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EXECUTIVE SUMMARY

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The aim of this project (EEL2003/01) is to make recommendations on the feasibility of estimating non-fishing eel mortality from hydroelectric turbines and other point sources such as, dams, culverts, and drain clearance.

Information on drain clearance practices throughout New Zealand was obtained from regional councils, and the literature and internet searched for any relevant studies on the effects of these activities on stream communities, particularly eels. From replies to a questionnaire to regional councils, the estimated total length of waterways cleared in New Zealand each year is 15 500 km, most of which is drains (66%), stockwater races (19%), and natural waterways (12 %). Three councils are responsible for nearly half the total length of waterways cleared in New Zealand: Environment Waikato (22%), Selwyn District Council (16%), and Environment Southland (11%). The frequency with which waterways are cleared is highly variable, ranging from several times per year to every 10 years, or "as required", and the most common methods used are herbicide spray and mechanical excavation. Less common methods include hand-cutting weeds and mechanical cutting using weed-boats. The total annual cost to regional and district councils to maintain waterways is about $5.8 million. Drain clearance results in a highly variable and unstable environment, providing poor habitat for many native fish species, although eels may be less adversely affected. The few published studies in New Zealand on the effects of mechanical or chemical drain clearing on mortality of eels have been inconclusive. However, anecdotal reports indicate that eels are frequently scooped out of drains by mechanical excavators and dumped on the bank side, where they die if they are unable to return to the watercourse. Estimating the number of eels killed by drain clearance operations requires information on 1) the extent of managed waterways, and knowledge of the type and frequency of clearance, 2) estimates of eel mortality associated with the major types of clearance, and 3) extrapolation to provide estimates of the total eel mortality throughout New Zealand associated with major types of waterway clearance. Possible methods to achieve these estimates are outlined.

A significant proportion of longfin female eels in habitats affected by anthropogenic in-stream barriers is unable to reproduce. To determine the proportion of migrant eels affected, an estimate of the reproductive output from each catchment is required. Where the only downstream route is through turbines, models to estimate mortality can be used to estimate the percentage of migrants able to survive passage. Where other routes are available (e.g., through a bypass or spillway), information on average river flow, flood flows, extracted flow, and storage capacity, can be used to determine the frequency of spills and thus the probability that migrant eels are able to use the spillway/bypass route. Where spilling is frequent, a large proportion of migrants may be able to use this route, although survival estimates during passage with flood flows are lacking. Obtaining a better estimate of eel mortality from anthropogenic barriers will require data on timing of the migration and estimates of the number and size of migrant eels produced by the upstream catchment. With knowledge of the characteristics of the barrier it would then be possible to estimate the proportion of migrants able to safely pass. Until most of these parameters, notably biological factors, can be measured accurately, we consider it appropriate to assume that eel populations upstream of major hydro dams, major water reservoirs, and flood pumps do not contribute to the reproductive output of the population.

We conclude that it is feasible to estimate non-fishing eel mortality from drain clearing, hydroelectric dams, and other point sources. Methods to achieve this are documented.

1. INTRODUCTION

1.1 Eel resource

The longfin (*Anguilla dieffenbachia*) and shortfin (*A. australis*) eels are important to both commercial and customary fishers. While the extent of the customary harvest is uncertain, Licensed Fish Receiver returns for the commercial fishery in 2000–01 totalled about 1079 t. However, concerns have been expressed about the well-being of longfins (Jellyman et al. 2000b, Hoyle & Jellyman 2002), and "for most areas it is not known if recent catch levels are sustainable or are at levels that would allow the stock to move towards the size that will support the maximum sustainable yield" (Annala et al. 2004). In addition to high levels of fishing mortality, eels are also subject to both direct and indirect mortality from non-fishing human activities (anthropogenic mortality). These include mortality resulting from drain clearing and during downstream migration through hydroelectric turbines and other anthropogenic barriers.

The effects of hydroelectric power generation, barriers to migration, and drain clearing on eel mortality have not been investigated in New Zealand. The aim of this project is to make recommendations on the feasibility of estimating eel mortality from these factors.

1.2 Waterway modification in New Zealand

The New Zealand landscape has been highly modified over the last 150 years with vast wetlands drained and native forests clear-felled to create pasture. Only one-quarter of New Zealand's native forests remain. Before human habitation in New Zealand, vegetation was abundant along the banks of all streams, rivers, and lakes. Streams in forested areas were characterised by high levels of shade, cool water, and a constant supply of organic material such as leaf litter and wood (Figure 1). The land adjacent, riparian zone, can be thought of as a buffer between the terrestrial and aquatic environments (Quinn 1994). The riparian zone has a number of functions in maintaining stream health, including buffering land-based processes by intercepting runoff, stabilising stream bank and stream bed morphology (particularly during flooding), providing shade, and maintaining a healthy environment for in-stream fauna and flora (MacGibbon 2001, Parkyn & Davies-Colley 2003) (Figure 2).

In an attempt to create more productive farmland, wetlands and low-lying pastoral areas in New Zealand were, and continue to be, drained by modifying existing streams or creating artificial surface and subsurface drains. Wetlands act as giant sponges, retaining large volumes of water which are slowly released in times of drought (McDowall 1990). Ecological benefits include buffering of floods, providing nutrient for wetland flora and fauna by settling organic matter, and converting dissolved nitrate into atmospheric nitrogen (denitrification). The purpose of drains is to increase the rate of surface runoff, thereby lowering the water table, and to reduce the impacts of floods. To ensure a consistently high flow, meandering streams are straightened, riparian vegetation is often removed, and aquatic vegetation is periodically cleared (Figure 3). Modified streams typically lack pools, riffles, debris such as logs and boulders, and there is little overhanging cover from undercut banks or riparian vegetation. Depth is virtually constant along the length to ensure maximum flow. Run-off into these drains is often nutrient-rich and can contain high sediment load, particularly during heavy rainfall. As a consequence of settlement ingress, drains gradually become shallower, while sediment accumulation and high nutrient content can lead to prolific growth of aquatic weeds, accelerating sediment trapping and reducing flow.

Wetlands covered at least 670 000 ha before European settlement, but have now been reduced to about 100 000 ha (Ministry for the Environment 1997), representing a loss of 85% to farming, urban development, hydro reservoirs, and flood control. Estimates of remaining wetland in Southland are

37%, Waikato 25%, Rangitikei Plains 2%, and Bay of Plenty less than 1% (MacGibbon 2001). In Canterbury, Te Waihora (Lake Ellesmere) was formerly twice the current size of 200 000 ha. (www.doc.govt.nz/Community/001~For-Schools/003~Field-Trips/010~Canterbury/Te-Waihora-Lake-Ellesmere/010~The-Natural-Landscape.asp).

Wetlands drainage has resulted in greatly reduced available habitat for eels, particularly shortfins which prefer slower-flowing coastal habitats such as lagoons, estuaries, and lower reaches of rivers. Channeling natural streams and creeks into drains has substantially modified the habitat, although these often remain productive areas for eels. Eels prefer habitat that offers cover and in the modified drains aquatic weed provides both daytime cover and nighttime foraging areas. Loss of weed and natural debris can thus result in significant displacement of eels to other areas. If mechanical means are used to clear drainage channels and watercourses, there is a high probability that eels will be scooped out onto the banks, and left to die. A proportion of the population may also receive fatal mechanical injuries.

1.3 Barriers to downstream migration

Concerns about declining eel abundance, and development of management initiatives to reverse the decline, have elevated interest in the effects of anthropogenic barriers on eel migration (Richkus & Dixon 2003). Although the problem of upstream passage is now well recognised, and means of allowing juvenile eels to reach upstream habitats have been provided at most barriers, the population as a whole remains unsustainable unless sufficient sexually mature adults are able to reach the sea to spawn. The issue of downstream passage appears the more important when one considers that upper catchment populations contain a predominance of large females, and therefore bearers of the greatest number of eggs (Aprahamian 1988, Chisnall & Hicks 1993). Lower catchments, where barriers are less prevalent, tend to support mainly males.

Hydroelectric dams alone have blocked access to 35% of the total longfin habitat in New Zealand, an area capable of sustaining a biomass of about 3 614 t of longfin eels (Graynoth in press). Although natural barriers historically excluded eels from many river systems now exploited for hydro generation (e.g., Arapuni Gorge on the Waikato), major dams have reduced access to riverine habitat that would have been capable of sustaining a biomass of about 460 t of eels in the North Island and about 1200 t in the South Island (Graynoth in press). This represents 12% of the 13 400 t of eels estimated to reside in New Zealand rivers. These results indicate that anthropogenic barriers have significant effects on both the upstream and downstream migration of eels, particularly for longfins. The effect is amplified when one considers that Lakes Te Anau and Manapouri (Fiordland National Park) provide about 73% of New Zealand's longfin eel lake habitat protected from fishing pressure. Even if unimpeded upstream passage was possible, the area would contribute little to spawning escapement if mature eels migrate through West Arm Power Station on their way to spawning grounds (Beentjes et al. 1997).

