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 DONALD JOHN JELLYMAN ON BEHALF OF MERIDIAN ENERGY LIMITED

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1. QUALIFICATIONS AND EXPERIENCE

1.1 My full name is Donald John Jellyman.

1.2 I have the following qualifications:

a. B.Sc (Hons), and Ph. D. (1974) from Victoria University of Wellington;

b. I am a member of the New Zealand Freshwater Sciences Society, and the American Fisheries Society.

1.3 I am a fisheries biologist with over 30 years of experience. I have been employed as a freshwater fisheries scientist with the National Institute of Water and Atmospheric Research Limited (NIWA) from July 1992 to the present. My role is research leader, freshwater fish. Prior to that I was employed as a fisheries scientist with the Ministry of Agriculture and Fisheries (1972 – 1992). My involvement and knowledge of the fisheries values of the Mokihinui River commenced in 1987 when I organised and participated in 2 drift dives of 4 sections of the upper river as part of a national research programme I ran investigating headwater trout fisheries throughout New Zealand. In 2006, I carried out an eel survey of the mainstem Mokihinui River and North and South Branches. I have also carried out a literature review of factors associated with downstream eel passage, which lead to development of a model to determine the likely impacts on eel passage of various flow regimes.

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 Project (MHP):

- Investigation of the native freshwater fish and fisheries of the Mokihinui River.

- Investigation of the movement and passage of trout in the Mokihinui River.
- Investigation of periphyton and invertebrates of the Mokihinui River.
- Investigation of the aquatic biodiversity of the Mokihinui River.

I have been involved in the preparation of the following reports:

a. Bonnett, M.; Jellyman, D.; Graynoth, E.; Kelly, G.; Henderson, R. 2007. Mokihinui River Proposed Hydropower Scheme: Native Freshwater Fish and Fisheries Report. NIWA Client Report CHC2007-060. 61 p ("the NIWA report").

b. Hayes, J.W.; Hay, J.; Bickel, T.; Closs, G.P.; Bonnett, M.L. 2007. Mokihinui River Proposed Hydropower Scheme: Trout Movement and Passage. Cawthron Report No 1383. 55 p.

c. Norton, N.; Rouse, H.; Bonnett, M.; Kilroy, C.; Suren, A.; Carter, J.; Jellyman, D. 2008. Mokihinui River aquatic biodiversity – an analysis in the context of the Waters of National Importance (WONI) ranking framework. NIWA Client Report CHC2008-046. 50 p.

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

1.6 I have also reviewed:

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

i. Jowett, I.G. (2007). Instream habitat and flow regime requirements in the Mokihinui River. NIWA Client Report HAM2007-150. 43 p.

ii. Suren, A., Kilroy, C. 2007. Mokihinui River Proposed Hydropower Scheme: Periphyton and Invertebrates Report. NIWA Client Report: CHC2007-111. 72 p.

iii. Flöder, S.; Spigel, R. 2007. Mokihinui River Proposed Hydropower Scheme: Lake Water Quality and Habitat Report. NIWA Client Report: CHC2007- 122. 87 p.

iv. Hicks, D.M.; Rouse, H.L.; Tunnicliffe, J.; Walsh, J. (2007). Mokihinui River Proposed Hydropower Scheme: Sediment Report. NIWA Client Report CHC2007-117. 142 p.

v. Henderson. R., McKerchar, A. 2007. Mokihinui River proposed hydropower scheme: Hydrology report. NIWA Client Report: CHC2007-134. 72 p.

b. The review for the Department of Conservation of the Mokihinui Hydro Proposal AEE application and Freshwater Ecological technical reports, including the section on native fish compiled by Dr. Richard Allibone of Golder Associates

c. The Section 42A Officers report compiled by Mr David Cameron on behalf of the West Coast Regional Council

d. Relevant submissions of others, namely

i. West Coast Greens, Top of the South Greens, of the Green Party of Aotearoa.

ii. Mrs Metiria Turei, MP.

iii. South Island Eel Industry Association

2. SCOPE OF EVIDENCE

2.1 I have been asked by Meridian to prepare evidence in relation to the actual and potential effects on the MHP on eels. This includes:

a. Background on the eel stocks and fishery of the Mokihinui catchment;

b. Overview and findings of the field surveys carried out in the Mokihinui River;

c. Identification of the potential adverse effects of the MHP on eel stocks;

d. Recommendations on mitigation and monitoring;

e. Response to issues raised by submitters in respect of eels; and

f. Conclusions.

3. EXECUTIVE SUMMARY

3.1 Longfin eels are the most common and widespread native fish in the Mokihinui catchment. They are listed by the Department of Conservation as a species “in gradual decline”, and hence escapement of adult eels to spawn is a major thrust of stock conservation. The Mokihinui stock provides for a small commercial fishery, and an undocumented customary fishery.

3.2 Compared with other rivers, the longfin eel stock in the Mokihinui catchment is characterised by relatively large but slow growing eels; recruitment is regular and densities are relatively high. The overall longfin stock constitutes about 0.2% of the national stock of longfins.

3.3 A hydro dam has the potential to effect eel stocks through impeded up and downstream passage, and by changing a river habitat to a lake. Estimates of the relative biomass in the existing river versus the projected lake indicated that the lake might sustain a lower biomass than the river. However, it is recognised that the biomass estimate for the lake will be conservative as the model assumes that eels are confined to the littoral zone, whereas they are known to forage more widely.

3.4 Upstream recruitment would be maintained by regular “catch and carry” of juvenile eels caught in a downstream ramp and trap system. Providing for successful downstream passage of migrating eels is more difficult but regarded as necessary. A combination of bars (25 mm spacing) and a slow approach velocity (< 0.5 m/s), will prevent eels entering turbines. A migration model indicated that 60-70 % of migrating eels will move at flows < 150 m^3/s. At such flows it should be feasible to intercept these eels, and either guide them into a bypass or a “trap and transfer” system, then transport them downstream to continue their migration. The remaining migrating eels should move on increased flows (150 – 1,200 m^3/s) when they will be able to negotiate the spillway. Monitoring of these migrations is important to improve predictions of the timing and extent of eel migrations, and the way that diversion systems are operated to maximise escapement. Such measures if well designed and implemented, should substantially reduce the potential adverse effects on eel stocks in the Mokihinui River.

4. THE PROPOSAL

4.1 I confirm my evidence is based on the project proposal as described in the Assessment of Environmental Effects, brief details of which are described in Appendix 1.

5. BACKGROUND ON MOKIHINUI CATCHMENT EEL STOCK AND FISHERY

5.1 The eel stock in the Mokihinui River is almost entirely comprised of the endemic longfin eel (*Anguilla dieffenbachii*). Although they continue to be a commercially fished species, longfin eels are classified by the Department of Conservation (DoC) as a threatened species ("a species in gradual decline", Hitchmough 2007), in recognition that national stocks have shown significant reductions over past years. Much of the stock management emphasis by the Ministry of Fisheries is on maximising escapement of spawning eels, to ensure adequate levels of recruitment are maintained.

5.2 Sexually mature adult longfin eels migrate to sea in autumn to spawn in tropical waters thought to be in the vicinity of Fiji. Eels breed only once and die after spawning. After hatching, eel larvae drift on ocean currents for up to 10 months before arriving offshore of New Zealand. Juvenile eels migrate into streams and rivers in spring, and progressively work their way upstream each summer until they find suitable habitat where they may stay and grow. Shortfin eels do not penetrate as far inland as longfin eels, and tend to populate the lower reaches of rivers, as well as coastal lake and estuaries.

5.3 The Mokihinui River is accessible to both customary and commercial eel fishing, except for the Mokihinui Forks Ecological Reserve (241 km^2). The Lyell Range – Radiant Range Stewardship Area (564 km^2) established under section 25 of the Conservation Act 1987, may be fished with a permit from DoC.

5.4 A review of South Island commercial eel fishing (Beentjes and Chisnall 1997) did not mention the Mokihinui River as a significant fishery, and the area "north of the Buller River to Mokihinui River" had an estimated annual catch of only 2.2 tonnes (< 1% of the total South Island catch). The river was not listed as a major area for mahinga kai in presentations by Kati Mahaki kaumata to the Waitangi Tribunal, although the Tai Poutini Tuna/Eel Management Committee's "Eel Management Plan" (1999) listed a reserve of 160 acres "On the south bank of the Mokihinui River" as one of 58 reserves set aside as a mahinga kai site by the 1860 Arahura Deed of Sale.

6. FIELD SURVEYS

6.1 Quantitative information on eel distribution, species composition, sizes, and growth rates were needed for the MHP investigations for two reasons – firstly to put the Mokihinui River eels stocks in the context of other West Coast rivers, and secondly as inputs into population simulation models. Simulation models were required to predict spawning escapement (the number of spawning eels migrating downstream in an average year), and how these eels could obtain safe passage past the proposed dam.

