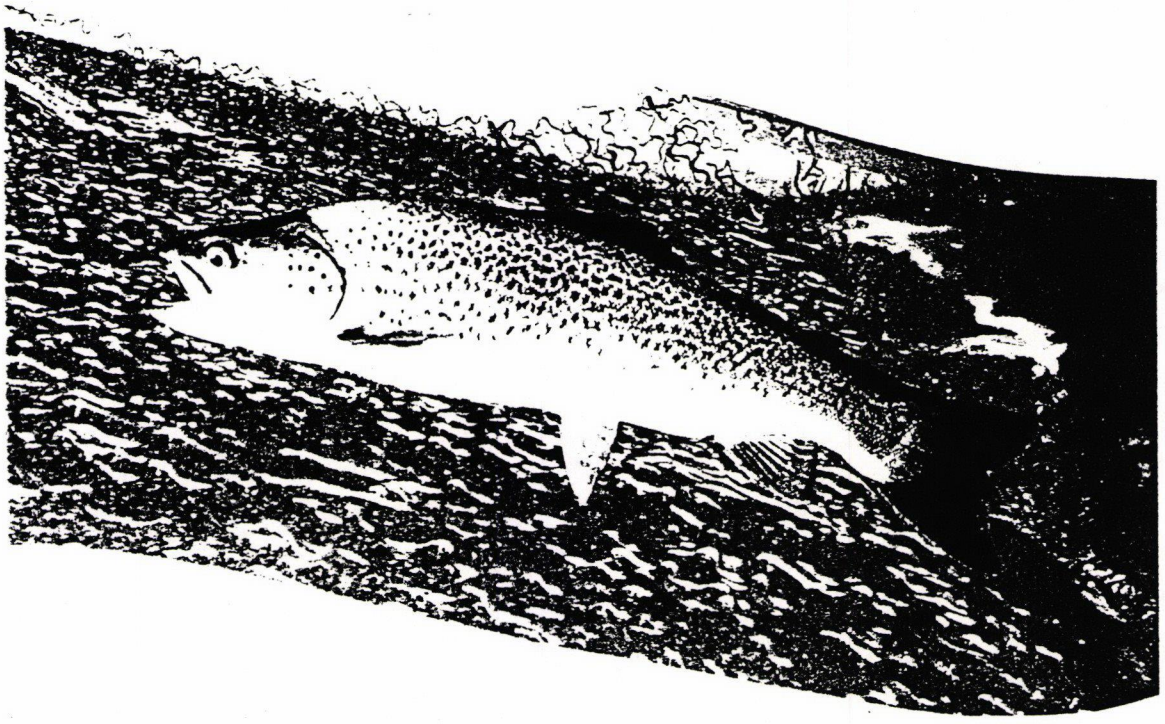
FISH PASSAGE PROBLEMS AND OPTIONS FOR FISH PASSAGE AT MARAROA WEIR

REPORT PREPARED FOR THE ELECTRICITY CORPORATION OF NEW ZEALAND

AND THE WAIAU RIVER WORKING PARTY



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EXECUTIVE SUMMARY

This study examines options for maintaining fish passage over the Mararoa Weir.

The weir has the potential to control the upstream distribution of several species of native and introduced fish. It is generally conceded that fish passage must be provided over the weir. What is required is a low maintenance, highly effective fish pass. A further variable is that ECNZ may release a compensation flow down the Waiau River. It would be desirable to integrate both the fish pass and the compensation flow structures.

Siltation and the deposition of gravel, exacerbated by diversion of the Mararoa River directly toward the control gates, appears to have totally blocked up the existing fish pass. Desiltation and maintenance is made particularly difficult by the encased design. The interior is essentially inaccessible. Therefore the cost and logistics involved with keeping this fish pass working, are probably unreasonable under present day economic realities.

Most fish migrate up to the weir after a fresh, attracted by the volume of spilled water. Fish numbers build up below the weir when the gates finally close. Public concern over the fate of the trout and elvers which can be seen below the weir detracts from the image of ECNZ as a good corporate citizen. Past tagging studies indicated that brown trout did not migrate through the fish pass. Rainbow trout did use the fish pass. An examination of size-frequencies and ages of eels above the Mararoa Weir indicated that recruitment of these migratory fishes had been reduced since the weir was built. Eels still remain common above the weir, these long-lived fishes are well adapted to maintain populations in habitats where access may only be possible at intervals. But without an effective fishpass eels will eventually become greatly reduced in numbers in the upper catchment.

An effective fish pass structure faces the following constraints: It has to be built within a reasonable cost envelope and must conform to existing structures and their operation. Water velocities within the fish pass have to be low enough to allow elvers and other small native fishes upstream. The fish pass must be deep and wide enough to allow adult trout to swim upstream. The entrance of the fish pass must be located at or immediately below a point where a barrier to further upstream movement for fish is present. This barrier must remain an effective barrier over a wide range of flows.

There appear to be at least six options to allow fish passage across the Mararoa Weir:

1. Modify the downstream wing wall on the true right bank of the weir to prevent buildup of gravels in this area. Clean out the existing fishpass, lengthen and raise the intake to reduce the ingress of silt, add more baffles, floor roughening and widen the entrance area. These modifications could ensure eel and lamprey passage and may allow brown trout to make an easier passage.

2. Construct a wider, lower gradient fish pass from the head of the existing fishpass, out through the side of the weir and along the rockwall to the area where the existing

fish pass used to discharge. This fish pass could be a Denil type fish pass or it could be an "artificial-natural" stream type, using cobbles imbedded into the bottom of the channel to brake water-flows and thus allow small fish to move upstream. or a combination of the two. This new exposed fish pass would be more accessible and therefore easier to maintain. It must allow adult trout plus a range of native fishes and small trout to move upstream. Denil fishways are a design which functions effectively over a wide range of flows.

3. Direct the compensation flow over the left bank of the overflow weir adjacent to the right bank abutment of the control gate structure. This flow would then be diverted around the tip of this structure to discharge into the lower end of the stilling basin pool. Fish attracted by this flow would enter a Denil-type fish pass built to zigzag up the right bank abutment to intersect with the resting-chamber of the existing fish pass.

4. Direct the compensation flow over the overflow weir on the right bank side. Abstraction of compensation water from this side of the weir would avoid the silt and gravel problems associated with the Mararoa River side. This compensation flow structure could also act as a water deflector to protect a Denil-type fish pass built up the side of the overflow weir. At low river levels, fish would swim in the compensation flow up the channel formed by the hydraulic jump, to the base of the compensation flow discharge. At this point they would encounter the fish pass entrance and could continue upstream. Diversion of the compensation flow around the tip of the right bank abutment of the control gate structure would allow fish to move up to the fish pass from the stilling basin pool, at all river levels.

5. Construct a dedicated channel on the true right bank of the Waiau River to take the full compensation flow over the weir. Use a velocity barrier (effective at flood flows?), below the bridge and divert fish up the channel at all times. It is considered that a compensation flow structure that can cope with the varying water levels above the weir and still allow fish passage, will have to be both complex and expensive.

6. Spills from the Mararoa weir are quite frequent. On average, water is spilled for 35% of the time. Sixty-six percent of the spills involve volumes less than 10 m^3/sec. Reports on fish movements supports the concept of targeting fish passage after flood events. Observation of flows beneath the control gates at Mararoa Weir, on the recession phase of a flood, showed there was then a clear space beneath the bottom of the gates and the water. The level differential between the upstream and downstream water surfaces was not great and it was considered that at such times, mature trout should be able to swim through the weir. If most trout migration is on the recession phase of a flood, then it may be possible to manipulate gate settings so that fish can get past the weir at these times. Water level differentials are of course much less. At the recession phase of a flood, a dirty Mararoa River may be left to flow down the Waiau for quite lengthy periods.

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INTRODUCTION

Why is a fish pass needed at the Mararoa Weir ?.

It was accepted by the engineers designing this structure that a fish pass was to be an integral part of the design. The reasons behind this acceptance had to do with political pressure. The then Southland Acclimatisation Society campaigned effectively for provision of access from the Waiau River for the stocks of trout and Atlantic Salmon that spawned in the Mararoa River and the Whitestone River.

The design was chosen on the recommendation of Mr R. Little of the Ministry of Agriculture and Fisheries. Successful fish passes are few and far between in New Zealand and there were few local precedents. This design was developed in Canada by the Quebec Department of Tourism, Fish and Game (Michel & Nadeau 1966). Discussions with overseas fish pass experts has since revealed that few, if any other of this design have been built elsewhere in the world (K. Bates, C. Katopodis, pers comm.).

Despite this lack of popularity , the Borda Orifice proved a good design. Velocities within the fish pass were low enough to allow small native fishes such as smelt and bullies through the pass (Field Dodgson 1981). The functional parts of the fish pass are a series of 16 borda orifices (Fig 1). There is a head loss of between 200-400 mm between each orifice owing to the resistance it provides to the water flow. Between each orifice the flow expands into chambers where fish can rest. The highest water velocities are at the mouthpiece of each orifice (Aspden 1972) where fish encounter velocities of 1.86 m/s (Jowett 1989). The fish pass required an average flow of 10 cusecs, an amount of water then considered sufficient to meet the energy needs of perhaps 6000 people (Field-Dodgson 1977).

Fig 1. shows the basic principles of the borda orifice design and the patterns of water flow which develop. Although the fish pass apparently functioned well, allowing even weak swimmers such as bullies, smelt, lampreys and elvers upstream, it was considered that brown trout appeared to find water velocities excessive at the entrance (S. Sutherland pers comm.). On the other hand, Jowett (1989) thought the water velocity of 0.12 m/s through the entrance was too low (?) to provide sufficient attraction for fish. Rainbow trout used the fish pass and were recaptured well upstream. Brown trout always seemed to be the species for which the fish pass presented the greatest difficulty (Field Dodgson 1981).

One of the major constraints on building a fish pass at this site was the requirement that it functioned over a range of water levels. At high water levels parts of the fish pass would become pressurised and accordingly the whole structure has been encased within a concrete tunnel. This step alone has made the fish pass impracticable. Maintenance is virtually impossible as the interior of the fish pass is almost inaccessible.