1.4 Objectives

Overall objective

To estimate the non-fishing mortality of freshwater eels (*Anguilla* spp.).

Specific objective

To undertake a feasibility study on establishing an estimate of the mortality of eels caused by hydroelectric turbines and other point sources of mortality caused by human activity.

2. METHODS

2.1 Drain clearing

To quantify the extent of waterways cleared and methods used, a questionnaire (Appendix 1) was sent to all regional councils in New Zealand. Obtaining returns from all councils sometimes required sending additional questionnaires and multiple phone calls. Eventually responses from all areas were received. Some questionnaires were followed up with a less formal verbal interview. Information on waterway category (drain, natural waterway, stockwater, race etc.), length (km), frequency of clearing, methods used, costs, and comments were requested. For some areas we were informed that district councils within the larger regional council boundaries are responsible for waterway management and these were contacted where appropriate. The term 'drain clearing' is frequently used generically to describe the practice of removing silt and weeds from waterways, whether natural or modified, and this terminology is also used in this report.

We reviewed national and international literature on the effect of habitat modification and drain clearing/channelisation on the ecology of stream communities, including eels and other fish. An internet search was also carried out to locate 'grey' literature and miscellaneous reports on drain clearing activities in New Zealand, specifically any studies that dealt with mortality of eels and other fish.

We provide recommendations on the feasibility and methods to estimate eel mortality from drain clearing throughout New Zealand.

2.2 Barriers to downstream migration

We reviewed national and international literature on potential effects that anthropogenic barriers such as hydro dams have on downstream migration of eels. We then use Patea Dam as a New Zealand case study, and provide estimates of mortality through turbine and spillway passage. Recommendations are provided on the information required to better estimate eel mortality from anthropogenic barriers.

3. RESULTS AND DISCUSSION

3.1 Drain clearing

3.1.1 Management of waterways in New Zealand

Maintenance of all natural waterways, including those modified into drains, is the responsibility of the regional councils under the Resource Management Act (RMA) – they have a statutory obligation to avoid, remedy, or mitigate adverse environmental effects on waterways. As a rule, however, regional councils only maintain waterways that have a wider community benefit and thus would not have involvement in individual farm properties. Landowners seeking to modify a natural waterway must apply to their regional council for permission. Approval to modify a natural waterway can be carried out pursuant to a permit (if the effect is thought to be small), or as either a notified or non-notified consent if the effect is more wide ranging. If the work proceeds through a consent process, all interested parties (public, landowner, Department of Conservation, Fish & Game New Zealand, iwi, Commercial Eelers Association, etc.) are generally consulted before the consent is approved or declined. For larger natural waterways, regional councils generally use a 'catchment wide consent' that enables work to be carried out when required, e.g., catchment work on the Taieri and Clutha Rivers. It is desirable that drain clearing is controlled by regional councils so that codes of practice can be implemented to minimise the environmental damage to both the habitat and wildlife.

Land users and regional councils are becoming increasingly aware of sustainable land and water management practices. For example, the Ministry for the Environment has published a guide for managing waterways on farms, emphasising sustainable water and riparian management (MacGibbon 2001). Environment Waikato[1] and the Otago Regional Council[2] have produced similar documents for local landowners. The Wellington Regional Council (Masterton Division) applies a condition on resource consents issued to farmers clearing drains that fish and eels removed must be returned to the stream, and have also coordinated a working group including farmers and operators to develop best practice methods (Liz Burge, Wellington Conservation Board, pers. comm.). Other regional councils to have implemented codes of practice or environmental guidelines include Bay of Plenty, Hawke's Bay, Waikato, Canterbury, and Marlborough (Hudson & Harding 2004).

Guidelines for drain clearing suggested in the draft Ngati Kahungnunu Rohe Eel Management Plan (Anonymous 2003) include use of a grab bucket (bucket with slotted base that removes only weed but allows eels and other fish to pass through); employing only trained and experienced digger operators who understand the value of waterways and how to minimise damage; restricting clearing to summer, when eels are most active and able to recover, and selective clearing of weeds from one side of the drain, alternating between years. The Department of Conservation has recently provided an extensive list of channel clearing practices that would reduce environmental impacts and restore natural features to streams (Hudson & Harding 2004).

The benefits of healthy waterways have been convincingly demonstrated in experimental studies on 'constructed wetlands' which have been shown to intercept runoff from dairy farms and reduce markedly the nutrient export from intensive grazing, particularly nitrogen (Tanner et al. 2005). Many regional councils actively encourage dairy farmers to provide a fenced buffer strip along natural waterways to prevent stock from entering waterways, promote growth of the riparian vegetation, and stabilise banks (Figures 4 and 5). The Otago Regional Council estimates that about 80% of waterways are currently inaccessible to dairy stock, and have a target of 100% exclusion by June 2005.

3.1.2 Regional council survey

Questionnaire responses were received from 26 regional and/or district councils representing virtually the entire country. The information provided in the questionnaires in unlikely to include all work carried out by farmers on private properties. For example, in the Waikato it was estimated that only 50% of drains are administered by Environment Waikato, with the remainder being farm drains managed by land owners. However, most farm drains are ephemeral, and hence do not provide significant fish habitat.

The total estimated length of waterways cleared in New Zealand each year is about 15 500 km (Table 1), most of which (66%) are drains followed by stockwater races (19%, all in Canterbury), and natural waterways (12%). Three councils are responsible for nearly half the total length of waterways cleared in New Zealand: Environment Waikato (22%), Selwyn District Council (16%), and Environment

[1] A guide to Managing Waterway on Waikato Farms (www.ew.govt.nz/ourenvironment/water/documents/cleanstreams.pdf).

[2] Environmental considerations for clean streams: a guide to managing waterways in Otago

Southland (11%). The frequency with which waterways are cleared is highly variable, ranging from several times per year to every 10 years or as required. Thus, disturbance to waterways is a function of frequency. For example, drains maintained by the Christchurch City Council are cleared several times a year, but those maintained by Environment Waikato are cleared only every 10 years.

A wide range of methods is used to clear waterways of which the most common are herbicide spray and mechanical excavation using a digger or backhoe. Less common methods include hand cutting, mechanical cutting using weed-boats, grass carp, and flushing with seawater. Mechanical excavators are used as necessary to remove accumulated debris and silt. Most councils have codes of practice or policies to minimise disturbance to waterways (Appendix 1). A common practice is to clear only sections of the waterway or one side each time and to leave the banks intact. A few councils also require contractors to return any eels and other fish that may be removed from the water. Less invasive methods, such as spraying and weed cutting, are used up to several times per year in some areas. Several Councils have commissioned studies on the ecology of waterways in their area (Appendix 2).

The costs to New Zealand regional and district councils to maintain waterways varies greatly, depending on the length of waterways cleared, frequency, and the method used, but total about $5.8 million at an average of $240,000 per region. Hand clearing and mechanical excavation are the most expensive method, estimated by one council at about $4.00 and $2.50 per metre, respectively, compared to only $0.23 per metre for spraying. Cost estimates vary between regions and much of the work is contracted out. Comments recorded on the questionnaire are given in Appendix 2.

3.1.3 Literature review

3.1.3.1 Implications of habitat modification on stream ecology

Several studies have examined the effects of habitat degradation on freshwater fish communities in streams and rivers. Niemi et al. (1990) reviewed 150 case studies on the response of freshwater systems in the United States to disturbance or stress such as application of herbicides, flooding, dredging, drought, logging, and channelisation (i.e., drain clearing). They concluded that channelisation had the severest effect on fish and macroinvertebrate communities with recovery times as long as 52 years. Similar conclusions have been reached in other studies, with progressive channelisation of tributaries believed to be one of the key factors in the reduction in density and distribution of many fish species (Granado-Lorencio 1991, Gammon & Gammon 1993, Shields et al. 1995).

The immediate effect of channeling a naturally flowing stream and removing macrophyte beds is a decrease in overall depth and an increase in current velocity (Kaenel & Uehlinger 1998). Periodic drain clearance thus creates highly variable and unstable habitat for both fish and invertebrate communities, which are prone to large-scale swings in flows between dry and flood conditions. Fish communities in the Connecticut River streams in the United States are less stable and less complex in environments with highly variable flow and unpredictable flow regimes (Bain et al. 1998). In Australia, a dramatic decline in native fish species, including eels in the Murray-Darling River system, has been attributed to a range of factors, including habitat degradation, water flow regulation and extraction, pollution, and introduction of exotic fish species (Fisher 1996).

The effects of large-scale habitat loss and modification on eels and other native fish species in New Zealand are clearly significant, but difficult to quantify. Native fish diversity and abundance in Waikato River tributaries is related to habitat type, and is higher in pastoral streams directly below forest than in streams flowing directly through indigenous or native forest (Hanchet 1990). In a similar study on distribution and abundance of native fish species in 16 tributaries of the Waikato

River, of 12 fish species caught, most were low in abundance and patchy in distribution (Swales & West 1991). Only longfin eels and common bully were abundant and widely distributed, and the conservation status of other species was listed as either rare or endangered. The reasons given for the low abundance included loss and degradation of habitat from native forest clearance, wetland drainage, and agricultural development. Eels appear to benefit from the conversion of forest to pasture. Hicks et al. (2004) showed that fish biomass (eels made up 96–99% of the biomass) in pasture streams was between 81 and 90 g/m^2, compared with only 19–20 g/m^2 from plantation forest streams, and 13 g/m^2 from native forest streams;. Thus, pastureland streams maintain a much higher biomass of eels than forested streams, mainly due to increased light levels, water temperatures, and more dissolved inorganic nitrogen.

