IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of an application by Meridian Energy Limited for resource consents for the Mokihinui Hydro Project

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STATEMENT OF EVIDENCE OF ROBERT HAYS SPIGEL ON BEHALF OF MERIDIAN ENERGY LIMITED

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1. QUALIFICATIONS AND EXPERIENCE

1.1 My full name is Robert Hays Spigel.

1.2 I have the following qualifications. I hold a PhD degree in Civil Engineering from the University of California, Berkely, an MSc degree in Civil Engineering from the University of Pennsylvania, Philadelphia, and an AB degree in history from Princeton University, New Jersey.

1.3 I am a senior scientist in the Hydrodynamics Group at NIWA in Christchurch. I carry out research and consultancy work on circulation, mixing and the thermal regimes of lakes, reservoirs, rivers and estuaries, usually in relation to their impact on water quality. In doing so I interact extensively with biologists, chemists and geologists. Prior to working for NIWA, from 1978 – 1999 I was a lecturer in the Civil Engineering Department at the University of Canterbury, where I taught courses and supervised post-graduate research in fluid mechanics, hydrology and hydraulic engineering. I have done theoretical and experimental work on the dynamics of inflows, outflows and wind mixing in lakes and reservoirs. Results of this work have been published in reports and articles in scientific journals.

1.4 I have read the Code of Conduct for Expert Witnesses (Rule 330A, High Court Rules and Environment Court Practice Note) and I agree to comply with it. I have complied with it in the preparation of this statement of evidence.

1.5 I have been involved in the following work in relation to Meridian Energy Limited's (Meridian's) Mokihinui Hydro Proposal (MHP):

a. Mokihinui River Proposed Hydropower Scheme: Lake Water Quality and Habitat Report NIWA Client Report (2007), CHC 2007-122 co-authored by Dr S. Floeder and myself;

and I have prepared my statement of evidence in reliance on this work.

1.6 I have also reviewed:

a. Aspects of the reports and statements of evidence of other experts giving evidence on behalf of Meridian relevant to my area of expertise, including:

i. Henderson, R.; McKerchar, A. (2007). Mokihinui River Proposed Hydropower Scheme: Hydrology Report. NIWA Client Report CHC2007-134, National Institute of Water and Atmospheric Research.

ii. Hicks, D.M.; Rouse, H.L.; Tunnicliffe, J.; Walsh, J. (2007). Mokihinui River Proposed Hydropower Scheme: Sediment Report. NIWA Client Report CHC2007-117, National Institute of Water and Atmospheric Research.

iii. Suren, A.; Kilroy, C. (2007). Mokihinui River Proposed Hydropower Scheme: Periphyton and Invertebrates Report. NIWA Client Report CHC2007-111, National Institute of Water and Atmospheric Research.

b. The review by Dr Marc Schallenberg for DOC of the lake and water quality report prepared by Dr Floeder and myself,

c. A submission by West Coast Branch and Top of the South Greens Province of Greens Party of Aotearoa New Zealand.

2. SCOPE OF EVIDENCE

2.1 I have been asked by Meridian to prepare evidence in relation to actual and potential effects of the MHP on the water quality of the Mokihinui River.

3. EXECUTIVE SUMMARY

3.1 Our study found that the existing Mokihinui River has good water quality, with high clarity and low levels of nitrogen and phosphorus concentrations when compared with national averages and to national guideline values.

3.2 The proposed reservoir will be deep and narrow with steep sides. It will be thermally stratified from spring to autumn, despite the frequency of large flows that occur in the river. In the first 5 to 10 years following impoundment, the decay of flooded vegetation will add an extra burden to oxygen demand. Within this post-impoundment period, anoxic conditions, which are commonly found in newly filled reservoirs, are likely to occur below 25 to 30 m during summer over the first 4 to 5 years, and possibly for as long as 7 years.

3.3 Considerable habitat suitable for trout will still exist during this post-impoundment period, and habitat for eels and whitebait (which are species that normally remain in shallower areas) will be unaffected. Migration of trout, eels and whitebait will be unaffected within the reservoir.

3.4 In the long term, partial depletion of oxygen will occur in summer in bottom waters. The reservoir will contain low to intermediate nutrient concentrations that will support low to intermediate levels of phytoplankton. The formation of nuisance algal blooms and surface scums is unlikely. I expect the reservoir to evolve into a lake with good water quality.

3.5 High water quality will allow light to penetrate to a depth of up to 5.8 m, providing for a productive submerged littoral zone estimated as 12.5% of the reservoir's total area. This represents the maximum potential area because it does not account for wave action on those parts of the shoreline that will be subject to high wave energy. The reservoir will not be at risk to nuisance aquatic macrophyte growth, and I view the potential for macrophytes to grow in the Mokihinui reservoir as a positive aspect, both as a statement as to water quality, and for the ecological values associated with a healthy macrophyte population.

3.6 The dam will have a single outlet 13 m below the spillway crest, to withdraw water for power generation. Because of the short residence time of the reservoir (12.6 days), the position of the outlet will determine the position of the main thermocline (the region over which temperatures change most rapidly with depth), which is expected to form just below the outlet and extend over a further depth of 10 to 15 metres.

3.7 All but the highest inflows will enter the main body of the reservoir within or above the thermocline, then flow more or less directly to the outlet. Water below the thermocline will remain almost completely isolated during the stratified season, with outflows being directly supplied by recent inflows.

3.8 Because downstream flows will have a character that closely mirrors that of inflows, I predict that the effects on the aquatic ecosystem downstream of the dam will be minor or less than minor.

3.9 There is a chance that oxygen-depleted water could be discharged downstream during the first few years of operation. I have described circumstances under which this could occur and operating strategies that could be used to avoid or minimise any potential effects of such occurrences. I agree with the conditions of consent proposed by Meridian which describe monitoring of oxygen and temperature as depth profiles in the reservoir near the dam and at two points in the river downstream of the dam, and of wind speed and direction at the dam site. Information from monitoring would allow operators to respond appropriately, should the need arise.

4. THE PROPOSAL

4.1 I confirm my evidence is based on the project proposal, a summary of which is provided in Appendix 1.

5. EXISTING ENVIRONMENT

5.1 I will describe existing water quality and associated habitat of the Mokihinui catchment and River, and will include comparison with other West Coast rivers.

Water quality parameters

5.2 There are no existing data for the Mokihinui River in the New Zealand National River Water Quality Network (NRWQN) database, so for the purposes of this study NIWA collected 10 water quality samples from the river (Appendix 2). The samples were collected at roughly one-month intervals from a site on the lower river near Seddonville, 3 km downstream of the proposed dam site. Table 1 shows summary statistics for the key water quality parameters that were measured. I will present results from the table shortly, and then put them into context by comparing them with values in other rivers. Before doing so I note that differences between mean and median values in Table 1 are partly attributed to the high variability of flow in the Mokihinui River. The water quality samples were collected under a variety of flow conditions, and concentrations can be expected to be different under different flow conditions. This is especially true for the particulate fractions, as opposed to the dissolved fractions, of the nutrients nitrogen and phosphorus.

5.3 Average water temperature of the 10 water quality samples is 13.3 °C. Data from temperature loggers that were deployed at various locations along the river showed that the river has a seasonal temperature pattern, as is common in most New Zealand rivers. Daily mean temperatures measured in the Mokihinui range from a minimum of around 5.5 °C at the end of winter to a maximum of around 17.5 °C at the end of summer. Superimposed on this seasonal pattern are smaller daily fluctuations of around 1 °C to 2 °C.

5.4 Clarity of the water is high under normal flow conditions, with a maximum recorded value of 4.7 m (as black disk horizontal viewing distance), but decreases with flow, due to the effects of suspended sediment transported by the river.

5.5 The river water is oxygen-saturated (101%). Its average conductivity (referenced to 25°) is 99.8 µS cm^{-1} and pH is neutral (7.17).

5.6 Average total nitrogen concentration is 123 mg N m^{-3}. Total nitrogen can be broken up into various components or fractions. This is important when considering how much of the total nitrogen is actually available to plants to support their growth. Of the total nitrogen, 84 mg N m^{-3} is dissolved in the water, the remaining 39 mg N m^{-3} being bound up with particulate matter, either organic or inorganic. The dissolved component also consists of organic and inorganic fractions. It is the inorganic fraction of the dissolved component that is most important for primary production (in other words, plant growth) in rivers and lakes. The dissolved inorganic nitrogen compounds include nitrite, nitrate and ammonium, and amount to 19.4 mg N m^{-3}.

5.7 Similar considerations apply to phosphorus and its compounds. The average concentration of total phosphorus in the Mokihinui River is 25 mg P m^{-3}. Of this, 5.5 mg P m^{-3} is dissolved in the water, of which 2.75 mg P m^{-3} is associated with organic compounds and 2.75 mg P m^{-3} with inorganic compounds. As with nitrogen, it is the dissolved inorganic component, referred to here as dissolved reactive phosphorus, that supports primary production.

5.8 The average concentrations for dissolved inorganic nitrogen and phosphorus concentration in the Mokihinui River are characteristic of streams with low to intermediate levels of nutrients (Biggs 2000).

5.9 The question that is usually of greatest concern is whether enough nitrogen and phosphorus are present to allow excessive or nuisance plant growth. This depends not only on individual concentrations but also on whether the nitrogen and phosphorus are present in balanced amounts. This is as true for microscopic phytoplankton as it is for rooted macrophytes. Ratios of nitrogen to phosphorus in the range of 7 to 10 are generally felt to be in balance for plant growth, either in terms of total nitrogen and total phosphorus or in terms of the dissolved inorganic components of nitrogen and phosphorus (Biggs 2000, Close and Davies-Colley 1990, Hillebrand and Sommer 1999). Although most of the time nitrogen to phosphorus ratios for the Mokihinui samples were above this range, this was reversed for the two samples that followed a period of high flows in November. On average, nitrogen to phosphorus ratios are slightly higher than 10. I conclude, then, that on average nitrogen and phosphorus are roughly in balance. At any given time, however, one or the other of the nutrients may be in relatively short supply. Phosphorus is likely to be in short supply more often than nitrogen, and when this occurs, lack of phosphorus could limit or restrict algal production.

5.10 The average dissolved organic carbon content is 1.72 g C m^{-3}. Carbon bound in organic compounds is an alternative carbon source (to dissolved carbon dioxide) for many primary producers, and it is the only carbon source for most bacteria. Dissolved organic carbon also affects water colour.

Comparison with the other rivers

5.11 To set the water quality of the Mokihinui River into context we carried out a comparison with two other West Coast Rivers, the Grey and the Buller, as well as with national average statistics. We used the water quality data from these two NRWQN baseline sites for the comparison, as their catchments are the ones most similar, of all those in the NRWQN, to the catchment of the Mokihinui upstream of Seddonville. All of the comparison statistics are shown in Table 1.

