BEFORE THE ENVIRONMENT COURT
AT CHRISTCHURCH

ENV-2010-CHC-115, 123, 124 AND 135

IN THE MATTER	**of Appeals pursuant to Section 120 of the Resource Management Act 1991**
BETWEEN	**WEST COAST ENT INC** **Appellant**
AND	**ROYAL FOREST AND BIRD PROTECTION SOCIETY OF NEW ZEALAND INC** **Appellant**
AND	**WHITE WATER NEW ZEALAND INC** **Appellant**
AND	**DIRECTOR GENERAL OF CONSERVATION** **Appellant**
AND	**WEST COAST REGIONAL COUNCIL AND BULLER DISTRICT COUNCIL** **Respondents**

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STATEMENT OF EVIDENCE OF
MARC SCHALLENBERG
FOR DIRECTOR GENERAL OF CONSERVATION
Dated: 15 May 2012

Department of Conservation, West Coast *Tai o Poutini* Conservancy
Private Bag 701, Sewell Street
HOKITIKA
Ph 03 756 9100
Fax 03 756 9188
Counsel Acting: A Cameron, D van Mierlo

AND	**MERIDIAN ENERGY LIMITED** **Applicant**
AND	**FRIDA INTA** **Section 274 Party**
AND	**WHANAU PIHAWAI WEST – RICHARD WAYNE BARBER AND IRI MAY BARBER MILNER** **Section 274 Party**
AND	**J MacTAGGART** **Section 274 Party**
AND	**ORION ENERGY NZ LTD, ALPINE ENERGY LTD, MAIN POWER NZ LTD AND ELECTRICITY ASHBURTON LTD** **Section 274 Party**
AND	**NZ RAFTING INC** **Section 274 Party**
AND	**ANN SHERIDAN** **Section 274 Party**
AND	**BULLER ELECTRICITY** **Section 274 Party**

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1. QUALIFICATIONS AND EXPERIENCE

1.1. My full name is Marc Schallenberg. I am a Limnology Research Fellow in the Zoology Department at the University of Otago, where I have been employed since 1994. Prior to that, I held a 1-year postdoctoral research fellow position at NIWA Christchurch. Prior to that, I obtained my PhD in Limnology from McGill University, Montreal, Canada (awarded 1993).

1.2. I have had 19 years professional experience in limnology[1]. My area of expertise is lake science and land-water interactions. I have authored or co-authored 42 peer-reviewed publications in international scientific journals, 4 book chapters, over 15 consultancy reports and I have given c. 30 national and international conference presentations. I have been the supervisor or co-supervisor of over 15 post-graduate research students.

1.3. I am or have been a member of the New Zealand Freshwater Sciences Society, the American Society of Limnology and Oceanography, the International Society of Limnology, and the Canadian Society of Limnology. I am an associate editor of the New Zealand Journal of Marine and Freshwater Research. I have refereed over 50 scientific manuscripts for at least 20 scientific journals. I have refereed research proposals for the National Science Foundation (USA) and I have been an expert reviewer for the Intergovernmental Panel on Climate Change (Working Group II, Fourth Assessment Report). I have been commissioned by a number of governmental, commercial,

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[1] Limnology is the study of fresh - and brackish waters.

and community organisations to provide scientific advice on matters related to the management of freshwater resources.

1.4. I have expertise in the limnology of hydroelectric dams, having published research on hydro-electric reservoirs in Northern Quebec (Schallenberg 1993), and the hydro-electric reservoirs, Lake Coleridge (Canterbury; Schallenberg et al. 1999), Lake Mahinerangi (Otago; Burns & Schallenberg 1996; Downes et al. 2008) and Lake Dunstan (Otago; Schallenberg & Burns 1997). I have studied at least 70 different lakes in New Zealand and 20 lakes in Canada.

1.5. I have not visited the site of the proposed Mokihinui Reservoir as my brief concerns predictions of the ecological state of the proposed reservoir and does not focus on values of the gorge. As such, I did not consider it necessary to personally visit the site to complete this evidence; however, I am familiar with the Mokihinui River and the area between Westport and Karamea and to assist with the preparation of my evidence, I have viewed numerous photos and maps of the site of the proposed reservoir.

1.6. I have read the Environment Court's Code of Conduct for Expert Witnesses, and I agree to comply with it. I confirm that the issues addressed in this brief of evidence are within my area of expertise, except where explicitly stated otherwise.

1.7. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed. I have specified where my opinion is based on limited or partial information and identified any assumptions I have made in forming my opinions.

1.8. In developing my evidence I have read the following reports on the water quality, habitats, and ecological processes of the proposed reservoir:

- Floeder & Spigel (2007)
- Spigel (2008a) - Statement of evidence of Robert Hays Spigel on behalf of Meridian Energy Limited
- Spigel (2008b) - Supplementary evidence of Robert Spigel on behalf of Meridian energy Ltd.
- Griffiths (2011) - Statement of evidence of Kerry Griffiths for Meridian Energy Limited including appendices by Dr Spigel, Sept. 26, 2011
- James (2011a) - Statement of evidence of Mark Richard James for Meridian Energy limited (Overview), Sept. 28, 2011
- James (2011b) - Statement of evidence of Mark Richard James for Meridian Energy limited, Sept. 26, 2011. Uncertainty of predictions and evidence from other lakes and reservoirs

2. SCOPE OF EVIDENCE

2.1. My evidence will deal with the following:

- The new habitats of the proposed reservoir,
- The limnological condition of the proposed reservoir,
- Key risks to the freshwater ecology of the Mokihinui catchment as a result of building the proposed reservoir. The key risks I will discuss include:

  a) Risk of internal nutrient loading and nuisance algal blooms in the reservoir

  b) Risk of the bottom waters of the reservoir becoming anoxic

  c) Risk of discharge of anoxic water and associated harmful substances to the lower Mokihinui River

  d) Risk of the reservoir becoming a net greenhouse gas emitter

- Uncertainty of predictions and evidence from other lakes and reservoirs
- Individual and cumulative magnitude of effects of the proposed reservoir

3. KEY FACTS AND OPINIONS

3.1. The proposed Mokihinui reservoir would replace 3.4 km^2 of virtually unmodified, wild, river and forest habitat with a reservoir which would have around 6% of its area colonisable by native aquatic plants. The remainder of the reservoir bed would not be suitable for macrophytes or plant life. Much of the water column and reservoir bed would be affected by anoxia during the period of thermal stratification, thereby making these areas uninhabitable for fish and invertebrates and also potentially negatively affecting the water quality and habitats of the epilimnion and the lower Mokihinui River.

3.2. Many of the potential negative ecological effects of the reservoir have not been highlighted because of the applicant's unsubstantiated assumptions that 30% of all flooded organic matter would be decomposable in the reservoir and 95% of this material would decompose in the first 5 years post-flooding. Therefore, the applicant has argued that the potential effects of nutrient enrichment and phytoplankton growth in the reservoir, anoxia of the bottom waters, and greenhouse gas production would be minor or less than minor. I disagree with this assessment and believe the negative impacts related to the decomposition of flooded organic matter such as substantial greenhouse gas production, internal nutrient loading, anoxia, and algal blooms could be substantial and could last for decades.

3.3. The applicant's model predicting key processes in the proposed reservoir has not been calibrated or validated and therefore large uncertainties exist in the model outputs.

3.4. The applicant's calculations of important effects such as oxygen consumption rates and greenhouse gas production have been oversimplified and have not accounted for typical ranges of variation around the simplistic parameter averages used in the calculations.

3.5. Unfortunately too few data exist from similar New Zealand reservoirs to shed light on the likely condition and effects of the proposed Mokihinui reservoir. Therefore, in a number of key arguments, the applicant was forced to use inappropriate data to predict outcomes of the reservoir. In contrast, data from some New Zealand reservoirs which showed negative effects did not appear in the applicant's analysis.

3.6. Many ecological outcomes predicted by the applicant were considered to cause minor or less than minor effects, even though large uncertainties existed in the predictions. My analysis suggests to me that a number of key effects of the proposed reservoir are likely to be adverse to the aquatic ecology. In my opinion, the applicant has not taken a precautionary approach in relation to these effects. Two important mitigation measures that could solve many of the potential problems I foresee would be the removal of vegetation and soil organic matter on the reservoir bed prior to flooding as has been done at other reservoirs (e.g. Lake Dunstan) and the implementation of a height-adjustable generation outflow or multiple generation takes at different heights on the dam.

4. NEW HABITATS OF THE PROPOSED RESERVOIR

4.1. The Mokihinui River above the gorge and proposed dam site is currently a largely unmodified free-flowing river, situated within a terrestrial ecosystem with few human-induced changes or impacts. Virtually the entire terrestrial catchment of the Mokihinui River upstream of the proposed dam is conservation estate and is currently protected from development by the conservation act. The proposed dam will create a 14 km long reservoir, replacing terrestrial and aquatic habitats (e.g. runs, riffles, pools, waterfalls, seepages, terrestrial and riparian vegetation) with reservoir habitats.

4.2. The types of new habitats which will be created by the proposed reservoir partly depends on the water residence times or flushing times of the epilimnion or mixed layer (in the case of plankton) and of the hypolimnion or bottom waters (in the case of benthic invertebrates). Water residence times of the mixed layer controls the length of time organisms can remain and reproduce in the mixed layer before being flushed out of the reservoir. Water residence time of the hypolimnion controls the oxygen availability and dynamics, which affects the rate of oxygen depletion and probability of anoxia in the bottom waters. Numerical modelling of the proposed reservoir indicates that it will be thermally stratified during summer (for 7 months; Floeder & Spigel 2007), resulting in a warm epilimnion and a cool hypolimnion, which will be virtually isolated from mixing and gas exchange with the epilimnion and the atmosphere during the warmest 7 months of the year. This creates an illuminated, warmer, upper aquatic environment and a dark, cool, deep aquatic environment during the summer months.