Habitat requirements of eels differ from those of native and introduced fish species, and eels appear to be less adversely affected by habitat degradation. For example, trout have largely disappeared from the Horokiwi Stream where they were plentiful in the 1940s (Allen 1951), but eel numbers appear to be unaffected (Jellyman et al. 2000a). The loss of trout is attributed to progressive habitat modification. Similarly, longfin eels remain abundant in Waikato River tributaries despite a decline in other native fish species (Swales & West 1991). Eels therefore appear to be very adaptable with the need for cover, which may have historically been provided by overhanging banks, logs, and pools in natural streams, often being met by dense aquatic macrophyte beds common in nutrient-rich farm drains. Unlike many other native fish species, eels do not lay eggs in the streambed, as spawning occurs at sea. Thus, eels are probably able to inhabit more marginal habitats. Both eel species display considerable 'ecological plasticity' (Glova et al. 1998) with respect to habitat choice. Longfins are generalists, occupying a wide range of habitats, except swamps. Shortfin are restricted to lowland lakes, swamps, and slow flowing water.

3.1.3.2 Mortality of eels during drain clearing

As described above, drains are periodically cleared of silt and/or aquatic macrophytes to improve water flow. Aquatic macrophytes can be removed by various methods such as mowing, cutting or application of aquatic herbicides, but these methods do not remove silt build-up. The only practical method to achieve this is with a mechanical excavator using a bucket attached to a hydraulic arm. The excavator operates from the stream bank and the spoil is dumped along the edges of the bank. During this procedure, invertebrates, eels, and other fish are often picked up and deposited on the bank along with the silt and macrophytes.

Few published studies have attempted to quantity or document the effects of mechanical or chemical drain clearing on mortality of fish and eels. Goldsmith (2000) compared the response of fish populations in small Southland streams to the effects of mechanical and chemical clearance of macrophytes. Fish populations were sampled before and six weeks after clearance of macrophytes. The main conclusion of the study was that native fish populations, which included longfin and shortfin eels, upland and common bully (*Gobiomorphus brevicus, G. cotidianus*) common river galaxias (*Galaxias vulgaris*), inanga (*G. maculatus*), and giant kokopu (*G. argenteus*), were unaffected by macrophyte removal by either mechanical clearing or chemical spraying, i.e., fish species richness, total density and individual density, were not significantly different before and after macrophyte clearance.

As part of a study, on the biological effects of dairy farming on water quality on the Toenepi Steam catchment in the Waikato, channel morphology, vertebrate and invertebrate communities, and water chemistry was compared before and after clearance of the stream using a mechanical excavator (NIWA, unpublished data). Fish species were not quantified, but eels were observed returning to the stream with few eels killed at the time; however, no eels were noted in the stream on subsequent visits over the next 9 months.

In a study carried out in the United States, Serafy et al. (1994) concluded that mechanical harvesting of macrophytes has only a short-term and minor impact on fish assemblages, but between 11 and 22% of fish are killed during the mechanical clearing process.

These results suggest that while mechanical excavation results in marked changes to the channel morphology and invertebrate communities, the indirect effects on eels and other fish are not as clear. The only dedicated study (Goldsmith 2000) suggests that the effects of both mechanical drain clearing and spraying on fish populations is only short term and recovery occurs within weeks.

Mortality of fish and eels as they are physically removed and dumped on the stream bank has not been quantified. Photographic evidence shows hundreds of eels dumped on the sides of farm drains following mechanical drain clearing in the Wairarapa (Anonymous 2002) (Figure 6). Eel mortality during drain clearing depends on whether the spoil is dumped in mounds or as a continuous wall along the banks of the drain. If the latter, then eels dumped on the outer side of the wall are unable to make their way over the mud wall back into the drain, and invariably die. Some eels remain in the excavated mounds where they may stay alive until the mud dries up, but when the spoil is spread evenly along the bank eels are able to escape back into the stream (Kelly Davis, pers comm.). Selwyn catchment residents report that harriers (*Circus approximans*) often follow the dragline around, in anticipation of being able to catch eels stranded on river banks.

A New Zealand company (Rotec Ltd) based in Hamilton has developed a rotary excavator which can be operated from either a boom or be rear mounted on tractors[3]. Unlike a conventional bucket excavator, the rotary excavator consists of a series of teeth attached to a circular frame. The frame spins at high speed so that macrophytes, silt, and debris are macerated and physically thrown over the nearby pasture. It is capable of removing objects such as sticks and stumps and it seems almost certain that any fish or eels removed by this method would be killed. This rotary excavator was not listed in the questionnaire responses by regional councils as an approved method, and its future role in drain clearing may be limited to smaller artificial drains on farm properties.

3.2 Barriers to downstream migration

3.2.1 Eel migration

Elvers migrate upstream during summer, sometimes over several years. Small elvers use surface tension to surmount damp, vertical surfaces, such as waterfalls, but are easily blocked by dry or overhanging structures. After reaching suitable habitat, the eels grow, often for several decades, before maturing and beginning the return trip to the sea. Downstream migration can be as perilous as the upstream journey, and the adult must negotiate the same waterfalls, dams, and other barriers, as well as any new structures that have been constructed since the upstream migration (Boubée et al. 2003).

Migrant female longfins range from 800 mm to over 1500 mm in length and males from 500 to 700 mm. Migrant female shortfins range from 500 to 1000 mm and males 350 to 550 mm (Todd 1980). In comparison to most other freshwater eel species around the world, adults of the two main freshwater eels present in New Zealand are large. The potential for injury or mortality while passing over barriers and through turbines is therefore greater in New Zealand than elsewhere.

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[3] www.modernconstruction.co.nz/rotec.html

3.2.2 Reproductive potential

The effect of barriers on the reproductive potential of the New Zealand eel population is even more important given that large eels are all females and that large eels produce more eggs than smaller individuals. The fecundity (F, egg numbers) of New Zealand longfin eels as a function of length (L, mm) is given by:

$$\log(F) = 4.1928 \log(L) - 5.9251 \quad \text{(Todd 1981)}$$

This suggests that a 1500 mm female can produce 25 million eggs, whereas an 800 mm female would produce only 1.8 million eggs. In terms of reproductive output, therefore, the loss of one large longfin equates to almost 14 smaller females.

3.2.3 Potential effects of barriers on downstream migrant eels

During downstream migration, eels may be confronted by instream barriers that delay or prevent their migration or cause some injury. These barriers may be installed for drinking or commercial water supply, irrigation, flood control, and hydro-electric generation. The following factors control the ability of eels to surmount and survive these obstacles during their downstream migration.

Passage

- Frequency and timing of spillway opening or dam overtopping (storage capacity).
- Presence of free passage route during the migration period (including fish bypass and pre-scheme migration routes).
- Minimum flow regime.
- Screening of intake(s).

Survival

- Height of dam (head).
- Type of spillway/bypass and level of injury sustained during passage over this route.
- Intake screens and intake velocity (i.e., level of entrainment and impingement).
- End use of the diverted water (e.g., flood pumps, turbine type and operating mode at hydro stations).

In addition to direct effects, barriers may delay migration, preventing eels from reaching spawning grounds at the right time and/or compromise the "quality" of the spawners (i.e., has the migrant eel retained sufficient fat reserves while being delayed to reach spawning sites and produce quality eggs/sperm?).

3.2.3.1 Passage

Frequency and timing of spills

Eels tend to migrate downstream during high flow periods (Boubée et al. 2001). At such times the storage capacity of the reservoir created by the dam is likely to be exceeded and surplus flow will be spilled, opening a route for downstream migrants. The proportion of migrants choosing this route will depend on the proportion of flow being spilled, the location of the spillway, turbine intake, and screening, and the eel behavioural response. In most cases, determining the proportion of migrants able to safely pass over a dam requires site-specific studies (see Patea case study below, Section 3.2.6).

With knowledge of average river flow, flood flows and frequency, extracted flow, storage capacity, and preferred migratory route taken by migrant eels, it should be possible to determine the frequency of spills, and thus the probability that migrant eels are able to use the spillway/bypass route.

Data on average river flow and total reservoir volume have been collated on a NIWA database, but there is currently no readily accessible information on storage capacity and extracted flow. To get this information the individual dam owners would need to be contacted.

At small structures it is expected that some flow is able to pass over the structure most of the time, and certainly during floods when eels migrate. The effect of these small structures on downstream migrating eels is therefore probably negligible. At major structures, such as hydro and water reservoir dams, however, spills are rare and do not always coincide with downstream eel migration. The probability of downstream migrants having free passage over spillways at major hydro and water storage dams is probably negligible, but until information on frequency of spills is collated, there is no way of determining if this assumption is correct.

