proliferation of periphyton in the Taharua River (possibly because of mobile pumice sand), they may be doing so in the Mohaka River below the Taharua confluence; the Mohaka has a more stable bed than the Taharua River. We recommend that nutrient and periphyton monitoring be extended into the Mohaka River.

2.3.4. *Water clarity, turbidity and suspended solids*

The water clarity guidelines used to assess effects in the Taharua are, in our opinion, inappropriate for trout; they are not stringent enough. The HBRC Proposed Regional Resource Management Plan water clarity (black disc) guideline is 1.6 m. Bioresearches have been assessing effects against the ANZECC (2000) guideline for upland rivers (0.6 m black disc), the ANZECC (2000) guideline for turbidity in upland rivers (4.1 NTU), the ANZECC (2000) guideline for suspended solids for the protection of aquatic life (6 g/m^3) and MfE's (2000b) suggestion that suspended solids concentrations less than 25 g/m^3 are not limiting to fish.

We suggest that the environmental bar for water clarity should be higher in upland rivers which are naturally clear and support highly valued trout fisheries. It should be aimed at maintaining water clarity at base flow above the 75th or 80th percentile of rivers sampled by Davies-Colley & Close (1990).

Water clarity (measured by the black disc method) and turbidity (NTU) are correlated, although there is also a reasonable degree of variability in this relationship between rivers (Davies-Colley & Close 1990). This means that neither of the two measurements can be deduced based on the other with a great deal of precision. Ideally river specific relationships between black disc and NTU should be determined on a case-by-case basis.

Since trout are visual predators and drift feeding is the predominant foraging behaviour in most rivers (especially those of moderate to steep gradient), increased turbidity (i.e. lower water clarity) is expected to have an adverse effect on trout because it reduces their foraging radius and their foraging efficiency. Indeed, experiments with brook trout in an artificial stream showed that although increased turbidity had no significant effect on mean daily consumption, specific growth rates were significantly reduced (Sweka & Hartman 2001). This occurred because trout abandoned drift feeding in favour of active searching − which is energetically more expensive − as turbidity increased. In other words, where drifting food is reasonably abundant, reduced water clarity reduces foraging efficiency with the result that trout spend more time (and energy) foraging in order to meet their food requirements (either by drift feeding or active searching). Extending this argument further, reduced water clarity can be expected to compound an already reduced growth rate where food is scarce and trout cannot achieve maximum daily consumption.

Rowe et al. (2003) found that turbidity had no effect on feeding rate for rainbow trout. However, these experiments were undertaken in tanks, where the lack of current would have precluded drift feeding, and trout would have to actively search for prey. An important confounding feature of Rowe et al.'s study design was that prey density in their experiments was exceptionally high relative to densities normally expected in nature (a result of the small size of the experimental tanks), meaning that there was a high probability of fish encountering prey items regardless of the level of turbidity.

Studies on the visual range of salmonids are much more relevant to drift feeding trout in rivers. Gregory & Northcote (1993) reported a log linear decline in the visual reaction distance to invertebrate prey with increasing turbidity for juvenile Chinook salmon. Barrett et al. (1992) also found that increased turbidity strongly reduced reaction distances of juvenile rainbow trout to drifting prey items in artificial stream channels.

An understanding of the mechanics of drift foraging is informative for appreciating the significance of water clarity to trout and the levels that are required to maintain energetic profitability. Hughes & Dill (1990) developed a drift foraging model for Arctic grayling, which describes the geometry of drift foraging and how this is related to fish and prey size, water temperature and velocity. The model predicts the reaction distance to drifting prey as a function of fish and prey size and water velocity. The influence of turbidity on prey reaction distance can also be factored in (see below). The reaction distance defines the size of the foraging area, which is assumed to be a simple semicircle perpendicular to the flow. Foraging area is, therefore, proportional to the square of the reaction distance, so a reduction in reaction distance will result in a larger proportional reduction in foraging area. This model has since been employed in a coupled drift foraging and bioenergetics model for brown trout developed by the Cawthron Institute (Hayes 2000), and subsequently successfully tested in the Maruia River (Hayes et al. 2000). A significant prediction arising from the model is that anything that reduces invertebrate prey size or water clarity favours small trout over large, and eventually ought to result in reduction in mean size of trout, with large trout becoming fewer (Young & Hayes 1999).

