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Fish Pass Design and Evaluation

Phase 1

Institute of Freshwater Ecology

NRA

National Rivers Authority

R&D Report 5

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Fish Pass Design and Evaluation: Phase 1

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R&D PROJECT 304 – FISH PASS DESIGN & EVALUATION

Statement of Use

This document is intended to be used as a source of detailed technical information on the major types of fish passes. The use, design and performance characteristics of the major types of fish passes are reviewed. The review is based on an NRA survey and an extensive literature review. In order to ensure the usefulness of the document from both a theoretical and practical point of view the document is to be used by fisheries staff and engineers within the NRA for 6 to 7 months, after which a revised definitive document will be produced which will incorporate appropriate amendments. Any comments/amendments that readers feel are necessary should be noted down during the period of use for possible inclusion after the 6 to 7 month period.

There are a number of points that the reader should take into account when using this document for reference:

1. SI and Imperial units are used throughout the report. For construction purposes the conversion table (appendix H) should be used for accurate conversion.

2. Figure 4.1, Schematic diagram of pool and traverse fish pass with notched traverses, gives a generalized diagram of a small pool and traverse fish pass. Great care must be exercised in the selection of the dimensions of the pool and weir fish pass in relation to the range of the expected flow regimes. This is because there are a number of cases where pool and weir fish passes of the smallest practicable dimensions possible have been built in rivers where the flow regime is too great for the pass to work properly.

In order to ensure that the definitive document is a useful, practical guide for NRA staff and others involved in the construction, design, choice, and use of fish passes it is imperative that comments on this interim document are made and sent to the Project Leader, Adrian Fewings, NRA Southern Region by January 31st 1994, the end of the review period. Your cooperation is appreciated.

<u>**For the 6 to 7 month period this interim document is for use by NRA staff only. No copies should be made without the prior permission of David Jordan, Head of FRCN, Bristol.**</u>

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FOREWORD

Fish pass installation represents a significant capital cost to NRA fisheries budgets. In order that this money is spent effectively, the most efficient and cost effective installation must be selected. Cost savings can be made by reducing design selection time and by selecting optimum designs for sites and target species. Information on basic design was summarized in 1984, but in recent years a wider range of fish pass designs and variants has been hydraulically tested using advanced computational techniques. However, the literature concerning hydraulic performance and effective utilization by fish species is diverse, poorly integrated and not available in summary form. A review of the literature from a UK perspective is a precursor to preparing a Manual to aid in appropriate design selection.

The assistance of Mr. Ian Pettman (IFE) and Dr. Ian Winfield (IFE) in compiling and reviewing this report is gratefully acknowledged. We also acknowledge Mr. Trevor Furnass (IFE) for the redrafting of the figures and his advice on the production of the report.

Useful comment and detailed information on design costing and practical aspects of fish pass construction were recieved from staff at Wallace Evans & Partners, Babtie, Shaw & Morton, Mr. T. Woolnough of Fishway Engineering and Dr. M. Beach of MAFF.

EXECUTIVE SUMMARY

The focus of the report concerns recent literature on the efficiency of a variety of fish passes. The hydraulics, design and maintenance of major fish pass types are reviewed with reference to ease of fish passage. Assent of weirsand passage through gates (with one exception) have not been addressed. A schematic diagram displays the layout of each design and details are summarized for each major type of pass both in the main text and in technical appendices. It was concluded that the multiplicity of fish pass design variants have often been well tested in theory and in the laboratory with respect to fish passage, but there is a dearth of follow-up validation exercises following construction. In particular insufficient emphasis has been given to developing methods to attract fish to fish pass entrances.

The swimming performance of a variety of fish relevant to the UK experience is reviewed and summarized in tabular form. The literature is largely focused on the passage of salmonid fishes, especially Atlantic salmon *Salmo salar*, brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss*. Although a number of coarse fish have been investigated, the coverage of this group is much more restricted with respect to both species and body size and there is little information on juvenile life stages.

The results of a questionnaire to NRA regions concerning experience and future proposals for fish passes are summarized, as are the views of a number of consultant engineers. Finally research priorities are identified and recommendations are made for further monitoring of fish pass performance.

KEYWORDS

Fish pass, pool and weir, Denil, vertical slot, swimming performance, eel passes.

1. INTRODUCTION

1.1 Design criteria

There is a large amount of literature documenting the successes and failures of fishpass installations around the world. The effectiveness of passes varies with design, species and site conditions. Passes for highly motivated salmonids are comonly thought to be successful, but it must be stressed that there are few critical analyses to support this view for the general design options available. Fish passes for other species and juvenile fish are more recent and not as well documented (Katopodis,1991). A good review by Banks (1969) on the upstream migration of salmonids covers the problems of flow at dams, diversions and fish passes; the effects of temperature caused by impoundment and the conflicting need for light in order to ascend obstructions with a preference for darkness or turbid water in unobstructed passage.

Larinier (1978) states that several factors will affect the choice and size of the pass:

- variation of upstream level during the migration season
- migratory species likely to use the pass
- the flow available for the pass
- the site available for the pass when there is an existing installation.

Orsborn (1987) gives four general elements of fish pass efficiency which are important to their design:

- to optimise speed and success of fish passage to minimize delay, stress, damage and fallback of fish
- minimize water use while achieving above, where there are competing water uses
- maximise the range of stream flow under which the fishway is operable by matching fish pass operation to flows during the period of desired fish passage
- minimize construction (and operation and maintenance) costs by using construction methods and materials appropriate to the remoteness and geometric, hydrologic and geologic characteristics of the site.

Boiten (1991) discusses fish pass design under three main headings -hydrology, biology and water management demands. Boiten (1991) states that flow hydrographs and flow duration curves can be used to determine the variation of discharges and water levels during the hydrological year. Boiten (1991) also states that fish migration experts should provide information on which species of fish need the highest priority and which are of secondary importance together with information on the expected migration period and the swimming and leaping capabilities of intended species.

A checklist of pertinent fish pass data is given by Bell (1986) (Appendix A). Bell (1986) states that a fish pass is recommended when the head difference is as low as 0.6 m, although limited fish passage may be possible where the head is <2.4 m. Two papers by Larinier (1987,1983) provide dimensioning criteria for various types of pass and basic principles which can be used as a guide for planning fish passage facilities. The latter paper includes a list of data required for the planning of such a facility.

1.2 Entrances and attraction

Poor entrance conditions have been identified as a common failing of unsuccessful fish passes. Fish pass entrances have two aspects; the actual positioning of the entrance and the attraction flow. (This has been mentioned in specific sections as being a problem but has not been discussed in detail.) The entrance should be placed at the furthest upstream point that the fish can reach. Carnie (1989) states that far too many passes have been constructed where the entrance is further downstream than the main flow of water passing over the weir into the pool below. Migratory fish are reluctant to turn back to find a route upstream and consequently they tend to congregate in the pool below the weir. It is very much easier and less expensive to build the entrance downstream where the construction can take place largely in the dry. Bell (1986) states that fish normally approach fish passes at a limited range of depths and ideally, attractive entrances should be placed at such depths. Most adult salmon would be between the surface and 1.8 m, and most other fish up to a depth of 3.6 m at dams and falls. Although these depths may vary depending on temperature, turbidity and oxygen levels.

Barry and Kynard (1986) report on the attraction of American shad to a fish lift with a tailrace and spillway entrance. The spillway, which was situated near the base of the dam passed 88% of the fish even though it operated for fewer days than the tailrace entrance although it was ineffective when spillage over the dam was high. The tailrace entrance was difficult to locate because of turbulence caused by the upwelling of discharge water from power generation which created a large boil directly in front of the entrance. Trivellato and Larinier (1987) used hydraulic models to study two fishpasses on the Loire and Dordogne Rivers. The main purpose of these studies was to optimise the position of the entrance and determine the discharge needed to provide adequate attraction to these sites.

Orsborn (1985) reports that a survey of current design practices and personal interviews led to the fact that attraction velocity must be considered in the light of the following guidelines:

- the orientation of the jet should be towards the area where the fish tend to accumulate (base of falls, downstream of spillway)
- the attraction velocity should be about 2.4 - 3.6 ms^{-1} which is a function of the size of the fish pass attraction opening and the amount of attraction flow
- each site should be analysed according to its special geometric, flow and fisheries characteristics.

Beyond that there is very little information available on design criteria for the velocity and amount of the attraction velocity required to lure fish into a fish pass. The only set of published data available was reported by Collins and Elling (1960) based on tests at the Bonneville Fisheries - Engineering Laboratory. Parallel channel tests were conducted which offered migrating fish a choice between two different velocities, which ranged from 0.9 - 3.96 ms^{-1}. A statistical analysis of the data showed that only when the higher to lower velocities were 3:1 or larger would a significant number of fish choose the higher velocity. Considering that the strength and persistance of a jet used to attract fish is a function of its shape and the momentum in the flow the results of Collins and Elling (1960) have been further analysed (Orsborn,1985) and are presented in appendix A as Table A.1 and Figure A.1, the latter showing an equation for fish attraction factor. This factor represents the two important factors in attraction flow:

- the difference in the momentum of the two parallel jets and
- the level of jet intensity as defined by their average velocity squared

These studies are restricted to North American species.

Pavlov (1989) reports that the velocity of the attracting flow should not be greater than the current threshold velocity of the fish, which is defined as the 'minimum current velocity which leads to an orientation reaction against the current (values range from 1-30 cm/sec)'. Increasing the attraction flow to 70 cm/sec resulted in an increase in *Abramis brama* and *Stizostedion lucioperca* entering the Ust'Manych hydraulic pass. This velocity was slightly less than the critical velocity of *A. brama* (80-115 cm/sec). When the velocity was reduced to 15 cm/sec no fish were attracted. Usually the attracting velocity is taken as 0.6-0.8 of the critical velocities e.g. 0.9-1.2 m/sec for *Salmo salar* and *S. trutta*. Attracting flow must be carefully aligned and must be parallel to or at an angle not exceeding 30 degrees to the main flow. The influence of the angle of the ramp on its efficiency is shown in appendix A as Figure A.2. Mallen-Cooper and Harris (1991) report on a vertical slot fish pass that has the water aligned at 45-90 degrees to the main flow, but there is no information given on its effectiveness.

Larinier (1991) also confirms that the bad location of entrances or insufficient water discharge is a problem at many fish passes. He recommends that 1-5% of the volume of the competing flow is provided on major rivers. This criterion is the same as for North America. Problems of entrances and attracting velocities are further discussed under the specific types of fish pass.

Blocking and guiding devices can be used to increase the efficiency of attracting fish into the pass and several methods are described by Pavlov (1989). Blocking devices can be either mechanical (a screen or barrier) or electrical, neither of which are particularly successful. The problem with the successful operation of electrical devices is in selecting the appropriate potential difference, since this varies for different species and sizes. A threshold stimulus for one fish could be critical for another. Electric screens are generally not successful in guidance , as shocked fish are generally swept downstream but can be used as barriers to prevent passage past the entrance. Various physical methods can be used for the guidance, large stones, ditches, bottom rapids and ledges, all of which can provide conditions which are attractive to migrating fish.

Poaching can be a problem at fish passes as fish tend to congregate and become easy targets. In the pool and weir section it has been suggested that resting pools should be covered with screens to deter poachers. Carnie (1989) also suggests that the pass should be located near the middle of the weir and that submerged orifice type passes should be considered as the fish are not so visible.

1.3 Summary

There is a general concensus in the literature that close cooperation between water authorities, hydrologists, fish migration experts and hydraulic design engineers is essential for the installation of successful fish passes, and that the location and species involved are unique in each case. Woolnough (1987) supports this close cooperation and says that preconceived ideas should be avoided . His view is that fish passage in the future can be successfully accomplished by demolition, Denils, fishway gates and fish locks. He also outlines design criteria and the application for approval under the Salmon and Freshwater Fisheries Act 1975. Schwalme, Mackay and Lindner (1985) report that substantial saving in construction costs can be achieved by decreasing the length of the fish pass (thus increasing the slope and water velocity) to the minimum that still allows efficient fish passage. They also found that fish have preferences for certain types of fish pass and this may require several different designs at the same site when the efficient passage of a variety of species must be accomplished. It may be possible to exclude undesirable species from upstream areas by building fish passes that exploit interspecies differences in fish pass preferences.

One of the most important aspects to the successful operation of a well designed fish pass is the entrance. It should be placed at the furthest upstream point which the fish can reach and in a position where the fish can find it. Bell (1986) suggests that it is located at a depth at which the fish approach. Attraction to this entrance can be provided by additional flow, which must not be greater than the swimming performance of the fish, and by guidance devices which provide attractive conditions to the fish.

Further investigation is required into attraction and guidance which is poorly reported in the literature, and into physical damage to fish during passage. Much has been written on downstream guidance, mortality and damage but there appears to be little or no information on upstream passage.

2. VERTICAL SLOT FISH PASSES

2.1 Introduction

A vertical slot fish pass consists of a rectangular channel with a sloping floor that is divided into a number of pools. Water flows down the channel from pool to pool through vertical slots, which can be either single or twin (Figure 2.1). A water jet is formed at each slot and energy is dissipated by jet mixing in each pool. Single jets do not dissipate energy as efficiently as twin jets and therefore a proportionately larger pool area is required for dissipating the energy. Orsborn (1987) states that vertical slot fish passes work well where large fluctuations in river stage occur and the fish pass flows are unregulated.

2.2 Hydraulics

The hydraulic characteristics of vertical slot fish passes are discussed in three papers; Andrew (1991), Katopodis (1991) and Rajaratnam, Van der Vinne and Katopodis (1986). Andrew (1991) states that the approximate discharge of vertical slot fish passes can be calculated with the formulae: $Q=3.32W(D+h)h^{0.5}$. Where Q is the discharge (m^3/s), W the total slot width (m), D the water depth on the downstream side of a baffle (m) and h the drop in water surface from the downstream side of one baffle to the downstream side of the next (m). He also states that the projection of the upstream nose on the centre baffles of both single and double jet fishpasses is very important. These projections can be clearly seen in Figure 2.1. When the jet is properly directed, there is a strong cross flow at the nose that controls the direction of velocity of approach to the slot. With adequate cross velocity at the nose the jet is directed into the pool and the flow remains stable, if not adequate it could create an unstable flow condition that could disorient the fish and reduce migration speed. Full details of major vertical slot fish passes in British Columbia are given in appendix B as Table B.1; for the pool dimensions and slot widths given, a good stable flow pattern with adequate rest areas is provided.

Eighteen designs of vertical slot fish passes were tested and reported by Katopodis (1991). The results, given in appendix B as Figure B.1, show that dimensionless discharge varied linearly with depth/width of flow. Rajaratnam, Van der Vinne and Katopodis (1986) present the results of an experimental study on the hydraulics of vertical slot fish passes with seven designs for slot and baffle placement (appendix B Figure B.2), in all designs the slot width was 0.305 m. Using these results a conceptual idea of uniform and non-uniform flow states has been developed with a rating curve for each design in terms of the dimensionless flow rate and the relative depth of flow (flow depth/slot width - appendix B Figures B.3 and B.4). A graph showing discharge for a single slot fish pass against pool depth taken from Bell (1986) is shown in appendix B as Figure B.5.

2.3 Fish passage

Andrew (1991) reports that some fish species accept vertical slot fish passes better than others. A three baffled fish pass with 0.3 m slots, 2.44 m x 3.66 m pools and a water depth of 1.83 m was used by higher proportions of chinook salmon and steelhead trout (67% and 60%) than American shad (32%), striped bass (22%) and sturgeon (20%). The latter three species also avoided weir fishways. Results of studies on model fish passes in Finland (Hooli, 1988) recommended that the fall height should be only half a fishes length, and that smaller fish needed more time to rise. 1.5 minutes per basin for 20 cm trout, 15-60 seconds per basin for 30 cm trout. At a vertical slot fish pass at Seton Dam, British Columbia (dimensional details are given in appendix B as Table B.1) *Oncorhynchus nerka* spend an average of only 48 seconds per pool. One fish passed through 31 baffles in only 11 minutes, the slowest fish required 45 minutes (87 sec per pool) (Andrew, 1991). Schwalme, Mackay and Lindner (1985) report that *Catostomus catostomus* and *C. commersoni* showed a preference for vertical slot over Denil. The results of their study on a vertical slot and two Denil fish passes (of slopes 10% and 20%) built into a weir on the Lesser Slave River are given in Table 2.1.

Table 2.1 Numbers of fish caught in fish pass traps during monitoring period May 12 - June 25 1984

Species	Vertical slot	10% Denil	20% Denil
C. catostomus	174	16	7
C. commersoni	130	41	9

2.4 Construction and maintenance

Vertical slot fish passes are usually constructed of concrete, with the baffles usually poured in place but precast baffles are becoming more common. The fish pass at Hells Gate, British Columbia has required little maintenance and shows little sign of concrete erosion after 45 years (Andrew, 1991). In South-eastern Australia (Mallen-Cooper and Harris, 1991) the fish pass channels were constructed using precast concrete culverts or *in situ* concrete. The baffles were either precast in concrete or fibreglass or made of fibre-reinforced cement sheet. The initial fibreglass baffles were unsuccessful as they flexed under pressure, which loosened and removed some mounting blocks.

Rytkonen and Hepojoki (1991a) report on a fish pass in Finland where the slots could be easily modified to make it into an overflow type fish pass with, if necessary, bottom orifices. A variable size and form of openings has an advantage when calibrating and adjusting the fish pass *in situ*.

Mallen-Cooper and Harris (1991) report that where a fish pass is built as part of a new weir the fish pass cost <4% of the total cost of the weir.

Bedload is normally swept through by normal water velocities but floating debris must be removed annually. Trash racks and gratings are provided to exclude debris that could obstruct the slots. The latest vertical slot fish pass to be built at Hells Gate is covered by a grating

0.10 m x 0.15 m which is sloping 18% toward the river (Andrew, 1991). This excludes debris and enables stranded fish to slide back into the river.

Advantages of vertical slot fish passes are that they provide a whole water column for ascent of both bottom and surface travelling fishes and that they can operate over a wide range of water levels. The ability to operate at low discharges means that they can conserve stored water (Katopodis, 1991). Its design is less simple than the pool and weir fish pass, but its advantage is that it is self regulating (Bell, 1986).

2.5 Summary

2.5.1 Velocities

0.2 - 1.5 ms^{-1}.
Slot width ranges from 0.29 - 0.61m. A pool width of eight times slot width and a pool length of ten times slot width give satisfactory results and minor variations can be made without affecting performance.

2.5.2 Strengths

Operates over wide range of water levels.
Provides whole water column for ascent for both bottom and surface travelling fishes.

2.5.3 Weaknesses

Some species (*Oncorhynchus tshawytscha, O. mykiss, Catostomus catostomus* and *C. commersoni*) accept vertical slot fish passes better than other species (*Alosa sapidissima, Rossus saxatilis, Acipenser transmontanus* and *A. medirostris*).
Debris can obstruct slots.

2.5.4 Costs

Unknown, but when built as part of new weir could be <4% of total cost of weir.

2.5.5 Working examples

There are two vertical slot fish passes in operation in the Northumbria region, at Hagg Bridge and Escomb. The latter is a combination pool and weir/vertical slot and was constructed in 1991. No further information was supplied (See appendix G Table 7.2).

2.5.6 Unknowns

No information on effectiveness with British freshwater fish.

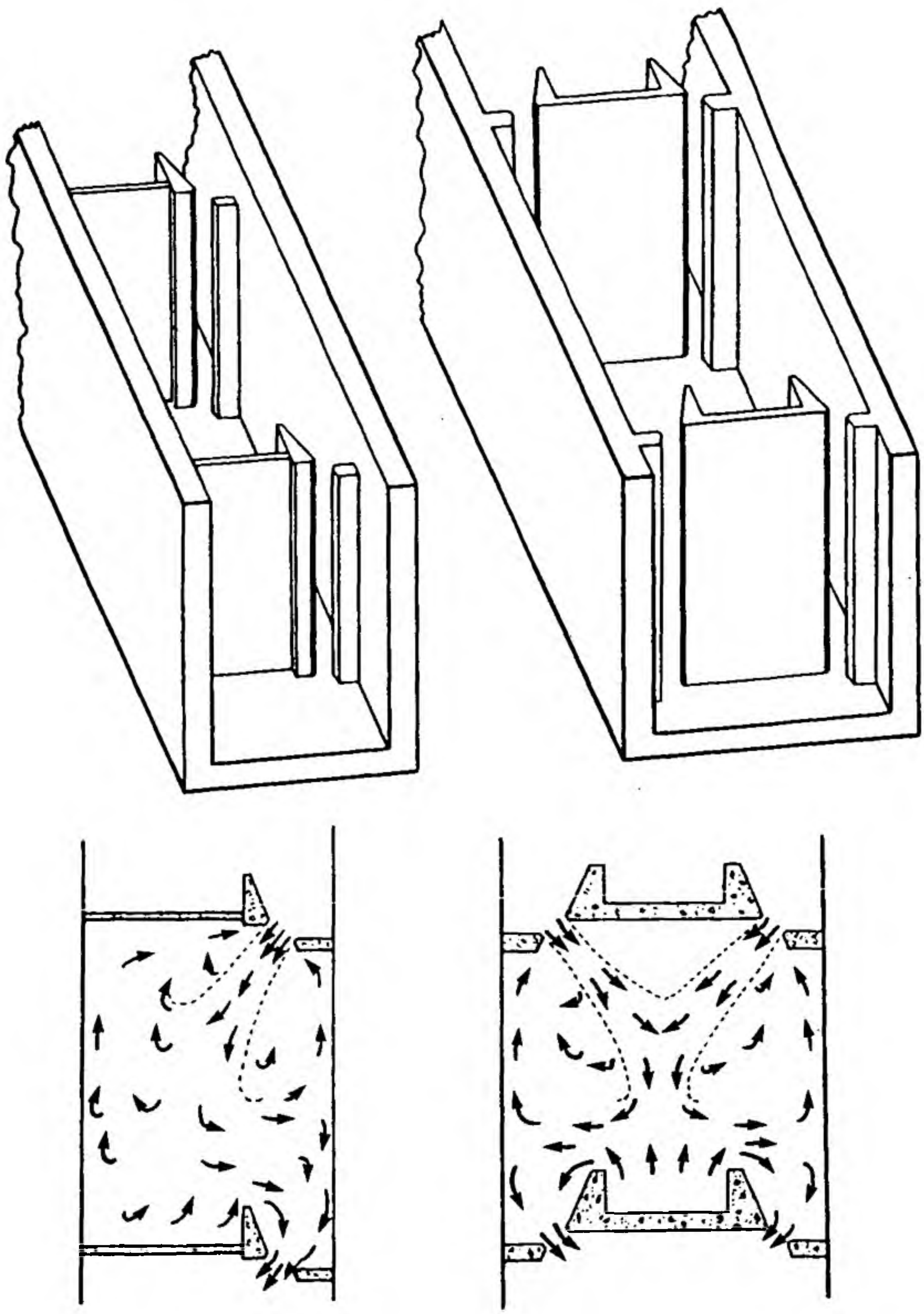


Figure 2.1 Single and double jet vertical slot fishways
Source: Andrew, 1991

3. DENIL FISH PASSES

3.1 Introduction

The Denil fishpass utilises closely spaced vanes or baffles on the floors and/or sidewalls of a sloping channel. These baffles which are set at an angle to the axis of the channel create secondary helical currents which result in a continuous dissipation of energy throughout the fish pass length (Figure 3.1). They are widely used throughout Europe but their efficiency has often been questioned and there are said to be limitations to their use by some migratory species linked with baffle dimension and slope (Larinier, 1991).

Details of the historical development have been given by Beach (1984). The recommended proportions given were based on the 1942 Report of the Committee on Fish Passes by the Institution of Civil Engineers (1942), which said that a channel width of 0.91 m with baffles set 0.60 m apart and sloping upstream at an angle of 45 degrees to the channel bed, the slope of which should not exceed 1:4. Large resting pools (3 m long x 2 m wide x 1.2 m deep) should be provided at vertical intervals of 2 m. Through such a channel, of length 9 m and gradient 1:5, the flow was measured as 0.6 $m^3 s^{-1}$, the mean water velocity 1.8 $m s^{-1}$ and the mean depth 0.91 m.

Details were also given of the drag and gravitational forces that were exerted on a fish during passage through a Denil. The comment was made that very few data exist on the relationship between flow and depth and it gives approximate equations for mean water velocity and flow. Further details on drag are given in the section on swimming performance in this report.

There are many versions of Denil fish pass, the majority however, are of the Alaskan steeppass type with side baffles at an angle to the walls or the plain Denil with planar baffles normal to the walls and at an angle to the floor (See Figure 3.2).

3.2 Hydraulics

Hydraulic characteristics of Denil fish passes are given in Katopodis and Rajaratnam (1983), Katopodis (1991), Rajaratnam and Katopodis (1984) and Rajaratnam, Katopodis and Flint-Petersen (1987). In the first of these, three designs are studied. The turbulent nature of the flow in the fish passes is described and extensive velocity measurements are presented. A semi-empirical method is developed for the design of Denil fish passes involving a fluid friction coefficient. In Rajaratnam and Katopodis (1984) the same authors develop rating curves for the "standard" and "non-standard" Denil which could be useful in the design of Denils over a range of slopes and discharges. Rating curves for the two types of Denil are given in appendix C as Figures C.1 and C.2. The hydraulics of six designs of Denil with varying dimensions are reported by Katopodis (1991), appendix C Figure C.3. A standard Denil as described by Rajaratnam and Katopodis (1984) has the following dimensions: B=0.56 m, b=0.36 m, and a=0.25 m, where B is the total width of the channel, b the free width between the baffles and a the distance between the baffles. (Figure 3.1). Using this standard Denil, if the depth to width ratio is less than one the flow has a uniform low velocity, when this ratio increases to three this low velocity region disappears and fish will have passage difficulties. For Denils with a ratio greater than three a modification is possible which will lower the ratio (Rajaratnam, Katopodis and Flint-Petersen, 1987), as shown in appendix C Figure C.4.

3.3 Recent design developments

The Alaskan steeppass was first developed in 1958 (Figure 3.2) and was mentioned in the report by Beach (1984). It was produced in modular form, specifically for situations requiring low onsite construction costs and an easy assembly. It was designed to be strong enough for point support and to be corrosion resistant and maintenance free. The installation of an Alaskan steeppass on the River Ouse in Sussex is given by Buckley (1989), she also lists eight features of the pass which confirm its economy and versatility (Appendix C).

Larinier (1983) describes a type of Denil which has low baffles in the floor of the pass but the sides are completely plain. The baffles are an unusual shape, Figure 3.3. A description of the Larinier type pass on the River Derwent is given by Harpley (1989) which has been so successful that at the time of writing two others were being planned. Larinier type passes in Normandy are described by Banks (1988) and he states that the French favoured this design in situations where the slope was between 1:10 and a maximum of 1:5. Steeper gradients required an orthodox Denil or pool and weir structure. The disadvatage of Lariniers was an inability to remain hydraulically efficient except within a fairly narrow range of upstream head. Too much water would drown the baffles, and cause the flow to race down the channel. Their advantages were cheapness in the right situations and a better capacity to cope with floating rubbish than passes with side baffles. They will also accept canoes. Banks also mentions the computer programmes used by the Conseil Superieur de la Peche which include a graphics package for producing scale drawings.

Results of investigations by Orsborn (1985,1987) indicate that the expensive and sometimes dangerous vanes on the floor and/or sidewalls of Denil and Alaskan steeppass fish passes may not be necessary to pass fish up a chute type fish pass efficiently. In tests simple roughness strips (3.8 cm x 3.8 cm) were attached every 15 cms to the floor of a 40 cm wide plywood chute. 100% of the chum salmon negotiated a 25% slope of 2.4 m length. Benefits of the simple roughened chute are given as: reduced air entrainment and turbulence, better attraction flow, better debris passage, fish swim to pass, inexpensive, small flow (about 1/3 of slotted fish pass), and ease of adding attraction flow with false floor conduit. Further laboratory tests are being conducted to determine the best floor baffle system together with field tests using several species of fish to determine performance curves for the design factors of slope, dicharge depth, fish speed and limiting conditions. Although Orsborn (1987) states that baffles can be injurious there appears to be no published literature which reports any damage to fish caused by passage through a Denil pass.

3.4 Fish passage

It is generally agreed that the flow pattern is complex and that fish need continuous swimming effort at their burst or higher levels of their prolonged speeds to navigate the entire fish pass length. Larinier (1991) suggests that they are only really adapted to running water species that possess sufficient capacities in terms of swimming speed and endurance. They are not well adapted to small fish (<25-30 cm) or to certain species particularly pike and perch. Although *Alosa alosa* do use Denils, observations suggests that this species is not at ease in negotiating the helical currents. In the same paper it is suggested that visual reference is an important factor in ascending and so those designs which have lower velocities along smooth walls (either floor or sides) should be used since these help to guide the fish.

Slope and length of the Denil can be used selectively to pass fish upstream while denying access to selected species of unwanted salmonids (Schwalme, Mackay and Lindner (1985) and Slatick and Basham (1985), Slatick and Basham (1985) found that American shad passed a Denils of 7.9 m length with a slope of 23.3% and 24 m length and slope of 28.7% at Bonneville, 11.9 m length and slope of 23.3% at McNary Dam, but only a few passed 15.2 m length and slope of 28.7% at Little Goose Dam and none passed 20.1 m length and slope of 27.3% at Bonneville. Pacific lamprey however successfully passed through Denils of all combinations of length and slope. Schwalme, MacKay and Lindner (1985) found that for ten species observed to use two Denils of differing slope the 10% was used in preference to the 20% and that pike ascended the Denils in preference to the vertical slot fish pass alongside. This paper also shows that even in the horizontal flume of the Denils, fish had higher water velocities and greater distances of high velocity flow to swim through than in vertical slots.

Katopodis (1991) mentions investigations into Denils in 1990 at three sites in Canada. One contains data about northern pike, another on the effectiveness of deterring sea lamprey and the other on two differing slopes. The author has been contacted for the results of these investigations with the reply that studies are still continuing and that the reports will not be available until late 1992.

3.5 Construction and maintenance

In contrast to other forms of fish pass the Denil must be kept completely free of debris as this can alter the flow characteristics of the baffles. They require more maintenance and supervision than the vertical slot or pool and weir versions. Buckley (1989) states that the steep pass on the River Ouse has proven highly efficient in passing debris such that its accumulation did not present problems.

Larinier (1991) suggests that Denils are particularly well adapted to old weirs with a sloping back whose height is not more than 2 m. He lists among its advantages: strong attraction flow, reduced construction costs and adaptation to moderate variations of upstream water level.

Mallen-Cooper and Harris (1991) report the results of an experimental Denil (unpublished data) used in steep sections of an old pool and weir fish pass in Australia. A 4 m long model of "standard" Denil fish pass with internal channel width of 325 mm was tested on a weir on the Nepean River near Sydney. This weir had a slope of 1 in 5.5, the pool dividers were removed and the model installed in the base at the same slope. In the trial 57-100% of Australian bass (fork length 118-210 mm) ascended the fishway. The results of this cost efficient remedy were encouraging.

Although several field assessments have demonstrated the utility of fish passes, more such assessments are neeeded particularly for species other than salmon. A computer aided fishpass design process with the aim of integrating results from various studies and reducing them to design criteria and schematic drawings for specific fish pass projects would be a worthwhile endeavour (Katopodis, 1991).

3.6 Summary

3.6.1 Velocities

Conventional: 0.6 - 1.8 ms^{-1}
Alaskan Steeppass: <1.0 ms^{-1}
Dimensions: Overall width 0.5 - 1.0 m, clear width between baffles 0.36 - 0.53 m, angle of baffles 30 - 40 degrees, and distance between baffles 0.25 - 0.6 m.

3.6.2 Strengths

Strong attraction flow.
Well adapted to old weirs, <2m high, with sloping back.
Modular form for low construction costs.
Alaskan steeppass - suitable for all UK migratory fish, slopes of 1:3 found to be satisfactory, preferred to pool and weir by several American species, uses very little water and can be ascended at flows as low as 100 ls^{-1}.
Larinier - suitable for gradients between 1:10 and 1:5, steeper gradients require orthodox Denil or pool and weir, no side baffles so debris passes through.

3.6.3 Weaknesses

Turbulent flows - not well adapted to small fish (<25-30 cm) or certain species (pike, perch, Alosa).
Lariniers not successful in all hydraulic conditions, high flows tend to drown baffles.
Must be kept free of debris as this can alter flow. No problems with debris accumulation reported for Alaskan Steeppass installed on River Ouse. Debris problems eased by installing shields or grills.

3.6.4 Costs

Modular Denil at 1990 prices = £15K for each 1 m increment in head.

3.6.5 Working examples

Details of 11 Denils were supplied as part of the Questionnaire Survey, these are reported in appendix G as Table G.2.
Information on two others was obtained through the literature search (Buckley, 1989 and Harpley, 1989).

3.6.6 Unknowns

Use of Denils by small and British non-migratory fish. North American coarse fish reported to use Denils - *Acrocheilus alutaceus, Alosa sapidissima* and *Ptychocheilus oregonensis*. Effectiveness of 1:3 gradients.
Use of roughness strips rather than expensive baffles. Resin bound plywood used successfully for baffles on River Cuckmere.

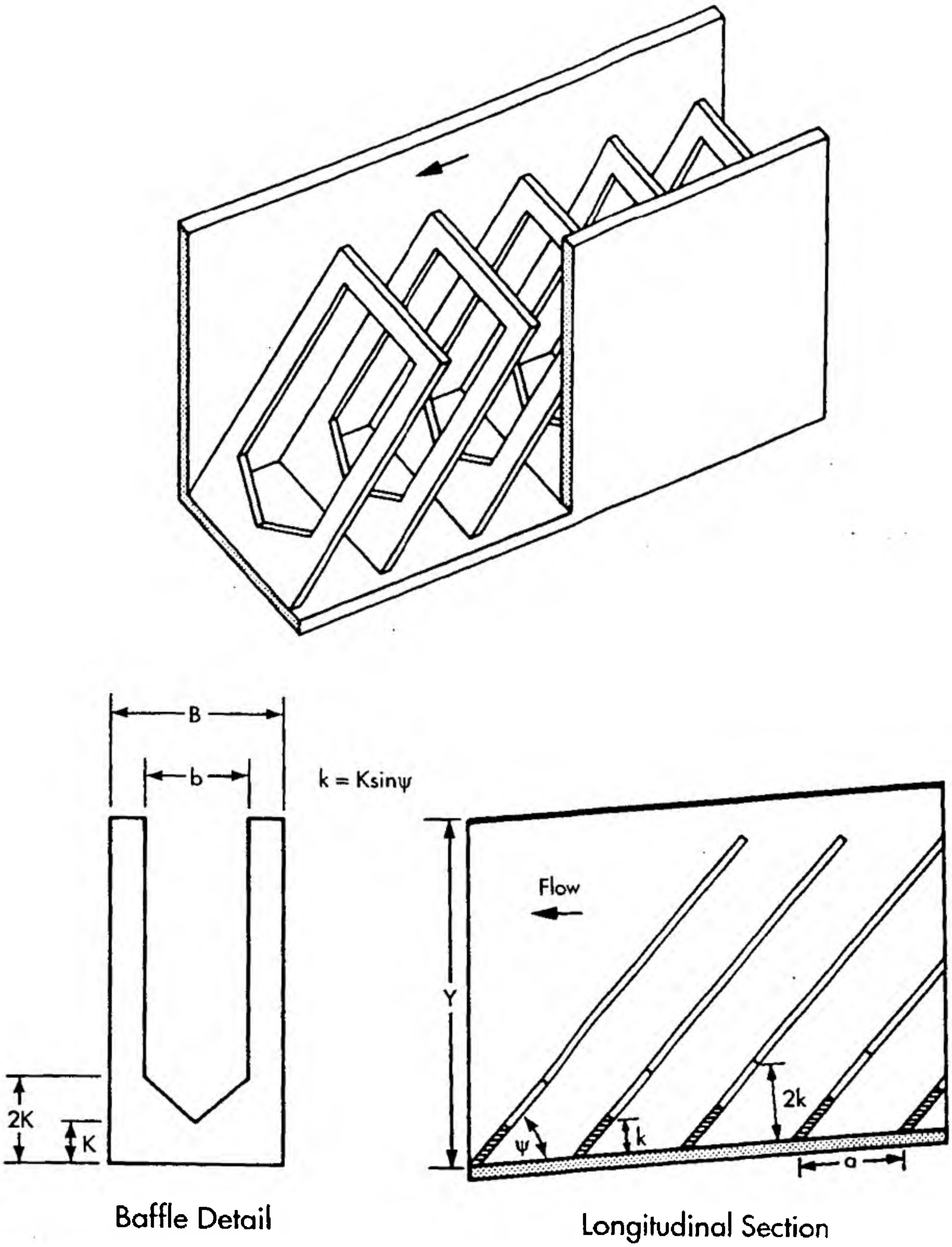


Figure 3.1 A schematic of the Denil fishway
Source: Katopodis & Rajaratnam, 1983

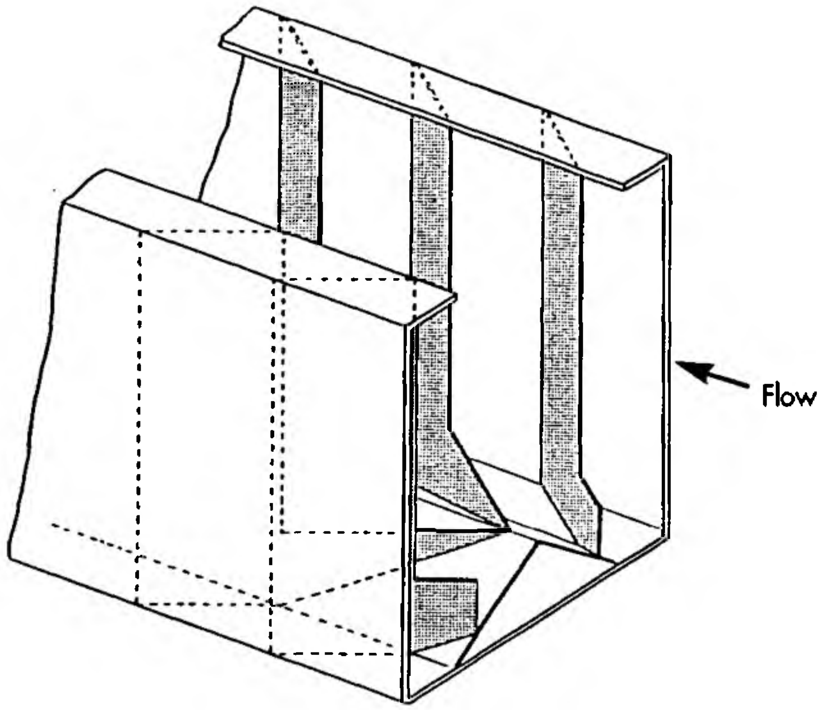


Figure 3.2 Detail of Alaskan steepass module
Source: Buckley, 1989

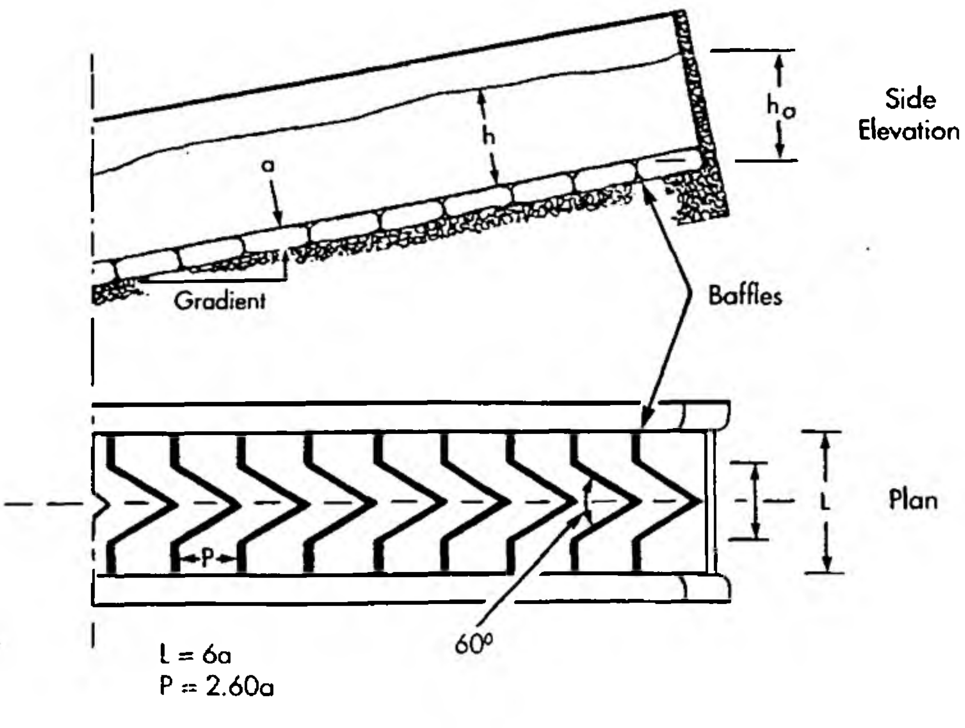


Figure 3.3 The Larinier Pass
Source: Harpley, 1989

4. POOL AND WEIR FISH PASSES

4.1 Introduction

These were the earliest type of fish passes to be constructed and they consist of a series of pools which are formed by a series of weirs. Water flows from the headwater side to the tailwater region (Figure 4.1). Fish pass over the weirs by swimming over them using their burst speed or as in the case of salmon and trout by jumping over them. They are still being built, more than 150 have been built in France in the last ten years (Larinier, 1991). New fish passes are being constructed either to the traditional design with notched overflow weirs or with modifications which include the addition of orifices in the weir walls, v-shaped overfalls and chutes.