5.12 When compared to national averages, the comparison shows that for the Mokihinui River at Seddonville:

a. water temperature is slightly higher than the national average;

b. water clarity is higher than the national average;

c. electrical conductivity (a surrogate for total dissolved solids and dissolved ionic concentrations) is similar to the national average;

d. in general, nitrogen concentrations are low compared to national averages:

    i. mean total nitrogen concentration is 31% of the national mean, and nitrate+nitrite concentration is only 5% of the national average, while,

    ii. mean ammonium concentration is 72% of the national average, and median ammonium concentration exceeds the national median by 17%;

e. phosphorus concentrations are low compared to national averages:

    i. total phosphorus concentration is 52% of the national average, and

    ii. dissolved reactive phosphorus concentration is only 28% of the national average.

5.13 In summary, the higher clarity and lower nitrogen and phosphorus concentrations indicate that the Mokihinui River has above-average water quality compared to national averages.

5.14 When compared to the Buller and Grey Rivers, the data show that:

a. water temperature in the Mokihinui is approximately 3 °C higher than in the Grey and Buller Rivers;

b. water clarity is about 1 m lower than in the Grey and Buller Rivers; and

c. conductivity is approximately twice that in the Buller River and the Grey River.

5.15 In terms of nitrogen and phosphorus, the water quality of the Mokihinui at Seddonville is more comparable to the water quality of the Grey at Waipuna than to the Buller at Longford, since:

a. total nitrogen and ammonium concentrations of the Mokihinui are in the range of the long term averages determined for the Grey River, and higher than those of the Buller River;

b. total and dissolved reactive phosphorus concentrations are in the range of the Grey River and higher than those of the Buller River.

Nitrate + nitrite concentrations in the Mokihinui River are lower than in either the Grey at Waipuna or the Buller at Longford.

5.16 The overall conclusion to be drawn from these comparisons is that water quality in the Mokihinui River is similar to that recorded in the NRWQN for the Grey River and the Buller River. It suggests that the Mokihinui River water quality is typical of many West Coast rivers. In a study of data from all 77 sites in the NRWQN, Maasdam and Smith (1994) found that the West Coast rivers have high water quality, in common with other rivers with relatively undisturbed catchments in the mountains of the South Island.

Comparison of Mokihinui water quality data with guidelines

5.17 Dr Floeder and I also compared water quality data for the Mokihinui River at Seddonville with water quality guidelines for New Zealand river ecosystems published by ANZECC and ARMCANZ (2000; the Australian and New Zealand Environment Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand). Although the guidelines were developed as a management tool, providing thresholds for action for “slightly disturbed” ecosystems, I think that they provide additional perspective and a useful yardstick to assess the existing water quality of the Mokihinui River.

5.18 The comparison provides further evidence for the high quality of Mokihinui River water. The water quality is better than guidelines for all nutrients, specific conductance and water clarity. Mokihinui River clarity is well above the guideline value, while all the nitrogen and phosphorus values are well below the guideline values. Nutrient enrichment is not currently a problem in the Mokihinui River. Oxygen saturations are between the upper and lower guideline limits and are not of any concern. pH values are at the lower end of the guideline range but indicate neutral waters in terms of acidity and also are not cause for concern.

Mokihinui River gorge habitat

5.19 Individual technical reports on periphyton, invertebrates, native fish and trout should be referred to for more specific detail on community compositions in the Mokihinui River Gorge. The evidence of Mr Jowett, Dr Hicks, Dr Kilroy, Dr Suren, Mr Bonnett, Dr Jellyman, and Dr Hayes all include some discussion regarding this gorge habitat.

6. ACTUAL AND POTENTIAL EFFECTS

6.1 I will now describe what I consider will be the most likely effects of the MHP on water quality. I will cover water quality of the new lake, change of aquatic habitat and effects on water quality downstream of the dam. Where appropriate, I will also suggest measures to avoid, remedy or mitigate adverse effects.

Potential Water Quality effects

6.2 The potential effects of the MHP on the water quality of the Mokihinui River fall into two main categories: 1) creation of the reservoir above the dam; 2) water quality below the proposed dam.

Creation of the reservoir

6.3 The proposed 14 km long ribbon lake will contain approximately 100 million cubic metres (0.1 cubic kilometres) of water when full, and cover an area of 3.37 square kilometres. Maximum depth (as the net head) will be 77 m at the dam, with depth decreasing relatively uniformly over the 14 km of length upstream to the Mokihinui Forks. The basin of the reservoir will be deep, steep (typically 45° side-slopes) and narrow (typically 200-400 m wide and 500 m at its widest point). Some lower portions of the tributaries to the gorge reach of the Mokihinui will also be inundated when the reservoir is formed.

6.4 The reservoir will have a mean hydraulic residence time of 12.6 days. This is the time, on average, that it takes for the river flow to replace the full volume of water stored in the reservoir; it is computed by dividing the total reservoir volume by the mean annual flow of 90.4 m^3 s^{-1}. Another way of looking at this is that every day, on average, approximately 8% of the reservoir volume is replaced by river inflow (this value being 1 divided by the residence time). The residence time based on the median river flow of 45.6 m^3 s^{-1} is 25 days.

6.5 There are three main areas that I will discuss in terms of the reservoir: 1) thermal stratification; 2) trophic status; and 3) depletion of oxygen in reservoir waters.

Thermal stratification of the proposed reservoir

6.6 Most New Zealand lakes and reservoirs that are deeper than 20-30 m undergo a seasonal mixing and thermal regime in which they are thermally stratified from late spring through summer and much of autumn, and mix completely during winter. By thermally stratified, I mean that in summer a layered temperature structure tends to form, with warmer water in the upper parts of the lake and colder water at depth. This is true for deep reservoirs on large rivers as well as for natural lakes. Thermal stratification occurs because most of the incoming solar radiation is absorbed within the upper 10 to 20 metres of the water column, with the absorption depth depending on how clear the water is. The layering is also influenced by the temperatures and the volumes of inflows and outflows. This is particularly relevant for the proposed

Mokihinui reservoir, where daily inflow and outflow volumes form a significant fraction of the total storage volume of the reservoir.

6.7 I used a computer model called Dynamic Reservoir Simulation Model ("DYRESM"; see Appendix 3) to get a better idea of the nature of thermal stratification that is likely to occur in the proposed Mokihinui reservoir. I used inflows from the Hydrology Report of Henderson and McKerchar (2007), climate data from the Hokitika Airport automatic weather station (Hokitika AWS) and water temperature data gathered for the MHP studies as inputs to the model. Although Hokitika is 150 km south of Seddonville, it is the closest West Coast weather station that had the climate data required to run the model with a record that overlapped the river flow record. Data from Westport AWS, which is 39 km from Seddonville, have similar values of long-term average wind speed, air temperature and sunshine hours to the Hokitika data. In the Mokihinui reservoir, the patterns of stratification will be dominated by inflows and outflows, and climate will exert a secondary influence. This is because of the reservoir's short residence time, and I will come back to this point in paragraphs 6.8 and 6.12. I have also run the model using wind speeds that are 1.5 times, and 0.7 times, those from Hokitikia AWS, to check the sensitivity of model results to wind speed. Hence, while we cannot expect that the model results will simulate detailed conditions on a day by day basis, they do provide results that are indicative of seasonal patterns and the range of conditions that can be expected. This is how I have used the model results for this study.

6.8 Representative results from the model are shown in Figure 1. The model predicts that thermal stratification will develop in the proposed reservoir in spring (September, October and November profiles). Strong winds and large floods can interrupt the development and strengthening of stratification but these effects are temporary. Stratification continues to strengthen in summer through December and January, until by late summer, in February, the upper layers of the lake are at their warmest, with maximum predicted surface temperatures of nearly 21°C. In summer, a well-defined thermocline (a region of strong temperature gradient) extends from near the outlet level, at a depth of 13 m, downwards with a thickness of 10–15 m. This main thermocline separates the warmer upper waters (the epilimnion) from the cooler bottom waters (the hypolimnion). The location of the outlet at a depth of 13 m and the strength of the withdrawals control the main thermocline's location. In other words, the main thermocline occurs where it does because of the dynamics of the outflow process. As water is withdrawn through the outlet, water above the outlet falls down to take its place. When the reservoir is stratified, an analogy can be made with a deck of cards, with the temperature layers being analogous to cards – as cards are withdrawn from the middle of the deck, the cards below remain where they are, while the ones above fall down to replace the cards that have been withdrawn. Since the water above the outlet is becoming progressively warmer through spring and mid summer, this has the effect of placing warmer surface water just above the colder bottom waters. Because water is slightly less dense when it is warmer the upper layers "float" on the cooler deeper layers. Vertical mixing then requires energy to push warmer water down and pull heavier water up. The withdrawal process thereby creates a thermocline that isolates bottom waters from surface waters. Once isolated, the temperature of the bottom waters will remain at a relatively constant value until autumn and winter mixing.

6.9 Figure 1 shows that the central part of the epilimnion in late summer (March) is at a temperature near 17.5 °C, corresponding to the maximum river inflow temperature, while bottom waters have only increased slightly above their winter minimum. The model predicts the occurrence of shallower thermoclines above a depth of 10 m. I have called these diurnal thermoclines in Figure 1, because they will strengthen during the day when the sun is out and weaken at night when air temperatures are cooler. These shallower thermoclines are dominated by the weather, while the main thermocline is controlled by inflow – outflow dynamics.

6.10 In autumn the surface layers cool, the main thermocline deepens and sharpens, and the temperature difference between epilimnion and hypolimnion decreases. Eventually the temperature difference becomes small enough that its stabilizing effects can be overcome by winds or floods, and the reservoir mixes over its entire depth. This is often referred to as autumn or winter overturn, especially when the mixing can be identified with a single storm or wind event. Winter mixing can be viewed as an annual event that resets the ecosystem to a kind of initial condition of maximum dissolved oxygen concentration, minimum light, minimum temperature and complete circulation.

6.11 I will briefly describe how stratification affects where river inflows go when they enter the main body of the reservoir, and how much mixing I expect them to cause.

6.12 Inflows less than around 500 cumecs will cause little mixing. In summer these inflows will enter the main body of the reservoir within or just above the thermocline, where their temperature matches the temperature in the reservoir. Although 500 cumecs is a fairly large flow, being 5.5 times the mean annual flow of the Mokihinui River, much larger inflows are necessary to cause significant mixing that could noticeably weaken thermal stratification in the reservoir. Inflows of around 1,000 cumecs will still enter the main body of the reservoir at the level where their temperatures match those in the reservoir, but they will push existing water in the reservoir downstream and mix with it before doing so. Mixing with existing reservoir water will increase with flow rate. In autumn, stratification will be weak enough that it could be broken down by inflows greater than 1000 cumecs. It would take flows greater than 2,000 cumecs to break down the stronger thermal stratification that occurs in summer months. So, although it is possible that inflows may break down stratification, this would be less likely in summer. It is more likely that inflow-induced mixing would temporarily interrupt the onset or strengthening of stratification in spring, or hasten the occurrence of autumn overturn.