Downstream bypasses and deliberate spills

At many sites, the resource consents under which the dam is operated has minimum flow conditions. If the intake is well positioned and the water is not used for hydro generation, this minimum flow condition could provide a bypass route for downstream migrants. There is currently no readily available information on the availability of downstream bypass routes at any dam.

Although controlled opening of spillways during migration events has been voluntarily implemented at Patea Dam, and has been considered elsewhere, most operators do not view this option favourably as it can result in the loss of generation. Furthermore, Government currently requires major hydro operators to report spill events, as these have been perceived as a mean of achieving higher spot market prices. This obligation has been interpreted by at least one major hydro-operator as a reason for not opening spillways as a mitigation activity. Until spillway opening becomes a requirement of resource consents, this potential passage route remains closed.

Similarly, flood control pumps mostly operate when water levels downstream of the stop banks are higher than those of the waterway up stream. Thus, even where a flap valve that provides free passage at low water levels is present, during periods of high autumn flows (i.e., when eels migrate) the only route available is through the pump. Wherever a flood pumping station is present, it is appropriate to assume that the only route available is through the pump.

Intake screening

Given the strong urge for mature eels to migrate downstream, where spacing between the screen bars of the intake is wider than the eel body, migrants will inevitably entrain at the intake and pass through the turbines. Where velocity is high and the mesh too small for the eel to pass through, eels will impinge on the screen and suffocate. In some cases an avoidance response can be exhibited at the intake, possibly in response to factors such as noise and visual cues, and eels will search for a "safer" route, and may return upstream until the next migration trigger (Watene et al. 2003).

Only where fine mesh (under 20 mm) screens are present and intake velocity is below 0.5 m/s will eels be able to avoid entrainment and/or impingement (Adam & Schwevers 1997). Although migrant longfin eels are larger than the European eels on which this recommendation is based, the mesh size criterion is appropriate for male shortfin and longfin and the velocity limits are suitable for females of both species.

Determining the risk of entrainment and impingement will require a good knowledge of the intake velocity, spacing between the screen bars, and size structure of the population. Most intakes in New Zealand were not designed to minimise entrainment or impingement of fish, and unless information to the contrary is available, it is appropriate to assume that all eels arriving at the dam either entrain or impinge on the screens.

3.2.3.2 Survival

Height of dam and passage through spillways

Overseas studies have shown that significant damage occurs to fish when the impact velocity on the water surface exceeds 15–16 m/s. This critical velocity is reached after a free fall of only 13 m for fish longer than 600 mm (Larinier & Travade 2002). For larger fish, such as eels, this hazard is the same whether they pass under free-fall conditions, or whether they are contained in the column of water. Thus, a spillway can only be considered a safe way for fish to pass over a dam where it is less than 10 metres high and fish are able to fall safely on the downstream side, with sufficient depth at the base of the dam, and there are no over-aggressive baffles (e.g., dragon teeth or rip-rap). For higher structures, studies at Patea Dam have shown that controlled spills (under 100 mm gate opening) over a smooth spillway with a flip bucket at the base can result in 100% survival rate. However, as the survival rates of eels under uncontrolled conditions is unknown, a conservative approach is recommended and survival rates of migrant eels passing through spillways over 10 metres high should be taken as negligible.

Effectiveness of bypass

Although downstream fish bypasses may be available at some hydro power stations, eels rarely use them (M. Larinier, CEMAGREPH, Toulouse, France, pers. comm.; A. Haro, USGS, Turners Falls, USA, pers. comm.). Difficulties in providing downstream passage arise because migrants use the main current to facilitate their migration (Behrmann-Godel & Eckmann 2003). Furthermore, although a bypass may be provided, eels using this route may be damaged during passage (e.g., right angle bends and rough surfaces causing abrasion; high relative head causing injury through pressure changes). Full knowledge of the bypass characteristics, with preferably some measure of survival rate, is required to assess the effectiveness of bypasses. Currently in New Zealand, there is at least one purpose-built migrant eel bypass (Wairere Falls, Mokau River, King Country) and fish passes for upstream migrants provide some downstream passage at another four sites (Motukawa Weir, Taranaki; Lake Waikare flood control gates, Waikato; Monowai Power Station and Mararoa Weir, Waiau River catchment, Southland). No doubt other downstream passage facilities exist at other barriers, but their effectiveness would need to be assessed.

End use of the diverted water

Eels entrained into drinking and irrigation intakes will be lost unless fine screens and bypass structures are installed. At flood control pumping stations, the type of pumps installed and the operating regime will determine survival rate. Flood control pumps normally operate in autumn during the downstream migration period, but unless these are of the Archimedes screw type, survival during passage is expected to be minimal. There is currently no available database on the location and types of pump installed for flood control and consequently no estimate of eel mortality at flood control pumps is possible.

Where water is used to generate electricity, the type of turbine installed and the characteristics of the plant will determine the proportion of migrant eels able to pass through safely. The three prevalent types of turbines used to generate electricity are Pelton (operating head 300–2000 m), Francis (40–700 m), and Kaplan (up to 70 m). All three types of turbines are in operation in New Zealand but Francis turbines are the most common (Table 2). If a dam has no downstream bypass, every mature eel reaching the dam must pass either through the turbines or over the spillway during their seaward migration.

3.2.4 Turbine passage

It is generally accepted that no fish survive passage through a Pelton turbine (Larinier & Travade 2002). With Francis and Kaplan turbines, four potential damage risks have been identified.

Mechanical

Mechanical damage is caused by contact with fixed or moving equipment, and is a function of the characteristics of the turbine (number of blades, revolutions per second, blade angle, runner diameter, hub diameter, discharge) and the size of fish. Model predictions suggest that potential for physical strike, and hence injury, increases with fish size (Cada 1990).

Pressure changes

Rapid pressure changes rupture the swim bladder and damage internal organs. The pressure changes that fish experience during passage through a power plant are a function of the turbine design and flow rate, fish swimming depth, location of the intake, and net head.

Cavitation

Cavitation is caused by localised regions of sub-atmospheric pressure and can cause pitting of the runner blades. It results in serious injuries in fish, notably skin lesions, which can be fatal. The incidence of cavitation decreases with increasing turbine efficiency, and therefore it is desirable to maintain high turbine efficiency to reduce fish mortality.

Shear

Shearing (exertion of forces in opposite direction) occurs at the boundaries of two adjacent bodies of water with different velocities and or direction. Long fish such as eels will be more vulnerable to this type of injury than small fish.

3.2.4.1 Mortality of downstream migrant eels passing through turbines

Predictive modelling

Prediction of fish mortality passing through Francis turbines is as follows:

$P = 100[SIN(6.54 + 0.218H + 118TL - 3.88D1m + 0.0078\,N)]^2$ (Larinier & Travade 2002)

Where, P is the percent mortality rate, H (m) is the net head, TL (m) is the length of the fish, $D1m$ (m) is the entrance diameter of the turbine at mid-height, and N (rpm) is the rotation speed.

This model was modified for Kaplan turbines.

$P = 100[SIN(16.55 + 61.65(TL/esp))]^2$ (Langon & Dartiguelongue 1997)

Eel mortality rate was estimated for a range of New Zealand power stations (Figure 7). Most downstream migrating eels, and especially females, would be killed where Francis turbines have been installed. Mortality rates are lower at Karapiro and Waipapa, which have relatively low heads and Kaplan turbines. These mortality estimates are considerably higher than figures obtained in North America where mortality rates as low as 9% have been measured (EPRI 2001). Canadian and US power stations included in the study were low-head plants, with large diameter, low rotation turbines For example, at the 23.8 m high Beauharnois Dam in Canada, eel mortality was 23.9% at the 6.39 m diameter (94.7 rpm) Kaplan turbines, and 15.8% at the 5.5 m (75 rpm) Francis turbines (Desrochers 1995). In contrast, most turbines in New Zealand operate at rotation speeds above 125 rpm and are therefore likely to cause much higher mortality (Figure 8). Thus, although existing mortality models overestimated mortality rate at some sites (Cada 1990), they appear appropriate for the types of turbines installed in New Zealand.

3.2.5 Indirect effects of dams on reproductive output

As eels become sexually mature, they stop feeding, mobilise their fat reserves, and undergo a complex physiological and physical change. If prevented from migrating, they will retreat upstream only to return at the next rain event, which could be as late as the following spring or autumn (Watene & Boubée 2005). This can lead to severe loss of condition (G. Williams, Taranaki eel fisher, pers. comm.). A significant delay in migration timing would therefore compromise the chance of successfully completing the long journey to the spawning ground and producing quality eggs. Therefore, where no downstream bypass is provided at hydro dams, the only opportunity for these adult eels to contribute to the reproductive potential of the population is for the migration to coincide with a period of spillway opening.

3.2.6 Case study – Patea River

Various methods are used to demonstrate the potential impact of hydro dams on outward migration of eels over Patea Dam.