Pool and weir fishpasses with notched overflow weirs were discussed by Beach (1984) and the design requirements based on the 1942 Report of the Committee on Fish Passes (Institution of Civil Engineers, 1942) and on subsequent experience gained by MAFF were given as:

- the change in water level acrosss a traverse should not exceed 0.45 m
- pools should have minimum dimensions of 3 m long by 2 m wide by 1.2 m deep
- each traverse should be 0.3 m thick with the notch 0.6 m wide and at least 0.25 m deep
- the downstream edge of both the notch and the traverse should be curved so as to reduce turbulence and provide an adherent nappe
- the pass entrance should be located easily by fish at all flows

An approximate flow of 0.13 $m^3 s^{-1}$ would be required to ensure the notch runs full, and the 0.45 m change in water level would result in a maximum velocity of 2.97 $m s^{-1}$."

4.2 Hydraulics

The hydraulic characteristics of pool and weir fish passes are discussed in three papers, Katopodis (1991), Rajaratnam, Katopodis and Mainali (1988 and 1989). The flow over weirs can be either plunging or streaming, as shown in appendix D Figure D.1, and a criterion has been established to predict the transition from plunging to surface streaming state (Rajaratnam, Katopodis and Mainali, 1988). Transition state flow equations have been developed (Rajaratnam, Katopodis and Mainali, 1989) to predict flow in pool-orifice and pool-orifice-weir fish passes. The former version has orifices in the weir wall with a flow rate such that there is no flow over the weirs and as such operates like a vertical slot pass or in a submerged orifice mode depending on the flow conditions, the latter has a flow rate which passes over the weirs as well as through the orifices. A summary of the results is presented by Katopodis (1991) in appendix D as Figure D.2.

Larinier (1991) states that diversity makes it impossible to standardise dimensions of pools but that there have been attempts to give a certain number of criteria based on swimming capacities and behaviour of the species in question. The drop per pool in France varies from 0.15-0.6 m (Larinier, 1991) depending on the migratory species concerned; 0.3-0.6 m (preferably 0.3-0.4) for Atlantic salmon and sea trout, 0.3-0.45 m (preferably 0.3 m) for brook trout, 0.2-0.3 m for shad, 0.15-0.3 m for other species (cyprinids, percids....) depending on species and length. The diversity of dimensions is illustrated in appendix D by Table D.1 which gives details of accepted design factors for 11 types of pool fish pass (Orsborn, 1985). Dimensions and discharges for three pool sizes as reported by Bell (1986) are given in appendix D as Figure D.3

4.3 Recent design developments

Various designs have been described in recent years for improving the basic pool and weir fish pass (Bates 1991, Boiten 1991, Clay 1991 and Orsborn 1985). Bates (1991) reports on a pool and chute version which has been developed to achieve a design that will operate through a wide range of stream flows without the need of an adjacent spillway for excess flow. It is a cross between a pool and traverse at low flows and a roughened chute at high flow. The weirs are v-shaped with a horizontal weir at the apex of the v as shown in appendix D Figure D.4. At low flows it performs as a pool and traverse with plunging flow, whereas at high flow a high rate of streaming flow passes down the centre of the fish pass while plunging flow and good fish passage conditions are maintained on the edges. He states that comprehensive design criteria have not been developed due to the difficulty in describing mixed plunging and streaming flow conditions within the fish pass. This may now have been partly resolved (Rajaratnam, Katopodis and Mainali, 1989). This design is intended for barriers where the total drop is up to 1.5 m and the high velocity streaming flow is expected to be very attractive to the fish. Pool and chute fish passes have been constructed in at least five situations in Washington State.

A pool type fish pass with v-shaped overfalls which is described by Boiten (1991) has been constructed in the Netherlands, especially in small steep rivers for the migration of salmon and trout. It consists of a series of pools, separated by overfalls at equal distance. These overfalls are constructed of sheetpiling covered by a batten which forms the crest, appendix D Figure D.5. The number of pools and overfalls depends on the head loss but the accepted drop between adjacent pools is usually 0.2-0.3 m. The optimum design for a fishway discharge of 2 m^3/s is given and appendix D Table D.2 gives the dimensions of 11 different designs all optimum for discharges ranging from 0.35 - 5.51 m^3/s.

Orsborn (1985) reports on a pool and weir fish pass with baffles, which has been developed based on the concept that fish can be stimulated to leap. Design criteria for this new configuration are given by Orsborn (1985,1987) in appendix D Figure D.6. The perforated or slotted baffles improve fish pass pool hydraulics by dissipating energy, directing flow, providing resting zones and guiding fish.

4.4 Fish passage

Lonnebjerg (1991) reports that pool and orifice fish passes are negotiated by salmon, trout, grayling, roach, perch and (seldom) pike and that the pool and weir are negotiated by salmon, trout and roach. Neither type of fish pass has been used by whitefish. At a fish pass on the John Day Dam, Columbia River (Monk, Weaver, Thompson and Ossiander, 1989) the passage of American shad was restricted or completely blocked through some sections. Tests showed that shad orientated toward surface flows, tending to reject submerged orifices as shallow as 2 m. In view of this the existing ladder was modified to provide overflows, and this proved to be 80% effective and did not affect the passage of three salmonid species. This is supported by Rideout, Thorpe and Cameron (1985) who report that shad prefer weir to orifice passage.

The behaviour of *Alosa alosa* appears to be similar to the American shad in that they appear more reluctant than salmonids to use pool fish passes (Larinier, 1991). Good passage for shad can be obtained with a large pool size, minor turbulence level, streaming flow, side passage and flow patterns presenting minor recirculation areas. This is further confirmed by Rideout, Thorpe and Cameron (1985) who found that modifying an Ice Harbour style pass from plunging to streaming flow greatly enhanced its efficiency. A total of 263 American shad were passed in 1983, but 4 563 were passed in 1984 after changes had been made.

4.5 Construction and maintenance

At the Red Bluff Diversion Dam (Vogel, Marine and Smith, 1991) fish were frequently observed within 15.2 m of the fish pass entrance but were not observed to move to the ladder. Results of investigations also showed delay and blockage of adult chinooks. Insufficient flow and general configuration of the entrance were not thought to be sufficiently attractive to upstream migrating salmon. Lonnebjerg (1991) reports that most of the old pool and weir type fish passes in Denmark did not function satisfactorily probably because of the small rate of flow and because the entrance was located too far downstream from the turmoil of the water leaving the power house or spillway. During the last 15 years several fish passes have been built at fish farms, with a flow of 0.100 m^3/s - 0.800 m^3/s with care being taken to locate the entrance correctly, and most appear to function satisfactorily.

Jowett (1987) reports that sediment will quickly accumulate in pools or areas of low velocity if the pass is installed on a river or reservoir that has filled up with sediment. In New Zealand vertical slot, Denil and Alaskan steeppass are commonly used to bypass river obstacles as they have fewer problems with sediment accumulation than the pool type. A summary of pool and weir fish passes in New Zealand with comments on their operation is given in appendix D as Table D.3.

Martin (1984) suggests that screens should be put over resting pools to deter poachers. The problem of poaching is further discussed in the introduction to this report.

Pool and weir fish passes are generally used at man-made structures where the head pool levels can be closely regulated. Their operation is deficient mainly in its lack of capability to operate under fluctuating operational pool levels unless a special regulating section is provided at the upper, or discharge end of the fish pass (Bell, 1988).

4.6 Summary

4.6.1 Velocities

0.35 - 2.2 ms^{-1}.
Velocities will vary with pool size and the drop between pools which ideally should be 3 m long by 2 m wide by 1.2 m deep and not more than a 0.45 m drop respectively.

4.6.2 Strengths

Have been in use for many years, therefore tried and tested.
Can be modified to have notches, orifices, v-shaped weirs etc. to suit particular situations.
Used by salmon, trout, grayling, perch, roach.
Maintenance free.

4.6.3 Weaknesses

Unable to operate under fluctuating water levels unless special regulating section is provided.
Shad reject submerged orifices, preferring overflow passage.
Difficulties in locating entrances that are too far downstream or with attraction flow which can be negated by overflow from weir.
Requires major construction.

4.6.4 Costs

1990 prices - £20K for each 1 m increment in head.

4.6.5 Working examples

Details of 34 passes were supplied as part of the Questionnaire Survey, these are given in appendix G as Table G.1.

4.6.6 Unknowns

Use of passes by small British coarse fish.
Use in Britain of simple structures like, log and plank sills, rather than major construtions (see Section 5).

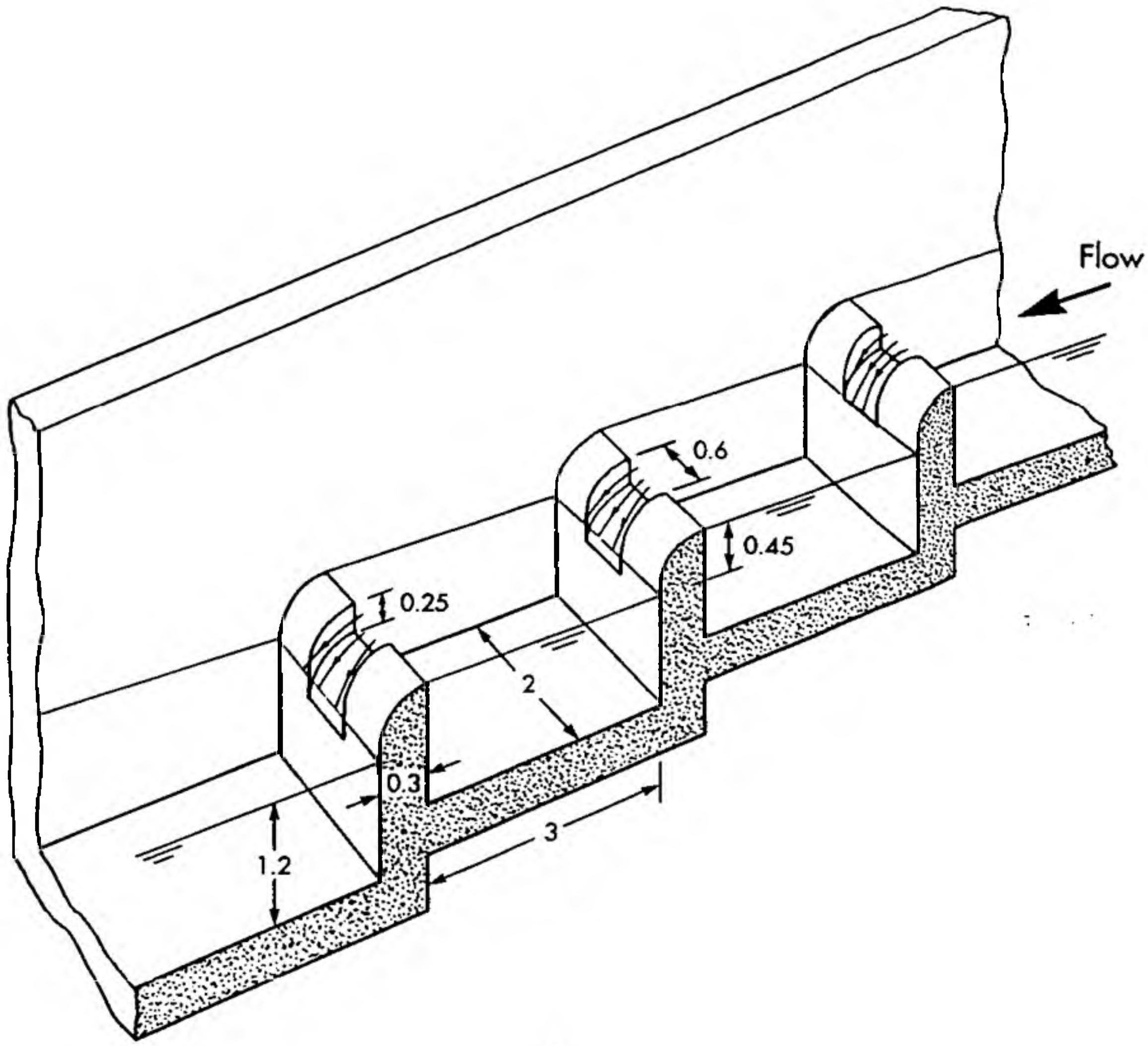


Figure 4.1 Schematic diagram of pool and traverse fish pass with notched traverses
Source: Beach, 1984

5. OTHER TYPES OF FISH PASS

Pool and weir, vertical slot and Denil fish passes are the most common ways of enabling fish to overcome obstacles. There are, however, other fish passage devices in use throughout the world. These include, locks, lifts, spirals, fishway gates and passes especially for eels.

5.1 Locks and lifts

Rather than a self-initiated, active movement, fish can be lifted passively by means of fish locks and lifts. These systems are limited by their intermittent mode of operation and failure of mechanical parts (Orsborn,1987). They are useful ways of passing a small run of fish over a high dam and there are many variations of fish lock in use throughout Europe, Russia and North America. The most common is the Borland type, with a sloping chamber, Figure 5.1. Other types which are primarily vertical chambered, appendix E Figure E.1, and have been used in the USSR where they have been fitted with "crowders". These have been added because the locks are required to pass young as well as mature fish and as these do not have the same urge to go upstream as salmon they have to be encouraged by being pushed in by the crowder (Clay, 1991). A number of locks were constructed in France between 1960 and 1975 but with a few exceptions have not proved satisfactory (Larinier, 1991) and they are now no longer considered as a viable fish passage device.

Fish lifts or elevators have also been developed in many countries. In North America the trapping and trucking version, as shown in appendix E Figure E.2, has mainly been used. A very effective elevator is the Warner fishlift at Cariboo Dam on the Brunette River, British Columbia (Orsborn, 1991). Over the past ten years fish elevators have been developed in France and eight have been built, and are considered to be the most successful upstream fish passage for shad (Larinier, 1991). There are two basic types depending on the size of the migrating population, one designed for a few thousand, the other for several hundreds of thousand individuals. In the former the fish are directly trapped into a hopper with a v-shaped entrance, which is raised with a relatively small quantity of water (0.2 m^3 - 0.75 m^3) until it reaches the top of the dam, it then tips forward and empties its contents into the forebay, appendix E Figure E.3. The height of the hopper should be 1.8-2.5 m for salmon. When the migrant population is larger the fish are attracted into a large holding pool and a mechanical crowder is used to force the fish to enter the hopper. The design of these lifts is based directly on the Holyoke fish elevator on the Connecticut River on the east coast of America, and two are now in operation. On the Garonne at Golfech power station and the Dordogne at Tuiliere power station. In 1989 the former passed about 66 000 shad with a maximum passage rate of >4 500/day. Twenty six species were observed to use it, as shown in appendix E Table E.1. The daily shad passage and water temperature at Tuiliere in 1989 is given in appendix E as Figure E.4. Further information on the Golfech fish lift is given by Puyo and Venel (1987).

Barry and Kynard (1986) investigated the attraction of American shad to fish lifts at Holyoke Dam. During high flows, fish were attracted to spillage over the dam, not the flow of the tailrace. Tagged fish were delayed an average of 4.6 days when river flows were high.

Three hydraulic and two mechanical fish lifts have been constructed in the USSR (Pavlov, 1989), and full details of these are presented in appendix E as Table E.2.

Jowett (1987) suggests the use of elevators for dams >30-35 m.

5.2 Spiral

Orsborn (1987) reports on a spiral fish pass developed in Canada by the Aeroceanics Fish Corporation. It is constructed of fibreglass-reinforced plastic with alternating vertical baffles projecting 0.23 m into the channel, Figure 5.2. One of the main construction benefits of a circular fish pass is that they are space and foundation efficient. A spiral fish pass has been in operation at Loch Doon Dam (see appendix G Table G.1 No.44) since 1936. It is a round tower about 12 m in height with a series of chambers rising spirally inside, which is entered via a conventional pool and weir fish pass. There are 15 pools in the tower and to compensate for variations in dam level, alternative chambers have float controlled sluice gates giving direct access to the loch. In the four years, 1987-1990, 840 5.4 - 6.4 kg salmon ascended this fish pass. Hosono (1991) reports on the research, development and construction of a spiral fish pass using pre-fabricated blocks. Unfortunately this paper is in Japanese.

5.3 Fishway gates

The Fishway gate (appendix E Figure E.5) as patented by Mr A.L.Woolnough of Fishway Engineering is a unique design of tilting gate which contains an integral fish pass. This fish pass is a prefabricated unit which can be varied to suit individual requirements. Its main advantages are:

- considerably lower capital cost than a conventional gate and separate pass
- requires simple, economic foundations
- can be fully automated or manually operated
- overshot blockage-free profile gives slow increase in discharge
- provides pass at natural congregation point
- can pass all species of migratory fish upstream
- can be ascended at very low flows
- utilizes hydrostatic pressure to assist in raising, therefore power requirements are low
- can be descended by canoe.

An expanded version of these advantages is given in Appendix E.

These fishway gates should not be confused with fishway gates as defined by the Japanese which are strictly speaking adjustable pool and weir type passes.

5.4 Eel passes

Dahl (1991) reports that elvers are normally poor swimmers and may perform swimming only in slow flowing and stagnant water. With increased water velocity they are forced down to the bottom or along the bank where they can find the necessary support for continued migration - more crawling than swimming. This crawling ability means that they are able to make their way up the vertical wall of a weir, as the algal and mossy growth will usually provide sufficient support. When they reach the top, however, they are invariably flushed or swept back by the water flowing over the weir. If elvers are not helped by means of an eel pass the area upstream of the barrier will gradually become devoid of eels.

A study of dam clearing by the European eel (Legault, 1988) in France observed that they can only move up on small vertical areas of the walls and that only the smallest individuals, <100 mm long, move up on the walls to try to pass over them. It concludes that the fitting of eel passes is a priority to protect this species.

In a guide to Danish weir owners, Dahl (1991), describes how to construct and establish eel passes. These passes consist of a stuffing material, which is easily permeable by water, shaped into a sausage held together by chicken wire and enclosed in a tube or wooden box. When corrctly packed the stuffing material must be easily penetrable for small eels and also reduce the water velocity so that they can wind their way through. The pass is mounted on the downstream facing side of the barrier and must be supplied with water over its entire length as small eels wil not be able to penetrate a dry eel pass. It must also reach right down to the foot of the barrier as eels will be unable to locate the entrance if it is back from the barrier. Various materials can be used for the stuffing, but the most suitable organic material and the one that is used most often in Denmark is heather. This, however, has several disadvantages in that it must be renewed at the beginning of each season and requires considerable maintenance as it is easily clogged up by sand, sludge and leaves. Dahl (1991) describes an artificial material, made of nylon, called ENKAMAT (trade name) which has proved suitable after being tested in the laboratory and the field. It requires less maintenance but must still be inspected regularly. He describes in detail how eel passes can be attached to both new and existing wooden and concrete weirs, and how they can be incorporated into existing pool and weir and Denil fish passes.

Eel passes are being attached directly on to weirs in the Rivers Severn and Avon in an attempt to halt the decline in eel numbers. They consist of a ramp, a resting pool and a trough, on a slope of 1:1.3, lined with a rough woven plastic matting. Attraction to the pass is provided by high pressure water pumped from the other side of the weir. It is estimated that each pass will cost £6 000. These passes have been developed by studying the Danish (see above) and the French (Antoine Legault's fish pass catalogue) experiences in eel passes, and from an on going National Rivers Authority project entitled Eel and elver stock assesment (NRA Project No. 256). This project has as one of its objectives - to evaluate and recommend elver pass designs appropriate to particular structures. Work is expected on a pass at Stanchard pit near Tewkesbury in April 1992.

At the Patea Dam, New Zealand (68m) a simple, relatively inexpensive elver pass was installed in 1984 after the completion of the dam (Jowett,1987). It consists of a 100 mm diameter PVC pipe filled with two 12 mm diameter polypropylene brushes (similar to a bottle brush) supplied with water from a header tank on the dam, appendix E Figure E.6. This pass began operation in January 1985 and in that season was used by large numbers of elvers. Usage was not monitored continuously but one spot check showed 150 elvers per hour emerging from the top end of the pipe. The concept, originally Dutch, was first tried in New Zealand on Lake Waikare in 1984 and there it operated successfully. At Patea the higher lift and consequently longer time of travel caused some elver mortality which has been attributed to daytime water temperatures of over 30 degrees C and the reduction in water quality caused by the wastes from large numbers of elvers. Shading and an increase in the rate of water supply have been suggested as a means of offsetting these problems. During its first year the pass did not appear to be size selective but it did appear that shortfinned eels were able to use it more successfully than longfinned eels.

The passage of American eels has been studied at the Moses-Saunders Power Dam at Cornwall, Ontario (Eckersley, 1982). This pass is a three sided wooden trough which criss-crosses the face of the ice sluice eight and one half times in a vertical lift of 29.3 m, appendix E Figure E.7, with level boxes at each end of traverse to provide resting areas. Angled wooden baffles and synthetic vegetation fastened to the bottom of the trough control the water velocity and provide substrate. The slope is 12 degrees with a total ladder length of 156 m. A pumping system provides water from the headpond as well as an attractant current at the base. The water depth is 1.5 cm-5.0 cm with a velocity of 15.3 m/min. The paper details modifications which have been made since its installation. The minimum time for an eel to ascend the ladder has been estimated at 70 minutes.

5.5 Miscellaneous

Lonnebjerg (1991) describes stream channels which have been constructed in Denmark, to bypass obstructions, during the last five years. These have a trapezoidal profile and a slope of between 10 and 20 per thousand with the smallest slopes for channels with greatest flow and depth. A pool fish pass at Holstebro was replaced in 1989 by a channel 655 m long including six resting pools, slope 10 per thousand, total head 5 m with bottom width of 2.75 m. The bottom and banks are covered with stones (150-300 mm), with larger stones placed every 2 m along the sides which cause further roughness and create local resting areas. The entrance is situated where the water leaves the turbines, with a grating to prevent the fish from swimming further upstream. The flow is regulated to 0.4 m^3/sec from March to September and increased to 1 m^3/sec from October to February when whitefish migrate.

Bates (1991) reports on recent experiences in Washington State for cost efficient fish passage for both adult and juvenile salmon. The structures described are intended for use on small tributaries and are simple, low cost and require a minimum of maintenance. Full construction and dimension details are given for log sills, plank sills, precast concrete fish passes, laminated beam weirs and a pool and chute fish pass. These designs are variations on the pool and weir system and the latter named is further described in the section on pool and weir fish passes. The current cost (1991) of constructing a log sill is given as US$1600, and of the 75 built during the last eight years none have failed. Construction specifications for each of the designs are available from the author.

5.6 Summary

5.6.1 Locks and lifts

Many variations of fish lock in use throughout world. The French no longer consider them a viable device.

Fish lifts considered to be most successful uptream passage for shad. Lifts used for dams >30-35 m.

5.6.2 Spiral

Space and foundation efficient.
Can be constructed using pre-fabricated blocks.
Little data available. One in operation on Loch Doon Dam (appendix G Table G.1) since 1936.

5.6.3 Fishway gates

Economic option compared with a conventional water control gate and fish pass.
Advantages:
Considerably lower capital cost than a conventional gate and separate pass.
Requires simple, economic foundation.
Can be fully automated or manually operated.
Overshot blockage-free profile gives slow increase in discharge.
Provides pass at natural congregation point.
Can pass all species of migratory fish upstream.
Can be ascended at very low flows.
Utilizes hydrostatic pressure to assist in raising, therefore power requirements are low.
Can be descended by canoe.

5.6.4 Others

Stream channels.
Log sills, plank sills and laminated beam weirs for use on small tributaries. Simple, low cost and require minimum of maintenance.

5.6.5 Eels

Considerable amount of work done on eel passes in Denmark and France.
Passes often require considerable maintenance.
New eel passes being constructed on rivers in NRA Severn Trent region at cost of £6 000
Thought, by consultants, to be unnecessary to provide separate passage for eels. Better to use artificial seaweed, polypropylene fibre, 'astroturf' or brushwood in notches of conventional pool and weir structures.

5.6.6 Unknowns

Studies on spiral fish passes and fishway gates. British examples of stream channels and log sills etc.

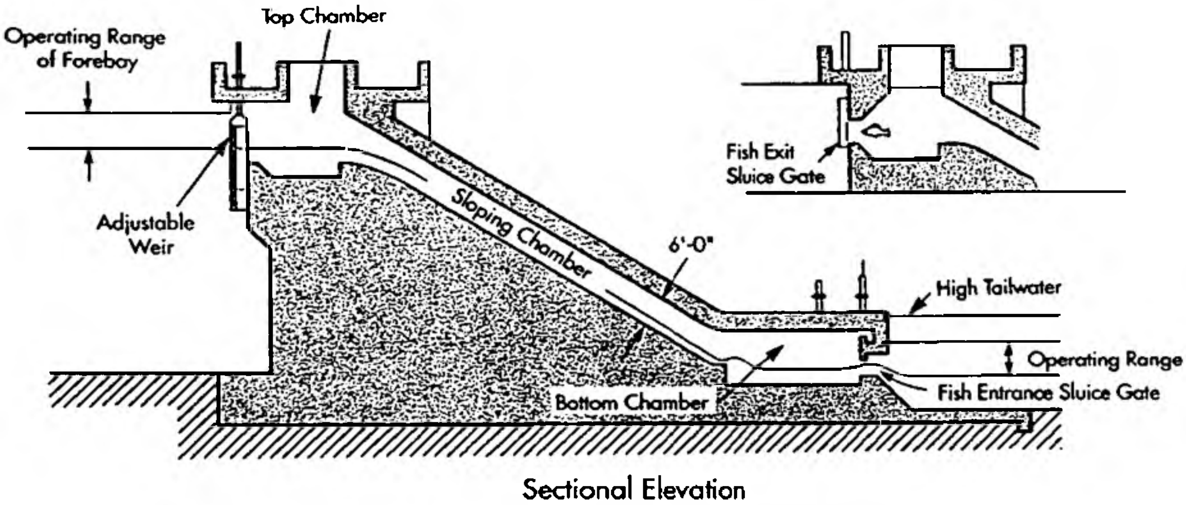


Figure 5.1 Schematic of a Borland fish lock
Source: Clay, 1991

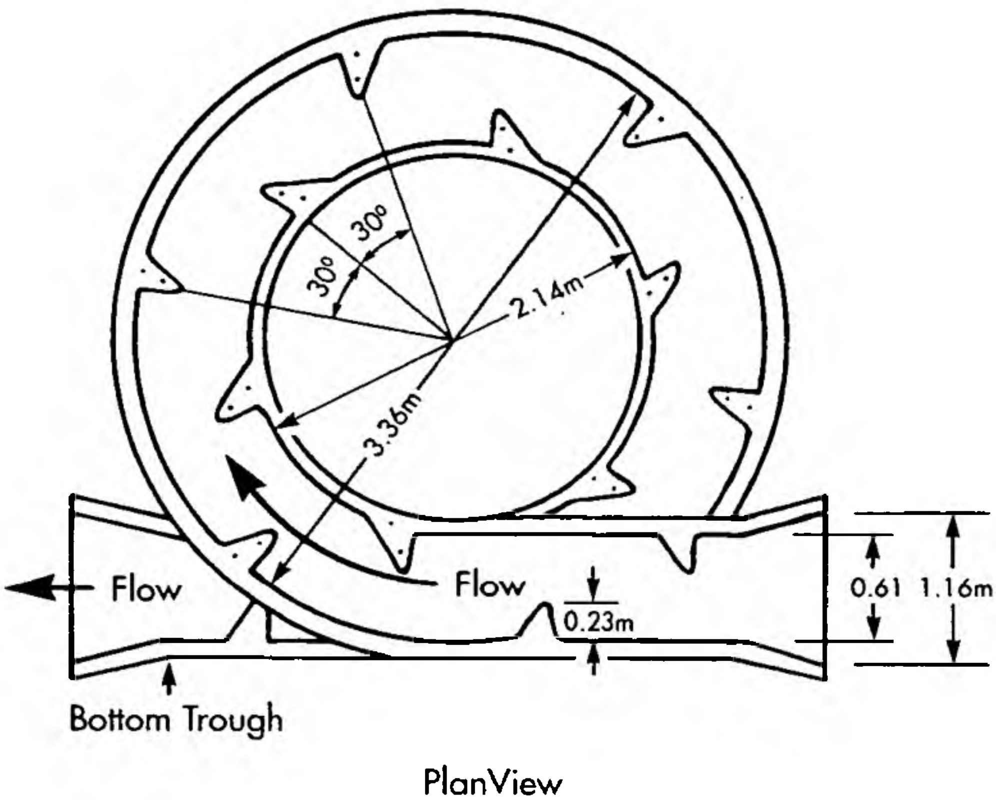


Figure 5.2 Aeroceanics fiberglass spiral fishway
Source: Orsborn, 1987

6. SWIMMING PERFORMANCE

In the report by Beach (1984) empirical formulae were given for predicting the maximum swimming speed by length of fish and water temperature and for the endurance of a fish swimming at this maximum speed.

6.1 Introduction

There are three aspects to a fish's swimming speed; it can be cruising, sustained or burst and is usually reported as cm s^{-1} or bl s^{-1} (body length). Cruising speeds can be maintained for long periods (>200 minutes) without resulting in muscle fatigue and are employed for normal migratory movement. Sustained speeds are of shorter duration (20 seconds - 200 minutes) and end in fatigue, it is used for passage through difficult areas. Critical swimming speed is a special category of sustained swimming and is defined as the maximum velocity a fish can maintain for a precise time period. Burst speeds can be maintained only for short periods (<20 seconds) and one used for feeding or escape purposes. Sustained and cruising speeds are often 50 -70% and 10 - 20% respectively of burst speed (Beamish, 1978). These aspects in turn depend upon biological and environmental factors. A review of the swimming speeds of fish has been written by Blaxter (1969).

6.2 Biological factors

Biological constraints of size (length, weight and condition), sex and disease are reported in several papers.

6.2.1. Size

Barnes, Peters and Grant (1985) report that the swimming speed of fish varies with fork length by a factor of $L^{0.5}$ and that the maximum burst speed (S_b) for fish of all sizes can be estimated by the formula $\log S_b = k + (\log L)^{0.5}$, where k is a constant. Using the formula sustained and burst speeds for various sized brook trout were calculated (Table 6.1).

Table 6.1 Estimated range of swimming speed for brook trout

FORK LENGTH	SUSTAINED SPEED	BURST SPEED
100mm	0.5 - 1.7	1.7 - 3.2 m s^{-1}
198mm	0.9 - 2.2	2.2 - 4.4 m s^{-1}
550mm	1.3 - 3.8	3.8 - 7.7 m s^{-1}

Winstone, Gee and Varallo (1985) related swimming speed to tail beat frequency and report that the distance moved during each body wave is about 0.7 of the fish's length. This information is taken from the previous report on fish pass design by Beach (1984). Beamish (1978) discusses the various swimming speeds together with their formulae and gives tables of cruising (21 species), burst (63 species), critical (26 species) and sustained (41 species) swimming speeds for numerous species, including many important in UK waters. Cruising, sustained and burst speeds for various species are also given by Bell (1986), although only a few are found in UK waters (appendix F Figures F.6, F.7 and F.8). Webb (1975), appendix F Figure F.1, shows the relationship between maximum speeds and length for several groups of fish. Swimming speeds for Atlantic salmon which were observed with radio-tracking ascending the Aberdeenshire Dee (Hawkins and Smith, 1986) are given in appendix F as Table F.1.

The condition of a fish depends on its weight relative to its length (Beamish, 1978) and its importance to swimming performance has been explored most thoroughly for salmonids. Generally domestic stocks of trout not only grow faster than wild but are heavier for a given length. The swimming performance of three stocks of brown trout are given in appendix E as Figure F.2. The performance of wild stocks of brook trout, even those which have been reared under hatchery conditions are consistently superior to domestic stocks of the same species.

6.2.2. Genetics

The genetic differences between migratory species are further investigated in three papers, Bernatchez and Dodson (1987), Taylor and Foote (1991) and Taylor and McPhail (1984). Taylor and McPhail (1984) propose that the difference in swimming performance between coastal and interior coho salmon is adaptive and related to the differences in the energetic demands of their migrations. Coastal salmon attained greater mean and maximum velocity during burst swimming but interior species had four to five times greater swimming stamina. The results of swimming speed measurements are shown in appendix F as Tables F.2 and F.3 (Coldwater River is the interior species). Two life history forms of *Oncorhychus nerka*, one anadromous (sockeye) and one not (kokanee) were studied by Taylor & Foote (1991). They found that the critical swimming velocity of six month old specimens of sockeye was 60.1 cm s^{-1} (8.3 bl s^{-1}) and that of the kokanee was 53.3 cm s^{-1} (7.3 bl s^{-1}). Hybrids of the two species had swimming performances similar to sockeye but with more variability. Both papers relate differences to morphological variations. A fusiform body shape, long caudal region and high vertebral count being associated with superior prolonged swimming performance and characteristic of migratory rather than non-migratory individuals (Taylor and Foote, 1991). Although Taylor and McPhail (1984) also relate body form to swimming performance they state that causal relationships cannot be established from the data. Bernatchez and Dodson (1987) also propose that costly migrations act as strong selective agents for evolution of traits that improve migratory success and investigated the hypothesis that anadromous fish behave so as to minimize energy cost per unit distance of migration. They studied 15 species and found that the energetic cost of migration varied only by a factor of five (1262-6463 kJ kg^{-1}) but that the length of migration varied by a factor of 36 (33 - 1193 km).

6.2.3 Stress

Stress response to migration has been studied by Congleton & Wagner (1988), who measured the plasma cortisol concentration of migratory smolts of chinook salmon and steelhead trout before and after passing through three flumes with different sized baffles. Characteristics of the flumes are presented in the paper, the flows and depth in each type are given in Table 6.2.

Table 6.2 Flow and depth of three flume designs

	SMALL BAFFLED	LARGE BAFFLED	CORRUGATED	
FLOW	0.14	0.71	0.85	m^3/s
AV.DEPTH	37	74	44	cm

slope = 3.4%

Flume design significantly affected post passage cortisol concentration in steelhead but not in chinook. Steelhead smolts that passed through the corrugated flume had the lowest concentrations. In daytime tests, cortisol concentrations were significantly lower in chinook that passed through completely darkened flumes than those that passed through partly darkened flumes. Concentrations did not, however, differ significantly in steelheads that passed through partly or completely darkened flumes.

6.2.4 Infection

Beamish (1978) reports that there is no information on the influence of bacterial or viral infection on swimming performance. However, Sprengel and Luchtenberg (1991), report on a reduction of the maximum swimming speed of European smelt and eel infected by endoparasites. The maximum swimming speed of non-infected smelt of 15 cm length was found to be 0.49 m s^{-1}. The presence of one nematode reduced average swimming speed by 14.7% to 0.42 m s^{-1}. More than three nematodes reduced average speed by 32.2% to 0.33 m s^{-1}. *Anguillicola crassus* in the swim bladder of eel reduced swimming speed from 0.72 m s^{-1} in uninfected fish to 0.59 m s^{-1} in eel with more than ten nematodes.

6.3 Environmental factors

Environmental factors such as temperature, pH, oxygen and water quality can also affect swimming performance and migratory success.

6.3.1 Temperature

Appendix F Figure F.3 shows how sustained swimming speed for seven species is affected by temperature, although none of the species are important in UK waters. These speeds typically increase with temperature to a maximum and thereafter declined. Temperature appears to exert little influence on burst speed although information at this level is scarce (Beamish, 1978). Winstone, Gee and Varallo (1985) report that an increase in temperature increases maximum swimming speed though endurance decreases. Critical swimming speeds at three different temperatures for *Coregonus clupeaformis* are reported by Bernatchez & Dodson (1985). At 5 degrees C - 63.0 cm s^{-1}, at 12 degrees C - 75.0 cm s^{-1}, and at 17 degrees C - 67.4 cm s^{-1}.

6.3.2 pH

Water pH between 6 and 9 had no measurable effect on the critical swimming speed of *Oncorhynchus mykiss (Salmo gairdneri)* (Ye and Randall, 1991), it ranged from 3.5 - 4.0 bl s^{-1}. At pH 4, 5 and 10 the critical velocity was only 55, 67 and 61% respectively of that recorded at pH 7. There was an increase in coughing and breathing frequency. Fatigue occurred earlier and blood lactate levels increased to a higher level in fish swum to exhaustion in acid or alkaline water, compared with fish in neutral water. The Arctic charr, *Salvelinus alpinus* was exposed to five levels of acidity between pH 6 and 3.8 (Hunter and Scherer, 1988). Swimming performance determined by critical swimming speeds was 67.5 cm s^{-1} or 4.4 bl s^{-1} for untreated fish (pH 7.8). Performance declined sharply below pH 4.5, and at 3.8 it was reduced by 35% after seven days of exposure, so adverse pH extends acute and chronic effects on swimming performance.

6.3.3 Oxygen

There appears to be a threshold oxygen concentration below which swimming performance is reduced (Beamish, 1978). Atlantic salmon (23.4 cm) sustained speeds of 50 and 70 cm s^{-1} (2.1 and 3.0 bl s^{-1}) for several hours until ambient oxygen was reduced to 4.0 and 4.8 mg oxygen litre $^{-1}$, appendix F Figure F.4. The effect of dissolved oxygen on burst swimming speed has not been measured, however, burst speed being dependent on anaerobic energy sources may be expected to be largely independent of ambient oxygen except that between swimming events the accumulated oxygen debt must be repaid before the next burst of swimming can realise its full potential.

