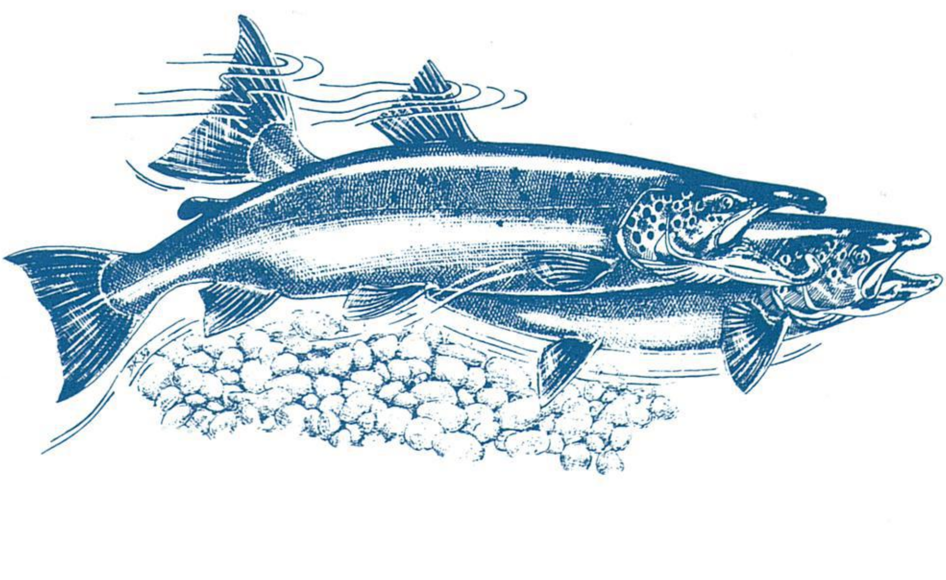
FISH PASSES AND SCREENS FOR SALMON

Report of the Salmon Advisory Committee



Ministry of Agriculture, Fisheries and Food
Scottish Office Agriculture, Environment and Fisheries Department
Welsh Office Agriculture Department

CONTENTS

PART II

PART III

APPENDICES

PART II

PART III

1. INTRODUCTION

The Salmon Advisory Committee was established by Fisheries Ministers in October 1986. Its membership is shown at Appendix A.

The terms of reference of the Committee are:

> 'To examine and report on those matters relating to the conservation and development of salmon fisheries in Great Britain which are referred to it by Fisheries Ministers.'

Two of the Committee's previous reports highlighted the impact of fish passes and exclusion screens on the stocks of salmon in Great Britain: *Factors Affecting Natural Smolt Production* and *Factors Affecting Emigrating Smolts and Returning Adults*. Ministers therefore agreed that the Committee should prepare a report on fish passes and screens. In addition, we considered that such a report would be of value to fishery owners and managers to assist them in carrying out their role in conserving stocks.

In preparing this report the Committee decided to:

- describe the circumstances in which it is necessary or desirable to provide fish passes or screens to ensure the safe passage of migrating salmon (adults and juveniles) for the maintenance and enhancement of fish stocks;
- review the criteria for the design of passes and screens; and
- consider and develop the practicality of measuring the effectiveness of such facilities.

The need to ensure that salmon could overcome man-made obstructions has been recognised for centuries, as has the requirement to prevent adult and juvenile salmon from being drawn into intakes. The development of hydro-electric power, involving the use of large dams and high-speed turbines, and the increasing abstraction of water for human consumption, agriculture and industry have also increased the need for effective passes and screens.

Migration of adult and juvenile salmon in fresh water is a fundamental characteristic of their life history which has been put at risk by man's activities. This report is based on the premise that the safe and easy passage of salmon past obstructions, and the protection of salmon from intakes and outfalls should be the normal standard.

The report stresses the importance of ensuring that passes and screens work effectively both for upstream and downstream migration. We are conscious that many species of fish other than salmon migrate or move through different sections of a river system and that the design of both passes and screens should also take these into consideration.

To illustrate the importance of passes and screens it is worth considering a river system where there are four obstructions or offtakes, each with a pass or a screen. If at each pass one-half of the adult stock is deterred or lost, or at each screen the same ratio of smolts is lost, then the cumulative loss of stock is substantial. Of 100 adults seeking to reach the top of the system to spawn, only six will get there, and of 100 smolts migrating downstream, again only six will pass the lowest offtake successfully.

Fish passes can be expensive to construct and so before deciding upon installing passes on natural obstructions, the costs and the expected benefits should be compared with alternative fishery management options. The cost of maintaining the pass must also be borne in mind in such assessments.

Consideration of the behaviour of fish and the performance of fish passes requires reference to data expressed in various scientific units. The units of measurement used in this report are defined at Appendix B. The superscript numbers used throughout this report refer to the publications listed in numerical order at Appendix G.

PART I

2. FISH PASSES

2.1 BACKGROUND

While fish passes have been used for centuries, the modern concept of pass design started to evolve in the early part of the 19th Century. At that time, the widespread development of weirs in rivers, built to provide water power for the rapid expansion of industrial activities, was having a detrimental impact on both the upstream and downstream migration of salmon. To overcome this, passes were built to enable fish to negotiate these obstructions.