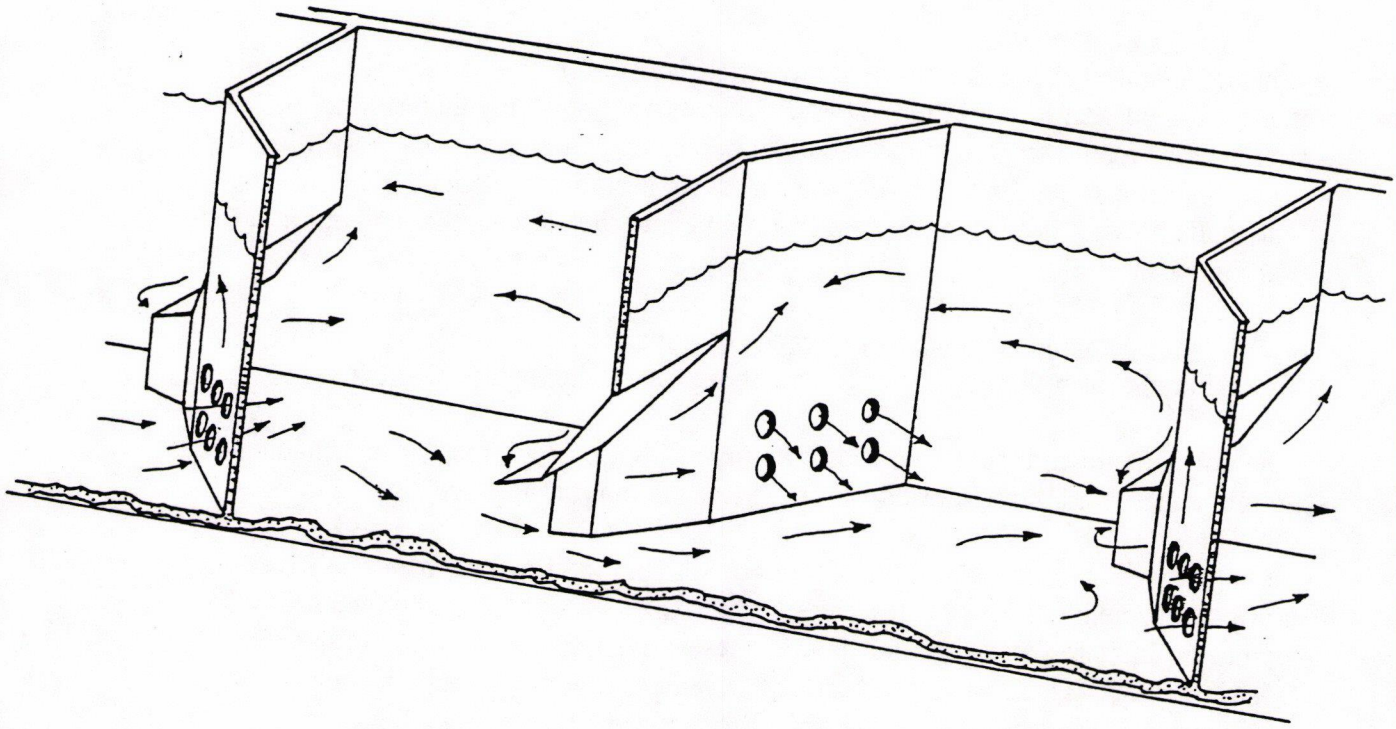


Fig 1. Borda orifice pass, showing baffle design and water flow patterns.

The manual for operation of the fishpass (M.L.C. fishpass operation, ECNZ files), discusses cleaning the fish pass;

"4.1 Cleaning of the fish pass
Most of the silt and some floating debris will collect in the silt trap. This should be flushed out by the removal of the cover plates on the silt trap. (the downstream channel will have to be pumped out [!] to do this)".

This hopeful approach is encountered again in;

"4.3 Upstream approach
Check the silt level and determine if any extensive silt removal is required to ensure the continued operation of the fishpass. Silt removal could [my underlining] be achieved by a number of methods apart from mechanical means. One possibility [my underlining] is to jet the silt during the shutdown period while opening the fishpass gate and allowing flow along the approach pipe into the silt chamber and out into the stilling basin.

4.4 Downstream channel and fish entrance chamber
Clean out silt from the fish entrance chamber. Check the bypass pipe exit.

The downstream channel may need some maintenance"[!]-[at present this channel no longer exists at all, being buried beneath an accumulation of gravels].

The reality of course was that the amount of silt coming down the Mararoa River was always sufficient to badly obstruct flows down the fish pass (S. Sutherland pers comm.). This problem with fine silt was present even before diversion of the Mararoa River. Then, when the Mararoa River was diverted directly toward the radial gates of the control structure, large quantities of river shingle began to arrive on every flood. The bed load of the Mararoa River is now passed through the control structure. Shingle swept into the stilling basin in front of the gates blocked up the entrance to the fish pass and covered the downstream channel. Various attempts were made to modify water flows around the entrance but the problem of shingle buildup has continued to the extent that only a weak flow now issues from the fish pass (Fig 2). It is considered that the fish pass interior is probably almost totally clogged with silt (S. Sutherland pers comm.).

This structure was designed in the halcyon days when financial management was less of a pressing problem and when staff numbers were far higher. Nowadays the facts are that maintenance costs of keeping the fish pass in operation in its present form are likely to greatly exceed what any reasonable person would consider worthwhile.

Although the fish pass was originally intended to allow rainbow trout upstream, the target species for fish passage over the Mararoa Weir at present appear to be brown trout and juvenile eels (elvers). Passage for lampreys also needs to be considered.

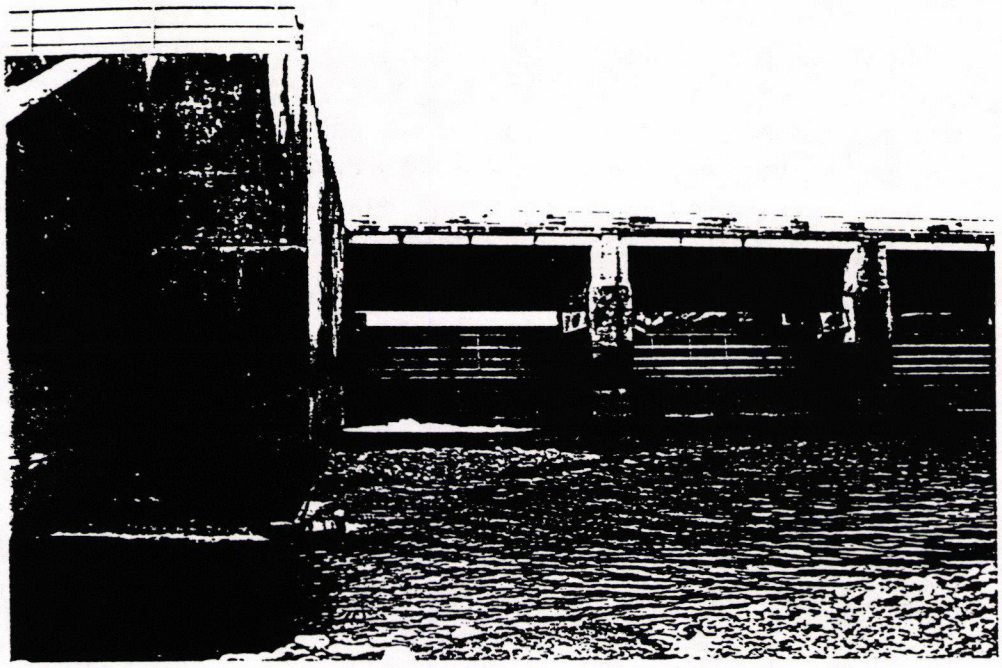


Fig 2: Fish pass entrance (left) at Mararoa Weir. Discharge into the stilling basin from wingwall is from a broken window in the fish pass. Note gravel deposition in the fish pass entrance area.

Elvers migrate upstream from the sea to find living places in the upper Waiau Catchment. Lampreys seek spawning sites in small tributaries upstream of the weir. All other fish in the upper catchment (including brown and rainbow trout), appear capable of forming landlocked populations, passage to and from the lower river or to the sea is not obligatory. However trout from the lower Waiau river formerly migrated upstream to the Mararoa and Whitestone Rivers to spawn (M. Rodway pers comm.).

The fish pass was trapped over 1978, 1979 and 1980. A quite remarkable trap was prefabricated and built within the fish pass by NZED engineers. Six species of fish, ranging from bullies to adult brown trout were caught in the trap. Tagging both rainbow and brown trout in the trap produced the disquieting information that all later recaptures of brown trout were caught from the Waiau River below the trap (Field Dodgson 1981). On the other hand, tagged rainbow trout were caught well up the Mararoa River.

There is evidence from other studies that brown trout within a river system can easily become sectioned into a series of populations by hydroelectricity development, despite installation of fish passes (Linløkken 1993). In that study it was estimated that less than 2% of the estimated stock of brown trout had used the fish passes provided. Lonnebjerg (1990) reported on a fish pass in Denmark successfully used by a range of weak swimming fish, that brown trout failed to use, apparently simply because of poor entrance siting.

Brown trout stocks in the Waiau river have evidently adjusted to construction of the weir. They are certainly common in the lower river and lagoon (C. Mitchell pers obs). Recent fisheries investigation in the lower Waiau River catchment have shown that brown trout fry and fingerlings can be very abundant in some areas, particularly the Orauea catchment (Mitchell & Davis-Te Maire 1994). Field-Dodgson(1981) reported that brown trout were observed spawning below the weir. If the fish pass was reinstated, would they in fact use it ?. Tilzey (1977) showed that brown trout were very accurate at homing back to the same tributary streams in which they had spawned previously. Brown trout stocks can be complex. Skaala (1989) showed that there was comparatively little gene flow even between seagoing and river resident stocks within the same river system.

It has to be accepted that, despite the best intentions, brown trout may not use any fish pass structure that may be provided for them. The risk of failure with this versatile and adaptable species appears to be particularly high.

METHODS

Discussions were held with M. Rodway, Manager of the Southland Fish and Game Council. He conveyed the concerns of the Council about the weir structure and the performance of the fish pass.

Files that dealt with the original decisions to build the fish pass were examined. Some of the original plans still available were studied. A range of reports and publications dealing with the fish pass were read. The concepts involved with reinstating fish passage were discussed with ECNZ staff and an impression was gained on the likely actions of ECNZ.

Mr S. Sutherland, Field Officer of the Southland Fish and Game Council opened up the fish trap facility of the fish pass. He also provided information on his experience of monitoring the trap.

The fish pass was inspected on four occasions. In March 1993 when the weir gates were fully closed and over a series of visits in February 1994. when the Mararoa River was in flood. At this time the radial gates were fully opened and large volumes of highly discoloured water were flowing down the Waiau River. Fine mesh fyke nets (3 mm. mesh) were set overnight below the fish pass entrance. Others were set upstream of the weir and left overnight. Concrete faces of the weir structure close to water level, downstream of the radial gates, were inspected at night by using 55 watt handheld spotlights.

Otoliths from a sample of 158 longfinned eels (*Anguilla dieffenbachii*) and 22 shortfinned eels (*Anguilla australis*) caught from known locations throughout the Waiau River Catchment were used to compare both minimum ages and the age structure of eel populations above and below the weir.

Otoliths were dissected from larger eels after the spinal cord had been severed and the muscles had relaxed. Dissection of otoliths from elvers was done under a binocular microscope using heads preserved in isopropyl alcohol. After a period of drying, all otoliths were broken in two and the broken face ground smooth using wetted 120 grit carborundum paper. Otoliths were then burned for approx 50 seconds to enhance the banding zones and then embedded, ground face down in clear silicone adhesive, on microscope slides. Viewing through the slide, contrasting light and dark zones were then counted across the otoliths at 100x magnification.

It proved impossible to handle elver otoliths in this fashion. Working under a binocular microscope, otoliths were broken underwater by pressure with a scalpel blade and after burning, embedded broken surface exposed, in silicone adhesive. These very small otoliths were then covered with a light vegetable oil to enhance the contrast between dark and light zones.

For all otoliths, the number of light, wide zones were then assumed to represent summers. Readings were made along as many strips across the otolith where the banding zones could be resolved. The total counts possible for all otolith

preparations from an individual fish were then summed. The mean of this figure was defined as the age estimate.

RESULTS

When first visited in 15/3/93, there was no sign of any fish life anywhere, either around the fish pass nor in the clear pool formed in the stilling basin. Nighttime observations were made on 24/1/94. At this time the Mararoa River was in flood and the control gates were fully open. A large volume of turbulent and discoloured water was flowing downstream from the control gates. Small accumulations of elvers attempting to climb the furthermost downstream concrete walls of the stilling basin were observed. These fish had managed to progress upstream through the rock rip-rap lining the downstream margins of the river channel, only to be blocked by water velocities past the returns on the smooth concrete walls of the stilling basin.