4.3. In limnology, the calculated water residence time of a reservoir is the theoretical time it takes for all the water entering a reservoir (inflow corrected for evaporation) to replace all the water within the reservoir (volume), assuming the water in the reservoir is entirely mixed. The theoretical water residence time is inversely related to the flushing time of a water body and is a key limnological parameter determining important aspects of reservoir condition. It not only determines important habitat characteristics, as explained above, but it also determines key ecological characteristics such as the proportion of inflowing nutrients and sediments trapped and sequestered by the reservoir (Vollenweider 1968), the period of potential growth of algae and zooplankton in the open waters of the reservoir (Pridmore & McBride 1984), and the potential for within-lake ecological processes to affect the physico-chemistry of the lake water (Rasmussen et al. 1989). The longer the residence time, the higher the sediment and nutrient retention efficiency, the greater the potential for growth of phytoplankton and zooplankton populations and the greater the potential for changes to water oxygen content, nutrient availability and water clarity.

4.4. According to Spigel (2008a), the reservoir will have a typical (median) water residence time of 25 days. This theoretical water residence time is integrated over the entire reservoir and over time, so, while the median water residence time will be 25 days, by definition, half of the time it will be longer than that. During summer the theoretical whole-reservoir residence time would be longer than the median time of 25 days, due to higher evaporation rates and reduced runoff. The Mokihinui River has frequent large floods, which would temporarily substantially reduce the water residence time.

4.5. During periods of thermal stratification in lakes and reservoirs, mixing between the warm epilimnion and cool hypolimnion would be restricted, effectively dividing the water body into two distinct water compartments (Floeder & Spigel 2007). The theoretical water residence time presented by the applicant is based on the whole volume of the reservoir. Thus, the theoretical water residence time based on the whole reservoir volume is no longer applicable and the two compartments will have distinct water residence times, depending on the inflow and outflow discharges to the two compartments. As I said above, key habitat factors are the water residence times of the epilimnion (for potential algal blooms) and the hypolimnion (for anoxia, nutrient internal loading and the concentrations of reduced iron, manganese, hydrogen sulphide, and other chemically reduced substances). The DYRESM modelling of Floeder & Spigel (2007) suggests that the point of outflow on the dam (13 m depth) determines the depth of the thermocline, separating the epilimnion and hypolimnion. Therefore, the outflow could often consist of a variable mixture of waters from both the layers. The temperatures (i.e. densities) of the inflowing water from the upper Mokihinui River determines whether the inflow would discharge to the epilimnion, hypolimnion or would progress toward the dam outflow along the thermocline, resulting in little mixing with, or flushing of, either the epilimnion or hypolimnion. These key aspects of the proposed reservoir's ecology will be discussed below.

4.6. Floeder and Spigel (2007; section 5.4.5) suggested that the hypolimnion of the proposed reservoir will experience high rates of oxygen depletion leading to anoxia in the bottom waters for the first 5 years of operation of the reservoir. This estimate appears to have been later revised to 10 years (Spigel 2008a; section 7.9). While I agree that anoxia would occur in the hypolimnion of the proposed system, I question the 10 year maximum duration of summer periods of anoxia because the calculation of oxygen depletion rate in the bottom waters is dependent on many, weakly substantiated assumptions about the oxygen uptake rate of the reservoir's water and the decomposition rate of submerged vegetation and organic matter in the flooded soils (see sections 5.4 to 5.6, below).

4.7. Anoxia in the bottom waters not only makes the hypolimnion uninhabitable to fish and invertebrates (only some protozoans and bacteria can live under anoxic conditions), but creates other unfavourable conditions such as the release of phosphate into the water column and the production of toxic hydrogen sulphide gas in the hypolimnion. These substances could also affect the epilimnion and Lower Mokihinui River habitats if mixed or diffused upward in the water column or if discharged downstream at the dam. While these conditions will be prevalent only during the summer stratified period, I show below (in sections 5.4 to 5.6, 7.1, 7.12 and 7.14) that Meridian Energy's 10 year estimate of the longevity of summer anoxia is based on very little evidence and is probably an optimistic prediction. Based on my experience and reading of the literature, I predict that the longevity of summer anoxia in the bottom waters of the proposed reservoir would negatively affect the habitats associated with the hypolimnion for decades, and possibly indefinitely.

4.8. A key habitat value of the proposed reservoir would be the area of reservoir bed that would be habitat for native macrophyte (aquatic submerged plant) flora. Floeder & Spigel (2007) estimated that 12.5% of the reservoir surface area would be colonisable by macrophytes, representing the creation of a new productive habitat. This estimate was based on the bathymetry of the proposed reservoir, the predicted light penetration into the proposed reservoir, and the operating range of reservoir. I agree with Dr James (2011b; section 6.74) that this estimate is an upper-estimate because important limiting variables for macrophytes such as bottom slope, substrate composition/grain size, sedimentation patterns, and wave action were not taken into account. Given the very steep slopes and rocky nature of the substrates to be flooded, I estimate that a large proportion of the sufficiently illuminated reservoir bed would be made up of rocks and gravels unsuitable for macrophyte colonisation. Therefore, probably only around 6% (0.2 km^2 or one 17^{th}) of the area of the bed of the proposed reservoir would be colonisable by macrophytes, and consequently, only this small area would exhibit native flora habitat values.

4.9. In summary, the proposed reservoir will replace 3.4 km^2 of virtually unmodified, wild, river and forest habitat with a reservoir which would have around 6% of its area colonisable by native aquatic plants. The remainder of the reservoir bed would not be suitable for macrophytes or plant life. The water column of the reservoir would typically be flushed every 25 days when the reservoir is isothermal (unstratified), but this will vary substantially with variation in the inflow rate. For example, the entire reservoir would flush in 13.6 hours at a flood flow of 2000 cumecs and it would flush in 71 days at a low flow of 16 cumecs. Unfortunately, the water residence times of the epilimnion and hypolimnion during the stratified period were not calculated. Much of the water column and reservoir bed would be affected by anoxia during the period of thermal stratification, thereby making these areas uninhabitable for fish and invertebrates and also potentially affecting the water quality and habitats of the epilimnion and the lower Mokihinui River.

5. THE LIMNOLOGICAL CONDITION OF THE PROPOSED RESERVOIR

5.1. A key argument of Floeder & Spigel (2007) and James (2011b) is that the proposed reservoir will initially undergo:

- a period of anoxia in the bottom waters (the hypolimnion),
- a period of elevated internal nutrient loading, and
- a period of elevated greenhouse gas production.

5.2. These phenomena are typical of reservoirs and eventually the limnological conditions of reservoirs may subsequently “settle down” to those typical of natural lakes. I agree with Meridian Energy’s witnesses that these negative effects would occur in the proposed reservoir, mainly because there is no proposal by the applicant to remove large amounts of vegetation and soil organic matter prior to flooding the reservoir bed. However, I disagree with

Meridian Energy's witnesses who argued that this initial state of high biological activity will last only 5 to 10 years. This unsubstantiated assumption has led to the initial unfavourable ecological conditions of the reservoir to be either downplayed and in some cases even ignored in Meridian Energy's assessment of the state of the proposed reservoir.

5.3. The duration of the unfavourable conditions of anoxia, internal nutrient loading, and elevated greenhouse gas emissions is the key point of difference between my understanding of likely state and condition of the proposed reservoir and that of the applicant's witnesses.

5.4. The applicant's estimation of the duration of the period of unfavourable conditions hinges entirely on the assumption that 95% of the decomposable flooded vegetation and soil organic matter will decompose within the first five years of flooding (Floeder & Spigel 2007; section 5.4.5). An examination of the basis of this assumption shows that it is no more than a guess. For example, Floeder & Spigel (2007; section 5.4.5) relied on the following assessments of the relevant time scales from the scientific literature:

(a) "a few years" (based on a large number of reservoirs)

(b) "more than 10 years" (a tropical reservoir)

(c) "7 years up to 20 years" (a tropical reservoir)

(d) "at least 4 years" (a Tasmanian reservoir)

(e) “at least 4 years” (Opuha Dam, Canterbury)

5.5. As studies b., d., and e. apparently did not determine the end point of decomposition of flooded organic matter, these estimates are not helpful in determining a likely time frame for the proposed reservoir. Only the information from studies a. and c. suggest that the decomposition rates had actually been measured until the end of the period of decomposition of flooded organic matter. However, even these estimates are vague and should not be relied upon to estimate the decomposition period for the proposed temperate reservoir, which will flood mature New Zealand forest and soils, for which no decomposition data exist. Therefore, based on the above information from Floeder & Spigel (2007), the time period during which the proposed reservoir will be influenced by decomposing flooded organic matter is uncertain at best.

5.6. I believe that the suggested time-to-decomposition of 5-10 years is an underestimate because, as indicated above, some of the reservoir information used by Floeder and Spigel (2007) is for tropical reservoirs which generally have much higher rates of decomposition than temperate reservoirs (see St Louis et al. 2000) and Floeder and Spigel (2007; Tables A5-1 and A5-2) assumed that only 30% of the organic matter to be flooded will be subject to decomposition. This proportion is unsubstantiated for New Zealand reservoirs, where it is known that flooded tree stumps and branches persist and presumably continue to decompose for at least 86 years (James et al. 2002; Lake Monowai flooded vegetation).