Hughes and Dill's (1990) drift foraging model predicts that reaction distance for a given prey size plotted against fish length reaches an asymptote (Figure 2). For 12 mm prey this asymptote is at approximately 1.4 m. However, the reaction distance to larger prey items is obviously greater (e.g. for a 60 cm fish with a 30 mm prey item the reaction distance is predicted to be approximately 3.6 m). The majority of drifting prey eaten by trout in New Zealand rivers is 12 mm or less (because most drifting invertebrates are in this size range). Therefore, it may seem reasonable that if water clarity is maintained above 1.4 m, the foraging area of drift feeding trout should not be substantially reduced. However, larger drifting prey items (including stoneflies, large swimming mayflies and large terrestrial invertebrates), although encountered less frequently, make an important energetic contribution to the diet of larger trout. Therefore, in order to maintain optimum foraging conditions a higher level of water clarity may be justified (e.g. the 3.6 m reaction distance for 60 cm fish to 30 mm prey item, as discussed above).

On the other hand, it is not certain whether the visual clarity measurements based on black disc are directly comparable to the ability of trout to perceive prey items (much smaller than the black disc) under similar conditions. This is an area that requires more research. Nevertheless, as discussed above, there is research supporting a negative relationship between turbidity and reaction distance in salmonids.

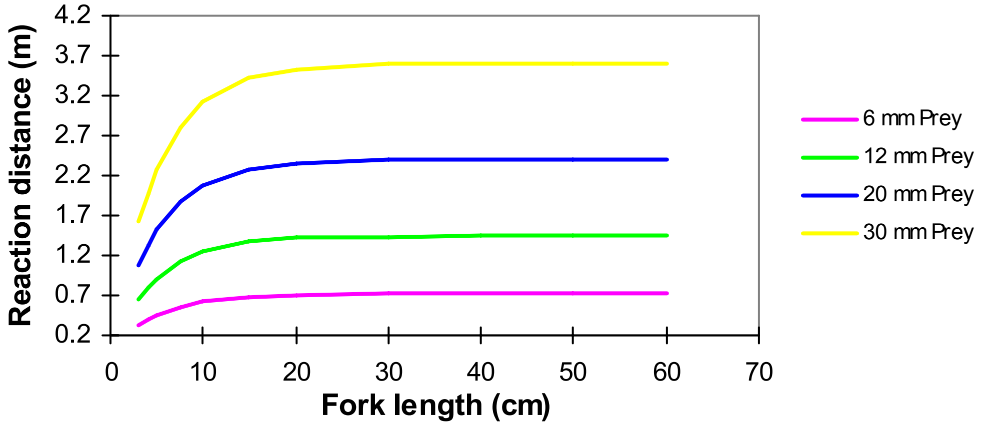

Figure 2. Reaction distance to drifting invertebrate prey relative to fish size, based on Hughes & Dill's (1990) drift foraging model, for a range of sizes of invertebrate prey.

Given the lack of equivalent empirical data for brown trout, the relationship reported by Gregory & Northcote (1993), for juvenile Chinook salmon (6-7 cm long), was used by Hayes (2000) to adjust the reaction distance predicted by Hughes & Dill's (1990) model for the effect of turbidity. It appears likely that this relationship underestimates the impact of increased turbidity on reaction distance when it scaled up for use with larger fish, especially at very high NTU levels. However, the results seem reasonable below about 10 NTU. Based on this adjusted model, the reaction distance, at 0.5 NTU (the lowest practical value for comparison), is predicted to be reduced by approximately 50% as turbidity increases to about 10 NTU (Figure 3). The maximum reaction distances to various prey sizes shown in Figure 2 are for the clear water (0.5 NTU) condition. It is possible to approximate the level of water clarity (as measured by black disc) that would be required to maintain reaction distances based on a relationship between NTU and black disc water clarity.