Six fine mesh fyke nets (3mm. & 6mm. stretched mesh) were set overnight at the base of the weir. A catch of 27 elvers and small eels (plus three large common bullies) were taken at the site of the exit from the fish pass, although the exit was buried by large quantities of shingle. The only species of eel caught was *Anguilla dieffenbachii*, which was to be expected, considering the dominance of this species in the upper Waiau system (Mitchell & Davis-Te Maire 1994). Eels from 11-56 cm. long were caught. Most were in the size range 11-21 cm. (Fig 3) and could be called elvers. It was interesting that all these eels had empty guts. It could be expected that the larger eels had been attracted into the nets to feed upon the smaller ones, but this was not the case. This lack of feeding may be common for upstream migrating eels, or perhaps it is a result of crowding below the weir and the general stress faced by these eels. Perhaps they were concentrated within an area that was inherently unfavorable for eels to live in. Analysis of growth rates of eels from the Waiau River found the growth rates of this sample to be the poorest in the catchment (Mitchell & Davis-Te Maire 1994).

Otolith aging of these eels showed that the elvers ranged in age from 2 to 8 years. Larger eels were from 15 to 28 years old (Fig 4).

The size frequency of 305 eels caught from throughout the Waiau Catchment was divided into the catch from above and below the weir (Fig 5). It can be seen that there is a relative lack of smaller eels in the upper catchment. This lack of smaller eels could be due either to the obstacle posed by the weir for upstream migrants over the past 17 years, or perhaps to the time taken for eels to migrate long distances upstream.

The age frequency of 76 longfinned eels caught from the Waiau Catchment above the weir was plotted (Fig 6). Only 5 of the eels appeared to be younger than the time the weir was built (17 years). The youngest eel was 14 years old. These 5 eels could even be errors in otolith reading, underestimates of age are the most likely error with this technique. But from this data only 7% of the population postdates the weir. In contrast 43% of 77 longfinned eels aged from below the weir were 17 years or younger. This pattern of longfinned eel age gives little support to any assertions that

the fish pass has allowed significant numbers of this species into the upper Waiau Catchment.

Surprisingly, no young eels were found among 18 eels caught from Deep Cove (Fig 6). Migrations of elvers should be expected at this new outlet from the upper catchment. Only one night was fished and so the fishing effort was limited. But this result may also perhaps reflect the small amount of eel habitat available at the head of the fiord. Old resident eels may be well entrenched, occupying all available territory.

A different impression of the impact of the fish pass was gained from an examination of the age frequency of 6 shortfinned eels (*Anguilla australis*) aged from above and 17 from below the weir. Although fewer of this generally lowland species were caught above the weir, their age frequency (7-29 years), was similar to the age frequency below the weir (6-31) (Fig 7). There is no evidence for a reduction in numbers of shortfinned eels after 1976.

A further issue is the behavior of eels once they move over the weir. Do they instinctively carry on up the Mararoa, ignoring the downstream route that leads to the vast habitats of the lakes and the inland Waiau ?. Fig 8 shows the ages of eels caught on the Mararoa side of the weir, including the Mavora Lakes, compared with the "Manapouri" side of the catchment. There is no evidence that younger longfinned eels were confined to the Mararoa side. In addition, shortfinned eels caught from Manapouri and the Balloon Loop area of the upper Waiau River were aged at 7,13 and 17 years.

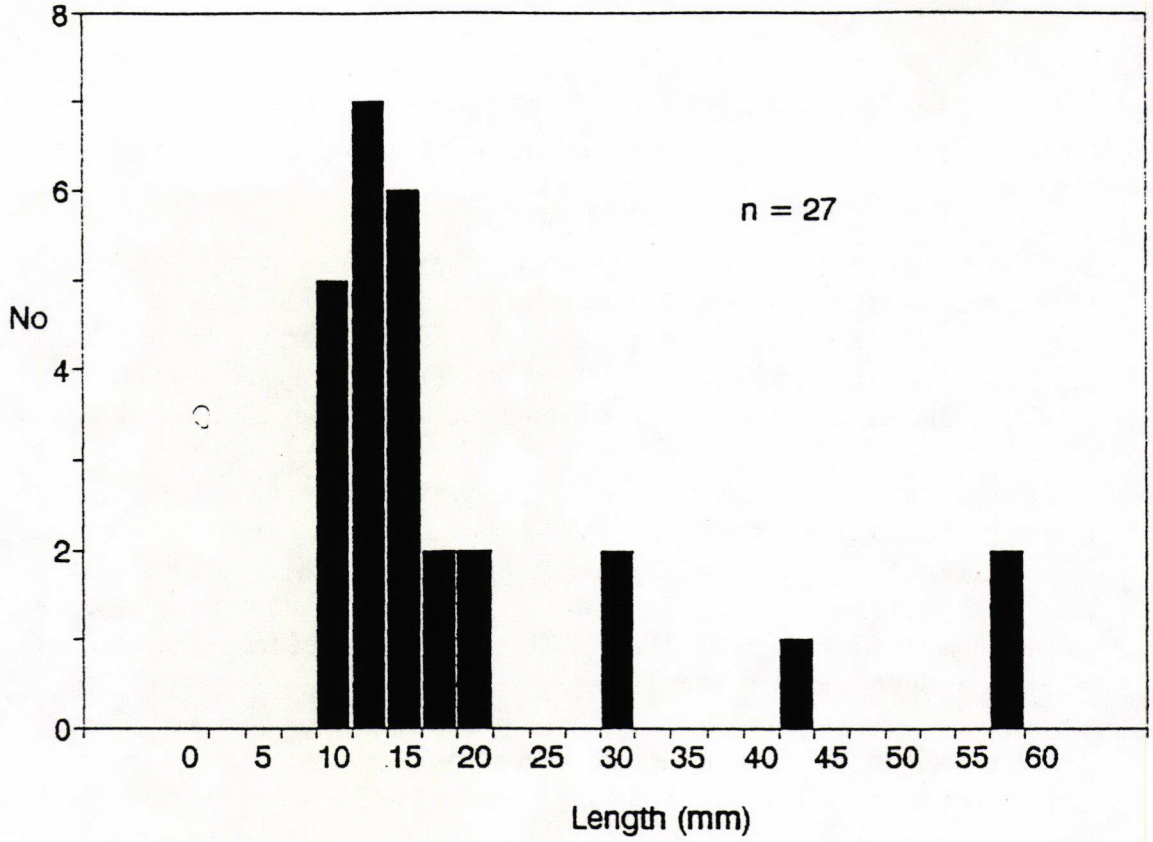


Fig 3. Size frequency of longfinned eels (*Anguilla dieffenbachii*) caught immediately below the Mararoa Weir (26/1/94).

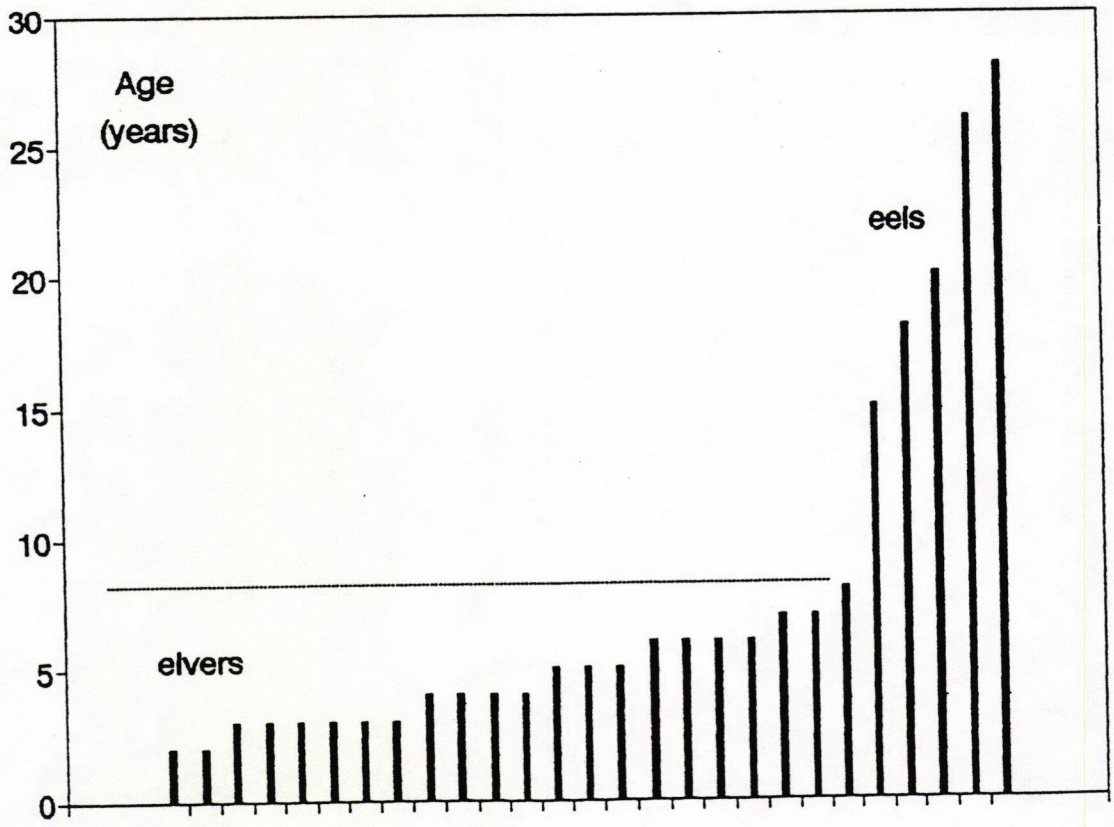


Fig 4. Ages of longfinned eels (*Anguilla dieffenbachii*) caught immediately below Mararoa Weir (26/1/94).