6.3.4 Pollution

Swimming performance has been identified as a potentially sensitive indictator of sublethal stress in fish, Beamish (1978), Cripe, Goodman and Hansen (1984), Little and Finger (1990) and Watenpaugh and Beitinger (1985), although almost all work has been performed with North American species. Little and Finger (1990) have evaluated swimming behaviour as an indicator of sublethal toxicosis in fish by reviewing pertinent toxicological literature and list 44 references. Concentrations and durations of exposure at which significant changes in both locomotory behaviour and survival were reported, appendix F Table F.4. Based on this information the average toxicant concentration that induced changes in swimming behaviour was <16% of the concentration that caused mortality. Watenpaugh and Beitinger (1985) report on the time to exhaustion of *Ictalurus punctatus* exposed to sublethal concentrations of nitrite. For control fish this was 40 minutes, however, after exposure to 0.5 mg NO_2-N/L it decreased to 20 minutes, and further decreased to nine minutes at 1.0 mg NO_2-N/L. The swimming stamina of *Cyprinodon variegatus* was 57% that of control fish when exposed to 0.0022 mg/l of the pesticide EPN, but swimming performance was not affected by Guthion up to 0.0005 mg/l (Cripe, Goodman and Hansen, 1984). Compared to other swimming behaviour variables the physical capacity to swim against water flow tends to be affected at relatively high toxicant concentrations and often presages mortality. Orientation to water flow, however, is altered at sublethal concentrations (Little and Finger, 1990). The effects of pulpwood fibre, fenitrothion and copper on the swimming performance of *Pimephales promelas, Salvelinus fontinalis* and *Salmo gairdneri (Oncorhynchus mykiss)* respectively are shown in appendix F as Figure F.5.

Swimming performance and speeds of fish are dependent upon biological and environmental factors as discussed above, but it would appear possible to generalise. Rytokonen and Hepojoki (1991b) and Boiten (1991) have divided fish into two groups, good swimmers and bad/common swimmers and arrived at the same results (Table 6.3).

Table 6.3 Cruising and burst speed ranges for good and bad swimmers

	CRUISING SPEED	BURST SPEED	
Good swimmers	1.0-1.5	2.0-2.5	m/s
Bad swimmers	0.5-1.0	1.0-1.5	m/s

6.4 Physical factors

Apart from actual swimming speeds the implications of profile drag, weight and buoyant forces on energy and power requirements of fish swimming through fish passage structures must be considered. Behlke (1988) discusses the forces affecting swimming fish, he considers only the fish's weight, buoyant force and profile drag and ignores virtual mass, turbulent buffeting and other effects. Equations are given for profile drag force, buoyant force, propulsive force, power and energy requirements. Energy calculations which do not recognise the difference between swimming and walking through a fish passage structure can underestimate, by as much as almost two orders of magnitude, the energy delivery necessary for a fish to get through the structure. Without a reasonable estimate of the design fish's absolute velocity as it moves through a passage facility, the energy necessary to be delivered by the fish cannot be calculated.

Although high water velocities can prove difficult or even impossible for fish to overcome, they are considered to be a major factor instigating the upstream movement of salmonids. Many studies have shown flow to be one of the most important factors controlling upstream migration. Studies suggest that if there is a minimum flow below which salmon and sea trout are not stimulated it is likely to be in the region of 0.4ADF (average daily flow) (Winstone, Gee and Varallo, 1985).

6.5 Eels and Alosa sp

McCleave (1980) reports that the swimming endurance of elvers, of average length 7.2 cm, decreased logarithmically with increased swimming speed. It was 3 minutes at 25 cm s^{-1} (3.5 bl s-1) and 0.7 minutes at 36 cm s^{-1} (5.0 bl s^{-1}). In still water burst speeds were maintained for 45m at 3.5 bl s^{-1}, for 15m at 5.0 bl s^{-1} and <10m at 7.5 bl s^{-1} before fatigue. The impact of tidal barrages and the dam clearing ability of *Anguilla anguilla* are described by Elie and Rigaud (1987) and Legault (1988).

The migratory behaviour of *Alosa alosa* has been reported by Belaud and Dautrey (1985) and Boisneau, Mennesson and Bagliniere (1985). The French experience of fish passes for *Alosa sp* is described by Vialle (1987). The sea lamprey has also been identified as important in British rivers and Beamish (1979) reports on its migration and spawning energetics.

Much has been written about the migration and swimming capabilities of salmonids. Most studies have dealt with North American species though limited observations have been made of *Salmo salar* and *S. trutta*. The actual mechanics and leaping behaviour have not been discussed here but information is readily available if required. This review has been an attempt to expand on the coverage of the Beach (1984) report and include details of other species such as eels, shad and lamprey which have been identified as important species in British freshwaters. The ability of fish to ascend specific fish passes is discussed in the section on that type of fishpass.

6.6 Summary

Table 6.4 Swimming speeds for fish of importance in UK waters

SPECIES	ENDURANCE SPEED		BURST SPEED	
	cms^{-1}	bls^{-1}	cms^{-1}	bls^{-1}
Salmo salar	50 - 100	2.1 - 4.0	300 - 600	5.8 - 8.4
Salmo trutta	67 - 213	0.2 - 2.7	213 - 381	8.2 - 10.5
Oncorhynchus mykiss	140	0.1 - 0.6	800	2.0 - 17.5
Esox lucius	5 - 210	0.8 - 12.7	300 - 450	
Rutilus rutilus			450	
Leuciscus leuciscus	170	9.2	110 - 240	11.0 - 13.2
Salvelinus alpinus	67	4.4		
Anguilla anguilla	0.3 - 170	0.2 - 3.5		7.5
Petromyzon marinus	17 - 41	0.9 - 1.7		
Perca fluvialis			145	12.6
Gymnocephalus cernua			133	12.7
Osmerus eperlanus	49			
Abramis brama	5 - 13	0.1 - 0.3		
Thymallus thymallus	90		330	

Little or no information is available on the swimming speeds of several fishes of high UK angling importance including roach *Rutilus rutilus, bream Abramis abramis, barbel Barbus barbus, chub Leuciscus cephalus, and grayling Thymallus thymallus*. Similarly limited information is available for the usually unwanted ruff *Gymnocephalus cernua*, which is currently expanding in range in the UK.

7. QUESTIONNAIRE SURVEY

In May 1991 a questionnaire of 19 questions was sent to the NRA regions in an attempt to survey existing and proposed fish passes (Appendix G). Five regions; Anglian, Northumbria, Severn Trent, Wessex and Yorkshire, have responded by returning completed questionnaires and/or information on fish passes. The quality of the responses varies greatly. Tables G.1 and G.2 present the results for 45 fish passes of the pool and weir and Denil type respectively. All tables, diagrams, plans and flow data referred to are held at the Institute of Freshwater Ecology together with the completed questionnaires. A further 20 questionnaires have been completed for fish passes but they contain a very limited amount of information (Table 7.1)

Table 7.1 Miscellaneous fish passes. Results of questionnaire survey.

No	Location	Fish Species	Type of Pass	Additional Information
47	Mill Weir, Framwellgate. Northumbria.	Salmon, sea trout, brown trout and riverine coarse spp.	Boxes - extended pool and weir	
48	Swinhope Burn. Northumbria.	Sea trout and brown trout.	Box ladder	
49	Riding Mill Weir. Northumbria.	Salmon, sea trout, brown trout, dace and chub.	Box pass + by-pass when gates raised.	Constructed 1979.
50	Hexham Bridge Weir. Northumbria.	Salmon, sea trout, brown trout, dace and chub.	2 box passes 4 diagonal walls.	
51	Chollerfold Weir. Northumbria.	Salmon, and sea trout.	Flumes cut in weir Box pass in N.bank.	Constructed 1960?
52	Derwent Haugh Weir. Northumbria.	Salmon and sea trout	Box pass.	
53	Rutherford Bridge Weir. Northumbria.	Salmon, sea trout, brown trout.	Crump dam - box pass. Dimensions of box: 2m x 2m x 0.5m deep	Head loss 2m. Concrete construction.
54	Warrins Hill Weir. Northumbria.	Salmon, sea trout, brown trout.	Crump dam - box pass. Dimensions of box: 1.5m x 1.5m x 0.5m deep.	Constructed 1989 in concrete. Head loss 0.75m

cont.

No	Location	Fish Species	Type of Pass	Additional information
55	Middleton Weir. Northumbria.	Salmon, sea trout, and brown trout.	Crump dam - control gap.	Head loss 1m.
56	Brouen Weir. Northumbria.	Salmon, sea trout and brown trout.	Crump dam.	Head loss 1m. Concrete construction.
57	Featherstone. Northumbria.	Salmon and sea trout.	Flume.	Constructed 1970.
58	Haydon Bridge Weir. Northumbria.	Salmon and sea trout.	Diagonal wall.	Constructed 1975.
59	Shittlehope Burn. Northumbria.	Sea trout and brown trout.	Channel in sloping weir.	
60	Museum Dam. Northumbria.	Salmon, sea trout, brown trout and coarse spp.	Flume.	
61	Hagg Bridge. Northumbria.	Salmon, sea trout, and brown trout.	Vertical slot.	Weir/bridge footing.
62	Escomb. Northumbria.	Salmon, sea trout, brown trout and coarse spp.	Vertical slot/pool.	Head loss 0.5m. Constructed 1991.
63	River Leven Barrage. Clyde RPB.	Salmon and sea trout.	No data. Contact given for further information.	Flow, temperature and water quality data available.
64	Awe Barrage. Clyde RPB.	Salmon and sea trout.	As above.	As above.
65	Judas Gap. Anglian.	Coarse fish.	Box.	Pass installed many years ago. Not used.
66	Loch Ken. Dumfries and Galloway Region.	Salmon and sea trout 12-14 lb, July - Sept.	6 barrage gates. 2 submerged chambers between barrage gates with opening between chambers.	Head loss 1.219m. Constructed 1930-35.

7.1 Summary

7.1.1 Pool and weir passes

Head loss

Head loss ranged from 0.5 to 3 m, with the exception of the Loch Doon Dam in the Strathclyde Region at just over 12 m.

Debris

No major problems reported even though only three passes have any means of excluding debris. Most report only flood related problems and two specifically mention weed cuts. Occasional checking and removal is necessary at most.

Fish species

Migratory salmonids are reported at 27 of the installations, and coarse fish at seven. No problems reported of any unwanted species.

Fish pass dimensions

Dimensions vary: Pool size from 1.5 m x 1.5 m to 4.4 m x 3 m.
Pool depth from 0.33 m to 1.4 m.
Drop between pools from 0.18 m to 0.68 m.

Some of the passes have notches or orifices.

Entrances

All are reported as being accessible at all times. The entrance was modified at Carreghofa Weir (Severn Trent) in 1983 to reduce its height, and the entrance on two weirs in the Wessex region (Ham and French) have adjustable boards. Problems of attraction flow and entrance effectiveness are reported on four weirs in the Wessex region (Keynsham, Avon, Twerton and Melksham).

Costs

Costs will depend upon the site. As most of the passes were constructed more than 15 years ago the information given does not reflect current costs. Keynsham Weir (Wessex) cost £70K in 1987 (2 m head loss), Carreghofa Weir (Severn Trent) cost £30K in 1976 (2.9 m head loss) and Castle Weir (Severn Trent) cost £60K in 1976 (2 m head loss).

7.1.2 Denil passes

Head loss

Head loss ranges from 0.5 - 2.86 m.

Debris

Two of the passes have some means of excluding debris, the Powick Weir (Severn Trent) has a vertical grid which is to be replaced by a sloping grid in the near future. Five of the other passes report problems which require periodic clearance.

Fish species

Migratory salmonids are reported at nine of the passes, and coarse fish at three. There appears to be no need to discourage any species.

Fish pass dimensions

Three of the eleven passes are reported as being Alaskan steeppass with type A baffles. The slopes are either 1:5 or 1:4 with various sized baffles and angles.

Entrances

Entrances always accessible with no reported problems of attraction.

Costs

Costs for passes constructed in 1989-90 range from £12K for Washford River (Wessex) (head loss 1.06 m) to £55K for Powick Weir (Severn Trent) (head loss 1.3 m).

7.1.3 Miscellaneous fish passes

The details given for a further 20 passes, Table 7.1, are too diverse and lacking in detail to be further summarised.

8. ENGINEERING CONSULTANTS VIEWS

The primary opinion extracted from interviews, was that fishpass selection and installation is still very much an art. This is for five primary reasons, which are not presented here in order of priority.

1. Fishpass contracts are usually of low value to Consultants, involve potential financial risk and may be an adjunct to a major construction. Consequently, few engineers have specialized in fish pass design, and projects are seen very much as 'one-off' assignments.

2. Historical emphasis has been placed on the hydraulic performance of primary fish pass structure in relation to theory and/or assumed fish requirements. Insufficient attention has been given to matters such as; prioritizing fish species where a mixed population of species exist; design and positioning of entrances to attract fish; critical attraction discharges; detail of fish behaviour and tolerances.

3. Inadequate dialogue or understanding between fisheries scientists and contracting engineers.

4. Inaccessibility of literature or lack of key summary guidelines.

5. Site specific requirements, ie. each project is constrained by local site configuration, specific design requirements and cost limitations, so that standardization has not been obtainable.

Following from this assessment a large number of observations were made with respect to cost. Some rules-of-thumb are available, but no prescriptions can be given because of point (5) above. No views expressed by individual Consultants conflict with those given by others but these views must necessarily be seen as personal opinions which are included here for information, and as a basis for further evaluation.

8.1 Factors relevant to capital cost

Cost of a modular fish pass is usually less than 4% of the cost of obstructing structure.

Cost of a fish pass integral to a major engineered obstruction is usually less than 10% of the total project costs associated with the primary structure.

Modular Denil at 1990 prices =£15K for each 1m increment in head.

Pool & Weir at 1990 prices -£20K for each 1m increment in head.

Construction of pass whilst other on-site engineering is current can reduce total cost of pass by c. 20%.

Use of stainless steel in modular design doubles cost, but gives 'limitless' design life.

A percieved increase in requirement for estuarine fish passes in the UK will necessitate use of stainless steel with cost implication.

Design life for Denil and pool & weir is 'limitless' in principle but usefully seen as 40 years because of technological advance in design.

Fish pass can be incorporated into gauging weir without affecting modular calibration. Model test data available from Yorkshire Water.

For coarse fish reduce 'salmonid' Denil or pool & weir pass gradient to match swimming speed.

Consider design at 1:3 slope as effectively used in New England, instead of 1:4 UK common practice. This shortens structure and reduces areas of comers, producing large potential cost saving.

Resin-bound plywood is adequate for baffles - as durable as metal; used successfully on the River Cuckmere.

Eel passes are rarely worthwhile. Better to use artificial seaweed, polypropylene fibre, 'astroturf' or brushwood in notches of conventional pool & weir structures.

Cost-savings can be achieved in designs which force salmonids to jump. Although an unpopular option in the UK, 'jumping' is incorporated into successful French design.

Proportion of flow down pass need only be twice that down river per unit width. Has implications for flow depth, energy gradient and velocity and consequently width, with cost implication.

Fish lifts are mechanically complex, especially in a tidal environment and frequently fail. Design life is typically 10 years, and should be avoided unless space limitations dictate otherwise.

Spiral fish passes conserve space and can be built to modular design, but are not well tested.

Fishway gates are economic option compared with a conventional water control gate and fish pass.

Tidewater obstructions may only delay fish for a short period. Consider if this is acceptable before commissioning fish pass.

Avoid any designs which incorporate under-shot gates, as high pressure and velocity disables fish, and survivors are heavily predated.

Consider direct and indirect cost of demolition of redundant obstructions instead of installing fish pass.

8.2 Factors relevant to maintenance costs

Pool & weir is effectively maintenance free.

Denil requires debris clearance - reduced by installing shields and grills.

Debris shields are preferred to grills and mesh which collapse under ice pressure.

9. CONCLUSIONS AND GENERAL RECOMMENDATIONS

The report by Beach (1984) represents the most accessible and well known collation of information relevant to fish passage past man-made obstacles in the UK. The focus of the Beach report is upon design criteria to enable fish to negotiate structures such as sluice gates and weirs as well as fish passes. A good proportion of the report was devoted to flow control and measurement structures and how different designs can effect fish passage. However, considerable published research specifically concerned with innovative fish pass design and fish swimming performance has appeared in the last decade.

There is sufficient information on the detailed physical design of major fish pass types and variants to negate the need for detailed computer modelling of hydraulic design modifications. However, simple simulation may prove useful to explore the effects on flow of instigating cost-saving modifications such as steeper gradient passes.

The costs and design implications of fish pass construction are largely site specific, but there is a need to produce example costings for given design variants.

The direct and indirect costs of removing derelict in-channel obstructions rather than constructing a pass are often not considered seriously and need greater emphasis.

Although the multiplicity of fish pass design variations have often been well tested in theory or in the laboratory with respect to the *probable* ease of fish passage, but there is a glaring dearth of follow-up validation exercises following construction. A review of monitoring techniques to assess quantitatively the effectiveness of fish passes, for upstream and downstream migration of fish, is lacking.

Downstream migration and monitoring of fish passage has not been addressed in detail within this Report. The questionnaires confirmed that downstream migration is not perceived as a problem within the UK. There are few data to support this supposition and the stress and physical damage implications of fish passage needs evaluating.

The importance of correct siting and nature of attraction flows has been neglected in the past. These matters largely constrain fish usage and need further urgent consideration.

The literature provides a good coverage of swimming speeds and passage for the UK salmonids, Atlantic salmon *Salmo salar*, brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss*. Although a number of coarse fishes have been investigated, the coverage of this group is much more restricted with respect to both species and body size. In particular, the performance of juvenile fish is poorly researched and attention needs to be given to non-salmonid species.

There is a substantial amount of French literature concerned with both fish pass design and swimming performance covering species of UK interest - for example, Atlantic salmon, sea trout, shad, lamprey and eels. Many of these papers have been listed with abstracts (see French Language Papers) as well as being referenced within the main text. Increased accessibility to this archive through translation, data abstraction and site visits with French engineers and fisheries officers would be valuable.

There is a considerable body of American literature concerning the passage of fish through culverts and modificiations of culvert design for fish passage. It might be appropriate to assess this literature for UK application.

A closer liaison between fisheries experts and engineers might help prioritize species. This could be addressed through the production of a fish pass design checklist prepared by a biologist and engineer.

10. RECOMMENDED PHASE II PROGRAMME

The focus of Phase II is the preparation of a detailed selection and design Manual relevant to UK needs. In conjunction with the Manual preparation the following should be considered.

Detailed design specifications of the primary modern fish passes appropriate to the UK situation, together with information on 'standard' variants to design should be collated.

Detailed costings for each design should be obtained, including consideration of the actual cost of utilizing 'non-standard' materials such as stainless steel and resin-bound plywood.

The cost and design implications of adopting French fish pass designs which involve fish having to jump, should be evaluated.

The importance of correct siting and nature of attraction flows to encourage target species and discourage unwanted species needs attention. Key matters are the strength of attraction flow, angle of incident flow, the use of attractors (such as aeration, turbulent noise generation and pheremones) and the detail of siting intakes in relation to flow regime, channel geometry and guide vanes.

The design of shields and gratings (often added after the main design phase) to exclude debris and minimize maintenance costs at the upstream ends of passes, needs greater emphasis, but implications for fish attraction and cost need evaluation.

The implications of adopting design changes needs reviewing in respect of British MAFF policy and potential changes in EC law and practice related to experience in continental Europe.

A fish pass selection procedure inevitably will involve evaluation of a multiplicity of information concerning fish species requirements, fish pass design variants, constrained by cost and site details. The production of an expert system to aid in the design process should be considered.

Much of the primary information on swimming ability is inaccessible to the non-biologist. These data could usefully be incorporated in the Manual, in a more user-friendly fashion for the UK engineer through the use of tables and graphics.

The literature on fish counters needs review and evaluation. Counters should be installed and operated during critical periods on existing or proposed fish passes to evaluate performance of designs.

A check-list of questions and potential problems for the fish pass design process should be prepared by a biologist and a specialist consulting engineer. This would be incorporated in the Manual as an aid to non-specialists.

Little or no information is available on the swimming abilities of several fishes of high UK angling importance including roach *Rutilus rutilus*, bream *Abramis brama*, barbel *Barbus barbus*, chub *Leuciscus cephalus*, and grayling *Thymallus thymallus*. Similarly only limited information is available for the usually unwanted ruffe, *Gymnocephalus cernua*, which is currently expanding in range in the UK. Further information for these species, especially concerning burst speed, could be obtained through laboratory experiments.

Review literature on stress and physical damage to migrants passing through fish passes.

Review American literature on culvert passes.

APPENDIX A - PERTINENT FISH PASS DATA: Figures, tables and additional information

PERTINENT FISH PASS DATA (BELL, 1986)

FISHWAY STRUCTURES AT DAMS AND NATURAL OBSTRUCTIONS

Fishways, fish passes and fish ladders are all terms used to describe methods of passing fish upstream at dams and natural obstructions. With some types of configurations, limited fish passage may be possible when the head is less than eight feet; however, fishways are recommended when there are head differences as low as two feet, as blocks may be formed by insufficient water depth for swimming.

The size of the structures, their location and the flows through them, whether at natural or man-made obstructions, should be based on the same criteria. As site conditions vary, special consideration in design is almost always required.

Of many fishway patterns, the two most commonly used are the pool and weir type and the vertical slot type.

The pool and weir fishway is the oldest of the designs and is generally used at man-made structures where the head pool levels can be closely regulated. Its operation is deficient mainly in its lack of capability to operate under fluctuating operational pool levels, unless a special regulating setion is provided at the upper, or discharge, end of the fishway system.

The vertical slot fishway is in common use on the Pacific Coast. It repeats a constant flow pattern at all operating depths and is best adapted to conditions where head pool regulation is not possible. Its design is less simple than the pool and weir fishway, but its advantage is that it is self regulating.

The Denil fishway and its variations, such as the Alaska steep pass fishway, have been found to have selected application as they must be carefully engineered for width and depth relationships to provide the low velocity required in their design. They must be kept completely free from debris, as this can alter the flow characteristics of the baffles. The relationship of the baffle to the open area is critical and these systems require more supervision than do the other two systems described. The customary slope in a Denil fishway is one to six, and an individual run is approximately 30 feet long. Resting pools between runs are requuired.

To aid the designer, a checklist of pertinent fishway data follows.

Fishway design data

Pool sizes and shapes. See Figures F,G, and H-A, H-B, and H-C (Bell, 1986).

Maximum flows in fishways (energy must be dissipated in each pool). Based on energy dissipation of 4 foot pounds per second per cubic foot of water in pool, or maximum velocity of 4 fps in Denil type.

Resting areas. Assumed to be velocities of 1 fps or less in pools, or 0.1 of normal swimming speed. Denil requires special resting pools.

Orifices (number and size). One or two per pool may be used.

Discharge volume through a vertical slot or per square foot of orifice. See Figure L (Bell, 1986).

Drop between pools. 12 inches, but should be tailored to requirements of species to be passed, or slope for Denil type.

Average maximum velocities over weirs or through orifices. 8 fps maximum, or based on drop per pool. Maximum of 4 fps in Denil.

Entrance velocities. 4 to 8 fps.

Water depth as a weir measurement over a pool weir. 6 inches minimum and 12 inches maximum.

Transportation or directional flow velocities in flat areas or drowned-out areas of fishways. 1 to 2 fps.

Exit locations. See Figures A,B,C,D,M,P, and AA (Bell, 1986).

Travel time through fishway. Assume 2.5 to 4 minutes per pool, or 15 seconds in a Denil swim section. Denil should provide equivalent time in resting pools.

Space for fish in pool. 0.2 cubic feet per pound of fish.

Space in trapping or holding area. 1.5 cubic foot per 5 pounds of fish.

Peaking of salmonid fish during passage. Assume 60% from daylight to 1 pm and 40% from 1 pm to darkness. Night passage may equal 3 to 5% of day's total.

Entrance eddies. Recommended that cross velocitiy not exceed 2 fps at zero fishway discharge. Less if small fish are to be passed.

Auxiliary water introduced into fishway for entrance attraction or transportation velocities. Velocities over diffusion area - 0.25 to 1.0 fps.

Grated opening. Usually 1/4 inch less than minimum fish head width of species to be passed, with 50% of area assumed to pass flow.

Counting stations. Described in text.

Control section to match forebay regulations for pool type fishway. Described in text.

Collection system. Described in text.

Temporary fishways during construction. Described in text.

Source of auxiliary water supply. Gravity (with energy dissipators), pumps or special turbines.

Fish locks and lifts. See Figures S and T (Bell,1986) and description in text.

If shad are involved, surface and wall side passageway must be provided. This species generally rejects orifice openings at depths as low as six feet, and many become trapped in square corners.

Sturgeon have not been passed successfully in pool type fishways, but lock passage is possible.

Light and shadow patterns may determine the movement of various species in a fishway system regardless of the velocity pattern.

Fish accumulate when pool hydraulic patterns are altered. If the design includes turn pools, fish will accumulate at that point. In entrance bays and transportation channels, any break in flow continuity must be avoided.

Square corners, particularly in turn pools, should be avoided as fish jump at the upwellings so created.

At sites where bed load will be encountered, either the orifice or vertical slot baffle fishway is recommended.

Trash racks may be required. If so, the opening must be adapted to the width of the largest fish to be passed (usually 12 inches for large salmon). There is no evidence to indicate that fish refuse to pass through trash racks at normal trash rack velocities (two feet per second or less).

Fish jumping usually is avoided by the provision of adequate swimming depth, orifices or slots. Jumping still may occur as the phenomenon is not fully understood, although it is known to be triggered by shadow patterns or upwelling. See Figures BB and CC (Bell, 1986). Protective fencing may be required to prevent the fish from leaving the fishway. In narrow fishways a screened arch may be provided. Darkened fishways do not prevent movement of fish and tunnel fishways may be used. These should not be pressure conduits and head room should be provided.

Hydraulic instability occurs between the upper range of plunging flow and the lower range of shooting flow. Typical weir crests are shown on Figure J (Bell, 1986), with the shaped weir crest the most stable. Bottom orifices are a stabilizing influence and must be of a size capable of passing fish. The Ice Harbor weir (see Figure G, Bell, 1986) was developed to provide pool stability in weir type fishways. Figure Y (Bell, 1986) shows hydraulic instability forming.

Fixed weir and orifice type fishways have limited capability for adjusting to pool elevation changes and can be either starved or drowned. There are a number of special pool regulating sections in use, such as orifice controls or those that depend on the addition or subtraction of pools by the use of telescopic or tilting weirs or stop logs. A regulating section has ben developed to accommodate rapid pool changes. Hydraulically satisfactory designs for automatic control systems with vertical slot nonoverflow walls, bleed off and add-in diffusers, auxiliary water supply, and movable-board underwatrr counting station and for revised overflow weirs downstream have been developed by models. See Figure FF (Bell, 1986). This section was prototype model tested and field constructed and operated. It was designed specifically for the passage of shad, but also demonstrates excellent performance for salmon passage.

A special control weir is needed if fish are to be trapped or held. This can be a V-trap arrangement, a finger trap, or a jump-over weir. A V-trap works as does a tunnel in a fyke net. A finger trap is shown on Figure J (Bell,1986), and one design for a jump-over weir is shown on Figure K (Bell,1986). The finger trap and jump-over weir both require close water regulation. The jump-over weir is particularly useful where fish are to be sorted or delivered into an anaesthetizing tank where dilution must be held to a minimum. When using finger traps, an escape area must be provided at both ends to prevent fish from being held against the fingers and killed.

The movement of the fish throughout the day is not uniform and it may be expected that between daylight and 1 p.m. as much as 60 per cent of the day's run may pass, and between 1 p.m. and darkness, 40 per cent. Twenty per cent of a day's run has appeared in a single hour. Night counts indicate low passage (3 to 5 per cent) and early daylight hours show good passage.

Large fish (above 20 pounds) may hesitate to use shallow over-flow entrances.

Fishway capacity normally is not a design problem, as the hydraulic criteria usually control design. (See list of pertinent fishway data).

Adult fish approaching the base of a dam or obstruction are usually within the top 12 feet, with the most betwen the two and six foot depth levels. Fishway entrances should be positioned to take advantage of this distribution. Horizontal or vertical orifices or weirs should be adjustable to tail water changes. Methods of regulation include mechanically adjusted gates or buoyant gates.

Orifices with darkened background are not entered by the fish as readily or those with the backgrounds lighted (either naturally or artificially). The light source may be by penetration through the water from either downstream or above the orifice with the latter, under the natural conditions of daylight, producing better and longer entrance attraction.

Figures A,B,C and D (Bell, 1986) indicate the pattern of spillway operations to maintain effective condtions at a fishway entrance. In Figure A (Bell, 1986) all of the spillway gates are in operation, giving a crowning effect in the center of the river, and using a high velocity to guide the fish to the fishway entrances. As the flows in the river diminish and fewer open spillway gates are required, the center gates are closed first. This is shown on Figure B (Bell, 1986). As the flows diminish further, the gate closure is entended toward the ends of the spillway, as shown on Figure C (Bell, 1986). The use of center gates only for minimum spills results in attraction of fish to that area and generally this type of regulation should be avoided.

Depending on the type of energy dissipator, a submerged or surface type jump may be created. (See Figure E, Bell,1986). Fishway entrances are generally placed at or near the crest of this jump at a predetermined flood flow level. The crest position moves upstream as flow diminishes and side entrances are used to match the upstream position. Figure E (Bell,1986) also shows the shortened training walls required. A leading velocity is created and picketed leads or gate manipulation is utilzed to bring the fish to the bay adjacent to the fishway structure and thence into the fishway proper.

As the operation of a multiunit powerhouse is not predictable as to time of operation of specific units, a collection system may be provided which extends across the powerhouse, generally with openings over each unit. End entrances also should be provided. Typical arrangements are shown on Figures Q,U, and V (Bell,1986). Usually each opening over the turbines is supplied with 30 cubic feet of water per second or more. Uneven levels in the tail race may require the use of cantilevered leaf gates in the collection system for the control of the water level.

Shore located entrances are preferred as the shore line provides a lead. Eddy control is required. Fish are attracted to the discharges by both spillways and turbines, and move away from these influences during darkness hours when they may seek velocities of one foot per second or less for resting. The early morning movement of the returning fish to the obstruction appears to produce the greatest activity in the fishway. Casual discharges at any time may attract fish, and they may remain in the general vicinity for hours after the flow is cut off. Intermittent spills can be used to attract fish to desired locations.

Flows from the fishway entrances may be augmented by auxiliary water introduced either into an entrance bay or a collection system in which case an entrance discharge can be made up, thus permitting continuation of the transportation flow. Figures O,P and U (Bell, 1986) show typical arrangements for bottom diffusers. Side diffusers may be used but it is more difficult to provide uniform velocities through them, and they require special directional vanes. Gratings over the diffuser are utilized to prevent the fish from entering the larger discharge area, with subsequent delay in movement.

Transportation flows are required in flat runs, such as collection systems and drowned-out portions of a fishway, because of rising tail water. Auxiliary water is introduced into the drowned-out pools as shown in Figure E, section B-B (Bell, 1986). Designs have been developed to supply or reduce the flows automatically as the tail water rises and falls.

Fishway exits are customarily placed well above any possible drawdown effect, or away from strong currents. A slight positive downstream current for leading is advantageous. Under the most favorable conditions some fish are still found to drop downstream through fishways or turbines (perhaps up to 4 per cent of a day's run). This wandering phenomenon is not understood; however, drop backs may include fish that have moved above their home streams.

Barrier dams, specially constructed to divert fish to a fishway system, are now being used under certain project conditions, as restricted spillway areas, widely fluctuating tail water levels, economics, and at projects where collecting, sorting and hauling are necessary. Figure AA (Bell, 1986) shows a barrier connected with a fishway at a natural falls. Special hydraulic conditions are created to lead the fish to the entrances. (See chapter "Artificial guidance of fish", Figures I and J, Bell, 1986).

High dams have complicated the designs for fishways as fish have rejected fishway systems that use surface flow and with the principal discharge of the river supplied from deep outlets. This phenomenon is not fully understood. Temperature and water quality (including taste and odor) are considered to be principal factors.

Counting strations may be required. The most simple type counts fish over a weir. Fish may be more readily seen against a white painted board. A V-lead to an adjustable counting board has been in general use; more recent advances in dersign use an underwater station at which fish are directed to pass near a glass window. Back panel lighting may be provided in addition to surface lighting. Television counting is possible at such stations, with the fish activating the camera as they pass through a resistance tunnel. The presence of people at these underwater stations appears to have no influence on the movement of fish and public view windows are provided at some dams.

Counting stations may be located within the fishway system or at the outlet or exit end. Because of the changing hydraulic patterns, fish tend to linger above a counting station area and frequently move back and forth. Counting stations at the exit end minimize this movement. White areas also appear to alarm fish, with some turning back before they have completely crossed the painted area.

The closure of counting stations results in accumulation of fish below the stations. It is recommended that an extra large pool be provided below any counting station. Most counting stations provide for an adjustable distance between the fish and the observer to compensate for water clarity where species identification in desired.

Many designs for counting stations are available.

There are no fish locks in operation on the Pacific Coast. Those that were constructed in the past were operated in conjunction with fishways. All lock operations have been discontinued in favor of fishway pasage. (See chapter "Locks and mechanical handling").

Figures O, P, S and T (Bell, 1986) show the general configuration of locks in relation to the total fishway systems and a progression of developments. Figure P (Bell, 1986) shows a paired set of locks with entrances at entrance bay level and with no holding pool. Figures O,S and T (Bell, 1986) show fish locks located above the entrance bay level which provides a short run of fishway to an entrance pool. The McNary Dam lock chamber shown on Figure O (Bell, 1986) was used during construction for transporting fish by bucket into the lock chamber, which demonstrated the fact that this system is capable of collecting and holding fish. Present day entrance pools would have a crowder for which there are several designs, such as a sweep moving along a track. In principle, they insure the movement of the fish out of the entrance pool without a time delay.

Deep reservoirs in river areas cause problems to fish migration, both adults and juveniles, through the slack waters. Temperature is a factor in migration and salmonid type fish will leave a warmed surface to seek cooler depths. In many of the reservoirs south of the 45th parallel and east of the modifiying coastal conditions, areas of low oxygen level have formed below the thermocline. The environmental conditions, therefore, in such half lakes are such that either the temperature or the oxygen level may inhibit the migration or residence of cold water fish. The lack of leading velocities in reservoirs to fish that are accustomed to river conditions has caused wandering, both up and downstream; in search of an exit from the reservoir. This behavior pattern at this time is not understood, as certain of the salmonid species accustomed to passing though lake areas continue to home without the apparent problems of wandering demonstrated by the river-accustomed fish. Delay by wandering can be fatal because of the energy utilization. (See pages 21 and 22 of chapter "Useful factors in life history of most common species", and pages 62 and 61 of chapter "Spawning Criteria"). It is recommended that all factors pertaining to fish passage at high dams be completely explored before considering any upstream passage system. Attempts to move downstream migrants from reservoirs have not met with universal success. Floating surface type collectors have been successful in two reservoirs. In one, a variable depth collector, as shown on Figure L (Bell, 1986), has been successful in capturing migrants. Experiments indicate that fish will pass under surface collectors when following their desired temperature gradient. Multilevel or adjustable depth entrances make possible attraction at varying temperature levels. (See chapters "Avoidance", "Artificial guidance of fish", "Temperature effects on fish" and "Downstream migrants - movement of".)

Special downstream passage is not usually provided at low head dams (100 feet or less). (See chapter "Passage of fish through turbines, spillways and conduits").

Models may be used to predetermine many project conditions and to permit design alterations to favor fish passage. (See Figures DD and EE, Bell, 1986). The location of the jump crest for various river flows can be determined by models such as shown on Figure EE (Bell, 1986).

Nitrogen entrainment may occur under many spillway conditions. This factor requires special consideration as the depth of water in the stilling basin is a major factor in concentrating entrained nitrogen.

The same criteria should be applied in the design of temporary fishways that are used during periods of construction as for permanent structures, although the structural materials used may be less durable. In lieu of fishways, a diversion tunnel or open by-pass may be used to pass fish, if suitable swimming velocities can be maintained. (See chapter "Swimming speeds of adult and juvenile fish"). As construction procedures vary, each project must be evaluated as to potential blocking conditions that may be created during construction. Temporary trapping and hauling have been used as a means of passing fish during construction periods. Such facilities should be designed in accordance with the criteria in the chapter "Locks and mechanical handling".

Table A.1 Data reduction and velocity combinations for analyzing the selection of the higher velocity channel by silver and chinook salmon and steelhead trout using the momentum difference between two attraction flows and their average momentum

Test condition		Percent of choosing higher velocity					Velocity combinations		
							Momentum Difference	Average Momentum	Fish attraction factor
V1 (f/s)	V2 (f/s)	Silver (%)	Chinook (%)	Steelhead (%)	$V1^2$	$V2^2$	$(V1^2-V2^2)$	$[1/2(V1+V2)]^2$	$\frac{V1^2-V2^2}{[1/2(V1+V2)]^2}$
8.00	2.00	83	93	79	64.00	4.00	60.00	25.00	2.39
8.00[a]	4.00	86	68	59	64.00	16.00	48.00	36.00	1.33
8.00	6.00	46	45	52	64.00	36.00	28.00	49.00	0.57
6.00	2.00	83	87	73	36.00	4.00	32.00	16.00	2.00
6.00	4.00	68	62	64	36.00	16.00	20.00	25.00	0.80
4.00	2.00	100	73	67	16.00	4.00	12.00	9.00	1.33
Special tests:									
12.89	2.69	--	90	76	166.2	7.24	158.9	60.68	2.62

Source: Orsborn, 1985

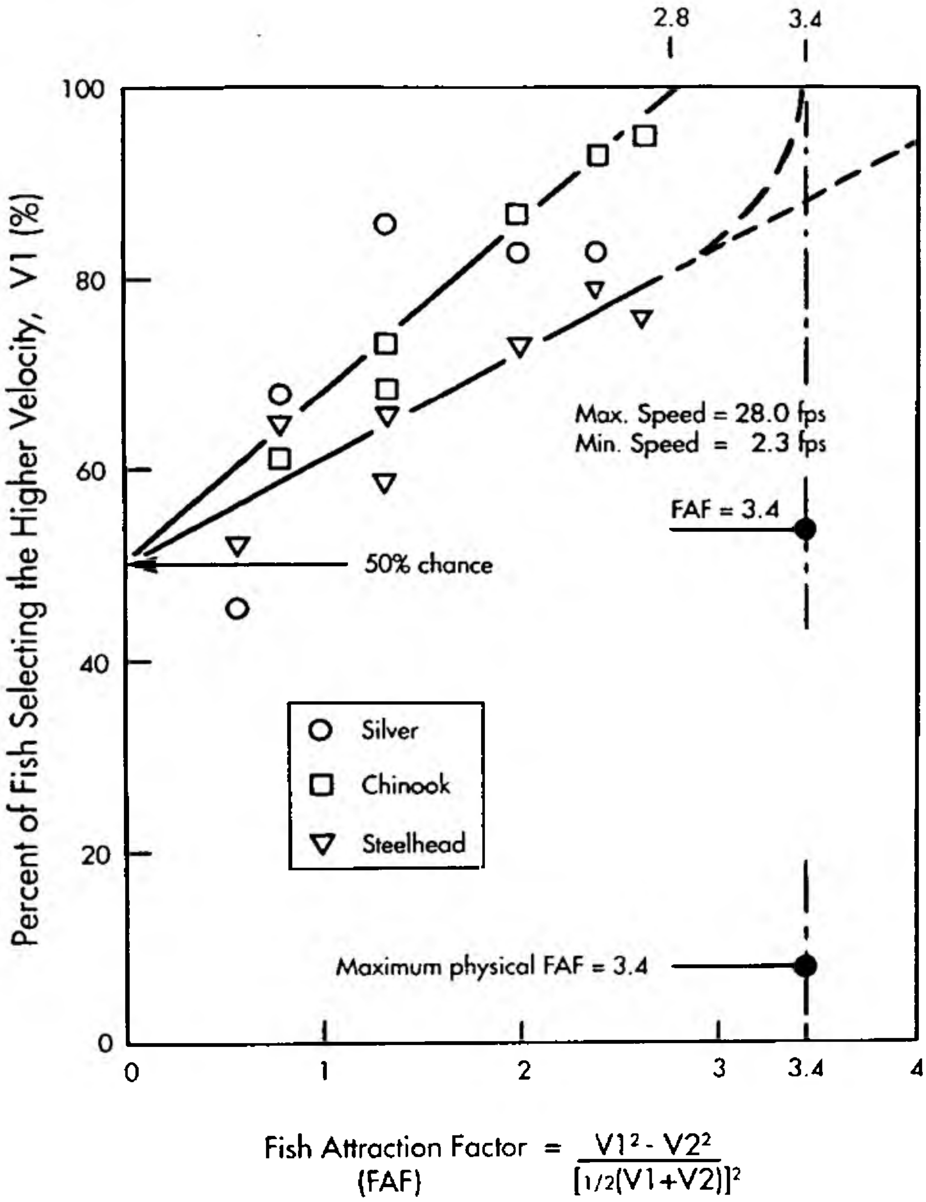


Figure A.1 Choice of higher velocities by upstream migrating salmon and steelhead related to momentum level in the attraction flows as defined by the momentum difference divided by the average momentum in the two jets.

