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Dissolved Oxygen Changes and Ecosystem Metabolism in the Motupipi Catchment – Implications for River Health Assessment

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Dissolved Oxygen Changes and Ecosystem Metabolism in the Motupipi Catchment – Implications for River Health Assessment

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EXECUTIVE SUMMARY

A recent review of surface water quality and stream health throughout the Tasman District identified some concerns in the Motupipi Catchment. In an effort to determine the causes of these concerns, the Tasman District Council has been undertaking a series of further studies. One of these studies has included detailed measurements of dissolved oxygen fluctuations at five sites throughout the catchment in January/February 2006, and at two further sites in the neighbouring Te Kakau Stream. Dissolved oxygen is an important factor controlling the types of organisms that will be found at a site. Sensitive species will die if dissolved oxygen concentrations become too low. Dissolved oxygen concentrations can also be used to calculate the rates of plant growth and oxygen uptake that occur in rivers. Oxygen is produced during the daytime by algae and other aquatic plants as they photosynthesise, while oxygen is used up by all the organisms living in the river as they respire. These ecological processes can be used as an indicator of river health.

Daily changes in dissolved oxygen saturation at each site had characteristic patterns with some very large daily fluctuations at the Motupipi up-stream (u/s) Watercress, Motupipi at (@) Reilly's and Powell @ Reilly's sites. Powell @ Glenview was the only site where oxygen saturation was consistently high enough to ensure that sensitive biota would not be detrimentally affected. The pattern of oxygen saturation at the Te Kakau @ Haldane site was somewhat different to the other sites with complete anoxia (i.e. zero oxygen) occurring for part of the day.

Rates of plant production (GPP) ranged from 0.2 $gO_2/m^2/day$ at McConnell to 28 $gO_2/m^2/day$ at Motupipi u/s Watercress. Rates of plant production were generally low at McConnell and Powell @ Glenview and indicative of healthy conditions. However, rates of plant production at Motupipi @ Reilly's, Motupipi u/s Watercress and Te Kakau @ Feary were considerably higher and indicative of poor ecosystem health.

Rates of oxygen uptake (ER) ranged from 1.8 $gO_2/m^2/day$ at McConnell to 78 $gO_2/m^2/day$ at Te Kakau @ Feary. Rates of oxygen uptake at McConnell, Powell @ Glenview and Powell @ Reilly's were indicative of healthy or satisfactory ecosystem health. Whereas, rates of oxygen uptake at Motupipi @ Reilly's, Motupipi u/s Watercress and Te Kakau @ Feary were among the highest recorded anywhere and indicative of poor ecosystem health.

The poor stream health that has been recorded previously in the Motupipi Catchment is likely related to the low concentrations of dissolved oxygen. However, other factors such as water temperature, pH and sediment may also be responsible for the lack of sensitive indicator species present in the catchment. The main reason for the low oxygen concentrations is the high rates of oxygen uptake and plant production that were observed, although inputs of groundwater containing low concentrations of dissolved oxygen and the low potential for oxygen exchange through the river surface are also contributing to this problem.

Plant production and oxygen uptake are driven by abundant nutrients, stable flows and relatively clear water allowing ample sunlight to reach the river bed. Given the complex hydrology of the Motupipi Catchment it is difficult to determine the source(s) of nutrients and faecal bacteria that are getting into

the system, although several developing methods (stable isotope analyses and microbial source tracking) might be helpful.

The water quality problems currently faced in the Motupipi catchment are probably the legacy of activities in the catchment over many years. Initiatives involving the restriction of stock access to waterways, riparian plantings, and more careful nutrient management would be expected to improve stream health in the catchment. However, any improvements may take a considerable amount of time. Further information on the sources of water in different parts of the catchment and the relative importance of ‘old’ nutrients from the aquifer versus ‘recent’ inputs from the land would be helpful for targeting restoration efforts.

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1. INTRODUCTION

A recent review of surface water quality throughout the Tasman District identified some concerns in the Motupipi Catchment with poor water clarity, low oxygen concentrations and high concentrations of nutrients and faecal indicator bacteria compared with other sites in the district (Young et al. 2005). The composition of stream invertebrate communities are often used as an indicator of the health of waterways and results from samples collected at two sites in the Motupipi Catchment indicated very poor ecosystem health at these sites (Young et al. 2005). The amount and types of periphyton (or algae) growing on the riverbed is also used as an indicator of river ecosystem health and again there were concerns at the two sampling sites in the Motupipi Catchment with regular abundant blooms of periphyton (Young et al. 2005).