The importance of the form and location of the pass was recognised in Scottish regulations made in 1865. These applied to mill dams and were incorporated in The Salmon Fisheries (Scotland) Act 1868 as Schedule G. They included a requirement that:

> 'There shall be a salmon pass or ladder on the downstream face of every [mill] dam, weir or cauld capable of affording a free passage for the ascending fish at all times when there is water enough in the river to supply the ladder.'

There were further provisions in the Regulation in relation to the size and geometry of passes, and it emphasised the need to place the foot of the pass where the flow of water provides the best lead for the fish to approach it.

Recognition that the entrance to a pass was an essential feature was emphasised by Calderwood who wrote in 1930, 'The entrance is the most important part of any pass. One may have the best pass in all other respects but if fish do not find the entrance the whole structure is useless'[1]. Whereas these comments were written primarily in relation to upstream migration, they are just as pertinent to the downstream migration of smolts and kelts and, for both, the entrance to the pass is an integral part of the whole structure.

The configuration of a pass should generally be such that salmon must be attracted into it and be able to pass through it under all conditions when they may seek to pass the obstruction.

2.2 REQUIREMENT FOR PASSES

The obstructions which may require the provision of fish passes can be put into four categories: natural obstructions; existing man-made obstructions; new man-made obstructions; and tidal barriers.

2.2.1 Natural obstructions

The provision for access for salmon to the rivers, lakes and streams above natural obstructions is a way of increasing the area in which they can spawn and thus enhancing the production of smolts and, in due course, the stock of fish in a river. It may also extend the length of river available for salmon fishing. We acknowledge that there will be locations where extending the range of salmon is not appropriate in order to avoid interference with established ecosystems and natural fisheries. Some falls may act as partial obstructions and, for example, allow only large fish to pass. In these cases, consideration should be given to whether easing access and perhaps allowing more small salmon to migrate upstream would be appropriate.

The geological structures which normally create waterfalls or flows of high velocity may be of a form where the construction of a traditional pass is difficult and expensive. In such places, other types of passes such as fish lifts may provide a more economical means of facilitating the passage of fish, and indeed there should be opportunity for innovation. Some waterfalls may be tourist attractions or be in areas of special landscape or conservation value. The form of a pass at such locations may be dictated by its visual impact or its construction may be prevented altogether.

2.2.2 Existing man-made obstructions

Fish passes are most frequently built to provide access over existing man-made weirs and dams. Some such obstructions have resulted in the reduction of salmon populations in rivers, whereas others may have been built after the decline of stocks due to other causes such as industrial pollution. Where the upstream movement of migratory salmonids has been prevented for some time, new fish communities and recreational fisheries may have developed in areas upstream of the obstruction. In such situations, it should not be assumed that the installation of a pass will always be desirable, and the potential impacts of reintroducing migratory salmonids should be fully assessed.

Before designing a fish pass, consideration should be given to modifying or even breaching the obstruction to improve the passage of salmon. Where a pass is required, the choice of design will depend upon local circumstances. Each pass is site-specific and must be designed to take account of the height and shape of the obstruction, the river flows, the available space and other characteristics of the particular location.

2.2.3 New man-made obstructions

The purpose of building new weirs or dams in rivers is generally to provide a head of water for power generation or abstraction. Such obstructions will often create a complete barrier to the upstream movement of migratory fish unless a fish pass is included in the structure. In addition, even relatively minor structures, such as culverts and bridge foundations, may restrict fish migration, particularly under low river flows. Similarly, structures designed to gauge river flows or improve drainage may also impair fish movements. The potential impacts of all such engineering works should be fully assessed at the planning stage, and an appropriate fish pass should be incorporated into the design if it is required.

It should not be assumed that it will always be possible to design a fish pass that will completely mitigate the adverse effects of a new obstruction and prevent it from having any impact on fish movements. This should therefore be taken into account when considering the possible impact of any new obstruction on fish stocks.

2.2.4 Tidal barriers

Tidal barriers are built for a number of purposes including hydro-electric power generation, amenity, navigation, the avoidance of flooding, or to prevent the ingress of salt water to low-lying rivers and drains in order to improve agriculture. The development of tidal barriers on the estuaries of rivers supporting salmon has created a requirement for fish passes at a point in the upstream and downstream migration of salmon where little is known about their behaviour. Because of this uncertainty, particular care is required to ensure that fish can move through these barriers successfully and without delay. In some tidal barriers, the water level outside the barrage will rise higher than that inside, and this may impose the need for special facilities to allow both upstream and downstream migration at different stages of the tide.

Returning adult salmon will have both the normal difficulties associated with finding and negotiating the fish pass, and the need to make the very rapid transition from a seawater environment to fresh water. Fish appear to move rapidly from sea water to fresh water in some rivers, but little is known of the physiological and behavioural processes associated with this transition.

The requirement for the safe downstream passage of smolts and kelts must not be overlooked. By its nature, a tidal barrier is likely to create a substantial freshwater lake in a length of the river where previously tidal movement would have provided guidance to smolts in their seaward migration. Tidal barriers are also likely to result in downstream migrants passing more rapidly from fresh water to salt water. The effects of these factors on smolts at such a critical stage in their emigration from fresh water is not known.