3.2.6.1 Biomass estimates

The potential biomass of female longfin eels in the Patea River after the construction of the Patea Dam was estimated using GIS models based on measurements of stream gradient and flow (Graynoth & Niven 2004). It is estimated that upper reaches supported 121 t of eels. The construction of Patea Dam flooded about 173 reaches and the resulting Lake Rotorangi has an area of 6.17 km^2 and perimeter of 104 km. Assuming that the littoral zone covers about one-third of the lake bed, and that the lake supports 60 kg per ha of longfin eels, Lake Rotorangi could contain about 12 t of eels (Graynoth & Niven 2004). The combined biomass from above Lake Rotorangi and the lake is estimated to be 127 t.

In general, female migrants are a small percentage of the total biomass of eels present. The percentage varies depending upon sex ratios, growth rates, recruitment, natural mortality, fishing mortality, and weather conditions (Jellyman et al. 2000b). Fishing can have very dramatic effects on the survival of large female eels (Hoyle & Jellyman 2002) and hence on these percentages. For unfished populations, estimates range from 2.3% in slow growing stocks to 8.1% in stocks with very high growth rates. In contrast, in heavily fished populations the percentage can drop to only 0.04%. In the Aparima River, for example, migrant females make up about 1% of the total biomass of eels present (Jellyman & Graynoth 2002).

There is no information on fishing pressure in the Patea catchment, but the upper Patea River and Mangaehu Stream appear relatively accessible to fishers and a 1% figure may be appropriate. If this is the case, then an average of 1.3 t of female longfins may migrate downstream each year to the Patea Dam. If the waters are not fully stocked or are heavily fished then the numbers of migrants may be considerably less than 1.3 t. These figures are likely to be accurate only to about ± 50%. Refinement of the model and, in particular, collection of biomass information from the area would improve its accuracy considerably.

3.2.6.2 Estimated losses through turbines

Beentjes et al. (1997) and Watene & Boubée (2005) provided information on the size structure of migrant eels in the Patea catchment. Given the screen size installed (Table 3) it is expected that, except for very large female longfins, all migrant eels (males and females of both species) would entrain at the intake and would have to pass through the turbines. Eels unable to pass through the screen probably impinge and suffocate. Few migrant eels are expected to pass through the smaller screen of the auxiliary turbine (U4), but high velocity is expected to lead to impingement (this has been confirmed by station staff).

Based on turbine characteristics (Table 3) and the simplified formula provided by Larinier & Travade (2002), it is estimated that no longfin females and about 13% of the male biomass would survive passage through the main turbines. The figure for shortfins is about 1% for females and 28% for males. No migrant eels able to pass through the auxiliary turbine (U4) screens are expected to survive. Thus, if the only passage route was through the turbines, none of the 1.3 t of female longfin estimated to be currently produced by the catchment upstream of Patea Dam would survive.

3.2.6.3 Spillway passage

A cursory examination of reservoir characteristics (Table 4) and flow records below Patea Dam indicate that the spillway is opened to pass flood flows in about three out of four years in May to June, coinciding with the female longfin eel migration period. During these flood events, passage survival is probably minimal, but this should be confirmed. In addition, Trustpower partially opens one of the spillway gates about three times at night each autumn to allow the downstream passage of eels. The controlled gate openings are made at night for about 1.5 h during periods of heavy rainfall when eels are expected to run. Some of these openings coincide with major flood events. From observations made while the spillway was deliberately opened for the first time in autumn 1998, it was estimated that 2600 migrants (males and females) passed safely over the dam that year (3 nights of 1.5 h each) (Grant Williams, Taranaki commercial eel fisher, pers. comm.). Using the 1996 migrant catch composition reported by Beentjes et al. (1997), this number equates to about 0.2 t of longfin females and to 13% of the total biomass of female longfin migrants that are currently estimated to move downstream from the upper catchment.

Watene & Boubée (2005) also monitored spillway openings in 2000 and 2001. In 2000, 7.4 kg of female longfins were collected during a 2.5 h spill. In 2001, 13.5 kg were caught in 1 h of spilling. Assuming three such targeted spills each year, the biomass of longfin females passing safely over the spillway is estimated at about 30 kg per annum. This equates to about 2% of the total biomass of female longfin migrants that are currently estimated to arrive at the dam.

Based on these observations, we estimate that up to 10% of the female migrant biomass may survive by passing over the spillway when opened to facilitate eel migration. Given that no longfin females survive passage through the turbines, this is the only proportion of downstream migrant we expect to outmigrate at this site. However, this estimate may be considerably higher if migrant eels survive passage with flood flows.

4. CONCLUSIONS ON THE FEASIBILTY OF ESTIMATING NON FISHING MORTALITY

4.1 Drain clearing

As part of this study we have established the extent and types of drains that are cleared throughout New Zealand, the types of equipment/methods that are used, and the frequency and policy of drain clearance. We have also reviewed the national and international literature on the effects of drain clearing on aquatic habitats and eels. This information provides the starting point for estimating eel mortality from drain clearing throughout New Zealand.

To estimate the number of eels killed by drain clearing operations requires information and estimates at three key points.

1. Estimation of the extent of managed waterways, and knowledge of type and frequency of clearance.
2. Estimates of eel mortality associated with major types of clearance.
3. Extrapolation to provide estimates of total eel mortality throughout New Zealand associated with major types of waterway clearance.

To elaborate on these in turn.

1. Estimation of the extent of managed waterways, and knowledge of type and frequency of clearance

The questionnaire used in this report provides a comprehensive estimate of the length of waterways that are managed by various methods. However, because the management practices vary between councils, it is not possible to estimate specific lengths of waterways that are cleared at given frequencies by particular methods. For example, Environment Bay of Plenty used six methods and four clearing frequencies to clear drains (see Table 1). An added complication was that a number of councils identified that clearing was on an "as needed" basis, meaning that a regular clearing frequency could not be assigned to such waterways.

The use of a GIS-based layer of drains is an alternative technique to establish the lengths of managed waterways throughout New Zealand. Currently, data for drains exist in a variety of files held by NIWA (Snelder & Biggs 2002), but considerable work would be required to convert to GIS format and consolidate them into a national database. Also, the current database does not include natural waterways, which would need to be identified as managed waterways. Given that natural waterways constitute 12% of managed waterways within New Zealand (see Table 1), any current GIS-based estimate would be conservative.

The only realistic method for partitioning individual waterways according to the method and frequency of clearance is to use a combination of GIS layers plus local knowledge. We suggest that several of the larger regions be chosen (Waikato, Southland, Selwyn), and local engineers and drainage contractors asked to identify the usual methods associated with each waterway. This information could then be digitised on a new GIS layer using a combination of NIWA's River Environment Classification (REC) with an overlay of NIWA's local drain layer.

2. Estimates of eel mortality (or eel displacement) associated with the major types of clearance.

The two most common methods of drain clearing are herbicide spraying to control weeds and mechanical excavation to both remove weeds and silt build-up (see Section 3.12). For weed cutting and spraying, the problem is likely to be more one of displacement of eels rather than mortality. Weed cutting occurs during daylight hours when eels would usually be sheltering at the base of weeds or within the sediments. As cutting usually trims weeds rather than cutting them at the base, direct mortality from this method is expected to be low. If it was decided to assess the effect of cutting and spraying, this would require a series of 'before and after' studies, i.e., electric fishing or a depletion fyke-netting study to estimate population size before and after spraying/cutting. Alternatively, an upstream control reach could be compared with cleared reaches.

Mechanical excavation is considered by most observers to result in the highest mortality of eels. It should be feasible to monitor eel mortality from such operations by counting eels deposited on banks. In some sediment clearing operations in Canterbury, local runanga employ people specifically to collect and return eels stranded during mechanical clearing. This approach could be extended, and records kept of the numbers, species, and size of eels returned, as well as those observed to be dead.

To obtain robust estimates of mortality of all combinations of techniques, frequencies, and conditions, would be impractical. However, it is assumed that the more important impact is that from mechanical excavation of sediment, as this is the practice that is usually associated with considerable direct mortality of eels. It is recommended that greatest emphasis be placed on observations of mechanical excavation, and that this include observations on sites that differ in width and frequency of clearing to see whether there are any obvious differences between these.

3. Extrapolation to provide estimates of the total eel mortality throughout New Zealand associated with major types of waterway clearance

The results from the site-specific estimates of mortality from drain clearing would need to be scaled up to give a regional assessment of the effects of drain clearing. The next step would be to extrapolate the results to a national level, based on the lengths of managed waterways of the different types identified in the questionnaire. A major assumption would be that the results from the regions studied are representative of those regions not studied. There is considerable uncertainty at each level of estimation/extrapolation, and it would not be possible to provide error bars for New Zealand-wide estimates.