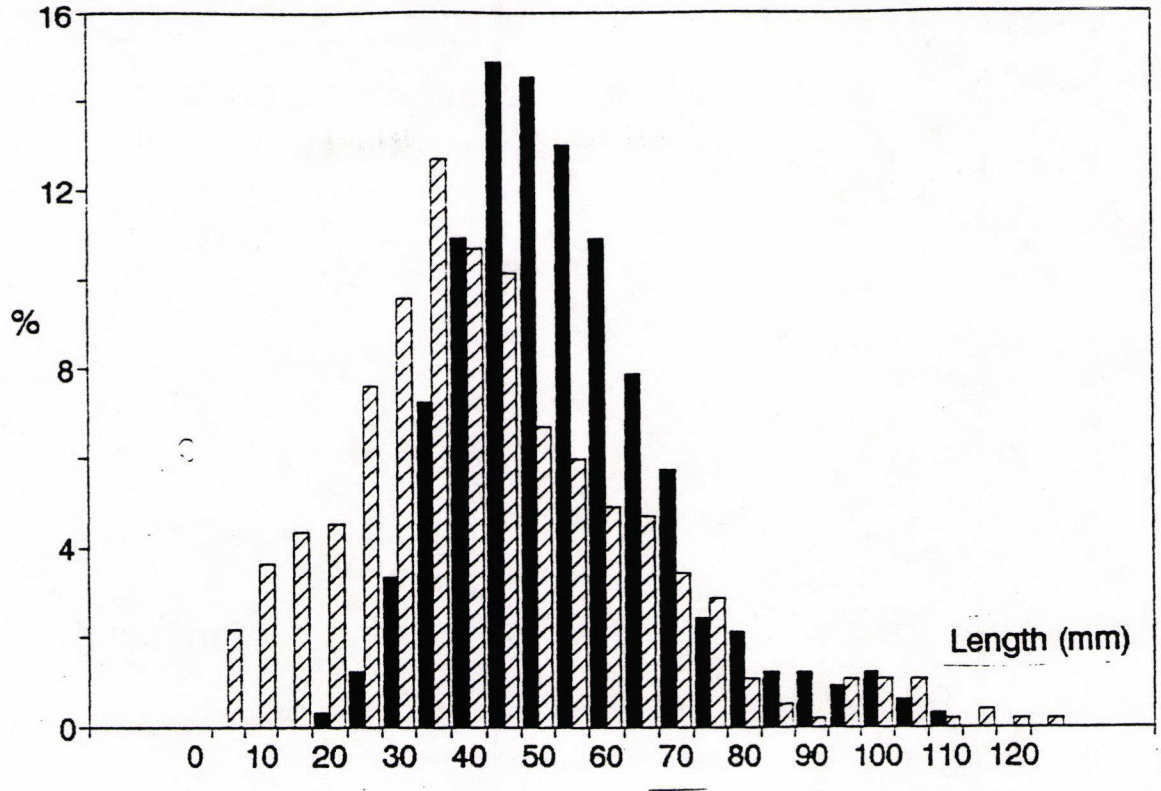


Fig 5. Smoothed size frequency (3 point moving average) of a sample of 102 eels caught in the Waiau River catchment above Mararoa Weir (solid) compared with the smoothed size frequency of a sample of 202 eels caught from the lower Waiau River. Note the pronounced skew toward smaller eels from the lower river.

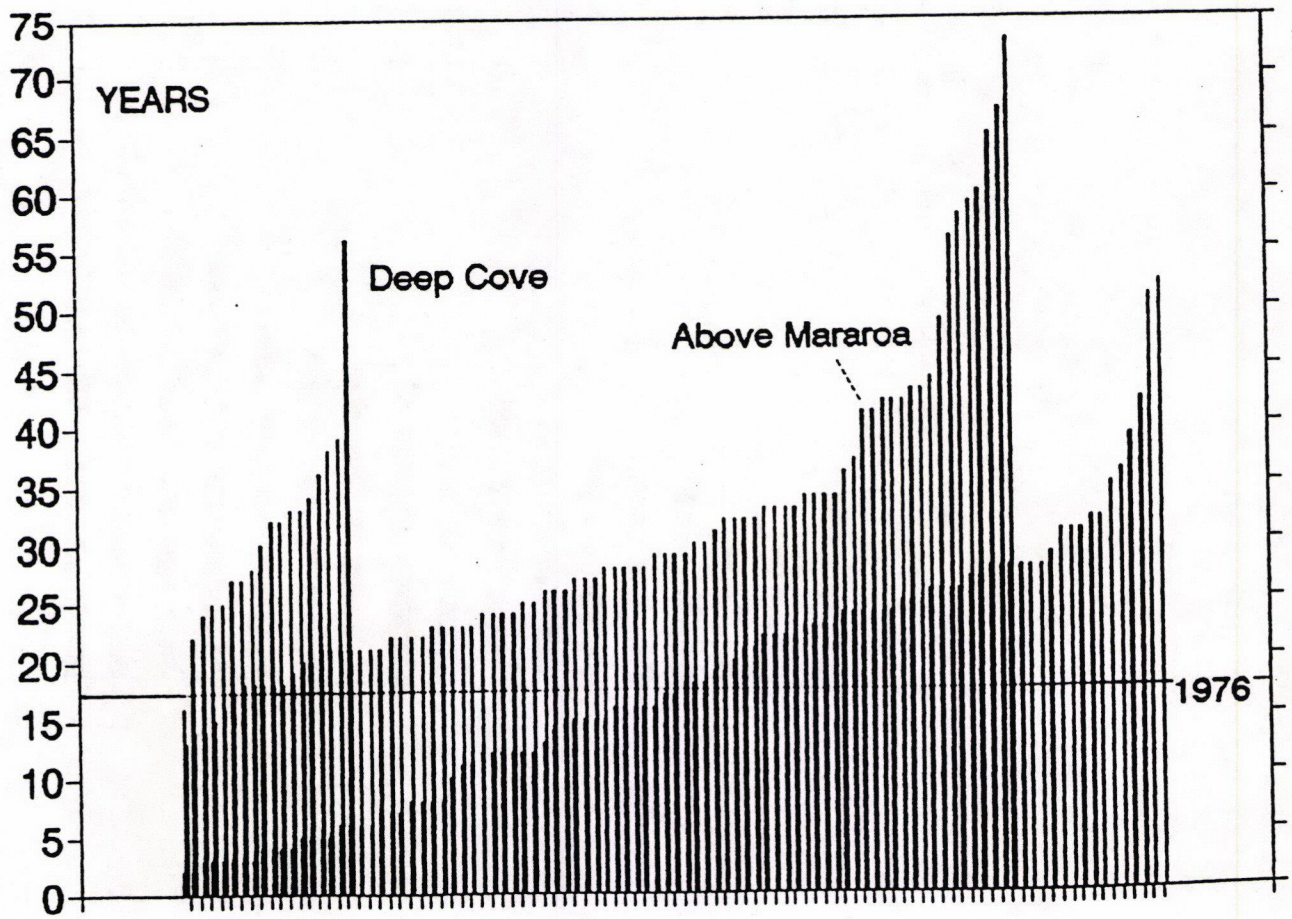


Fig 6. Age distribution of Longfinned eels caught from above and below Mararoa Weir and from Deep Cove. The line marks the year of completion of Mararoa Weir. Most of the population above the weir is older than the weir.

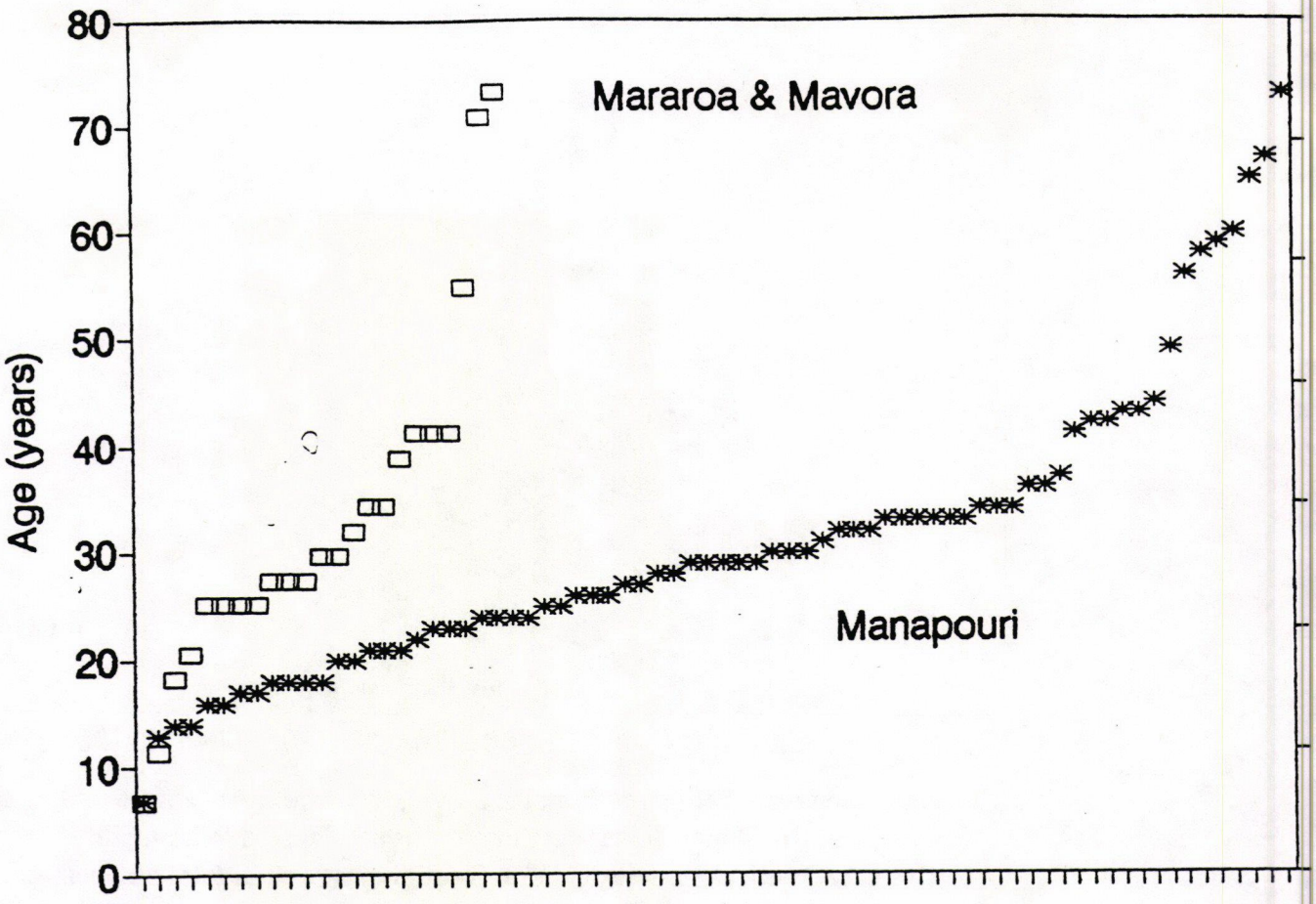


Fig 7. Comparison of age distribution of Longfinned eels caught from the Mararoa River side of the weir and from the Manapouri side. Note there is little evidence for a disproportionate concentration of younger eels on the Mararoa side.

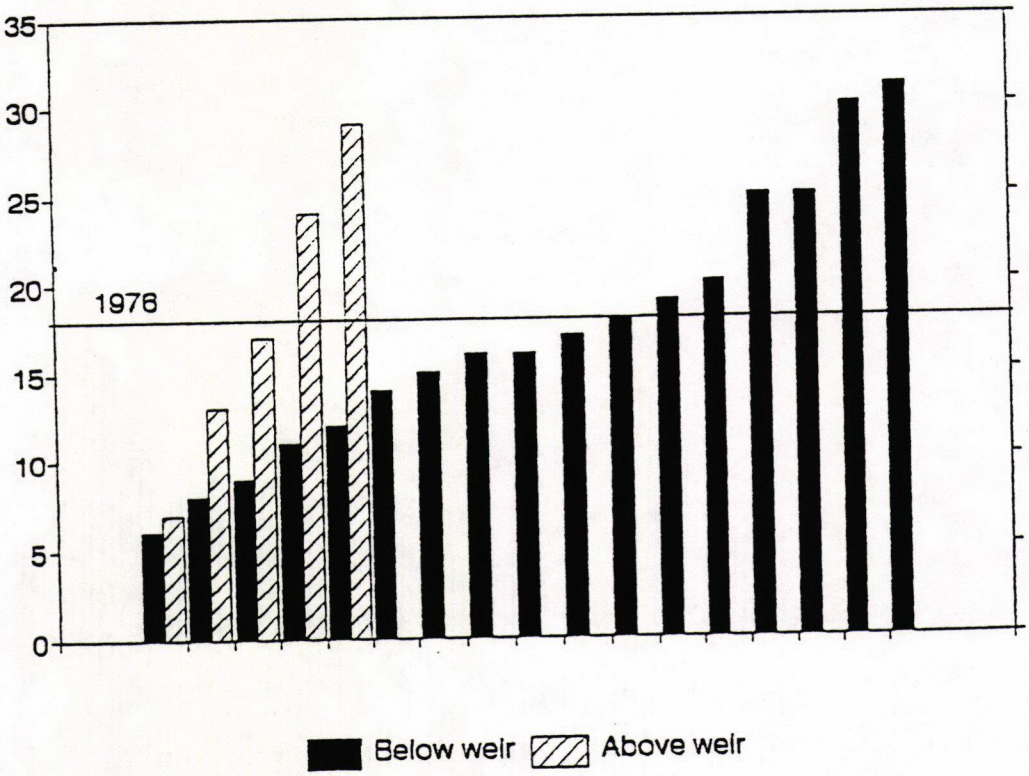


Fig 8. Age distribution of shortfinned eels caught from above and below Mararoa Weir. The line marks the year of completion of Mararoa Weir. It appears as if there has been recruitment of shortfinned eels over the weir since then.