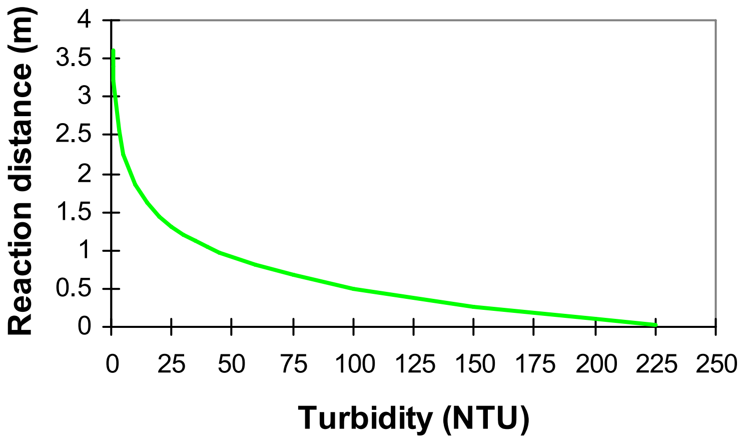

Figure 3. Attenuation of the predicted reaction distance of a drift foraging salmonid with increasing turbidity. Based on Hughes & Dill's (1990) foraging model predictions (for a 60 cm trout with 30 mm prey), modified by the NTU versus reaction distance relationship from Gregory & Northcote (1993).

Based on the relationship reported in Davies-Colley & Close (1990) for 190 observations in 96 New Zealand rivers at base flow, the clear water condition, represented by 0.5 NTU in Figure 3, would equate to approximately a 5 m black disc water clarity reading. This level of water clarity would arguably be appropriate to maintain optimum drift feeding conditions in rivers managed for their outstanding or regionally significant trout fishery values. For lesser valued fisheries some level of reduction in foraging area should be permissible. Reducing foraging area by 5% or 10% would be expected to produce similar reductions in energetic returns from foraging. Foraging area is proportional to the square of reaction distance, so a reduction in reaction distance will result in a larger proportional reduction in foraging area. Reductions of approximately 5% and 10% in foraging area would result from reduction in reaction distance of approximately 3% and 5%, respectively. This would be the result of a turbidity guideline or consent condition which stipulated a maximum turbidity under baseflow conditions of 0.6

NTU or 0.7 NTU, respectively, which in turn would translate roughly to 4.75 m or 3.75 m black disc (based on the coarse relationship between black disc and NTU in Figure 3 of Davies-Colley & Close (1990).

Water clarity levels ≥5 m are close to, or above, the 80th percentile of the 96 rivers sampled by Davies-Colley & Close (1990, Figure 3 in that paper) at base flow, and this would be an appropriate guideline for rivers which naturally maintain such clarities and support outstanding or regionally significant trout fisheries. An appropriate guideline for lesser valued trout fisheries would be 3.75-4.75 m, placing these rivers between the 60th and 75th percentiles for water clarity. These appear to be reasonable levels, especially given that aesthetics (including water clarity) generally play an important role in the level of enjoyment derived from trout fishing.

The above discussion assumes a river naturally sustains base flow water clarity levels above the recommended guideline. Where this is not the case, because of underlying geology of mudstone for example, site-specific or reference stream water clarity guidelines could be derived by examining historic water clarity records and setting guidelines based on historic exceedence levels. For example, if the guideline for water clarity were set at the value naturally exceeded 90% of the time (excluding flood events), then the guideline would be expected to be breached 10% of the time if the current state was maintained, but would be exceeded more frequently if the state were to decline. However, this approach will not work in situations where streams are already degraded and when no reference streams or historical water clarity data are at hand.