Source: Osrborn, 1985

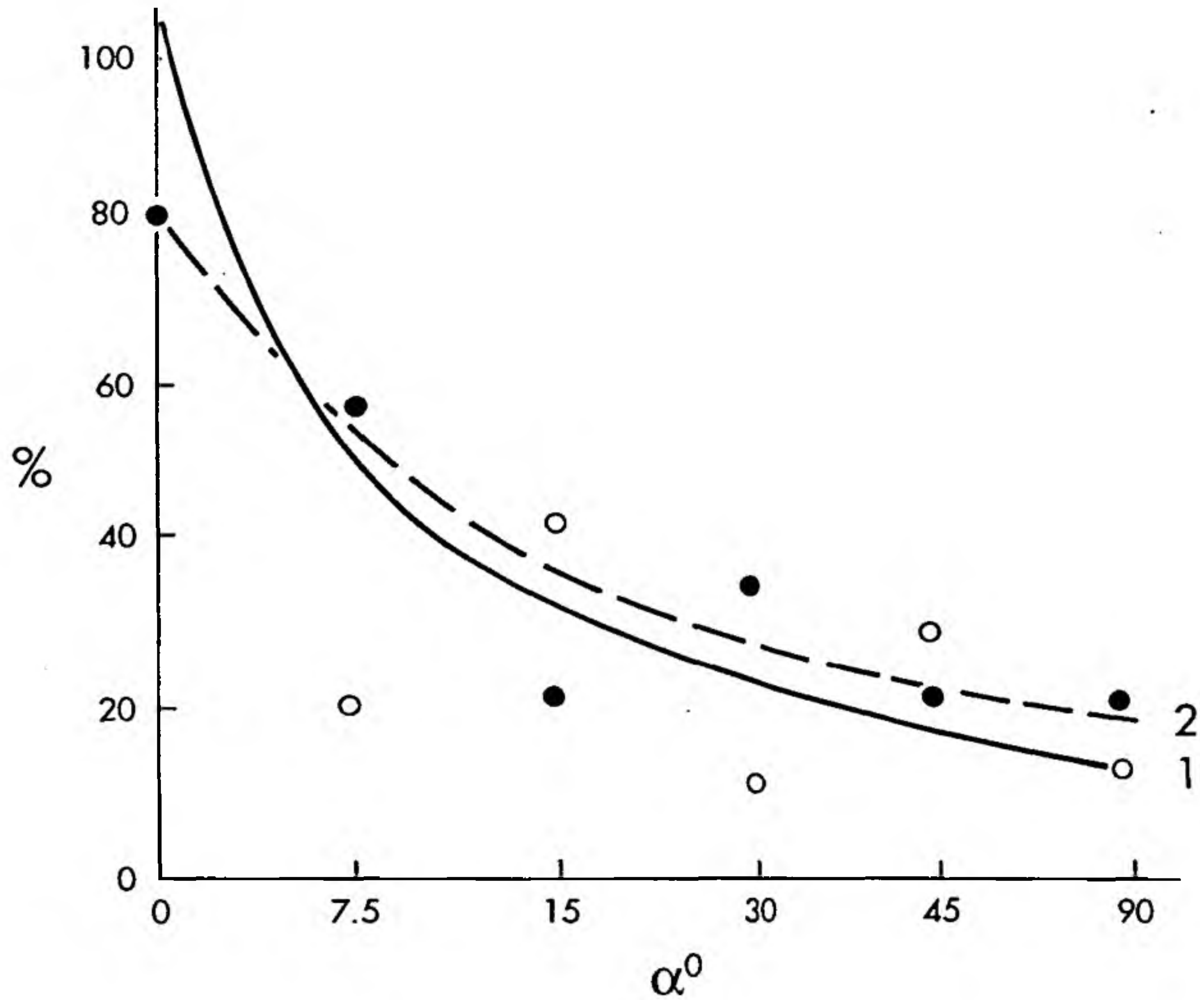


Figure A.2 Influence of the angle of the ramp on the efficiency, expressed as a %, of fish entry to the fish collector.

Source: Pavlov, 1989

APPENDIX B - VERTICAL SLOT FISH PASSES: Figures and tables

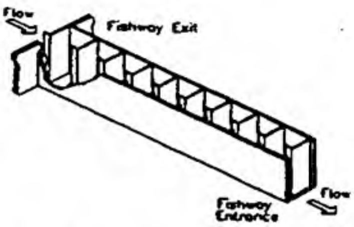
Table B.1 Major vertical-slot fishways operating in British Columbia

Location	Pool width (m)	Pool length (m)	No. of baffles	Slot width (m)	Head/ baffle (m)	Baffle height
Double jet						
Hell's Gate left bank low level	2.74	3.66	10	0.41	0.24	2.7
left bank main	6.10	5.49	7	0.61	0.18	12.2
left bank high level	2.74	3.05	13	0.38	0.20	5.6
left bank upper level	2.74	3.05	11	0.41	0.25	7.9
right bank main	6.10	5.49	9	0.61	0.27	12.2
Bridge River Rapids right bank upper	5.64	5.49	8	0.61	0.38	4.4
right bank lower	5.64	5.49	7	0.61	0.38	7.6
Single jet						
Yale Rapids left bank upper	2.74	3.05	6	0.41	0.26	6.6
right bank upper	2.74	3.05	5	0.41	0.21	3.8
right bank lower	3.05	6.10	3	0.41	0.20	5.0
Great Central Lake Dam	2.44	3.05	18	0.41	0.30	2.6
Stamp River Falls high level	2.44	3.05	19	0.40	0.30	3.6
low level	2.44	3.05	37	0.40	0.30	3.6
Sproat River Falls	2.44	3.05	15	0.40	0.30	1.5
Seton Dam	2.44	3.05	32	0.41	0.21	2.4
Cowichan River low level	2.44	3.05	16	0.41	0.30	2.7
high level	2.44	3.05	8	0.41	0.30	2.7
Nitinat River	2.00	3.00	9	0.30	0.23	2.0
Kakweiken River long channel	2.44	3.35	20	0.30	0.30	2.6
short channel	2.44	3.35	8	0.30	0.30	2.6
Moricetown,Bulkley River left bank	1.83	3.05	12	0.29	0.30	2.4
right bank	1.83	3.05	12	0.29	0.30	2.4
Meziadin River	2.44	3.05	33	0.41	0.30	1.5
Naden River lower	1.83	3.05	8	0.30	0.30	1.5
upper	1.83	3.05	8	0.30	0.30	1.5
Koksilah River	2.43	2.32	20	0.30	0.23	1.8
Embley River	1.83	2.44	17	0.30	0.24	2.4
Bonaparte River Falls	3.50	3.50	21	0.30	0.45	2.0
Nicola River Dam	3.00	3.00	8	0.30	0.30	2.3

Source: Andrew, 1991

Figure B.1 Vertical slot fishways.

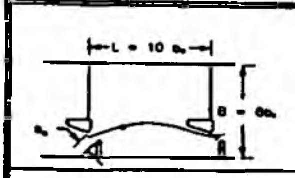
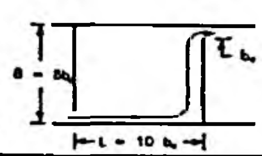
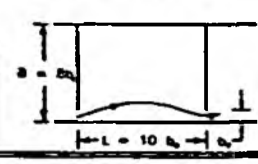
Source: Katopodis, 1991

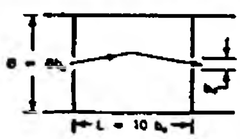
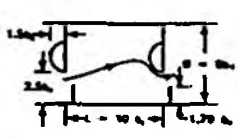
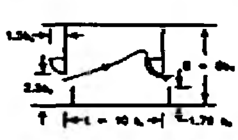


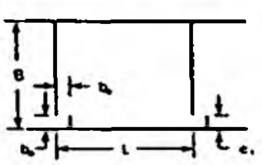
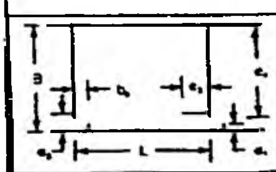
$$Q_* = \frac{Q}{\sqrt{g S_o b_o^5}} = \alpha\left(\frac{y_o}{b_o}\right) + \beta$$

$$u_m = \sqrt{2gh}$$

$$5\% < S_o < 15\%$$

LAYOUT (plan view) u/s ↔ d/s	DESIGN	α	β
	1	3.77	-1.11
	$1.90 < y_o/b_o < 9.02$ DESIGN 2 α=3.75, β=-3.52 NOTE: sill at the slot $2.46 < y_o/b_o < 9.51$		
	3	2.84	-1.62
	$2.30 < y_o/b_o < 25.70$		
	4	5.85	0.67
	$1.77 < y_o/b_o < 10.79$		

LAYOUT (plan view) u/s ↔ d/s	DESIGN	α	β
	7	2.91	-3.22
	$4.53 < y_o/b_o < 24.28$		
	17	3.27	0
	$3.60 < y_o/b_o < 9.38$		
	18	3.71	0
	$3.64 < y_o/b_o < 7.48$		

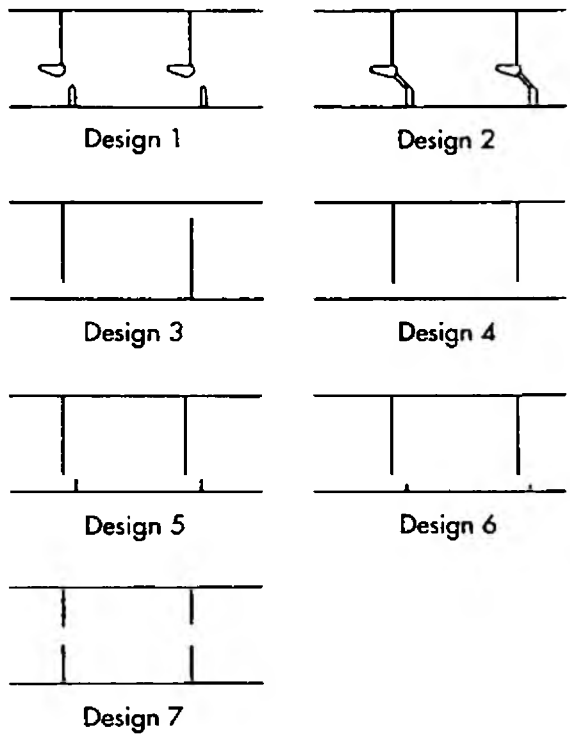
LAYOUT (plan view)	DESIGN	CONFIGURATION	α	β	COMMENTS
	5	$B=8b_o$; $L=10b_o$; $e_1=b_o$	2.67	-0.52	$2.17 < y_o/b_o < 13.29$
	6	$B=8b_o$; $L=10b_o$; $e_1=0.5b_o$	3.77	-1.11	$2.17 < y_o/b_o < 10.0$
			2.84	-1.62	$10.0 < y_o/b_o < 13.55$
	8	$B=8b_o$; $L=5b_o$; $e_1=0.5b_o$	1.66	0	$1.93 < y_o/b_o < 12.62$
	9	$B=4b_o$; $L=5b_o$; $e_1=0.5b_o$	1.65	0	$1.97 < y_o/b_o < 11.61$
	10	$B=2.67b_o$; $L=5b_o$; $e_1=0.5b_o$	1.4	0	$2.0 < y_o/b_o < 12.37$
	11	$B=8b_o$; $L=15b_o$; $e_1=0.5b_o$	2.98	0	$1.71 < y_o/b_o < 12.1$
	12	$B=4b_o$; $L=15b_o$; $e_1=0.5b_o$	3.11	0	$2.26 < y_o/b_o < 12.63$
	13	$B=2b_o$; $L=15b_o$; $e_1=0.5b_o$	4.13	0	$3.85 < y_o/b_o < 12.22$
	14	$B=8b_o$; $L=10b_o$; $e_1=0.5b_o$; $e_2=2b_o$, $e_3=1.33b_o$; $e_4=7b_o$	3.21	0	$3.07 < y_o/b_o < 13.04$
	15	$B=8b_o$; $L=10b_o$; $e_1=0.5b_o$; $e_2=2b_o$, $e_3=2b_o$; $e_4=7b_o$	2.89	0	$3.3 < y_o/b_o < 12.83$
	16	$B=8b_o$; $L=10b_o$; $e_1=1.79b_o$; $e_2=2b_o$, $e_3=3.17b_o$; $e_4=5.54b_o$	3.59	0	$3.19 < y_o/b_o < 12.87$

Notation

B	width of fishway	Q_+	dimensionless discharge for plunging flow
b_o	fish passage opening width	Q_t	dimensionless discharge for transional flow
D	diameter of culvert	S_o	slope of fishway bed
F_f	dimensionless fish speed	t	fish endurance time
F	dimensionless water velocity	ʟ	dimensionless fish endurance
g	gravitational acceleration	U	fish speed
h	hydraulic head	V	water velocity
l	fish length	X	fish swimming distance
L	pool length, baffle spacing	y_o	characteristic depth of flow
Q	discharge through fishway	z_o	height of baffle, weir, sill
Q_o	discharge through orifice	$\alpha, \beta, \eta, \lambda, C, K$	coefficients
Q_w	discharge over weir	ξ	relative maximum fish swimming distance
Q_*	dimensionless fishway discharge	ν	kinematic viscosity of water

Figures B.2 Vertical slot fishways - all designs

Source: Rajaratnam, Van der Vinne and Katopodis, 1986



Figures B.3 Circulation patterns - all designs.

Source: Rajaratnam, Van der Vinne and Katopodis, 1986

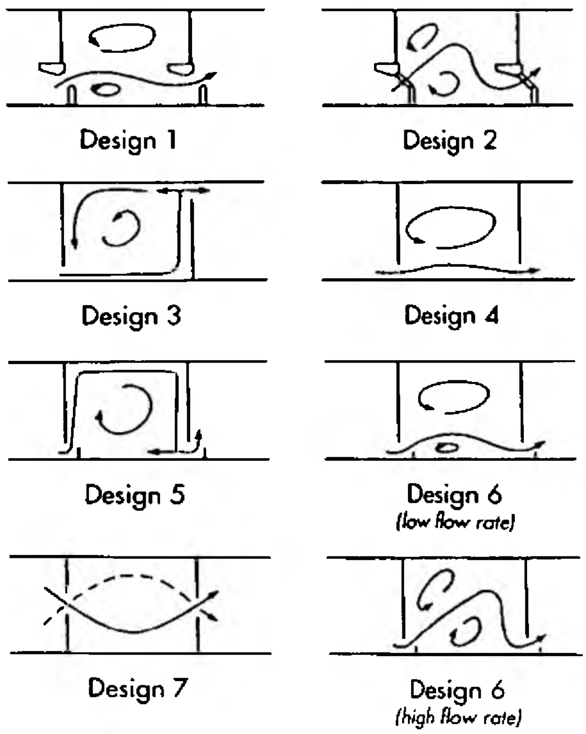


Figure B.4 Rating curves for vertical slot fishways.

Source: Rajaratnam, Van der Vinne and Katopodis, 1986

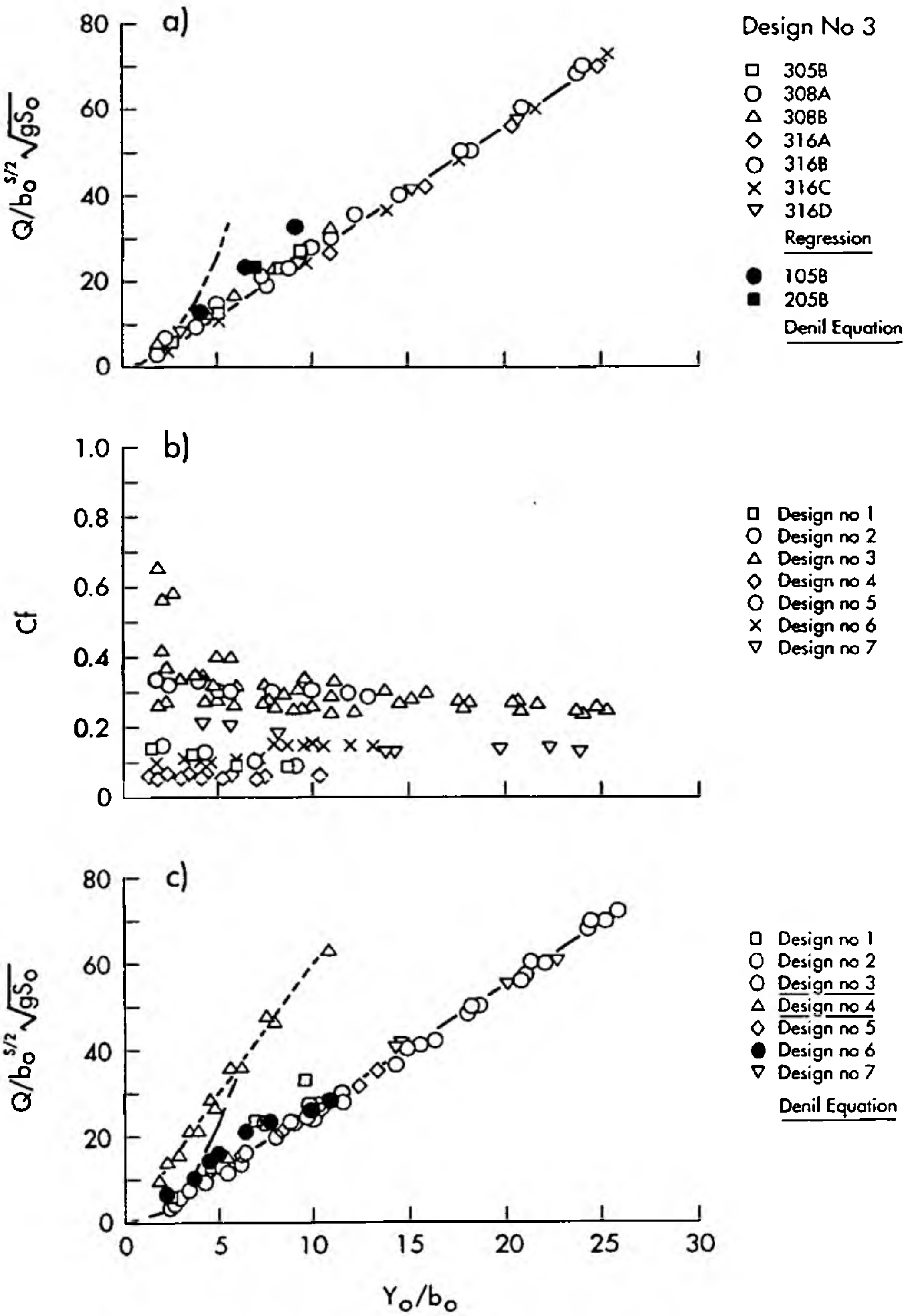


Figure B.5 Discharge for single slot fishway.

Source: Bell, 1986

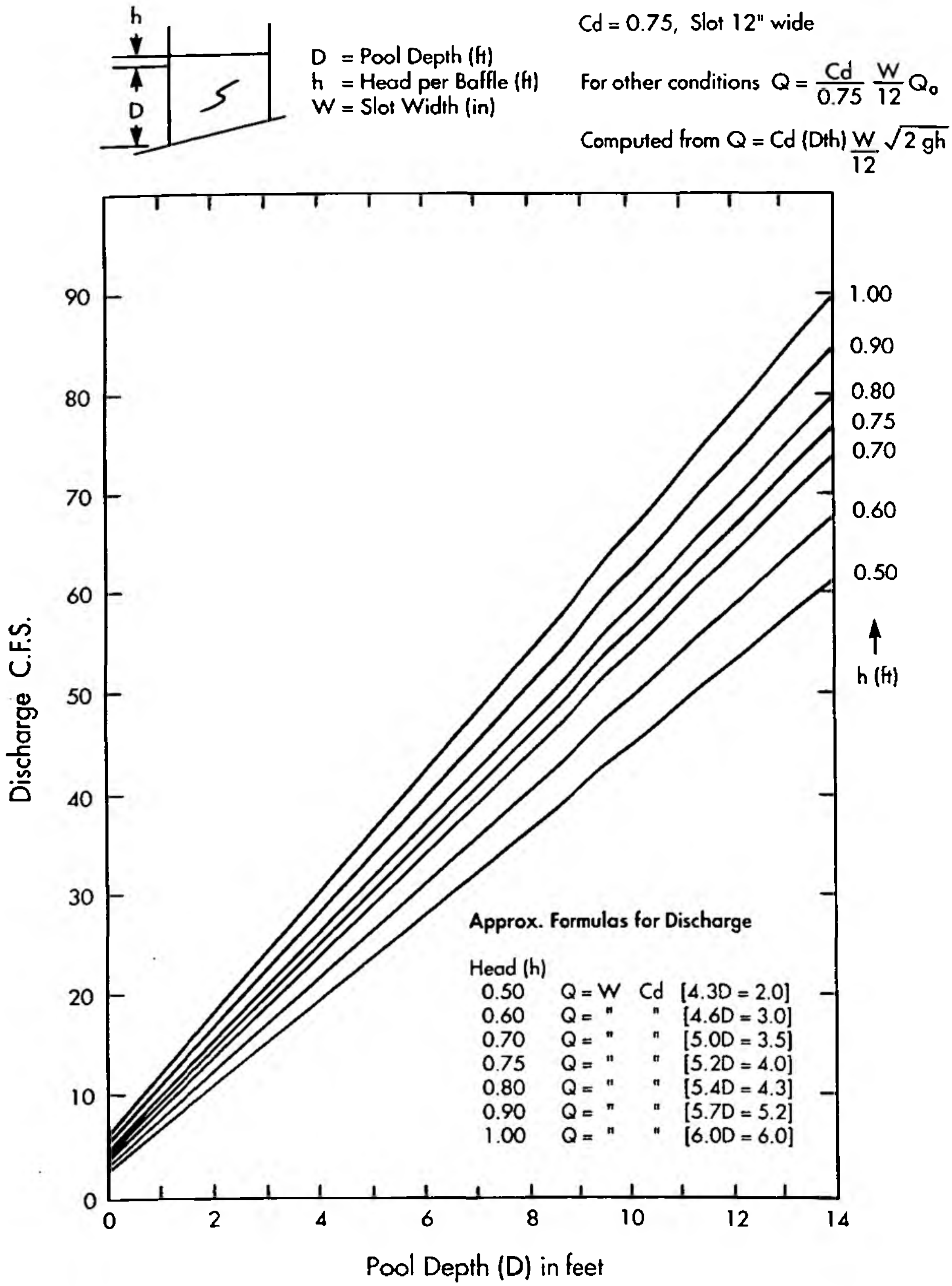
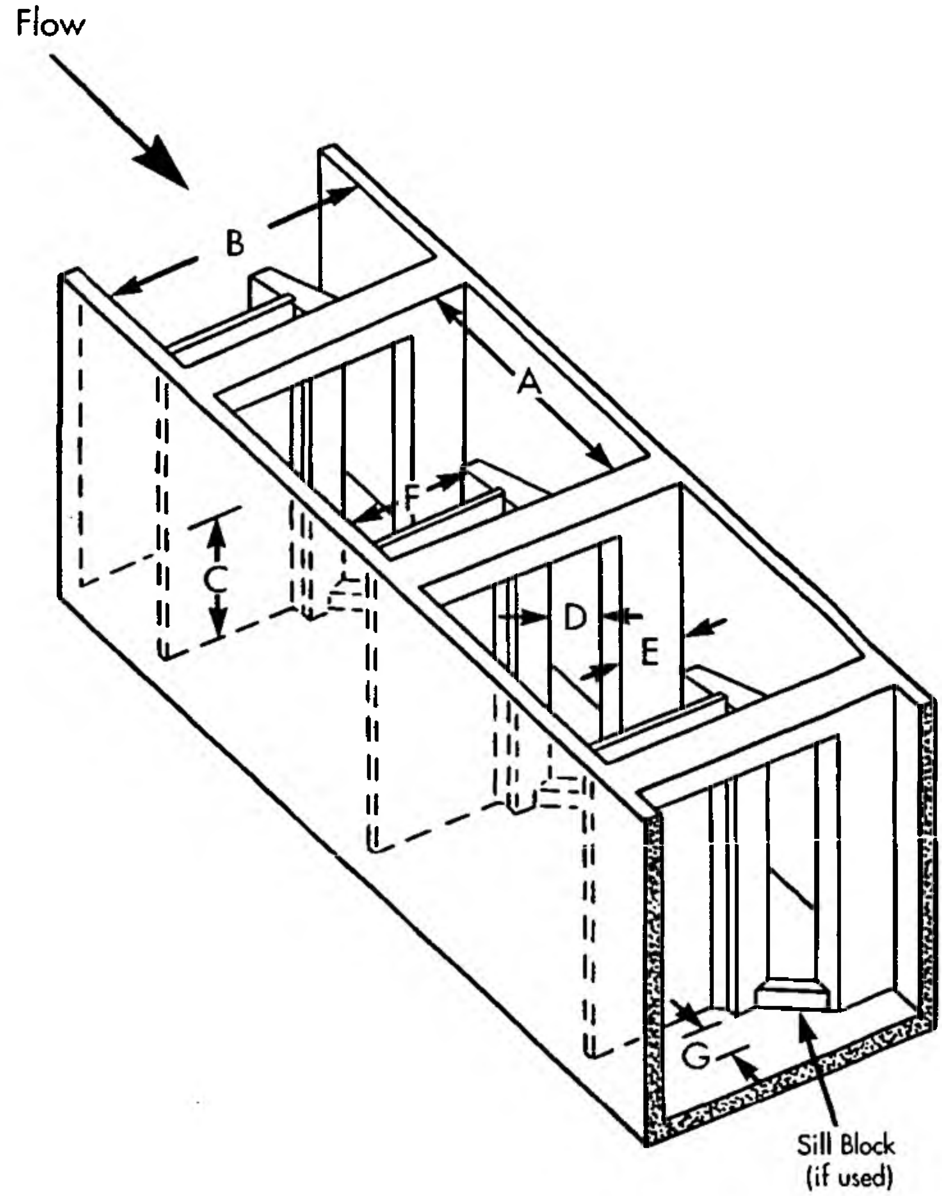


Figure B.6 Vertical slot fishway.

Source: Bell, 1986



A	Pool Length	6'	8'	10'	
B	Pool Width	4'	6'	8'	
C	Water Depth (min)	2'	3'	3'	
D	Slot Width	0.5*	0.75*	1.0*	* Sill Block in place
E	Wing Baffle Length	9"	1'-3 5/8"	1'-3 5/8"	
F	Wing Baffle Distance	2'	3'-1"	3'-7"	
G	Displacement of Baffle	4'	5'-0 1/2"	5'-0 1/2"	
	Discharge per foot of Depth above Block in CFS	3.2	4.8	6.4	
	Drop per Pool	1'	1'	1'	

Table B.2 Details of vertical slot passes taken from the published literature

Location	Head Loss	Fish species/ effectiveness	Fish Pass Dimensions				
			Length	Slope	Slot width	Baffle height	Pools
British Columbia		Various Oncorhynchus			0.29-0.61m	See Table B.1	See Table B.1
Stamp River Falls (low level) British Columbia	11.3m				0.40m	3.6m	2.44m wide x 3.05m long
Kirkakka-kongas Finland	2m	Typical of Finnish inland waters; white-fish species, perch, burbot & a few trout	30m		15cm		Depth 75cm
Keminmaa Finland		Whitefish of 8-36cm length used in study.		1:12	7cm		length 86cm width 65cm
Lesser Slave River Canada					0.31m		
Aurajoki River Finland	5.5m				0.3m		$3x3.5m^2$
South-eastern Australia	1.5-6.4m						1.0x1.5m (Nepean River) 2x3m (Murray River)
Bell					Fig B.6		Fig B.6

Flow	Entrance	Maintenance/ Construction	Comment	Ref.
			See Table B.1. All slot widths with pool dimensions given provide good stable flow pattern with adequate rest areas.	Andrew (1991)
			17 of 37 baffles in solid rock tunnel. Despite high ascent & dark passage, functions well with no reported fish rejection.	Andrew (1991)
$0.3\text{-}1.5ms^{-1}$			Model Scale 1:2. Height diff. between basins 10cm. .	Hooli (1988).
$32\ ls^{-1}$			Water depth 50cm. Model Scale 1:4.	Hooli (1988)
$0.23\text{-}0.68ms^{-1}$ through slots			1.9m between baffles, channel width 2.3m, height slot 1.2m.	Schwalme, Mackay & Lindner (1985)
$0.5\text{-}0.7m^3/s$				Rytkonen & Hepojoki (1991a)
	Close to weir wall, water discharging from entrance aligned 45-90° to flow of stream.	Trash racks of steel bars & grids to cover precast concrete or fibreglass (see text).		Mallen-Cooper & Harris (1991)
Fig B.6			See Fig B.6	Bell (1986)

APPENDIX C - DENIL FISH PASSES: Figures, tables and additional information

Eight features of a Denil pass that confirm its economy and versatility (Buckley, 1989)

A literature search confirmed the economy and versatility of the pass:

1. The pass is suitable for all U.K. migratory fish (Bachelier, 1968).

2. Runs up to 15 m showed no reduction in efficiency of passage (Slatick, 1975), (Slatick and Basham, 1985). Lengths of 60 m had proved satisfactory with sockeye salmon (Blackett, 1987). The apparent limits of the continous type of ladder have been calculated in terms of the fish's power requirements and total energy expenditure. (Ziemer and Behlke, 1966).

3. Slopes of 1:3 have been found satisfactory. Successful ascents of 1:2 have been observed (Slatick, unpublished) though at these gradients erratic surging and surface depression along the centre line were observed. (Ziemer, 1962).

4. Water velocities in the pass are below 1 ms^{-1}. Water energy is 10% that of an unbaffled trough (Ziemer, 1962).

5. The pass was preferred to a pool and traverse by several American species (Fulton et al, 1953, Slatick, 1975), though it utilised 40-50% more water.

6. A substantial number of fish are passed per unit time. Maximum rates of 11 fish/minute have been recorded (Slatick, 1975). Individual fish of up to 20 kg can utilise the passes (Farr, 1983).

7. The pass uses very little water and can be ascended at flows as low as 100 $l\ s^{-1}$.

8. The issuing water draws fish without hesitation (Ziemer, 1962), though the turbulent circular flow patterns caused by the vanes were not as good as the high velocity water stream from a vertical slot pass. Entrance extensions improved attraction (Blackett, 1986).

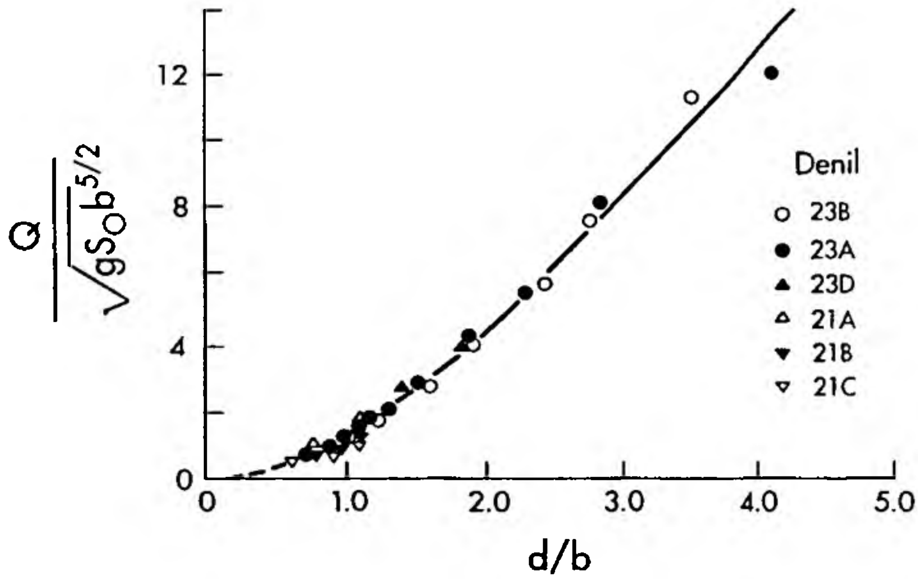


Figure C.1 Discharge rating curve for standard Denil fishway.

Source: Rajaratnam and Katopodis, 1984

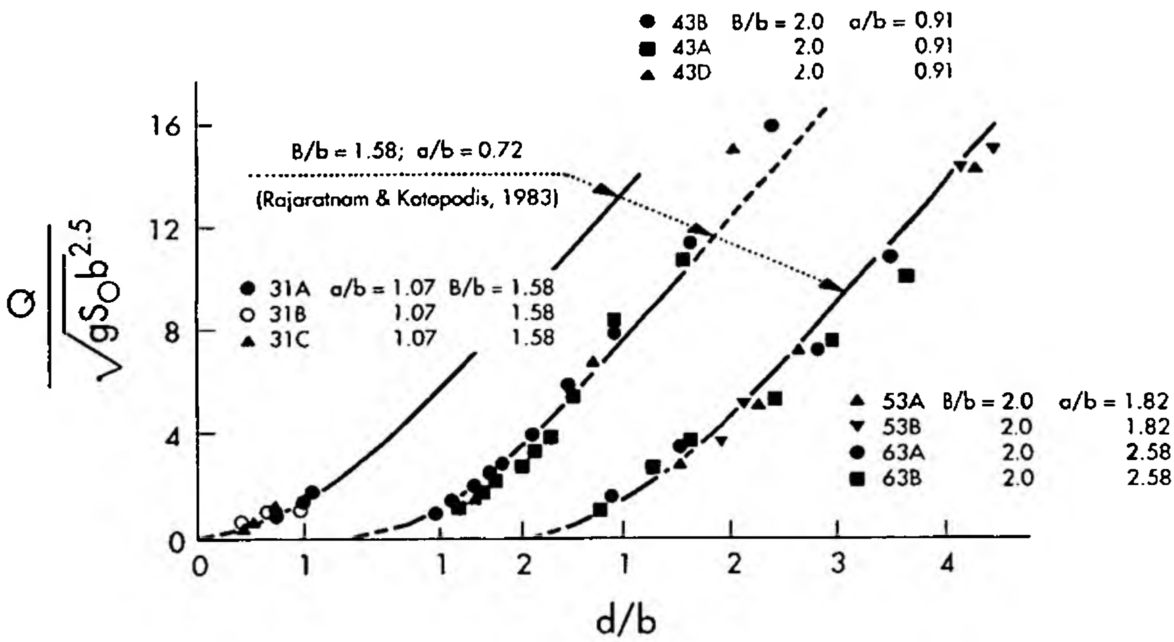
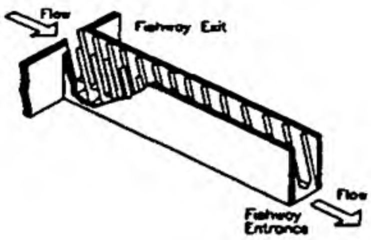


Figure C.2 Rating curve for nonstandard Denil fishways.

Source: Rajaratnam and Katopodis, 1984

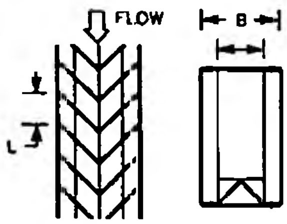
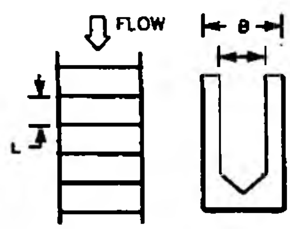
Figure C.3 Denil fishways

Source: Katopodis, 1991



$$Q_* = \frac{Q}{\sqrt{gS_o b_o^5}} = \alpha\left(\frac{y_o}{b_o}\right)^\beta$$

$$5\% < S_o < 31.5\%$$

LAYOUT (plan, elevation)	DESIGN	CONFIGURATION	α	β	COMMENTS
STEEPPASS 	1	B/b_o=1.58, L/b_o=0.715	0.97	1.55	$0.1 < y_o/b_o < 1.4$
PLAIN DENIL 	2	B/b_o=1.58, L/b_o=0.715	0.94	2.0	$0.5 < y_o/b_o < 5.8$
	3	B/b_o=2, L/b_o=1.37	1.12	1.16	$0.5 < y_o/b_o < 1.2$
	4	B/b_o=2, L/b_o=0.91	1.01	1.92	$1 < y_o/b_o < 5$
	5	B/b_o=2, L/b_o=1.82	1.35	1.57	$1.3 < y_o/b_o < 4.6$
	6	B/b_o=2, L/b_o=2.58	1.61	1.43	$0.8 < y_o/b_o < 4.3$

Notation

B	width of fishway	Q_+	dimensionless discharge for plunging flow
b_o	fish passage opening width	Q_t	dimensionless discharge for transional flow
D	diameter of culvert	S_o	slope of fishway bed
F_f	dimensionless fish speed	t	fish endurance time
F	dimensionless water velocity	t_*	dimensionless fish endurance
g	gravitational acceleration	U	fish speed
h	hydraulic head	V	water velocity
l	fish length	X	fish swimming distance
L	pool length, baffle spacing	y_o	characteristic depth of flow
Q	discharge through fishway	z_o	height of baffle, weir, sill
Q_o	discharge through orifice	α,β,η,λ,C,K	coefficients
Q_w	discharge over weir	ξ	relative maximum fish swimming distance
Q_*	dimensionless fishway discharge	ν	kinematic viscosity of water

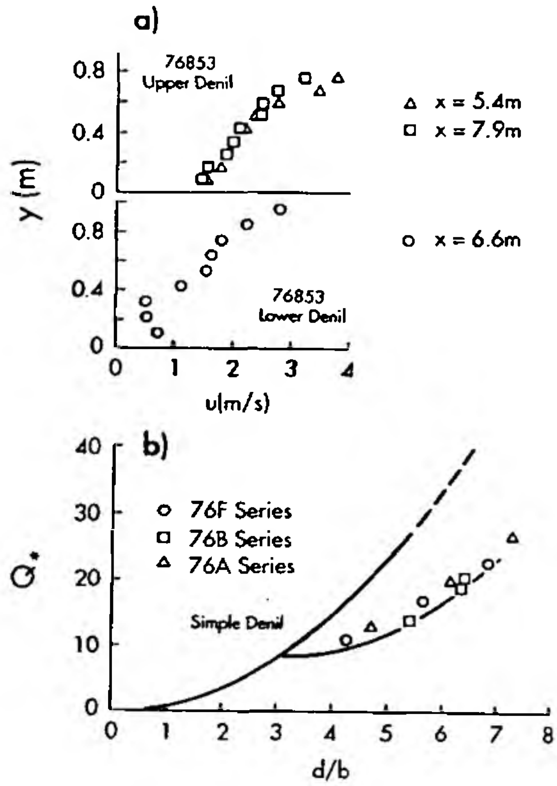


Figure C.4 Flow characteristics of two-level Denil fishways.