In an effort to find the cause of the issues that were identified, the Tasman District Council has been undertaking a series of more detailed studies in the Motupipi Catchment. One of these studies involved detailed monitoring of dissolved oxygen concentrations at five sites throughout the catchment in January/February 2006 and at two sites in the neighbouring Te Kakau Stream. Dissolved oxygen is an important factor controlling the types of organisms that will be found at a site. Sensitive species will die if dissolved oxygen concentrations become too low (Dean & Richardson 1999). Guidelines suggest that dissolved oxygen concentration should be maintained above 80% Saturation or 6.5 mg/L for the protection of river ecosystem health (ANZECC 1992).

Dissolved oxygen concentrations can vary considerably throughout the day and can be used to calculate the rates of oxygen production and uptake (jointly called metabolism) that occur in the river. Oxygen is produced during the daytime by algae and other aquatic plants as they photosynthesise, while oxygen is used up by all the organisms living in the river as they respire. These ecological processes can be used as an indicator of river health and provide information on the balance between energy supply and demand in a river (Young et al. 2006).

This report summarises the results from the dissolved oxygen monitoring and metabolism calculations. The metabolism results are compared with criteria used to distinguish between healthy and unhealthy systems. High oxygen uptake rates appears to be one of the issues facing the Motupipi Catchment and the report provides some options for how to deal with this issue.

2. SITE DESCRIPTION AND METHODS

The Motupipi Catchment is located at the lower end of the Takaka Valley in Golden Bay (Figure 1). Groundwater is the predominant source of water in much of the catchment and is sourced from both the shallow Takaka River gravels and also the deeper limestone aquifer (Joseph Thomas, pers. comm.). Several of the tributaries of the eastern side of the catchment deliver little water directly into the Motupipi River during stable flow periods. However, floods from these tributaries are the primary cause of flow variation in the lower Motupipi River.

Dissolved oxygen loggers were deployed at four sites (Figure 1, Motupipi u/s Watercress, Motupipi @ Reilly's, Powell @ Reilly's, McConnell Creek) on 26th January 2006 and programmed to record dissolved oxygen concentration, water temperature and specific conductivity every 15 minutes. All loggers were calibrated according to the manufacturer's instructions and deployed together at the Motupipi u/s Watercress site for one hour to check that all loggers were reading consistently. Differences among the loggers were corrected before further data analysis. The loggers were retrieved on 3rd February 2006 and three of them were re-deployed at alternative sites (Figure 1; Powell @ Glenview, Te Kakau @ Haldane, Te Kakau @ Feary) until 10th February 2006.