5.7. Similarly, I do not believe enough evidence exists to support the estimated short durations of either anoxia, trophic upsurge[2] (Ostrofsky & Duthie 1978), or peak greenhouse gas production. To some degree, these are all linked to the decomposition of flooded organic matter. In contrast, I believe that, without the removal of vegetation and organic soils from the reservoir bed prior to filling, flooded organic matter is likely to continue to decompose and to negatively affect the condition of the proposed reservoir for decades. Thus, the unfavourable conditions of the proposed reservoir during the initial period of decomposition should not be ignored (as in the case of Meridan Energy's prediction of trophic state of the proposed reservoir) or minimised, but should be considered to be an important and potentially decades-long phase of environmental impact of the proposed reservoir.

5.8. Floeder & Spigel (2007) calculated that the proposed reservoir would be oligotrophic[3], based on the nitrogen and phosphorus concentrations in the Mokihinui River (James 2011a,b). I disagree with this finding because the approach used is flawed. It ignores internal nutrient loading (nutrient loading from decomposing material within the reservoir itself) which is an important consideration when assessing the future trophic state of a reservoir.

5.9. Newly formed reservoirs often exhibit a post-impoundment pulse of biological activity in the form of phytoplankton[4] productivity and biomass accrual due to plant nutrients released by the bacterial decomposition of organic matter in and on the flooded soils. This is sometimes referred to as a

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[2] A period of high biological activity following the filling of a new reservoir

[3] A limnological term indicating a low trophic state (i.e. low levels of nutrient enrichment and phytoplankton biomass)

[4] Microscopic photosynthetic organism, including algae and cyanobacteria, which live suspended in the water

period of trophic upsurge and Floeder & Spigel (2007) and James (2011a) acknowledge that a period of trophic upsurge would occur in the proposed reservoir. However, they discount or ignore (in the case of trophic state calculations) the importance of this period because it is assumed to be temporary. Similarly, they did not consider the internal load of phosphorus contributed by sediments overlain by anoxic bottom waters into their calculation of trophic state because they also predicted periods of anoxia to be a temporary feature of the reservoir, lasting only up to 10 years.

5.10. The condition of anoxia in the bottom waters and sediments results in the dissolution of metal oxy-hydroxides in the sediment, which are effective binders of phosphate. Consequently, anoxia in the bottom waters usually results in rapid and substantial releases of phosphate into the water column. For example, in 1995, I recorded up to 500 μg/L of phosphate in the anoxic bottom waters of Lake Hayes, while the epilimnion had less than 10 μg/L of total phosphorus (see Appendix 1). In Lake Hayes, this internal load of phosphate fuels autumn phytoplankton blooms when the lake de-stratifies and also provides a substantial boost to winter phosphate concentrations, which fuel spring phytoplankton blooms in the lake (Mitchell & Burns 1981). Similarly, phosphate release into the hypolimnion of the proposed reservoir could be diffused and/or mixed into the epilimnion by turbulence and mixing due either to wind, currents (exacerbated by flood flows) or temperature variations, where it could fuel phytoplankton growth. When the phytoplankton biomass dies, a proportion of it sediments to the hypolimnion where it rapidly decomposes, consuming oxygen. This increases the oxygen demand in the hypolimnion, which can further enhance the release of phosphate from the lake sediments into the water column. In this way, internal nutrient loading can initiate positive feedbacks[5] in lakes and reservoirs which lead to a progressively increasing trophic state and more deoxygenation. Such positive feedbacks can be very difficult to manage and mitigate, once they become established. I will discuss the potential for internal nutrient loading to contribute to phytoplankton blooms in more detail in sections 6.2 and 6.4, but I point out here that ignoring these sources of nutrients likely amounts to a substantial underestimate of the potential trophic state of the proposed reservoir.

6. RISK OF NUISANCE ALGAL BLOOMS IN THE PROPOSED RESERVOIR AND RISK OF THE BOTTOM WATERS OF THE PROPOSED RESERVOIR BECOMING ANOXIC

6.1. As I have stated above, I believe that the risk of nuisance phytoplankton blooms has been understated by the applicant's witnesses for two reasons.

6.2. Firstly, the water residence time of the summer epilimnion has not been separately estimated. The proposed reservoir will be thermally stratified in summer, the time of year when phytoplankton (planktonic algae and cyanobacreria) is most likely to bloom. To understand the possible influence of the hydraulic residence time on potential phytoplankton blooms, the residence time or flushing rate of the summer mixed layer must be considered. Secondly,

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[5] In complex systems, a positive feedback process or cycle reinforces itself by modifying conditions to favour the enhancement of the same process or cycle.

the phosphorus content of the proposed reservoir has been underestimated by not accounting for internal nutrient loading due to the anoxic hypolimnion and the decomposition of organic matter from flooded soils and vegetation. For example, Floeder & Spigel (2007) estimated that 30% of the stock of flooded organic matter would be readily decomposable (Table A-5.1). While likely to be an underestimate of the decomposable fraction, 30% still represents 202 T dry mass of organic matter per hectare of flooded land, which (assuming a conservative C:P ratio of 1000:1) represents 202 kg P per ha, which could be mineralised.

6.3. Sunlight, nutrients and temperature are the main drivers of phytoplankton growth in lakes and reservoirs. At times when these are not limiting phytoplankton growth, some species of phytoplankton can exhibit doubling times in the range of 0.12 to 7.5 days (Westlake 1980), reflecting a range of doubling times from 8.5 doublings per day to one doubling per 7.5 days. Thus, assuming one doubling per day (approximate logarithmic midpoint of this range) for phytoplankton in the reservoir in summer, then each phytoplankton cell would give rise to 128 cells (2^7) within one week. In other words, a starting concentration of 1000 cells/ml could grow to 128,000 cells/ml in one week.

6.4. In lakes and reservoirs of short water residence time, the physical flushing of cells can reduce the population growth rate through dilution, but this is dependent on the flushing rate, or water residence time of the water body. Floeder & Spigel (2007) have estimated a median whole-reservoir water residence time of 25 days (by definition, the water residence time would be longer than this value 50% of the time) and a mean water residence time of 12.6 days (75%

of the time the residence time would be longer than this value; Floeder & Spigel 2007, Fig. A.4-2). It has been shown that wash-out rates of < 1 week can effectively limit phytoplankton population growth rates (Uhlmann 1968). Given that:

(a) water residence times have not specifically been calculated for the summer mixed layer,

(b) the inflowing rivers in summer with a flow below 500 cumecs are predicted to flow along the thermocline during summer (James 2011a; section 6.14), substantially avoiding the mixed layer, and

(c) lower inflow volumes and longer residence times will coincide with summer fine weather periods, which also favour algal growth,

I think it is likely that water residence times for the summer mixed layer could at times be longer than the estimates presented for the whole reservoir. This indicates that phytoplankton would have a greater potential to bloom than has been stated because the mixed layer water residence time could be substantially lengthened, reducing the washout of phytoplankton cells.

6.5. Given sufficient sunlight, a favourable temperature for growth, and a residence time substantially longer than the population doubling time, then the availability of nutrients becomes a key factor for phytoplankton growth. The calculation of mean nutrient concentrations in the proposed reservoir does not account for within-reservoir sources of nutrients such as the decomposition and mineralisation of organic matter in flooded vegetation and soils or the large pool of phosphate bound in flooded soils and sediments that would be released into the water column under anoxic conditions. In my view, the nutrient availability for phytoplankton growth and proliferation has been substantially underestimated. Thus, the applicant's analysis of N:P ratios have not accounted for internal nutrient loading and are likely to be inaccurate, at least until periods of anoxia cease to exist in the proposed reservoir (if they ever do).

6.6. The dominance of cyanobacteria in lakes and reservoirs is undesirable because cyanobacteria cells can form large colonies visible to the naked eye, float to the surface and forms scums which can be blown onto shores/beaches, and some species of planktonic cyanobacteria can produce toxins (e.g. *Anabaena, Microcystis, Cylindrospermopsis, Nodularia*). When the availability of nitrogen (N) relative to the availability of phosphorus (P) is less than the balanced requirement for phytoplankton (known as the Redfield ratio), cyanobacteria may become dominant because they have the ability to convert inert nitrogen gas into a form available for plant growth. Floeder & Spigel (2007) argued that the relatively balanced N:P ratio of the Mokihinui River water would result in a similarly balanced N:P ratio in the proposed reservoir. Accordingly, so the argument goes, there would be little likelihood of cyanobacteria becoming dominant in the proposed reservoir. However, the potentially large releases of phosphate from bottom sediments during times when the hypolimnion is anoxic were not taken into account. Thus, the predicted levels of phosphate in the water should be revised upward, which would decrease the N:P ratio, potentially favouring nitrogen-fixing cyanobacteria. In other words, the additional consideration of internal phosphate release strongly suggests that the nutrient availability in the proposed reservoir could favour cyanobacteria over algae. Therefore the risk of cyanobacteria becoming the dominant phytoplankters in the proposed reservoir, and the associated risks of cyanobacterial blooms, surface scums and toxin production have been underestimated because internal nutrient loading to the reservoir was ignored.

6.7. In summary, in my opinion, the risk of phytoplankton blooms, including cyanobacterial blooms, in the proposed reservoir have not been adequately assessed because internal nutrient loading has not been accounted for and this has the potential to increase phytoplankton productivity and biomass in the proposed reservoir as well as resulting in nutrient ratios more favourable to nuisance cyanobacteria.

6.8. The potential for a trophic upsurge in the proposed reservoir was discounted as a minor or less than minor effect (Spigel 2008a; section 6.35) based on published observations on Lake Dunstan (Schallenberg & Burns 1997). Lake Dunstan, is not an appropriate reservoir for comparison for a number of reasons:

(a) Lake Dunstan has large upstream lakes which retain much of the organic matter transported from the reservoir’s catchment

(b) The vegetation and soils of the Lake Dunstan area are characteristic of an arid climate. Grasses and low shrubs dominate the vegetation and the soils have a low organic matter content compared with the area to be flooded in the Mokihinui catchment.