6.13 It is difficult to estimate the likely frequency of such large inflow-induced mixing events. Mr Henderson has presented evidence in which he gave a value of 1840 $m^3 s^{-1}$ for the median annual flood (average return period of 2 years) and 2170 $m^3 s^{-1}$ for the flood with an average return period of 5 years. These flows correspond to instantaneous peaks, whereas in order to cause significant mixing or very large disturbances that would significantly alter stratification, flows would need to persist at the specified level for a long enough time to have an effect. This is either the time for the flow to travel most of the length of the reservoir, or the time for an internal wave to bring the thermocline to the surface, whichever is shorter. For the Mokihinui reservoir in summer and autumn, the two time scales are roughly comparable, being at least 10 hours in autumn and 4 hours in summer. Thus, frequencies would be somewhat less than those calculated from instantaneous peaks that could occur at any time of year. I have had Dr Alistair McKerchar carry out an annual flood frequency analysis for flows averaged over a range of periods, from 3 hours to 24 hours, using the same Mokihinui River flow record used by Mr Henderson and Dr McKerchar to derive frequencies for annual instantaneous peak flows. From these results, in combination with the above considerations for the time required to alter stratification, I conclude that floods large enough to significantly alter stratification could occur on average every other year for autumn stratification and once every 5 years for summer stratification. While such flood-induced mixing events could bring bottom water to the surface, this water will mix with and be rapidly diluted by flood waters.

Trophic status of the proposed reservoir

6.14 The terms “oligotrophic”, “mesotrophic” and “eutrophic” were originally introduced into the limnological literature in 1919 to classify water types in terms of their nutrient content and their ability to support poor, intermediate or rich communities of phytoplankyon. Since then, other water quality characteristics such as water clarity and extent of oxygen depletion have come to be associated with these terms. Water quality generally declines from the clear, oxygenated and nutrient-poor waters of oligotrophic lakes, with their low levels of phytoplankton biomass, to the more turbid, nutrient-rich waters of eutrophic lakes, with their associated algal blooms in surface waters and low oxygen concentrations in bottom waters. Mesotrophic lakes occupy an intermediate position. The trophic status of a lake refers to its position or classification along this scale.

6.15 Dr Floeder and I used a two-step process to predict the likely trophic status of the Mokihinui reservoir. Both steps involved simple models based on empirical correlations of a kind that are widely used in practical limnological applications. The only alternative to this approach would involve much more sophisticated and complex modelling, for which the necessary data are not available. Dr Floeder and I believe that our approach makes the best possible use of the data available, and provides general predictions that are reasonable, robust and consistent with comparisons to other lakes and information from the NRWQN database and national water quality guidelines.

6.16 The first step involved predicting the mean annual concentrations of total phosphorus, total nitrogen and chlorophyll-a that will occur in the reservoir, based on average concentrations and flows in the river and on reservoir size. Chlorophyll-a concentration is widely used as a measure of algal biomass in limnology, oceanography and water quality studies. Because the reservoir has such a short residence time, the model (from Dillon and Rigler 1975) predicted that the total phosphorus and total nitrogen concentrations in the reservoir would be the same as those in the river. This is true whether the mean annual flow or the median annual flow is used in the calculation. A second correlation, based on regression equations in Burns et al. (2000), was used to predict in-lake average chlorophyll-a concentration from the predicted value of in-lake total phosphorus. I considered that an equation based on total phosphorus alone was appropriate for chlorophyll-a prediction because of the low concentrations of dissolved phosphorus observed most of the time in the river and the possibility that phosphorus is a limiting nutrient for algal productivity more often than nitrogen, as mentioned in paragraph 5.9. However, this second correlation does not account for residence time, and therefore may overestimate chlorophyll-a concentrations in reservoirs with short residence times, where there is not time for maximum potential biomass to develop.

6.17 The second step involved predicting trophic status based on the in-lake total phosphorus, total nitrogen and chlorophyll-a concentrations found from the first step. I used the trophic level classification developed by

Burns et al. (2000, their Table 1.4, reproduced in Appendix 4), derived from data for a range of New Zealand lakes.

6.18 Based on the average total nitrogen concentration of 123 mg N m^{-3}, the reservoir would be classified as oligotrophic. If nitrogen were the limiting nutrient, the average chlorophyll-a concentration would be 1.5 mg chl-a m^{-3}. However, based on the average total phosphorus concentration of 25.0 mg P m^{-3}, and on the average chlorophyll-a concentration of 6.6 mg chl-a m^{-3} (derived from the total phosphorus value), the reservoir would be classified as eutrophic. The reason for the inconsistency between the trophic status predicted as oligotrophic using nitrogen, versus eutrophic using phosphorus, is that the mean total phosphorus value is very strongly influenced by an exceptionally high concentration of 173 mg P m^{-3} measured on 30 November 2006 toward the end of an extended period of high river flow that lasted for most of November. This value is 20 times greater than the average of concentrations measured on all other occasions, and originally I suspected it might be in error. However, it also coincided with the highest value of total nitrogen and the lowest value of water clarity recorded over the entire sampling period, and, as with total nitrogen, was mainly composed of particulate, rather than dissolved material. Hence I believe the measurement is real and is associated with suspended sediment carried by the river at high flow. If this single point were excluded, the predicted value for total phosphorus would be 8.5 mg P m^{-3}, for chlorophyll-a 1.9 mg chl-a m^{-3} and the trophic status would be oligotrophic. While I do not think the single high value of total phosphorus should be excluded, because it does represent the effect of high flows in transporting higher concentrations of nitrogen and phosphorus, I think that the prediction of eutrophic status is unrealistic. The estimated total phosphorus and chlorophyll-a concentrations, without the extremely high total phosphorus value, are close to the boundary between oligotrophic and mesotrophic systems and I think that a realistic prediction for trophic status is that the reservoir will be mesotrophic. To push the classification into that of a eutrophic system would require more than a doubling of the nitrogen and phosphorus concentrations that occur in the river under normal flow conditions, which is very unlikely even if a much longer sampling record existed. I therefore predict that most of the time the nutrient concentrations in the Mokihinui reservoir will be on a low to intermediate level. This will support a low to intermediate level of primary productivity, and the formation of nuisance algal blooms and surface scum is unlikely.

6.19 In order to provide a context for these lake water quality predictions, we compare the data for the proposed Mokihinui reservoir with three existing reservoirs (Ohakuri, Rotorangi, and the Dunstan Arm of Lake Dunstan) and with a natural lake, Lake Brunner, in Table 2.

6.20 The volume of the proposed Mokihinui reservoir will be very similar to that of Lake Ohakuri, but the dam construction in a narrow gorge will result in a much longer and deeper lake. These features are likely to resemble the Dunstan Arm of Lake Dunstan. It can be expected that Mokihinui reservoir will display a gradual shift from river to lake characteristics as one travels downstream from the upper reaches toward the dam. Such a gradual shift occurs in Lake Ohakuri and the Dunstan Arm. Maximum depth of the Mokihinui reservoir will be greater than in Lake Ohakuri and in the Dunstan Arm, and will be more comparable to Lake Rotorangi and Lake Brunner. Residence times for Lake Rotorangi (83 days) and Lake Brunner (1.2 years) are long in comparison to the mean residence time of the proposed Mokihinui reservoir (12.6 days), which in turn is longer than in the Dunstan Arm of Lake Dunstan (3.3 days) and Lake Ohakuri (6.9 days).

6.21 Based on chlorophyll-a concentrations and Secchi disk depths in summer and autumn (mean chlorophyll-a concentration 9.3 mg chl-a m^{-3}, mean Secchi depth 3.2 m in 1978), Coulter et al. (1983) characterised Lake Ohakuri as mildly eutrophic. Based on 10 years of data, the Dunstan Arm can be characterised as oligotrophic. Lake Rotorangi has been described as predominantly mesotrophic by Burns et al. (2000) and mesotrophic to eutrophic by Taranaki Regional Council (2006). Lake Brunner has been characterised as oligotrophic to mesotrophic, based on a long-term data set (Kelly and Howard-Williams 2003) before its water quality became at risk as a result of increasing dairy farming in its catchment.

6.22 The estimated average chlorophyll-a and total phosphorus concentrations are much lower for the Mokihinui reservoir than for Lake Ohakuri. Total nitrogen and total phosphorous concentrations predicted for the proposed reservoir in the Mokihinui Gorge are in the range of the ones determined for the Dunstan Arm of Lake Dunstan and Lake Brunner. This is consistent with our estimation of the trophic state.

6.23 Our predictions for the trophic status and water quality of the proposed Mokihinui reservoir apply to the long term. During the first 4 to 7 years of the reservoir's life, decay of submerged vegetation will cause anoxia in the hypolimnion in summer, higher than normal release of carbon dioxide and methane into the atmosphere, and possibly higher levels of phytoplankton production and biomass.

Depletion of oxygen in the proposed reservoir, release of greenhouse gases and trophic upsurge

6.24 Dissolved oxygen concentration in the hypolimnion of a stratified lake is considered as a fundamental determinant of overall ecosystem health. Because of the barrier to mixing formed by the thermocline, hypolimnion water is subject to oxygen depletion by microbial respiration in any stratified lake. In particular, decay of submerged vegetation uses and therefore depletes dissolved oxygen.

6.25 In my opinion, long-term Lake Brunner data provide a guide to summer oxygen depletion levels that can be expected to occur in the long-term in the Mokihinui reservoir, once the effects of decomposition of flooded vegetation have largely disappeared. Although there are obvious differences between Lake Brunner and the proposed reservoir in terms of residence time and basin shape, I think Lake Brunner provides a valuable point of reference because of its geographical location, its depth, and the similarity of historical total nitrogen and total phosphorus concentrations to those predicted for the Mokihinui reservoir. The Lake

Brunner data indicate that 62% saturation formed an approximate lower limit to summer oxygen concentrations in the hypolimnion at a depth of 70 m and temperatures of around 9.5 °C over the period 1992-2002. I expect that somewhat lower levels (40 - 50%) will occur in the proposed reservoir. This is mainly because of the larger ratio of wetted soil surface area to water volume in the Mokihinui Reservoir compared to Lake Brunner. Given the complexities involved in predicting hypolimnion oxygen concentrations, I cannot rule out the possibility that oxygen depletion may lead to even lower concentrations than 40-50% saturation levels in the long term. However this is my best estimate based on comparison with other reservoirs and lakes, taking account of geographic location, catchment characteristics, hydrology, water temperatures and nutrient loads.