4.2 Anthropogenic barriers

Existing information indicates that a significant proportion of eel habitat is affected by anthropogenic barriers. The Patea Dam example has illustrated that it is possible to make meaningful estimates of mortality associated with downstream passage at hydro dams. Extrapolation to the whole country would involve accumulation of physical information about hydro dams (see Tables 2 and 3) in catchments where eels occur naturally or have been transferred. Perhaps the greatest uncertainty involves effects of hydro dams on previous recruitment, and hence estimates of upstream densities, growth rates, and ultimately numbers of migrants. If outcomes from the predictions of migrant survival at any particular hydro dam indicate nil survival of eels traversing the turbines or spillway, then recruitment and upstream growing conditions are non-issues, as such dams would make no contribution to the national reproductive output of longfins. However, it would be important to have robust information on the potential reproductive losses anthropogenic barriers cause.

To obtain a better estimate of eel mortality incurred through the installation of anthropogenic barriers, the following information is required (see also Table 5).

- Estimates of the number of migrant eels within the catchment upstream of the barrier (assuming no limit on recruitment)
- Size structure of migrants.
- Type of intake screen installed (to estimate the proportion of the migrants entrained).
- Estimate of intake screen impingement losses.
- Turbine or pump characteristics and operating regime.
- Proportion of the peak migration period when the spillway is open or is overtopped.
- Ability of eels to survive passage over the spillway and measure of injury at various flows. (As interim criteria for uncontrolled spills we propose 0% mortality at spillways less than 10 m in height and 100% for higher structures. For controlled spill over a sloping spillway with opportunities to absorb the fall at the base, 0% mortality, and at other sites, 100%).

5. RECOMMENDATIONS

5.1 Drain clearing

The results suggest that it should be theoretically feasible to provide an estimate of eel mortality from drain clearing. We recommend that further work be carried out initially on several key regions such as Southland, Canterbury, and Waikato that could act as case studies. As stated above, the extent, type of managed waterways, and frequency of clearance should first be quantified. Second, mortality from the main methods (mechanical excavation and herbicide spraying) should be estimated using field trials. Finally, the results could be extrapolated to provide an estimate of mortality throughout New Zealand.

5.2 Anthropogenic barriers

To obtain a better estimate of downstream migrant losses caused by anthropogenic barriers, more accurate population estimates, species composition, sex ratio and size distribution are required. Survival of migrant eels passing over, or through, anthropogenic barriers depends on the characteristics of the site. We recommend that a database of each site be established. Tables 2–5 list the parameters that should be recorded. Mitigation activities in place should also be collated.

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Table 1: Length of different waterway cleared (km) with frequency of clearing (superscript) and methods used (subscript). Data from all New Zealand Regional and/or District Councils involved in stream/drain clearing.

	Length (km) of waterway cleared with frequency and methods							
District/regional council	Natural waterway	Drain	Stockwater race	Irrigation race	Canal	Other	Total (km)	Comments
Whangarei District Council	${}_{1,3,4}750^{2}$	${}_{1,3,4}250^{2}$	0	0	0	0	1000	
Kaipara District Council	0	${}_{2,3}326^{3,4,5}$	0	0	${}_{2,3}81.5^{3,4,5}$	0	407.5	
Auckland Regional Council	${}_{4}16^{5}$	${}_{4}80^{5}$	0	0	0	0	96	
Environment Bay of Plenty Regional Council	0	${}_{1,2,3,4,5,7}440^{1,2,3,4}$	0	0	0	0	440	Other method is saline water flushing.
Hawke's Bay Regional Council	${}_{1,2,3,4}70^{1,6}$	${}_{1,2,3,4}430^{1,4}$	0	0	0	0	500	Mechanical excavation every 5–20 years; other methods more frequently.
Environment Waikato	${}_{4}100^{6}$	${}_{3,4}3160^{6}$	0	0	${}_{3,4,5}200^{3}$	0	3460	Drains and natural waterways cleared every 10 years.
Horizons Regional Council (Manawatu-Wanganui)	0	${}_{3,4}780^{5}$	0	0	0	0	780	
Greater Wellington Regional Council	${}_{1,3}5^{1}$	0	0	0	0	0	5	
South Wairarapa District Council	${}_{3,4}27.5^{2,3}$	${}_{3,4}54.5^{2,3}$	0	0	0	${}_{3,4}72.7^{2,3}$	154.7	Spray annually and mechanical excavation every 1–7 years.
Kapiti Coast District Council	${}_{1,4}23^{1,2}$	${}_{4}36.2^{2}$	0	0	0	${}_{3}2.2^{5}$	61.4	
Nelson City Council	${}_{1}26^{5}$	0	0	0	0	0	26	
Tasman District Council	${}_{3}2^{2,3}$	0	0	0	0	0	2	
Marlborough District Council	${}_{2,3,5}45.3^{1,2,6}$	${}_{1,3,4}133.9^{1,2,6}$	0	0	${}_{3,4}5.4^{2}$	0	184.2	Mechanical excavation every 7–10 years.

Table 1 – *continued*

	Length (km) of waterway cleared with frequency and methods							
District/regional council	Natural waterway	Drain	Stockwater race	Irrigation race	Canal	Other	Total (km)	Comments
Environment Canterbury	$_{2,3,4}$ 81 [1,2]	$_{1,2,3,4}$ 658 [1,2]	0	0	0	0	739	
Westland District Council	0	$_{4}$ 200 [6]	0	0	0	0	200	*Mechanical excavation every 7–10 years.*
Buller District Council	0	$_{4}$ 10 [5]	0	0	0	0	10	
Grey District Council	$_{1,2}$ 7.7 [1]	$_{1,2}$ 1200 [1,2,3]	0	0	0	0	1207.7	
Christchurch City Council	$_{1,2,3}$ 316 [1]	$_{1}$ 124 [1]	0	0	0	0	440	
Waimakariri District Council	0	$_{2}$ 131 [2,3]	$_{1,2,3}$ 150 [2,3]	$_{2,3}$ 150 [2,3]	0	0	431	
Ashburton District Council	0	0	$_{2,3}$ 365	0	0	0	365	
Mackenzie District Council	0	$_{4}$ 5.5 [5]	$_{4}$ 70 [4]	0	0	0	75.5	
Selwyn District Council	$_{2}$ 15 [5]	$_{3,4}$ 351 [2,5]	$_{2,3,4}$ 2063 [2,5]	0	0	0	2429	
Timaru District Council	0	$_{2}$ 48 [2]	$_{2}$ 258 [2]	0	0	0	306	
Waimate District Council	0	$_{3,4}$ 2 [3]	0	0	0	0	2	
Otago Regional Council	$_{4}$ 10 [5]	$_{3,4}$ 535 [2,5]	0	0	0	0	545	
Environment Southland	$_{3,4}$ 350 [6]	$_{3,4}$ 1300 [6]	0	0	0	0	1650	Every 1–10 years.
Totals	1 845	10 255	2 906	150	287	75	15 518	

Table 1 – *continued*

Key to frequency and methods

Frequency of clearing	**Methods of clearing**
1 = several times per year	1 = hand cutting/pulling/raking
2 = annually	2 = mechanical cutting (mower, rotary cutter etc.)
3 = every 2 years	3 = chemical (diquat, roundup, glyphosphate etc)
4 = every 3-5 years	4 = mechanical excavation with backhoe/digger or dragline etc.
5 = according to need	5 = fish (grass carp)
6 = other (specify)	6 = manipulating water level
	7 = other

Table 2: Characteristics of turbines installed in some New Zealand hydro stations. V1, absolute velocity at entry of turbine; N, rotation speed; spa, spacing between the blades; Dim, diameter of turbine through centre of blades; No., number of blades; W1, relative velocity at entry to turbine; –, not available.

Location	Turbine type	Head (m)	V1 (m/s)	N (rpm)	spa (m)	Dim (m)	No.	W1 (m/s)
Arapuni (Waikato R.)	Francis	53	14.94	214	0.512	2.12	13	16.30
Clyde (Clutha R.)	Francis	60	6.8	125	0.942	3.90	13	10.22
Karapiro (Waikato R.)	Kaplan	30.5	14.8	167	2.725	4.34	5	20.0
Matahina (Rangitaiki R.)	Francis	61	9.54	128.6	0.638	3.05	15	12.5
West Arm (Lake Manapouri)	Francis	178	41	250	0.609	3.10	16	8.9
Roxburgh (Clutha R.)	Francis	45	6.35	136.3	0.773	3.69	15	11.21
Waipapa (Waikato R.)	Kaplan	16.5	–	125	3.823	4.87	4	–

Table 3: Patea power station turbine characteristics. N, rotation speed; spa, spacing between the blades; Dim, diameter of turbine through centre of blades; No., number of blades.

Unit	Turbine type	Head	Screen gap (mm)	N (rpm)	spa (m)	Dim (m)	No
1–3	Francis	58	45	428	0.391	1.62	13
4	Francis	58	19	1000	0.055	0.229	13

Table 4: Characteristics of the Patea Dam and Lake Rotorangi.

Variable	Value
Surface area	6.14 km^2
Operating range	2 m (normal operation)
Estimated storage	24 million m^3
Average inflow	24.66 m^3s^{-1}
Max. station outflow	60 m^3s^{-1}
Residual flow	1.4 m^3s^{-1}

Table 5: Additional information required to better define the effects of dams on downstream migrants eels.