6.2 Detailed results of the surveys are contained in Bonnett et al. (2007). Other than fyke netting, which was only for eels, the surveys were for all species of native fish and included:

a. March 2006. Electrofishing and fyke netting (for eels) surveys of mainstem and tributary sites upstream of the proposed dam site to collect quantitative data on eel populations in the river. This was the primary eel survey, although additional distribution data came from the following additional surveys;

b. April 2006. Electrofishing surveys of tributary streams in the lower section of the Mokihinui River gorge;

c. February 2007. Electrofishing surveys of higher altitude tributary stream sites in the upper river; and

d. April 2007. Surveys of tributary streams and mainstem sites of the lower Mokihinui River (i.e. below the proposed dam site).

7. FINDINGS

Eel species composition and size

7.1 Longfin eels were the most common and widespread native fish species caught, comprising 57% of all native fish sampled (N = 1,053) during the 2006 and 2007 surveys. Eels were present in all tributaries sampled, as well as within the mainstem river. A single shortfin eel was collected from the lower reaches of the mainstem (near SH67 bridge), but the remainder of the 605 eels caught throughout the catchment were all longfins (99.8%). This was not unexpected, as longfins typically dominate the recruitment into West Coast streams (Jellyman et al. 1999).

7.2 The length-frequency distribution of longfins caught by fyke nets (Figure 1) shows good representation of smaller eels (< 550 mm), and a long “tail” on the right side of the graph indicating a lightly fished population. Immature eels cannot be sexed by external characters, but longfins > 750 mm are all females and represented 30% of the eels in the present sample. Similarly the size distribution of electrofished eels (Figure 2) shows a good representation of juvenile fish indicating regular recruitment takes place. Overall, there appears to be a healthy population of both smaller and larger longfin eels in the Mokihinui River.

7.3 The Mokihinui River has a reputation for containing very large eels, and although many large eels were caught during the March 2006 survey, including fish in excess of 6 kg, the size of eels encountered was not regarded as exceptional - a total of 10 fyke netted eels (2.4%) and one electrofished eel exceeded 1 m in length. The mean length of longfins from the Mokihinui River exceeds that from most commercially exploited South Island rivers, and also from most rivers that are less accessible/seldom fished (Table 1), indicating a lightly fished (and probably slow-growing) population. Overall then, the reputation for very large eels was not confirmed.

Ages and growth rates of eels

7.4 Because NIWA has considerable information on the growth rates of West Coast eels (e.g. Beentjes and Chisnall 1997), we only killed 9 eels to confirm anticipated growth rates. An analysis of eel otoliths (inner ear bones) showed these eels (length range 500 – 762 mm) ranged from 33 to 44 years old. The relationship between length and age of eels is shown in Figure 3. The annual growth rates of individual eels ranged from 13 to 18.0 mm/year, with an average of 15.0 mm/year. Based on this average growth rate, and a relationship between length and weight (NIWA unpublished data), eels would average 26 years of age before being large enough to enter the commercial eel fishery (at the threshold weight of 220 g).

7.5 The average annual growth increment of 15 mm/year for Mokihinui eels is below the average of 23 mm/year for South Island longfins (calculated from data in Beentjes 1999), and is relatively slow. At 15 mm/year average growth, migrating females (mean length 1,150mm) would average 72 years old when they migrate to sea to spawn. Although this is “old”, it is considerably less than the 93 years estimated by Jellyman (1995) for female longfins from Lake Rotoiti.

Abundance of eels

7.6 Catch per unit effort (CPUE) is a standard measure of catch rates, which provides an index of fish abundance; catches are expressed as either the number or weight of fish for a given sampling effort – for eels, this is normally the weight of eels (kg) per net per night. Provided the capture method is standardised, CPUE can be used to compare catch rates between sites, and populations.

7.7 CPUE (kg/net/night) estimated from the nightly catches in the Mokihinui River (Table 2) ranged from 1.7 to 21.3 kg/net/night. Overall, a total of 457 kg of eels was caught during the six days of fyke netting. To compare these results with those available from the commercial eel fishery, CPUE needs to be estimated for commercial-sized eels (> 220 g), and first night fishing only (as commercially fished nets are supposed to be lifted daily) – this gives an average of 7.7 kg/net/night.

7.8 Compared with CPUEs from commercial fishers in the Westland region from 1991-2006 (average of 5.7, range 4.0 – 7.8 kg/net/night; data from Beentjes and Dunn 2008), the average of 7.7 kg/net/night for the Mokihinui River was relatively high. The largest longfin eel catches in the South Island come from Southland, and here the average CPUE (1991-2006) ranged from the 4.0-7.2 kg/net/night, with an average of 5.2 (data from Beentjes and Dunn 2008), again less than in the present study.

7.9 Fyke netting procedures in the present study were different from those used by commercial fishers – to maximise the chances of catching eels in a given area and hence get the most accurate assessment of the population, we set nets at regular but close intervals (40 m), whereas commercial fishers only place nets at the most likely places to maximize catches of eels. The method we adopted ensures catches are comparable between reaches, but would produce overall lower CPUE values than commercial fishing practices. The fact that our catches exceed those from the commercial fishery indicated that the river contained a relatively large population of longfin eels.

Summary

7.10 In summary, the Mokihinui River has a widely distributed stock of eels, virtually all longfins, that show evidence of regular recruitment and not having been subject to much commercial fishing; growth rates are slow but densities are relatively high. The river has a reputation for containing very large eels, although sizes of eels caught in the present survey were not exceptional.

8. POTENTIAL EFFECTS OF THE MHP ON EEL STOCKS

8.1 The potential effects of a dam on eels are threefold:

a. Impeded upstream recruitment;

b. Change of a portion of the catchment from a riverine to a lake environment; and

c. Impeded downstream migration of adult eels.

Upstream recruitment of juvenile eels

8.2 A dam in the lower river will block the upstream passage of juvenile eels (elvers, approximately 60 mm to 120 mm in length), and some assisted means of upstream passage will be required. There can be operational problems with elver passes and their efficiency reduces with the height of the pass. Experience suggests that a pass is unlikely to be effective for the 80-85 m dam proposed. The alternative is a “catch and carry” system (where elvers are trapped by attracting them to a small ramp emptying into a holding box, for later manual transferral upstream). Similar systems operate successfully on a number of hydro dams throughout New Zealand (e.g. Karapiro Dam, Patea Dam, Matahina Dam, Manapouri Lake Control), and collectively 3-4 million elvers are caught and transferred upstream annually. Such a system should also provide passage for other migratory fish such as koaro, as presently happens at the Patea Dam, Taranaki.

8.3 Given the simplicity of the technology involved, and the considerable national experience with "catch and carry" systems, in my opinion this will be an effective means of maintaining upstream passage for juvenile eels on the Mokihinui River.

8.4 An additional benefit of the catch-and-carry process is the opportunity to provide robust data on annual recruitment of longfin eels. The Ministry of Fisheries has initiated collection of annual recruitment data at a series of hydro stations throughout New Zealand (Martin et al. 2006). The only West Coast South Island site is the Arnold Dam, but because of operational problems, this has not proven to be a very satisfactory site and the possible future redevelopment of the dam means that future data are unlikely to be comparable with data collected to date. Hence, provision of data from a new West Coast site would be a very welcome addition to the recruitment database.

Change from a riverine to a lake environment

8.5 Longfin eels inhabit rivers and lakes on the West Coast. However, both these environments are rather different (differing flow regimes, differing habitats and food sources), and could potentially support different quantities of eels. Therefore, an attempt was made to compare potential lake production of eels with present river production.

8.6 From GIS measurements, the reach of the mainstem of the Mokihinui River that will be inundated by the dam is 15 km long; our river productivity model suggests this presently supports about 6,050 kg of longfins (excluding those in tributaries). The reservoir created by the MHP will be about 337 ha in area, an estimated 12.5% of which will support a littoral zone for rooted plants of 3 to 5.8 m deep. Based on a production of 60 kg/ha (the figure used to produce estimates of national production in lakes), this littoral area might support about 2,530 kg of eels, less then half the biomass in that reach of the river presently.

8.7 However, the assumption of eels being confined to the littoral zone is a conservative one (e.g. eels in Lake Wakatipu have been caught as deep as 120 m, well beyond the littoral zone; Jellyman and Todd 1980). In the Mokihinui hydro lake, eels could readily forage in deeper waters, and possibly in the hypolimnion (>30 m deep) when oxygen levels are predicted to increase to tolerable levels some five or so years after lake formation. Therefore the actual biomass will exceed the predicted biomass of 2530 kg, but by how much is uncertain. For example, if eels utilised depths to 11 m, the potential production from the lake would be equivalent to that of the present river.

Impeded downstream migration of adult eels

8.8 To simulate the impact of the MHP on downstream eel migration, a number of steps were required. These steps are summarised in Figure 4, and were:

a. Field studies to provide quantitative data on species proportions, growth rates, and abundance;

b. Use of a GIS based regression model (Graynoth and Niven 2004) to estimate the biomass of longfin eels in reaches throughout the catchment. The model is based on measurements of longfin eel biomass in the West Coast and Southland, and uses GIS statistics on physical features of the Mokihinui River together with associated eel/habitat relationships, to estimate the total weight (biomass) of eels per reach. The individual reach biomasses can then be summed to give the total estimated biomass per tributary, mainstem, or at whatever scale is required;

c. Develop a population simulation model that uses these biomass estimates together with length frequency and growth rate data, to predict the population structure, including the number and sex proportions of migrating eels; and

d. Develop a model to estimate the proportion of the total number of migrating eels that are likely to migrate under varying flows (flow bands). From these results, a series of mitigation options can then be developed to minimise the loss of migrating eels.