DISCUSSION

One of the major aims underlying the demands for the first fish pass was to allow the passage of rainbow trout. The then Southland Acclimatisation Society was the prime mover in getting a fish pass built....

"The Southland Acclimatisation Society initiated the idea of having a fish pass but Agriculture and Fisheries were sceptical of its inception. The Societies aims were: 1) To get fish up the fish pass to enable the continuation of the normal spawning run. 2) The lower Waiau is the major issue of the Manapouri system, it is the only well established rainbow trout fishery of the South Island, and the major objections were its severance from the Manapouri Lake system." (from Field-Dodgson 1977).

The results of trapping studies (Field-Dodgson 1981) showed clearly that rainbow trout could successfully negotiate the fish pass when it was functioning. Rainbow trout tagged in the fish pass were later caught well up the Mararoa River. Over a six month period in 1978, roughly equivalent numbers of mature brown and rainbow trout (148-173), were caught going upstream and the 207 juvenile brown trout caught obviously outnumbered the 107 juvenile rainbow trout. Lampreys were also found in the trap. Considering the relatively coarse mesh size of the trap, the capture of even a few bullies and smelt was reassuring. Most native fishes and elvers could be expected to swim right through the trap meshes without being caught.

Brown trout have now become the fish of greatest concern to the Southland Regional Fish and Game Council. Significant numbers of mature brown trout can sometimes be seen in the pool immediately below the weir. The opinion is that these are upstream migrants prevented by the weir from continuing on to spawn (M. Rodway pers comm.). Although an excellent rainbow trout fishery has developed in the Mararoa River, based upon spawning fish migrating upstream from Lake Manapouri, experienced anglers consider brown trout to offer a premium angling experience.

The impact of the Mararoa Weir on the native fish populations of the upper Waiau Catchment remains a matter of concern. This point was mentioned by the National Park Board at meetings with NZED in 1977.

"The National Park Board want to maintain a free way for the native species that are present in the system, and they place emphasis on the native species". (Field-Dodgson 1977).

The problem the Mararoa Weir can present to eels has been seen by other people at first hand. Henderson (1992) reported his observations of the wastage of migrating elvers;

"3.2 An example of the effect of this diversion (the Mararoa Weir) was seen by me and my family in 1979/80. We have spent some very enjoyable (and at times very profitable) evenings over the holidays fishing in the weir area.

3.3 As we approached the weir this particular afternoon along the Blackmount Road we could see huge flocks of gulls in the vicinity of the weir. Most gull activity was

centered just downstream of the weir on the far (west) side in the area of the flood spillway. The Waiau had been high for some time, perhaps a fortnight or more, but now the weather had improved and Electricorp were holding more water in Manapouri which meant the river level had dropped quickly over the day or two preceding our visit.

3.4 The sight that met our eyes as we walked across the weir was incredible. The gulls were gorging themselves on young eels. Most of them were between 100 and 200 mm long. They had been left behind in shallow pools by the receding river. They had swum up the Waiau from the sea and had been prevented from completing their journey to the lakes by the weir. (the fish ladder is ineffective.)

3.5 There were many hundreds and thousands of these little fish over an area of perhaps 1/2 to 1 acres. I would estimate perhaps 10 to 20 tons in total and the gulls had been feasting on them for probably a day before we got there. The pools they were in were draining away leaving them exposed to the sun and the gulls. In places they were up to 400 mm deep.

3.6 The events of that afternoon left a lasting impression on me and my family. The waste of those eels shriveling in the sun unable to complete their journey because of man's interference is something I will never forget."

Over the period of time since the fish pass was built, and owing to the apparent lack of action on the part of [NZED/Electricorp/The Electricity Corporation of New Zealand], a considerable groundswell of local opinion against the weir has developed. If something is done, then it has to work and it has to be as cost-effective as possible. Even if only a compensation flow in the vicinity of 10 cumecs as recommended by Jowett (1993) is returned to the river, then some alleviation of the more visible fish passage problems should occur. For example, mass strandings of elvers will be unlikely to happen and trout may be more inclined to move into and back out of the stilling basin.

From the viewpoint of the Fish Passage Regulations, as administered by DoC, ECNZ must also consider the more difficult problem of providing effective fish passage over the weir.

There are a number of more or less obvious options for improving the present fish pass:

1. Extend the wingwall on the true right bank downstream, to prevent the buildup of gravels in this area. Clean out the existing fishpass, add more baffles, floor roughening and widen the entrance area. These modifications could ensure that eel and lamprey passage was reinstated and they may allow brown trout to make an easier passage. To attract this species into the fish pass an alternate entrance is suggested. This would be built as an aluminium flume with internal baffles, attached to the stilling basin wingwall and extending upstream to a fish collection point dictated by flows (Fig 9).

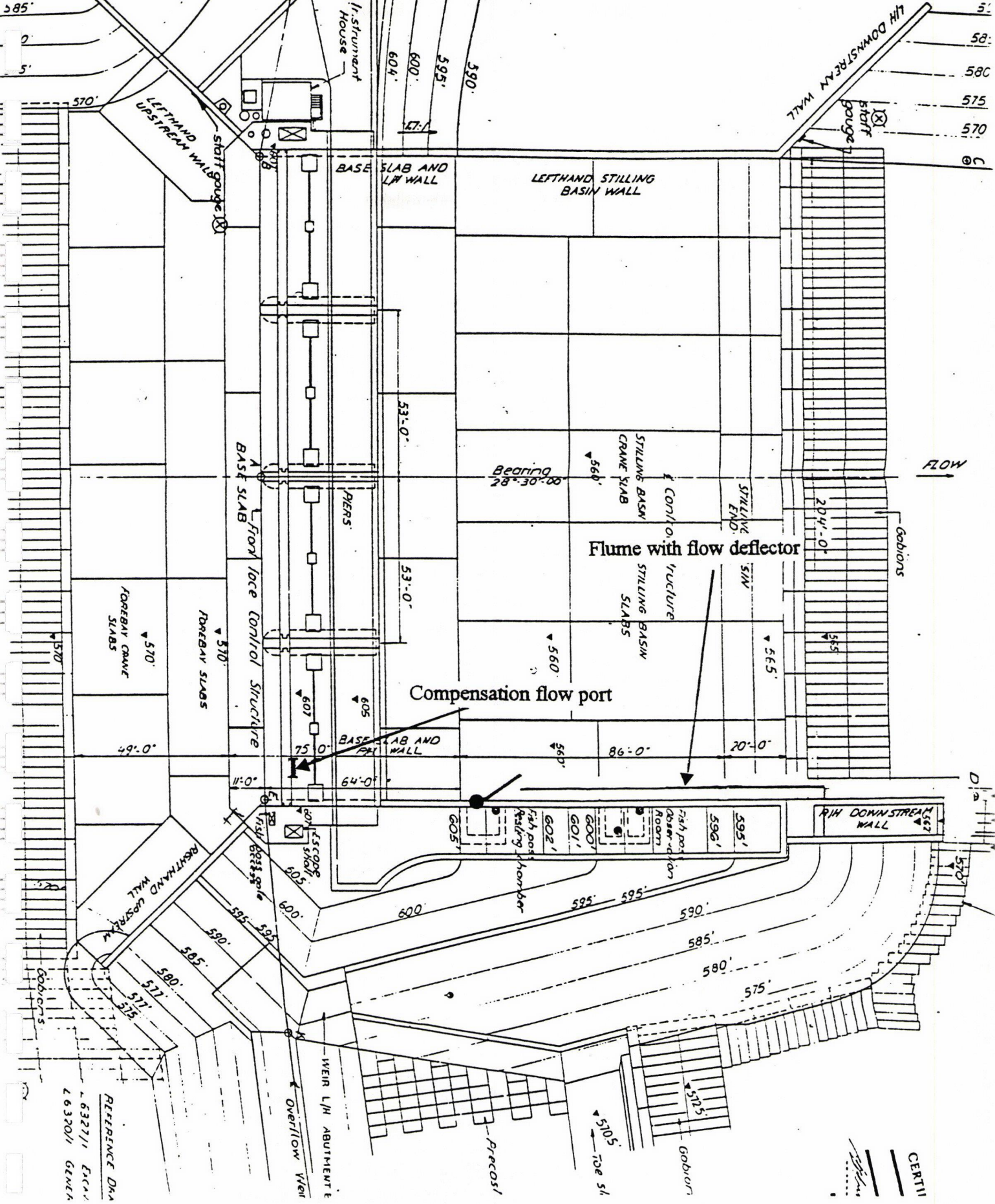


Fig 9. Alternative fish pass configuration for the Mararoa Weir Control Structure. Repair existing fish pass, install flume to bring existing entrance close to the compensation flow.

The advantages of this option are that:
The cost of modifying the present fish pass are likely to be very much less than completely building something new. The design appears to be inherently sound. This fish pass has already been shown to allow both rainbow trout and a range of relatively weak swimming native fishes upstream. There are few other fish passes in New Zealand where this has occurred.

The entrance of the existing fish pass is close to a favorable site (although it would be better if it were shifted a short distance further upstream). Entrance siting is critical for the success of fish passes. At any flow fish will instinctively move upstream to the base of the control gates. An obvious route upstream must then be presented to the fish. They will not think about going back downstream to find a fish pass entrance sited some distance below this point of blockage. No matter how clever or expensive the design, the fish pass will be a failure. It is at this point, where the fish are prevented from progressing any further upstream, that the fish pass entrance should be provided.

Among the disadvantages of this option are that the entrance structure, attached to the wall of the stilling basin (Fig 9), would be vulnerable to damage or even to complete loss during flood events. In addition there is a widespread opinion that the fish pass is a failure. Really it is only weakness in the ancillary design, and a lack of forethought into the needs for continual maintenance of a relatively sophisticated in-river structure that has caused the problems (combined with unforeseen changes resulting from diversion of the Mararoa River).

However if the fish pass is seen as essentially a public relations problem, then remodeling of the existing structure could be seen as less than wholescale commitment. If brown trout again refuse to use the fish pass (as they have a high probability of doing so, based on overseas researches), then ECNZ may be criticised for doing too little. However the probable costs for even modifying the existing structure are likely to be so high that publication of these costs could allay public criticism to a considerable extent.

At the time of reconstruction, consideration has to be given to designing in a simple and effective cleaning system. If that is impossible then a new fish pass is required.