3. REGULATIONS RELATING TO FISH PASSES

3.1 LEGISLATION

The legislation relating to fish passes in England & Wales differs from that in Scotland. In both jurisdictions, however, the legislation requires that anyone creating a dam in a river frequented by salmon or migratory trout should provide a fish pass. Passes are subject to the procedures outlined below.

3.1.1 Legislation in England & Wales

The legislation which determines the requirements for passes in England & Wales is laid down in Sections 9 to 12 and 18 of the Salmon and Freshwater Fisheries Act 1975 (the 1975 Act).

These Sections were amended by the Environment Act 1995 with effect from 1 April 1996. In this report we refer to the provisions as amended. Copies of Sections 9 to 12 and 18 of the 1975 Act showing the various amendments are attached at Appendix C. The following summary is for guidance only; the relevant Sections of the Act should be referred to for their full terms.

Section 9 states that the owner or occupier of a new dam or a dam subject to repair or reconstruction of half of its length, shall, if so required by the Environment Agency (the Agency), make a fish pass of such form and dimensions as it may approve. There is also a requirement for the pass to be maintained in an efficient state and provision for the Agency to carry out the work and recover the costs if this is necessary. These provisions apply only in waters frequented by salmon or migratory trout.

Section 10 gives power to the Agency to construct and maintain a fish pass in any dam so long as no injury is done to milling power or navigation. In a similar way, the Agency may alter or abolish or restore to its former state of efficiency any existing fish pass or free gap, or substitute another fish pass.

Section 11 sets out the approval procedures for fish passes. Approval given by the Agency is provisional unless it is stated otherwise, and remains thus until it notifies the applicant that the pass is functioning to its satisfaction. During the period while the approval is provisional, the Agency may revoke the approval, and when it does so it may extend the period within which a pass must be made. The Agency may approve and certify any pass if it is of the opinion that it is efficient, whether it was constructed under this Act or not, and, once approved, a pass should be deemed to conform with the Act notwithstanding that it was not constructed in the manner and by the person specified in the Act.

Section 12 creates offences associated with: wilful alteration to a pass; obstruction to a pass making it less efficient; and altering a dam or the bed or banks of a river to make a pass less efficient. The owner of a dam is deemed to have altered it if he allows it to fall into disrepair or if it is damaged, and he will be required to repair it within a reasonable time. This section also states that any person who acts to prevent salmon passing through a fish pass or obstructs their free passage shall be guilty of an offence.

Section 18 makes it an offence to obstruct any person carrying out work authorised under Sections 9 and 10; provides that the Agency shall not carry out work under Section 10 unless reasonable notice has been served on the owner or occupier of the dam, fish pass or free gap; and provides for the payment of compensation to any person sustaining a loss as a result of any damage caused to a dam as a result of work carried out under Section 10.

3.1.2 Legislation in Scotland

The current Scottish legislation is in the Salmon Act 1986. Under Section 3(2) the Secretary of State has power, after consulting such persons as he considers appropriate, to make regulations with respect to:

> 'the construction and alteration of dams, including mill dams, or lades or water wheels so as to afford a reasonable means for the passage of salmon.'

Such regulations have now been made. These are The Salmon (Fish Passes and Screens) (Scotland) Regulations 1994 which are attached to this report at Appendix D. The following summary is for guidance only; the Regulations should be referred to for their full terms.

The Regulations apply to dams in, and offtakes from, waters which ordinarily contain upstream migrating salmon. The Regulations do not apply to works which have been authorised under the Electricity (Scotland) Act 1979 and the Electricity Act 1989, nor works used for the abstraction of water for the purposes of providing a water supply in accordance with the approval of the Secretary of State. This is because, under other legislation, the Secretary of State must consider the arrangements for fish and fisheries before approving or consenting to such works.

For the purposes of the Regulations a fish pass means any device which facilitates the free passage of salmon both upstream and downstream; an offtake includes a lade; and the operator of a dam or offtake is the owner or any other person who occupies or controls it. The Regulations apply with effect from 1 January 1995 to all dams and offtakes built after that date and to all other dams and offtakes with effect from 1 January 2000 and 1 January 1998, respectively.

Regulation 3 requires every new dam or mill dam built, renewed or repaired after 1865 to be made and maintained watertight.

Regulation 4 requires the operator of every dam to ensure that it is provided with a fish pass which facilitates the free passage of salmon except when, for natural reasons, the flow of water in the river is so low that salmon would not reasonably be expected to seek passage.

Regulation 5 requires the operator of a lade to ensure that it is provided with a sluice to control the flow of water so that it shall not exceed that which is required for the purpose for which the abstraction is made.

Regulation 7 states that any work carried out to comply with these Regulations, or for maintenance, must be done in such a manner as to ensure the minimum practicable interruption to the passage of salmon.

Regulation 8 provides that the old byelaws which were re-enacted as Schedule G of the 1868 Salmon Act remain in force for fish passes at existing mill dams until the year 2000.