(c) Existing trees and shrubs above the 7m isobath of the proposed reservoir were removed before filling, reducing the amount of organic matter available for decomposition[6].

(d) The study of Lake Dunstan that was cited only examined the reservoir for 1 year and did not identify the magnitude or duration of the trophic upsurge in that reservoir.

6.9. The above issues make it very questionable to try to predict the likely magnitude and duration of the trophic upsurge for the proposed reservoir based on information from Lake Dunstan.

7. RISK OF THE BOTTOM WATERS OF THE RESERVOIR VECOMING ANOXIC

7.1. Spigel (2008a,b) and James (2011a,b) state that the hypolimnion of the proposed reservoir will become anoxic for up to the first 10 stratified periods after the filling of the reservoir, which I have argued in sections 5.4 and 5.5 is at best a guess and is probably an underestimate. The degree of anoxia will depend on the rate of oxygen depletion from the decomposition of organic matter in the hypolimnion and the rate of oxygen replenishment from water entering the hypolimnion during the stratified period. During

[6] Clutha Dam (Clyde Dam) Empowering Act 1982, Part1, condition 13.

inflows of less than 500 cumecs, Drs James and Spigel stated that the inflowing water during the stratified period would most likely flow along the thermocline or enter the epilimnion, indicating that there will be no replenishment of oxygen in the hypolimnion from river water. Therefore, options to mitigate anoxia, phosphate release and hydrogen sulphide formation would be to either aerate the hypolimnion and/or to remove as much vegetation and soil organic matter as possible from the area to be flooded. The removal of vegetation and soil organic matter is sometimes carried out prior to filling dams, as was done prior to the filling of Lake Dunstan (see footnote 6).

7.2. The hypolimnia of lakes and reservoirs are virtually separated from the mixed layer by water density gradients and, consequently, there is little if any mixing between these distinct layers of water. This effectively prevents atmospheric re-oxygenation of the hypolimnion during the stratified period. During this time, a hypolimnetic oxygen budget can be used to determine the expected depletion rate of oxygen in the hypolimnion. Unfortunately, a hypolimnetic oxygen budget was not presented by Meridian Energy's witnesses.

7.3. As discussed in section 6.4 and 7.1, the witnesses for the applicant stated that during the stratified period there would be little oxygen input to the hypolimnion from the inflowing waters. So an oxygen budget for the hypolimnion requires estimates of the oxygen present in the hypolimnion at the onset of stratification as well as estimates of oxygen loss rates due to the decomposition of:

(a) settling phytoplankton,

(b) dissolved organic matter in the hypolimnetic water at the onset of stratification, and

(c) decomposable organic matter in flooded vegetation and soils

7.4. Schallenberg & Burns (1999) demonstrated the dependence of areal hypolimnetic oxygen depletion rates on epilimnetic chlorophyll a concentrations (i.e. phytoplankton biomass) in New Zealand lakes (see Fig. 1). This strong relationship emphasises that it is important to accurately predict the phytoplankton biomass in order to accurately predict the magnitude and duration of trophic upsurge in the proposed reservoir. As I argued in sections 6.1 to 6.5, I believe that Meridian Energy's witnesses have underestimated the levels phytoplankton biomass which will likely be achieved in the proposed reservoir, at least during the period of trophic upsurge.

7.5. In Griffiths (2011; Appendix 5, section 6), Dr Spigel predicted the hypolimnetic oxygen conditions for the proposed reservoir based on the observed oxygen dynamics in the hypolimnion of Lake Brunner. He predicted that the long term depletion (including settling phytoplankton and dissolved organic matter, but not including flooded vegetation and soil organic matter) would result in a late summer deep water oxygen concentration of around 40-50% of saturation (somewhat lower than Lake Brunner due to differences in the morphologies of the lake compared to the proposed reservoir).

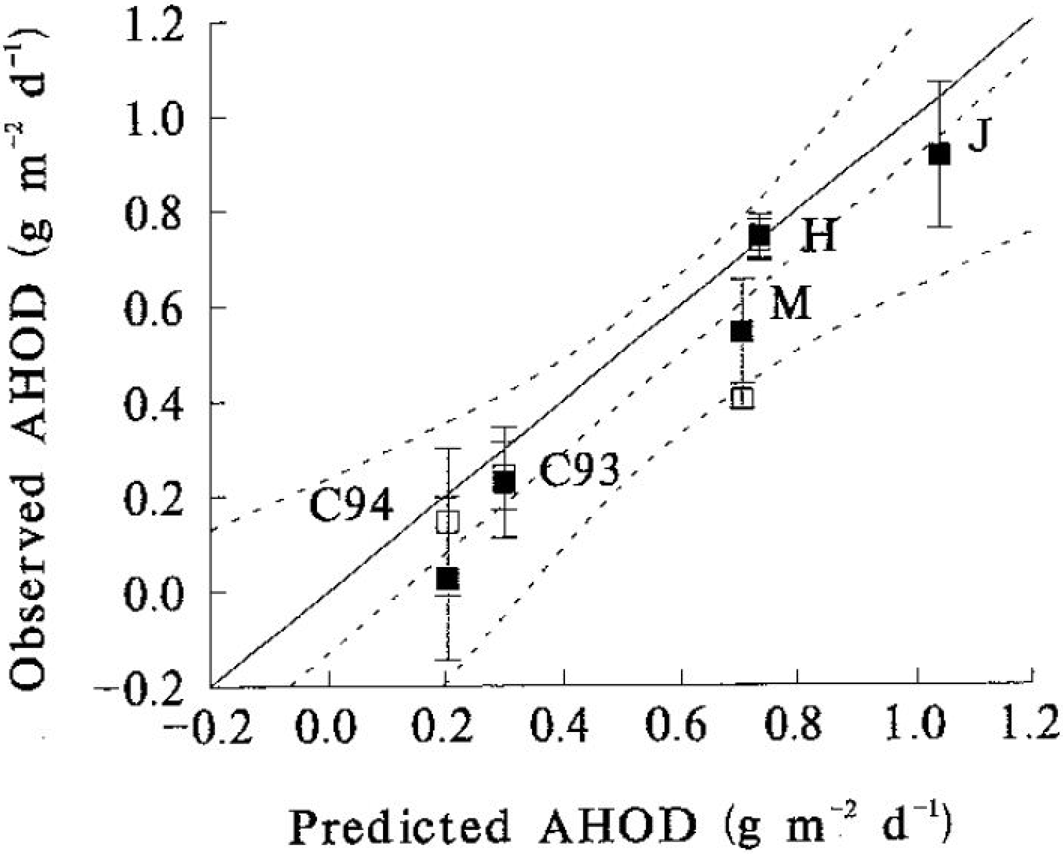

Figure. 1: Correlation of measured (observed) summer areal hypolimnetic oxygen depletion rate (AHOD) and the AHOD rate predicted for each lake based on a model from Vollenweider and Janus (1982). The model used epilimnetic chlorophyll a and the ratio of mean depth to euphotic depth to predict AHOD. The dark squares have been corrected for oxygen diffusion across the thermocline. J – Lake Johnson, H – Lake Hayes, M – Moke Lake, C93 – Lake Coleridge in 1993, C94 – Lake Coleridge in 1994.

7.6. If Dr. Spigel's approach is correct, then the breakdown of phytoplankton produced in the reservoir and dissolved organic matter input from the catchment will consume around 50% of the oxygen available in the hypolimnion at the onset of stratification, leaving around 50% of the oxygen in the hypolimnion to be respired in the decomposition of flooded vegetation and soils over the summer stratified period. Thus, a crude oxygen budget and estimate of the likelihood of the hypolimnion becoming anoxic can be obtained by comparing the oxygen available for decomposition of flooded organic matter in the hypolimnion with the oxygen demand from standing stock of decomposable organic carbon available.

7.7. Using information from Floeder & Spigel (2007), I estimated that the hypolimnion of the proposed reservoir would amount to one third of the volume of the reservoir and would occupy one half of its area (30 million m3 and 170 ha, respectively). Using Floeder & Spigel's value of 10 g/m^3 of free oxygen available in the water at the onset of stratification, 150T of dissolved oxygen would be available for the decomposition of flooded vegetation and soil organic matter.

7.8. Floeder & Spigel (2007; Tables A.5-1, A.5-2) assumed 70% of the flooded vegetation and soil organic matter would be sequestered and that only 30% of the estimated 703 T dry mass per ha would be decomposed. They also assumed that 95% of this decomposition would occur in the first 5 years after flooding, which I have argued in sections 5.4 to 5.6 has not been substantiated by any robust data and appears to be an underestimate. In contrast to these assumptions, a more realistic approach would be to consider that all the organic matter except branches and tree trunks would be decomposable in an exponential fashion over time. This represents 485 T of dry mass per ha and 69% of the flooded vegetation and soil organic matter.

7.9. DYRESM modelling estimated that the annual stratified period would last for up to 7 months (Floeder & Spigel 2007). Assuming that the hypolimnion covers half the reservoir (170 ha) and that carbon represents 50% of the dry mass of organic matter, this would constitute a standing stock of 41,000 T of organic carbon from flooded vegetation and soils which would be available for decomposition in the hypolimnion. This compares to 17,100 T C estimated from the dry mass value used by Floeder & Spigel (2007).