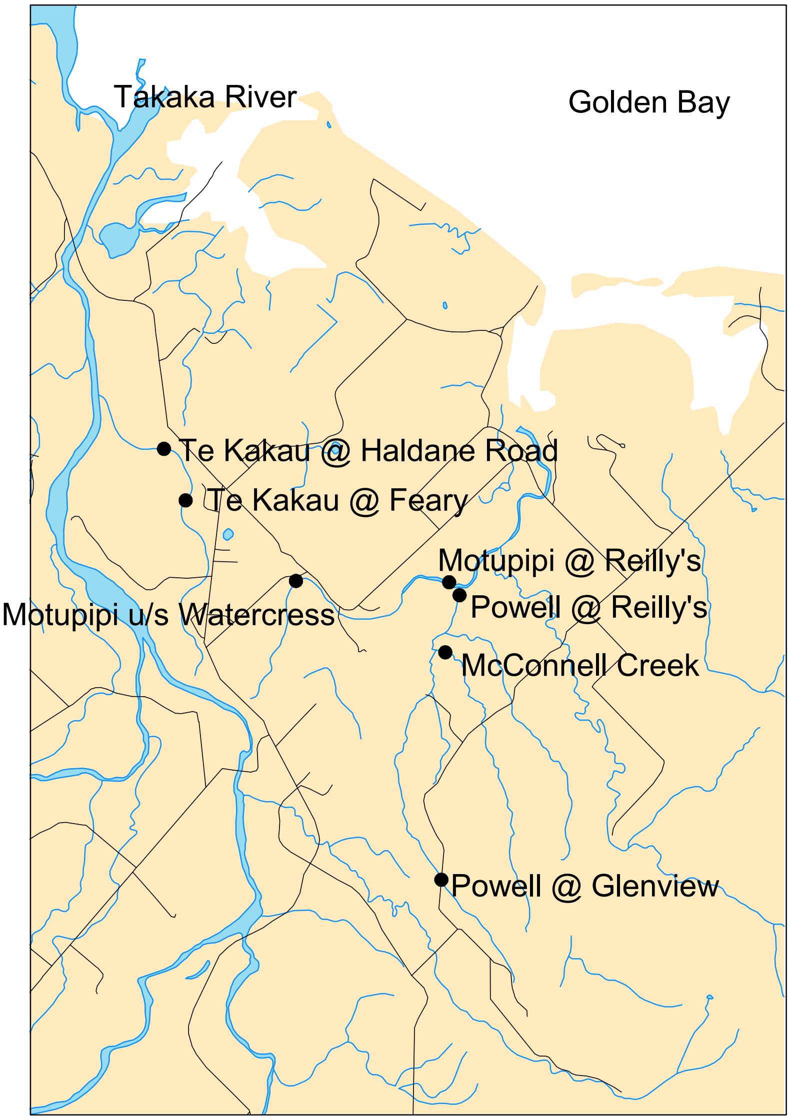

Figure 1. Location of the study sites.

Metabolism values were calculated using the RiverMetabolismEstimator spreadsheet model (version 1.2) developed by Young & Knight (2005). The approach used by the model is given in Appendix 1. This analysis gives values of production and respiration per unit volume. An areal estimate is obtained by multiplying the volume based estimates by average reach depth (m) which allows comparison among stations with different depths. Average reach depth for most sites was estimated from cross-section measurements taken during flow gauging by TDC staff, except at the two Te Kakau sites where the cross-sections were clearly not representative of average conditions along the reach and at McConnell Creek where gauging has not been conducted. For these sites average depths were estimated based on field observations.

For each calculation the following parameters were recorded:

- Gross primary productivity (GPP) = plant growth rate
- Ecosystem respiration (ER) = oxygen uptake rate
- Reaeration coefficient (K) = ability for oxygen to diffuse through the river surface
- R^2 value of the regression used to calculate ER and K = reliability of the data

3. RESULTS

3.1. Oxygen Curves

Daily changes in dissolved oxygen saturation at each site had characteristic patterns with some very large daily fluctuations (Figure 2). Powell @ Glenview was the only site where oxygen saturation was consistently high enough to ensure that sensitive biota would not be detrimentally affected. The Motupipi u/s Watercress site had very large fluctuations in oxygen saturation, with low dissolved oxygen saturation at night (<40%) and very high oxygen saturation for a short period during the day (Figure 2). Very large fluctuations in oxygen saturation were also recorded at the Powell @ Reilly’s and Motupipi @ Reilly’s sites (Figure 2). Daily fluctuations in oxygen saturation at the McConnell Creek, Powell @ Glenview and Te Kakau @ Feary sites were more similar to that observed in other rivers throughout New Zealand, although the minimum dissolved oxygen saturations observed at McConnell and Te Kakau @ Feary were below levels where sensitive fish and other organisms would be expected to be affected (Dean & Richardson 1999). The pattern of oxygen saturation at the Te Kakau @ Haldane site was different to the other sites with complete anoxia (i.e. zero oxygen) occurring for part of the day.