2. Construct a wider, lower gradient fish pass from the head of the existing fishpass, out through the side of the weir and along the rockwall to above the area where the existing fish pass used to discharge. From this point the channel would continue back upstream down the wall of the stilling basin to a point close to the radial arm gates. Gradient of the channel should remain constant throughout all these changes in direction. Siting the entrance within the stilling basin pool would make the entrance obvious to fish within the stilling basin, after the gates had closed. This fish pass could be a Denil type or a "artificial-natural" stream type, using cobbles imbedded into the bottom of the channel to brake water flows and thus allow small fish to move upstream. This new exposed fish pass would be easier to maintain and should allow a range of native fishes plus small trout to move upstream (Fig 10).

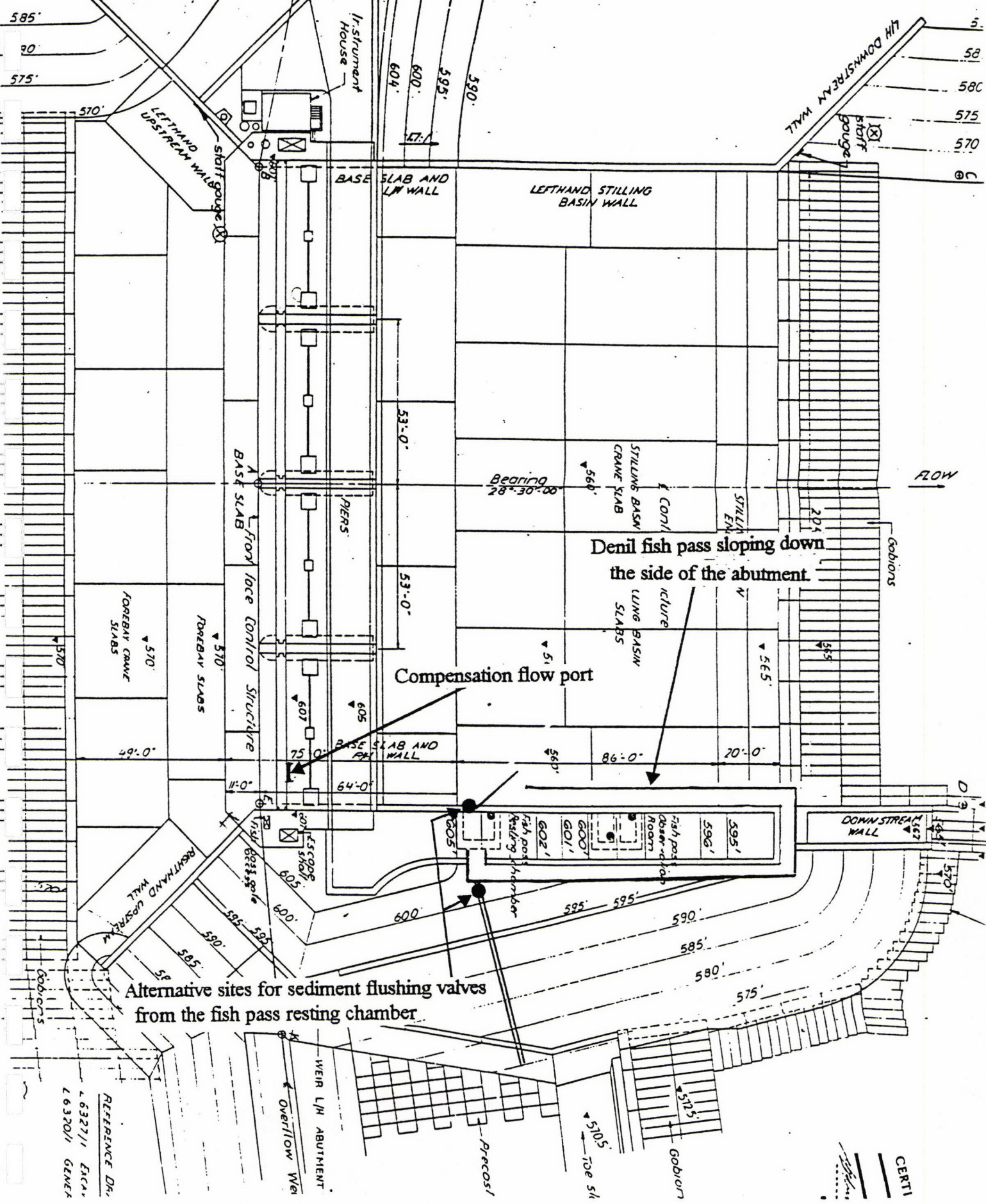


Fig 10. Alternative fish pass configuration for the Mararoa Weir Control Structure. Denil fish pass attached to right-hand stilling basin abutment, with entrance close to compensation flow discharge. Fish pass uses existing exit.

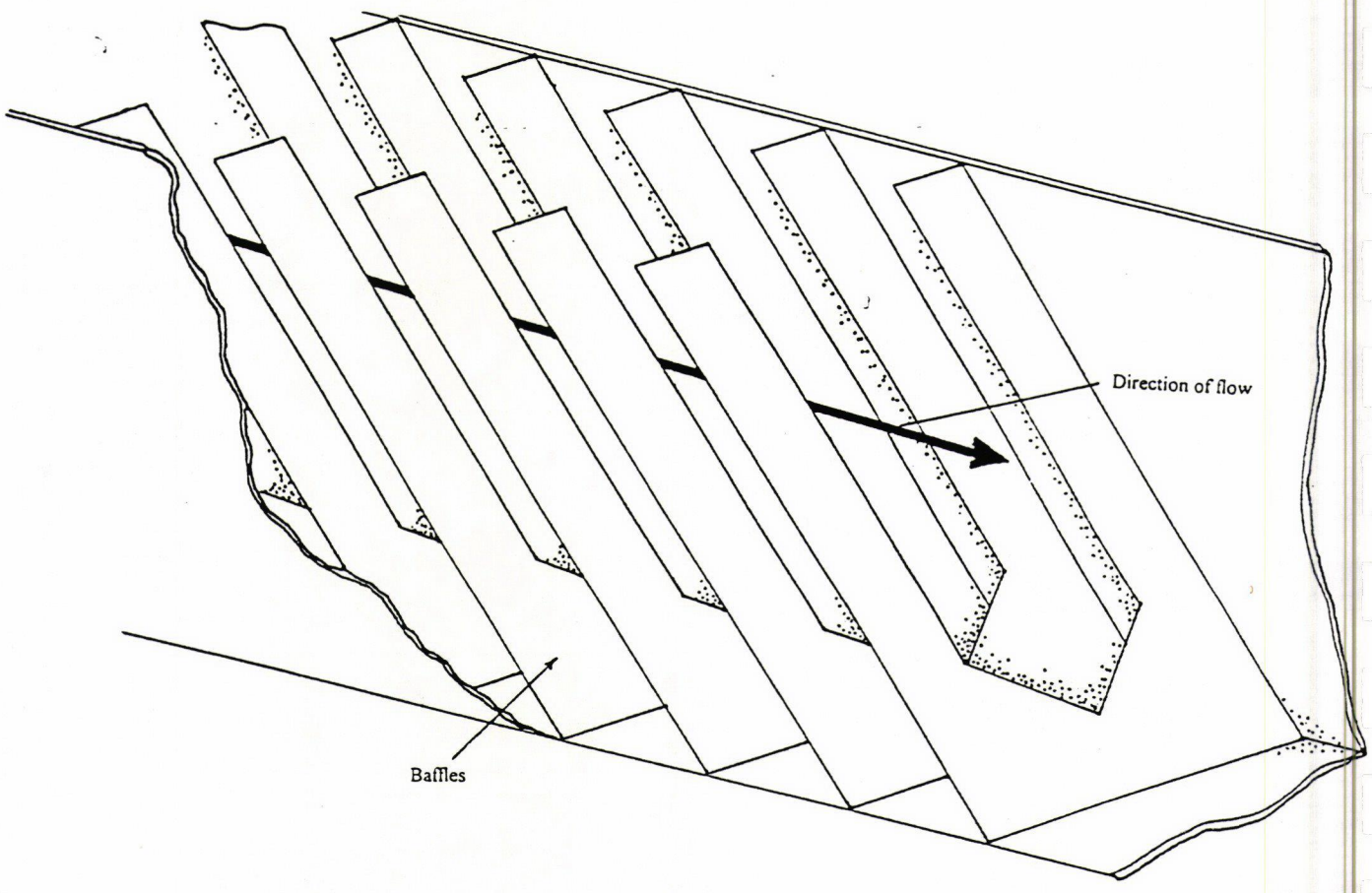


Fig 11. Baffle layout for a Denil Fishpass.

The advantages of this option are that a low gradient Denil-type fish pass can allow a wide range of fishes upstream, including small, weak swimming species (Sato 1990). Fig 11. shows what the baffle layout in a Denil-type fish pass looks like. One advantage of the Denil design is that they are relatively insensitive to variations in head. Another feature is that vertical velocity profiles decrease toward the bottom (Katipodis 1990). Small, weak swimming fish can move upstream in this zone. A cobble lined 'artificial-natural" channel offers fish an infinite range of variations in water velocity. Studies overseas (Lonnebjerg 1990) have shown that a range of weakly swimming fish will also use this type of fish pass. In contrast, these fish would not use more standard designs, based upon engineered flumes with highly efficient baffles at intervals, where there are great changes in water velocity over short distances. If it really was the poor swimming ability of brown trout which prevented them from successfully negotiating the former fish pass then this more natural structure may have greater success. In addition it can be expected that small native fish will find it much easier to make passage within the boundary layer presented by the cobble substrate. A gradient in the range of 3^0-10^0 is required to maintain sufficiently low water velocities for small fish in an "artificial-natural" stream channel.

Maintenance would also be easier owing to the open form of the new channel. If it is quick and relatively inexpensive to jet out accumulated silt then it is more likely to happen. The existing exit from the fish pass which has already been pierced through the weir could also be used.

If the public can observe the fish pass working then a favorable impression is given. Periods when the fish pass requires maintenance are also likely to be reported.

As for option 1, one disadvantage of option 2 is that the entrance structure, set along the wall of the stilling basin, would be vulnerable to damage or even complete loss during flood events:

3. Divert the compensation flow over the overflow weir, adjacent to the right bank abutment of the control gate structure. This flow would then flow around the tip of this structure to discharge into the lower end of the stilling basin pool. A Denil type fish pass would then be built to zigzag up the right bank abutment to intersect with the fish pass resting-chamber of the existing fish pass (Fig 12).

The advantages of this option are that fish pass would be protected from flood flow damage, apart from floods sufficient to overtop the overflow weir. Diverting the compensation flow around to the stilling basin should attract fish into this substantial flow of water and concentrate them at the entrance to the fish pass. An accessible fish pass should be easier to maintain.

The disadvantages of this option are that there is inadequate space for a very low gradient fish pass. There could also be significant costs for providing secure foundations for a fish pass on the riprap sides of the abutment. Construction of a compensation flow structure designed to deliver a constant flow from a varying head will be difficult (read costly) over the weir crest.