8.9 These steps and the findings are discussed in more detail below.

Estimated size of longfin eel stock

8.10 For this, the multiple nights fishing data from the South Branch at Forks Hut were used (Table 2). Catch (minus that of the lowermost net as this net attracts eels from beyond the study reach; Jellyman and Graynoth 2005) were used in the maximum likelihood method of Carle and Strub (1978) to estimate the total number of eels within the fished reach (262 m). The resulting estimate was 132 longfins (SE=12) weighing 185 kg, which equates to 705 kg/km. Using the nightly capture efficiency determined from this site, biomass estimates could be made for the other sites, and these ranged from 98 kg/km to 705 kg/km, with a mean of 306 kg/km.

8.11 Another (Independent) estimate of biomass was made from a GIS based model. This is explained in more detail in the NIWA report but uses relationships between eel biomass and physical features of waterways (mean flows and stream gradients) to predict eel biomass throughout a whole catchment. This model gave very similar results to the above maximum likelihood method, ranging from 94 kg/km to 604 kg/km with a mean of 346 kg/km. The overall agreement between the GIS-based model and the maximum likelihood method (13% difference) was well within the expected margin of error of ± 50%. Therefore the GIS estimates of biomass were validated by the field studies and could be used to estimate the biomass of eels throughout the catchment.

8.12 Much of the Mokihinui River catchment is relatively steep, and will therefore support a relatively low biomass of eels (<50 kg/km). The highest biomass of eels is likely to be found in the main stem and major tributaries. The GIS model indicates a total stock of 23 tonnes of longfins eels present within the catchment; this represents about 0.2% of the national stock of longfin eels (10,300 tonnes).

8.13 When the total biomass is expressed relative to the size of the catchment (kg/km^2; Table 3), the estimated density of eels in the Mokihinui is substantially less than in either the Grey or Buller Rivers. A high proportion of the Mokihinui stock is located in the Mokihinui Forks Ecological Area and is protected from fishing. Much of the remainder is in the Lyell Range – Radiant Range Stewardship Area and may be commercially fished with a permit.

Population simulation model

8.14 A population simulation model (Jellyman et al. 2000) was used to estimate the spawning escapement of male and female longfin eels upstream of the proposed dam site. This model is explained in more detail in the NIWA report. The model used growth rates from eels aged in the present study, and estimates of survival rates were based on research undertaken in small coastal streams (Graynoth et al. 2008).

8.15 The model estimated that the 23 tonnes of eels would be comprised of 227,000 eels, of which about 800 will become migrants each year - 660 males, and 115 females (Table 4). While these numbers of females are not large on national scale (0.2% of the national stock of longfins), with an average fecundity of 7.6 million eggs (Todd 1981), these eels could contribute as many as 874 million eggs.

Eel migration model (passage of migrating eels)

8.16 A review of conditions when migrating eels were likely to move downstream (Jellyman and Henderson 2006), indicated that downstream migrations were principally triggered by increased flows (Table 5). Thus the model we developed was one where migration was triggered by increased flow.

8.17 Four flow "bands" were provided by Damwatch, as the likely spillway-related flows for the MHP:

a. Band A = at flows up to 150 m^3/s there would be no spillway discharges, and migrant eels could be diverted past the dam through a bypass pipe and/or catch-and-carry system installed through the dam below crest height;

b. Band B = at flows from 150 to 1,200 m^3/s, water flows over the spillway, but the flip bucket does not "flip" (produce a hydraulic jump); eels are swept down the spillway, and in and out of the flip bucket;

c. Band C = flows from 1,200 to 150 m^3/s (a receding flood) cause the flip bucket to operate, and any migrating eels are thrown some distance into the plunge pool (distance thrown depends on flow); and

d. Band D = at flows above 1,200 m^3/s, spillway flows cause the bucket to flip, and eels are thrown out into the plunge pool. This has the effect of producing a tongue of water that sweeps out to varying distances from the bucket (e.g. up to 80 m at 2,100 m^3/s flow).

8.18 The model that we developed relied on descriptions of eel migration patterns and environmental "triggers" known from other catchments.

a. It was assumed that during the preferred migration season (March – May), instream flows were the primary factor initiating downstream migrations, and that flows in excess of the median (46 m^3/s) would trigger migration; and

b. It was also assumed that eels will maintain a constant swimming speed during migration, and that not all eels will migrate on the same night i.e. migration generally occurs over a few nights per season but it could not be assumed that all maturing eels would migrate in any one flood.

8.19 Threshold triggering flows were combined with estimates of eel swimming speeds, and knowledge of eel behaviour upon approaching a dam, to develop a model of the relationship between flow and the number of migratory eels captured at the Aniwhenua Power Station, Bay of Plenty (where catches of migratory eels were recorded daily). The performance of the Aniwhenua model was then tested against further data on migratory eels recorded at the Wairere Falls Power Station (Mokau River, Taranaki), where there was a strong association between actual and predicted numbers of eels migrating for the year (2002) of greatest flow variability (Figure 5). For the other year, 2003, a year of reduced flow variability, the model did not perform as well. However the much reduced flow variability in that year is not characteristic of the

Mokihinui River where freshes and floods are reasonably frequent during the migration season.

8.20 The model was then applied to hydrological and eel population data from the Mokihinui River. Hydrological records were available for 21 years (March 1972 – December 1993). A flood might trigger the downstream migration of eels throughout the catchment, and thus the model had to account for the various times required for eels to reach the dam. Assuming a conservative swimming speed of 0.5 m/s, all migrating eels in the upper Mokihinui River catchment could potentially reach the proposed dam site within 24 hours.

8.21 The model was then tested for sensitivity to four factors:

a. The proportion of eels that migrate in any one flow event. As not all eels migrate in any one flood, the model was tested using different proportions of the total number of migrating eels that might migrate during one flood. These were referred to as "cap" values. For sensitivity analysis, proportions ranging between 30 – 60% per flood were tested;

b. Threshold flows that trigger migration. As the magnitude of flows which would "trigger" migration in the Mokihinui River was unknown, various threshold flow values were tested (i.e. 1 – 4 times the median);

c. Migration flow limit – the proportion of the annual eel migration which migrates on a given flood is thought to be proportional to flow, but presumably would have a limit, as eels may not migrate when flows become very high. Various flow limits were tested (i.e. 3 – 6 times the flow divided by the median flow (a standard measure of flow variability); and

d. The varying duration of flow events, i.e. the number of days in flood - it is possible that, during a flood of long duration, eel migration only occurs in the first day or so. Various values of flood duration – how many days that the flood would trigger migration - were tested (i.e. 1-7 days).

8.22 Using the values considered most appropriate from the Aniwhenua model results (i.e. a minimum threshold of the median flow; a "cap" of 40% of eels that would migrate on a given night; a maximum of 5 times the median flow as the upper limit when eels would migrate, and a maximum of 5 days per flood available for migration) the model (Table 6) predicted that all eels in the upper Mokihinui River will migrate during either Band A (< 150 m^3/s), or Band B (150 – 1200 m^3/s). The reason that no eels migrated during either Band C (receding flood) or Band D (extreme flood) is because the model predicts that eels will have migrated earlier (in Bands A and B); also the time that the flow is in either Band C or D is very small (~ 2%). Sensitivity tests of the model (Appendix 2) reinforced the predictions of approximately 2/3 of eel migrating during Band A, and 1/3 during Band B, with virtually no eels migrating during Band C or Band D flows.

8.23 The model also predicted that there are sufficient floods each year within the Mokihinui catchment to stimulate all maturing longfin eels to migrate. As flows within the river are extremely variable, the threshold flows that trigger a migration are liable to be larger than those that trigger migrations in the more stable Rangitaiki and Mokau Rivers that were studied by Boubée et al. (2001) and Boubée and Williams (2006), and hence a greater range of trigger thresholds were simulated during sensitivity testing. Flow variability in the Mokihinui River is such that not only are all eels predicted to migrate each year, but they are likely to do so within the first month of the migration season. Thus for the MHP, the mean number of days per year to achieve complete migration of the almost 800 migratory eels, was 16 days (range, 8 – 48 days, over the 21 years of record).

8.24 Overall then, the proportion of eels predicted to migrate at flows < 150 m^3/s is about 60-70%. To facilitate downstream eel passage in this flow band (Band A) would require installing a diversion and catch-and- carry transport system. For Band B flows (smooth spillway flows), estimates of spillway velocities are 30 - 40 m/s (Nigel Connell, Damwatch, pers. comm.), and such flows are not likely to cause any problems for migrating eels. For instance, induced spillway flows are used to enable passage of migrating eels at the 82 m high Patea Dam (Watene and Boubée 2005); this spillway also has a flip bucket, and eels successfully negotiate the dam during periods when opening of the spillway gates (80 -150 mm) provides a smooth spillway flow, similar to that predicted for Band B flows in the present situation.