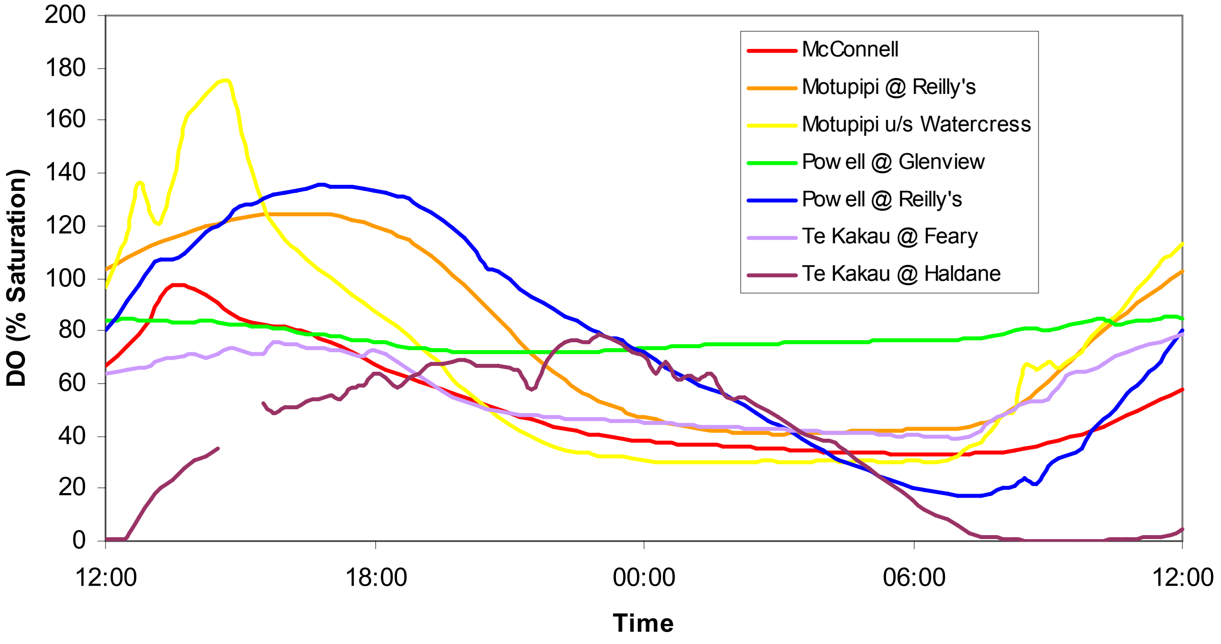

Figure 2. Examples of the daily changes in dissolved oxygen saturation at each of the sites.

Another feature to note with these oxygen curves is their shape, particularly at night. Oxygen saturation was almost constant throughout the night at McConnell, Motupipi @ Reilly's, Motupipi u/s Watercress, Powell @ Glenview and Te Kakau @ Feary, whereas oxygen saturation continued to drop steadily throughout the night at Powell @ Reilly's. This is related to the amount of oxygen that is able to diffuse through the river surface. At most of the sites diffusion of oxygen into the river eventually matches oxygen uptake via respiration. However, oxygen changes at Powell @ Reilly's during the night are almost entirely controlled by respiratory uptake with only a tiny influence of diffusion through the river surface. The very late peak in oxygen saturation at Te Kakau @ Haldane (at about 23:00 compared to 13:00-18:00 at the other sites) also suggests that little oxygen exchange is occurring, which may contribute to the anoxia at this site (Chapra & Di Toro 1991).

3.2. Ecosystem metabolism

Ecosystem metabolism was successfully calculated at all the sites except Te Kakau @ Haldane. There were some unusual spikes and irregularities in the data from this site and the extremely low reaeration coefficient may also have been responsible for difficulties with the regression of the oxygen deficit against the rate of change in oxygen concentration.

Rates of plant production (GPP) ranged from 0.2 $gO_2/m^2/day$ at McConnell to 28 $gO_2/m^2/day$ at Motupipi u/s Watercress (Figure 3). GPP was generally low at McConnell and Powell @ Glenview and indicative of healthy conditions according to the criteria suggested by Young et al. (2006) (Figure 3). However, rates of GPP at Motupipi @ Reilly's, Motupipi u/s Watercress and Te Kakau @ Feary were considerably higher and indicative of poor ecosystem health (Figure 3). Rates of GPP at Powell @ Reilly's were intermediate between these extremes and indicative of satisfactory ecosystem health (Figure 3).

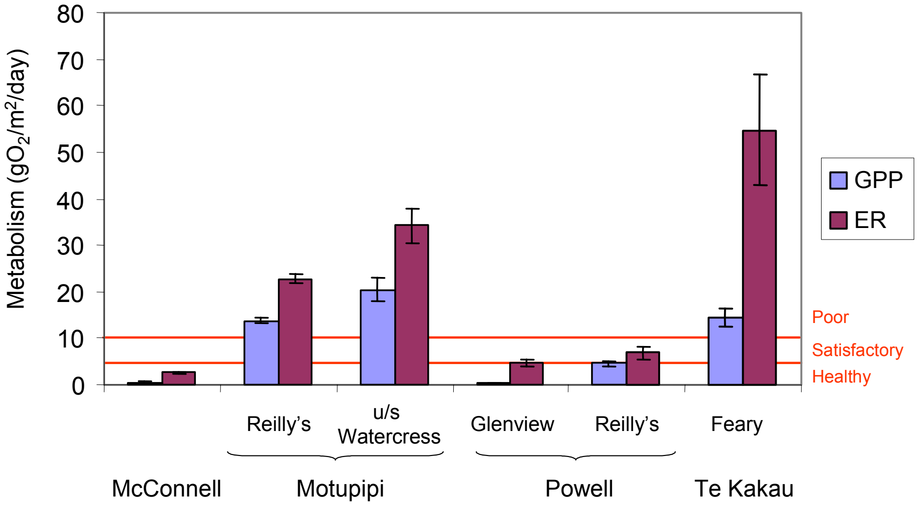

Figure 3. Average rates of plant production (GPP) and oxygen uptake (ER) at each of the sites. Thresholds for 'healthy', 'satisfactory' and 'poor' ecosystem health are shown with red lines.