Water clarity (as measured by black disc and turbidity) and suspended solids can vary greatly over time, depending on rainfall and activities in the catchment (e.g. disturbance by stock). Sedimentation events likewise may be highly temporally variable. Frequent monitoring may therefore be required to detect intermittent turbidity events. The ideal is continuous turbidity monitoring.

2.3.5. Siltation and riparian condition

Pulses of suspended solids will be accompanied by siltation of the stream bed. Frequent or continuous monitoring of water clarity or turbidity ought to pick this up, but infrequent monitoring may not. Pulses of turbidity, and entrained sediment, from frequent or irregular cow crossings for bank grazing may be missed by infrequent monitoring, but over time do substantial damage through siltation of the stream bed. Salmonids are particularly sensitive to the direct effects of sedimentation (by silt and sand) of their spawning habitat (small to medium sized gravels) and to indirect effects through sediment smothering their benthic invertebrate food resources (Waters 1995). HBRC’s monitoring programme would benefit by including an assessment of the distribution of spawning habitat and regular bank walks to assess stream-bed sedimentation.

If instream cover in the form of open (unembedded cobbles, boulders and stream debris) is uncommon then overhanging vegetation (grasses and shrubs) may be critically important for cover for juvenile trout. Assessment of riparian condition could be done during the same surveys - including incidence of trampling and grazing of banks and instream vegetation by stock. Note that trout eggs (buried in the stream bed gravel) are also sensitive to trampling by stock and people (Roberts & White 1992).

3. SUGGESTED CHANGES TO MONITORING

3.1. Limiting factor analysis

To be most effective, monitoring programmes for trout and other fish need to be underpinned by a limiting factor analysis which considers the sensitivity of the various life history stages to the range of potential effects. Many physical and biological features influence the abundance of salmonid populations and it is crucial to identify the factors that limit production (Reeves et al. 1991; Hartman et al. 1996). There may be specific daily or seasonal periods when food, cover, water quality, or predation act to control the size of a specific population. Examples of potential limiting factors include maximum daily stream temperature during summer, limited (or degraded) spawning habitat during autumn – winter (including elevated water temperature), and limited rearing habitat during spring – summer or winter. In some cases a single factor may limit production.

In some situations, a single limiting factor may apply - such as very restricted, or absent, spawning habitat. In most cases it is an oversimplification to attribute population limitation to a single factor. Overall abundance of a population is a reflection of the way the animals respond to the total environment. Several physical and biotic factors, acting alone or in concert, can potentially limit production. They shape habitat preference, determine patterns of behaviour, and ultimately affect annual production levels.

Pitfalls can be minimised when doing a limiting factor analysis by obtaining: 1) knowledge of the life histories of the species present, 2) detailed and accurate habitat inventory information of the area, 3) an appreciation of the complexity of the ecosystem, and 4) a perspective of processes occurring in the catchment.

A limiting factor analysis begins with the spawning stage and progressively works through the juvenile and adult stages – giving consideration to the water quality and physical habitat requirements of each in the context of measured and potential effects. A full limiting factor analysis, with supporting investigations at each life stage to determine which is limiting, is very time consuming and expensive. Nevertheless, it is valuable to at least undertake a desk-top exercise to identify the key life history stages, their critical habitat requirements, the spatial distribution of those habitats, and potential limiting factors – which include naturally limiting factors (e.g. limitation in areal extent and quality of spawning habitat) and effects. This can help structure a monitoring programme and ensure that critical parameters are not omitted.