6.26 I estimated oxygen demand from submerged vegetation and soils over the first five years following filling of the reservoir, and this demand has been compared with the oxygen supplied to the reservoir by the inflowing river. Full details of the method of estimation are given in my report.

6.27 I calculated yearly oxygen demands in the first five years to be as shown in the table below:

Table – Yearly oxygen demands in the first five years

Year	Oxygen demand (tonnes O_2)	Demands averaged over total lake volume (g O_2 m^{-3})
1	12,550	128
2	6,890	70
3	3,780	39
4	2,070	21
5	1,140	12

A long-term background summer oxygen demand in the order of 6 to 7 g O_2 m^{-3}, corresponding to partial oxygen depletion of 40 to 50% saturation, can be added to these amounts. The total amount of dissolved oxygen that is supplied to the reservoir by the inflowing river every year is on average 28,500 tonnes O_2 (291 g O_2 m^{-3}). This is well in excess of the yearly oxygen demands. In addition oxygen will be supplied through the water surface as reaeration by wind-mixing.

6.28 However, during summer I have predicted that, because of thermal stratification, water below the thermocline will be isolated from river inflows and wind-mixing. Negligible amounts of dissolved oxygen will therefore be supplied to the hypolimnion in summer. The only oxygen available to offset the demand in summer in the hypolimnion will be oxygen stored in the water there before stratification developed. This will be in the order of 11 g O_2 m^{-3}, the saturation oxygen concentration at a temperature of 10°C. Over the 4-month period December to March, when stratification is strongest, the oxygen demands corresponding to the decaying vegetation could be estimated as one-third of the yearly demands given above, i.e., 43, 23, 13, 7, 4 g O_2 m^{-3} in years 1-5. This demand is great enough, when compared with the saturation level of 11 g O_2 m^{-3} available at the start of stratification, to completely deplete oxygen below the thermocline before the end of summer in years 1 to 3, and also in years 4 to 5 if the background summer demand of approximately 6-7 g O_2 m^{-3} is accounted for. This means the water below the thermocline will become anoxic in summer, and this condition will persist until the majority of vegetation decomposition has taken place.

6.29 The timing for the above amounts was determined by assuming that 95% of the total organic carbon load would decay within 5 years, with an exponentially declining pattern. This carbon load consists mostly of carbon in foliage, litter and humus. It does not include woody material in thicker stems, branches and tree trunks, which may take several tens of years to decay, and that will have a very small effect on oxygen depletion on a seasonal basis. In my evidence, when I refer to the post-impoundment period, it is this 95% decay time scale that I am referring to. My choice of 5 years for the value for this time scale was based on examining published reports of decay of flooded vegetation in reservoirs of a range of sizes, residence times and vegetation types ranging from tropical rainforests to temperate and boreal forests. It is impossible to accurately predict the time scale that will apply to the Mokihinui Reservoir, or any reservoir for that matter, from first principles – the complexities are too great and there are too many unknowns. Although uncertainty therefore surrounds the exact value of the time scale for decay, I think 5 years is a reasonable estimate for the expected value, and that 10 years represents an upper limit. Changing the time scale would not affect the estimates of total carbon load or oxygen demand, but would alter the pattern over time in which the demand is exerted. If the time scale were 10 years, anoxic conditions could persist for the first 5 to 7 summers, rather than 4 to 5 summers.

6.30 The potential effects of anoxia include the following: death of all organisms that require oxygen and cannot escape from anoxic regions; generation of hydrogen sulphide and methane in the water column and from sediments; release of ammonium and dissolved phosphorus from sediments and decaying plant material; and dissolution of iron and manganese from sediments. As fish can swim and avoid these conditions, fish would survive and be able to find food in littoral regions and in tributaries. There would still be considerable habitat suitable for trout, in terms of dissolved oxygen and temperature, in the main body of the reservoir above the base of the thermocline. Eel and whitebait mainly inhabit the shallower regions of a lake, where plant cover is available. This depth is governed by availability of light for photosynthesis, estimated as 5.8 m, which is above the thermocline. Migration of trout, eels and whitebait within the reservoir would be unaffected by anoxia. Invertebrates in the hypolimnion would not survive. In the long-term, when the worst effects of decomposition have passed, dissolved oxygen will be available and the hypolimnion will become permanently habitable again and will be recolonised by fauna that require oxygen.

6.31 A concern about reservoirs is their release of carbon dioxide and methane, both greenhouse gases, into the atmosphere. These gases are the main end products of the microbial decomposition of flooded organic matter. International studies of carbon dioxide and methane fluxes from existing reservoirs and lakes have shown that reservoirs and natural lakes are sources of these gases to the atmosphere.

6.32 While it is not possible to calculate likely greenhouse gas emissions from the proposed reservoir, we can make some general statements and present representative values based one of the few long term studies that collected data on greenhouse gas emissions from reservoirs over periods of more than 20 years. The study, carried out by Tremblay et al. (2005b), documents how greenhouse gas emissions changed over time following initial impoundment in Canadian boreal reservoirs, and was based on “the biggest database of greenhouse gas fluxes from water bodies worldwide.” Their results showed a rapid increase in greenhouse gas emissions shortly after flooding and then a return to values observed in natural lakes and rivers within 10 years for carbon dioxide and 4 years for methane. They found that both the patterns and magnitudes of the fluxes from the Canadian reservoirs were similar to those found in other studies from temperate climates. They also compared their findings with those from tropical regions, and found that emissions were higher and declined more slowly in tropical regions.

6.33 Although the variability in their data is considerable, representative values for peak post impoundment values on a per unit area basis (from Tremblay et al 2005b), are 10,000 mg CO_2 m^{-2} day^{-1} for carbon dioxide, and 100 mg CH_4 m^{-2} day^{-1} for methane. Multiplying these values by the reservoir surface area of 3.37 km^2 gives corresponding values for the reservoir of 33,700 kg CO_2 day^{-1}, and 337 kg CH_4 day^{-1}. Values for long term fluxes on a per unit area basis (from St Louis et al 2000) are 1,500 mg CO_2 m^{-2} day^{-1} for carbon dioxide and 20 mg CH_4 m^{-2} day^{-1} for methane. Corresponding values for the reservoir are 5,055 kg CO_2 day^{-1}, and 67 kg CH_4 day^{-1}. These values are included in a table in Appendix 5. The value for long term emissions of methane is from St. Louis et al. (2000) and is greater than that given by Tremblay et al. (2005b). The values for long term carbon dioxide emissions from the two studies are the same.

6.34 The carbon dioxide and methane emissions can be combined as CO_2 equivalents in terms of their global warming potential by multiplying the methane emissions by a factor of 21, as explained by St Louis et al. (2000). These values are also included in Appendix 5 and, on an annual basis for the entire reservoir, amount to 14,800 tonnes CO_2 year^{-1} for the post-impoundment peak and 2,400 tonnes CO_2 year^{-1} for the long term.

6.35 A third effect that can result from decay of submerged vegetation in a newly created reservoir is a temporary increase in dissolved nitrogen and phosphorus concentrations, that in turn can lead to temporary increases in phytoplankton, zooplankton and fish production. The extent and severity of this effect, sometimes called “trophic surge” or “trophic upsurge”, depends on many factors, among them residence time, water temperatures, climate, and submerged soil and plant characteristics. The effect may not occur at all (Tadonleke et al. 2000), it may only last for a few months (Godyn et al. 2003), or, more commonly, it may last for 2 to 3 years after which conditions gradually return to those found in natural waters (Tremblay et al. 2005a). It is more severe and lasts longer in large tropical reservoirs (Pavia 2001). I expect nutrient levels to increase in the hypolimnion under anoxic conditions during the post-impoundment phase, although I cannot predict how much. These nutrients will become available for uptake by phytoplankton as the thermocline mixes downward during late autumn, and then be flushed from the reservoir during the period of winter mixing. The observations of Schallenberg and Burns (1997) on the trophic state of Lake Dunstan after filling seem relevant to the proposed Mokihinui reservoir: if the Mokihinui reservoir does experience a trophic upsurge, the very short residence time and the high inputs of suspended sediment should reduce the duration and magnitude of a post-impoundment pulse of production. Therefore, the effect of a “trophic surge” in the lake and downstream of the dam for the first 4 to 5 years are predicted to be minor or less than minor.

Water quality in the submerged tributaries

6.36 I expect the water quality in the reservoir sidearms (flooded tributaries) to be similar to that in the main stem of the reservoir, and any additional effects due to creation of the sidearms to be negligible. In the three cases (Rough and Tumble Creek, Maori Creek, Specimen Creek) where the sidearm valley is long and narrow enough to create conditions that are different from the main reservoir, the flushing rates are high enough to maintain water quality in the inundated reaches at least as good as that in the main stem. However, I note that in all the inundated tributary reaches that are deep enough to extend below the thermocline, water quality below the thermocline in the inundated reaches in summer will be the same as that in the main body of the reservoir.

Water quality below the proposed dam

6.37 Most of the water discharged downstream through the penstocks will come from the epilimnion and thermocline, and will therefore be oxygenated and at a temperature and water quality that closely matches inflow temperatures and water quality.

6.38 During an approximately 5 year post-impoundment phase when anoxic conditions occur in summer below the thermocline, there are three possible circumstances where deoxygenated water may be able to be drawn into the penstocks (and thus discharged downstream). These are:

- a. As very large inflows (discussed in paragraphs 6.12 and 6.13) push existing reservoir water ahead of them, it is possible that hypolimnion water close to the dam would be forced upward and then drawn into the outlet. Although there is no simple theoretical framework to test this, the downstream effects of this circumstance occurring would be minor or less than minor for the following reasons.
  - i. During large floods there will be a considerable volume of water flowing over the spillway, which will act to dilute any

deoxygenated discharge from the powerhouse within a short distance downstream of the dam. One would expect mixing and dilution to be vigorous and much more effective and rapid than ordinary aeration at lower flows.

ii. If there appeared to be a likelihood that hypolimnion (i.e. deoxygenated) water was about to be discharged through the powerhouse, it would be possible to release water in the penstocks through the bypass valve, which would aerate it very efficiently, as a temporary measure until the risk passed.

b. A sudden increase in generation outflows (high inflows) following a long period (weeks) of low flows would increase the range of depths in the reservoir from which outflows are taken, possibly drawing anoxic water into the penstocks. The downstream effects of this circumstance occurring would be minor or less than minor for the following two reasons.

i. A large fraction of the flow in the withdrawal layer that entered the penstocks would still come from the epilimnion, be fully oxygenated, and therefore dilute the outflow by the time it passed through the turbines.

ii. Unlike the first circumstance, this one could be avoided completely by modifying the operating strategy, e.g. by increasing outflows gradually, as proposed for summer ramping rates, or by discharging through the bypass valve (which would aerate the outflow very efficiently) until sufficient water was flowing over the spillway to dilute the outflow.

c. Upwelling of hypolimnion water under very strong, sustained winds blowing upstream from the dam that could raise hypolimnion water to the level of the outlet. The modelling results from DYRESM indicate that this will not occur, even when wind speeds of 1.5 times those recorded at Hokitika AWS are used in the model. The model computes an index at every time step that is a measure of the severity of upwelling. The results show that upwelling will not bring waters from below the thermocline to the level of the outlet when the lake is stratified. This is because the strength of stratification and the limited straight wind fetch over the reservoir will restrict upwelling to water within the upper thermocline. This water may be partially deoxygenated. However, potential adverse effects could be avoided by releasing water through the bypass valve.