Rates of oxygen uptake (ER) ranged from 1.8 $gO_2/m^2/day$ at McConnell to 78 $gO_2/m^2/day$ at Te Kakau @ Feary (Figure 3). Rates of ER at McConnell, Powell @ Glenview and Powell @ Reilly's were indicative of healthy or satisfactory ecosystem health (Figure 3). Whereas, rates of ER at Motupipi @ Reilly's, Motupipi u/s Watercress and Te Kakau @ Feary were very high and indicative of poor ecosystem health according to the criteria suggested by Young et al. (2006) (Figure 3).

The balance between GPP and ER is a useful measure of the sources of energy driving a stream ecosystem. If GPP equals or exceeds ER then organic matter produced within the system is probably supporting the food chain, whereas if ER greatly exceeds GPP then organic matter from upstream or the surrounding catchment is being used to maintain the ecosystem. The ratio of GPP:ER (or P/R) ranged from 0.05 (Powell @ Glenview) to 0.8 (Powell @ Reilly's). The P/R ratios indicated that these sites were generally relying on organic matter from upstream or the surrounding catchment to support the food chain. No particularly high values of P/R were observed and all sites had P/R ratios that were indicative of healthy ecosystems (Figure 4).

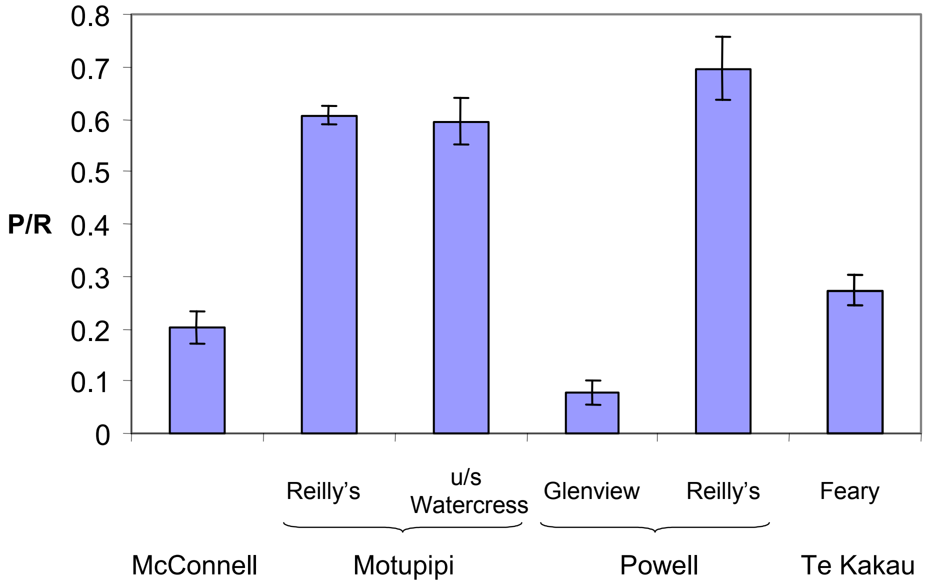

Figure 4. Average ratios of GPP to ER at each of the sites.

4. COMPARISON WITH OTHER RIVERS

The rates of ecosystem metabolism at some of the sites in the Motupipi Catchment were very high, even in comparison with rivers draining intensive agricultural land in other parts of New Zealand and internationally (Figures 5 and 6; Wiley et al. 1990; Young & Huryn 1996; Webster & Meyer 1997; Wilcock et al. 1998; Young & Huryn 1999; Mulholland et al. 2001; Hall & Tank 2003; McTammany et al. 2003). Plant growth rates at the Motupipi u/s Watercress, Te Kakau @ Feary and Motupipi @ Reilly's sites were similar to the highest levels that have been observed elsewhere (Figure 5). Rates of oxygen uptake were also very high and particularly at Te Kakau @ Feary which was higher than anything recorded previously (Figure 6).