The Hydro-Electric Development (Scotland) Act 1943 made provision for the establishment of a Fisheries Committee to advise on schemes proposed by the North of Scotland Hydro-Electric Board for hydro-electric development and to advise on possible damage to fisheries or fish stocks. Provisions for the Fisheries Committee were consolidated in the Electricity (Scotland) Act 1979 and later extended in the Salmon Act 1986 to include private generators of hydro-electricity. Its continuance was provided for in the Electricity Act 1989.

3.2 APPROVAL PROCEDURES

The procedures for obtaining approval for the construction of a fish pass at a man-made obstruction are different in England & Wales from those in Scotland, as a result of differences in the legislation referred to in Section 3.1.

3.2.1 Approval procedure in England & Wales

The procedures which apply from 1 April 1996 require approval by the Environment Agency for passes covered by Section 9 of the Salmon and Freshwater Fisheries Act 1975. A typical chain of events leading up to the provision of a new fish pass might be as follows:

Consult with the Agency to determine whether an obstruction requires or will require an approved pass.

↓

Design a pass for the site.

↓

Submit design to the Agency and obtain provisional approval.

↓

Submit application to the local planning authority and obtain approval.

↓

Construct the pass.

↓

Submit evidence of efficient performance to the Agency.

↓

Obtain final approval from the Agency.

Passes constructed by or on behalf of the Agency under Section 10 do not require approval under the Act. Thus, no separate authority is responsible for approving the design of schemes proposed by the Agency. We note that under this legislation the Agency may also be placed in the position of having to approve or refuse a pass in relation to a scheme to which it has formally lodged objections or has another interest. This would appear to give rise to a potential conflict of interest.

3.2.2 Procedure in Scotland

In Scotland, the Regulations have direct effect and thus there is no provision for official approval of the design or of the completed fish pass. It is appropriate to consult the Scottish Office publication, *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon*[2].

The chain of events might be as follows:

Determine whether the proposed or existing obstruction needs a fish pass as required by the Regulations, consulting with the District Salmon Fishery Board and/or The Scottish Office as appropriate.

↓

Design a pass for the site.

↓

Submit application to local planning authority and obtain approval.

↓

Construct the pass.

3.3 ASSESSMENT OF PERFORMANCE

In England & Wales, the procedures require both that the pass operates efficiently and that it is maintained in this condition. In Scotland, the Regulations require that a fish pass facilitates the free passage of salmon. Thus, in both cases the concept of the performance of the pass is raised and this is discussed further in Section 6.

4. TYPES OF PASSES

4.1 FISH PASSES

A number of recent publications have described the different types of fish pass that may be used and have provided technical information on these designs. Appendix A of the Scottish Office publication *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon*[2] provides a useful review of various types of pass and is reproduced in full at Appendix E of this report. The Committee is grateful to the Scottish Office for allowing us to use these notes as part of this report. We believe that this publication provides very helpful information on the implementation of the new legislation in Scotland. Detailed consideration of the hydraulics of passes is outwith the scope of this report but is extensively covered in a Canadian working document entitled *Introduction to Fishway Design*[3].

The selection of an appropriate type of pass for a particular location will depend upon various characteristics of the site, including the nature of the obstruction, the amount of space available and the range of river flows to be accommodated. It is important that the best engineering and biological advice is taken when deciding upon the type of pass to use and designing the particular application. While the design of the structure may also be determined by cost, it is important that this does not compromise its working efficiency.

4.2 BYPASS STREAMS

Where land is available adjacent to a barrier and the topography allows, it may be possible to construct a bypass stream which will provide easy access past an obstruction for fish migrating upstream. Stream gradients should be between 1 in 30 and 1 in 100, resulting in a stream length of between 30 m and 100 m for every metre of height of the weir. As a result, bypass streams are usually only suitable for relatively small weirs because quite large areas of land are needed for their construction.

One attraction of bypass streams is that they can be formed to provide suitable stream-bed conditions for spawning and habitat for juvenile production. They can thus contribute to the productivity of the river. The potential of this type of fish pass merits further investigation.

4.3 TRAPPING AND TRUCKING

A further approach to the problem of providing a safe passage for fish past an obstruction is to trap them and transport them to a point beyond the obstruction. This method is appropriate for both returning adults and downstream migrating smolts, but it is dependent on ensuring that the capture, handling and transfer processes do not cause damage or undue stress to the fish.

'Trapping and trucking' is inevitably an expensive way of moving fish but there may be locations where this is the most effective way of achieving the objective of safe passage.

5. DESIGN OF PASSES

5.1 APPROACH

The usual approach to designing a fish pass is to follow a series of steps, broadly as follows:

- obtain details of the obstruction and topographical information on the site;
- obtain details of the flow to prepare a flow duration curve, and the relationship between the water level and the river flow upstream and downstream of the obstruction;
- determine river flows at which the pass will be required to operate;
- select the type of pass which is most suitable for the location to allow satisfactory operating conditions, gradient, length and the provision of resting pools; and
- prepare a layout which incorporates the preferred design, paying particular attention to features which are known to be important in relation to both upstream and downstream migration, such as approaches and entrances.

5.2 HYDRAULICS

The concept of reducing the velocity of the current to allow fish to ascend without difficulty has long been the basis for pass design. Attempts to relate the predicted water velocities in a pass to the swimming ability of the fish have only been incorporated into fish pass design relatively recently.