8.25 It is worth briefly considering the “worst-case’ scenario i.e. what are the implications for migrating eels in the unlikely event that the diversion scheme does not operating successfully at flows < 150 m^3/s? For this we need to review the likelihood of eels being stimulated to migrate, but the flows being too low (< 150 m^3/s) to result in spillway discharges. Using a conservative migration “trigger” as twice the median flow (i.e. an increase from 46 to 92 m^3/s), then there is an average of 3.0 such events per year when such “trigger” flows do not result in spillway flows – should eels choose to migrate during these latter events they would then be subject to delay at the dam until the next spillway flow occurred. The average length of such a delay is 30 days (range 2-68 days). Given that migrating eels accumulate at locations like Lake Ellesmere where they may attempt (unsuccessfully) to migrate for several weeks until the lake is opened to the sea, then a delay of a few weeks is of little consequence.

8.26 Such simulations underscore the importance of having actual migration information from the Mokihinui River, as opposed to using data from other rivers that have less flow variability. The suggested monitoring of downstream eel passage in the Mokihinui River (section 9.12) would provide more definitive answers about the stage of the hydrograph when eels migrate – for instance, should this monitoring indicate that no eels arrived at the dam until flows exceeded 150 m^3/s, then there would be no need for a diversion facility at all. However, the more conservative approach adopted here is to advocate for this facility unless subsequent information indicates that it would not be required.

Summary of potential adverse effects on downstream migration

8.27 An estimated average of 660 male and 115 female longfin eel will migrate downstream each year. If no remedial actions or mitigation were considered, then the majority of these eels (60-70%) would probably attempt to migrate on increasing flows, but in doing so would enter the turbines where the majority would be killed by a combination of mechanical strikes and pressure changes. Being larger, the female eels would have a much higher probability than males of being killed by a mechanical strike.

9. MEASURES TO AVOID, REMEDY OR MITIGATE ADVERSE EFFECTS

9.1 To mitigate the effects of the proposed dam on the longfin eel population, a series of measures are suggested to provide access beyond the dam for juvenile eels, and downstream passage for migrating eels. Both options involve some “catch and carry” whereby eels are encouraged to enter a trap/holding box, and then manually transferred upstream (juvenile eels) or downstream (migrating adult eels).

Elver trap

9.2 An elver trap will need to be installed at the base of the dam, at a site where elvers naturally congregate in their endeavours to migrate upstream. Traps are relatively simple, being an inclined ramp leading to a holding box; the ramp has water flowing down it and additional attractant water at the ramp entry is often advisable. A small aerated trailer-mounted tank (e.g. 500 litres) is required to transport fish upstream. Figure 6 shows the trap at the Patea dam where approximately 500,000 elvers are collected and transferred upstream annually.

9.3 Elver traps are normally operated only during summer months, from about mid December to the end of March, whereas other species of fish migrate over a longer season. If a trap system is also to be used to transfer galaxiids and other migrant species in the Mokihinui River, it is recommended that it should operate over a longer season, from August through to April. Monitoring of the catch and transfers is recommended to refine knowledge of fish migration patterns, and the subsequent operation of the system could be modified as required. The benefits for fishery managers of obtaining data on elver recruitment have already been discussed. Furthermore, the elvers can be released into preferred habitats.

9.4 Elver “catch and carry” systems are operated at more than 12 dams or weirs) nationally, and some of these have been in operation for more than 10 years (Martin et al. 2006). In my opinion a "catch and carry" system on the Mokihinui River would be an effective means of maintaining upstream passage for juvenile eels.

Intake screens

9.5 Because of their instinct to follow flows, migrating eels are known to enter penstocks where, as a consequence of their size, most are killed by passage through turbines. To avoid this, exclusion bars are needed at penstock intakes. While greater emphasis is placed on ensuring successful emigration of females, the well-being of males is also important. Implications for bar spacing of eel exclusion grates are that such spacing should exclude all females and a high proportion of males. Migrating longfin females have a minimum length of 750 mm, while males range in length from 480 – 740 mm with an average length of 620 mm (Jellyman and Todd 1982). From the relationship between the eel length and head width for longfin eels (Appendix 3), it would be assumed that a 30 mm bar spacing should effectively exclude all longfin females, the primary target, and above-average sized male longfins.

9.6 However, recent observations on bar spacing and eel behaviour (summarised in DWA 2005) indicate that eels are adept at squeezing through apertures slightly narrower than their head width. In a recent study of eel passage at a small New Zealand hydro station (Boubée and Williams 2006), it was noted that a 30 mm screen allowed for eels as large as 700 mm to enter turbines. Thus a bar spacing of 25 mm is recommended. As well as an appropriate bar spacing, intake screens need to have a low approach velocity to avoid eels being becoming impinged - a velocity of less than 0.5 m/s is recommended as eels are able to free themselves from screens if velocities do not exceed this (DWA 2006). Intake screens would only be required during the migration season.

Capture or diversion of downstream migrating eels

9.7 For eels migrating downstream at flows < 150 m^3/s, it should be feasible to intercept these at the proposed dam, and either guide them into a bypass or a "trap and transfer" system, then transport them downstream to continue their migration.

9.8 Trapping downstream migrating eels is more difficult than trapping elvers. Given that the eels are much larger, correspondingly larger facilities are required. Because eels are moving downstream, usually during periods of increased flows, any trap or netting facilities must be able to operate under conditions when the water is discoloured and can contain significant amounts of debris. It is usually impractical to try and put a barrier net across the full width of the river/lake upstream of the dam, and hence some diversion system is usually installed to encourage the eels to move laterally so that they can be either captured or encouraged to enter a bypass.

9.9 A number of systems have been trialled, or are in use at New Zealand dams. These include:

a. Submerged lights, which have been trialled as a diversion mechanism in the lower Waikato River. However, high water turbidity associated with increased flows usually meant the lights were ineffective; there is more scope in a large lake if water clarity remains high during floods, although this is unlikely in the Mokihinui hydro lake.

b. A submerged bypass (10 cm diameter), has proved effective at the Wairere Falls dam on the Mokau River. During small floods and freshes, a high proportion of migratory eels located and used the bypass, although at higher flows eels were more attracted to the higher discharges at the spillway. Although there is a cost to generation through lost water, such bypasses only need to operate over relatively short periods of time (e.g. March – May, early hours of the evening). During freshes and floods, a bypass should operate continuously, but the dam will normally be discharging excess water during these times anyway;

c. Spillway discharges; at Patea dam, the bottom-opening spillway gates are opened 80 -150 mm for a 1-2 hour period after dark, usually for three consecutive nights following significant rainfall; during these periods, a high proportion of eels migrate; and

d. Netting; there have been attempts to intercept migratory eels through netting programmes. A large upstream barrier net has been used on the Aniwhenua Dam canal, to capture migrating eels. Similarly, large fyke nets have been used in Lakes Aviemore, Benmore and Waitaki, to capture eels prior to their downstream migration - such eels are then manually transported downstream of Waitaki Dam for release into the Waitaki River. Large fyke nets have also been trialled on Lake Manapouri, to intercept eels prior to their entry into the Manapouri power station. Such netting is labour-intensive though, and until we know more about the swimming habits of migrating eels in large lakes – and improve catch efficiency with stationary nets - an automated system is preferred.

9.10 Trials are planned in the Mokau River for the use of low-voltage electricity, possibly in conjunction with submerged lights; underwater sound systems may also be investigated (these encapsulate sounds within a bubble curtain, and can be used in areas of low background noise to “scare” or divert fish towards a bypass or capture facility).

9.11 Resolution of possible downstream diversion facilities for the MHP will require a “workshop” approach that incorporates information on hydrology (flows and turbidity relationships), biology (behaviour of eels encountering obstacles), and engineering (structural opportunities). At this stage, a subsurface bypass (reinforced by low voltage electricity and possibly night lights to encourage diversion towards such a bypass) leading to a holding cage, would seem appropriate. Until final design of the dam is completed, and all new information on the hydrology and biology assimilated, it would seem premature to commit to a particular solution.

9.12 Irrespective of the system used, an important aspect of the successful deployment is gaining a greater understanding of the local environmental conditions that trigger eel movement. At this stage, the modelling uses information on eel migration patterns and behaviour from other catchments. For improved predictions, it will be necessary to obtain a clearer picture of eel migration timing and patterns in the Mokihinui River during autumn; the best option for this is probably using DIDSON acoustic camera technology in combination with monitoring of environmental factors such as river flow, rainfall, water temperature and turbidity. The monitoring would enable a more effective model to be developed and assist in determining the most appropriate means of diverting eels at flows < 150 m^3/s. As previously noted though, should this monitoring indicate that no significant migrations took place at flows < 150 m^3/s, then there would be little point in installing a diversion system.

9.13 Whilst at this stage the final method or methods to be used to assist downstream passage of migrant eels cannot be determined, the range of available options is such that there is a high degree of confidence an effective method or methods will be available, and the overall effect on downstream migrating longfin eels will not be significant.

9.14 The monitoring and mitigation of any potential effects during the construction stage of the project (including monitoring of elvers and downstream migrating adult eels, operation of the bypass canal, fish stranding) are addressed in the Aquatic Ecology Management Plan.

10. ISSUES RAISED BY SUBMISSIONS

Submission by West Coast Greens, Top of the South Greens, of the Green Party of Aotearoa.