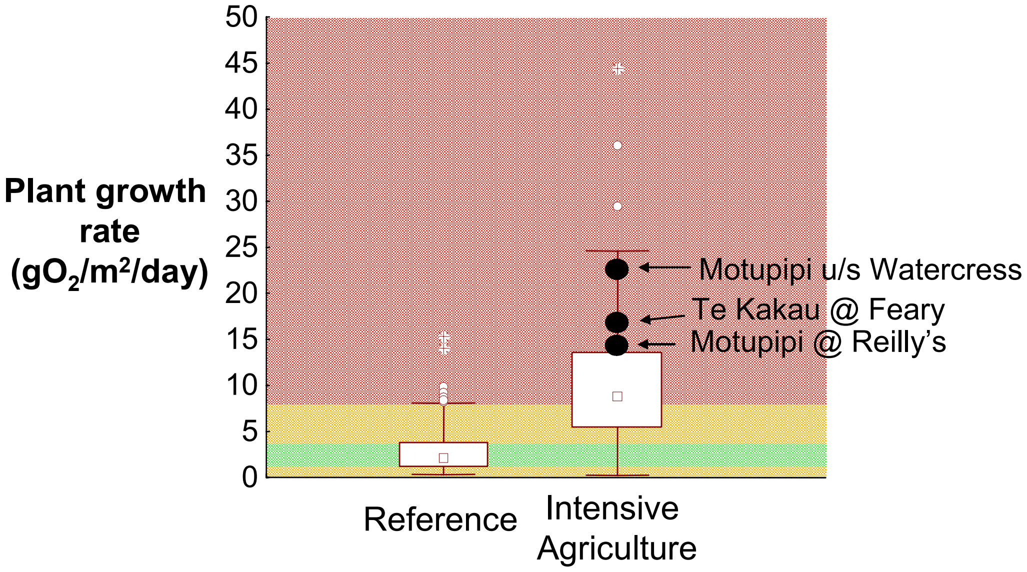

Figure 5. Box plots showing a comparison of plant growth rate measurements with those measured in other parts of New Zealand and internationally. The box represents the central 50% of data around the median, while ends of the whiskers represent the 5th and 95th percentiles. Measurements indicating good, satisfactory and poor ecosystem health are shown with green, orange and red shading, respectively.

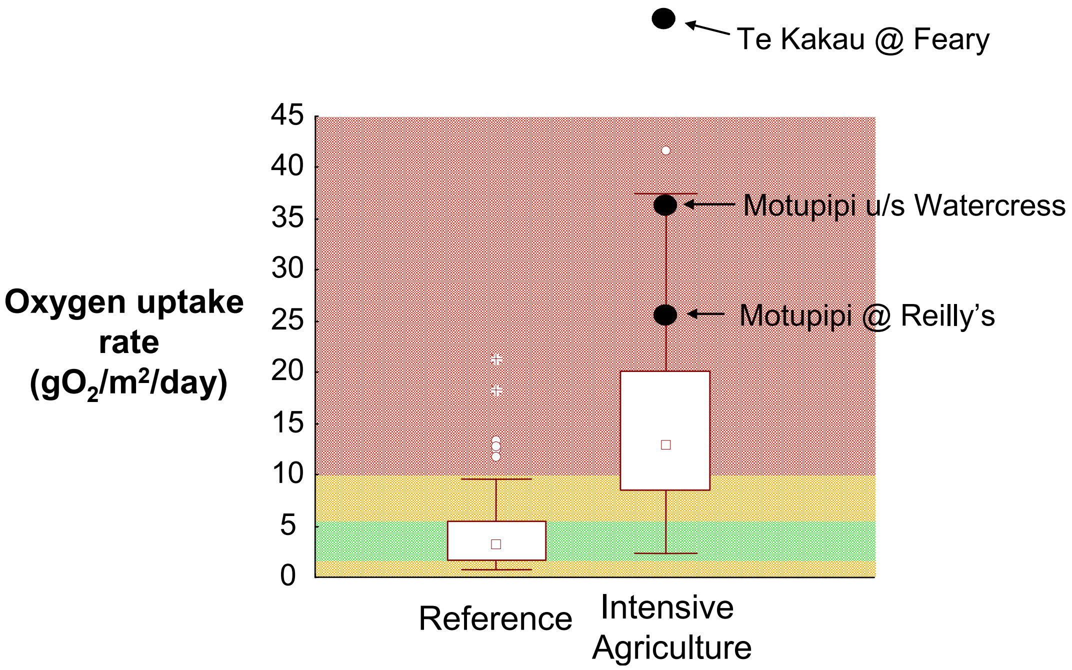

Figure 6. Box plots showing a comparison of oxygen uptake rate measurements with those measured in other parts of New Zealand and internationally. The box represents the central 50% of data around the median, while ends of the whiskers represent the 5th and 95th percentiles. Measurements indicating good, satisfactory and poor ecosystem health are shown with green, orange and red shading, respectively.