Key life history stages include: spawning, fry, and adult. Each has specific habitat and water quality requirements. Spawning habitat consists of loose gravels with low levels of fine sediment, usually in the tails of pools and runs (or heads of riffles) where the bed slopes upward in the direction of the flow. Brown trout fry/juvenile habitat consists of shallow slow to moderately following areas, including riffles and stream margins, with plenty of cover in the form of open cobbles and boulders, instream debris, as well as overhanging grasses and shrubby vegetation. At the fry stage, stream margins are most important and then as the fish grow they move into deeper, faster water – particularly cobble/boulder riffles, but if this habitat is rare, overhanging vegetation is critical. Adult trout prefer deeper water (>0.3 m deep) and slow to moderately flowing (<0.7 m/s, and ideally 0.3–0.6 m/s). Cover is very important in the form of boulders, instream debris, undercut banks, overhanging bankside vegetation, deep water, or water where the surface is disturbed by turbulence obscuring the view from above.

A more detailed account of brown trout habitat requirements is given in Raleigh et al. (1986). Hayes & Jowett (1994) provides additional information on habitat requirements of large adult trout in New Zealand rivers, including the upper Mohaka.

Water quality is important too, for all life stages. Trout have the highest water quality requirements (e.g. in terms of water temperature, dissolved oxygen, and water clarity) of all of New Zealand's freshwater fishes. Dissolved oxygen and water clarity are discussed in other sections of this report, and for a more detailed account of the dissolved oxygen and water temperature requirements of trout see Hayes & Young (2001).

Food can also be limiting. In most streams aquatic invertebrates are the staple food for trout, augmented with terrestrial insects – mainly over summer. Benthic invertebrates eaten by trout mainly occur in riffles and moderate to fast flowing runs. Good quality substrate for benthic invertebrates is open gravels, cobbles and boulders with low levels of embeddedness with silt and sand. Emergent aquatic vegetation, especially watercress on stream margins, can double as good habitat for aquatic invertebrates and also trout. Intact riparian vegetation, particularly in the form of long grasses and scrub is important to ensure a good supply of terrestrial invertebrates (and for refuge habitat for adult aquatic invertebrates).

3.2. Water quality

3.2.1. Dissolved oxygen

Monitoring of oxygen levels (percent saturation and dissolved oxygen concentration) should be undertaken by spot sampling at dawn or by continuous logging over a 24 h period. Value can be added to the latter by modelling stream metabolism (respiration and plant production rates) as has already been done on one occasion on the Taharua River (Young et al. 2006).

This approach can yield information on stream health based on stream ecosystem function (processes) and comparative analyses can be made over time and with other rivers (Young et al. 2006). The direct relevance of this approach to maintenance of trout populations though is likely to focus on minimum oxygen levels.

3.2.2. Nitrogen

Monitoring to date has provided a good record for analysing changes in nitrogen over time and down the Taharua River, and comparison with other rivers. The background information we have presented in Sections 2.3.2 and 2.3.3 should enable more thorough interpretation of the monitoring results for nitrogen and their relevance to stream health in general and to trout in particular. The link between nitrogen and oxygen levels in the context of stream metabolism modelling is relevant and more attention should be given to monitoring diel oxygen variation.

The reference to potential toxicity of nitrate to trout eggs/embryos (SCRWQCB 2004) is also relevant and suggests that the recorded nitrate levels in the Taharua River could be a cause for concern. However, verifying whether, and why, nitrate is toxic to trout eggs and, if so, whether it is in fact causing egg mortality in the Taharua River would require significant research effort, beyond the scope of HBRC's monitoring budget.

3.2.3. Periphyton/algae

We recommend that nutrient and periphyton monitoring be extended into the Mohaka River in order to assess whether elevated nitrogen and phosphorus from the Taharua River is promoting periphyton proliferations there. The Mokaha has more stable, hard substrate than the Taharua for periphyton attachment, and supports an even more highly valued trout fishery.