6.39 Success of the mitigating strategies in paragraphs 6.38a and b depends partly on rapid and efficient mixing taking place between flow from the tailrace and flow from the spillway immediately downstream from the dam. The efficiency of this mixing should be checked as soon as it is feasible to do so after construction of the dam. Minor adjustments may be necessary to the tailrace exit to ensure that rapid mixing occurs.

6.40 The aerated water from the bypass valve will still contain traces of sulphide, manganese, iron, and ammonia, and additional time for complete oxidation of these reduced species will be required. I cannot predict likely concentrations or decay times, although I expect maximum decay times to be in the order of a few tens of minutes or less. There are two sources of dilution that will reduce possible effects of such releases. The first is that any anoxic water in the penstocks will itself be diluted with water from the upper part of the epilimnion. This is because the top of the inlet extends high into the epilimnion, to approximately 94 m above sea level, 6 m below the spillway crest. The second is that there is also likely to be water flowing over the spillway. Because of the transient nature of such an event, its infrequent occurrence and the combined mitigating effects of aeration and dilution, I expect its effects on fish, invertebrates and periphyton in the river downstream to be minor or less than minor.

6.41 If anoxic water were discharged downstream, and if all of the downstream flow were made up of the generation outflow (120 cumecs and this was anoxic), then only a very limited amount of reoxygenation (less than 20% saturation) could be expected to take place even by the time the river reached the coast. Hence, release of significant quantities of anoxic water downstream of the dam needs to be avoided when this comprises all or most of the downstream flow. I consider that such an occurrence is highly unlikely, and there are effective strategies that can easily be implemented to avoid partial anoxic releases.

6.42 I do not expect there to be any effects of the proposed reservoir on water quality in tributaries downstream of the dam.

Potential effects on Mokihinui River gorge habitat

6.43 The loss of river habitat is likely to lead to changes in community composition for periphyton, invertebrates and fish due to changes in physical habitat. For example, Suren and Kilroy (2007) note that most of the invertebrates currently present in the Mokihinui River are intolerant of slow flowing, deep water conditions, and as such will disappear from that section of the river. It is likely that a new fauna adapted to slow flowing and deep waters will take its place.

6.44 The loss of river habitat is an unavoidable consequence of building a dam and inundating the Mokihinui Gorge area. To some extent that loss is offset or mitigated by the creation of a new lacustrine habitat.

6.45 I have already stated that the proposed Mokihinui reservoir will have low to moderate nutrient levels, supporting low to moderate algal productivity. The evidence of Mr Henderson indicated that the proposed reservoir will have a varial (wetted and dried) eulittoral zone of between 97 and 100 m above sea level, which can be considered unproductive habitat. My report contains details regarding further calculations for estimating lake habitat such as depth for light penetration and estimates of productive littoral zone, and estimates of macrophyte growth. In brief, high water quality will allow light to penetrate to a depth of up to 5.8 m, i.e. light can penetrate to 91 m when at 97 m operating level. This provides for a productive submerged littoral zone estimated at 12.5% of the reservoir's total area. This estimate represents an upper limit because it does not account for wave action on those parts of the shoreline that will be subject to high wave energy.

6.46 This lake environment will provide good habitat for macrophytes, although not to nuisance aquatic weed levels. Dr. Floeder arrived at this conclusion by applying a method developed by Clayton and Champion (2006) for assessing risk of nuisance weeds in New Zealand's hydroelectric lakes. I agree with Dr. Floeder's conclusion and am happy with the method she used. This method involves calculating a score that accounts for effects of lake level fluctuation, water clarity, shoreline shape and exposure to wave action, and the slope and substrate of the littoral zone. The score for the Mokihinui was similar to that of other New Zealand hydro lakes and reservoirs in which macrophytes occur, but not to nuisance weed levels. The score was below that of other New Zealand hydro lakes and reservoirs in which macrophytes can occur to nuisance weed levels.

6.47 Discussions with Dr Murray Hicks indicate that there is likely to be some deposition of silt and fine sand in the littoral zone following floods because of the suspended sediment load carried by the river into the reservoir. However, it is not possible to determine the likely extent or severity of this deposition in sufficient detail to determine whether its net effect will be beneficial, destructive or neutral to the quality of the littoral habitat. If this deposition is severe, it could act to smother plants in the littoral zone. If it is not too severe, then the deposition could improve the habitat by providing areas with improved substrates and slopes compared to the steep and rocky conditions that currently predominate. Given the steepness of the shoreline I do not think excessive deposition will occur, but rather that the latter outcome is more likely. In any event, I do not think this is an issue of concern.

6.48 Dr Floeder assessed the potential for macrophytes to grow in the Mokihinui reservoir as positive, because of the importance of littoral zones as fish and invertebrate habitats and their potential contribution to the productivity of the whole lake system. I agree with this assessment. The extent of the benefit of the new lake habitat to aquatic ecosystems is discussed by other experts such as Dr Kilroy, Dr Suren, Mr Bonnett and Dr Hayes. The creation of the reservoir also gives rise to recreational benefits that are discussed by Mr Greenaway.

Potential mitigation of effects

6.49 I have outlined a potential effect whereby deoxygenated water could possibly be discharged downstream in the first four to seven summers of operation. Possible operating strategies to ensure that effects remain minor or less than minor are:

a. Monitoring to determine oxygen levels at the outlet and downstream of the dam.

b. Operation methods of the power station to ensure that after long low flow periods outflows are increased gradually.

c. Operation methods of the power station to ensure that during extreme wind events anoxic water does not enter the outlet.

d. If in the unlikely event anoxic water was drawn into the outlet then the bypass valve would be activated. This would aerate the water until the risk of anoxic water had passed or the water level in the reservoir had increased to activate the spillway.

6.50 Recommended trigger levels for the above strategies have been set out in the Aquatic Ecology Management Plan (attached as Appendix 6), and I will explain them here. The trigger levels are based on real-time measurements of oxygen and temperature recorded by sensors moored at the dam at depths below the spillway crest of 13 m (coinciding with the outlet invert), 20 m (near the base of the thermocline) and 35 m (within the upper hypolimnion). Additional information will be provided by wind speed and direction measurements made on land near the dam. All sensors, including wind speed and direction, will have a sampling interval of 10 minutes. Information from the three oxygen-temperature sensors and from the wind speed and direction sensors will be used to alert the Scheme operators as to when water in the penstocks needs to be diverted through the bypass valve.

6.51 There are three levels of alert, the final one being that for which water in the penstocks is diverted through the bypass valve until flow over the spillway is great enough to ensure a dilution that will maintain oxygen concentrations above 80% saturation downstream (which corresponds to approximately 8 mg/litre for the range of temperatures expected in the river downstream from the dam in summer). The initial alert occurs when dissolved oxygen concentrations at the 35 m sensor drop below 8 mg/litre and show a steadily declining trend over the preceding 5 days. This will indicate that more severe oxygen depletion below the thermocline can be expected in the following weeks, possibly leading to anoxia. The second alert occurs when oxygen concentration at the 20 m sensor drops to 8 mg/litre. This indicates the possibility that oxygen-depleted water from greater depths may be moving upward toward the intake, and may arrive at the intake within the next hour or so. The final level of alert occurs when oxygen concentrations at the 13 m sensor drop to 8 mg/litre and show a declining trend over the previous hour. If concentrations at the 13 m sensor drop below 8 mg/litre, and there is no flow over the spillway, then the bypass valve should be opened. This is conservative because the water drawn into the penstocks will consist of water not only from 13 m below the crest, but also water from shallower depths (up to 6 m below the crest); the water from shallower depths will contain higher concentrations of dissolved oxygen and therefore dilute the oxygen deficit at 13 m. If there is flow over the spillway, then lower oxygen concentrations can be allowed at the 13 m sensor before opening the bypass valve. Methods for determining the limiting concentrations are given in the Aquatic Ecology Management Plan.

6.52 As a check on these alerts, oxygen concentrations measured by the oxygen-temperature sensor in the tailrace will be observed at these times. Oxygen concentrations in the tailrace should always be greater than or equal to those measured at the 13 m sensor. If this is observed not to be the case, it may indicate a malfunction of one or the other of the sensors, and signal the need for maintenance. In any event, oxygen concentrations in the tailrace will not be allowed to drop below 8 mg/litre. If it appears that they are about to do so, the bypass valve will be activated, subject to the same considerations for dilution by flow over the spillway as for the 13 m sensor.

6.53 Circumstances that might lead to the need for the bypass valve to be used are large flood flows entering the reservoir and very strong and prolonged winds blowing upstream from the dam. In terms of approximate magnitudes that could alert the operators to the possibility of trigger conditions occurring, floods greater than 1000 m^3/s and wind blowing upstream with speeds exceeding 10 m/s for 2 hours are appropriate to start with. These values may be altered as experience is gained with the monitoring system and with how conditions in the reservoir respond to floods and strong winds.

6.54 The trigger levels recommended above and in the Aquatic Ecology Management Plan are intended to be part of an overall ‘adaptive management strategy’ for avoiding or mitigating potential adverse effects. As such I envision that the trigger levels and the operation strategies could change as experience is gained with the monitoring system and with how conditions in the reservoir respond to floods and strong winds.

6.55 The cause of anoxic conditions below 25-30 m in the post-impoundment period is the decay of organic matter that will be submerged when the reservoir is filled. I considered the clearing of vegetation prior to dam filling, but conclude that because of the relatively large amount of labile organic carbon contained in litter and humus, and the very small fraction contained in foliage and wood, that the removal of standing live trees alone (or even including fallen dead trees) would have a minor impact on stocks of labile organic carbon. For removal of vegetation to be effective, litter and humus would also have to be removed, which is not a feasible or a desirable option. This is because of the length of time that a very large area of bare soil on steep slopes would be exposed to erosion, the enormous volumes of sediment that would be generated, and the dangers involved in operating the necessary equipment on the steep slopes in the gorge.

6.56 I recommend that a programme be put in place to monitor the seasonal evolution of oxygen and temperature as depth profiles in the reservoir near the dam (as described in paragraph 6.50), and at two points in suitable cross-sections (one in the tailrace channel and one in the river) downstream of the dam. I also recommend that a weather station, consisting at minimum of wind speed and direction measuring equipment, be installed in a suitable location at the dam site. These recommendations have been included in the consent conditions drafted by Meridian.