Source: Rajaratnam,Katopodis and Flint-Peterson, 1987

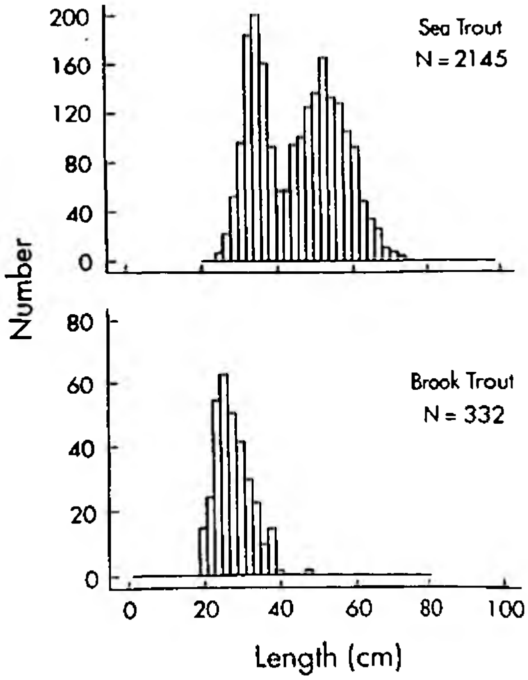


Figure C.5 Sea trout and trout passage of a small Denil fish pass in Normandy

Source: Larinier, 1991

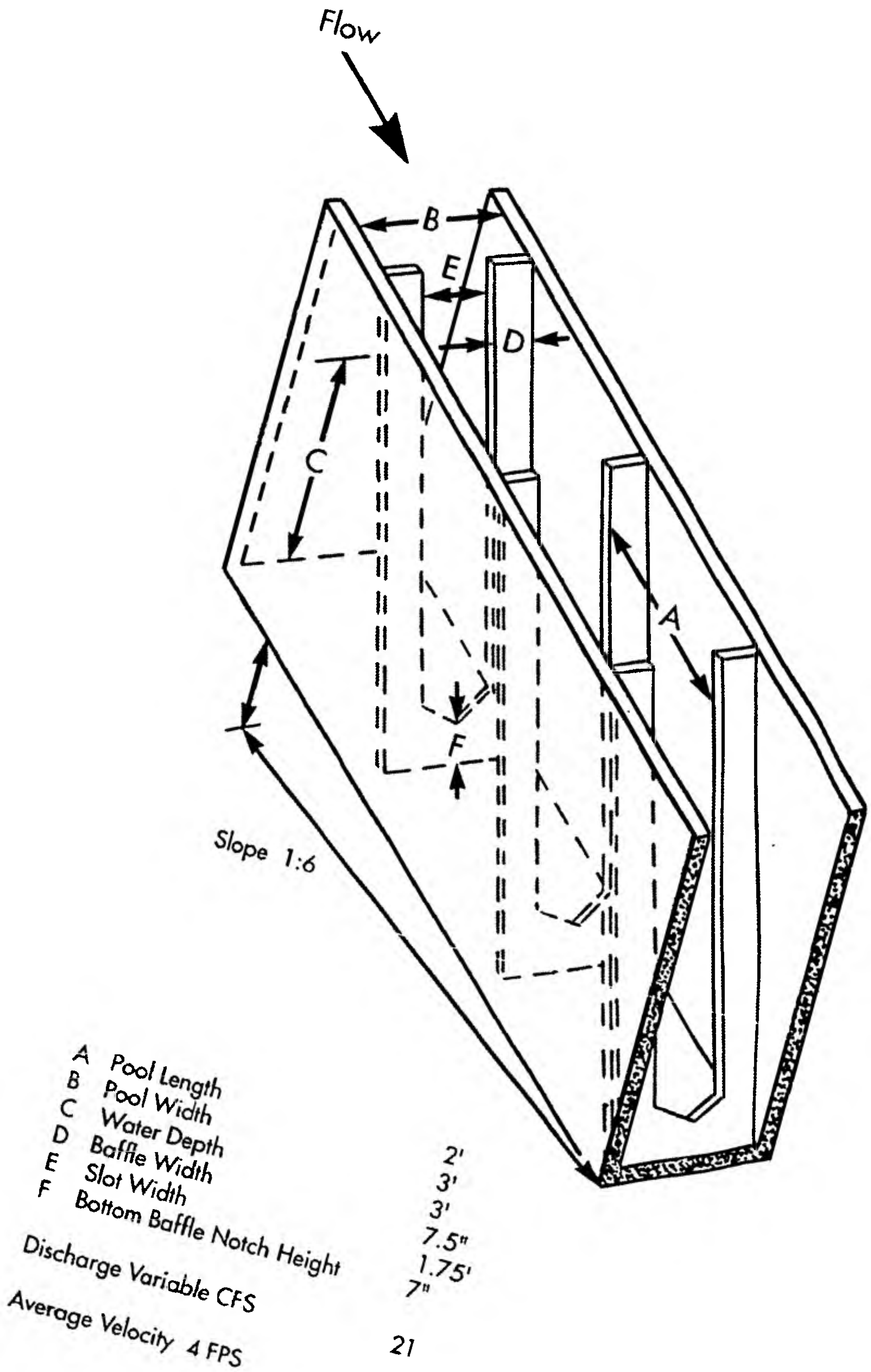


Figure C.6 Denil fishway

Source: Bell, 1986

Table C.1 Details of Denil fish passes taken from the published literature

Location	Head Loss	Fish species/ effectiveness	Fish Pass Dimensions				
			Length	Slope	Channel width	Free width between baffles	Spacing between baffles
Tange, Denmark	10m	Negotiated by brown trout, sea trout, rainbow trout, grayling, roach, perch, white bream, bream & tench	8 lengths 6.55m	1:5		0.30-0.31m	
Denmark Type I				1:4 - 1:6	0.56-0.9m		
Type II		Sea trout >0.9m length successfully pass. Also used by brown trout 0.25m	14m no resting pools	1:4 or 1:5	0.5-0.7m	0.38m	
France		Results of 6mths trapping in small Denil (width 0.96m, slope 1:5) in Normandy see Fig C.5.		range from 1:5 - 1:66		0.6m trout up to 1m for salmon & sea trout	
Bonneville Dam USA		Coho, sockeye & pink salmon	Sections 3.1m long	24%	0.56m	0.36x0.56 m	

Flow	Entrance	Maintenance/ Construction	Comment	Ref.
$0.150m^3/s$	Electric fence to prevent fish moving further upstream than entrance - had little or no effect. Positioning of entrance to blame for few trout.	Grating & scum log to prevent drifting twigs from clogging. Sand & small pieces of weed swept through.	7 resting pools. Trapping between 27.10.80 & 30.6.82 resulted in 10,080 migrating fish being caught. Of these only 23 were sea trout. 11 species altogether.	Lonne-bjerg (1991)
Hydraulic design under-taken according to Larinier (1983).		Types I & II constr-ucted at many sites. Some made of pre-fabricated elements made of impreg-nated pine & ply-wood. Others have walls & bottom of concrete & baffles of wood. Last 10 years several constructed of pre-fabricated glass fibre reinforced elements.	Only a very few whitefish and pike use Denils in Denmark. Zander have never been observed to do so.	Lonne-bjerg (1991)
				Larinier (1991)
$0.16m^3/s$		Aluminium		Slatick & Basham (1985)

Table C.1 continued

Location	Head Loss	Fish species/ effectiveness	Fish Pass Dimensions				
			Length	Slope	Channel width	Free width between baffles	Spacing between baffles
Frazer Lake, Kodiak Island, Alaska	10m	Sockeye salmon	60m 3 resting pools 60m no resting pools	22%			
Lesser Slave River Canada		Of 10 species observed to be using both Denils - 10% used more than 20%		10% 20%			
Bell				1:6	3'	1.75'	2'

Flow	Entrance	Maintenance/ Construction	Comments	Ref.
			Salmon capable of ascending continuous fishpass without visible fatigue or resting. No overall conclusive advantage for salmon passage with or without resting pools.	Blackett (1987)
Average $0.76ms^{-1}$ (floor 0.42, surface 2.25) Average $1.07ms^{-1}$ (floor 0.42, surface 2.85)				Schwalme, Mackay & Lindner (1985)
21 cfs			See Fig C.6	Bell (1986)

cfs - cubic feet per second

APPENDIX D - POOL AND WEIR FISH PASSES: Figures and tables

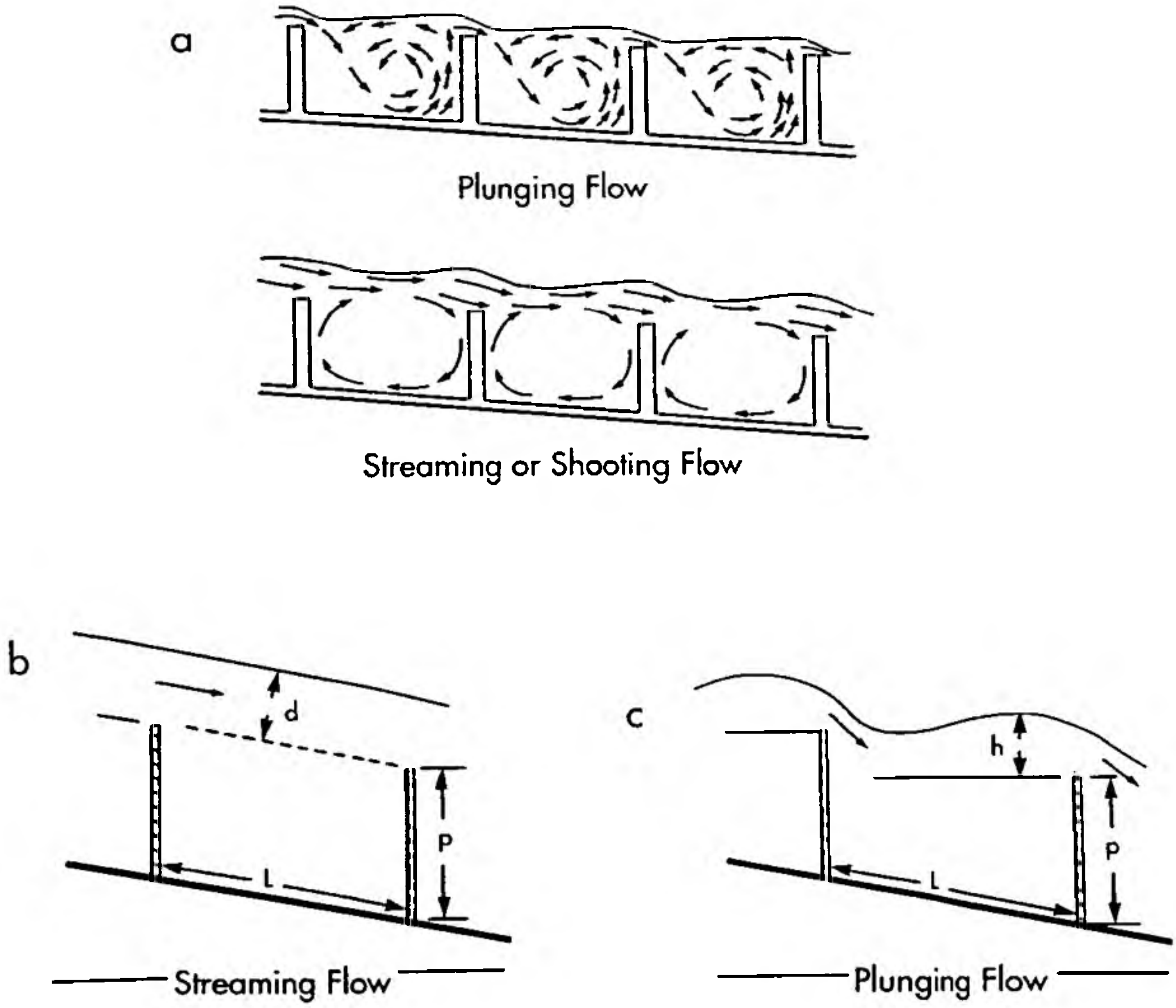
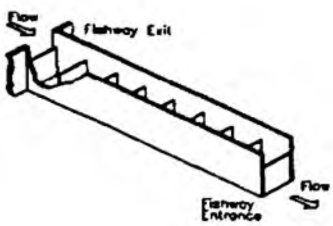
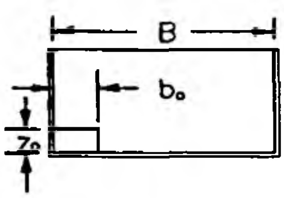
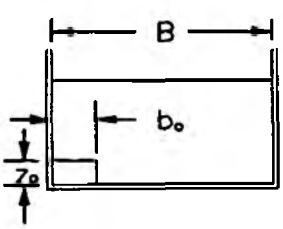


Figure D.1 Pool and weir fishways - definition sketches.

Source: Rajaratnam, Katopodis and Mainali, 1988

Figure D.2 Pool and weir fishways.

Source: Katopodis, 1991

LAYOUT	DESIGN	TYPE	EQUATION	COMMENTS
	WEIR	streaming plunging transition	$Q_* = \frac{Q_w}{b_o y_o^{1.5}\sqrt{gS_o}} = 1.5\sqrt{L/y_o}$ $Q_+ = \frac{Q_w}{b_o h^{1.5}\sqrt{g}} = 0.61$ $Q_t = \frac{Q_w}{b_o S_o L^{1.5}\sqrt{g}} = 0.25$	$4 < L/y_o < 95$ $5\% < S_o < 15\%$
	ORIFICE	corner $y_o >> z_o$ $y_o < z_o$	$Q_* = \frac{Q_o}{\sqrt{gS_o b_o^5}} = 3.77\left(\frac{y_o}{b_o}\right) - 1.11$ $Q_* = \frac{Q_o}{\sqrt{gS_o b_o^5}} = 1.94\left(\frac{y_o}{b_o}\right)$	$2.0 < y_o/b_o < 2.31$ $0.35 < y_o/b_o < 1.0$
	WEIR and ORIFICE	corner orifice plunging corner orifice streaming	$\frac{Q_w}{Q_o} = \frac{0.61}{2.25\sqrt{S_o}}\cdot\frac{B}{b_o}\cdot\left(\frac{h}{b_o}\right)^{1.5}$ $\frac{Q_w}{Q_o} = \frac{1.5}{2.25}\cdot\frac{B}{b_o}\cdot\frac{y_o}{b_o}\cdot\sqrt{\frac{L}{b_o}}$	$Q = Q_w + Q_o$ $Q_o = 2.25\sqrt{gS_o b_o^5}$ use Q_o from WEIR design

Notation

- B width of fishway
- b_o fish passage opening width
- D diameter of culvert
- F_f dimensionless fish speed
- F dimensionless water velocity
- g gravitational acceleration
- h hydraulic head
- l fish length
- L pool length, baffle spacing
- Q discharge through fishway
- Q_o discharge through orifice
- Q_w discharge over weir
- Q_* dimensionless fishway discharge
- Q_+ dimensionless discharge for plunging flow
- Q_t dimensionless discharge for transional flow
- S_o slope of fishway bed
- t fish endurance time
- t_* dimensionless fish endurance
- U fish speed
- V water velocity
- X fish swimming distance
- y_o characteristic depth of flow
- z_o height of baffle, weir, sill
- $\alpha,\beta,\eta,\lambda$,C,K coefficients
- ξ relative maximum fish swimming distance
- ν kinematic viscosity of water

Table D.1 Accepted design factors applied to pool, weir and port fish ladders

Designer or author (type)	Hp (ft)	Q (ave) (cfs)	V (ave) (fps)	dw (ft)	Pool space	Wc (ft)	Oh (feet)	Ow	Pool dimensions L(ft)	B(ft)	d (ft)	Weir shape	θ	Slope
Menzies (1934) (Type C)	1-2.5	5-6	Near sea 6.5-8 Away sea 5-6.5						14-15	9-10		trapezoidal	90	1/6
Bonnyman (1958) (Type D)	1.5	39	10				2.25 diameter		17	10			90	1/11.3
McCloud & Nemenyi (1939) (Type A&D)	0.75			0.33 - 0.50			1.0	0.83	3	2.5	3	Rectangular	90-type A 41-type D	1/4
Committee on Fish Passes (1942) (Type C)	1.5 (max)	12	8(max)	0.75 (min)		2			10	6	4	Rectangular	90	1/6.7
Committee on Fish Passes (1942) (Type D)	2 (max)	24					1.5 length = 3-4.5'	1.5	10	4	4		90	1/5
Decker (1946) (Type C & D)	1 (max)						1.0	0.83	5-8	5-8		Cipolletti	90-type A 41-type D	1/5 to 1/8
Fischer (1964) (General)	1-strong swimmers 0.6-0.75 (pink,chum)		4-8		4 ft^3 fish				From pool space	From pool space	2 (min)		90	1/10

cont.

Table D.1 cont.

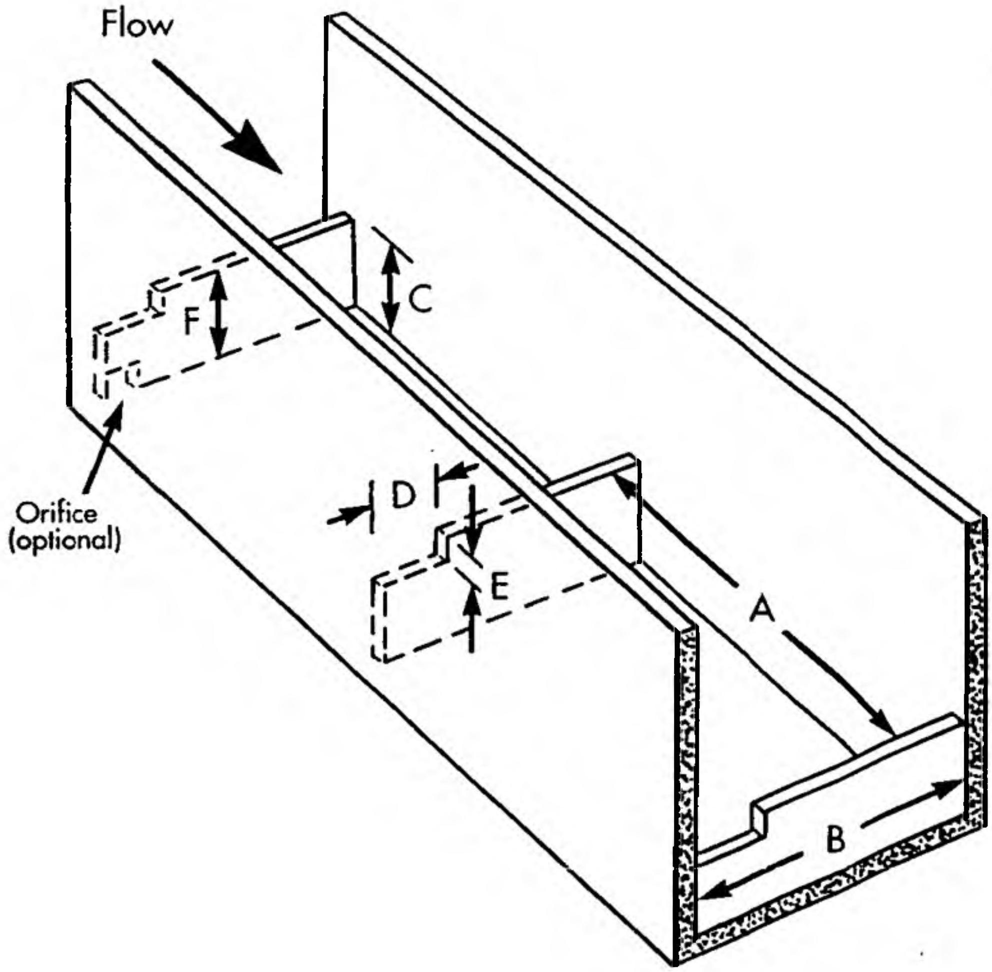
Designer or author	Hp (ft)	Q(ave) (cfs)	V(ave) (fps)	dw(ft)	Pool space	Wc (ft)	Oh (feet)	Ow	Pool dimensions L(ft)	B(ft)	d(ft)	Weir Shape	θ	Slope
Ziemer (General)	0.75-1	= pool cross sectional area	3-8 1 resting	0.5-1	4 ft^3 fish		1.0	0.83	10x Hp	2.5x Hp	3xHp		90	Slope
Sakowicz (1962) (General)	1.3-1.6 (salmon)	35	9 (max)			2.6	1.6	1.6	16.4	9.8	2.6			1/10
Rizzo (1969) (Type A)[b]	1	4ft-lbs sec ft^3	3-8	1					14-18	10-18	6.5	Rectangular	90	1/10
Bell (1973)[b] (Type A)	1-salmon 0.75-shad	4ft-lbs sec ft^3	2-8 fps	1-salmon 0.5-trout	0.2 ft^3 lb fish	B/2	1.5	1.25	8-20	6-20	6	Rectangular	90	Salmon 1/10 Shad 1/13

Notes: [a] Test fish from Iowa River (species: carp, shad, quillback, catfish,herring, perch, and buffalo fish)
[b] Ice Harbor Type
Hp = head between pools, Q = flow, V = velocity, dw = depth over weir, Wc = weir crest length, Oh = orifice height, Ow = orifice width, d = pool depth, θ = orifice baffle wall angle.

Source: Orsborn, 1985

Figure D.3 Pool and weir fishway.

Source: Bell, 1986



A	Pool Length		6'	8'	10'
B	Pool Width		4'	6'	8'
C	Water Depth		3'	4'	6'
D	Slot Width		0.5'	0.5'	0.5'
E	Slot Depth		0.5'	0.5'	0.5'
F	Baffle Height		2.5'	3.5'	5.25'
Water Depth in Notch			12"	12"	15"
Discharge in CFS		Minimum	1.65	4.0	4.0
		Normal	5.0	12.3	25.0
		Maximum	24.0	36.0	48.0
Drop per Pool			1'	1'	1'

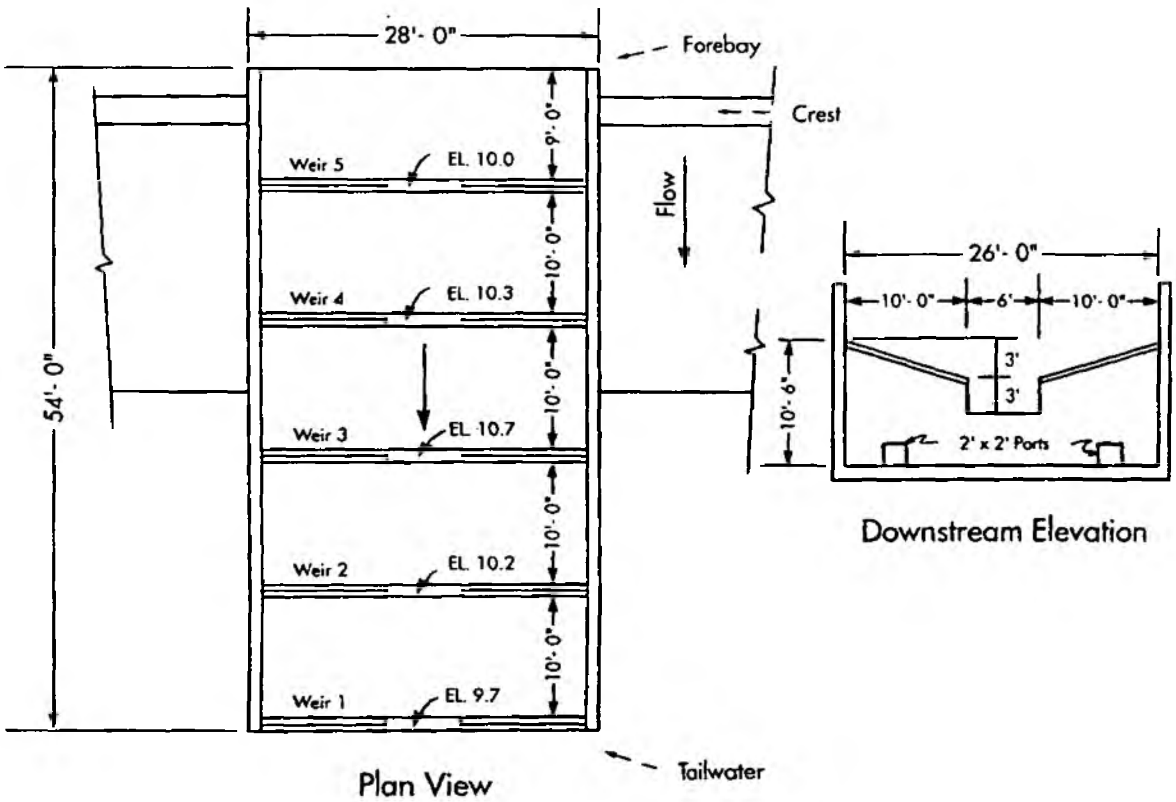


Figure D.4 Town Dam pool and chute fishway.

Source: Bates, 1991

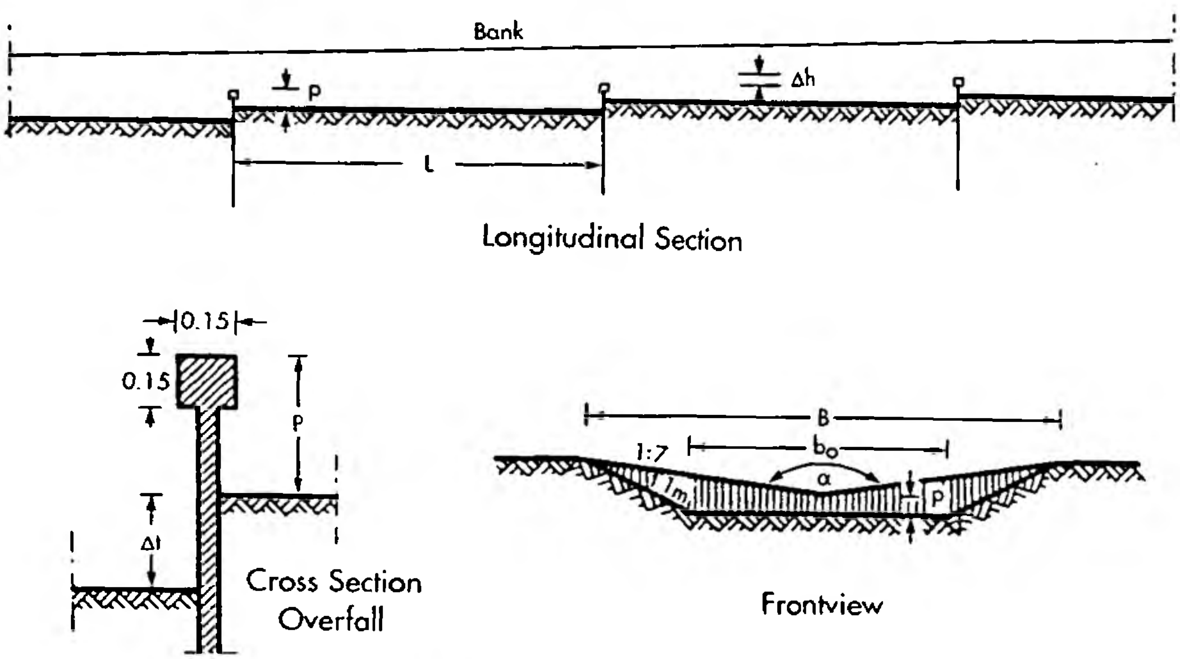


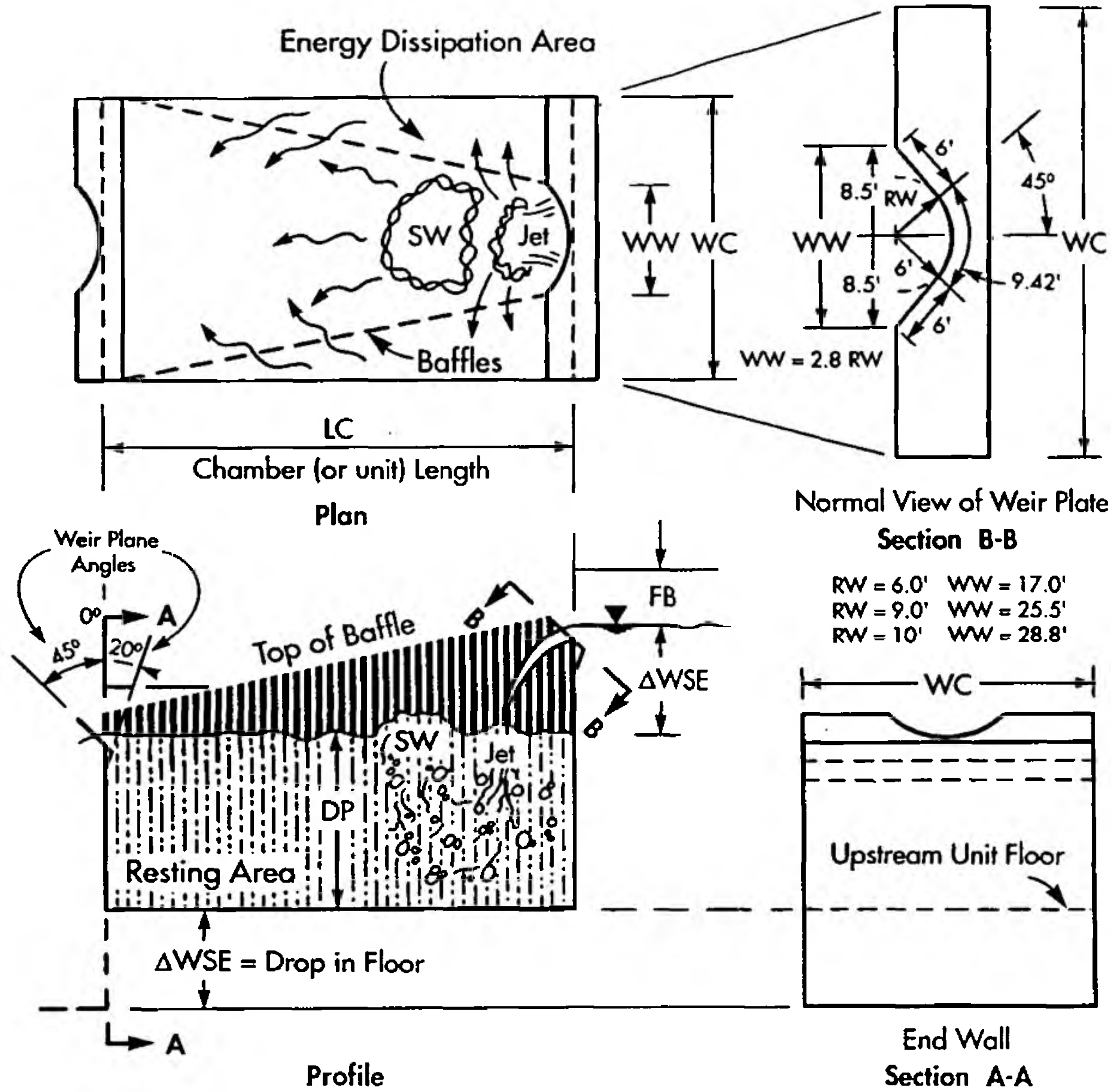
Figure D.5 Layout of the V-shaped pool fishway.

Source: Boiten, 1991

Table D.2 Dimensions for eleven different designs of pool and weir fish passes with v-shaped overfalls

Design nr.	Flow (m^3/s) (Qd)	Dimensions optimum design (m) Pool drop (dt)	Pool length (L)	Pool width (B)	Pool depth (P)	Crest length (d)	Non-aerated nappe B_2	max.velocities (m/s) Behind the crest	Pool
1	0.35	0.125	3.75	5.00	0.20	0.075	1.65	1.74	0.53
2	0.56	0.15	4.50	6.00	0.24	0.090	1.98	1.91	0.58
3	0.82	0.175	5.25	7.00	0.28	0.105	2.31	2.06	0.63
4	1.14	0.200	6.00	8.00	0.32	0.120	2.64	2.21	0.67
5	1.54	0.225	6.75	9.00	0.36	0.135	2.97	2.34	0.71
6	2.00	0.25	7.50	10.00	0.40	0.150	3.30	2.47	0.75
7	2.54	0.275	8.25	11.0	0.44	0.165	3.63	2.59	0.78
8	3.15	0.30	9.00	12.00	0.48	0.180	3.96	2.70	0.82
9	3.85	0.325	9.75	13.00	0.52	0.195	4.29	2.81	0.85
10	4.64	0.35	10.50	14.00	0.56	0.210	4.62	2.92	0.88
11	5.51	0.375	11.25	15.00	0.60	0.225	4.95	3.02	0.92

Source: Boiten, 1991



DP = Depth of Pool
FB = Freeboard
LC = Chamber Length
RW = Radius of Weir
SW = Standing Wave

WC = Chamber Width
WW = Top Weir Width
ΔWSE = Drop in Pool; Change in Water Surface Elevation

Figure D.6 Recommended geometry for new weir of pool fish ladder.

Source: Orsborn, 1985

Table D.3 Hydroelectric scheme fish passes in New Zealand

River or scheme	Construction date	Fishpass type	Comments
Opuiaki (Tauranga)	1978	Pool and weir	1.4 m rise in steps of 0.3 m; large step at exit could prevent passage depending on flow conditions and weir plate adjustment
Omanawa (Tauranga)	1978	Pool and weir	Similar to above
Parea R (Patea PS)	1984	Eel pass	100 mm PVC pipe fitted with polypropylene brush allows elvers to climb over the 64 m dam; simple, inexpensive with low water demand
Mangamni R (Motukawa PS)	1930	Pool and weir	Poor design which would never operate satisfactorily. 600 mm drop between rather small pools; flows vary with headwater level and are often inadequate
Waiau R (Opunake PS)	1923	Pool and weir	6 m of vertical lift, recently refurbished, may operate for some native fish; small pool size
Branch R	1983	Weir and orifice	4 m of vertical lift; incorporates sediment sluicing facilities; small pool size creates excessive turbulence at design flow
Arnold R (Arnold PS)	1932	Weir and orifice	Operated satisfactorily when first constructed but closed in 1938 to prevent upstream passage of eels
Waitaki R (Waitaki PS)	1934	Pool and weir	20 m vertical lift; too steep with inadequate entrance and attraction flows; demolished in 1951
Aviemore	1967	Pool and weir	3 m vertical lift; used successfully by rainbow and brown trout and sockeye salmon
Waiau R (Manapouri Lake control)	1976	Borda orifice	4.7 m vertical lift; operates reasonably but some problems with entrance and maintenance

Source: Jowett, 1987

Table D.4 Details of pool and weir fish passes taken from the published literature

Location	Head Loss	Fish species/ effectiveness	Fish Pass Dimensions				
			Pool size	Pool depth	Drop between pools	Orifice	Notches
Norway (general)			2.5 x 4m	1.2 - 1.5m	Varies usually >50cm		
Mattiselva	45m						
Harpfossen River Gudbrands-dalslagen	22m						
Australia							
Mt Crosby Bisbane River	3.5m	Sea mullet, barramundi, lung fish, Australian bass	2.5m wide x 1.5m long & 2.5m wide x 2.5m long	400mm & 700mm	250mm		
Burnett River Barrage - Bundaberg	7.3m	Sea mullet, barramundi, lung fish	Series of pools		250mm		
Burnett River Mundaberra	5.2m		Top step 500m				
Fitzroy River Barrage	3.6m	Sea mullet, barramundi, Australian bass	2.6m long x 1.8m wide	500mm	150mm		

Flow	Entrance	Maintenance/ Construction	Comment	Ref.
0.35 - 1.0 m^3/s		Concrete	Most of the fish passes in Norway are of this type. 500m long with 105 pools 56 pools	Grande (1991)
Range 0.9-1.2 m/s Max. 1.9 m/s	Major problem with entrance which can experience a drop of around 500mm if tailwater below weir is low.		Velocities low enough for all likely users except possibly small mullet (<50mm). Generally considered to operate successfully.	Barry (1991)
		Made by insertion of concrete drop slabs in a channel.	Passes most sizes of mullet but barramundi do not appear to use it. Effective up to medium river overflows but in flood conditions turbulence near entrance precludes fish from entering.	Barry (1991)
			Depth of step makes access almost impossible during low to medium flows. At high flows drowned out and most fish able to pass.	Barry (1991)
1.9-2.1 m/s	When tide is within 1/3 of low tide, bottom end of fish pass apron is too high above river bed for fish to gain access.			Barry (1991)

Table D.4 continued.

Location	Head Loss	Fish species/ effectiveness	Fish Pass Dimensions				
			Pool size	Pool depth	Drop between pools	Orifice	Notches
Australia cont. Burdekin River	7m	Barramundi, Jungle perch	5m long	1.5-2.5m			
Red Bluff Diverson Dam Sacramento River, California		Chinook salmon					
St. George Fish pass Magaguadavic River, New Brunswick	13.4m	In 1983 used by 940 Salmo salar	43 pools, 2 large resting pools		305cm		
Badush Dam Tigris River Iraq		3 species of Barbus					
Columbia River, Ice Harbour Baffle			3m length x 4.8m wide			Sub-merged 0.45m square	0.6m in central part of weir
Denmark			2 x 3m	0.7 - 1.0m	0.3 - 0.4m		0.3 - 0.5m wide

Flow	Entrance	Maintenance/ Construction	Comment	Ref.
1.3-2.2 m/s	Poor entrance conditions with overflow from weir (425m wide) creating significant distraction.		No research on effectiveness. Local opinion is that it is not working effectively.	Barry (1991)
	Entrance flow 2.5m^3/s, auxillary attraction flow 7.1m^3/s. Total 9.6m^3/s		Difficulty in locating entrance	Vogel, Marine & Smith (1991)
		Reinforced concrete. Trash rack over exit hole, vertical steel bars 20cm apart.	Improvement needed for locating attraction water during high water periods.	Martin (1984)
	Entrance velocity >0.6m/s	Concrete.	190m long - divided into 3 sections. Modelling of fishpass resulted in changes to original design.	Petkovic & Zdravkovic (1991)
			Recommended for large fish passes with large runs of salmon & trout.	Clay (1991)
		Some built traditionally with concrete, others from reinforced concrete embedded in stones.		Lonnebjerg (1991)

Table D.4 continued.