10.1 The submission (p 3) contends that "*catch and carry*" of juvenile eel passage "*has not worked in other areas*". This is incorrect (see section 8.2) as between 3-4 million elvers are caught and transferred upstream annually at over 12 dams and weirs throughout New Zealand.

10.2 The submission concludes that there is little understanding of the migratory stage of the eel life cycle, the methods suggested to facilitate downstream passage are "*woefully inadequate*", and will result in considerable turbine mortality. All these comments are substantially incorrect. A lot is known about eel migrations, although the report acknowledges that there is no substitute for local observation on the environmental conditions associated with eel migrations. The problem of achieving downstream passage of migrating eels at hydro stations is a universal one, with no "silver bullet". The recommended approach represents the best available advice based on observations and modelling undertaken so far (and described in my evidence) and a number of systems operating successfully in New Zealand. The suggested methods include specific (conservative) provision to exclude eels entering the turbines through both intake screens and low approach velocities.

10.3 Page 19 of the submission says *"NIWA admits its abundance estimates are out by about 50%"*. Again this is incorrect. The report states (section 3.5.4) that the difference between biomass estimates from field measurements and a GIS-based model prediction were 13%. The above reference to ± 50% is misquoted from *"The overall agreement is well within the* ***expected*** *[my emphasis] margin of error of ± 50% ".*

10.4 Page 19 of the submission also *says "For NIWA to say that, as numbers in the Grey and Buller Rivers are greater, therefore the Mokihinui population is not so important is to undermine the importance of the Mokihinui population. This is unacceptable"*. Again this is a misrepresentation of what the NIWA report actually said. The report (section 3.5.5), compared overall biomass estimates for the Mokihinui with the nearby Grey and Buller Rivers; we concluded *"When the total biomass is adjusted for size of catchment (kg/km^2), the estimated density of eels in the Mokihinui is substantially less than in either the Grey or Buller Rivers"*. There is **no** comment about relative importance, or any attempt to undermine the significance of the Mokihinui eel stock.

10.5 Page 19 of the submission suggests that in large floods, migrating eels will be flung a further 80 m downstream from the flip bucket. However, the flow model we developed (report section 4.2.8 and subsequent sensitivity tests) did not result in any eels using flows when the flip bucket would operate i.e. the model predicted that all eels would migrate *before* the flip bucket operated.

10.6 The submission then states *"The grating NIWA recommends installing to prevent fish loss to turbine intakes will not prevent most male eels from being sucked into the turbines and diced". It also suggests that achieving an intake water speed of "< 0.5 cumecs" "seems highly unlikely"* (presumably this is meant to read " < 0.5 m/s). In answer to these concerns, the NIWA report suggested that a 30 mm bar spacing might be too coarse, but did not give a recommended spacing. The present evidence suggests that 25 mm spacing would be more appropriate, as this should prevent entry of all male and female migrating longfins. The NIWA report recommended an approach velocity of 0.5 m/s, and this has been adopted as one of the design criteria.

10.7 The issue of *"catch and carry"* is further queried - *"the trap is miserably small"* (despite the NIWA report giving no dimensions), and the suggestion by NIWA to monitor eel migrations is likened to the need to sacrifice *"the whole population… for knowledge of breeding habits"*. This is incorrect, as the NIWA report recommends monitoring of downstream passage as a means of *"gaining a greater understanding of the local environmental conditions that trigger eel movement. Such data can then be used to produce a site-specific prediction of nights when downstream migration is anticipated, thus reducing effort and possibly loss of stored water to operate passage facilities".* The approach NIWA recommends is conservative. If more site-specific knowledge of eel migration patterns is obtained, it may be possible to refine (reduce) or target the times when the "catch and carry" system is required.

Submission by Mrs Metiria Turei, MP.

10.8 This submission has two major concerns regarding eels. The first is that as longfin eels are classified as *"chronically threatened"* and in *"gradual decline"*, the estimate 227 000 eels "represents the potential loss from the impact of the MHP". The second issue disputes the statement in the NIWA report that mitigation measures for eels *"if well designed and implemented, should substantially reduce the potential adverse effects on eel stocks in the Mokihinui River"*, and also mentions the lack of supporting evidence.

10.9 To answer these concerns, eels are listed by the Department of Conservation as a species in gradual decline only (Hitchmough et al. 2007). The potential for the MHP to disrupt eel migrations is a fundamental part of the NIWA report, and considerable attention is drawn to that and to identifying appropriate mitigation. We remain confident that the recommendations we have made will result in a high probability of success for eel passage. In terms of supporting evidence, the NIWA report commented on the improvements made to juvenile eel passage at Patea Dam, and the use of *"catch and carry"* options to transport several million juvenile eels upstream each year. It also noted that migrating eels successfully negotiate the Patea Dam spillway, a very similar design to that suggested for MHP. Migrating eel diversion schemes are in their infancy, and even overseas these are site-specific as *"one size doesn't fit all"*. Thus while the approaches successfully used elsewhere provide guidance, I would expect the best solution for the Mokihinui River eels will be one which has regard to the specific information relating to this river (hydrological, biological, and engineering) which is available at the time the dam is constructed.

South Island Eel Industry Association

10.10 This submission contends that the MHP will adversely affect the upstream migration of juvenile eels (which "*has never properly worked on any other hydro scheme*"), and prevent downstream migration of breeding adults which will in turn adversely affect the sustainability of the freshwater eel fishery. Finally it states that the further monitoring advocated "*proves doubt in their minds that the mitigation measures they [NIWA report] recommend will be effective*".

10.11 To deal with these in turn. The quantities of juvenile eels (3-4 million annually) transported above dams and weirs in New Zealand has already been mentioned. The claim of "*depauperate eel populations upstream of hydro dams (and) large masses of elvers trapped immediately downstream of these dams*" is not supported by any data in this submission. Historically there were aggregations of elvers below dams, and these will still occur at dams with inadequate upstream passage facilities. Certainly improvements are required to facilities at some dams (e.g. Arnold dam on the Grey River), but the system, if well maintained and monitored, has the capability of providing an efficient means of upstream passage. Reasons for "*depauperate eel populations upstream of hydro dams*" could include inadequate passage for juveniles, overstocking, unsuitable habitat (e.g. impact of lake drawdown), and even excessive harvest.

10.12 The NIWA report argues for the importance of maintaining downstream access for migrating eels on the basis that, even though the net contribution of Mokihinui catchment longfins is relatively small (0.2% of the national stock), the national stock is in decline and "*Arguably the most effective freshwater stage to focus on for ensuring sustainability of stocks is the silver (sexually maturing downstream migrant) eel, and its escapement to sea*". Again, a major emphasis of our report is to provide the most appropriate options for ensuring this.

10.13 Monitoring is a responsible corollary to mitigation. The timing of downstream passage of migrating eels is based on modelled data from elsewhere in New Zealand. All models contain assumptions, and it is always preferable to use "local" information than information from elsewhere. The NIWA report proposes that local information is obtained to enable development of an improved model that would result in both better predictions of the timing and extent of eel migrations, and the way that diversion systems are operated to maximise escapement.

11. SECTION 42A OFFICER'S REPORT

11.1 In his review of assessment of effects of aquatic ecology and water quality, Mr. David Cameron concluded that the MHP is likely to have no more than minor effects on native fish populations below the dam, and that because the dam would prevent the migration of fish upstream (including juvenile eels), and downstream (migrating adult eels), the passage of such fish past the dam should be assisted. He concluded that there was insufficient information on the likely performance of both up and downstream trapping methods "*to reliably determine whether the potential effects on these populations would be minor or more than minor*".

11.2 In response, I refer to paragraph 9.3 where I state that capture of upstream migrating juvenile eels is carried out at more than 12 sites throughout New Zealand, with over 10 years experience at some sites. The location of the intake to such ramps and traps is critical to their success, so until further design plans are available, it is not appropriate to attempt to provide firm details.

11.3 The diversion and capture of migrating eels is a more difficult issue, as migrations generally occur during floods when capture conditions can be challenging. Also there is no universally accepted mechanism to divert migrating eels (see paragraph 9.9). In the present situation, a "workshop" and adaptive management approach has been adopted (see paragraph 9.11) that will enable collation of relevant hydrological, biological and structural data. Most eels (approximately 67%) are expected to migrate at flows < 150 m^3/s,and the suggested option to divert them to a holding facility involves use of lights and/or electricity; at flows < 150 m^3/s, the remaining 40% of migrating eels are expected to use the spillway. In addition to the above, migrating eels will be excluded from entering the penstocks by installation of intake bars during the migration season.

11.4 While it is inappropriate to attempt to establish firm design criteria at present, I am confident that with the commitment of Meridian to use the best available information to design and implement a site-specific diversion and capture (“catch and carry”) system, then potential negative impacts on migrating eels will be minor.

Mr Cameron also noted that:

- Construction effects on native fish had not been assessed.
- There is risk of the combined effects of increased periphyton biomass, increased bed armouring, and reduced invertebrate habitat reducing food production for native fish downstream of the dam.