The hydraulic and hydrodynamic behaviour of most types of passes have been studied and analysed, and information has been published from which discharges and flow velocities can be calculated. Detailed information for successive-pool and for roughened-channel passes can be found in *Introduction to Fishway Design*[3] and *Fish pass design – criteria for the design and approval of fish passes and other structures to facilitate the passage of migratory fish in rivers*[4]. These types of pass are described at Appendix E.

In successive-pool passes, turbulence is necessary to dissipate energy in water flowing through the pass. However, excessive turbulence and air entrainment disorientate salmon and will make a pass ineffective. Some recent work has been directed at assessing the extent of this problem[5]. This has provided a formula for calculating volumetric power dissipation, which allows a quantifiable approach to pass design. It is suggested in recent work that the volumetric power dissipation in a salmon pass should normally be less than 200 W m^{-3}, although higher figures can be accepted in some circumstances[5].

VOLUMETRIC POWER DISSIPATION

The formula for calculating volumetric power dissipation (vpd) is as follows:

$$\text{vpd} = \frac{p\,g\,q\,d}{v} \quad \text{W m}^{-3}$$

where:

	p	=	density of liquid (approx. 1000 kg m^{-3} for water)
	g	=	acceleration due to gravity (9.81 m s^{-2})
	q	=	flow in the pass (m^3 s^{-1})
	d	=	drop between pools (m)
	v	=	volume of water in pool (m^3)

5.3 ENTRANCES FOR UPSTREAM MIGRANTS

Section 2.1 refers to the entrance to a pass being an integral part of the whole structure and points out that, if a salmon cannot find the entrance, the pass is useless. In too many cases, passes have been built with badly located entrances and with flows from the entrances which do not attract upstream migrants.

The flow of water from the downstream end of the pass must therefore have sufficient velocity to attract fish. Tests have shown that if the ratio of the outflow velocity from the pass to the velocity in the receiving pool is at least 3:1 then fish will be attracted to the pass. However, the velocity must not exceed that which salmon can overcome and an optimal velocity of 2 to 2.4 m s^{-1} has been recommended[5].

The influence of the angle between the flow from the pass and the main flow is also important. The attraction of fish to a pass falls away very quickly as this angle increases, and the best configuration has the attraction flow parallel to the main flow. In addition, fish should not be able to reach a position where they have to turn back to find the entrance to the pass. There should therefore be no holding area between the pass entrance and the obstruction itself.

It is also most important that there is sufficient depth of water at the entrance to the pass to allow for changes in water level at different river flows. In some cases the natural processes of erosion of the river bed may be accelerated by the pattern of flow over a dam or weir which may then lead to changes in the downstream water level. If the depth downstream of the obstruction is decreased it may create difficulties for the fish; it may even leave the entrance standing above the water. When designing a new pass, account should therefore be taken of the possibility that the water level will change.

5.4 DOWNSTREAM MIGRATION

There is a need to ensure that downstream migrating smolts and kelts can find the upper entrance to the pass unless they can find alternative safe passage. In contrast to the extent of information on upstream migration of salmon, much less is known about the pattern of downstream migration of kelts, or about their behaviour at the entrance to passes. Downstream passage over obstructions is commonly thought to present less of a problem than upstream movements because it has been assumed that the fish will be transported downstream by the flow of the river water. This has led to an emphasis on the design of passes for upstream migration with little regard to the movement of smolts and kelts.

In a natural river there is generally a gradual acceleration of the water towards the crest of a fall. At many fish passes, however, there is a rapid transition from deep water to the shallow water at the crest of the weir. The associated high acceleration in flow appears to be recognised by smolts, which seek to avoid it. Smolts have been observed swimming parallel to the face of a dam and moving some distance away from the face where the flow of water accelerates at the upstream entrance to a pass. Consequently, they may not easily find the entrance to the pass and may thus be delayed in their migration.

Smolts can tolerate high water velocities but may be liable to physical damage if a pass has high volumetric power dissipation or badly shaped baffles.

Two examples of the parameters on which passes have been designed in the past.

Since the 1860s, design of fish passes at mill dams in Scotland was based on the requirements of Schedule G of the 1868 Act which laid down outline sizes, as follows.

The width of the pass to be:

- not less than 4 ft in rivers less than 100 ft wide at the site of the dam;
- not less than 5 ft in rivers between 100 ft and 200 ft;
- not less than 6 ft in rivers greater than 200 ft.

The upper sill to be not less that 6 inches below the lowest point in the crest of the dam for the whole width of the pass.

The inclination to be no steeper than 1 in 5 and preferably 1 in 7 or 1 in 8.

In all cases, passes are to be provided with breaks or stops to lessen the velocity of the current sufficiently to allow fish to ascend without difficulty.

Schedule G also contained recommendations in relation to the size and position of brakes in passes, but did not insist on them 'provided some other perfectly efficient arrangement is substituted'.

The basic design requirements, based on the report of the Institution of Civil Engineers in 1942, for a pool and traverse type of fish pass in England & Wales since 1978 were as follows.

(a) The change in water level between pools should not exceed 0.45 m.

(b) Pools should have minimum dimensions of 3 m long by 2 m wide by 1.2 m deep.