Summary of effects

6.57 The proposed Mokihinui reservoir will be thermally stratified in summer. In the long term the reservoir is expected to have low to moderate algal productivity sustained by low to moderate levels of nutrients. There will probably be moderate water clarity. Anoxia in bottom waters of the reservoir can be expected in the first four to seven years of operation, when the Mokihinui reservoir stratifies in summer. The anoxia will be most severe in the first year and will gradually decline over time. I have estimated that after five to ten years conditions will within 95% of long-term values and anoxia will not be an issue. Once the process of decay is completed, and organic matter, dissolved organic carbon and catabolic products are flushed downstream or buried within the reservoir, the Mokihinui reservoir will evolve into a lake system of good quality.

6.58 During the post-impoundment period when anoxic conditions occur we expect that emission of greenhouse gases will be higher than is normal for natural lakes or old reservoirs. These emissions will then decline to levels that are characteristic of natural lakes or old reservoirs.

6.59 During the post-impoundment period when anoxic conditions occur there may be higher nutrient concentrations and higher rates of phytoplankton production than in the long term. If the Mokihinui reservoir does experience such a trophic upsurge, the very short residence time and the high inputs of suspended sediment should reduce the duration and magnitude of a post-impoundment pulse of production.

6.60 I expect effects on the water quality downstream of the dam to be minor or less than minor, both in the long term and during the post-impoundment period when anoxic conditions occur, for reasons explained earlier.

6.61 Water discharged downstream from the dam should have a temperature and quality similar to mean daily values in the inflowing rivers. Discharge of anoxic water downstream of the dam is unlikely. I do not expect there to be any effects of the proposed reservoir on water quality in tributaries downstream of the dam. With regard to the Class AE Water management target established by the Regional Water Management Plan, I expect that discharges from the dam will meet these requirements for temperature, pH, oxygen, sedimentation and contaminant-release.

6.62 The loss of river habitat in the main stem and lower reaches of some tributary streams is an unavoidable consequence of building a dam and inundating the Mokihinui gorge area. The loss of river habitat is likely to lead to changes in community composition for periphyton, invertebrates and fish due to changes in physical habitat.

6.63 To some extent that loss is offset or mitigated by the creation of a new lacustrine habitat. The proposed Mokihinui reservoir will have low to moderate nutrient levels, giving low to moderate algal productivity. It will have a varial (wetted and dried) eulittoral zone of between 97 and 100 m, which can be considered unproductive habitat. High water quality will allow light to penetrate to a depth of up to 5.8 m, i.e. light can penetrate to 91 m when at 97 m operating level. This provides for a productive submerged littoral zone estimated as a maximum of 12.5% of the reservoirs total area. This provides good habitat for macrophytes, although not to nuisance aquatic weed levels.

7. ISSUES RAISED BY DOC REVIEW

7.1 Dr Marc Schallenberg has posed a number questions and criticisms of our original report in a review that he carried out for the Department of Conservation. I will summarise the main issues raised by Dr Scallenberg's review and present our response, and point out where I have addressed some of these issues in the evidence I have already presented.

7.2 Dr Schallenberg made a general comment that input data used to model stratification, to predict the likely water quality of the reservoir, and to assess the effects of outflows from the reservoir on the river downstream, were insufficient to make strong inferences, and that a large degree of uncertainty should be acknowledged. Furthermore, he suggested that some quantitative estimate of uncertainty should be presented, either in terms of error analysis or sensitivity analysis. I have included acknowledgement of uncertainty in my evidence, especially as it applies to the predictions for long term trophic status of the reservoir, long term summer oxygen depletion in bottom waters, and the duration of the post-impoundment period when decay of submerged vegetation exerts an effect on oxygen depletion. I have also presented results from sensitivity analyses to quantify uncertainty in relation to modelling thermal stratification, as described in the following paragraph.

7.3 With regard to data used to model stratification, Dr Schallenberg specifically questioned the relevance of using climate data from Hokitika AWS. I had addressed this question in our original report, and have reiterated my response in paragraph 6.7 as to the appropriateness of using that data. In response to Dr Schallenberg’s comments on the need for sensitivity analysis, I have carried out two additional model runs, one using wind speeds that are 1.5 times those from Hokitika AWS used in the original run, and the second using 0.7 times the Hokitika AWS wind speeds. Wind speed is the parameter most likely to differ between sites, and the parameter especially singled out by Dr Schallenberg. The results from these extra runs are much the same in terms of the features of stratification and mixing on which the conclusions are based in our original report and in the evidence presented here. This relative insensitivity to wind speed is caused by the dominant role played by inflows and outflows, rather than wind, in setting the depth and strength of the main thermocline.

7.4 With regard to water quality data used to predict trophic state, I agree with Dr Schallenberg that it would be good to have more than 10 samples on which to base our conclusions. However, I have tried to make the best and most reasonable use of the data I have. By comparing the data with the more extensive database of the NRWQN, with ANZECC and ARMCANZ (2000) guidelines, and with water quality in existing reservoirs and a lake, I have broadened the effective coverage of the available data. The data fall within a range characteristic of West Coast rivers with undeveloped catchments. This increases my confidence in the reasonableness of the conclusions I have drawn concerning the likely trophic status of the proposed reservoir. These conclusions are quite general and allow for a range of detailed outcomes for individual parameters.

7.5 Dr Schallenberg has suggested that the conclusions depend heavily on the use of mean hydraulic residence time, which is biased by high flows, and that variation in residence time throughout the year should be accounted for. In response I have now explained, in paragraph 6.16, that the results are the same whether mean or median residence time is used. The only way to account for more detailed variation would be with a complex, process-based aquatic ecosystem model that could be run on a daily basis coupled with a hydrodynamic model such as DYRESM. This would be a major undertaking, and data required to run such a model are simply not available.

7.6 Dr Schallenberg has identified seiching (which refers here to long-wave oscillations of surfaces of constant temperature), and the upwelling associated with it under strong winds blowing upstream from the dam, as a potential mechanism for bringing anoxic water to the level of the outlet, where it could be discharged downstream. Dr Schallenberg cites his experience in observing very large excursions of the thermocline in Lake Coleridge. His point is a valid one and in fact was considered, but not reported, in the final version of our original report. As now explained in paragraph 6.38c, Lake Number calculations made as part of the original model run, and again for the run using 1.5 times the wind speeds of the original run, indicate that upwelling strong enough to bring hypolimnion water to the outlet will not occur on the Mokihinui reservoir. I have now included discussion of upwelling in my evidence (paragraph 6.38c), and recommended that measurement of wind speed be included as part of the monitoring programme for the reservoir. With regard to the example of Lake Coleridge, I note that the extent of any upwelling depends on the strength of stratification, wind speed and the length of unobstructed wind fetch. Lake Coleridge is a rather unique system in which thermocline excursions are exceptionally large (Schallenberg et al. 1999). These can be explained in terms of its much longer wind fetch, the stronger winds to which it is exposed, and smaller temperature difference between epilimnion and hypolimnion compared to the proposed Mokihinui reservoir.

7.7 Dr Schallenberg has used the term "crude" to describe the carbon budget that was used to estimate the oxygen demand caused by the decay of flooded vegetation in the post-impoundment period, and has questioned several of the assumptions used in making calculations. It is not practical for me to address each one of Dr Schallenberg's criticisms individually here, but I can make the following general comments.

7.8 In my opinion the approach we used was appropriate, made maximum realistic use of available information and is similar in "crudeness" to many models and calculations currently used to quantify aspects of the carbon cycle. I was particularly fortunate to have information from Tate et al. (1997), Beets (1980) and R. Bartlett (pers. comm.) that allowed me to make estimates relevant to the Mokihinui catchment of total organic carbon stocks and the forms in which they appear (for example, as leaves, branches, or litter). It is true that many assumptions were necessary to carry out the calculations. These were all made with consideration after reviewing available scientific literature and discussions with colleagues. For example, wood from tree trunks and branches was not included in the oxygen demand calculations because the very long time scales involved in its decay makes its contribution on an annual basis negligible compared with that of leaves and humus. The calculations and assumptions were presented in detail so that an interested reader could assess them for his/herself, and redo them if they wished. It was not felt necessary or practical to present sensitivity analysis for the calculations, given the number of variables that would need to be tested; the provision of sufficient information to allow interested readers to perform their own calculations; but mainly because the chief purpose of the calculation was to determine whether anoxia would occur, and how long it would persist. Changing the assumptions would not alter the conclusion that anoxia would occur, and that it would persist for a significant fraction of whatever timescale were chosen for 95% completion of the decay phase.

7.9 As explained in the report and in my evidence, the timescale for 95% completion of the vegetation decay phase was chosen independently of the carbon budget calculations, as it is not possible to calculate it from first principles with the information available. Although we feel that 5 years is a realistic estimate for this timescale for the Mokihinui, I accept Dr Schallenberg's point that some estimate should be presented of the uncertainty surrounding this value. Based on the material I reviewed for the original report, the discussions I had then with colleagues and new material that I have since found in the scientific literature, I have suggested in my evidence that an upper limit for the 95% decay timescale is 10 years.

7.10 Dr Schallenberg thought that we excluded the single large total phosphorus concentration of 30 November 2006 when making our assessment of the likely trophic status of the Mokihinui Reservoir. This is not the case and we tried to make this clear in our report. Further clarification is given in paragraph 6.18 of my evidence.

7.11 I have made an effort to address other issues raised by Dr Schallenberg on greenhouse gas emissions, trophic upsurge and sediment deposition in the littoral zone in my evidence.

8. ISSUES RAISED BY SUBMISSIONS

8.1 A submission has been made by the West Coast Branch and Top of the South Greens Province of Greens Party Aotearoa New Zealand that contains a section on the Water Quality and Habitat Report. I consider that appropriate responses to most of the issues raised in this submission have been covered in the original report or in my evidence, including our responses in Section 7 to Dr Schallenberg's review. There does appear to be a general misunderstanding regarding our assessment of effects, in the statement that "NIWA's conclusion that effects of the reservoir will be minor, or less than minor, are, once again, incredulous." My assessment of minor effects refers specifically to the water quality in the river downstream of the reservoir, which I expect to have a character similar to that in the inflowing river, for reasons explained in the report and evidence. The effects on the flooded reaches of the river, upstream of the dam, have not been described as minor, and are discussed in the original report and in my evidence, and in the evidence of other witnesses.

9. RESPONSE TO S42A REVIEW OF PROPOSED CONSENT CONDITIONS

9.1 The section 42A report has included as Appendix 3 an evaluation of the draft consent conditions. I shall comment on the suggestions by the Reporting Officer in the following sections. I shall refer to the Reporting Officer's comments by reference to the page number in Appendix 3, Meridian's proposed condition number and the Reporting Officer's comment or heading number.