11.5 Construction of the MHP and disturbance of instream habitat, a potential increase in fine sediments and the diversion could have potential effects on native fish. Provided the construction process is undertaken carefully to minimise potential effects and in accordance with the Environmental Construction Management Plan, potential effects on native fish should be no more than minor. Therefore it is appropriate that possible construction effects and the other issues raised by Mr Cameron are addressed through the Aquatic Ecology Management Plan prepared by Meridian and submitted to the Consent Authority. The plan includes measures to mitigate any adverse construction effects, to monitor periphyton in the river downstream of the dam site, to monitor macroinvertebrate and native fish communities downstream and upstream of the dam site, and to monitor the catch and transfers of native fish, to refine and maximise the effectiveness of the proposed mitigation measures.

12. CONCLUSIONS

12.1 The eel stock of the Mokihinui River is comprised almost entirely of longfin eels, and characterised by relatively large size and high density, regular recruitment and slow growth. My estimate is that the longfin eel population in the Mokihinui River represents 0.2% of the national stock, but on the basis that this species is in "gradual decline" and therefore of some conservation importance. I have recommended mitigation measures which I believe will ensure the Mokihinui longfin eel population is sustained and the effects of a dam will be minor.

12.2 Trap-and-transfer of upstream migrating juvenile eels (elvers) is comparatively simple. Experience gained at other hydro stations will ensure that such a system will operate effectively.

12.3 Longfin eels are found in both riverine and lake habitats, and the creation of new lake habitat should offset the loss of riverine habitat, with little change in eel stocks.

12.4 Facilitating safe downstream passage of migrating eels is a more challenging but solvable issue. An understanding of the numbers of eels actually migrating under given flow conditions would assist in the design of appropriate facilities (for the flow band < 150 m^3/s). Current thinking would involve a subsurface bypass and possibly low voltage electricity or arrays of lights to reinforce diversion of eels to this bypass.

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Table 1: Mean lengths of fyke netted longfin eels from other South Island waterways. ** = regularly fished reach; * = seldom fished reach

Location	N	Length (mm) Mean	SE	Range	Reference
West Coast Rivers					
Mokihinui River	421	677	7	288 - 1160	Present study
Company Creek	211	766	18	250 - 1330	NIWA unpubl. data
Lake Rotoiti [1]	107	705		398 - 1203	Jellyman 1995
Buller River	282	532	5	410 – 930	Beentjes and Chisnall 1997
Grey River *	210	516	6	410 - 1050	Beentjes 1999
Grey River **	106	702	14	440 – 990	Beentjes 1999
Hokitika River	109	548	7	440 – 930	Beentjes and Chisnall 1997
East and South Coast Rivers					
Upper Clutha River and lakes [2]	2687	837	3	300 - 1220	NIWA unpublished data
Taieri River **	185	532	5	430 - 1100	Beentjes 1999
Taieri River *	218	619	7	470 – 950	Beentjes 1999
Mataura River	885	517	2	430 - 1050	Beentjes 1999
Oreti River	570	534	3	350 - 1090	Beentjes 1999
Waimakariri River	183	579	7	450 - 1030	Beentjes 1999

[1] = in National Park; [2] = data from 1949.

Table 2: Summary of nightly catches (number and weight) of longfin eels from fyke net sites in the Mokihinui River

	Night 1		Night 2		Night 3		Totals	
Site (no. of nets fished)	No.	Kg	No.	Kg	No.	Kg	No.	Kg
Mainstem at Rough and Tumble Creek (7)	25	35.26						35.26
Mainstem at Maori Stream (7)	14	11.95						11.95
Mainstem at Lake Perinne (7)	31	30.20						30.20
Lower North Branch (7)	41	48.27						48.27
Upper North Branch (6)	28	14.78						14.78
South Branch at Forks Hut (7)	85	149.06	18	16.14	38	32.21	141	197.41
Middle South Branch (6)	59	61.06					59	61.06
Upper South Branch (6)	82	58.51					82	58.51
Total	365	409.09	18	16.14	38	32.21	421	457.44

Table 3: Estimated biomass (tonnes) of longfin eels in selected South Island rivers (excludes lakes in these catchments). * = upstream of proposed dam.

River	Upper reaches protected	Small streams	Total not fished	Open to commercial fishing	Total biomass	% not fished	Biomass upstream of dams	Kg/km^2
Mokihinui*	11	1	12	11	23	52	0	32
Grey	19	37	56	185	241	23	49	61
Buller	47	32	79	241	320	25	0	49

Table 4: Estimated population structure of longfin eels in the Mokihinui River derived from the simulation model, including the average number of male and female eels maturing and migrating each year.

	Size class	Number	Mean Wgt. (g)	Tonnes
Population	Small (<150 mm)	69206	2	0
	Medium (150-299 mm)	97020	26	3
	Large juveniles (300-399 mm)	31749	90	3
	Adults/Males (400-699 mm)	24747	322	8
	Females (>700 mm)	4933	1852	9
	Total	227655	99	23
Migrants per annum	Adults/Males (400-699 mm)	660	442	0.3
	Females (>700 mm)	115	3547	0.4
	Total	776	900	0.7

Table 5: A summary of environmental parameters associated with migrations of silver eels in New Zealand.

Author	Rainfall/flow	Lunar cycle	Pressure changes	Temperature
Downes 1918	During floods	Not moonlit nights		
Best 1928	During early stages of floods	Not moonlit nights unless raining		
Cairns 1941	During floods			
Burnet 1969	Largest runs always associated with rain	Low catches on full moon	Depressions important but could not dissociate from rain/water level	
Todd 1981	Largest runs always associated with rain	Low catches on full moon	Important when associated with rainfall and dark moon phases	
Boubée et al. 2001	Floods primary stimulant	No obvious effect	No obvious effect	No thresho temperature, but < 11^{o}

			inhibiting
Watene, Boubée and Haro 2003	Largest runs associated with rain	Most movement during new moon	
Boubée and Williams 2006	Rainfall main stimulant	No obvious effect	

Table 6: Proportion (%) of time that flow bands occur, and eels are predicted to migrate during these flows.

Flow band	**Time in flow band (%)**	**Eels moving in flow band (%)**
A. < 150 m^3/s	81	67
B. 150 – 1200 m^3/s	17	33
C. 1200 – 150 m^3/s	1.0	0
D. > 1200 m^3/s	0.5	0

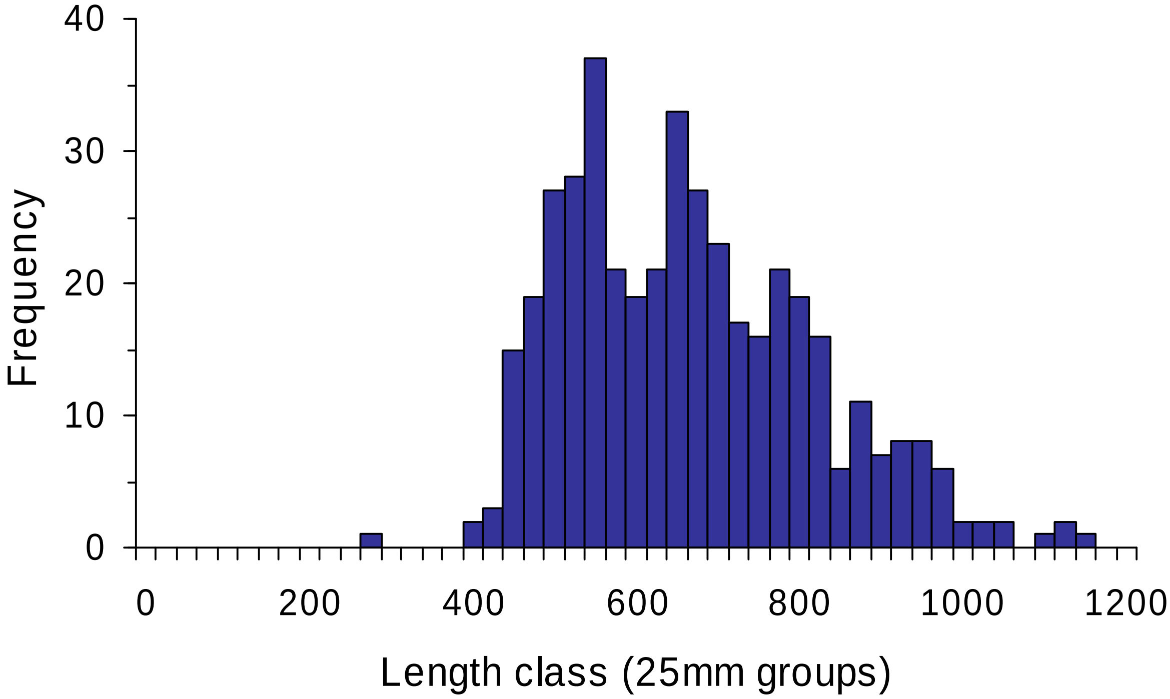


Figure 1: **Length-frequency of longfin eels caught by fyke netting in the Mokihinui River, March 2006.**