Location	Head Loss	Fish species/ effectiveness	Fish Pass Dimensions				
			Pool size	Pool depth	Drop between pools	Orifice	Notches
France			2.5-3.0m long		0.15-0.6m (see text)	Min. width 0.3m salmon, 0.45m shad	
Netherlands			3.75m-11.25m long x 5.0m-15.0m wide	0.2-0.6m	0.125-0.375m		
Tikkurilankoski Keravanjoki River, Norway	3.5m	Salmon & sea trout			0.3m	$0.4m^2$	
Aviemore Power Station, New Zealand	3m	500-1000 brown trout & rainbow trout use fish pass annually	2.44m wide 3.35m long	1.8m	0.3m	Each weir 2x 0.46m square orifices - later blocked off	
Branch river	4m		1.9m x 1.2m	1.5m	0.3m		

Flow	Entrance	Maintenance/ Construction	Comment	Ref.
			Slope <7% - >25%. Most common 10-12%. No overflow submerged orifices fish passes used.	Larinier (1991)
0.35-5.51 m^3/s			Dimensions of optimum design given in Table D.2.	Boiten (1991)
			During salmon migration velocities vary 2-2.5m/s.	Rytkonen & Hepojoki (1991b)
Average $0.9m^3/s$	Works even though discharge is 1/130th of power station discharge (Columbia River - recommend 1/20th)	Cost $650,000 (1983)	Further details on specific fish passes in New Zealand, see Table D.3.	Jowett (1987)
Designed for $1m^3/s$ with bypass			Pools do not adequately dissipate energy - they are only about 25% of size required.	Jowett (1987)

APPENDIX E - OTHER TYPES OF FISH PASS: Figures, tables and additonal information

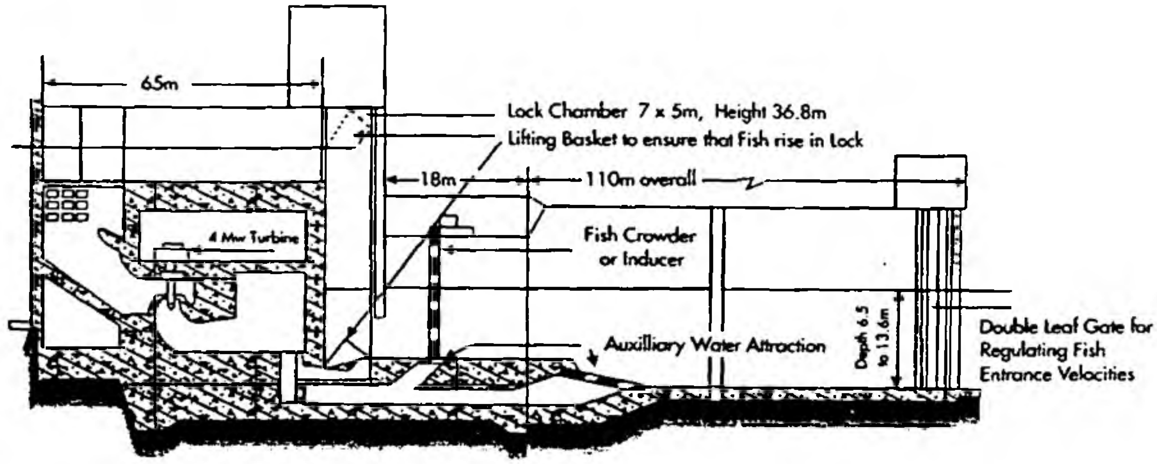


Figure E.1 The Tzymlyanskij fish lock on the Don River, USSR.

Source: Clay, 1991

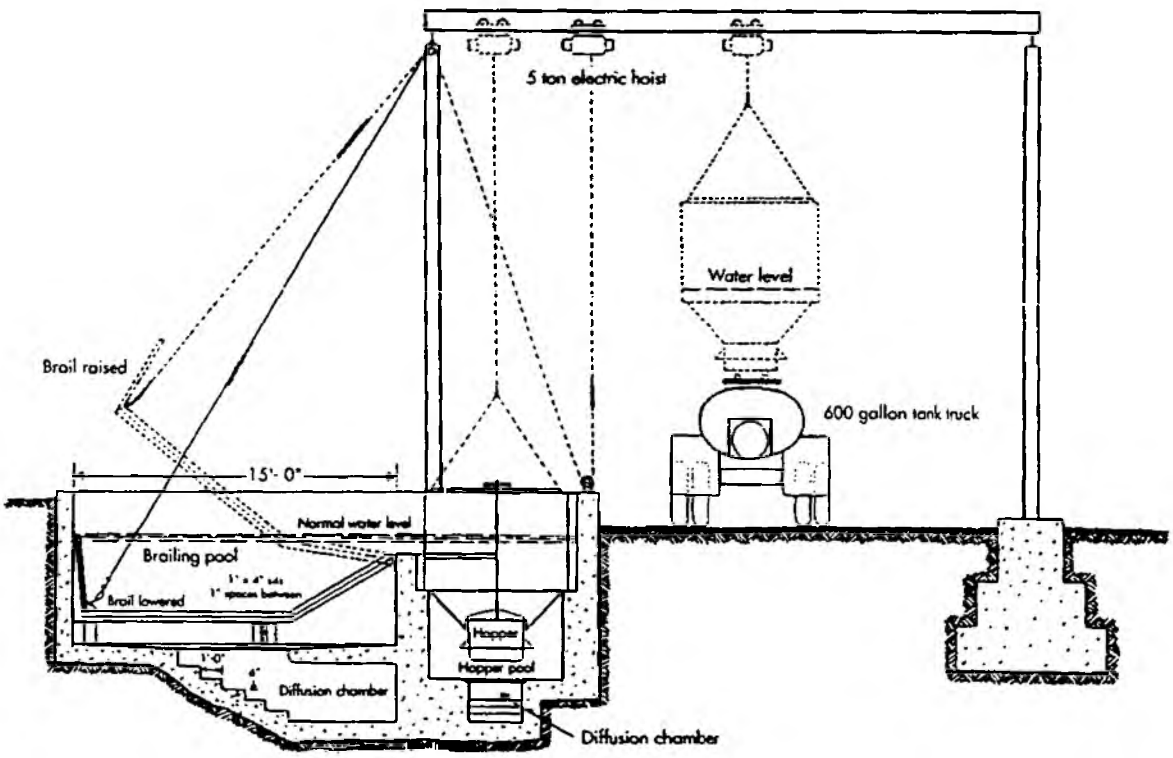
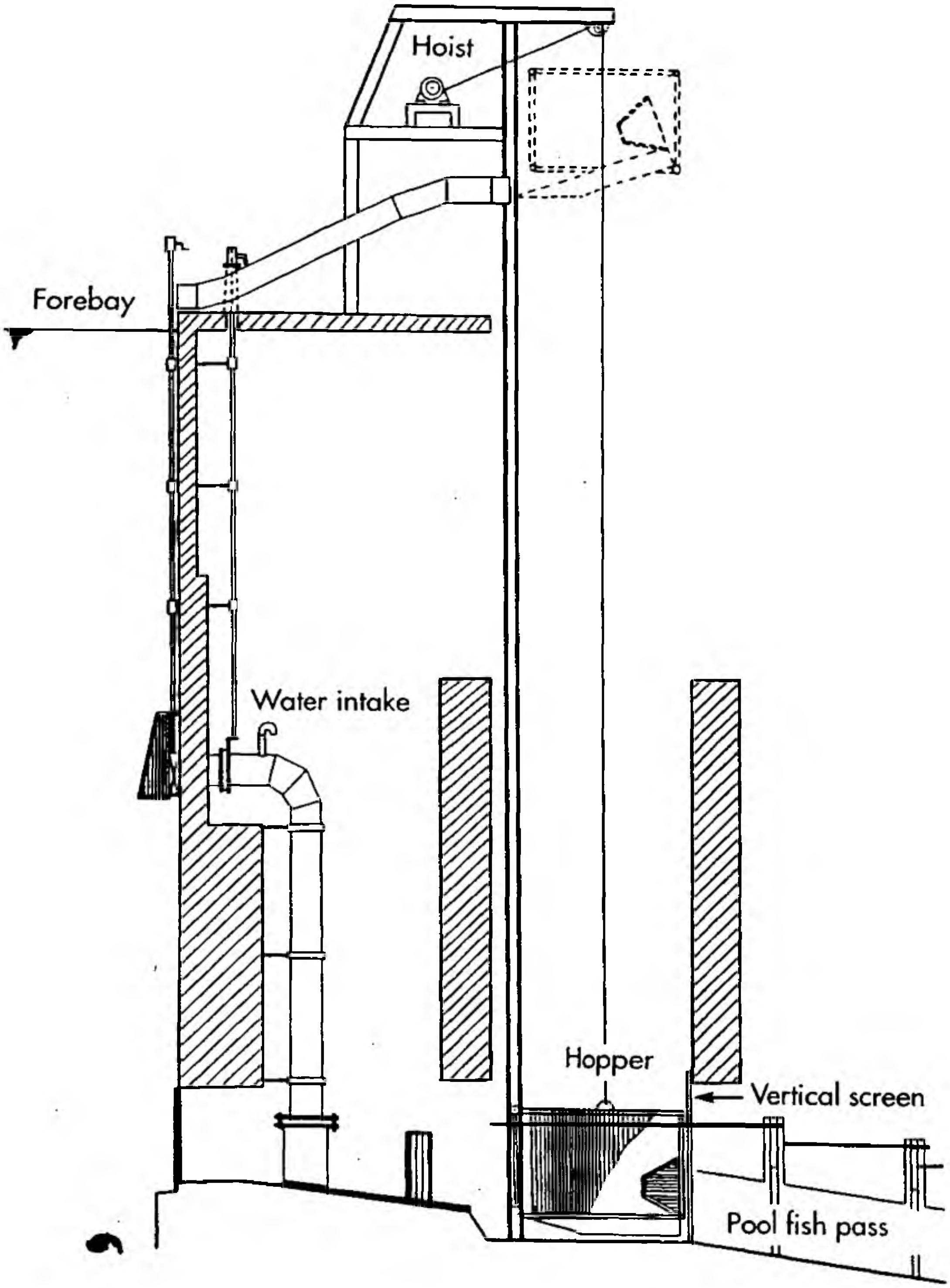


Figure E.2 A fish lift or elevator using the trapping and trucking principle.

Source: Clay, 1991

Figure E.3 Poutes fish elevator.

Source: Larinier, 1991



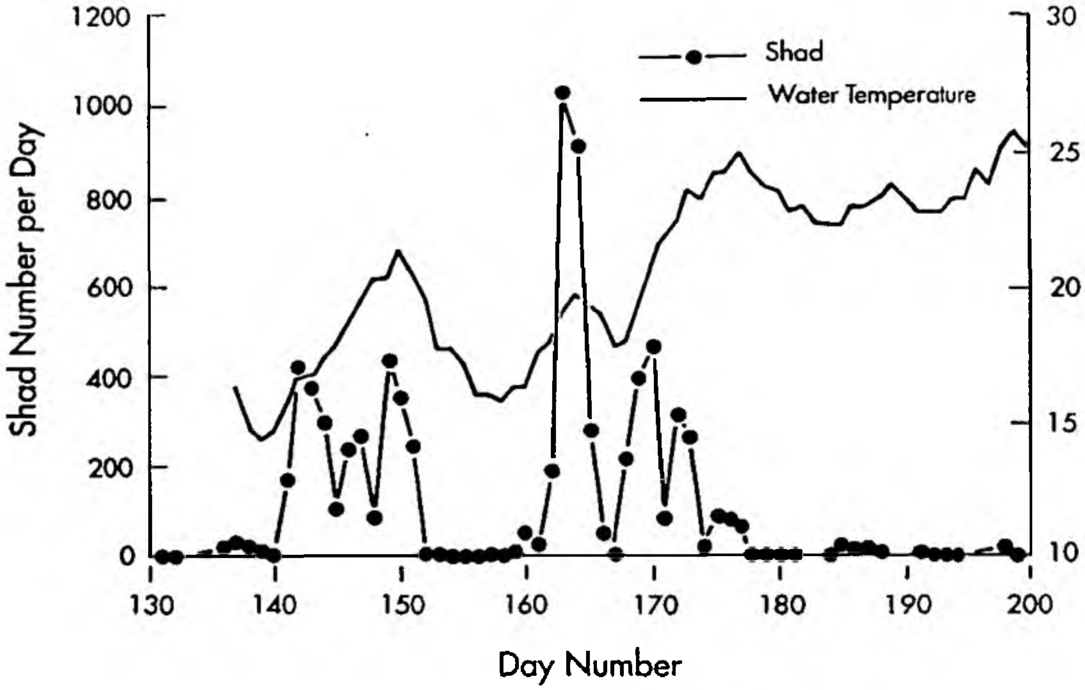
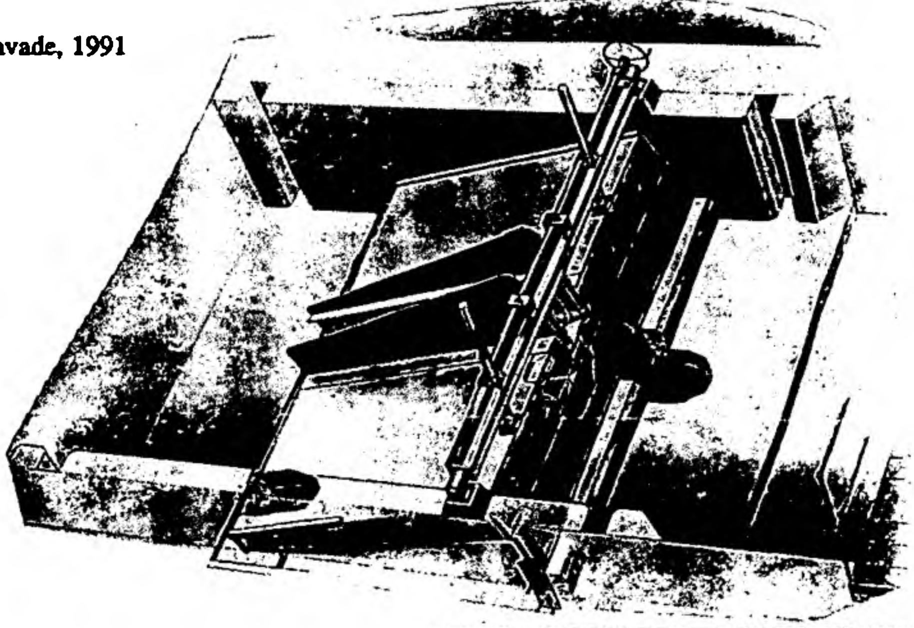


Figure E.4 Tuilieres fish elevator (1989) daily shad passages and water temperature.

Source: Travade, 1991



THE FISHWAY GATE

The Fishway Gate is a unique design of tilting gate which contains an integral fish pass. It permits upstream water levels to be controlled while providing an easy ascent for migratory fish, all within a single mechanism.

The main advantages are:

1. Considerably lower capital cost than a conventional gate and separate pass.
2. Requires simple, economic foundations.
3. Can be fully automated or manually operated.
4. Overshot blockage-free profile gives slow increase in discharge.
5. Provides pass at natural congregation point.
6. Can pass all species of migratory fish upstream.
7. Can be ascended at very low flows.
8. Utilizes hydrostatic pressure to assist in raising, therefore power requirements are low.
9. Can be descended by canoe.

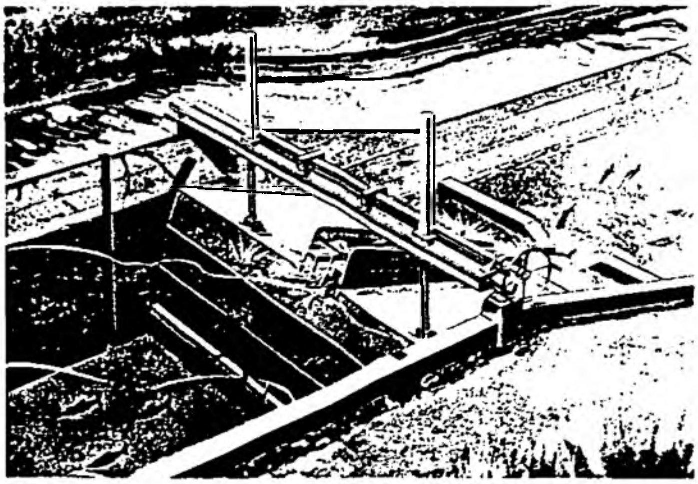


Figure E.5 The fishway gate.

Table E.1 Example of fish passages:Golfech fish elevator on Garonne (1987-1989)

Common name	Scientific name	Number of fishes 1987	1988	1989
Migr. species				
Atlantic salmon	*Salmo salar* (1)	24	24	1
eel	*Anguilla anguilla*	4 970 (u)	1 166 (u)	13 322 (u)
sea lamprey	*Petromyzon marinus*	11	16	370
sea trout	*Salmo trutta trutta* (2)	51	48	7
shad	*Alosa alosa*	18 224	13 779	66 401
undet.salmonids	(1) or (2)	22	18	5
Fluviat. species				
barbel	*Barbus barbus*	2 414 (u)	1 258 (u)	3 284
bleak	*Alburnus alburnus*	217 (u)	18 787	1 003
bream	*Atalbramis brama*	3 830	3 256	10 743
blenny	*Blennius fluviatilis*	2	0	0
silver bream	*Blicca bjoerkna*	presence	presence	presence
carp	*Cyprinus carpio*	9	32	20
catfish	*Ictalurus melas*	3 433	2 908	1 486
chub	*Leuciscus cephalus*	6	3	50
goldfish	*Carassius auratus*	1	6	presence
largemouth bass	*Micropterus salmoides*	13	9	7
mullet	*Mugil capito*	0	1 583	404
perch	*Perca fluviatilis*	7	1	4
pike	*Esox lucius*	2	4	6
pike-perch	*Lucioperca lucioperca*	90	572	250
roach	*Rutilus rutilus*	presence	presence	presence
rudd	*Scardinus erythrophtalmus*	presence	presence	presence
sunfish	*Lepomis gibbosus*	5	9	2
tench	*Tinca tinca*	2	2	2
trout	*S.trutta fario, S.gairdneri*	32	17	29

Source: Travade, 1991

Table E.2 Details of the major fish passes in the USSR

	Volgograiskiy	Tsimlyanskiy	Krasnodarskiy	Saratovskiy	Kochetovskiy	Fedorovskiy
River impounded	Volga	Don	Kuban'	Volga	Don	Kuban'
Construction begun	1961	1955	1975	1969	1969	1982
Type	hydraulic fish lock	hydraulic fish lock	mechanical fish-lift	mechanical fish-lift	sluice fish-pass	sluice fish-pass
Hydraulic head(m)	23	20	13-17	13-17	1-3	1-4
Collection gallery:						
length (m)	80	129	71	172	68	69.3
width(m)	8.5	6	10	8	10	9
flow depth(m)	5.7-14.4	6.5-13.6	2.5-6.5	9-13.5	1.8-4.5	1.4-4.8
Attractive regime:						
V_{max}(m/sec)	0.8-1.2	0.8-1.0	0.6-1.4	0.8-1.4	0.6-2.0	0.8-1.8
cycle time(min)	120	120	90-240	30-180	15-180	120-240
Species passed:						
Abramis spp.		+	+		+	+
Acipenser guldenstadti	+	+	+	+	+	+
Acipenser stellatus	+		+	+	+	+
Chalcalburnus chalcoides					+	+
Clupea harengus	+			+	+	+
Cyprinus carpio		+				+
Coregonus lavaretus	+			+		
Huso huso	+					
Siluris glanis		+				
Vimba vimba			+		+	+
Total number passed each year:	c. 1 million	c. 200 000	c. 1 million	c. 1 million	c. 1 million	c. 500 000
Number of Acipenseridae:	c. 20 000				c. 2 500	c. 1 500

Source: Pavlov, 1989

Figure E.6 Pipe eel pass over the Patea Dam in New Zealand.

Source: Clay, 1991

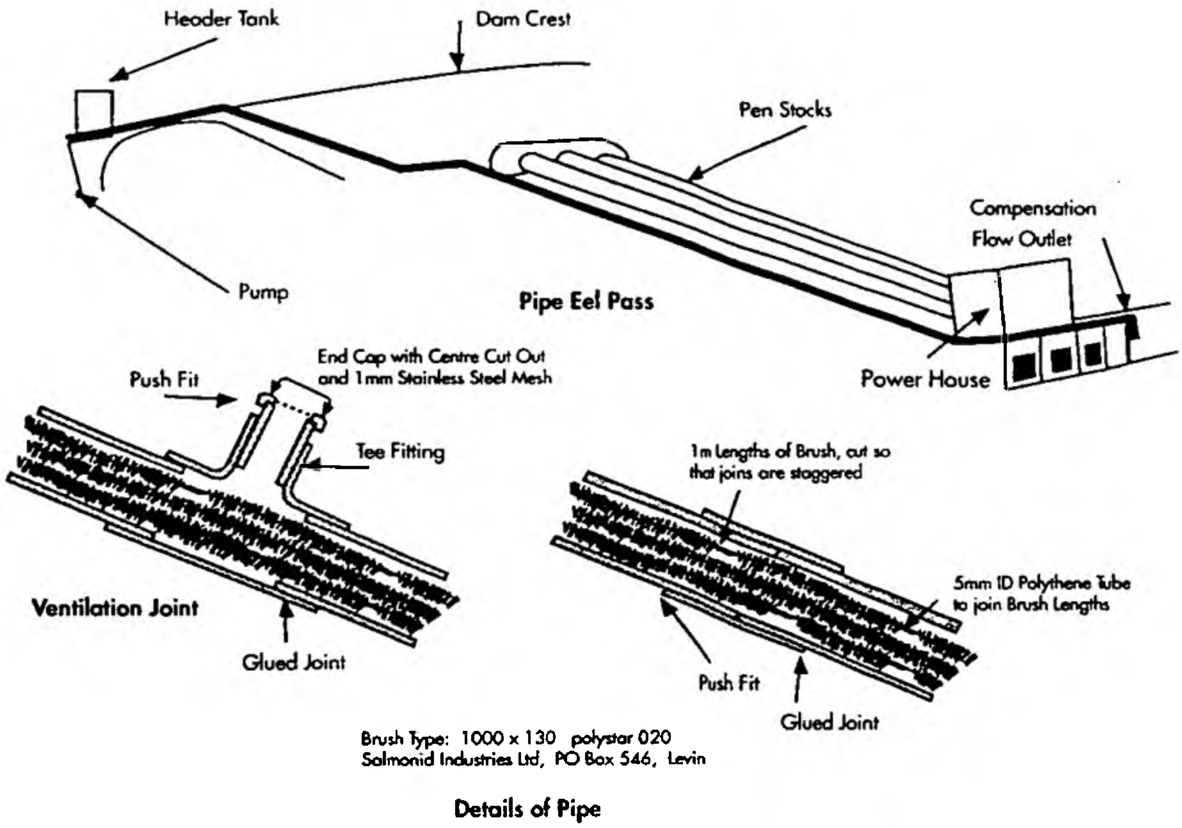
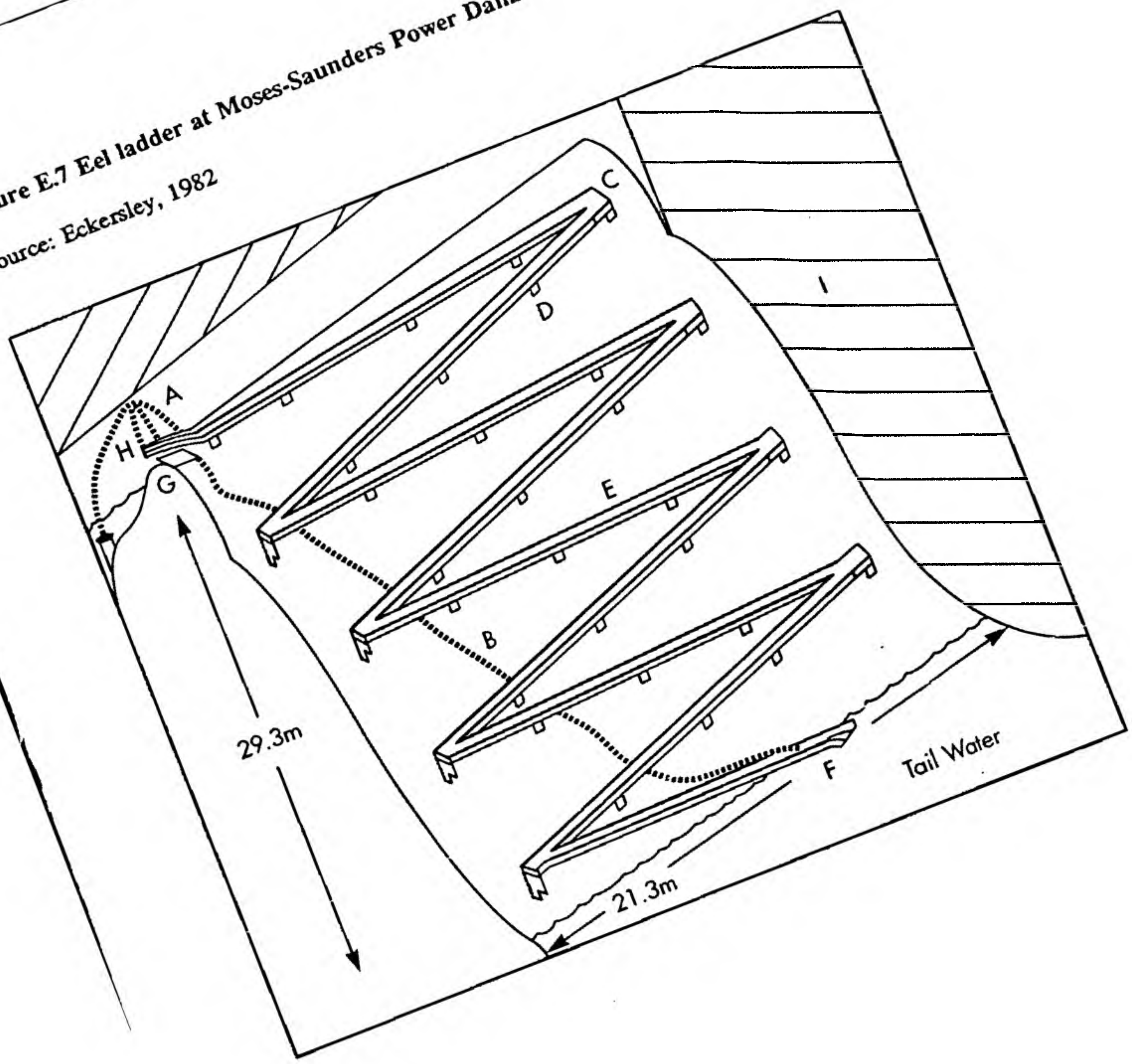


Figure E.7 Eel ladder at Moses-Saunders Power Dam.

Source: Eckersley, 1982



THE FISHWAY GATE - ADVANTAGES

General

Much more economic than next alternative
Uses existing technology
Simple innovative design
Safe for river users

Economic

<u>Capital</u>
Simple form economic to design
Plain shape simple to fabricate
Can be fully factory assembled
Lends itself to modular construction
Requires low power supply
Simple economic foundations
High benefit/cost ratio

<u>Running</u>
Robust form resists impacts
Low poer consumption
Can be fully automated
Blockage free profile

Biological

Can pass selected species of migratory fish upstream
Safely passes adults downstream
Safely passes juveniles downstream
Almost impossible to poach
Presents pass at natural congregation point
Can be of any migrant capacity
Enhances anadromous fish stocks
Can be ascended at low flows
May be used to sort by species

Hydraulic

Slow increase in discharge - no hunting
No high velocity jets to cause cavitation
Utilizes hydrostatic pressure to raise
Will not vibrate or "drum"
Only requires low flows to operate

Aesthetics and Amenity

Can be descended by kayaks
Gate is below water
No obstrusive superstructure
Can be descended by drift boats
Can be descended by rafts

Applications

Tidal barrage locks to minimise saline intrusion
Automatic level control at the upstream of large fish ladders
To release artificial "freshnetts" to encourage migration and improve fishing
Can sort by species in some cases, e.g. square fish, U S salmonids
Provides maximum water retention with minimal flow for fish passage
Seasonally variable retention levels
Can be used to pass logs
Can be used to pass ice
Can be adapted as hatchery intakes
With suitable controls, can give early warning of floods
Controls can be operated by solar power
Controls can "bridge" power cuts
Obviously such a versatile mechanism has many other uses.

Source: Mr A L Woolnough, Fishway Engineering

APPENDIX F - SWIMMING PERFORMANCE: Figures and tables

Figure F.1 Relation between maximum specific speeds and length for several groups of fish.

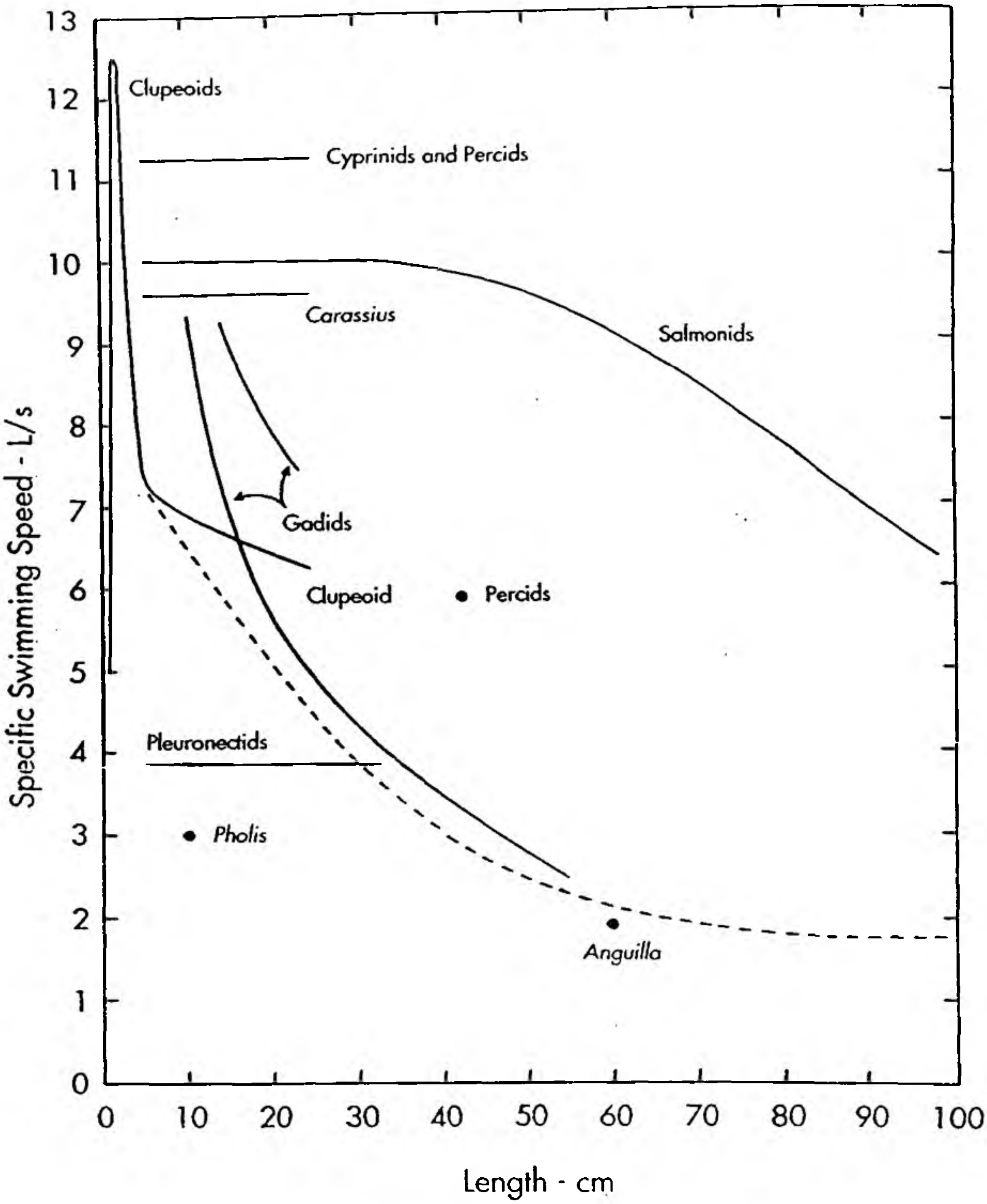


Figure F.1 Relation between maximum specific speeds and length for several groups of fish.

Source: Webb, 1975

Table F.1 Calculations of swimming speeds for Atlantic salmon during the initial phase of up-stream migration.

Fish	Fork length (cm)	Swimming speeds km d^{-1}	ms^{-1}	bls^{-1}	Prevailing flow rate (m^3s^{-1}) Park	Woodend
C	72	21.30	0.27	0.34	124.85	104.36
D	69	19.08	0.22	0.32	40.14	31.45
		14.53	0.17	0.24	43.85	35.09
		29.81	0.35	0.50	22.04	25.01
E	75	20.74	0.24	0.32	24.04	24.66
		25.10	0.29	0.39	26.03	28.68
		25.07	0.29	0.39	29.42	37.64
G	56	21.49	0.25	0.45	23.75	21.03
H	62	33.44	0.39	0.63	31.35	24.09
		22.13	0.26	0.42	31.01	22.93
I	58	36.98	0.43	0.74	32.16	26.15
J	65	25.17	0.29	0.45	48.27	31.50

Source: Hawkins, 1986

Figure F.2 **Comparison of swimming performance among three stocks of brown trout *Salvelinus fontinalis*.**

Source: Beamish, 1978

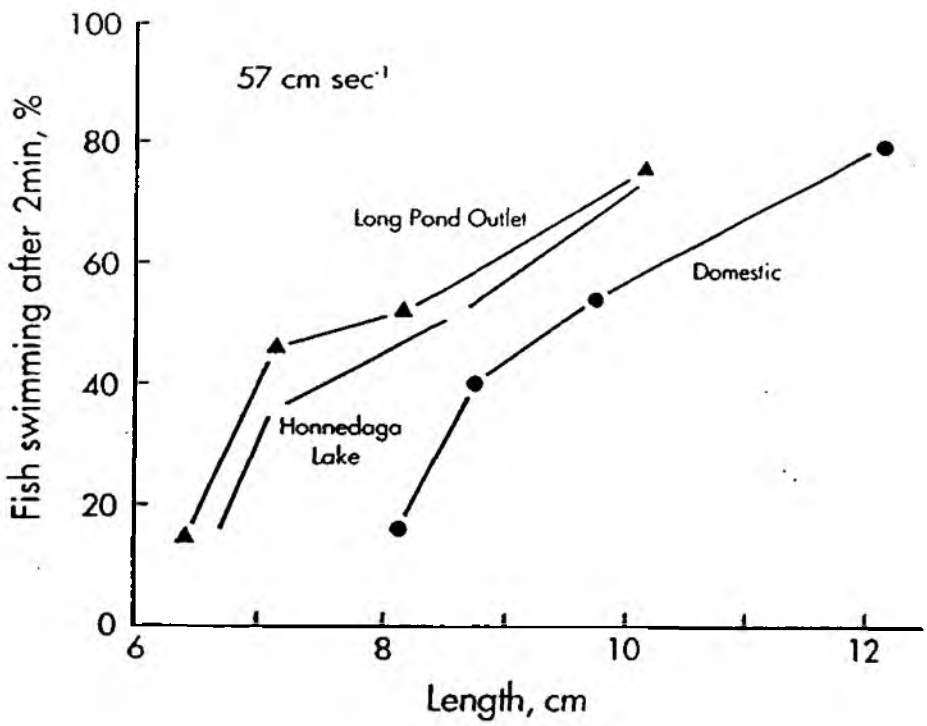


Figure F.2 Comparison of swimming performance among three stocks of brown trout, *Salvelinus fontinalis*.

Source: Beamish, 1978

Table F.2 **Adjusted mean and mximum velocities (cm s^{-1}) attained per burst from ANCOVA analysis.**

Group	Adjusted V_{mean} Mean	SD	N	Adjusted V_{max} Mean	SD
Wild					
Coldwater River	62.9[a]	6.07	30	102.3	13.87
Morrison Creek	71.8[a]	11.96	28	104.7	12.31
Wade Creek	74.1	7.28	30	104.7	11.18
Laboratory-reared					
Coldwater River	58.8	7.77	29	90.7	10.51
Morrison Creek	66.1	9.26	30	97.9	13.45
Wade Creek	66.1	5.03	30	102.1	16.15

Notes: a = slopes of standard length - velocity not equal between these groups ($p<0.05$)
Underlined mean values differ significantly from each other (ANCOVA, $p<0.05$)

Source: Taylor and McPhail, 1984

Table F.3 Prolonged swimming performance of wild and laboratory-reared juvenile coho salmon

Population	Standard length (cm) Mean	SD	N	Test velocity (cms^{-1})	FT_{50}(min)	SD
Wild-reared						
Coldwater River	4.92	0.134	12		63.5	14.6
Wade Creek	5.07	0.122	11	34.3	28.3	9.1
Coldwater River	4.96	0.162	10		79.9	36.03
Morrison Creek	5.03	0.166	12	34.7	9.2	3.58
Wade Creek	5.13	0.143	12		29.4	3.82
Morrison Creek	5.06	0.198	12	35.4	9.9	4.73
Coldwater River	5.05	0.161	11		79.9	11.46
Morrison Creek	5.22	0.132	11	35.7	16.7	5.16
Wade Creek	5.08	0.218	11	35.5	33.4	7.36
Laboratory-reared						
Coldwater River	5.17	0.202	10		105.9	10.4
Morrison Creek	5.20	0.170	11	36.1	9.1	4.6
Coldwater River	5.38	0.208	10		80.5	10.3
Wade Creek	5.33	0.136	10	37.1	28.5	6.5
Wade Creek	5.18	0.114	10		28.8	10.1
Morrison Creek	5.11	0.127	11	36.1	8.9	5.1
Coldwater River	5.22	0.211	11		104.2	40.8
Wade Creek	5.37	0.221	9	36.7	9.2	3.8
Morrison Creek	5.38	0.208	11	37.5	16.6	5.2

Source: Taylor and McPhail, 1984

Figure F.3 Prolonged swimming speed and temperature.

Source: Beamish, 1978

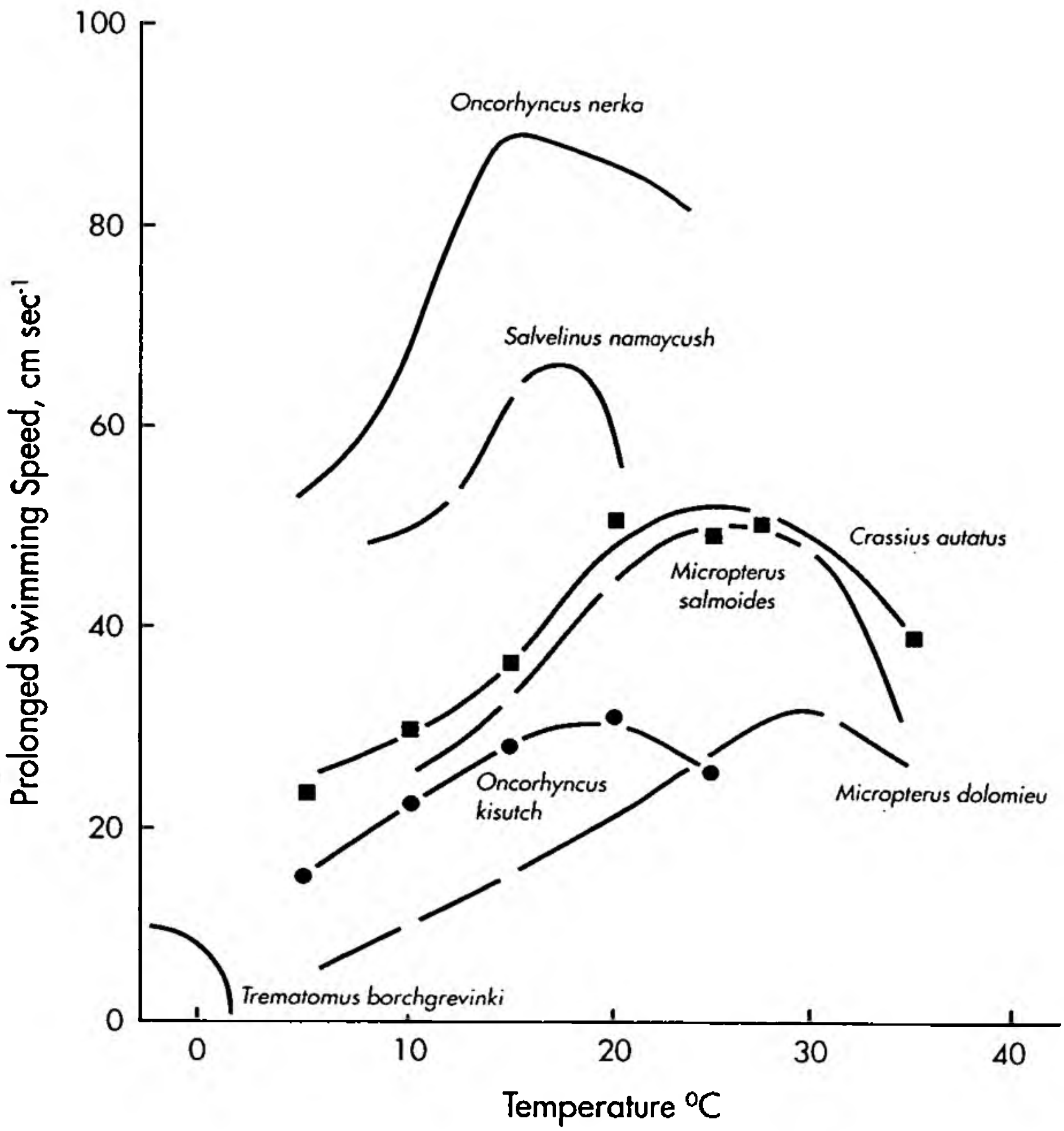


Figure F.4 Swimming speed and ambient oxygen concentration.