3.2.4. Water clarity, turbidity and suspended solids

Consideration should be given to installing a continuous turbidity meter in the Taharua River. Our experience with another dairy-monitored catchment, the Waikakahi Stream, South Canterbury, has been that turbidity logging provides very useful data for detecting episodic turbidity events and for demonstrating to farmers the effects they are having on the stream. Continuous turbidity/water clarity data would also allow effects to be interpreted with respect to frequency and duration (not just magnitude) and guidelines incorporating these features might be able to be developed as has been done elsewhere for suspended sediment (c.f. Newcombe & MacDonald 1991; Newcombe & Jensen 1996).

In our opinion HBRC and Bioresearches have been underestimating the effects of temporal and spatial changes in water clarity/turbidity in the Taharua; the guidelines being used are inappropriate for drift-feeding trout (see section 2.3.4). Effects in this context are potential effects because in the absence of monitoring data on trout growth it is not possible to ascertain whether potentially harmful levels of water clarity are having negative effects on the fish. Therefore we recommend that the guidelines be revised upon peer review of our recommendations (in section 2.3.4) and the monitoring data reassessed against them.

3.3. Instream and riparian habitat

3.3.1. Spawning habitat and stream bed sedimentation

A trout spawning survey should be undertaken (June – early July) to determine the distribution of spawning habitat. The presence of spawning fish and redds (nests in the gravel) indicate spawning habitat. This should be followed by an assessment of the quality of spawning habitat, particularly addressing the degree of sedimentation and identification of fine sediment sources. An assessment of the vulnerability of redds to trampling by stock could also be undertaken at the same time.

Quantitatively determining the quality of salmonid spawning habitat can be a difficult and time consuming undertaking. It usually involves taking gravel samples from redds and estimating either the percentage of fines (silt and sand fractions) or geometric mean particle diameter and its variance. These measures can then be used to estimate embryo incubation mortality based on published correlative studies (Shirazi & Seim 1979, 1981). Incubation mortality can also be directly estimated by digging up a sample of redds near the end of the incubation period and calculating the proportion of eggs that are dead (Hobbs 1937, 1940). A combination of the two approaches allows one to determine whether there is a problem and whether it is related to infiltration of spawning gravels with fine sediment (Hay 2005).

If detailed investigations of this nature are beyond the scope of monitoring likely to be undertaken by HBRC then it would be worth using indices for assessing stream bed siltation.

Shirazi & Seim (1979) developed a visual method for assessing the quality of spawning gravel calibrated against quantitative estimates of geometric mean particle diameter and variance. However, this method would still require substantial effort to set up and the subjective visual assessment may vary between observers.

Heavy siltation is obvious even to the casual observer. Often it can be seen blanketing the stream bottom and filling in the spaces between cobbles and gravel. Where surface blanketing is less obvious (e.g. in riffles), plumes of sediment will be released when the bottom is disturbed with the foot. However, the challenge is to quantify what is otherwise a subjective visual assessment. LandCare Research has made progress in this area. They recently reviewed methods for characterising riverbed substrates and settled upon a quick visual assessment of dominant substrate size and proportion of fine sediment at points along cross-sections in runs as being appropriate for catchment wide assessment and monitoring of fine sediment deposition (Phillips & Basher 2005).

NIWA has also contributed to this subject with the 'quorer' – colloquially termed the 'Irish rubbish tin' (Quinn et al. 1997; http://www.niwascience.co.nz/ncwr/tools/quorer/). This is a cost-effective, quantitative option for regional councils to assess fine sediment levels and the results are directly relevant for interpreting benthic macroinvertebrate samples and trout spawning habitat. With the 'quorer' method, a 24 cm diameter x 32 cm PVC pipe is placed on the stream bed and the top 5–10 cm of substrate disturbed to suspend fine sediment. Water samples are then taken of the 'slurry' and analysed for suspended sediment concentration. The mean suspended sediment concentration within the pipe is subtracted from the ambient concentration in the stream to give the contribution from the stream bed.

At a larger, mesohabitat scale, measurement of residual pool depth and volume are proven parameters that correlate with trout carrying capacity (Lisle & Hilton 1992, 1999; Bryant et al. 2004). They provide measures of infilling of pools with fine sediment and bed-load. These are relevant parameters because infilling of pools reduces trout carrying capacity.