(c) Each traverse should be 0.3 m thick with the notch 0.6 m wide and at least 0.25 m deep.

(d) The downstream edge of both the notch and the traverse should be curved so as to reduce turbulence and provide an adherent nappe.

(e) 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 as given above runs full, and the 0.45 m change in water level would result in a maximum velocity of 2.97 $m s^{-1}$.

5.5 SWIMMING ABILITY

An important factor in the design of a fish pass is the swimming ability of salmon in terms of speed and endurance. The subject of swimming ability is addressed in *Fish pass design – criteria for the design and approval of fish passes and other structures to facilitate the passage of migratory fish in rivers*[4], and this report draws extensively from that work.

A fish propels itself through the water using waves of contraction of the lateral muscles. Two types of swimming are recognised: cruising and burst activity. Cruising, which can be maintained for long periods, uses the red or aerobic muscles. Burst swimming uses the white or anaerobic muscles, which can contract rapidly and powerfully using glycogen stored in the muscle cells. The duration of this latter form of swimming is limited to the time taken for the store of glycogen in the muscles to be used up. A totally exhausted fish can take as long as 24 hours to recover. It is doubtful if any fish would voluntarily exhaust itself to this extent, but rest periods of an hour or more may often be necessary following burst activity during ascent of a pass.

The speed at which a fish can swim increases with body length, but is sensitive to temperature, cold muscles contracting more slowly than warm ones. Figure 1 shows the maximum swimming speeds against fish lengths at various temperatures. It will be seen that large fish can swim faster than small fish and that the maximum speed at which fish of all sizes can swim rises with increase in temperature.

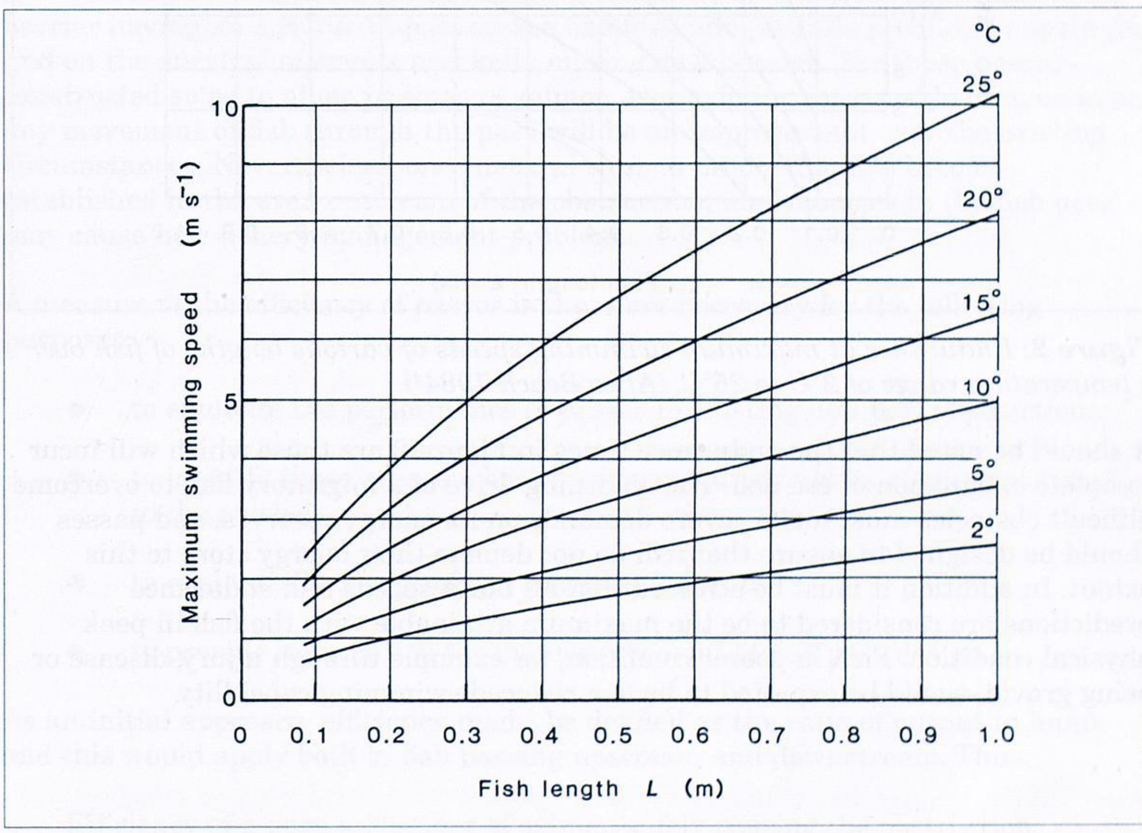


Figure 1: *Maximum swimming speeds against fish length over a temperature range of 2°C to 25°C. (After Beach 1984*[4]*)*

Endurance, the ability of fish to sustain maximum swimming speeds over a period of time, is similarly determined by both body length and temperature and is governed by the amount of glycogen which is stored in the cells of the white muscles and the rate at which it is used. As temperature increases, there is a marked reduction in endurance time at maximum swimming speed (Figure 2). This is partly because the higher speeds at higher temperatures deplete the glycogen store more rapidly. Larger fish have longer endurance times because they have a greater glycogen store.