Source: Beamish, 1978

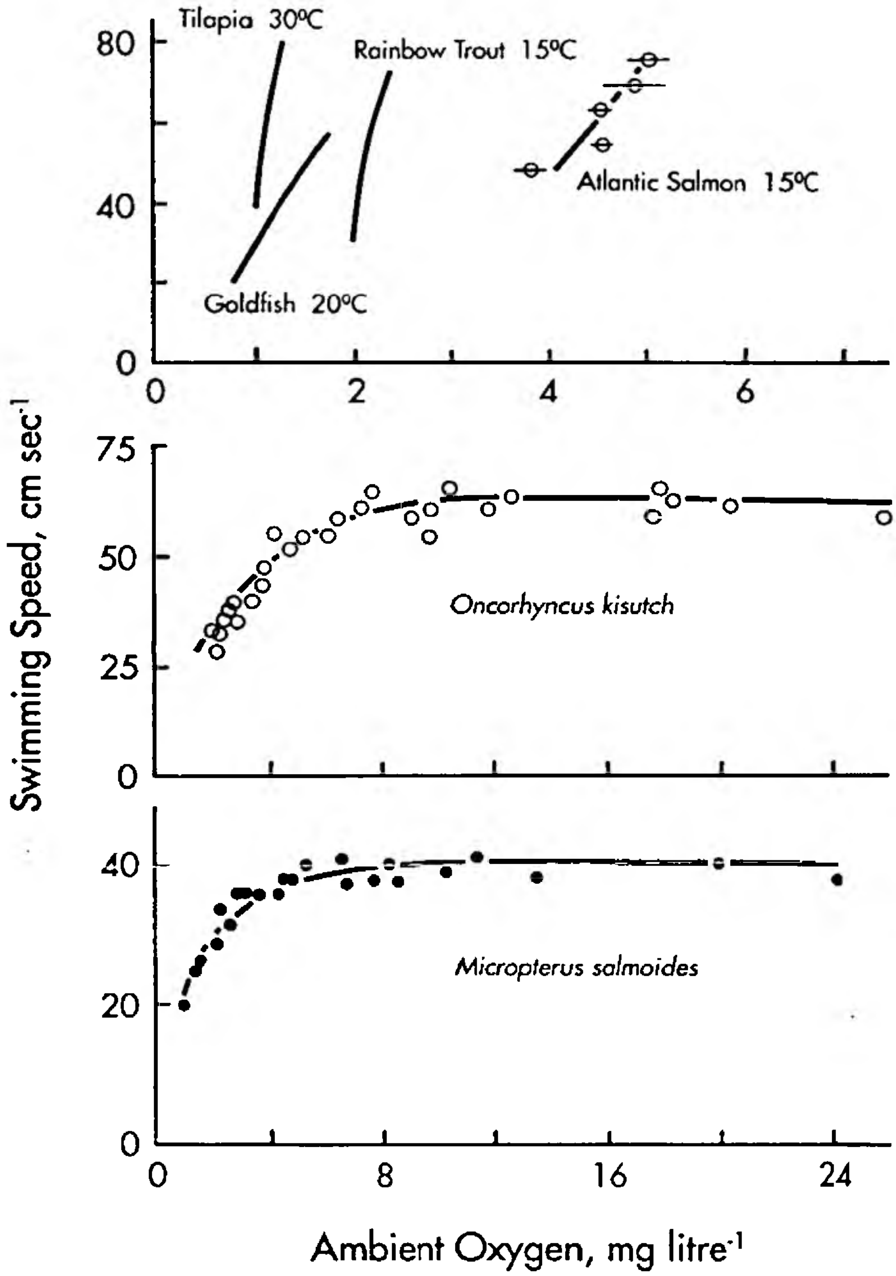


Table F.4 Contaminant concentrations and exposure durations that cause significant changes in swimming behaviour compared with exposures that induce mortality in aquatic organisms

Species Contaminant and reference	Parameter measured*	Behaviour exposure		Lethal exposure	
		µg/l	Duration	µg/l	Duration
Oncorhynchus kisutch					
Fenitrothion (Bull and McInerney, 1974)	FM,SC	480	2 h	1 300	96 h
Kraft mill effluent (Howard, 1975)	SC	3.7-9.0% v/v	18 h	18-45% v/v	96 h
Oncorhynchus mykiss					
Carbaryl	SC	1 000	96 h	1 950	96 h
	A	1 000	96 h	1 950	96 h
Chlordane	SC	>20	96 h	42	96 h
	A	2	96 h	42	96 h
DEF	SC	5	96 h	660	96 h
	A	50	96 h	660	96 h
Pentachlorophenol	SC	>20	96 h	52	96 h
(Little et al, 1989 and Johnson and Finley, 1980)	A	2	96 h	52	96 h
Diquat	R	500	24 h	90 000	24 h
Simazine	R	1 000	24 h	200 000	24 h
(Dodson and Mayfield, 1979)					
Copper pH 6 (Waiwood and Beamish, 1978)	SC	10	96 h	40	96 h
TCDD (Mehrle et al, 1988)	FM	0.000038	27 d	0.00176	21 d
	A	0.000038	19 d	0.00176	21 d
Phenol (Smith and Bailey, 1988)	FM	8 000	7 min	8 900	96 h
Salvelinus fontinalis					
Fenitrothion (Peterson, 1974)	SC	500	24 h	1 500	24 h
Malathion (Post and Leasure, 1974)	SC	40	10 d	120	5 d
Copper sulfate (Drummond, Spoor and Olson, 1973)	A	6-9	2 h	9.5	>161 d
Aluminum pH 5.6 (Cleveland et al 1989)	A,FM	142	30 d	142	30 d
	SC	68	60 d	142	60 d
Carassius auratus					
Parathion (Rand, 1977 and Johnson and Finley, 1980)	FM	330	24 h	1 830	96 h
DDT (Weis and Weis, 1974)	FM	1	3 d	30-100	96 h
Cyprinus carpio					
Distillery effluent (Gill and Toor, 1975)	A	20% v/v	24 h	17.6% v/v	48 h
DDT (Besch et al, 1977)	R	50	3-4 h	57	48 h

cont:

Table F.4 cont.

Species Contaminant and reference	Parameter measured[a]	Behaviour exposure		Lethal exposure	
		µg/l	Duration	µg/l	Duration
Pimephales promelas					
TNT (Smock, Stoneburner and Clark, 1976)	FM,A	460	96 h	2 580	96 h
Ptychocheilus lucius					
Shale oil (Woodward, Little and Smith, 1987)	SC	1 700	96 h	4 200	96 h
Arius felis					
Copper (Steele, 1983)	FM	50	72 h	>200	72 h
Lepomis macrochirus					
Methyl parathion (Henry and Atchison, 1984)	FM	3	10-14 d	4 380	96 h
Cadmium	A	100	3 d	500	14 d
Chromium	A	50	3 d	>24 000	14 d
Zinc (Ellgaard, Tusa and Malizia, 1978)	A	100	3 d	>5 000	14 d
DDT (Ellgaard, Ochsner and Cox, 1977)	A	0.008	8 d	0.2-1.0	96 h
Fluorene (Finger et al, 1985)	SC	1 000	30 d	1 000	30 d
	A	1 000	30 d	1 000	30 d
Micropterus salmoides					
Copper	A	100	6 h	960	48 h
Cadmium	A	100	16 h	1 500	48 h
Phenol	A	1 000	5 h	20 400	48 h
Ammonia	A	500	16 h	16 700	48 h
Cyanide (Morgan, 1979 and Morgan, 1977)	A	50	5 h	100	48 h
Pseudopleuronectes americanus					
Polyoxyethylene monolaurate (Wildish, 1974)	A	1 000	24 h	>10 000	24 h

Notes: [a] A, activity (frequency and duration); FM, form (posture and pattern); SC, swimming capacity; R, rheotaxis.

Source: Little and Finger, 1990

Figure F.5 Effect of contaminants on swimming speed.

Source: Beamish, 1978

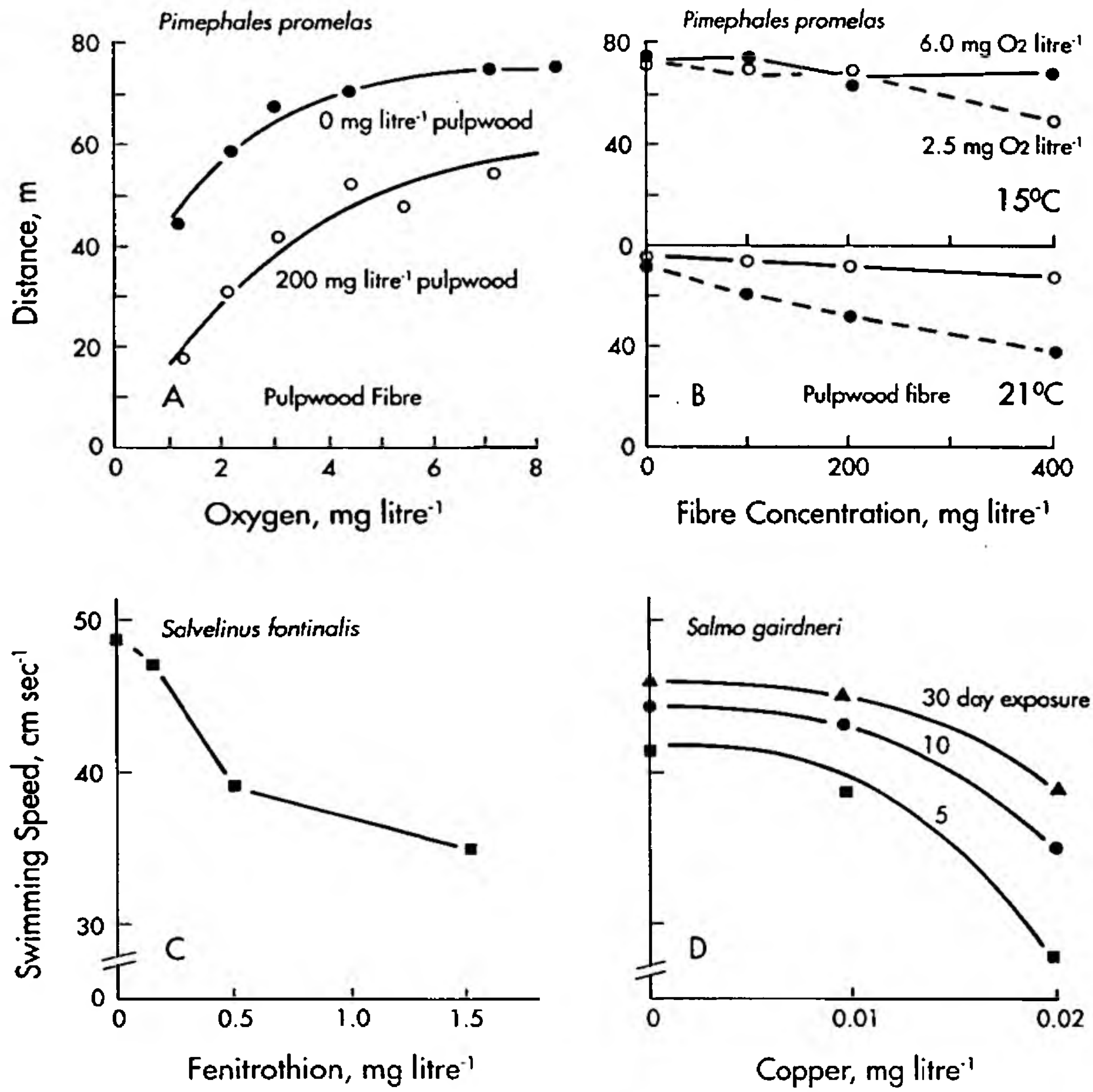


Figure F.6 Relative swimming speeds of adult fish.

Source: Bell, 1986

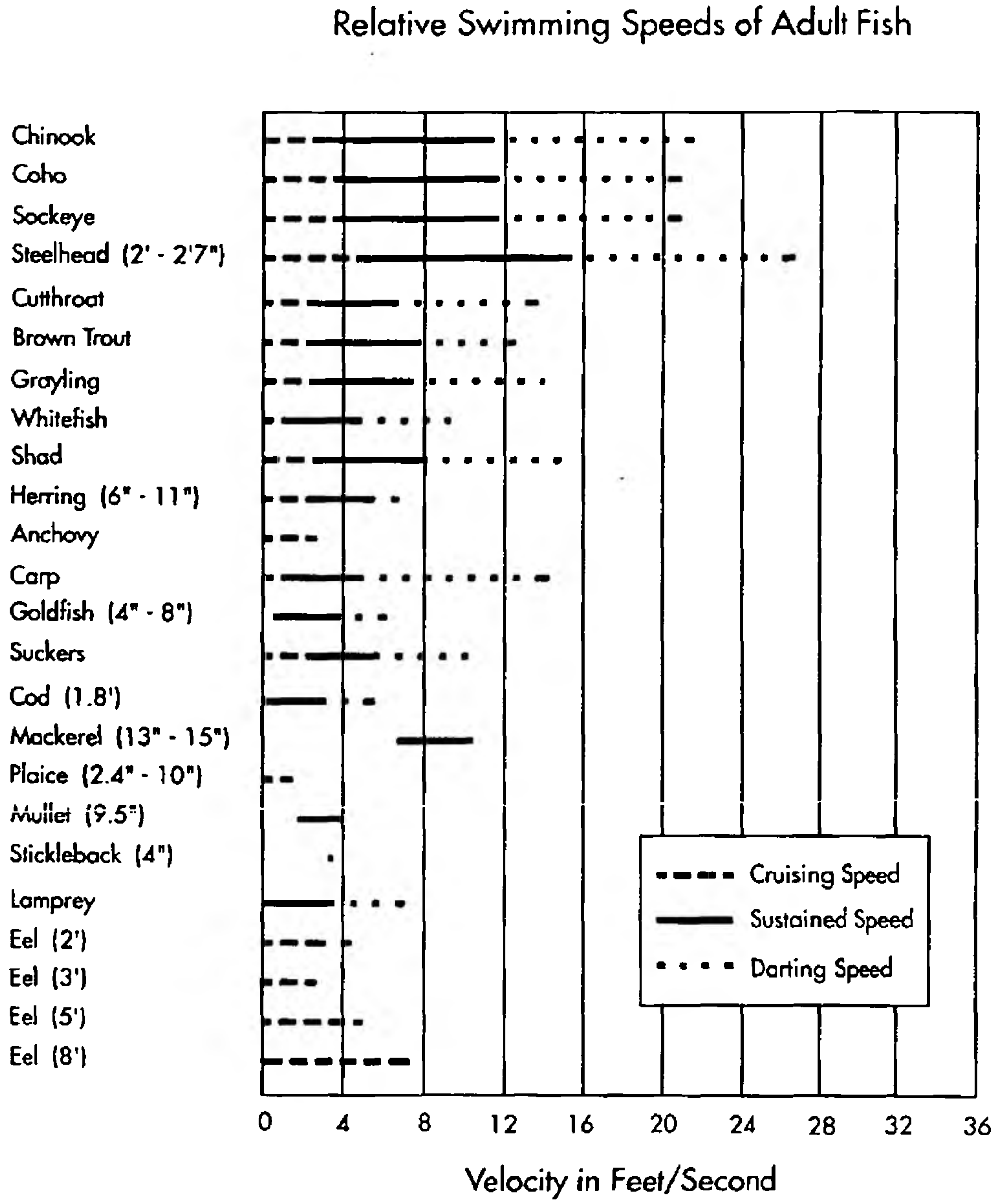


Figure F.7 Relative swimming speeds of young fish.

Source: Bell, 1986

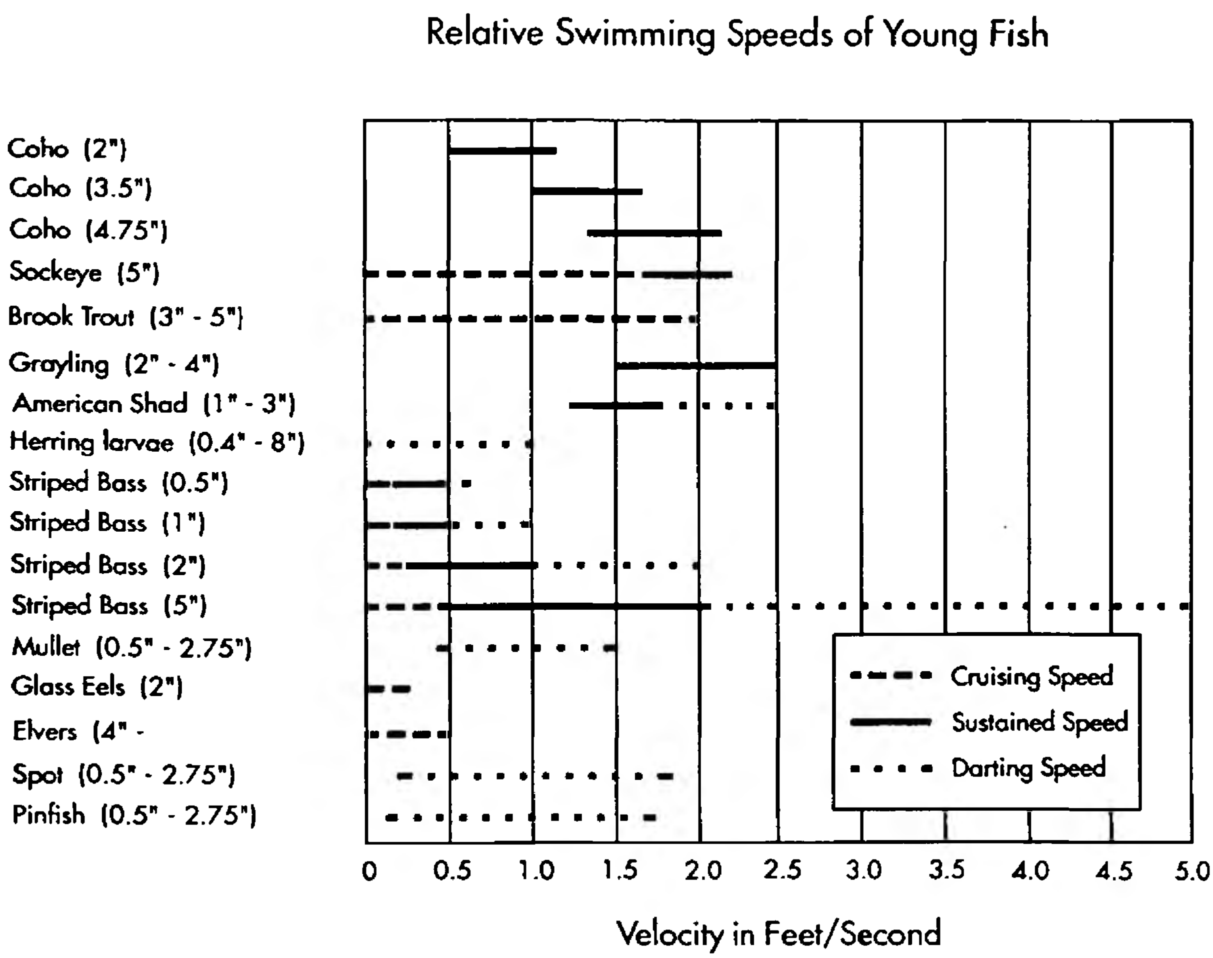


Figure F.8 Relative swimming speeds of MacKenzie River fish.

Source: Bell, 1986

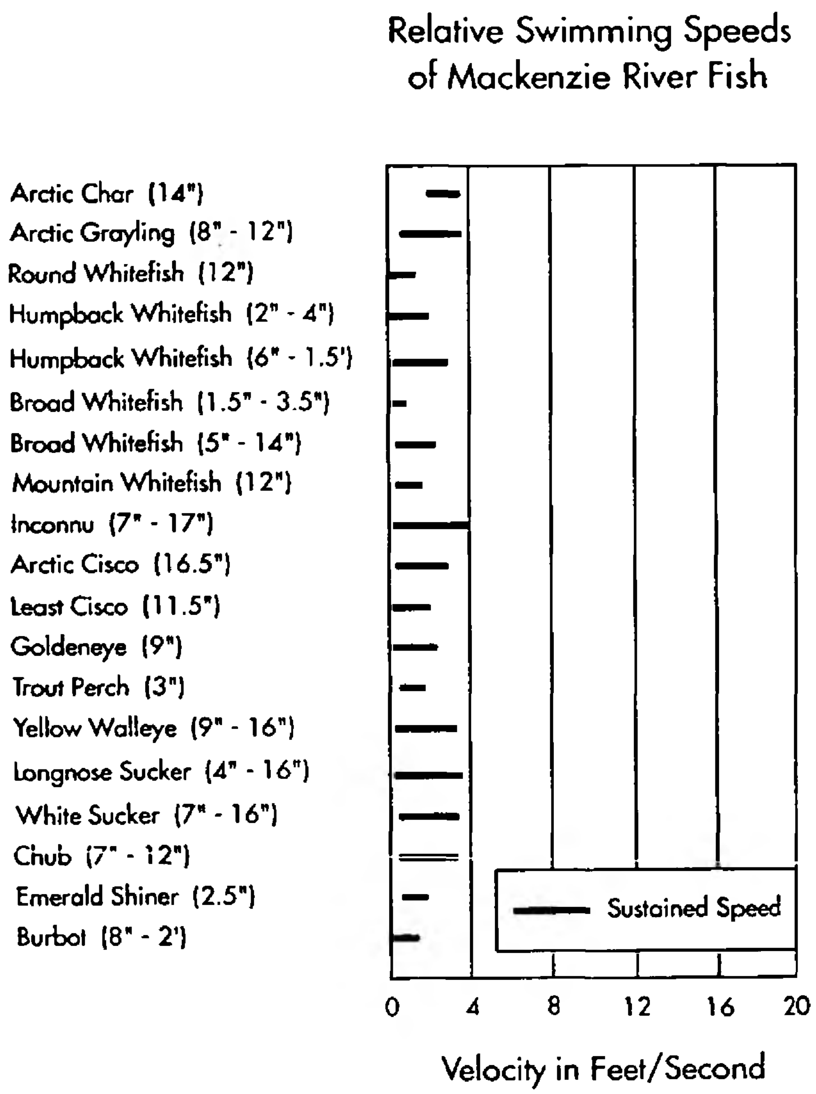


Table F.5. Swimming speeds for fish, identified as important in British waters, taken from the published literature.

Species	Length	Weight	Temp.	Swimming	
				Cruising	Sustained
Salmo salar				44-69cmsec^{-1}	
" "	50-70cm			12-25cmsec^{-1}	
" "	53-87cm			0-17cmsec^{-1} (0-0.2lsec^{-1})	
" "				54cmsec^{-1}	
" "	35cm				
" "					
" "	75-85cm				
" "					
" "	15-20cm		1-14°C		70-100cmsec^{-1} (3-4 lsec^{-1})
" "	23.4cm	110.3g	15°C		50-76cmsec^{-1} (2.1-3.2 lsec^{-1})
" "				4.0 fps (0.2-1.4bls^{-1}) 2bls^{-1}	12.0fps
Salmo trutta				2.2fps	6.2 fps
" "	Adult			0-3fps	3-7fps
" "	13-37cm		10-15°C		
" "	34cm	34.1g			92cmsec^{-1} (2.7 lsec^{-1})
" "	30cm			3 bls^{-1}	
" "				0.2-2.2 bls^{-1} 2.2 fps	6.2 fps

lsec⁻¹ - lengths per second   fps - feet per second   blsec⁻¹ - body lengths per second

Speeds		Comments	Ref.	Original data
Critical	Burst			
			Beamish (1978)	Carlin (1968)
			"	Malinin (1973)
		Max. 104cmsec⁻¹ (1.3 lsec⁻¹)	"	Stasko (1975)
			"	Letovaltseva (1967)
	347cmsec⁻¹		"	Denil (1909)
	300cmsec⁻¹		"	Lavollee (1902)
	429-600cmsec⁻¹ (5.8-8.4 lsec⁻¹)		"	Denil (1937)
	805		"	Lane (1941)
		Salinity 0-30%	"	Byrne et al. (1972)
		O_2 3.8-5.0mg/l	"	Kutty & Saunders (1973)
	23.2fps	Observed max. 26.5fps	Orsborn (1985) Winstone (1985)	Calderwood (1930)
	12.7 fps	Observed max. 12.8fps	Orsborn (1985)	
	7-12.5fps		Bell (1986)	
	137-305 cmsec⁻¹ (8.2-10.5 lsec⁻¹)		Beamish (1978)	Blaxter & Dickson (1959)
			"	Magnan (1929)
			Winstone (1985)	
	12.7fps	River Tywi	Winstone (1985) Orsborn (1985)	

Table F.5 continued.

Species	Length	Weight	Temp.	Swimming	
				Cruising	Sustained
Esox lucius					
" "	16.5cm				210cmsec^{-1} (12.7 lsec^{-1})
" "	37.8cm				148cmsec^{-1} (3.9 lsec^{-1})
" "	12-62cm	7-1800g	12°C		
" "	80cm		0.5°C	5.5cmsec^{-1} (0.8-1.6 lsec^{-1})	
Anguilla anguilla	69-96cm			55-72cmsec^{-1} (0.6-0.9 lsec^{-1}) Mean	
Rutilus rutilus					
Salvelinus alpinus	35.5cm		12°C		
Leuciscus leuciscus	10.0-21.4 cm		14°C		
" "	"		"		
" "	18.2cm				170cmsec^{-1} (9.2 lsec^{-1})
Petromyzon marinus	14.5-39.0 cm	5-100g	5°C		16.6-33.6 cmsec^{-1} (0.9-1.2 lsec^{-1})
" "	"	"	10°C		16.8-34.7 cmsec^{-1} (0.9-1.2 lsec^{-1})
" "	"	"	15°C		24.2-41.3 cmsec^{-1} (1.1-1.7 lsec^{-1})

Speeds		Comments	Ref.	Original data
Critical	Burst			
	360-450 cmsec-1		Beamish (1978)	Stringham (1924)
			"	Gray (1953)
			"	Magnan (1929)
19-47cmsec-1 (0.8-1.6 lsec-1)			"	Jones et al (1974)
		Max. 300cmsec-1 (3.8 lsec-1)	"	Poddubny et al (1970)
		13-173cmsec-1 (0.2-2.0 lsec-1) Range	"	Tesch (1974)
	455cmsec-1		"	Lane (1941)
100.2cmsec-1 (2.8 lsec-1)			"	Jones et al (1974)
	110-240 cmsec-1 (11.0-11.2) lsec-1		"	Bainbridge (1960)
	46-90cmsec-1 (4.2-4.4 lsec-1)		"	"
			"	Gray (1953)
		Endurance	"	Beamish (1974)
		"	"	"
		"	"	"

Table F.5 continued

Species	Length	Weight	Temp.	Swimming	
				Cruising	Sustained
Perca fluviatilis	11.5cm				
Gymnocephalus cernua	10.5cm				
Osmerus eperlanus	15cm			Max speed 0.49ms^{-1}	
Anguilla anguilla	32cm			Max speed 0.72ms^{-1}	

Speeds		Comments	Ref.	Original data
Critical	Burst			
	145cmsec^{-1} (12.6 lsec^{-1})		Beamish (1978)	Komarov (1971)
	133cmsec^{-1} (12.7 lsec^{-1})		"	"
			Sprengel & Luchtenberg (1991)	
			"	

Table F.6 Swimming speeds for non-British fish, taken from the published literature

Species	Length	Weight	Temp.	Swimming	
				Cruising	Sustained
Oncorhynchus tschawytscha				3.4fps	10.8fps
O. keta				1.6fps	5.2fps
O. kisutch				3.4fps	10.6fps
O. gorbuscha				1.8fps	5.6fps
O. nerka				3.2fps	10.2fps
Salmo clarki				2.0fps	6.4fps
O. mykiss				4.6fps	13.7fps
Anguilla australis	55-80 (LCFmm)		17-20°C	0.2ms^{-1}	0.34ms^{-1}
" "	Adult Elver				
Australian elvers					
Galaxias maculatus	52-73 (LCFmm)		17-20°C	0.19ms^{-1}	0.36ms^{-1}
" "					
" "					
Retropinna retropinna	56-67 (LCFmm)		17-20°C	0.19ms^{-1}	0.27ms^{-1}
" "					
Galaxias fasciatu	44-55 (LCFmm)		17-20°C	0.19ms^{-1}	0.29ms^{-1}
" "					

Speeds		Comments	Ref.	Original data
Critical	Burst			
	22.4fps		Orsborn (1985)	
	10.6fps		"	
	21.5fps		"	
	11.3fps		"	
	20.6fps		"	
	13.5fps		"	
	26.5fps		"	
	0.57ms^{-1}		Mitchell (1989)	
	1.26ms^{-1} 0.74ms^{-1}	Max speed (2-5 mins) 0.31ms^{-1} 0.37ms^{-1}	Jowett (1987)	Strickland & Mitchell (1983)
0.75ms^{-1}			Mitchell (1990)	
	0.47ms^{-1}		Mitchell (1989)	
	1.25ms^{-1}	Max speed (2-5 mins) 0.38ms^{-1}	Jowett (1987)	Strickland & Mitchell (1983)
1.25ms^{-1}			Mitchell (1990)	
	0.50ms^{-1}		Mitchell (1989)	
	0.93ms^{-1}	Max speed (2-5 mins) 0.23ms^{-1}	Jowett (1987)	Strickland & Mitchell (1983)
	0.43ms^{-1}		Mitchell (1989)	
	Can climb past high velocity water.	Max speed (2-5 mins) 0.34ms^{-1}	Jowett (1987)	Strickland & Mitchell (1983)

Table F.6 continued

Species	Length	Weight	Temp.	Swimming	
				Cruising	Sustained
Galaxias cotidianus	30-42 (LCFmm)		17-20°C	$0.24ms^{-1}$	$0.28ms^{-1}$
" "					
Mugil cephalus	85-96 (LCFmm)		17-20°C	$0.15ms^{-1}$	$0.19ms^{-1}$
" "					
" "					

Speeds		Comments	Ref.	Original data
Critical	Burst			
	$0.6ms^{-1}$		Mitchell (1989)	
	$1.03ms^{-1}$	Max speed (2-5 mins) $0.29ms^{-1}$	Jowett (1987)	Strickland & Mitchell (1983)
	$0.25ms^{-1}$		Mitchell (1989)	
	$0.28ms^{-1}$	Max speed (2-5 mins) $0.19ms^{-1}$	Jowett (1987)	Strickland & Mitchell (1983)
$0.3ms^{-1}$			Mitchell (1990)	

APPENDIX G - QUESTIONNAIRE SURVEY: Questionnaire and tables

Questionnaire on potential barriers to migrating fish and the effectiveness of fish passes.

This questionnaire has been compiled with the aim of collating and evaluating information on existing and proposed fish passes in the U.K. To make this study as comprehensive as possible would you please give as many details as possible for each question and attach extra sheets of data if necessary. Please answer all questions. If there is no data available please answer to that effect.

Please use one form per obstruction.

BARRIER DATA

1. Location and nature of barrier. (e.g. dam, weir, diversion, intake, lock, tide gate). For location please give NRA region or equivalent, river and site name.

2. Head loss at site (metres).

RIVER DATA

3. River flow and level frequency data (especially data for low flow years).

4. Water temperature statistics. Please indicate what data is available and give minimum and maximum figures for each month.

5. **Water pH and any quality data available. Please give details.**

6. **Debris problems. (extent/timing of likely debris e.g. weed cuts, trees, gravel, ice, leaves etc.)**

7. **Means of excluding debris. If gratings are used please give size of openings.**

8. **Fish species. List those species that are or were important with details of size, numbers and time of year expected. Is there a need to discourage some species. (e.g. coarse fish)?**

FISHPASS DATA

9. **Type of fishpass in operation. (e.g. pool-and-weir, denil, vertical slot, combination or any other). Please be as specific as possible. Give constuction date and details of any modifications.**

10. **Water velocity and/or discharge through the fishpass. Please give minimum, maximum and normal range. (m/s or m^3/s).**

11. Physical dimensions of fishpass. These will vary depending on type of fishpass but should include some of the following. Length, width and depth of pools, drop between pools, slope, number and size of baffles, width and number of slots, number of pools.

12. Entrance and exit. Means of attraction and its effectiveness, i.e. is the entrance always accessible?

13. Transit time of fish through fishpass.

14. Effectiveness of fishpass. Please give details of any monitoring or studies conducted into its use - published or unpublished.

15. Downstream movement of fish. Any provisions and if so how effective? Please report any problems and/or solutions at water supply intakes.

16. Cost of fishpass construction (capital, maintenance and operational). Please give actual figures or as % of total cost of barrier. Give date if not current costing.

17. Construction details.
(Materials/methods/configurations/durability/construction time). Please send copy of blueprint plans if available.

18. Was any temporary provision made for fish passage during construction of barrier? If yes please give details.

19. Please give any further details or comments that will contribute to this study.

Thank you for your cooperation.

Table G.1 Pool and weir fish passes. Results of questionnaire survey
N/A = data not available N/D = no data given (no response to questions)

No.	Location	Head Loss	Flow Data	Temperature (degrees C)
1	Chippenham Weir Wessex	3m	Detailed information for 1986-91 and 1975-76. See Flow Data 1	Data for 1986-91 supplied. See Table A Min.2. Max.21
2	Keynsham Weir Wessex	2m	Detailed information for 1986-91 and 1975-76. See Flow Data 2	Data for 1986-91 supplied. See Table B Min.1. Max.20.
3	Albert Mill Wessex	1.8m	Detailed information for 1986-91 and 1975-76. See Flow Data 3	Data for 1986-91 supplied. See Table C Min.4. Max.19.
4	Seagry Weir Wessex	1.5m	Detailed information for 1986-91 and 1975-76. See Flow Data 4	Data for 1986-91 supplied. See Table D Min.3. Max.19.
5	Avon Weir Wessex	1m	Detailed information for 1986-91 and 1975-76. See Flow Data 4	Data for 1986-91 supplied. See Table D Min.3. Max.19.
6	Twerton Weir Wessex	2.5m	Detailed information for 1986-91 and 1975-76. See Flow Data 5	Data for 1986-91 supplied. See Table E Min.2. Max.20.
7	Melksham Weir Wessex	3m	Detailed information for 1986-91 and 1975-76. See Flow Data 6	Data for 1986-91 supplied. See Table F Min.1. Max.20.

pH	Water Quality	Debris	Fish Species
Data for 1986-91 supplied. See Table A. Range 7- 9. Mean 7.96	Extensive range of determinands available on computer archive.	No obvious problems other than flood related branches. Boom across radial gate to protect this. No other means of excluding debris.	No known migratory salmonids. Coarse fish and some brown trout. Eels seen to move up.
Data for 1986-91 supplied. See Table B. Range 7-9.2. Mean 7.93	Extensive range of determinands available on computer archive.	No obvious problems other than flood related branches etc. Occasional pallets or larger items. 2 vertical support pillars for pass spaced approx. 1m apart have some effect.	Designed primarily for sea trout. Recently installed trap catching chub up to 30cm, possibly associated with spawning movements.
Data for 1986-91 supplied. See Table C. Range 7.4-9.0. Mean 7.96	Extensive range of determinands available on computer archive.	No obvious problems other than flood related branches etc. No means of excluding debris.	Built in 1988 with a view to sea trout rehabilitation. No information on effectiveness.
Data for 1986-91 supplied. See Table D. Range 7.2-8.4. Mean 7.91	Extensive range of determinands available on computer archive.	No obvious problems other than flood related branches etc. No means of excluding debris.	No known migratory salmonids. Coarse fish and some brown trout.
Data for 1986-91 supplied. See Table D. Range 7.2-8.4. Mean 7.91	Extensive range of determinands available on computer archive.	No obvious problems other than flood related branches etc. No means of excluding debris.	No known migratory salmonids. Coarse fish and some brown trout.
Data for 1986-91 supplied. See Table E. Range 7.3-8.9. Mean 8.0	Extensive range of determinands available on computer archive.	In floods large amount of debris comes down river especially in autumn which accumulates behind floating boom. Grid on fishpass 1.5 inch spacings,with opening of 2 feet on upper portion of grating.	Some evidence that sea trout may use this part of the river. Coarse fish and some trout present.
Data for 1986-91 supplied. See Table F. Range 7.5-8.3 Mean 7.94	Extensive range of determinands available on computer archive.	No obvious problems other than branches etc. in flood events.	No known migratory salmonids in this section of river. Some evidence of sea trout and occassional stray salmon in lower river. Coarse fish and some brown trout present.

Fish Pass Details					
Flow	Pool Size	Pool Depth	Drop	No.Pools	Additional Data
N/A	2.5mx1.5m	N/D	0.33m	5 + holding pool	See Diagram 1
N/A	3mx1.5m	1.26m	N/D	4	Width of traverse opening 0.6m. See Diagram 2
N/A	3mx?	N/D	N/D	3	Notch in weir 600mmx300mm. See Plan 3.
N/A	2mx2m 2.5mx3m 3mx3m	0.33m	0.18 - 0.30m	4	See Diagram 4
N/A	2mx2m 2.5mx3m	0.75m	0.30m	2	See Diagram 5
N/A	3.0mx1.3m	1m	0.35m	5	See Diagram 6
N/A	1.5mx1.5m	1m	0.30m	4	

Entrance/Exit	Maintenance/Construction	Comments
Submerged piling directs flow to an extent 45 degrees to form attraction zone in front of weir	No known data on costs or construction	See:Flow Data 1 Table A Diagram 1
Entrance always accessible, attraction by angled entrance towards centre of weir. Probably not 100% effective	Construction cost approx. £70,000 in 1987. No information available on construction	See:Flow Data 2 Table B Diagram 2
Entrance always accessible.	£2,000 paid for materials in 1988. Labour costs unknown-absorbed by mill refurbishment company. No information available on construction.	See:Flow Data 3 Table C Plan 3
Entrance always accessible. Attraction appears spread across river.	No known details of costs or construction.	See:Flow Data 4 Table D Diagram 4
Entrance always accessible. Flow through fish pass quite attractive although radial gate will also attract fish and at times will have the major flow.	No known details of costs or construction.	See:Flow Data 4 Table D Diagram 5
Outflow of water at 90 degrees to radial gate. Entrance always accessible. Major attraction from overspill gate is at opposite side of river.	No details given of cost or construction.	See:Flow Data 6 Table E Diagram 5
Attracted by flow of weir. In times of low flow and also with radial gate present effectiveness of pass attraction could be low.	No known details except of concrete construction.	See:Flow Data 6 Table F

Table G.1 cont.