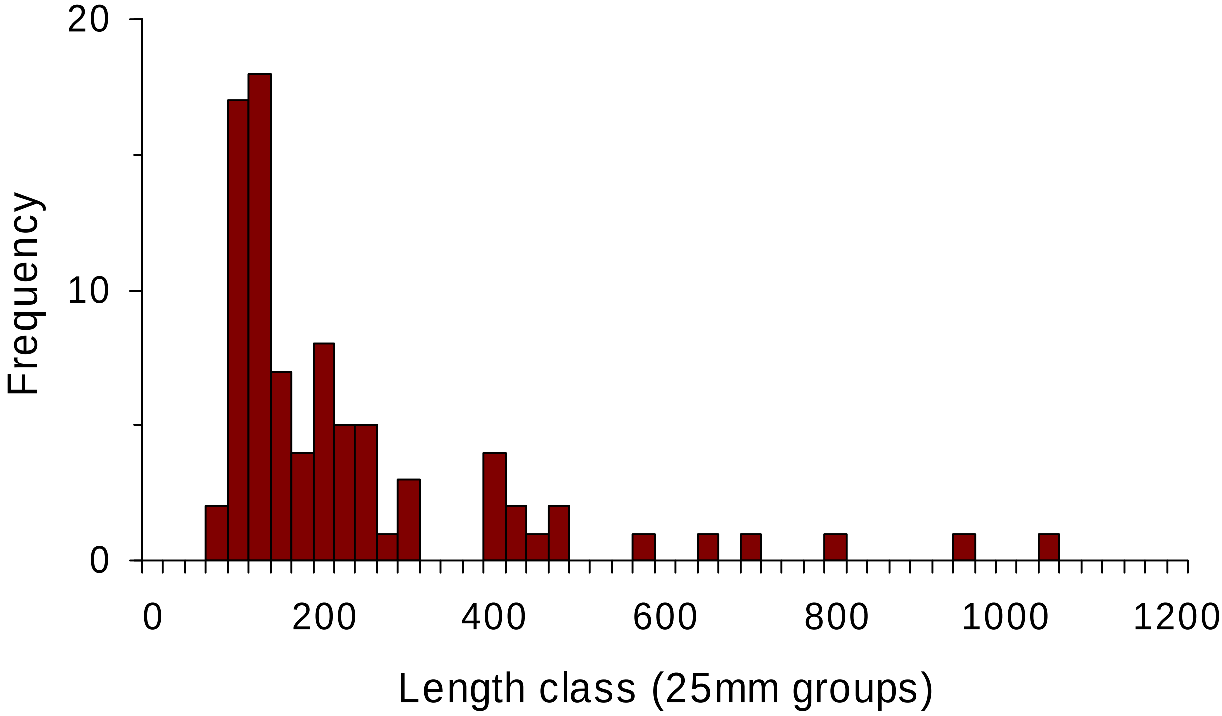


Figure 2: **Length-frequency of longfin eels caught by electrofishing in the Mokihinui River, March 2006.**

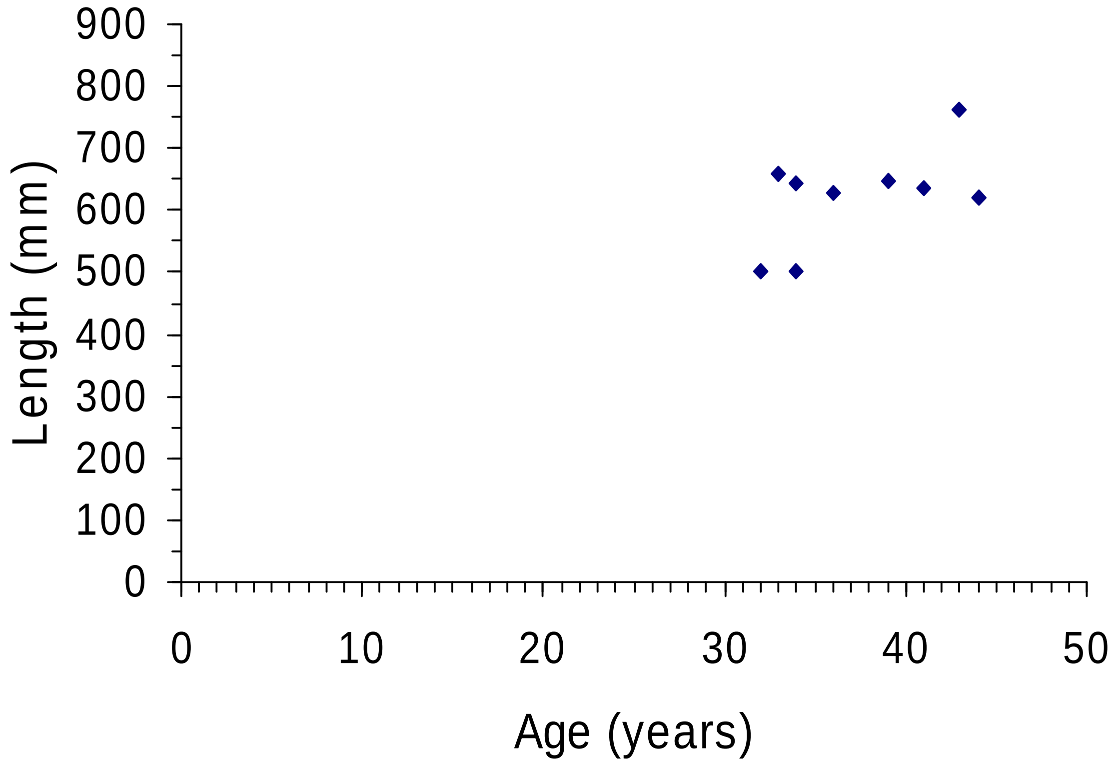


Figure 3: The relationship between the length and age of longfins from the Mokihinui River.

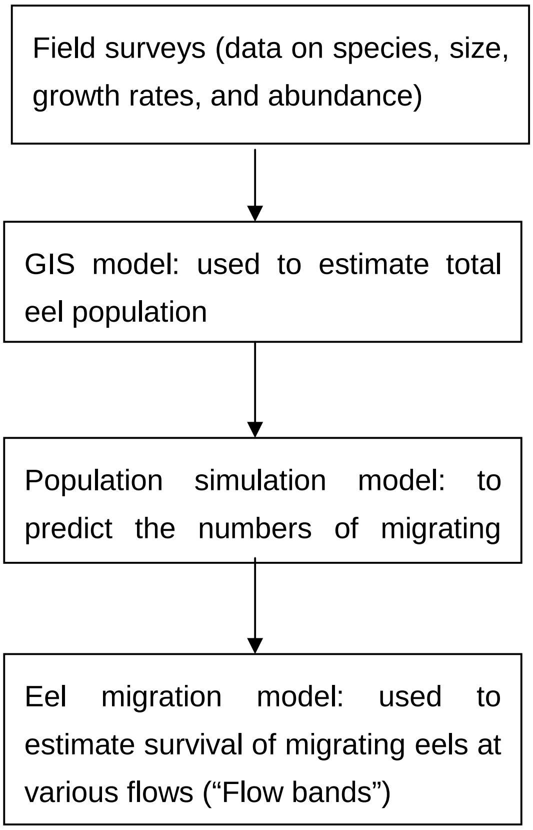


Figure 4 . **Sequence of development of models to predict the effects of hydro development on migrating eels in the Mokihinui River**

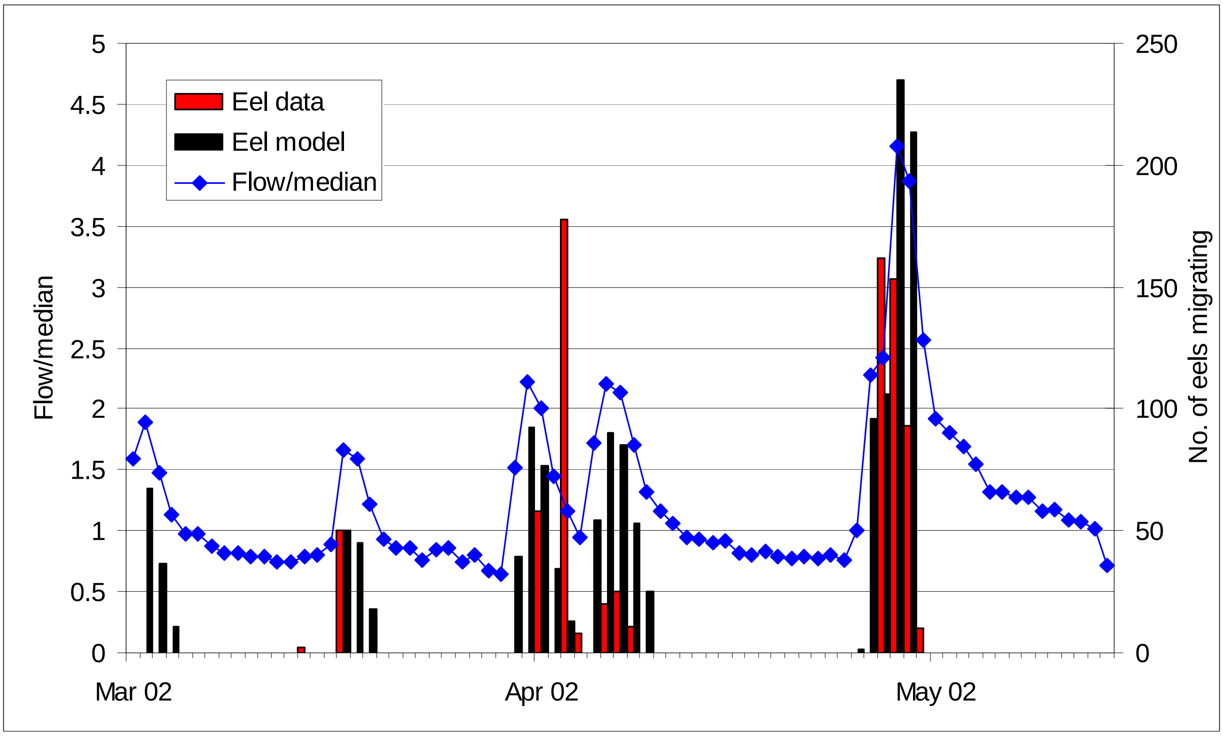


Figure 5: **Actual and predicted catches of silver eels at the Wairere Falls power station, 2002.**