7.10. In Fig. 2, I show the decomposition rate of the organic matter stocks as estimated by Floeder & Spigel (2007) where 30% of the total organic matter standing stock is decomposable and 95% of this is decomposed within 5 years of flooding the catchment (complete decomposition by c. 10 years post-flooding) along with three more conservative decomposition scenarios where 69% of the total organic matter standing stock is decomposable and 95% of it is decomposed alternatively within 10 years, 30 years and 60 years.

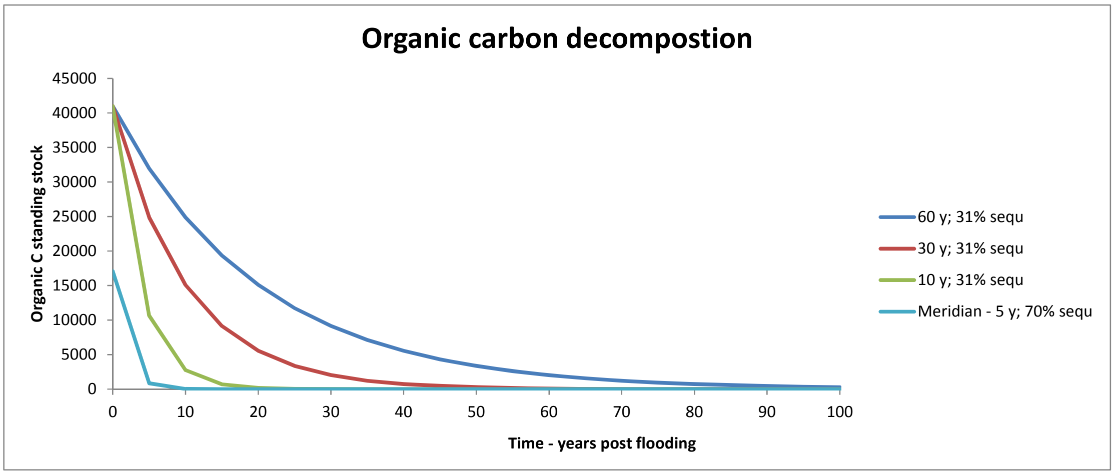

Figure 2: Decomposition scenarios for flooded organic matter standing stocks. The y-axis represents the flooded organic carbon standing stocks assumed to be available for decomposition.

7.11. By calculating annual organic carbon decomposition rates for these scenarios, annual rates of oxygen demand in the hypolimnion can be calculated (Fig. 3) and then compared with the available pool of hypolimnetic oxygen (50% of oxygen present at the onset of stratification). These calculations can be used to estimate the number of years post-flooding in which periods of hypolimnetic anoxia can be expected (Fig. 4).

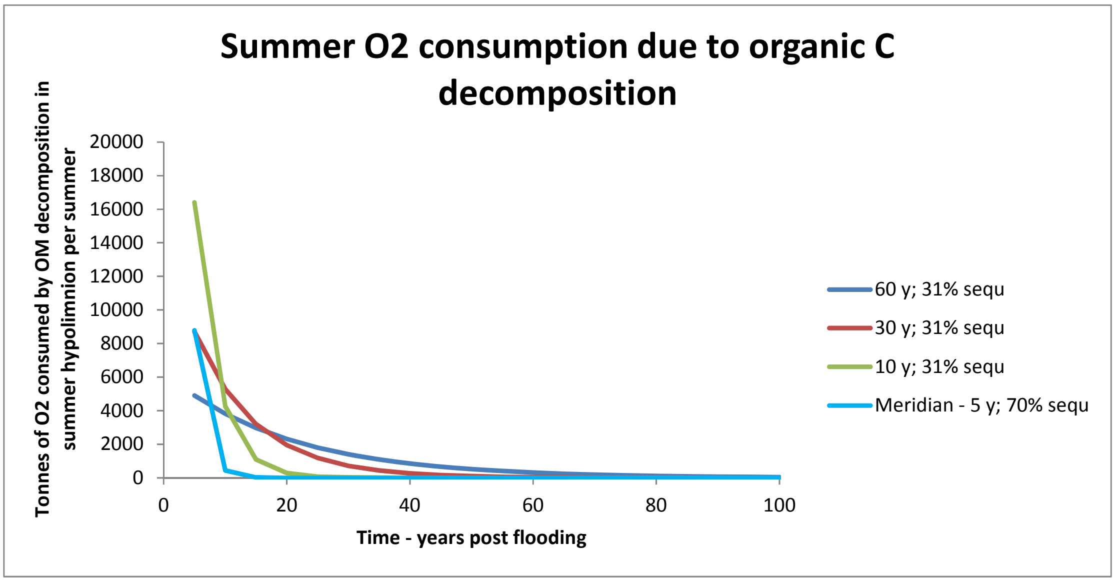

Figure 3: Summer hypolimnetic oxygen consumption due to the decomposition of flooded organic matter.

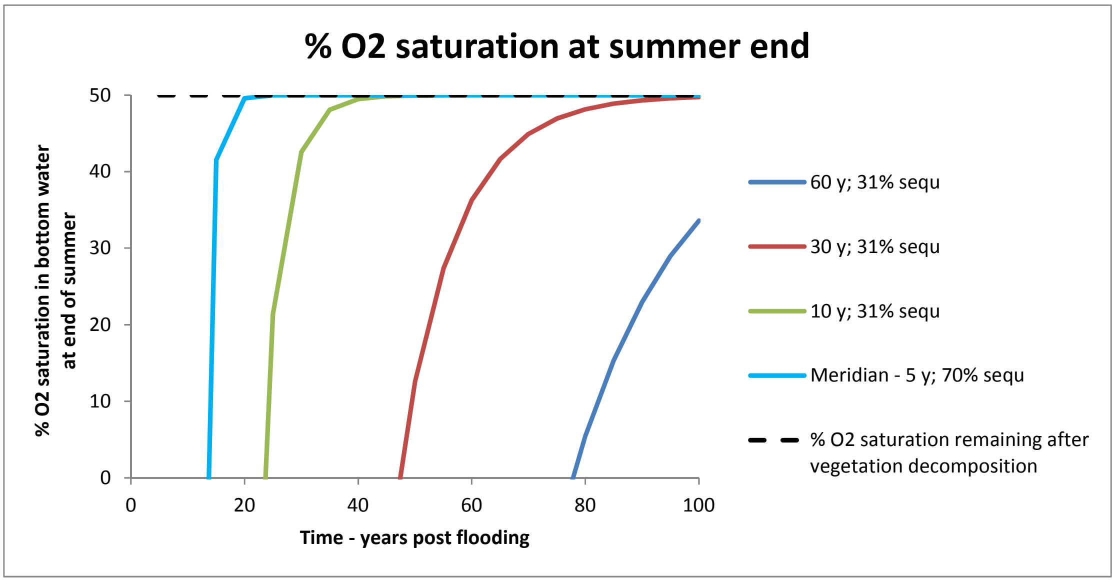

Figure 4: Percent O2 saturation in the hypolimnion at the end of the stratified period under four decomposition and two sequestration scenarios.

7.12. Figure 4 shows the estimated hypolimnetic oxygen status under the decomposition scenario assumed by Meridian Energy, which suggest that hypolimnetic anoxia (defined here as < 10% oxygen saturation) should occur for 13 years. This contrasts with other scenarios assuming larger pools of decomposable organic matter and slower decomposition rates, which show that anoxia could persist for 24, 43, and 83 years.

7.13. Above, I argue that Meridian Energy's scenario which suggests that the period during which hypolimnetic anoxia would be likely to occur is short-lived compared to other realistic scenarios. Unfortunately, given the serious paucity of relevant data which is available to inform this type of modelling, it is difficult to know which of these scenarios is the most realistic.

7.14. The Opuha Reservoir (Canterbury) is an example of a reservoir which was predicted to remain mixed and to not undergo periods of anoxia. Its inflows are of good water quality and, consequently, the reservoir was predicted to also exhibit good water quality. However within one year of filling, the reservoir stratified, exhibited algal blooms and its hypolimnion became anoxic (see sections 10.7 and 10.8 for a more detailed discussion of the Opuha Reservoir). Equipment to aerate the hypolimnion was installed and Environment Canterbury required the consent holders to install temperature and oxygen sensors at 5m and 30m depth in the reservoir, and to commence aeration whenever the hypolimnetic dissolved oxygen saturation dropped below 40%. This has occurred every year but one since 1999 and the rate of oxygen depletion has been similarly rapid every year, with no significant reduction over 10 years (Adrian Meredith, Environment Canterbury, pers. comm.).

7.15. As I stated above in sections 6.2, 6.5 and 7.15, it is likely that the predicted phytoplankton biomass for the proposed reservoir has been underestimated because internal nutrient loading was not accounted for. I also believe that hypolimnetic oxygen depletion rates have probably been underestimated and I consider it likely that hypolimnetic anoxia and associated internal nutrient loading will continue beyond the maximum 10 year time frame estimated by Meridian's witnesses. Thus, internal phosphorus loading will probably continue to promote a positive phytoplankton - anoxia feedback loop for a considerable period of time, possibly lasting for decades.