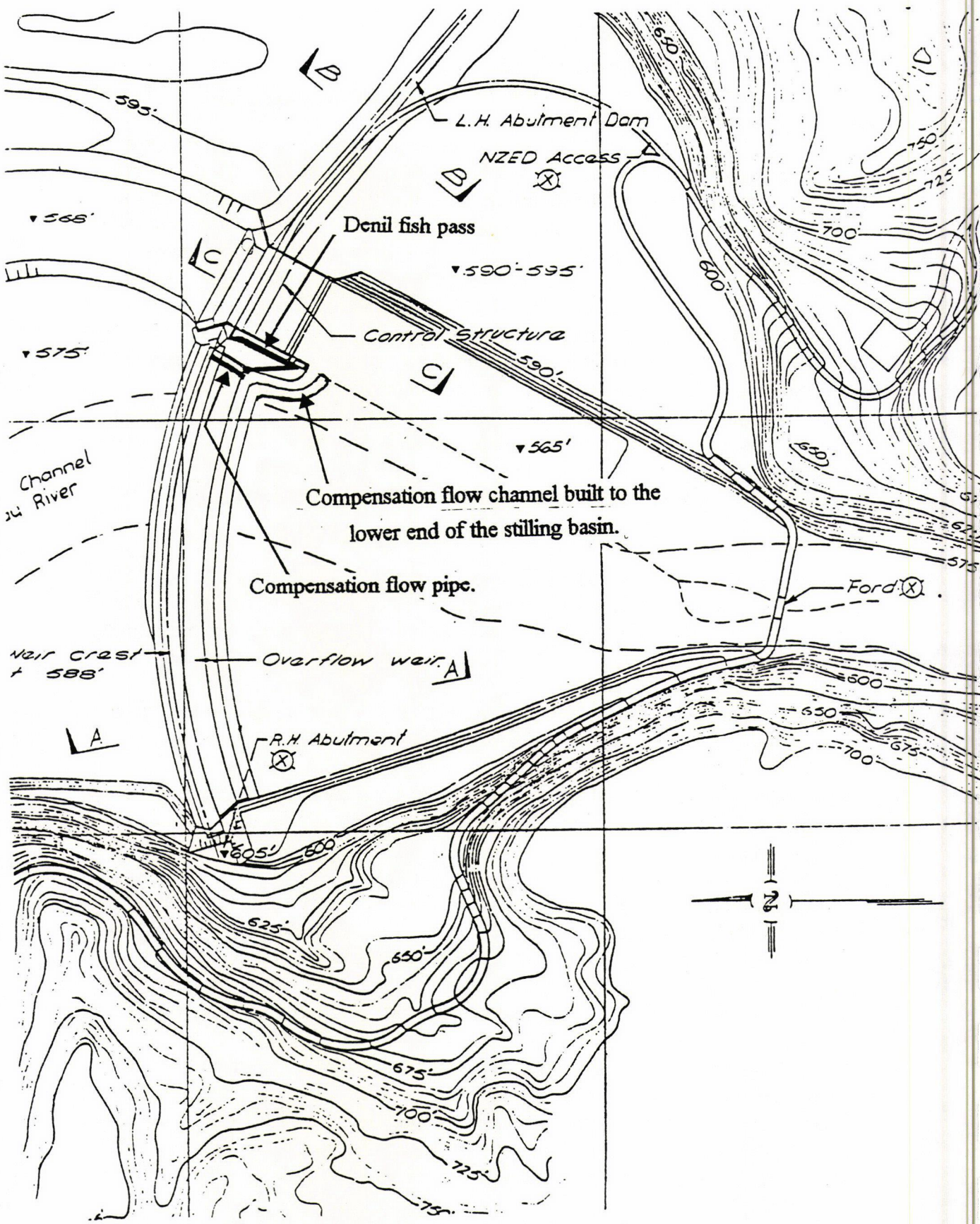


Fig 12. Alternative fish pass configuration for the Mararoa Weir Control Structure. Denil fish pass built to intercept the hydraulic jump channel and using the existing exit to the fish pass.

4. Divert the compensation flow over the overflow weir on the right bank side. The compensation flow structure could also act as a water deflector to protect a Denil type fish pass built up the side of the overflow weir. At low river levels, fish would swim up the channel formed by the hydraulic jump, attracted by the compensation flow discharge. At the end of the channel they would encounter the fish pass entrance and could continue upstream. Diversion of the compensation flow around the tip of the right bank abutment of the control gate structure would allow fish to move out from the stilling basin pool and up to the fish pass at all river levels (Fig 13).

The advantages of this option are that fish would enter the upper river well away from the flow through the control gates, which could perhaps sweep weak swimmers back downstream if the gates were opened at the time. Fish attracted into and confined within the channel formed by the hydraulic jump would also easily locate the entrance to the fish pass.

The disadvantages of this option are that fish may be vulnerable to predation or poaching while confined within the channel. In addition, construction of a compensation flow structure designed to deliver a constant flow with a varying head may be difficult (and expensive) over the weir crest.

5. Construct a dedicated channel to take the full compensation flow on the true right bank of the Weir. Use a velocity barrier (effective at all flows), below the bridge to divert fish into this channel (Fig 14).

The advantages of this option are that: The gradient from the top of the weir down to a likely discharge point would be considerably less than for the existing fish pass or for any proposed modification of the fish pass. Therefore mean water velocities down the channel will be relatively low (particularly for the case of a boundary layer type fish pass). This implies that the metabolic costs for fish to swim up the fish pass will be reduced. If the inherent difficulty and energetic cost of making passage is what deterred brown trout from using the existing Borda orifice design then this particular problem will be minimised in this low gradient channel. If the fish pass is a natural part of the channel assigned to carry a compensation flow then it is more likely the structure will receive ongoing attention and maintenance.

Disadvantages of this option are that a compensation flow structure to cope with the varying water levels behind the weir, and still allow fish passage, will have to be both complex and expensive. In addition fish have to be convinced to move up the compensation flow channel. It must be borne in mind that the recession phase of flood flows down the Waiau River are considered to be the main period when fish tend to move upstream. The volume of water discharged through the control gates at these times is likely to orders of magnitude greater than any flow down a dedicated compensation flow channel. Therefore fish will tend to swim right past the entrance to the fish pass and will concentrate at the base of the control gates as formerly. And the probability that they will move back downstream to find the fish pass channel will be low.

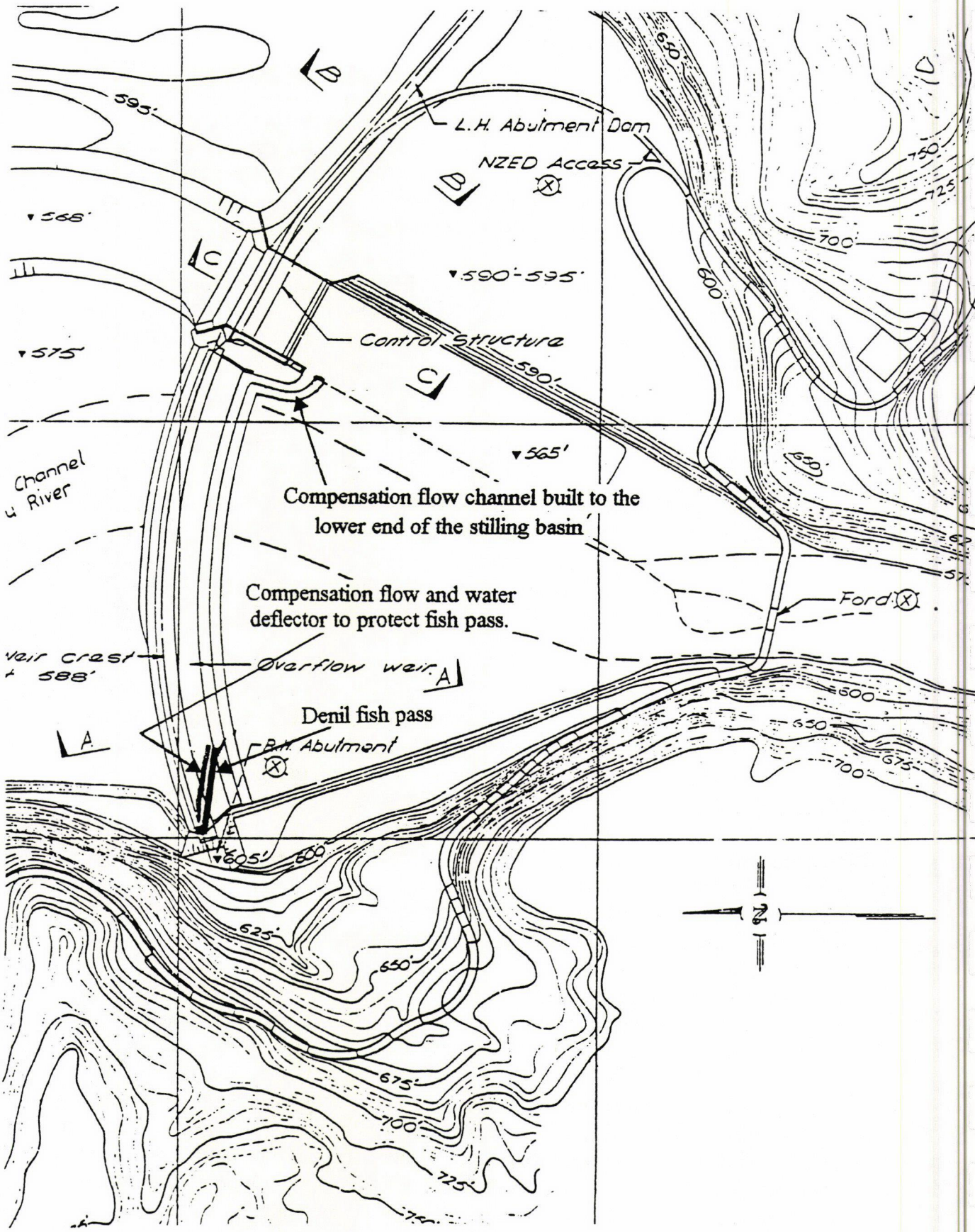


Fig 13. Alternative fish pass configuration for the Mararoa Weir Control Structure. Denil fish pass set on 10° slope up the side of the overflow weir. Compensation flow is adjacent to fish pass. Hydraulic jump acts as a channel at low river levels