Pages 2-3, Condition 6, Reporting Officer comments (b), (c), (d) and (f)

9.2 In comment (b) the Reporting Officer has recommended the use of black disk visibility testing upstream and downstream once each week during normal working hours through the construction period. I do not think this should be included as a consent condition. Monthly monitoring is recommended in comment (d), which I do support (paragraph 9.3), and this monthly monitoring includes upstream and downstream measurements of black disk visibility. If the intention of the increase in frequency, from monthly to weekly, is to detect conspicuous changes in water clarity caused by discharges from the construction site, then I think this would be better accomplished by an event-based approach that allows for more flexibility in timing and method than the weekly measurement suggested in comment (b). In the Aquatic Ecology Management Plan, I have recommended use of a water clarity tube for upstream and downstream measurement of water clarity before, during and after a construction-activity event that is likely to cause a conspicuous change in water clarity. A water clarity tube measurement is easier to make than a black disk measurement, and the water clarity tube reading can be converted to a black disk distance for black disk distances less than 2.2 m, using formulas in Kilroy and Biggs (2002). Since it is the possible occurrences of low water clarity that are of concern, this limitation to 2.2 m should not be a problem.

9.3 I support the routine monthly testing proposed in comment (d). All parameters listed under comment (d) have been included in recommendations in the Aquatic Ecology Management Plan as well as additional parameters that will allow a better assessment of water quality. However, I question the need for two downstream sites during the construction period as suggested in comment (d), at 300 m and 500 m downstream of the point of discharge from the stormwater retention pond. The Aquatic Ecology Management Plan recommends a single site at 300 m downstream, if possible to coincide with the site to be used for operational monitoring following dam completion.

Page 7, Condition 13, second comment

9.4 This comment states that prior to dam construction, further investigation be undertaken to determine whether a low level outlet is required, and that this be peer-reviewed. I assume that the “low level outlet” in the comment would be in addition to the outlet 13 m below the spillway crest that is currently planned for the dam. The need for such an additional outlet from a water quantity point of view has been discussed in the evidence of Peter Amos. From a water quality point of view, I do not think it is necessary to include this requirement as a condition for consent. The possible water quality benefits of being able to withdraw water from a "low level outlet" relate to the potential for controlling how stratification, oxygen concentrations and mixing occur within the reservoir, and for controlling water quality of downstream releases. These are well documented in the scientific and engineering literature, and further investigation is superfluous and is not necessary for water quality reasons. The consent-holder is required to maintain water quality downstream to Class AE standards (as set out in the third schedule of the Resource Management Act). I have predicted (in my evidence and in the report on water quality prepared by Dr Floeder and myself) that this requirement can be met within the framework of the present design. Mitigation measures have been recommended to deal with possibilities under which the requirement could potentially not be met.

Pages 44-45, comment on conditions 101 and 102

9.5 Conditions 101 and 102 concern requirements for real-time monitoring of dissolved oxygen and temperature in the reservoir and in the river downstream, and with mitigation measures to prevent discharge of oxygen-depleted water downstream. The comment contains a number of points. The first point is the recommendation that the required monitoring be ongoing and not end after five years. I think it is reasonable to require that the need for monitoring be reviewed after the first five years, and then extended for a further period if necessary or prudent, but I do not think it is necessary to require as a consent condition that the real-time oxygen and temperature monitoring be required for the life of the reservoir. The Aquatic Ecology Management Plan recommends that the real-time oxygen and temperature monitoring, and the mitigation strategies dependent upon them, be carried out for the first five years of operation, and then be reviewed in light of the oxygen regime of the reservoir. If anoxic conditions are found to persist in summer below the thermocline for more than five years, the monitoring and mitigating strategies should continue for a longer period, to be determined at the time of the review.

9.6 The first bullet point in the comment calls for “regular monitoring of lakeside erosion and weed invasion and response”. The third bullet point calls for a weed eradication program. I will respond to the points relating to weed invasion and eradication, assuming that the comment refers to aquatic weeds. In the Aquatic Ecology Management Plan it is recommended that annual surveillance monitoring should be carried out to check for arrival and establishment of species of macrophytes that could possibly develop to nuisance levels. The annual survey should focus on those areas where such species are most likely to arrive. If macrophytes do become established to nuisance levels, as identified by annual surveillance monitoring, they are likely to be confined to very small areas and can be easily controlled by selective diquat spraying. These recommendations could be included as an additional consent condition, but they are sufficiently well-covered in the Aquatic Ecology Management Plan.

10. CONCLUSION

10.1 The proposed reservoir in the Mokihinui River Gorge will be temperature-stratified in summer, despite the variability and frequency of large flows that characterise the inflowing river hydrographs.

10.2 The reservoir will be anoxic below 25-30 m in the first four to seven summers after the reservoir is filled due to decomposing flooded terrestrial vegetation. Oxygen depletion below the summer thermocline will be most severe during the first summer, and effects will gradually subside over time. I predict that after four to seven years only partial depletion of oxygen will occur in summer below the thermocline, and that after five to ten years conditions will be those expected for a deep lake with low to intermediate concentrations of nutrients and phytoplankton.

10.3 Predictions of the mean concentrations of chlorophyll-a, total phosphorus and total nitrogen in the reservoir imply low to moderate productivity of the system, a positive indicator for water quality in the newly-formed reservoir. We therefore expect that the reservoir will evolve into a lake system of good quality once the initial effects of decaying vegetation subside.

10.4 From late autumn to early spring, when the reservoir is expected to be well mixed, water in the whole system is expected to be oxygen-rich and of good water quality. From spring to autumn (during stratification), water within and above the thermocline will be of good quality, and will consist primarily of recent river inflows. Water below the thermocline (hypolimnion water) is likely to be anoxic and highly enriched in the first summers, but partially oxygen-depleted and slightly nutrient-enriched in the long-term.

10.5 I expect the outflows to be drawn from within and above the main thermocline in summer, and waters below the thermocline to remain isolated until winter mixing. Hence water used for power generation and discharged downstream should have a temperature and quality similar to mean daily values in the inflowing rivers, and should be of good quality, both in the long-term and even during the initial years when the hypolimnion is anoxic.

10.6 Any anoxic water discharged downstream during the post-impoundment phase would have to pass through the turbines, not over the spillway. We consider this to be unlikely to happen and in the event that it does occur, mitigating activities can be implemented such that the effects would be minor or less than minor.

10.7 The loss of river habitat in the gorge section of the Mokihinui is unavoidable if a reservoir is created. To some extent that loss is offset or mitigated by the creation of a new lacustrine habitat. There will be a eulittoral zone between high and low water water (97-100 m) that will be unproductive habitat. But below low water level, high water quality will allow light to penetrate to a depth of up to 5.8 m, i.e. light can penetrate to 91 m when at 97 m operating level. This provides for a productive submerged littoral zone estimated at a maximum of 12.5% of the reservoir’s total area. This provides good habitat for macrophytes, although aquatic weeds will not grow to nuisance levels.

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Tables

Table 1: Comparison of Mokihinui River water quality data with NRWQN statistics based on the years 1989 – 2006, and with NRWQN data for Buller River and Grey River (1989 – 2006). Nitrogen-to-phosphorus ratios have not been calculated from mean or median nitrogen or phosphorus concentrations that are shown in the table, but have been computed from the individual sample values. Sample size for Mokihinui data: n=10, if not stated differently in the table. Sample size for NRWQN statistics: >16600, Buller River: > 206, Grey River: > 200.

		Mokihinui at Seddonville		**National Average**		**Buller at Longford**		**Grey at Waipuna**	
Parameter	**Unit**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**
Water clarity - black disk (n=9)	m	2.32	2.35	2.15	1.38	3.6	3.7	3.4	2.9
Temperature	°C	13.3	13.9	12.5	12.3	11.0	10.6	11.1	10.6
Dissolved oxygen (n=4)	%-sat	101	101	101	101	100	100	100	100
Spec. Conductance	$\mu S\ cm^{-1}$	99.8	101.5	112	87.8	56.1	55.8	49.3	51.3
pH		7.17	7.25	7.67	7.66	7.65	7.65	7.44	7.48
Ammonium	$mg\ N\ m^{-3}$	7.9	7.0	11	6	3.9	3.0	5.7	4.0
Nitrate + nitrite	$mg\ N\ m^{-3}$	11.5	8.0	249	99	29.6	24.0	30.6	25.5
Total nitrogen (TN)	$mg\ N\ m^{-3}$	123	103.6	402	245	101	81.8	129	102
Dissolved reactive phosphorus (DRP)	$mg\ P\ m^{-3}$	2.75	1.5	9.7	4.9	1.4	1.0	2.1	2.0
Total phosphorus (TP)	$mg\ P\ m^{-3}$	25	8.8	48	17	14.1	4.8	27.3	5.0
TN : TP		11.62	10.8			18.6	16.4	20.3	17.5
Dissolved inorganic Nitrogen : DRP		12.85	11.3			31.5	27.0	20.2	15.9

Table 2: Comparison of some predicted aspects of the proposed reservoir with Lake Dunstan (Clutha River), Lake Ohakuri (Waikato River), Lake Rotorangi (Patea River) and Lake Brunner. Lake Dunstan data are for the Dunstan Arm from a 1-year (April 1994 – March 1995) study by Schallenberg and Burns (1997), except for total nitrogen (TN), total phosphorus (TP) and dissolved oxygen data courtesy of Otago Regional Council (1997-2006). Hydraulic data for Lake Ohakuri are from the main basin (exclusive of the Whirinaki arm); mean flow data are based on a long term data set (1969-1978). Total nitrogen (TN) and total phosphorus data (TP) are summer averages (1978-79). Lake Brunner data are based on a long-term (1992-2006) data set (Kelly and Howard-Williams 2003). Lake Rotorangi data are cited from TCB (1988), TRC (2006) and Burns et al. (2000).

	Proposed reservoir in the Mokihinui Gorge	**Lake Brunner**	**Lake Dunstan, Dunstan Arm Clutha River**	**Lake Ohakuri Waikato River**	**Lake Rotorangi Patea River**
Date operational		Not applicable	1993	1961	1984
Volume (10^6 m^3)	98.6	2,260	159	95.4	175
Surface area (km^2)	3.37	41.1	3.36	6.7	6.17
Maximum depth (m)	80	109	60	37.5	56
Approx length (km)	12	9.4	17	7.5	46
Mean flow (m^3 s^{-1})	90.3	60	560	161	24.5
Mean hydraulic residence time, volume/flow (days)	12.6	430	3.3	6.9	83
Thermal stratification	Likely	Yes	unknown*	Yes	Yes
Oxygen depletion	Likely in first 5 years, partial thereafter	Partial	No	Yes	Yes
Trophic status	Mesotrophic	Oligotrophic – Mesotrophic	Oligotrophic	Eutrophic	Mesotrophic – Eutrophic
TN (mean, mg N m^{-3})	93.8 -123**	171	80	193	580
TP (mean, mg P m^{-3})	8.5 – 25**	6.56	4.1	31	15.1

* No temperature data available from deeper parts of Lake Dunstan

** Range in total nitrogen (TN) and total phosphorus (TP) values correspond to average values excluding and including data of 30 November 2006, as explained in paragraph 6.18.