Topic	Information required
Storage	Abstracted flow
	Actual storage capacity
	Proportion of time spills occurs February to June
Bypass	Flow
	Diameter
	Location (including depth of intake)
	Screening
	Head
	Any intermediate use (e.g., passage through turbines)
	Consent requirement on spillway opening
	Effectiveness (including preferred passage routes of migrants)
Screening	Screen mesh type and size
	Through-screen velocity
Flood control stations	Location
	Pump characteristics (type, size, head etc)
	Operating regime.
Hydro station	Turbine and plant characteristics
	Operating regime
Biology	Downstream migrant size distribution (for entire season)
	Confirmation that existing biomass model is appropriate for catchment.

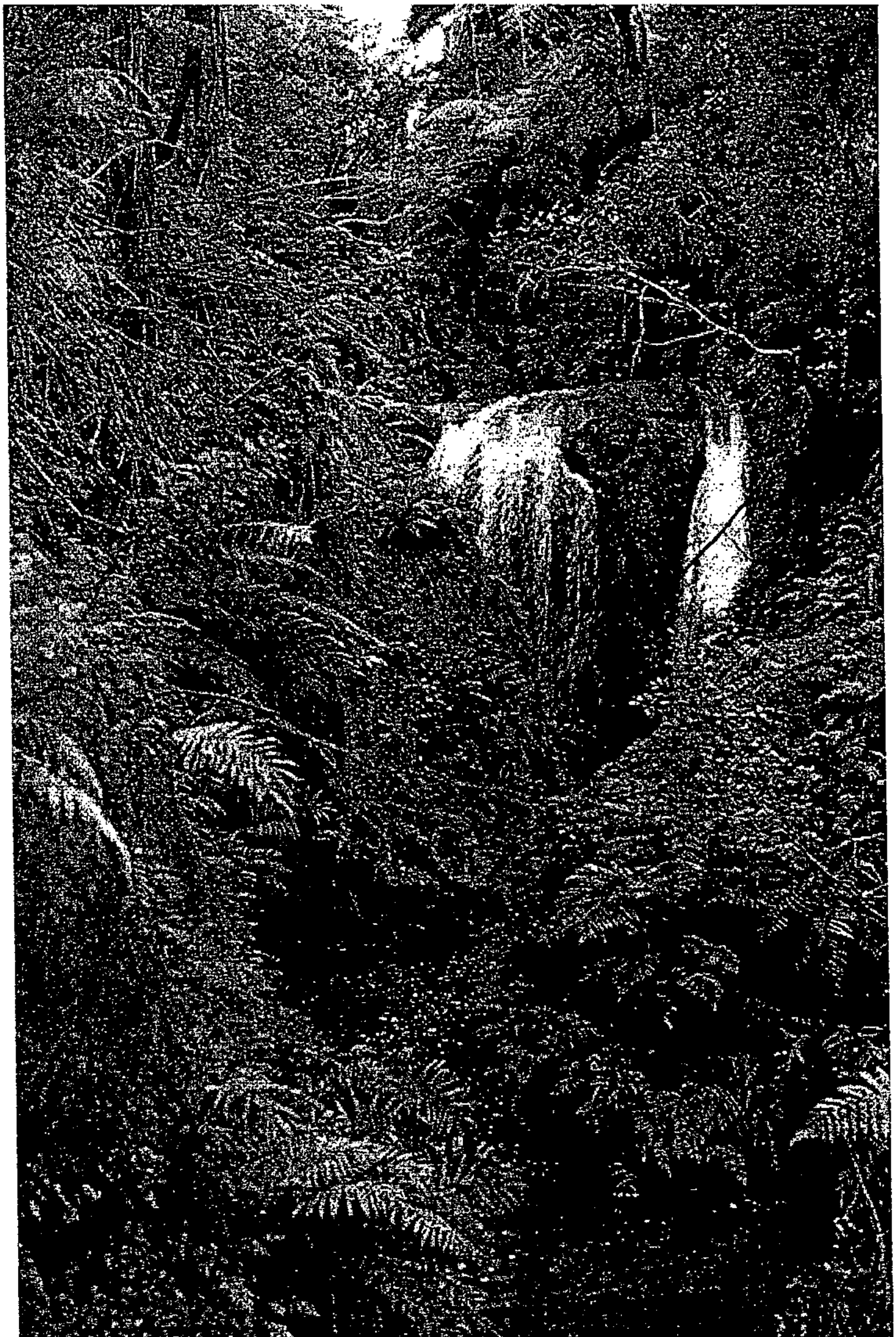

Figure 1: An unmodified stream with riparian strip, overhanging vegetation, riffles and pools (photo by Ministry for the Environment).

Figure 2: A fenced stream flowing through farm land with a well managed riparian margin (photo by J. Quinn).

Figure 3: A New Zealand farm drain with no riparian buffer zones and stock grazing down to the waters edge (photo by L. Nguyen).

Figure 4: A Southland farm drain that has been fenced to prevent dairy cows from grazing near the water's edge, but where sheep have been allowed in to graze (photo by A. Willsman).

Figure 5: A Southland farm drain that has been fenced to prevent stock from grazing near the water's edge (photo by A. Willsman).

Figure 6: Dead eels removed from a farm stream in the Wairarapa using a mechanical excavator (Photos by Greater Wellington Regional Council).

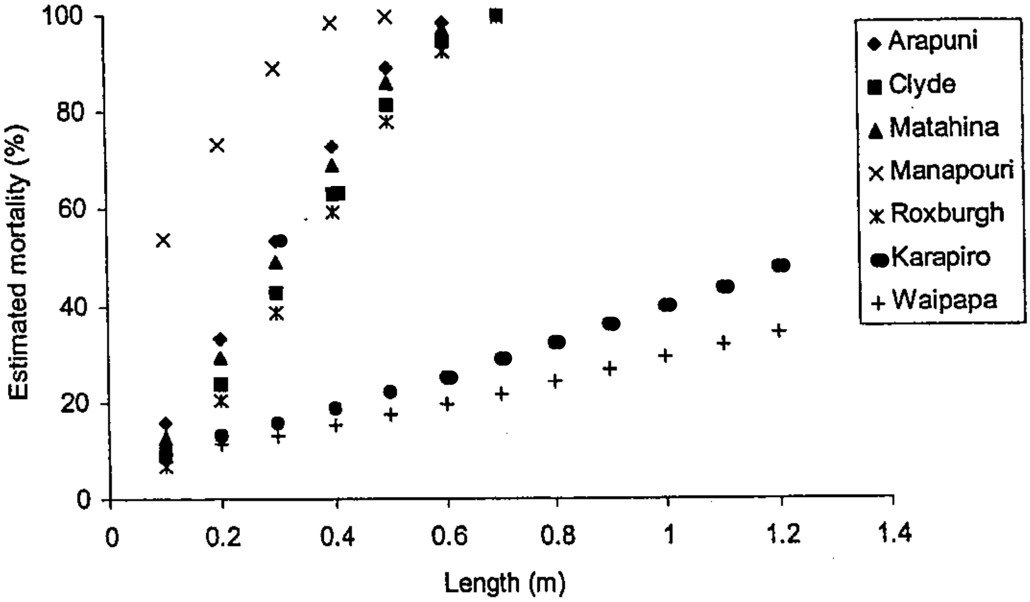

Figure 7: Eel mortality estimates based on Langon & Dartiguelongue (1997) formula for Kaplan turbines and Larinier & Travade (2002) simplified formula for Francis turbines.

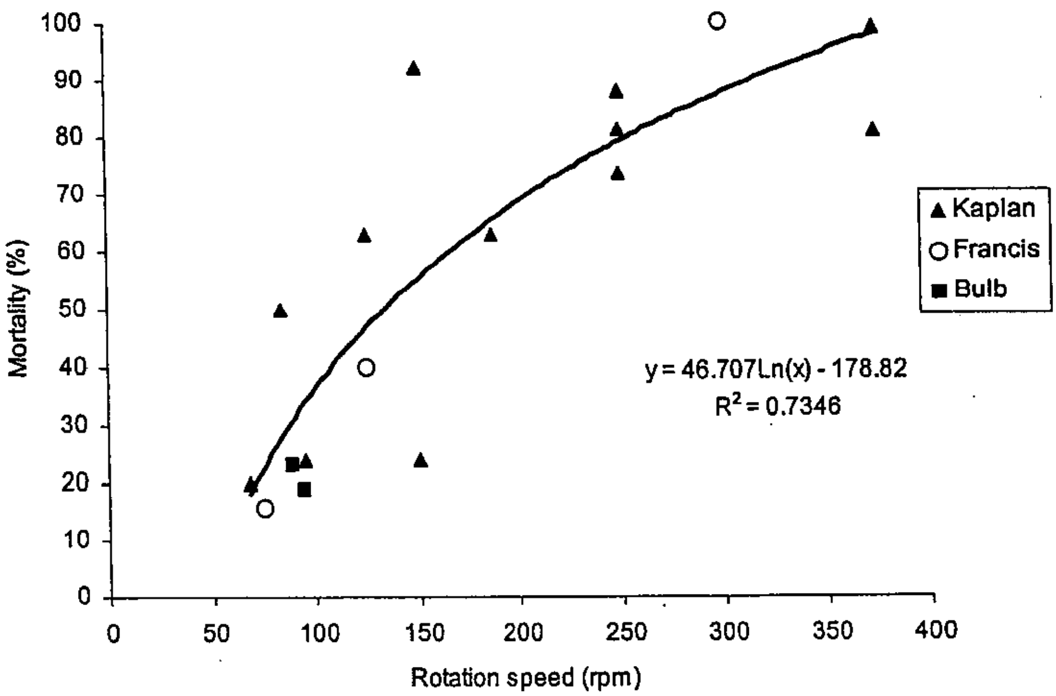

Figure 8: Plot of turbine rotation speed against mortality for eels between 450 and 897 mm. Raw data from Langon & Dartiguelongue (1997).