No.	Location	Head Loss	Flow Data	Temperature (degrees C)
8	Pulteney Weir Wessex	1.5m	Detailed information for 1986-91 and 1975-76. See Flow Data 8	Data for 1986-91 supplied. See Table E. Min.2. Max.20
10	Newbridge Sluice Wessex	0.5-1.5m depending on state of tide	Discharge frequency for River Tone at Bishops Hull available for 1962-87. See Flow Data 10	Monthly average figures 1985-90 Jan6.7 Jul17.0 Feb7.1 Aug17.6 Mar7.9 Sep14.2 Apr9.4 Oct11.1 May12.6 Nov7.7 Jun16.4 Dec9.2
11	Firepool Weir Wessex	1.9m	Same information as at Newbridge Sluice. See Flow Data 10	As above
12	Ham Weir Wessex	1m	Same information as at Newbridge Sluice. See Flow Data 10	As above
13	French Weir Wessex	1.8m	Same information as at Newbridge Sluice. See Flow Data 10	As above
14	Great Weir Wessex	1.4m	Mean monthly flows in cumecs for 1990 Jan 28.8, Feb 61.11, Mar 34.96, Apr 20.3, May 12.36, Jun 9.62, Jul 6.5, Aug 5.3, Sept 5.5, Oct 9.1, Nov 7.7, Dec N/A	20 readings for 1990-91. See Table H
15	Salisbury Generating Station Wessex	See Plan 15	Mean monthly flows in cumecs 1990 at East Mills Jan 17.96, Feb 51.14, Mar 24.66, Apr 14.41, May 10.24, Jun 9.16, Jul 6.43, Aug 4.13, Sept 4.04, Oct 4.95, Nov 5.01, Dec 5.76	As above

pH	Water Quality	Debris	Fish Species
Data for 1986-91 supplied. See Table E. Range 7.3-8.9. Mean 8.0	Extensive range of determinands available on computer archive	No problems. No means of excluding debris.	Pass may be used by sea trout which occasionally get caught.
N/D	N/D	Debris during winter months has often been removed upstream. The main problem can be that of 'cut weed' during Jul-Sept. No means of exclusion although pass located at end of weir which aids clearance.	Salmon and sea trout. Judged to be effective as fish regularly pass through this structure.
N/D	N/D	Mainly trees and branches Oct-March. No means of exclusion.	Salmon and trout. Work done during 1958-60 established that salmon do gain access through pass. Subsequent observations confirm this.
N/D	N/D	As above, but pass located adjacent to one bank.	Salmon and trout known to use this pass with success.
N/D	N/D	Mainly trees and branches Oct-March. No means of exclusion.	Salmon and sea trout Aug-Oct. Work undertaken in 1958-60 and subsequent observation indicate that pass is used successfully.
7-8	Class 1A	No problems and no means of exclusion.	Installed for migratory salmonids, no need to discourage any species. Fish regularly observed ascending pass.
7-8	Class 1A	As above	As above

Fish Pass Details					
Flow	Pool Size	Pool Depth	Drop	No. Pools	Additional Data
N/A	N/D	1m	N/D	2	Weirs have 1m wide traverses. See diagram 8
N/D	3.4mx2.24m	1.3m	0.2m-0.4m depending on tide	4	
N/D	2mx2.5m	1.3m	0.38m can be adjusted by boards to provide less turbulent flows	5	
N/D	4.4mx3.0m	N/D	0.3m can be adjusted to provide the least turbulent conditions	3	
N/D	3mx2.4m	1.4m	0.5m	4	Opening to each pool 1.2mx0.45m for fish to enter
unknown	Full details given on Plan 14				
unknown	Full details given on Plan 15				

Entrance/Exit	Maintenance/Construction	Comments
Entrance is in centre of crescent shaped weir, attraction in centre of white water.	No known details	See: Flow data 8 Table E Diagram 8
Entrance always accessible	No cost details known. Constructed of 0.3m reinforced concrete.	See: Flow data 10
Entrance always accessible	Cost £1,010 (1957). Modification costs in 1968 not identified. Constructed of 0.3m reinforced concrete.	Constructed June-Oct. 1957. Modified in 1968 to provide less turbulent flow conditions.
Entrance always accessible. Adjustable boards.	No cost details available. Constructed of 0.3m reinforced concrete.	Constructed 1968.
Entrance always accessible with adjustable boards.	Cost £1,010 (1957). Modification costs not identified. Constructed of 0.3m reinforced concrete.	Constructed June-Oct. 1957 and modified in 1968 to provide less turbulent flow.
Entrance always accessible.	Constructed in 1978 see Plan 14 for construction details.	See:Plan 14 Table H
Entrance always accessible.	Constructed in 1981 see Plan 15 for construction details.	See:Plan 15 Table H

Table G.1 cont.

No.	Location	Head Loss	Flow Data	Temperature (degrees C)
16	Standlynch Weir Wessex	See Plan 16	As for Salisbury Generating Station - see above	As above
17	Wild Weirs Wessex	0.6m	As for Salisbury Generating Station - see above	As above
18	Bickton Mill	2.3m	As for Salisbury Generating Station - see above	As above
19	Bickton Weir Wessex	See plan 19	As for Salisbury Generating Station - see above	As above
28	Carreghofa Weir Severn Trent	2.9m	Mean flow (long term to 1989)=478mld. Dry weather flow=54mld. Minimum flow=11mld. Detailed hydrometric records available.	1988-89 Min-5 Max-14 Mean-9
29	Castle Weir Severn Trent	2m	1988-89 Mean flow=4048mld. Dry weather flow=423mld. Minimum flow=91mld. Detailed hydrometric records available.	1988-89 Min-3 Max-20 Mean-11 Detailed records available.
30	Horstead Mill Anglian	1.5m	Data available but not supplied.	Data available but not supplied.
32	Sunderland Road Bridge Northumbria (weir/bridge footing)	N/D	N/D	N/D
33	Witton Park Northumbria (weir/ford)	N/D	N/D	N/D
34	Brownie S.T.W. Northumbria	N/D	N/D	N/D

pH	Water Quality	Debris	Fish Species
7-8	Class 1A	As above	As above
7-8	Class 1A or 1B	As above	As above
7-8	Class 1A	Prone to infrequent blockage by weed and other debris through summer months	As above
7-8	Class 1A	No problems and no means of exclusion	As above
1988-89 Min-6.8 Max-7.5 Mean-7.2	Data available on BOD, TOC, SS, NH_3, TON, conductivity, hardness, phosphate, DO and metals	Occasional tree debris removal required. No means of exclusion	Salmon - approx. 500-1000pa mostly Sept-Dec. Works well since 1983 modification. Pass is only means of access to important spawning tributary which supports up to 2000 spawning salmon per year
1988-89 Min-6.5 Max-8.4 Mean-7.3	As above	Occasional clear out of large floating debris required. No mean of exclusion	Salmon - main runs April-June and Sept-Nov. Mean numbers:2500. Min:1000, Max:5000. Very effective pass. Rod catches upstream have increased from 15% to 50% of total R.Severn salmon catch. Electronic counter.
Comprehensive data available but not supplied		N/D	Coarse fish and occasional sea trout. Effectiveness unknown.
N/D	N/D	N/D	Salmon, sea trout, brown trout and coarse species.
N/D	N/D	N/D	Salmon, sea trout, brown trout and coarse species.
N/D	N/D	N/D	Sea trout, brown trout.

Fish Pass Details					
Flow	Pool Size	Pool Depth	Drop	No. Pools	Additional Data
	Full details given on Plan 16				
unknown	Full details given on Plan 17				Tilting gates
unknown	Full details given on Plan 18				
unknown	Full details given on Plan 19				Notched weirs
N/A	Full details including modifications given on Plan 28				
N/A	Full details given on Plan 29			7	
Data available but not supplied	N/D	N/D	N/D	N/D	
N/D	N/D	N/D	N/D	N/D	
N/D	N/D	N/D	N/D	N/D	
N/D	N/D	N/D	N/D	N/D	

Entrance/Exit	Maintenance/Construction	Comments
Entrance always accessible.	Constructed 1987 see Plan 16 for construction details.	See:Plan 16 Table H
Entrance always accessible.	No information available on costs or construction.	See:Plan 17
Entrance always accessible.	Constructed 1978, see Plan 18 for details. Replaced existing fish pass - no indication as to why this was necessary.	See:Plan 18
Entrance always accessible.	Constructed 1987. For construction details see Plan 19.	See: Plan 19
Entrance modified in 1983 to reduce height of entrance and relocate it into main flow, downstream of the weir. Pass is always accessible but the river is primarily a spawning tributary with few salmon running before autumn.	Estimated cost £30,000 in 1976. Built in dry, adjacent to weir. Concrete structure. Construction time: approx. 2 months.	Originally constructed 1976. 2 additional pools/weirs added at downstream end in 1983. See: Plan 29
Fish readily find entrance.	Construction cost £60,000 in 1976. Maintenance cost £500 pa. Sheet piles/concrete construction. Construction time: approx. 3 months	See:Plan 29
Entrance always accessible.	Constructed circa 1960-1965. Costs unknown.	No further information given but contact given for further details (Dr J. Wortley).
N/D	Constructed 1991.	
N/D	Constructed 1989.	
N/D	N/D	

Table G.1 cont.

No.	Location	Head Loss	Flow Data	Temperature (degrees C)
35	Washerley Burn Northumbria	N/D	N/D	N/D
36	Swinhope Burn Northumbria	N/D	N/D	N/D
37	Staindrop Mill Dam Northumbria	2m	N/D	N/D
40	Tongland Dam Dumfries and Galloway Region	3.048m	Average flow = 31.8 m^3/s Minimum flow = 3.9 m^3/s Maximum flow = 308.0 m^3/s River flow controlled from barrage at Glenlochar.	Daily water temperature available for four year period 1979-82. See Table 10.
41	River Ayr Weir Clyde River Purification Board	N/A	Data available from Clyde RPB gauging station - none supplied	Monthly data available for at least 20 years. None supplied
42	Earlstoun Dam Dumfries and Galloway Region	2.134m	Maximum river flow dependent on discharge from Carsfad Power Station, fish pass release from Carsfad, inflow from Polharrow Burn and spillage and needle valve losses from Carsfad Dam.	N/A
43	Carsfad Dam Dumfries and Galloway Region	2.134m	Maximum river flow to Carsfad dependent on discharge from Kendoon Power Station, inflow from Polmaddy Burn and spillage and needle valve losses from Ken & Deugh Dams.	N/A

pH	Water Quality	Debris	Fish Species
N/D	N/D	N/D	Sea trout, brown trout.
N/D	N/D	N/D	Sea trout, brown trout.
N/D	N/D	N/D	Sea trout, salmon and brown trout.
N/A	N/A	Branches and twigs occasionally block orifices. Regular checking and clearing carried out. In extreme cold weather conditions ice forms but no significant problems experienced. No means of excluding debris.	Salmon 12-14 lb July-Sept. A few sea trout. No apparent need to discourage coarse fish. Salmon up / Kelts down 1986 1140 302 1987 2232 480 1988 3030 831 1989 2985 1228 1990 1636 550
Monthly pH data available for at least 20 years. None supplied.	Monthly water quality data available for at least 20 years. None supplied.	N/A	Salmon and sea trout.
N/A	N/A	Occasional problems with branches and twigs blocking orifices. Regular checking and clearing. In extreme cold ice forms but no significant problems. No means of excluding debris.	Salmon 12-14 lb July-Sept. No numbers available. No apparent need to discourage coarse fish. Pass very effective.
N/A	N/A	As above	As above

Fish Pass Details					
Flow	Pool Size	Pool Depth	Drop	No. Pools	Additional Data
N/D	N/D	N/D	N/D	N/D	
N/D	N/D	N/D	N/D	N/D	
N/D	N/D	N/D	N/D	N/D	
Normal $0.37m^3/s$ Min.$0.26m^3/s$ Max.$0.63m^3/s$	16' x 10'	4' 6"	2' 3"	27 plus 3 resting pools 70' x 25'	Total length fish pass = 700', gradient 1:10
N/A	N/A	N/A	N/A	N/A	
Normal $0.538m^3/s$ Min$0.510m^3/s$ Max$0.566m^3/s$	15' x 10'		2'	34 plus 3 resting pools, largest 70'x30'	Total length 700', gradient 1:11
Normal $0.453m^3/s$ Min$0.396m^3/s$ Max$0.510m^3/s$	15' x 9'		2'	33 plus 3 resting pools, largest 125'x30'	Total length 850', gradient 1:15

Entrance/Exit	Maintenance/Construction	Comments
N/D	Constructed 1988.	
N/D	N/D	
N/D	Concrete constructions.	
3 intake/exits are provided through dam (2'6" square) difference in level between each is 4' and reservoir provided for a drawdown of 10'. To allow for this 10' rise and fall automatic electrical control gates have been fitted to ensure accessibility at all dam working levels.	Capital cost (1935) = £11,000. 8.1% of total dam cost. Maintenance cost approx. £3,000 (1991). Operational cost is £2,000 (1991). Pools constructed using reinforced concrete. Class 'O' on base, class 'M' on walls.	Originally designed in 1930/35 to use submerged orifices. Although fish used the pass improvements were made to it and it was changed to overfall type.
N/A	Constructed 1990. Further information on pass construction available from: Catrine Whisky Bond, Catrine, Ayrshire.	
2 exits/entrances through dam measuring 2'6" square. 7 foot rise and fall - provided with automatic gates which ensure accessibility at all times.	Constructed 1930/35 at capital cost of £8,500, at 12.3% of total cost of dam. Maintenance cost approx. £3,000 (1991). Operational cost approx. £2,000 (1991). Pools constructed of reinforced concrete. Class 'O' on base, class 'M' on walls.	
As above.	Constructed 1930/35 at capital cost of £6,000, 5.4% of total cost of dam. Other details as above.	

Table G.1 cont.

No.	Location	Head Loss	Flow Data	Temperature (degrees C)
44	Loch Doon Dam Strathclyde Region	12.192m	Inflow from Loch Doon via Galla & Eglin Lanes and from Garpel Burn also inflow from indirect catchment of Deugh and Bow Burn.	Monthly readings from site below dam available but not supplied.
45	Thwaite Mills Yorkshire	1.1m	N/D	N/D
46	England Mills Yorkshire	N/D	N/D	N/D

pH	Water Quality	Debris	Fish Species
Monthly readings from site below dam available but not supplied.	Monthly readings from site below dam available but not supplied	No debris problems. In extreme cold ice forms but no significant problems. No means of excluding debris.	Salmon 12-14 lb Salmon up Kelts down 1987 26 11 1988 261 130 1989 185 44 1990 368 74
N/D	N/D	N/D	N/D
N/D	N/D	N/D	N/D

Fish Pass Details					
Flow	Pool Size	Pool Depth	Drop	No. Pools	Additional Data
Normal 0.453m^3/s Min0.396m^3/s Max0.510m^3/s	14' x 8'		2'	Ladder 6 + 2 resting pools. Circular tower 15.	Fish ladder below dam communicates with circular tower on upstream side of dam. Every second pool in tower has opening to dam.
N/D	3m long	1.2m	0.38m	3	Notches 0.6m x 0.25m. Full details given on Plan 45.
N/D	Full details given on Plan 46.				

Entrance/Exit	Maintenance/Construction	Comments
Entrance/exit 1'6" x 2'11". Hand operated control sluice operated from top of tower. Sluices give submerged access to ladder. Only one sluice opened at a time.	Capital cost £6,000 (1936) 7.5% of total dam cost. Maintenance and operational costs - as above. Reinforced concrete.	See Plan 44
N/D	N/D	See Plan 45. See: Reports/Memos 45. Information extracted from correspondence files. No questionnaire was filled in.
N/D	N/D	See Plan 46. See: Reports/Memos 46. Information extracted from correspondence files. No questionnaire was filled in.

Table G.2 Denil fish passes. Results of questionnaire survey

N/A = data not available N/D = no data given (no response to questions)

No.	Location	Head Loss	Flow Data	Temperature (degrees C)
9	Keynsham Park Weir Wessex	2m	Detailed information for 1986-91 and 1975-76. See Flow Data 3.	Data for 1986-91 supplied. See Table C. Min.4. Max 19.
20	Standlynch Mill Wessex	See Plan 20	Mean monthly flows in cumecs for 1990 at East Mills. Jan 17.958, Feb 51.141, Mar 24.660, Apr 14.41, May 10.243, Jun 9.167, Jul 6.434, Aug 4.125, Sept 4.044, Oct 4.946, Nov 5.010, Dec 5.758.	20 readings for 1990-91. See Table H.
21	Hum Weir Wessex	1m	Means monthly flows in cumecs for 1990 at Hum Court. Jan 3.418, Feb 7.982, Mar 2.142, Apr 1.306, May 0.758, Jun 0.550, Jul 0.364, Aug 0.337, Sept 0.347, Oct 0.654, Nov 0.773, Dec 1.026.	Data supplied for 1990-91. Range 3-19. See Table I.
22	Longaller Weir Wessex	2.86m	Discharge frequency for River Tone at Bishops Hull available for 1962-1987. See Flow Data 10.	Monthly averages for 1985-1990 Jan 6.7 Feb 7.1 Mar 7.9 Apr 9.4 May 12.6 Jun16.4 Jul 17.0 Aug17.6 Sept14.2 Oct11.1 Nov 7.7 Dec 9.2?
23	Washford River - upstream pass Wessex	1.06m	3 year discharge frequency (1985-87) River Washford at Beggearn Huish. See Flow Data 23.	N/D
24	Washford River - downstream pass Wessex	1.7m	As above.	N/D

pH	Water Quality	Debris	Fish Species
Data for 1986-91 supplied. See Table C. Range 7.4-9.0. Mean 7.96	Extensive range of determinands available on computer archive.	No problems yet encountered. No means of exclusion.	Installed for sea trout. No data on size of any run. There is seasonal migration of roach from main river, not yet known if they will use pass.
7 - 8	Class 1A	No problems. No means of exclusion.	Pass designed for migratory salmonids. No need to discourage any species.
7 - 8 See Table 9	DO, BOD and NH_3 data available. See Table 9.	N/D	Weir is major obstruction to dace (60-23mm) in autumn when large numbers enter Moors River. Salmon and migratory trout can ascend weir without much difficulty.
N/D	N/D	Problem from Oct-Mar. Pass located on inside of bend so much debris excluded from entering pass.	Salmon and sea trout - numbers not yet known. Run Aug-Oct. Pass to be monitored in 1991 - fish have been seen attempting to pass.
N/D	N/D	Problem during winter months - channel quite narrow & weir located in centre of channel. No means of excluding debris - but cleared regularly.	Sea trout upstream migration. Very effective pass - many fish electrofished upstream.
N/D	N/D	Not as much a problem as upstream pass - see above.	Sea trout. Very effective.

B - total width of baffle   Y - height of baffle   b - clear width of baffle

Fish Pass Details				
Flow	No. baffles	Size of baffles	Slope	Additional Data
Q 95% = 0.314 m^3/s		B = 910 mm Y = 920 mm b = 530 mm Angle = 45°		For full details see Plan 9
See Plan 20	14	B = 680 mm Y = 1110 mm b = 410 mm Angle = 45°	1 : 5	For full details see Plan 20
0.76 m/s		B = 780 mm Y = 475 mm b = 500 mm Angle = 30°		For full details see Plan 21
Q 95% = 0.63 m^3/s	15	B = 910 mm b = 530 mm Angle = 45° 0.6 m between baffles		Length = 9 m. Discharges into concrete pool 3 m x 1.5 m with min. depth of 1.2 m. Full details see Plan 22
Variable	14	B = 570 mm Y = 1070 mm b = 330 mm Angle = 45° 0.38 m between baffles	1 : 5	Length 5.21 m Full details see Plan 23
Variable	23	As above	1 : 5	Length = 8.5 m Full details see Plan 24

Entrance/Exit	Maintenance/Construction	Comments
Entrance always accessible, angled to create attraction zone in white water to front of weir.	Approx. cost £35,000 in 1990. Construction: river passed down through sluices. Weir left dry and sheet piling (cofferdam) placed in river. Prefabricated Denil brought to site.	See: Flow Data 3 Table C Plan 9
Entrance always accessible.	Baffles of 12 mm glass reinforced plastic. No cost details but construction information on Plan 20. Constructed 1987.	See: Table H Plan 20
Entrance will always be submerged and is located in the centre of the structure.	Cost estimated at £27,000. Due to be constructed summer 1991.	Report entitled - Appraisal report on improvements to facilitate the upstream migration of dace, contains much information with cost comparisons for other types of solution to the problem. See: Table I, Plan 21, Report.
Entrance open at all times. Attraction by discharge from pool across base of weir.	Installed in existing weir July 1990 - cost £27,000. Steel galvanised prefabricated pass in reinforced concrete channel.	See: Flow Data 10 Plan 22
Pass located in centre of weir and takes all flow for most of the year.	Constructed in 1989 - cost £12,000. Steel galvanised in sections and erected on site.	See: Flow Data 23 Plan 23
As above.	Constructed in 1989 - cost £13,000. Others details as above.	See: Flow Data 23 Plan 24

Table G.2 cont.

No.	Location	Head Loss	Flow Data	Temperature (degrees C)
25	Powick Weir Severn Trent	1.3m	Mean flow = 1114 mld Dry weather flow = 265 mld Min. flow = 70 mld	1988-89 Min. 5 Max. 18 Mean 11
26	Ashford Mill Weir Severn Trent	1.5m	1988-89 Mean flow = 906 mld Dry weather flow = 145 mld Minimum flow = 48 mld	1988-89 Min. 4 Max. 16 Mean 10
27	Beeston Severn Trent	2.4m	Low flow = 45 cumec Flood flow = 1130 cumec Measurements taken approx. 6 km downstream	25 year mean 16.3
38	Brouen Scar Weir Northumbria	N/D	N/D	N/D
39	Little Rubston Gauging Station Yorkshire	0.5m	N/A	N/A

Entrance/Exit	Maintenance/Construction	Comments
Entrance adjacent to large sluice providing additional attraction flow. Entrance/exit always accessible.	Constructed summer 1990 - cost £55,000. Prefabricated aluminium Denil pass in concrete supporting walls in weir sluiceway. Construction time. approx. 3 months.	
Adjacent by-pass channel and mill sluice provide extra attraction flow. Pass currently operated on Oct-Feb basis for main spawning run.	Constructed winter 1989-90. Cost £25,000. Maintenance costs not yet known but estimated at £500 pa. Prefabricated aluminium Denil in concrete supporting walls in old mill sluice channel. Construction time - approx. 2 months.	
Attraction by two ducts from top of pass plus main flow. Entrance always accessible.	Constructed in Nov 1984 - cost £15,000.	See: Plan 27. Report entitled - Reintroduction of salmon into the River Trent - a preliminary study which details obstruction and possible remedial action.
N/D	Modular unit constructed in 1987.	
Entrance always accessible	Cost approx £3,000 for Denil unit plus civil works for fitting. Pass opened June 1991.	See: Memo to Wessex area.

APPENDIX H – CONVERSION TABLE FOR IMPERIAL AND SI UNITS

THE METRIC SYSTEM

Linear Measure

1 inch	= 25.400 millimetres		1 millimetre	=	0.03937 inch
1 foot	= 0.3048 metre		1 centimetre	=	0.3937 inch
1 yard	= 0.9144 metre		1 metre	=	3.2808 feet 1.0936 yards
1 mile	= 1.6093 kilometres		1 kilometre	=	0.6214 mile

Square Measure

1 sq. inch	= 645.16 sq. mm.		1 sq. cm.	=	0.1550 sq. in.
1 sq. foot	= 0.0929 sq. m.		1 sq. m.	=	10.7639 sq. ft. 1.1960 sq. yds.
1 sq. yard	= 0.8361 sq. m.				
1 acre	= 0.4047 hectare		1 hectare	=	2.4711 acres
1 sq. mile	= 259.00 hectares				
1 hectare	= 10,000 m^2.		1 km^2	=	247.105 acres

Cubic Measurement

1 cubic inch	= 16.387 cubic cm.		1 cubic mm.	=	0.000061 cubic in.
1 cubic foot	= 0.0283 cubic m.		1 cubic m.	=	35.3147 cubic ft. 1.308 cubic yds.
1 cubic yard	= 0.7646 cubic m.				

Measure of Capacity

1 pint	= 0.568 litre		1 litre	=	1.7598 pints 0.22 gallon
1 gallon	= 4.546 litres				

MISCELLANEOUS CONVERSION FACTORS AND CONSTANTS

Section Modulus

1 $inch^3$	=	16.39 $centimetres^3$
1 $inch^3$ per foot of wall	=	53.7 $centimetres^3$ per metre of wall
1.86 $inch^3$ per foot of wall	=	100 $centimetres^3$ per metre of wall

Moment of Inertia

1 $inch^4$	=	41.62 $centimetres^4$
1 lb (f)	=	4.449 Newtons
1 pound per linear foot	=	1.4881 kilogrammes per linear metre
1 pound per square foot	=	4.883 kilogrammes per square metre
0.205 pounds per square foot	=	1 kilogramme per square metre
1 ton (f) per linear foot	=	32.69 kilonewtons per linear metre
1000 pound (f) per square foot	=	47.882 kilonewtons per square metre
1 ton (f) per square inch	=	15.444 Newtons per square millimetre
1 ton (f) per square foot	=	107.25 kilonewtons per square metre
100 pound per cubic foot	=	1602 kilogrammes per cubic metre
100 pound (f) per cubic foot	=	15.7 kilonewtons per cubic metre
1 ton (f) foot Bending Moment per foot of wall	=	10 kilonewton metres Bending Moment per metre of wall
1 metre head of fresh water	=	1 kilogramme per square centimetre
1 metre head of sea water	=	1.025 kilogrammes per square centimetre
1 cubic metre of fresh water	=	1000 kilogrammes
1 cubic metre of sea water	=	1025 kilogrammes
1 radian	=	57.3 degrees
Young's Modulus, steel	=	210 kN/mm^2
100 microns	=	01.mm = 0.004 inch

EQUIVALENTS OF METRES IN FEET

1 metre – 3·28084 feet

Metres	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
0		·3281	·6562	·9843	1·3123	1·6404	1·9685	2·2966	2·6247	2·9528
1	3·2808	3·6089	3·9370	4·2651	4·5932	4·9213	5·2493	5·5774	5·9055	6·2336
2	6·5617	6·8898	7·2178	7·5459	7·8740	8·2021	8·5302	8·8583	9·1863	9·5144
3	9·8425	10·1706	10·4987	10·8268	11·1549	11·4829	11·8110	12·1391	12·4672	12·7953
4	13·1234	13·4514	13·7795	14·1076	14·4357	14·7638	15·0919	15·4199	15·7480	16·0761
5	16·4042	16·7323	17·0604	17·3884	17·7165	18·0446	18·3727	18·7008	19·0289	19·3570
6	19·6850	20·0131	20·3412	20·6693	20·9974	21·3255	21·6535	21·9816	22·3097	22·6378
7	22·9659	23·2940	23·6220	23·9501	24·2782	24·6063	24·9344	25·2625	25·5905	25·9186
8	26·2467	26·5748	26·9029	27·2310	27·5590	27·8871	28·2152	28·5433	28·8714	29·1995
9	29·5276	29·8556	30·1837	30·5118	30·8399	31·1680	31·4961	31·8241	32·1522	32·4803
10	32·8084	33·1365	33·4646	33·7926	34·1207	34·4488	34·7769	35·1050	35·4331	35·7611

EQUIVALENTS OF FEET IN METRES

1 foot – 0·3048 of a metre

Feet	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
0		·03048	·06096	·09144	·12192	·15240	·18288	·21336	·24384	·27432
1	·30480	·33528	·36576	·39624	·42672	·45720	·48768	·51816	·54864	·57912
2	·60960	·64008	·67056	·70104	·73152	·76200	·79248	·82296	·85344	·88392
3	·91440	·94488	·97536	1·00584	1·03632	1·06680	1·09728	1·12776	1·15824	1·18872
4	1·21920	1·24968	1·28016	1·31064	1·34112	1·37160	1·40208	1·43256	1·46304	1·49352
5	1·52400	1·55448	1·58496	1·61544	1·64592	1·67640	1·70688	1·73736	1·76784	1·79832
6	1·82880	1·85928	1·88976	1·92024	1·95072	1·98120	2·01168	2·04216	2·07264	2·10312
7	2·13360	2·16408	2·19456	2·22504	2·25552	2·28600	2·31648	2·34696	2·37744	2·40792
8	2·43840	2·46888	2·49936	2·52984	2·56032	2·59080	2·62128	2·65176	2·68224	2·71272
9	2·74320	2·77368	2·80416	2·83464	2·86512	2·89560	2·92608	2·95656	2·98704	3·01752
10	3·04800	3·07848	3·10896	3·13944	3·16992	3·20040	3·23088	3·26136	3·29184	3·32232

Effective October 1986.

FRENCH LANGUAGE PAPERS

1. Belaud, A. and Dautrey, R. et al (1985) Observations on the migration behaviour of alewive (*Alosa alosa* L.) in the artificial canal of Golfech hydroelectric plant [F.e]., Annls Limnol., 21, No.2, 161-172.

For 4 consecutive years, daily fishing over a period of upstream migration of alewives (*Alosa alosa* L.) were performed on the site of Golfech: an hydroelectric plant on the Garonne river. This paper presents observations on the migratory behaviour of this fish in the artificial canal located between the plant and the confluence. The migration develops in spring when the water temperature reaches approximately 16 degrees C and, above this level, the maximal affluence of alewives corresponds with increasing temperature phases. The relationship between water temperature and capture abundance is significant if one considers the beginning of migration, then becomes inconsistent when the migration reaches the maximum. Similar to the thermal factor, there are hydraulic characteristics which influence the alewive migration (water flow through the different turbines, downstream level...). The various fishing operations indicate that alewives explore diurnally upward and downward the artificial canal by passing on the bottom. Every night or when the conditions are unfavourable they stay in deep water downstream in the river. Compared with previous observations the actual results indicate a typical migratory behaviour in an artificial canal.

2. Boisneau, P., Mennesson, C. and Bagliniere, J.L. (1985) Observations sur l'activite de migration de la grande alose *Alosa alosa* L. en Loire (France) [F.e], Hydrobiologia, 128, 227-284.

We studied the migratory activity of shad (*Alosa alosa* Linne) in the middle part of the Loire river, using stop net catches, in 1984. The migration started in the beginning of April, instead of February, as more usual. The end of migration is not precisely known, because of adverse hydrological conditions. During migration, the shad principally used the channel with the highest current velocity. The migration was disturbed by the presence of obstacles (weirs, dams of nuclear power stations). The daily and hourly activity of migration was strongly correlated with variations in water temperature. Shads did not run up at temperatures below 11 degrees C. The upstream limit of distribution was situated at more than 500 km from the estuary.

3. Denoziere, P. (1987) Legal improvements aimed at facilitating the installations of overpasses for fish. [F.e], La Houille Blanche, No.1/2, 149-153.

Currently, these improvements are essentially contained in the new fishing Law and mainly in article 411 of the new Rural Code. This article requires the enforcement of texts which are not yet known. However, the important measures of article 411 ought to allow many desirable improvements to be made including the restoration of overpasses in previous works which were poorly maintained or even had no water supply. Nevertheless, the related ways and means are uncertain because the content of the texts enforced are not yet known, this being the only possible way to obtain information about the interpretation of the Law in the light of the preparatory works. At the same time, a concession relating to the authorisation procedures or concession of works in question ought to be sought. Moreover, apart from the legislation on fishing, the Act of 15 July 1980 modifying that of 16 October 1919 and its applicable legal texts provide distinct possibilities for legal improvements to the crossing of works to be obtained.

4. Elie, P. and Rigaud, C. (1987) The impact of tidal barrage on the migraiton of amphihalins, a sub-family of salmon species, easily adaptable to fresh and salt water: i.e. the case of eels and the Arzal barrage. [F.e], La Houille Blanche, No.1/2, 99-108.

The Arzal barrage suddenly changed the fluo-estuarian working system of the Vilaine 14 years ago. The problems of overpass especially affect adult eels and also young eels during anadromous migration (increase fish catching, complete blockage of migration...), as well as the sedentary phase sub-adult function during their trophic (or other) movements. To increase the penetrability of the overpass or improve its crossing by young eels, a diversity of solutions are proposed: some of these solutions do not require physical development of the overpass but only require effective improvement (better management of vavles and sluices); others offer the guarantee of a subsequent permanent pass for fish likely to colonize the catchment area. Examples relating to this type of improvement are quite common abroad but do not exist in France.

5. Gregoire, A. and Travade, F. (1987) EDF's experience relating to fish ladders and efficiency follow-up. [F.e], La Houille Blanche, No.1/2, 65-72.

Since 1982, and in accordance with the provisions of the EDF/Environment Ministry/Energy State Secretarial agreement, EDF contributed to the national effort made to re-establish migrating fish populations, by providing measures intended to facilitate the crossing of a certain number of dikes. Currently, many undertakings have been completed. Amongst the main ones are those at Belleville in the Loire, at Bergerac in the Dordogne, at Poutes in the Haut-Allier and the fish lift in the Garonne and whose downstream part is currently in operation. Some research and follow-up activities concerning the effectiveness of these works are also being carried out.

6. Larinier, M. (1987) Fishways: principles and design criteria. [F.e], La Houille Blanche, No.1/2, 51-57.

The writer synthesizes knowledge basically used for constructing devices which enable migrating fish to pass through basin catchments. He describes the dimensioning criteria and utilisation conditions for various types of ladders (fish ladders in successive basins, slow-motion passes, lifts and sluices). The emphasis is put on the significance of the situation and attractiveness of these undertakings which must concern the level of improvement and rivers.

7. Larinier, M. (1983) Guide for planning passage facilities at dams for migratory fish. [F.e], Bull.Fr.Peche Piscic, No.Special Issue, 39pp.

The basic principles which can be used as a guide for planning fish passage facilities at dams or obstructions are outlined. Special reference is made to the attraction of fishway entrances. Information is presented concerning functional features and design parameters for different types of fish facilities: pool passes, Denil fishways, fish locks and fish lifts. A list of data required for planning fish facilities is included.

8. Larinier, M. and Trivellato, D. (1987) Hydraulic model studies for Bergerac dam fishway on the Dordogne river. [F.e], La Houille Blanche, No.1/2, 135-142.

A crossing device has been recently put into operation at the dam in Dordogne. This pass for fish of the type with successive basins with lateral vertical opening, has been designed to operate for flowrates varying from 50 to more than $800m^3/s$. A study carried out on a reduced model has made it possible to optimize the various characteristics of the undertaking. The flow conditions upstream and downstream of the pass have been specially considered. The study has also allowed for the required flow rates to be defined with the device's power to attract fish. The roundly shaped upstream head is intended to reduce maintenance problems in standard operational conditions. An adaption has been effected in the downstream part so that a trap and an observation tower can be installed.

9. Legault, A. (1988) The dam clearing of eel by climbing. Study in Sevre Niortaise. [F.e], Bull.Fr.Peche Piscic. No.308, 1-10.

A feature of the eel, *Anguilla anguilla*, anadromous migration is to crawl out of the water to pass over obstructions. This behaviour was studied in the freshwater area, in the downstream part of the Sevre-Niortaise watershed. On the dams where different sluices type can be observed, eels can only move up on small vertical areas of the walls. This crawling behaviour may be compared to a climbing one. Under these conditions, the climbing is very selective: only the smallest individuals (<100mm long) can move up on the walls and try to pass over them. Very few of them succeed in clearing dam due to the configuration of these structures. Thus, climbing observations are not necessarily related to actual clearing of the dam. Other ways to clear dams seems to be few, so the limitation of dams effects on the eels colonization of watershed area is essential. The fitting of eel passes, which use climbing behaviour is a priority to protect this species.

10. Ombredane, D., Fontenelle, G., Ohresser, H. and Rochepeau, S. (1987) Dam overpassing by migratory adult salmonids. An analysis of the leaping behaviour with the view of a better management. [F.e], Bull.Fr.Peche Piscic. No.305, 67-80.

The leaping behaviour of migratory salmonids has been studied at two small dams (<2m) on the River Blavet. A very small proportion (<9%) of the total activity leads the fish to pass over the dams. For each gate, a successful jump can only be observed when a stong attractive current, a deep pool and an open gate are combined. Even when the gates are closed, the water leaks lead up to 50% of unsuccessful attempts. A reduction of 25% was obtained by plugging the leaks. The discussion of the results shows that a simple management of these kinds of dams can improve their clearing by adult migratory salmonids.

11. Puyo, C. and Venel, A. (1987) A scale model contributing to the engineering studies of the Golfech fish lift. [F.e], La Houille Blanche, No.1/2, 81-87.

A 1/10 scale reduced model of the attraction basin with a fish lift at Golfech hydraulic dam was built in 1984 at the Sogreah laboratory for the Equipment Management of EDF. Despite the severe constraints imposed upon hydraulics by civil engineering, a complete set of suitable devices have been built and which approximately dissipate the energy of the waterfall, normally distribute the flow rates in the feeding basins, with flow rates complying to the specifications sheet. The proposed device is high-performance and does not require any handling of adjustment devices apart from the valves at the right of the outlets.

12. Roguet, M. and Larinier, M. (1987) Methodological and prospective aspects relating to maintenence and restoration of migration channels. [F.e], La Houille Blanche, No.1/2, 143-147.

In the first part the emphasis is placed on scientific and technical components relating to the pass devices. The progress of the technique in this field, whether it is to assume migration upstream or downstream, is first and foremost supplied by experiment and the follow-up of existing installations. The second part refers to more general problems posed by the protection and restoration of stocks of migrating fish.

13. Trivellato, D. and Larinier, M. 1987) The use of hydraulic models to study fish facilities on large rivers. In Restoration of salmon rivers, edited by M Thibault and R. Billard, Jouy-en-Josas: INRA. 149-157.

Fish facilities at the Belleview weir on the Loire River, the Bergerac dam on the Dordogne River, and the Golfech powerhouse on the Garonne River were optimized by the use of hydraulic model studies at the "Institut de Mecanique des Fluides" at Toulouse. In the first two fishways, flow conditions, i.e. flow velocity, drop between pool and rate of energy dissipation per unit of volume, were studied in relation to tailwater and headwater fluctuations. The main purpose of these studies was to optimize the position of entrances and determine the discharge needed to provide adequate attraction at these sites. The modelling resulted in design changes that should improve fish passage.

14. Vialle, M. (1987) Ladders for alosa: CNR's experience. [F.e], La Houille Blanche, No.1/2, 59-64.

The spawning place of migrating fish and of alosa in particular is the Rhone basin, 66km from the sea in Le Gardon. To reach it the alosa must cross two major obstacles due to the evelopment of the Villabregues waterfall by the Compagnie Nationale de Rhone, i.e. the shelf of Beaucaire and that of Gardon. To overcome these two obstacles, two fish ladders have been built. One of them links the outlet to the old arm of the Rhone. It was built in 1979. The tests and measurements have made it possible to take into account and verify the hypotheses relating to speeds, turbulences and the attraction rate. In 1985, some modifications were made to improve efficiency. An observation campaign planned in 1985 and intended to verify the working of this ladder had to be brought foward to the Spring of 1986.

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