8. RISK OF DISCHARGE OF ANOXIC WATER AND ASSOCIATED HARMFUL SUBSTANCES TO THE LOWER MOKIHINUI RIVER

8.1. Anoxia in the bottom waters of lakes and reservoirs alters the chemistry and biochemistry of the waters in a number of ways. The removal of free oxygen shifts microbial decomposition processes to new metabolic pathways whereby first nitrate, then sulphate, and then carbon dioxide change their oxidation states, resulting in the build-up of ammonium (solute), hydrogen sulphide (gas) and methane (gas). In addition, under anoxic conditions, sediment-bound metals such as iron and manganese suddenly become chemically reduced, which results in the solublisation and release of reduced iron and manganese, along with associated elements such as phosphate, to the water column. Furthermore, the biochemical reduction of nitrate, sulphate and carbon dioxide removes protons from the bottom waters, raising the alkalinity and pH. Ammonium has a moderate toxicity to aquatic organisms at pH below 8, but when pH rises above 8, the ammonium converts to ammonia gas, which is highly toxic to aquatic life, especially salmonids (ANZECC 2000). These biochemical and chemical changes make anoxic bottom waters toxic to higher organisms including fish and invertebrates. Therefore, the discharge of anoxic water into the Lower Mokihinui River should not be allowed.

8.2. I agree with James (2011a,b) that there is a risk that anoxic waters could be discharged from the dam. The two key conditions promoting this would be either: i) a flood (e.g. > 500 cumecs) of the upper Mokihinui River or ii) strong westerly winds, with either of these occurring during the time of anoxia in the bottom waters. Fig. 5 illustrates how these two events could cause anoxic hypolimnetic water to be discharged from the dam outlet.

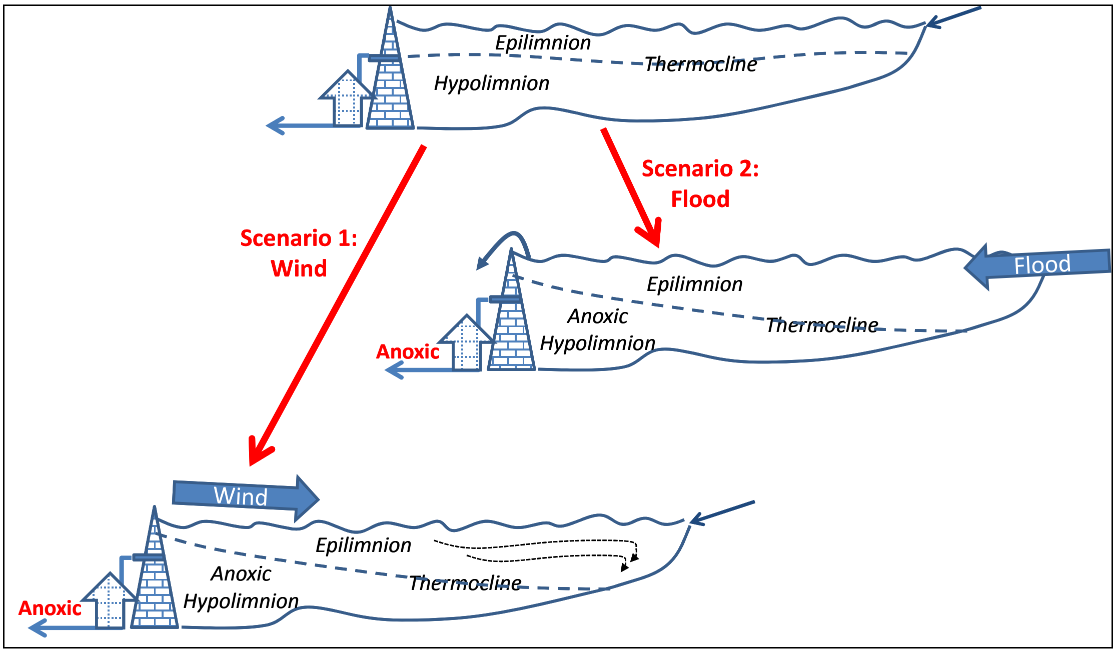

Figure 5: Scenarios leading to discharge of anoxic hypolimnetic water to the Lower Mokihinui River. Scenario 1 is a strong westerly wind pushing warmer surface water to the upstream end of the reservoir. Scenario 2 is a large flood pushing hypolimnetic water toward the dam.

8.3. In scenario 1, the discharge would be undiluted by surface water. James (2011a) stated that spillage of epilimnetic water over the dam in scenario 2 would dilute the anoxic discharge and thereby mitigate its effect. Nevertheless, this would result in a mixing zone of indeterminate length downstream of the dam within which aquatic organisms would be suddenly exposed to physico-chemical conditions to which they are not adapted. Such conditions would never have occurred in the undammed river.

8.4. Spigel (2008a,b) stated that the DYRESM model is not able to provide information on thermocline tilting. Based on other calculations done using wind data from Hokitika airport, Spigel (2008a,b) acknowledged that some tilting of the thermocline of the proposed reservoir could occur as a result of westerly winds (Scenario 1). I also caution that wind data from Hokitika cannot provide an accurate indication of the likelihood of thermocline tilting because of the much steeper topography at the site of the proposed dam and reservoir. It should be noted that high westerly winds are often associated with high rainfall events on the West Coast (Mr. Henderson’s evidence for Meridian Energy), and so it is likely that the two scenarios in Fig. 5 (westerly winds and floods) would co-occur at the proposed reservoir, exacerbating the risk of thermocline tilting and the discharge of anoxic water.

8.5. Another consideration that was overlooked in the modelling of discharges of anoxic water from the dam is that oxygen profiles for the proposed reservoir were not modelled. Therefore, no estimates are presented for the upper depth limit to which anoxia in the hypolimnion could spread. While one may assume that anoxia will be restricted to the hypolimnion, I have often measured anoxia within the thermoclines of lakes and I provide two examples from Lake Hayes and Lake Johnson to show this (Fig. 6). This decoupling of oxygen and temperature profiles can occur due to the decomposition of dead phytoplankton biomass at the thermocline or due to the slower rate of diffusion of oxygen downward in water compared to the rate of diffusion of heat. Thus, if the proposed reservoir also exhibited oxygen depletion in the thermocline, the discharge of anoxic water and associated noxious substances to biota in the lower Mokihinui River could potentially occur, even without a tilting of the thermocline. Therefore, to reduce the potential for hypolimnetic anoxia and the discharge of anoxic water to the lower Mokihinui River, the removal of the vegetation and organic soils from the bed of the proposed reservoir prior to flooding should be required.

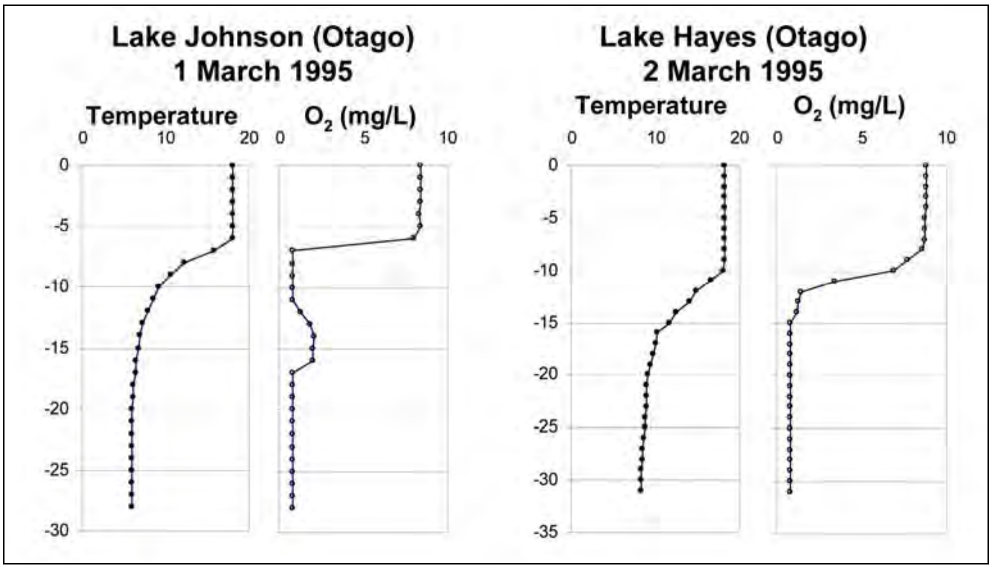

Figure 6: Temperature and oxygen depth profiles showing substantial de-oxygenation in the thermocline, above the hypolimnion, in Lakes Johnson and Hayes (M. Schallenberg unpubl. data). The thermocline is the zone in which temperature declines rapidly (e.g. -1 degree per m).

8.6. I am aware of two New Zealand reservoirs, which have spilled anoxic waters containing high levels of noxious solutes. The Maitai Reservoir (Nelson) develops high levels of dissolved manganese in its anoxic bottom waters and the discharge of this anoxic hypolimnetic water into the lower Maitai River may be responsible for the declining fishery and the proliferation of cyanobacteria in the river (Holmes 2010).

8.7. As discussed above, the Opuha Reservoir (Canterbury) is susceptible to hypolimnetic anoxia and prior to the addition of aeration equipment, the Opuha dam discharged anoxic waters high in iron, manganese, ammonia, phosphate and hydrogen sulphide into the lower Opuha River. Sampling and observation of the river showed precipitation of iron, manganese and humic compounds as a dense humic iron floc onto the substrate, and substantial concentrations of dissolved iron, manganese, ammonia and phosphates in the water. Benthic algal and macroinvertebrate communities were typical of severely polluted rivers with high biomasses of cyanobacteria and green algae (Adrian Meredith, Environment Canterbury, pers. comm.).

8.8. Whether the proposed dam would discharge anoxic water to the lower Mokihinui River would depend on the depth of the thermocline at the dam, which may vary on short time scales due to winds, changes in inflow rates and changes in reservoir water level. Any discharge of anoxic water to the lower Mokihinui River, with its harmful constituents, would produce a polluted and noxious mixing zone downstream of the dam. Within the mixing zone, aquatic organisms would be exposed to physico-chemical conditions to which they are not adapted because they would never have experienced such conditions in the undammed Mokihinui River. The effects of low oxygen concentrations, high metals concentrations, hydrogen sulphide, ammonia and elevated high pH would constitute an extreme perturbation to the ecosystem. Without detailed toxicity data, it is very difficult to model the severity and longitudinal distribution of such negative effects on the biota and, therefore, any discharge of anoxic water should be avoided, possibly by designing a dam outlet which could move upward and/or by removing vegetation and organic soils from the bed of the proposed reservoir prior to filling.