Figures

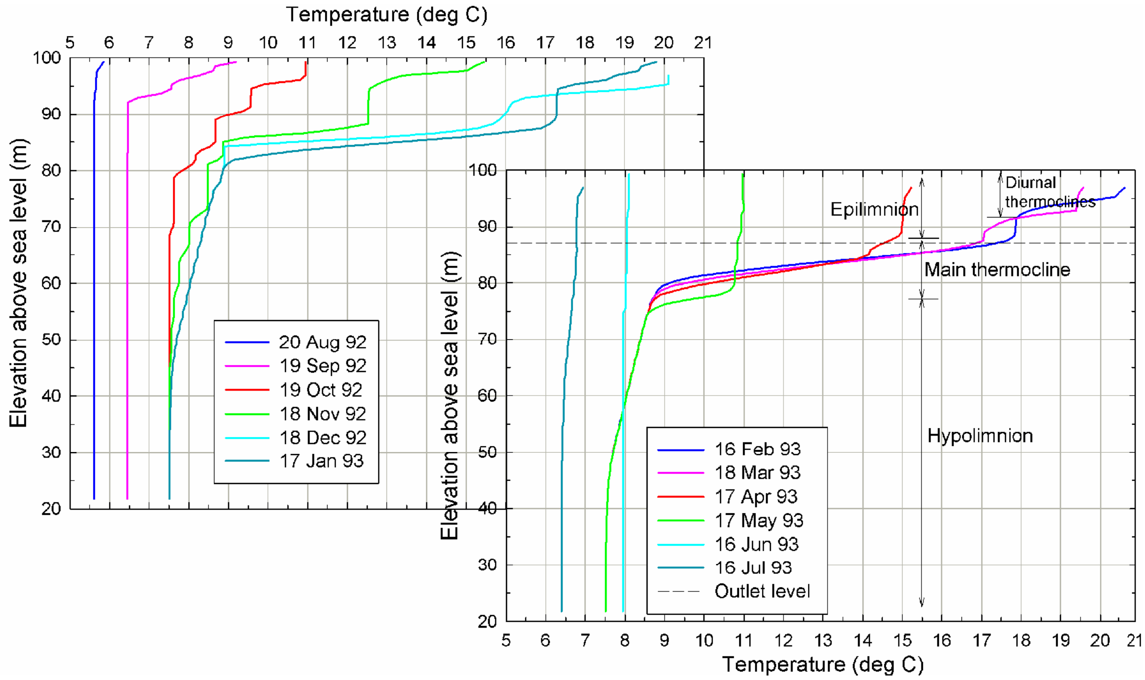

Figure 1: Seasonal variation of temperatures in the proposed reservoir, based on model predictions. The terminology shown for thermal stratification is most relevant to a fully-developed summer profile such as the one shown for February.

APPENDIX 2 – Water Chemistry and Water Quality Data: Mokihinui River at Seddonville

Date Collected	DRP mg P m^{-3}	NH4-N mg N m^{-3}	NO3-N mg N m^{-3}	TDN mg N m^{-3}	DOC g C m^{-3}	TDP mg P m^{-3}	DIN mg N m^{-3}	Part N mg N m^{-3}	Part P mg P m^{-3}	TN mg N m^{-3}	TP mg P m^{-3}	DIN:DRP	TDN:TDP	TN:TP
3/11/2005	1	10	5	40	<0.5	3	15	13.60	1.90	53.60	4.90	15.00	13.33	10.94
5/12/2005	4	12	18	118	2.6	6	30	42.15	8.95	160.15	14.95	7.50	19.67	10.71
7/01/2006	3	11	33	81	<0.5	6	44	11.15	2.40	92.15	8.40	14.67	13.50	10.97
8/02/2006	2	8	6	46	<0.5	5	14	24.00	4.20	70.00	9.20	7.00	9.20	7.61
27/03/2006	1	4	4	22	3.0	3	8	9.70	1.10	31.70	4.10	8.00	7.33	7.73
30/11/2006	8	14	12	199	3.7	13	26	187.00	160.00	386.00	173.00	3.25	15.31	2.23
18/12/2006	7	6	16	97	2.3	11	22	18.05	2.90	115.05	13.90	3.14	8.82	8.28
9/01/2007	<1	5	5	99	1.2	4	10	19.70	3.00	118.70	7.00	20.00	24.75	16.96
15/02/2007	<1	5	6	59	1.7	1	11	11.40	1.40	70.40	2.40	22.00	59.00	29.33
13/03/2007	<1	4	10	79	1.9	3	14	53.40	8.60	132.40	11.60	28.00	26.33	11.41

Date Collected	Conductivity (µS)	DO (%-saturation)	Temp (^oC)	Turb	pH	Black Disk (m)	Cloud coverage
3/11/2005	102	101	13.3	1	7.87	Not done	8 / 8
5/12/2005	49.9	Not Taken	14.3	Not Taken	6.36	0.8	1 / 8
7/01/2006	97.2	Not Taken	11.4	Not Taken	7.19	2.3	8 / 8
8/02/2006	101	Not Taken	15.6	Not Taken	6	2.35	3 / 4
27/03/2006	114.8	Not Taken	16.7	Not Taken	7	4.7	7 / 8
30/11/2006	66.1	Not Taken	10.4	Not Taken	7.22	0.06	8 / 8
18/12/2006	95.5	Not Taken	13.5	Not Taken	7.42	1.35	8 / 8
9/01/2007	120.5	98.4	16.4	Not Taken	7.75	3.32	8 / 8
15/02/2007	122.3	104.7	6.7	Not Taken	7.28	3.67	6 / 8
13/03/2007	129.1	101	15.1	Not Taken	7.58	2.36	8 / 8

APPENDIX 3 - DYRESM computer model description

In this study I used the University of Western Australia – Centre for Water Research's computer model DYRESM (Dynamic Reservoir Simulation Model) that predicts temperature profiles in lakes and reservoirs. The model has been widely applied in Australia, New Zealand and overseas, and has been documented in the scientific literature by Imberger (1979) and Imberger and Patterson (1979, 1990), who give overviews and further references. Further documentation can also be found at http://www.cwr.uwa.edu.au/ with links to "services" and "models". The model utilizes information on lake bathymetry (areas within depth contours; volumes below depth contours; outlet elevation(s)); daily meteorological data (incoming solar radiation, cloud cover, wind speed, air temperature, humidity, rainfall); and daily inflow and outflow data. It accounts for all major physical processes that cause thermal stratification and vertical mixing within a lake or reservoir.

The model is referred to as "one-dimensional" because it only simulates vertical variations in water properties. The basic output from the model is a series of daily temperature profiles (and profiles of salinity and density if required). The profiles are meant to be representative of conditions averaged over the horizontal extent of the lake. Hence the model is applicable to lakes in which vertical variations are generally much more pronounced than horizontal variations.

APPENDIX 4 – Trophic level classification of Burns et al. (2000)

Trophic levels and values of trophic level index (TLI) that separate them, from Burns et al. (2000). Annual averages of total nitrogen (TN), total phosphorus (TP) and chlorophyll-*a* (Chl-a) concentration, and Secchi disk depth that correspond to boundaries of different trophic levels are based on data from 23 lakes used to develop TLIs. Bold figure indicate the ranges where the proposed Mokihinui reservoir lies. The two sets of ranges for total phosphorus and chlorophyll-a correspond to the mean value of total phosphorus computed including and excluding the very high concentration of total phosphorus measured on 30 November 2006, as discussed in paragraph 6.18 of my evidence.

Lake type	**Trophic level index (TLI)**	**TN (mg N m^{-3})**	**TP (mg P m^{-3})**	**Chl-a (mg m^{-3})**	**Secchi disk (m)**
Ultra-microtrophic	0 – 1	16 – 34	0.84 – 1.8	0.13 – 0.33	33 – 25
Microtrophic	1 – 2	34 – 73	1.8 – 4.1	0.33 – 0.82	25 - 15
Oligotrophic	2 – 3	**73 – 157**	**4.1 – 9.0**	**0.82 – 2.0**	15 - 7
Mesotrophic	3 – 4	157 – 337	9.0 – 20.0	2.0 – 5.0	7 – 2.8
Eutrophic	4 – 5	337 – 725	**20 – 43**	**5.0 – 12.0**	2.8 – 1.1
Supertrophic	5 – 6	725 – 1558	43 – 96	12.0 – 31	1.1 – 0.4
Hypertrophic	7 – 8	> 1558	> 96	> 31	< 0.4

APPENDIX 5 – Estimates for post-impoundment peak and long term carbon dioxide and methane emissions

	CO_2 and CH_4 emissions per unit surface area					CO2 equivalents*	CO2 equivalents*
	CH_4 mg CH_4 m^{-2} day^{-1}	CH_4 mg C m^{-2} day^{-1}	CO_2 mg CO_2 m^{-2} day^{-1}	CO_2 mg C m^{-2} day^{-1}	CH_4 + CO_2 mg C m^{-2} day^{-1}	CH_4 + CO_2 mg CO_2 m^{-2} day^{-1}	CH_4 + CO_2 kg CO_2 m^{-2} $year^{-1}$
Post impound-ment peak	100	75	10,000	2,730	2,805	12,100	4.42
Long-term	20	15	1,500	410	424	1,920	0.70

	CO_2 and CH_4 emissions, totals for surface area of reservoir, 3.37 km^2					CO2 equivalents*	CO2 equivalents*
	CH_4 kg CH_4 day^{-1}	CH_4 kg C day^{-1}	CO_2 kg CO_2 day^{-1}	CO_2 kg C day^{-1}	CH_4 + CO_2 kg C day^{-1}	CH_4 + CO_2 kg CO_2 day^{-1}	CH_4 + CO_2 tonnes CO_2 $year^{-1}$
Post impound-ment peak	337	252	33,700	9,200	9,453	40,777	14,884
Long-term	67	50	5,055	1,380	1,430	6,470	2,362

* A factor of 21 was used for global warming potential on a mass basis, direct and indirect effects, of CH_4 as CO_2 for a 100-year period, the approximate life of a reservoir (St. Louis et al. 2000)

Post impoundment peak values are from Tremblay et al. (2005b). Long term values are from Tremblay et al. (2005b) for CO_2 and St. Louis et al. (2000) for CH_4. Long term values for CO_2 are the same for both studies, but that for methane is larger in the study of St. Louis et al. (2000).

APPENDIX 6 – Draft Aquatic Ecology Management Plan