Appendix 1: Questionnaire on stream/drain clearing practices sent to New Zealand regional and district councils.

Reply from: ____(Give name of Regional/ District Council)

Completed by: ____________________ Contact No.: ____________

Questions:

1. **Is your council involved in aquatic weed management in drains?** Yes or No (If the answer is "No", then please ignore the rest of the questionnaire, and simply return to the address on the bottom of this questionnaire. If the answer is "Yes", then please continue.
2. Please fill in as much of the following table as possible:

For the columns "Frequency of Cleaning" and "Method(s) used", please enter the appropriate numbers from the lists below.

Type of Waterway	**Extent (km) managed for aquatic weeds**			*** Frequency of cleaning**	**# Method(s) used**	**Comments**
	By regional / district council	**By permitted activity**	**By notified consent**			
Natural waterway						
Drain						
Stockwater race						
Irrigation race						
Canal						
Other (specify)						

*** Frequency of cleaning**

1 = several times per year
2 = annually
3 = every 2 years
4 = every 3-5 years
5 = according to need
6 = other (specify)

 # Method(s) used

1 = hand cutting/pulling/raking
2 = mechanical cutting (mower, rotary cutter etc.)
3 = chemical (Diquat)
4 = backhoe/dragline etc
5 = fish (grass carp)
6 = *manipulating* water level
7 = other (specify)

Comments – Could include such things as whether the complete drain cross-section is cleaned, or whether banks are done in alternate years etc.

Questions (cont.)

3. Has your council commissioned any studies on the impact of drain clearance on aquatic biology? If so, please list.
   - .
   - .
   - .

4. What is the annual cost of waterway cleaning in an average year (including the cost of maintaining *equipment*)? If possible, give costs by Method(s) used, listed in question 2 *(see # above)*, otherwise just give total cost.

Method(s) Used	Annual cost ($)

Total cost $ _______________

Appendix 2. Comments received from regional and district councils involved in drain clearing (see Table 1) ordered from north to south

Kaipara District Council
Some inland drains cleared only every 10 years with banks being cleared from alternate sides. Drains and canals into the river are cleared more often when required because of the very heavy silt build up. Methods about 50/50 between machine clearing and spraying.

Environment Bay of Plenty Regional Council
Weed-cutter boat is the preferred option as it avoids use of chemicals and excavation of drain beds and banks. Saline water flushing is used in tidally affected coastal areas where floodgates are held open for periods to allow seawater to backflow up selected drains.

Hawke's Bay Regional Council
Drains and streambeds – Wherever possible banks are mown 3 times each year to encourage a dense sward of good grass cover to maintain channel efficiency and bank stability.

Emergent weeds are sprayed twice each year in most channels using Roundup or equivalent herbicide. Submerged weeds generally cut by a weed boat every 6–14 weeks.

Council has a policy of minimising the use of mechanical excavation to clear drains because it is the most expensive method and is the most disruptive to the drain environment, i.e., it gradually destroys design grade and cross-section of the channel by deepening and widening with each clearance. When an excavator is used to clear drains it is only to remove silt and debris build-up and material removed is kept to a minimum (every 5–8 years). Where it is needed more frequently, the policy is to remove weeds only. For natural waterways, excavation may be as infrequent as 15–20 years.

Environment Waikato
Natural waterways – There are a few streams with aquatic weed issues. Consents are provided for excavating channel as well as aquatic weed removal.

Drains – All artificial watercourses most of which are small or dry in summer. The frequency of clearing is becoming less due to fencing and use of spray. Most drains have only their beds cleared, except peat steams where bed and one batter are trimmed. Drains that are cleared more frequently are partly cleared in any one year to reduce impact (i.e., not all of the length is cleared). Longer drains have one-tenth cleared each year. Grass carp are used at seven sites.

Canals – Larger artificial watercourses where aquatic weeds are an issue. Clearing frequency higher than that of drains.

Environment Waikato is involved in funding a national project on sustainable drain management initiated by the Department of Conservation.

Horizons Regional Council (Manawatu-Wanganui)
Drains – Drains are maintained ki as needed. Submergent weeds are normally cleared with mechanical excavator and emergent weeds are sprayed using glyphosate. Machine clearing and spraying is restricted to the bottom section of the drain. Banks are touched only when rebattering is done and this happens infrequently.

Greater Wellington Regional Council
Natural waterways – A consent is held to spray in spring and autumn with the herbicide diquat. Currently in the process of formulating a hand-clearing contract to maintain weed growth at an

acceptable level. Hand clearing is a permitted activity under the freshwater plan. Limitations are being set on the use of chemicals.

South Wairarapa Regional Council
Drains – Only aquatic weeds are targeted. Bank damage sometimes occurs with either spray drift or by mechanical removal of weeds.

Stockwater race – Bank vegetation not a concern unless it impedes water flow.

Irrigation race – Chemical used is Roundup.

Kapiti Coast District Council
Only use herbicide spray (glyphosate) on urbanised stream bank edges to control pest plants.

Nelson City Council
Natural waterways – No clearing at present as no resource consent to do the work. When it has been done, stream banks cut where necessary and riparian controlled by mechanical cutting and diquat. Only partial width is cleared each time.

Tasman District Council
Natural waterways – Control of *Lagorasiphon*. LINZ funds costs of chemicals and application.

Marlborough District Council
The floating weed-cutter boat is used in slow flowing deeper streams, e.g., Opawa and Taylor Rivers. Lower Opawa weed is cut 3–4 times per annum depending on tide cycles, whitebait migration, etc. In Blenheim and areas of high public usage a mechanical excavator is used every 7–10 years approximately, or where access is not possible, hand-weeding is employed. For other waterways herbicide sprays are used, which are about one-tenth the cost of a mechanical excavator. Emergent weeds are sprayed with glyphosate and submergent weeds with diquat once or twice annually if required.

Studies commissioned – The ecology of Spring Creek-Awarua. Cawthron Report 611. Ecological assessments of spring-fed streams on the Wairau Plains. Cawthron Report 737.

Environment Canterbury
Natural water – Discharge of herbicides covered by resource consent. Other methods authorised/permitted by a rule in a regional plan.

Drains – Mix of methods used in all areas to minimise impacts. Hand-weeding and weed-cutter boats also used, particularly in Halswell.

Christchurch City Council

Natural water – Natural waterways include rivers and Environmental Asset Waterways and methods vary on different reaches of the rivers and streams. Generally cut twice per year.

Drains – Weeds in all utility waterways hand-hoed at least two times per year.

Other – Methods and frequency dependent on size and function of pond or lake.

Rivers vary from full cut to centre-cut depending on location. Christchurch City Council is experimenting with various methods to find the most cost-effective and efficient method. Environmental asset waterways are generally full-cuts with a margin left on the side. Utility waterways are generally full-cuts. Many and varied studies have been carried out, mostly by NIWA.

Waimakariri District Council
Natural waterways and drains – Banks are usually left untouched, otherwise instability occurs and flora and fauna disturbed. For some waterways clearing timed to suit window of opportunity for less disturbance of aquatic life cycles e.g., eels.

Stockwater and irrigation race – Usually bottom silt removed.

Waimakariri District Council have a policy of returning eels and other aquatic life to waterways during clearing operations.

McKenzie District Council
Drains – Most drains carry water only during a storm event.

Stockwater race – Cleared by farmers who are supplied by the stock race systems.

Selwyn District Council
Drains – about 65% of drains are cleared annually.

Stockwater race – Main races cleared annually and others as required, but usually no less than every 2 years.

Timaru District Council
Drain and stockwater race – waterway is divided in three length sections and sprayed annually for 2 years and mechanically cleared in the third year. The sections not mechanically cleared in any one year are sprayed. Clearing is carried out during January/February/March as determined by a working party consultation workshop as having the least disruptive environmental impact.

Otago Regional Council
Natural waterways – Typically cleared every 5 years or so.

Drains – Glyphosate used when water level is low. Usually drain bottoms only are cleared by mechanical excavator. Vegetation on banks may be mowed, but not killed, to encourage bank stability.

Relevant reports – Otago Regional Council. Environmental considerations for clear streams: a guide to managing waterways in Otago.

Environment Southland
Natural water and drains – Most work carried out under section 418 of Resource Management Act (RMA) and the remainder by notified consent.