9. RISK OF THE PROPOSED RESERVOIR BECOMING A GREENHOUSE GAS EMMITTER

9.1. It has been known for almost two decades that hydroelectric reservoirs emit elevated amounts of greenhouse gases (GHGs) including carbon dioxide, methane and nitrous oxide (e.g. Rudd et al. 1993), compared to natural lakes. Both latitude and the age of reservoirs have been shown to correlate with amounts of GHGs emitted (St Louis et al. 2000; Barros et al. 2011).

9.2. Methane is a potent GHG, with 21-25 times the potency of carbon dioxide over a 100 year time scale. Methane is produced in anoxic sediments and water and is emitted from the reservoir surface as gas bubbles. Therefore, the number of years that anoxia in the hypolimnion will occur in the proposed reservoir will play a large role in determining the duration of substantial methane production and GHG emissions from the proposed reservoir.

9.3. In estimating the GHG contribution of the proposed reservoir, Dr. Griffith relies on Dr Spigel’s estimate of 5 years for the decomposition of 95% of the decomposable organic matter in the reservoir and 10 years until the reservoir behaves like a natural lake in terms of decomposition, anoxia and internal nutrient loading. As I state in sections 5.4 to 5.6, this assumption is based on very little robust data and is a guess, rather than a scientifically supported estimate. I argue that the proposed reservoir would be just as likely to continue to decompose organic matter for decades, post-flooding (Fig. 4).

9.4. Dr. Griffiths evidence on GHG production relied on data in Tremblay et al. (2005), which the authors interpreted to suggest that the effects of flooded organic matter on GHG production lasts only a few years. The latest available data (Barros et al. 2011) do indeed suggest very weak trends of decreasing GHG production with increasing age of reservoirs (Fig. 7).

9.5. However, Figure 7 shows that the flux rates are highly variable among reservoirs and indicates that other reservoir-specific factors also play an important role. These are likely to include water temperature, duration of ice cover (in ice-covered lakes), amount of flooded organic matter, and oxygen availability. The proposed Mokihinui reservoir (warm temperate, ice-free, high organic matter standing stocks, stratified with low summer oxygen availability) would exhibit conditions more favourable to GHG production than the temperate and boreal reservoirs which dominate the published datasets (St. Louis et al. 2000; Barros et al. 2011).

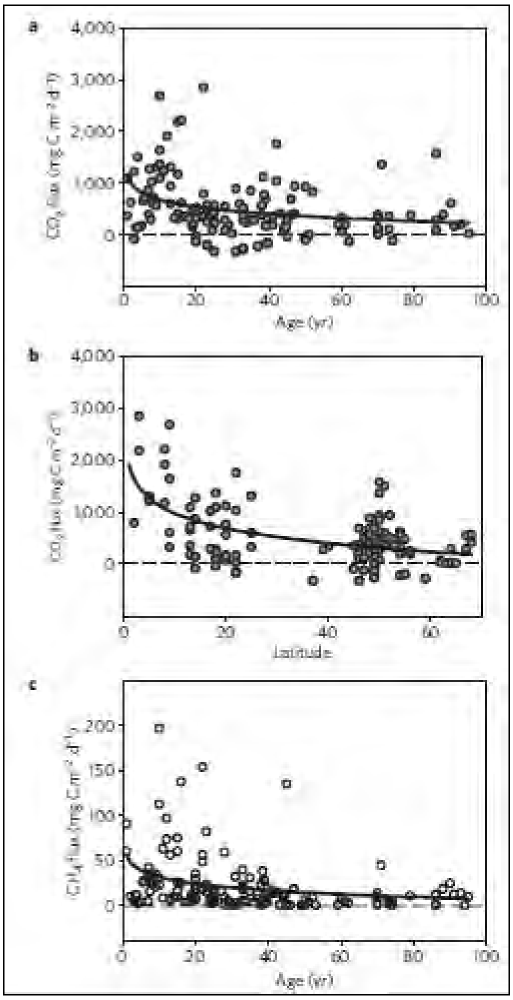

Figure 7: Fluxes of carbon dioxide (a) and methane (c) as a function of the age of reservoirs. From Barros et al. (2011)

9.6. Nevertheless, Griffiths (2011) assumed an initial period of enhanced GHG production of only 10 years and estimated the rates of GHG production as the averages for boreal reservoirs, as reported in St. Louis et al. (2000). The values used were 1,400 mg C per m^2 per day for carbon dioxide and 20 mg C per m^2 per day for methane. I consider the value for carbon dioxide to be reasonable compared to Fig. 7a, but the value for methane seems to be very low in relation to Fig. 7c. I also consider the time period over which these values have been applied (the first 10 years post-flooding) to be too short (see Fig. 4 and Figs 7a,c).

9.7. The graphs in Fig. 7, show large amounts of variation in GHG production, especially in the first 40 years post flooding. This is because different reservoirs have differences in the factors driving GHG production. For example, the reservoirs in these datasets come from wide variety of climatic zones and vegetation zones. St. Louis et al. (2000) attempted to account for this variation by examining GHG production vs. age relationships for a subset of reservoirs from Wisconsin, which provided a dataset of reservoirs of different ages but from a similar climate and vegetation zones. This analysis was summarised in St. Louis et al. (2000) as follows

> "Wisconsin reservoirs still had much higher greenhouse gas emissions than natural lakes in the same geographic area… or terrestrial surfaces before flooding, demonstrating that fluxes of greenhouse gases from reservoirs do not become similar to nearby lakes even after eight decades of flooding."

9.8. Thus, I feel that the assumptions made in the analysis of potential GHG production from the proposed reservoir are probably substantial underestimates, when integrated over the life of the reservoir. Judging from the assumptions made and literature data available, I think that the estimates made by Meridian Energy could be as low as one fifth of the total life-cycle GHG production that could occur from the ecological perturbations due to the proposed reservoir. My conclusion also takes into account the fact that most published studies have only examined gas fluxes across the surface of reservoirs while ignoring degassing of the reservoir outflow, which may also be a substantial source of GHGs to the atmosphere from reservoirs (International Rivers 2008).

9.9. Finally, Griffiths (2011) compared the estimated GHG emissions for the proposed Mokihinui reservoir with those that would occur if an equivalent amount of electricity were to be generated from thermal sources (e.g. natural gas). I think this comparison is not relevant to the NZ situation because New Zealand's electricity is currently sourced from approximately 70% renewable energy sources. With ever-increasing reliance on co-generation, wind farms, and tidal energy, this may rise to 80% in the coming decades. Therefore, a more relevant comparison would be to relate the GHG production estimate from the proposed reservoir to that which would be produced if the equivalent amount of electricity were to be obtained from the current national grid (70% renewable energy) and from wind farms and other renewable sources of electricity, which could plausibly replace the electricity generation from the proposed Mokihinui hydro power scheme, if it were not to go ahead.

10. UNCERTAINTY IN PREDICTIONS AND EVIDENCE FROM OTHER LAKES AND RESERVOIRS

10.1. Predicting the dynamics, state and condition of the proposed reservoir has necessitated using complex numerical models, carrying out many calculations, and making many assumptions. Many of the estimates made are annual or monthly averages and little effort has been made to determine the variation in key state variables or the robust probabilities of experiencing unfavourable events, such as phytoplankton blooms or discharge of anoxic and toxic water from the dam. In my view, potential algal blooms, anoxia and the discharge of noxious water from the dam are the most serious potential consequences for aquatic organisms and recreation if the proposed dam is built. Yet little certainty exists about the likely frequencies and magnitudes of these key effects.

10.2. The major uncertainties relate to the water residence times of the epilimnion and hypolimnion during the predicted 7-month period of thermal stratification, the rate of oxygen depletion in the bottom water, the magnitude and effects of internal nutrient loading on phytoplankton, and the ecological impacts resulting from discharges of anoxic water containing toxic substances to the Lower Mokihinui.

10.3. Numerical models such as DYRESM are normally calibrated[7] to improve their predictive power. The models are then supposed to be validated[8] with an independent dataset to determine the accuracy of predictions. Neither calibration nor validation has been possible for the DYRESM model of the proposed reservoir, because the system modelled is a hypothetical one. Therefore, the model used to predict the thermal structure and hydrodynamics of the proposed reservoir is of questionable validity and should not be assumed to be as robust as other DYRESM models of reservoirs which have been calibrated and validated.

10.4. Based on my experience of sampling a number of reservoirs throughout New Zealand, I concur with the Applicant's witnesses that the proposed reservoir would indeed stratify during summer and that the main inflow

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[7] Model calibration occurs when model outputs are optimised to time series data by adjusting model parameters.

[8] Model validation is a key step which quantifies how reliable model outputs are at mimicking the dynamics of the system being modelled.

would flow along the thermocline most of the time. However, due to a highly channeled flow of water through the reservoir (along the thermocline), the water residence times of the epilimnion and hypolimnion would probably be longer than the water residence time calculated for the whole reservoir (assuming continuous and complete mixing). I also believe that the nutrient availability (mainly phosphorus) to the epilimnion and the duration of oxygen depletion in the hypolimnion have been underestimated due to:

- a lack of data for calibration and validation of model outputs (raising questions about the accuracy of the predicted thermal structure of the proposed reservoir, the destination of inflows during the stratified period, and the water residence times of the epilimnion and hypolimnion),

- the use of some unsupported assumptions to simplify calculations (including the assumption of no internal nutrient loading, that the whole lake water residence time is indicative of flushing rates, etc.), and

- the use of information from other systems which seem to have limited similarities with the proposed Mokihinui reservoir (e.g. using wind speeds data from Hokitika airport, comparing the likelihood of trophic upsurge with information from Lake Dunstan, using data from boreal and tropical reservoirs to predict GHG production etc.).