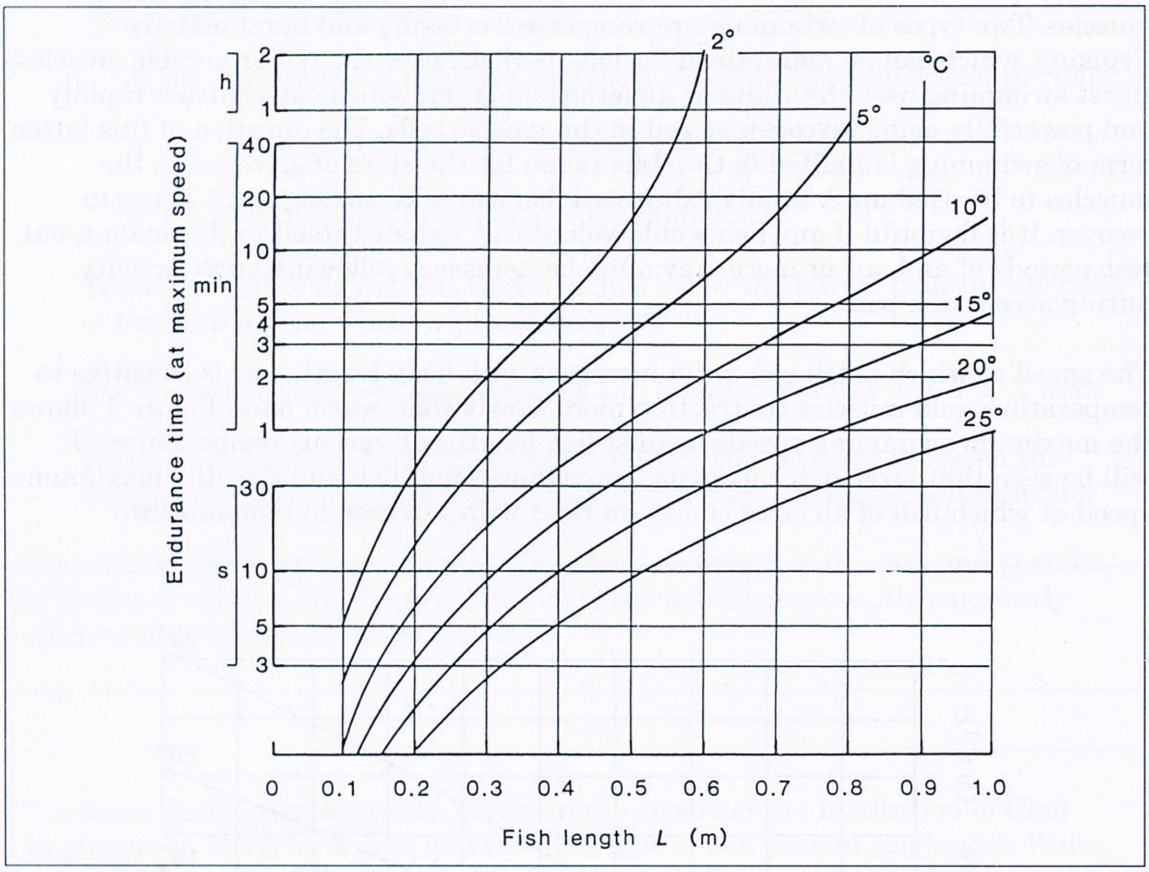


Figure 2: *Endurance at maximum swimming speeds of various lengths of fish over a temperature range of 2°C to 25°C. (After Beach 1984[4])*

It should be noted that the endurance times in Figure 2 are those which will incur complete exhaustion of the fish. The spawning drive of a migratory fish to overcome difficult obstacles must make severe demands on its energy reserves, and passes should be designed to ensure that fish do not deplete their energy store to this extent. In addition it must be stressed that all burst speeds and endurance predictions are considered to be the maximum attainable with the fish in peak physical condition. Fish in poorer condition, for example through injury, disease or being gravid, would be expected to have a reduced swimming capability.

6. EFFICIENCY OF PASSES

6.1 DEFINING EFFICIENCY

The Salmon and Freshwater Fisheries Act 1975 makes several references to the efficiency of fish passes. Section 9 makes it an offence to fail to maintain a fish pass in an 'efficient state' or to restore a fish pass 'to its former state of efficiency' if a dam is repaired or altered. In addition, Section 11 refers to a fish pass being 'efficient in all respects and for all purposes'. However, the parameters which could be used to assess efficiency are not given and the term is not defined.

The difficulties of both defining and measuring efficiency have been highlighted by studies of adult salmon on their return to the River Tay[6]. This work involved radio-tracking fish and recording their progress upstream. It showed that of ten fish reaching the River Tummel at Pitlochry, five did not ascend the fish pass at Faskally, but instead returned downstream to go elsewhere. This suggests that some fish may have been deterred by the dam and pass, although there is, of course, no comparable information on the movement of salmon at that point before the construction of the dam.