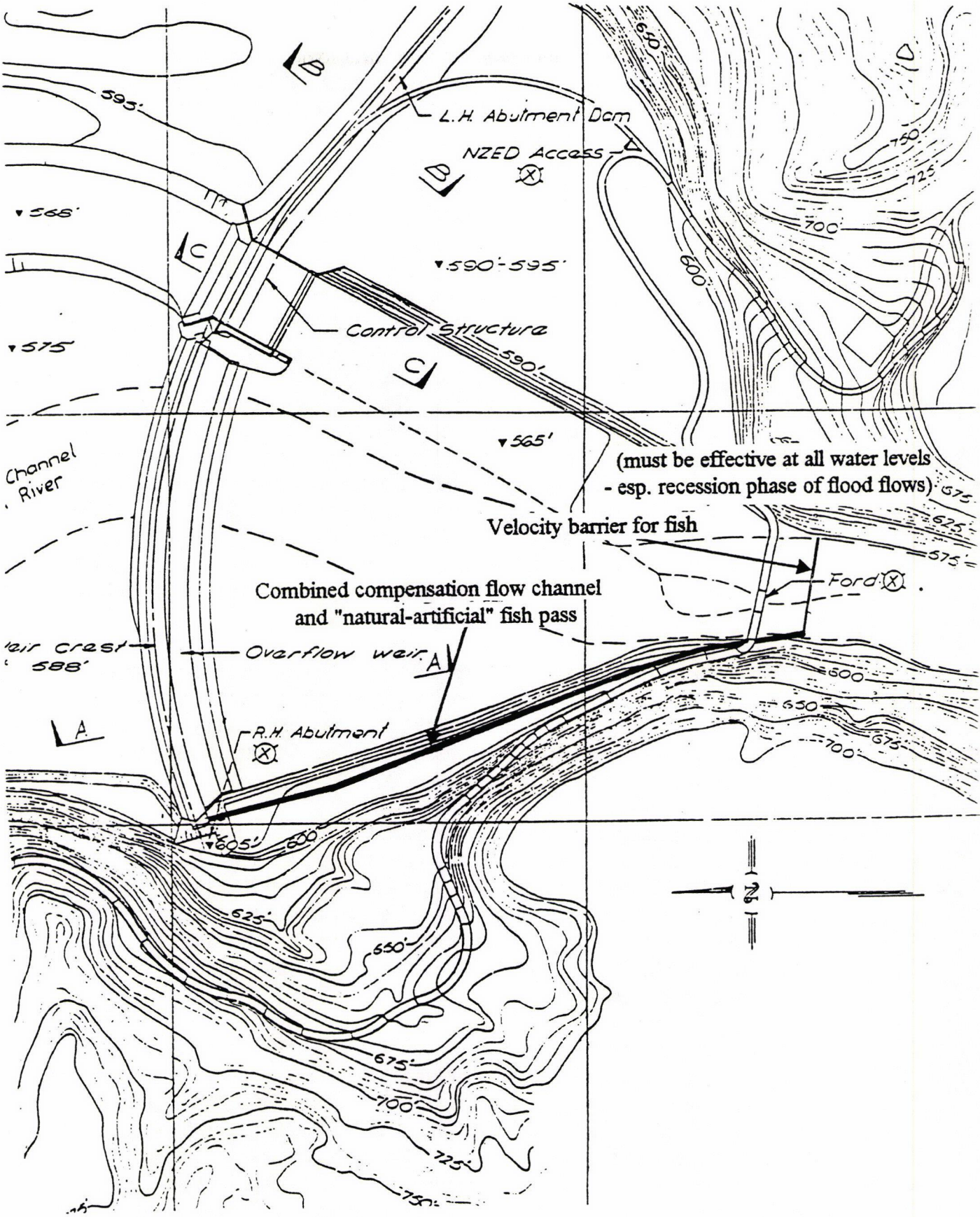


Fig 14. Alternative fish pass configuration for the Mararoa Weir Control Structure.

The response to this rather obvious problem is to build some type of velocity barrier to prevent fish from moving upstream to the control gates. This will be an expensive and difficult task. The volumes of water discharged down the channel during times of flood are huge, with an enormous erosive power. Even if a velocity barrier was designed for normal flows it is likely to be undercut and destroyed by flood flows. To design and construct a velocity barrier intended to function at the full range of flood flows is likely to well exceed the cost of actually constructing the compensation flow channel.

6. Observations of flows beneath the control gates at Mararoa Weir on the recession phase of a flood showed that there was a clear space beneath the bottom of the gates and the water (Fig 15). The level differential between the upstream and downstream water surfaces at this time was not great and it was considered that mature trout should then be able to swim through the weir. If most trout migration is on the recession phase of a flood then it may be possible to manipulate gate settings so that fish can get past the weir at these times. At the recession phase of a flood a dirty Mararoa River may be left to flow down the Waiau for quite lengthy periods. This flow could perhaps be tapered off in a manner to allow trout passage. A study of the frequency with which water is spilled from Mararoa Weir (Riddell 1993) showed that over a 14 year period water was spilled for 35% of the time. In four years, water was spilled for more than 50% of the time. For 66% of the time the weir was spilling, less than $10m^3$/sec was being spilt.

An examination of flow records for Mararoa Weir for the months of May June and July (Riddell 1993), when trout can be expected to migrate upstream, showed that about 4 spills can be anticipated over those months, every year. It may be possible that trout can get past the weir now. With some attention to detail, the window of opportunity could be widened significantly.

Of course the ultimate option would be to construct a second weir on the Manapouri side of the present weir. Such a lock arrangement would allow a essentially zero head discharge from the Mararoa River, allowing the full range of fish to swim past the weir. Shutting the Mararoa Weir and opening the second weir would then allow fish to move downstream to the lakes. Loss of clear Manapouri water while spilling dirty Mararoa water could also be avoided. Unfortunately economics are likely to rule this concept out at an early stage.

7. An alternative system for compensation flows. The simplest option for providing a compensation flow would be to set one of the radial arm gates so that it delivered the required flow. In practice this may be difficult to achieve with any degree of precision and a smaller, more precise structure may be required. This structure could be designed to provide an attractant flow to the fish pass entrance so that it also assists upstream fish passage at the same time. What is envisaged is a small radial arm gate set into the closest gate to the fish pass entrance. This radial arm gate could be automated to release a precise compensation flow through the full range of lake levels (Figs 9&10).

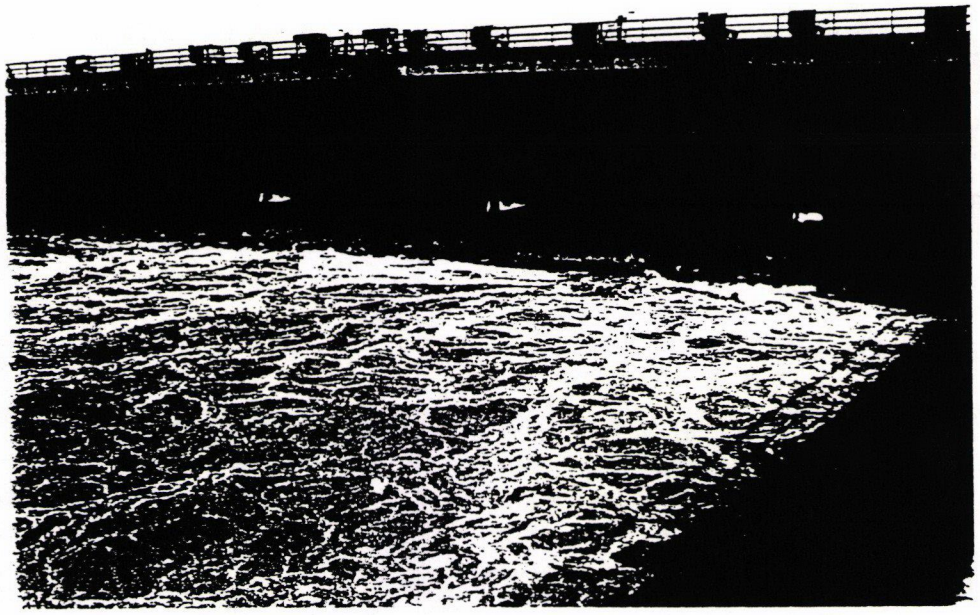


Fig 15. Recession phase of a flood at the Mararoa Weir. Note that the gates are clear of the water and that a relatively low head of water is present. Adult trout should be able to swim through the gates at this time.

The advantage of this compensation flow option is that provision of a compensation flow from the gates would be considerably cheaper than constructing a dedicated channel, breaching the weir etc. If the gate was cable-driven then raising the main gate would automatically close the compensation flow gate. As the gate was then lowered back into position, the cables of the compensation flow gate would take up the slack and the compensation flow would automatically be restored.

The disadvantages of this option are that care would be needed to ensure that the correct flow pattern was set up in the stilling basin. When they reach the velocity barrier formed by the flow discharging through the compensation flow gate, fish must be attracted into the alternative of the fish pass entrance,. It is envisaged that a flow discharging at the stilling basin water surface would be more "natural" for the fish than a gate which discharged at the base of the stilling basin structure. Problems of erosion of the base of the stilling basin caused by this asymmetrical discharge would also be less for a surface discharge. Costs for replacing one of the radial arm gates with a gate fitted with a port, rails etc., could be significant. An alternative for reducing this cost would be to schedule work for a period when the gates were opened and to attach a prefabricated compensation flow gate to the existing gate when it is lifted clear of the water:

CONCLUSIONS

It is obviously necessary to provide passage for some species of fish over the Mararoa Weir. However it is a difficult problem to provide the variables of flow and attraction flow that the full range of species that attempt to migrate over the weir will respond to. Elvers, lampreys and other native fish can be considered weak swimmers, trout are large strong fish. Based on previous experience the most intractable species will be brown trout. As adult trout are powerful swimmers and jumpers, some attention to gate settings may increase the chances of trout simply swimming past the weir on the declining phase of a flood flow.

In terms of cost-effectiveness, the most practical option for providing fish passage and a compensation flow that will also assist with fish passage, will probably be a dedicated compensation flow port on the radial gate adjacent to the fish pass entrance. Some study is needed to ensure that the correct flow pattern is presented, one that directs fish into a fishpass entrance as they move upstream, attracted toward the compensation flow. A well designed fish pass entrance attached to the side of the stilling basin wingwall could be effective for attaining this goal.

There are a range of fish pass designs which could be built over the weir. It is likely to be more cost-effective to utilise the existing fish pass exit which has already been pierced through the weir. Therefore, alternatives include making the existing fish pass more effective and easier to maintain, or building a new pass to bypass inaccessible sections of the fish pass. An open channel around the present wing wall could be jetted free of sediment at intervals using a truck mounted water blaster. But ideally the fish pass should be designed so that it does not need cleaning, or it can be cleaned by one man turning a valve

The fish pass exit into the river above the weir must also present fish with an area of relatively low water velocities as they leave the fish pass. The effect of water entrained into the compensation stream must be considered at the exit area. It would be futile to attract fish up the fish pass at considerable expense and foregone electricity generation, only to flush them back downstream immediately. Extending the entrance with a large diameter pipe directed toward the overflow weir is one approach. Raising the pipe so that it takes water from the surface layers may also help to reduce the intake of gravel.

RECOMMENDATIONS

Without access to costings and engineering expertise on the feasibility of these suggestions, it is difficult to recommend any one option over another. However my preference would be for a combination of a Denil fishway fitted onto the existing fishpass entrance (or perhaps let into part of the fish pass) and led around the right wingwall at a slope of between 5^0-10^0. This fish pass would need to extend around the wingwall to an entrance in the scour pool, below the gates and upstream of the accumulation of gravels in the stilling basin. Although Borda orifices can cope with variations in head level, the Denil portion of the fish pass will have to be sufficiently deep to allow for variations in head (Relative insensitivity to head is one of the advantages of this design).

Silt ingress into the fish pass could be reduced by extending the entrance up into the water column. Water velocity declines with depth in a Denil fishway. Placing large stones in the bottom between the baffles will further help create the static boundary layers needed for the passage of elvers and small fish. Passing the proposed compensation flow through a port on the right hand gate would provide an attraction flow to the entrance of this fish pass.

I see the major problem being secure fixing of the fishway where it extends into the stilling basin. If it could be housed inside the wingwall structure on this return, then it may be more secure. But maintenance could become difficult, as for the present design, if the pass was housed in this way.

A fish pass is likely to be necessary for eels and lamprey. Trout are much more powerful swimmers. The possibility of simply allowing adult trout to swim past the weir at times when the spill is $10 m^3$/sec or less should be considered.

ACKNOWLEDGEMENTS

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Although the responsibility for any errors and omissions is mine alone, Bill Chisholm, Neil Gillespie and his staff from Clyde provided input and constructive criticism to the draft. Thanks again.

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