10.5. All of these weaknesses in the analysis illustrate how extremely difficult a task it is to predict conditions of a hypothetical reservoir when almost no relevant data are at hand. Large uncertainties exist in the predictions of important characteristics of the proposed reservoir. These uncertainties and their associated risks have not been adequately stated in the assessment of environmental impacts, leaving the reader with a false sense of certainty about the ecological condition and impacts of the proposed reservoir.

10.6. One way of assessing the likelihood of negative effects occurring in the proposed reservoirs is to examine whether similar negative effects have been observed in other similar reservoirs and/or lakes. James (2011a) collected relevant information from other lakes and reservoirs, but also acknowledged that none of the lakes or reservoirs examined is a good comparator for the proposed reservoir. I agree with this assessment because, while each lake/reservoir has some similarities with the proposed reservoir, none of them has enough similarities to be a convincing model for the reservoir. Another limitation of the comparison is that for many lakes (such as the landslide lakes), the comparison relied on only two samplings of the lakes. Such minimal sampling of the lakes could easily miss events such as algal blooms or periods of anoxia. Nevertheless, some of the reservoirs used for comparison are eutrophic and showed substantial oxygen depletion in the bottom waters, supporting my opinion that the proposed reservoir could have phytoplankton blooms and ongoing problems with anoxia.

10.7. One reservoir which the witnesses for the Applicant did not examine is the Opuha Reservoir, Canterbury. The reservoir is 35 m deep and covers approximately 700 ha of Canterbury hill country. It was filled in 1998. As I mentioned in section 7.14, the Opuha reservoir became thermally stratified and had severe water quality problems including hypolimnetic anoxia, internal nutrient loading from flooded soils, and algal blooms (Adrian Meredith, Environment Canterbury, pers. comm.). This necessitated the retrofit of an aeration system to disrupt stratification and reduce anoxia and internal phosphorus loading to prevent breaches of water quality requirements in the operating consent conditions (New Zealand Herald 2003[9] ; Alpine Energy 2006[10]). The aeration system has prevented stratification, but the early summer rate of oxygen depletion in the hypolimnion has not decreased significantly in the first decade since flooding (Adrian Meredith, Environment Canterbury, pers. comm.). There have also been blooms of didymo and the potentially toxic cyanbacterium, *Phormidium*, in the downstream river and flushing flows have been employed to try to control these unwanted periphyton (Timaru Herald 2008b[11],c[12]). Finally, because the dam outlet is fixed in the lower part of the dam, releases of anoxic and nutrient rich bottom waters from the reservoir into the Opuha River caused ecological problems as well as tainting a drinking water supply:

> Release of anoxic bottom waters into rivers may have significant detrimental effects to benthic stream life, as initially occurred with the Opuha dam in South Canterbury[13].
>
> The storage dam encountered some problems arising from having flooded fertile farmland. There were occasions during the early part of its operation when the lower part of the lake became anaerobic, with elevated

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[9] http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=3529206

[10] www.alpineenergy.co.nz/disclosures/annual_report_2006.pdf

[11] http://www.stuff.co.nz/timaru-herald/news/772152/Flushing-clears-didymo-build-up

[12] http://www.stuff.co.nz/timaru-herald/news/4580805/Dam-blamed-for-river-ruin

[13] Suren et al. (2010)

levels of nitrates and manganese. This resulted in poor quality of released water from the dam because water is drawn from the lower part of the reservoir. An aerator has been installed by the dam operators to combat this. The lack of flushing flows in the river associated with operational issues in the dam have resulted in a build up of algae in the river. The operators have received some advice on the need to add sediment to the river, and further studies are being undertaken on the flow regime needed to enhance the water quality whilst maintaining the fishery. The problems with the ability to provide flushing flows are now resolved[14].

10.8. The experiences of the Opuha Reservoir illustrate some of the negative environmental impacts of reservoirs which could also become issues for the proposed reservoir. The applicant has not shown that the proposed dam will be sufficiently different in key ways from the Opuha dam so as to not result in similar problems.

10.9. I believe that Meridian Energy's attempt to predict the condition and environmental impacts of the proposed reservoir suggests an unrealistic level of confidence. Uncertainties are substantial at all levels of modeling and analysis. Perhaps the most useful type of information would have been detailed scientific information on similar reservoirs within New Zealand. Unfortunately, few reservoirs sufficiently similar to the proposed Mokihinui reservoir exist. Furthermore, few long term monitoring programmes have been carried out on New Zealand's established reservoirs to provide the sort of data that would

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[14] Harris et al. (2006)

be useful for predicting the impacts of new reservoirs, such as the one in question.

11. ASSESSING THE INDIVIDUAL AND CUMULATIVE MAGNITUDE OF THE ECOLOGICAL EFFECTS OF THE PROPOSED RESERVOIR

11.1. I have outlined what I consider to be the most important limnological risks associated with the proposed reservoir and I have outlined uncertainties in the identification of the likely ecological risks and the scientific analyses of the risks. These uncertainties are substantial and involve the lack of model calibration and validation, the use of data from elsewhere for calculations, and the use of numerous simplifying assumptions.

11.2. As such, it is difficult to address the magnitude of effects likely to result from the construction and operation of the dam. In the Opuha Reservior, the effects were great enough to i) warrant the installation of aeration equipment to de-stratify the reservoir in an attempt to improve water quality and to ii) alter the operating regime to try to minimise negative downstream effects.

11.3. James (2011a,b) acknowledged and discussed many of the uncertainties that I discussed above. I disagree with many of the conclusions in Dr James' reports stating that particular environmental impacts would be minor or less than minor. In my view, where uncertainties as to the effects of an environmental development project exist, a precautionary approach is appropriate. To take a precautionary approach requires the acknowledgment of possible worst-case ecological scenarios and the planning for scenarios with a substantial degree of precaution and prudence. I do not think such an approach has been advocated by the applicant with regard to the issues I have addressed in my evidence. Furthermore, this hydro-electric proposal should be assessed on the sum of its individual ecological impacts and their potential for interactions and feedbacks. For example, the potential positive feedback between anoxia, internal nutrient loading and phytoplankton productivity would be difficult to mitigate.

11.4. From a limnological perspective, a precautionary approach would involve the removal of vegetation as well as soil organic matter from the land to be flooded. Similarly, to account for the risk of discharging anoxic water to the Lower Mokihinui River, I suggest that the depth of the outlet at the dam be adjustable to ensure only epilimnetic water is discharged at all times. These modifications to the design and implementation of the reservoir would substantially reduce the main limnological risks to the reservoir and the aquatic habitat of the lower river, as I have discussed, above.

12. CONCLUSIONS

12.1. The proposed reservoir will alter the ecology of a virtually unmodified river of high conservation value and flood 3.4 km^2 of surrounding native forest and riverine habitat while providing c. 0.2 km^2 of habitat suitable for aquatic plants. The remainder of the lake bed will be barren of plants and probably have fewer invertebrates compared to the forest being flooded. The reservoir will be thermally stratified for

c. 7 months of the year during which time the bottom waters will become depleted of oxygen and will develop higher alkalinity, hydrogen sulphide gas and elevated concentrations of metals, ammonium and phosphate. As such, the bottom waters will be uninhabitable by plants and animals. The oxygenated water in the mixed layer will be suitable for fish and invertebrates if there is sufficient food and habitat for them.

12.2. The trophic state of the proposed reservoir will probably be higher than the oligotrophic state suggested by the applicant's witnesses because a positive feedback system will likely result from anoxia in the hypolimnion and subsequent internal nutrient loading fuelling phytoplankton production, which will eventually settle into the hypolimnion, fuelling greater decomposition and oxygen demand.

12.3. Strong westerly winds and/or floods could result in thermocline tilting, potentially allowing the discharge of anoxic hypolimnetic waters to the lower Mokihinui River. Downstream organisms will not previously have experienced, nor been adapted to, such poor water quality in the Mokihinui River and would be negatively affected by these discharges.

12.4. My suggested precautionary approach to mitigating these issues would be to remove organic matter in the area to be flooded and to construct the dam generation outflow to be adjustable to different depths, in order to discharge only oxygenated waters into the lower river.

12.5. Many uncertainties exist in the analyses of potential environmental impacts and these prevent the robust prediction of likely outcomes. Examination of data from other similar lakes and reservoirs shows that indeed some are eutrophic and many have problems with deoxygenation of their bottom waters. The Opuha Reservoir in Canterbury exhibited the full range of problems that I suggest could occur in the proposed Mokihinui Reservoir, necessitating the retrofitting of an aeration system and the implementation of environmental flow management because these problems were not foreseen during the resource consent process and gave rise to unacceptably adverse environmental effects.

12.6. The proposed Mokihinui reservoir would emit substantial greenhouse gases, especially during phases of anoxia. These phases will last until most of the flooded decomposable organic matter will have been decomposed – a process which could take decades, according to a study of Wisconsin reservoirs and according to my analysis of available data.

12.7. A robust risk assessment of this proposal should not only take into account its individual ecological effects, but also its cumulative effects and the potentials for individual effects to have synergistic interactions and to create feedbacks, which may prevent the success of planned or post hoc mitigations.

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