5. DISCUSSION

The poor stream health that has been recorded previously in the Motupipi Catchment (Young et al. 2005) is likely related to the low concentrations of dissolved oxygen. However, other factors such as water temperature, pH and sediment may also be responsible for the lack of sensitive indicator species present in the catchment. Maximum water temperatures recorded during the study were relatively low at most of the sites and not sufficiently high to stress invertebrates. The only exception to this was Powell @ Reilly's which experienced water temperatures up to 27.9 °C during the sampling period, and to a lesser extent McConnell which had a maximum temperature of 23.4 °C. The remaining sites (except Powell @ Glenview) are fed by groundwater and therefore temperature fluctuations are strongly buffered.

The primary reason for the low oxygen concentrations and large fluctuations in oxygen concentration was the high rates of ER and GPP that were observed. The rates of ER at Te Kakau @ Feary and Motupipi u/s Watercress were as high or higher than most values reported previously in the literature (Young et al. 2004). It is possible that the large input of groundwater into these spring-fed streams may be partially responsible for the high rates of ER that were calculated. Upwelling groundwater in the lower Takaka Valley is known to have low oxygen concentrations (approximately 60% saturation, Michaelis 1976) and therefore the ER calculations incorporate oxygen uptake within the aquifer as well as within the river (McCutchen et al. 2002). The other reason for the low oxygen concentrations is that most of the sites have limited exchange of oxygen between the water and the atmosphere due to their relatively narrow and deep channels.

The high rates of GPP and ER that were observed are driven by a combination of abundant nutrients, stable flows and relatively clear water allowing ample sunlight to reach the river bed. Nitrogen concentrations appear to be naturally high in the groundwater feeding these rivers, although increases in nitrogen concentrations that are typically observed along the length of the Motupipi River indicate that agricultural runoff may also be a source of nitrogen, either directly or via enrichment of the groundwater.

The high ratio of dissolved inorganic nitrogen to dissolved reactive phosphorus concentration in the water (>50 during the sampling period) suggests that phosphorus may be limiting plant production. Using intracellular nutrient concentrations, Biggs (1993) inferred nutrient saturation in the nearby Waikoropupu River and lower Takaka River. However, these assessments should be treated with some caution because more recent studies have indicated little relationship between N:P ratios (either in the water or within algal cells) and observed nutrient limitation (Francoeur et al. 1999). Another point to consider in this regard is that macrophytes (large rooted aquatic plants) were probably making a substantial contribution to the rates of GPP and ER that were observed, possibly sourcing phosphorus from the riverbed and thus unaffected by concentrations of nutrients in the water column.

Given the complex hydrology of the Motupipi Catchment it is difficult to determine the source(s) of nutrients and faecal bacteria that are entering the system. Options that could be used to help identify sources include stable isotope analyses (Karr et al. 2003) and microbial source tracking (Simpson et al. 2002). Stable isotope analyses require a distinct isotopic 'signature' among potential sources that can be used to determine the relative importance of different sources. Microbial source tracking involves the use of genetic and other methods (e.g. antibiotic resistance) to distinguish between different bacterial sources.

The water quality problems currently faced in the Motupipi catchment are probably the legacy of activities in the catchment over many years. Improvements to water quality will not be easy and may take a considerable amount of time. Further information is required on the sources of water in different parts of the catchment and the relative importance of 'old' nutrients from the aquifer versus 'recent' inputs from the land. Either way, the following initiatives will help to move things in the right direction:

- Restrict stock access to waterways and thus reduce faecal contamination and inputs of nutrients and sediment.
- Riparian plantings to stabilise the stream banks, provide shade and slow aquatic plant growth.
- Reduce nutrient inputs to waterways via nutrient budgeting/farm management plans and target effluent disposal to soils that can store/assimilate the nutrients

6. ACKNOWLEDGEMENTS

I thank Trevor James for initiating this study and liaising with landowners in the catchment. The initial data collection was funded as part of a nationwide project examining the potential of functional indicators for river health assessment with contributions from MfE and other stakeholders (including Tasman District Council). The data analysis and report preparation was funded by FRST via an Envirolink project (TSDC 15).