3.3.2. Benthic invertebrate (fish food) habitat

The quality and quantity of aquatic benthic invertebrate habitat is important for maintaining trout food. Traditional indices such as the MCI address the former. Quantity of benthic invertebrate habitat can be estimated with instream habitat surveys such as undertaken in the Instream Flow Incremental Methodology. The ratio of riffles to pools can be a guide to the adequacy of a trout stream, with 50% riffles sometimes regarded as good.

A shortcoming of most benthic invertebrate monitoring for detecting effects of siltation is that sampling is confined to stony riffles, whereas these are the last mesohabitats to experience and indicate siltation (owing to high water velocity). Siltation/sedimentation progressively impacts pools and then runs. If sedimentation is of concern then some attention could be given to assessing siltation and quality and quantity of benthic invertebrate habitat, and invertebrate community health, in runs.

3.3.3. Riparian habitat

Regular surveys should be conducted of riparian conditions with special attention given to detecting impact of stock grazing and trampling of banks, and stock directly accessing the river. Stream bank walks and quick riparian condition inventory would be helpful not only to assess trout habitat provided by riparian vegetation (e.g. overhanging vegetation) but also for detecting sediment and direct nutrient runoff sources and pathways to the river. Some information on riparian surveys and classification can be found in Bain et al. (1999), Quinn (1999), MfE (2000b), and Quinn et al. (2001).

3.3.4. *Monitoring/assessing trout growth and abundance*

Regional councils have responsibility for monitoring, and assessing effects on, fish habitat, including trout habitat (RMA 1991). However, it can be a difficult task to ascertain which features of habitat limit a trout population in a given river and the assessments of some habitat features are coarse and/or difficult to make. If monitoring programmes do not include an assessment of the outcomes of habitat condition then there will always be doubt over whether potential effects, as assessed with habitat parameters, are in fact realised. In respect of monitoring effects on trout habitat there ought to be some interest in assessing the outcome on trout abundance and growth (and possibly also condition). Regional councils may wish to collaborate with Fish and Game councils on this aspect of monitoring programmes. However, Fish and Game may not wish to participate in the Taharua monitoring programme because it considers the fishery has been captured by private interests (i.e. Poronui Station). In New Zealand law, title to fish and fisheries does not attach to land.

In the absence of baseline data, trout growth rate can be referenced to predictions of a temperature-dependent growth model (Hayes 2000). The consumption parameter (proportion of maximum consumption, C) in this model can be varied so that predicted growth rate matches observed growth rate. This gives an estimate of the degree of food limitation. The model is also capable of predicting growth rate based on temperature and estimates of invertebrate drift (Hayes et al. 2000). The effect of water clarity or turbidity on consumption of drifting food can also be modelled with this option. Used in this manner the model can isolate the effects of temperature, drifting invertebrate food supply, and water clarity/turbidity on growth. However, such an investigation would be lengthy and expensive – requiring seasonal drift sampling. As such it is beyond the scope of monitoring and falls into the scope of a detailed investigation of growth-limiting factors.

The absence of baseline (pre-impact) data also presents a problem for monitoring trout abundance. This requires that juvenile trout densities be compared with those in other rivers. Fortunately an international review of trout densities and their relationship with size dependent territory size (mainly small or juvenile trout) is available. Grant & Kramer (1990) provide a regression equation to predict the maximum density of juvenile salmonids based on their length ($\log_{10}$ density = -2.61 $\log_{10}$ fork length + 2.83). Using this relationship one could assess whether trout densities in the Taharua were at or below expected carrying capacity on the basis of space. A complementary analysis could be made on trout abundance estimates made by drift diving – comparing Taharua estimates with existing estimates made on rivers throughout New Zealand from the 100 rivers studies and subsequent Fish and Game dives (c.f. Teirney & Jowett 1990).

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