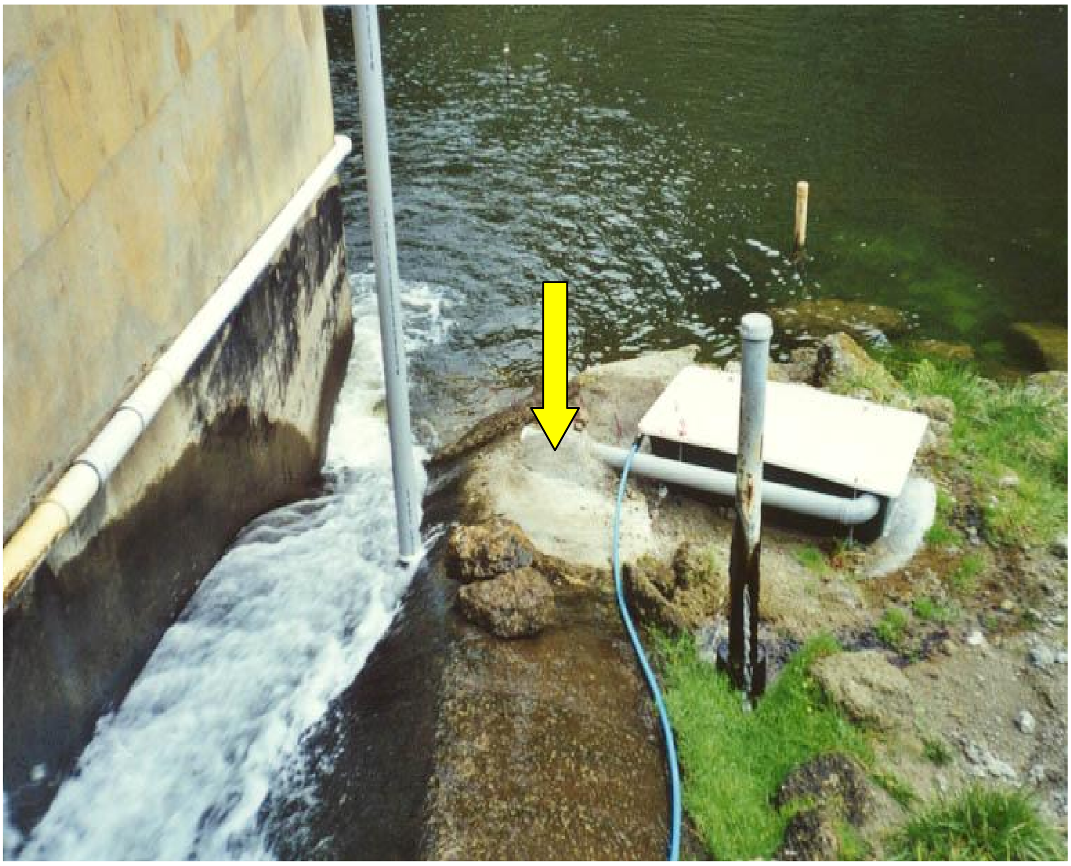


Figure 6: **Elver trap at the base of Patea Dam. The arrow shows the ramp that the elvers climb**

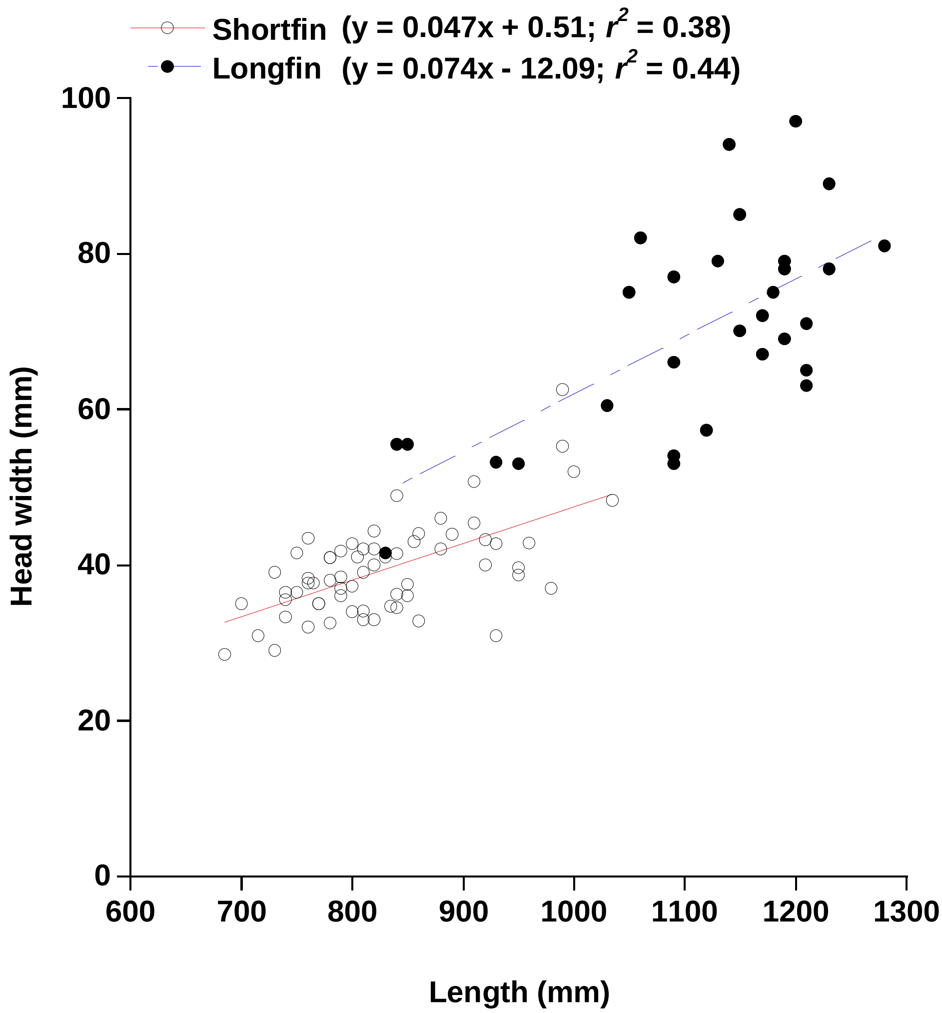
Appendix 2. Results of sensitivity tests of the eel migration model

Because of uncertainties in assuming that eels would respond to environmental changes in the Mokihinui River in a similar way they respond in the Rangitikei River (Aniwhenua Dam), the sensitivity of the models to varying the parameters was then tested. Results (Table 6) confirmed that Bands A and B were the flows when eels were most likely to migrate, and the proportions of eels migrating in these bands did not vary greatly with changes in the model parameters. As there were no eels moving during receding floods when the flip bucket would operate (flows < 1200 m^3/s), further sensitivity tests were run to estimate flip bucket threshold flows on receding flows. The results indicated that even if there were eels available (i.e. eels that hadn't migrated during the rising flood flows), the proportion being "flipped" would be very low, and range from nil at 1200 m^3/s, to 7-8% at 600 m^3/s. However, while this illustrated the low likelihood of eels encountering flows where the flip bucket would operate (and then only as flows fell to < 900 m^3/s), this scenario is not predicted to take place as all eels migrate at flows before the flip bucket operates.

Appendix Table 1: Sensitivity testing of the eel migration model: Proportion (%) of migrant eels estimated to migrate on the Mokihinui River. ***Note that data represent a typical year. Ranges represent estimated limits from testing the sensitivity of the model for each of the four factors.***

Flow band	Cap values	Threshold flow	Migration flow limit	Flood duration
< 150 m^3/s	65 – 67	67 – 78	65 – 71	65 – 70
150 – 1200 m^3/s	33 – 35	22 – 32	29 – 35	26 – 35
1200 - 150 m^3/s	0	0	0	0
> 1200 m^3/s	0	0	0	0 – 2

Appendix 3. Eel length-head width relationship



Appendix Figure 1: Eel length and head width relationship of migrant shortfin eels (*Anguilla australis*) and longfin eels (*A. dieffenbachii*) collected from the Wairere Falls Power Station, New Zealand, 2002–2003 (J. Boubée, NIWA, unpubl. data)