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Appendix 1. Approach used for the metabolism calculations

Mean daily ecosystem respiration (ER or oxygen uptake) and the reaeration coefficient (k) were determined using the night time regression method (Owens 1974) which uses only data collected in the dark (<2 µmol/m^2/s). Light data was not available so the night time period was determined by examining the oxygen data. Night time is typically the period between the fastest recorded reduction in oxygen concentration (dusk) and the highest recorded oxygen deficit (difference between the oxygen concentration at saturation and the observed concentration in the water) which occurs at dawn. The rate of change of oxygen concentration over short intervals during the night is regressed against the oxygen deficit to yield:

$$dO/dt = ER + kD \qquad (1)$$

where dO/dt is the rate of change of oxygen concentration (g/m^3/s), ER is the ecosystem respiration rate (g/m^3/s), k is the reaeration coefficient (s^{-1}), and D is the oxygen deficit (g/m^3). The slope of the regression line estimates k while the y-intercept estimates ER (Kosinski 1984).

The reaeration coefficient and ecosystem respiration rate obtained are then used to determine gross photosynthetic rate over the sampling interval using:

$$GPP_t = dO/dt + ER - kD \qquad (2)$$

where GPP$_t$ is the gross photosynthetic rate (g/m^3/s) over time interval (t). To compensate for daily temperature fluctuation, ER is assumed to double with a 10°C increase in temperature (Phinney & McIntire 1965) while the reaeration rate is assumed to increase by 2.41% per degree (Kilpatrick et al. 1989). Daily gross primary production (GPP, g/m^3/day) is estimated as the integral of all temperature corrected photosynthetic rates during daylight (Wiley et al. 1990).

Appendix 2. Daily metabolism records from each of the sites. Calculations with low R^2 values are shaded yellow and should be treated with caution.

Site	Date	GPP	ER	P/R	K	R^2
MotupipiReilly's	26/01/2006	15.4	22	0.70	11.7	0.97
MotupipiReilly's	27/01/2006	15.2	23.8	0.64	12.7	0.99
MotupipiReilly's	28/01/2006	14.6	23.4	0.62	12.1	0.99
MotupipiReilly's	29/01/2006	12.5	19.7	0.63	9.9	0.91
MotupipiReilly's	30/01/2006	13.8	23.7	0.58	11.7	0.81
MotupipiReilly's	31/01/2006	15.9	28.1	0.57	13.1	0.88
MotupipiReilly's	01/02/2006	11.6	20.6	0.56	10.2	0.88
MotupipiReilly's	02/02/2006	11	20	0.55	9.2	0.86
PowellGlenview	05/02/2006	0.4	3.9	0.10	10.7	0.49
PowellGlenview	06/02/2006	0.3	5.6	0.05	18.1	0.72
PowellReillies	26/01/2006	5.7	9.8	0.58	5.8	0.92
PowellReillies	27/01/2006	4.3	5.9	0.73	2.3	0.56
PowellReillies	28/01/2006	3.9	5	0.78	1.7	0.39
Te KakauFeary	04/02/2006	17.7	78.3	0.23	22	0.87
Te KakauFeary	05/02/2006	10.8	39.6	0.27	11.3	0.72
Te KakauFeary	06/02/2006	14.9	46.3	0.32	13.8	0.91
Motupipi u/s Watercress	26/01/2006	16.6	32.5	0.51	14.6	0.93
Motupipi u/s Watercress	27/01/2006	17.7	34.1	0.52	15.8	0.95
Motupipi u/s Watercress	28/01/2006	23.2	42.2	0.55	18.5	0.88
Motupipi u/s Watercress	29/01/2006	14.7	26	0.57	10.6	0.17
Motupipi u/s Watercress	30/01/2006	29	46.1	0.63	18	0.62
Motupipi u/s Watercress	31/01/2006	26.3	45.8	0.57	17.4	0.51
Motupipi u/s Watercress	01/02/2006	27.9	31.5	0.89	11.8	0.67
Motupipi u/s Watercress	02/02/2006	8.3	15.7	0.53	5.4	0.31
McConnell	26/01/2006	1.15	3.64	0.32	11.07	0.946
McConnell	27/01/2006	0.58	2.16	0.27	5.97	0.963
McConnell	28/01/2006	0.62	2.56	0.24	6.97	0.911
McConnell	29/01/2006	0.56	2.53	0.22	6.1	0.881
McConnell	30/01/2006	0.19	1.92	0.10	4.24	0.609
McConnell	31/01/2006	0.19	1.84	0.10	3.9	0.424
McConnell	01/02/2006	0.55	3.45	0.16	7.44	0.926