To be considered totally efficient, a pass would need to be found and used by all fish that would otherwise be obstructed by the barrier, without significant delay or exertion. In practice most, if not all, fish passes will fall short of this ideal. When new barriers are constructed any failure to achieve this standard can result in the barrier having an adverse impact on the fisheries and juvenile production upstream and on the survival of smolts and kelts moving downstream. For those passes constructed so as to allow passage of salmon over existing impassable obstructions, any movement of fish through the pass will be an improvement over the existing circumstances. Nevertheless, once natural salmon production has become established in the area upstream of the obstruction, inadequacies in the fish pass may cause new fishery management problems.

A measure of the efficiency of passes is therefore necessary for the following purposes:

- to evaluate the performance of passes in existing and new obstructions;
- to identify those passes where improvements would be of greatest benefit to the stocks;
- to evaluate the result of any modifications; and
- to provide information for the improvement of fish pass design.

As an initial approach, efficiency might be defined as the ratio of output to input, and this would apply both to fish passing upstream and downstream. Thus:

$$\text{Efficiency of a pass} = \frac{\text{Number of salmon safely passing the obstruction}}{\text{Number of salmon approaching the obstruction}}$$

Even if the pass was 100% efficient, a number of other factors must also be taken into account when assessing the effects of a pass on the salmon population, including whether:

- the upstream or downstream movements are delayed, thus for example reducing the numbers of adults that reach certain spawning areas or affecting the survival of smolts when they eventually reach the sea;
- the passage through the pass may affect the vulnerability of fish, particularly smolts, to predation; or
- the spawning success of the adult salmon is affected.

If the pass is not 100% efficient it may also be selective, limiting the passage of, for example, large or small fish, or early- or late-running fish.

6.2 MEASURING EFFICIENCY

6.2.1 Monitoring programmes

In order to assess the effects of an obstruction or the efficiency of a pass, it is our view that it is desirable to have information about the movement of fish before construction and to be able to compare this information with corresponding information after completion.

An effective monitoring programme should be incorporated into any proposal to build a fish pass. Ideally, the efficiency of the pass should be determined by counting the number of fish approaching the obstruction and the number exiting the pass. In addition, the behaviour of the fish should be investigated both as they negotiate the obstruction and subsequently. In practice this would require that counters be installed both downstream and upstream of the pass and that telemetry studies and other investigations be conducted on fish using the pass. This would usually be prohibitively expensive, and so a more limited monitoring programme may be appropriate.

In addition to studying the movements of individual fish, information on the state of the whole fish population, and on the fisheries, may assist in assessing the efficiency of a pass. The parameters which might be used include the numbers of early- and late-running fish moving upstream, the numbers of smolts and kelts migrating downstream, the catch per unit effort in fisheries above and below the obstruction, and redd counts and juvenile surveys above the pass. It should, however, always be remembered that there are large annual fluctuations in these parameters and for this reason they cannot be used to measure percentage efficiency.

6.2.2 Observations

Observations of numbers of fish accumulating below an obstruction, or jumping but failing to negotiate it, may indicate that a pass is required or that an existing pass is not working satisfactorily. Reduction in the numbers accumulating might therefore be expected if improvements had been made to the pass. However, such data are difficult to quantify and so will only be indicative of an improvement.

6.2.3 Fish counters

Placing resistivity fish counters both upstream and downstream of a new pass will generally be impractical, but the growing use of hydro-acoustic counters may provide a more adaptable method for installing counters in such locations for limited periods. It will also often be possible to build a counter into the pass itself, and many pass designs are well-suited to such installations. It is important that all counters are thoroughly tested and validated. Such counters should then provide information on the numbers and size of fish using the pass and the timing of their movements, without the need for catching or handling them, but will not provide information on the behaviour of fish approaching or leaving the pass.

Equipment currently available is generally less efficient at counting fish moving downstream than upstream. This is largely because of the swimming behaviour of the fish and the small size of smolts. Data on kelt movements may also be of limited value because both the number of kelts and the timing of their migration can be very variable between years.

6.2.4 Video surveillance

Time-lapse video recording has been widely used to validate fish counters[4,7]. Such overhead or underwater cameras might also be used to investigate the behaviour of fish in certain types of pass. For example video monitoring of the upper chamber of a Borland lift pass could be used to check that salmon exit from the lift and do not remain in the pass. Cameras could also be used to observe the behaviour of fish close to the entrances or in the pools of a pass.

6.2.5 Tracking

Tracking provides a means of studying the behaviour of fish in normal and modified environments. Modern telemetry techniques permit fish over about 10 cm long to be individually marked with radio or acoustic transmitters and then followed. This can provide information on their movement past the obstruction and their subsequent behaviour. Ideally, such movement should be compared with the behaviour of fish before the construction of the pass.

Telemetry tags may also be used to relay information on the activity of fish, their energy consumption or other physiological parameters. The opportunity to study heart rates, tail beat frequency and muscle activity in fish provides the basis for learning significantly more about the behaviour of fish at an obstruction, and the effort required and stress experienced on passage.

6.2.6 Redd counts

Redd counts can provide a crude estimate of the number of adult salmon spawning in a stream. However, redds are not always easy to count accurately and recent work carried out on the Girnock burn, a tributary of the River Dee in Aberdeenshire[8], has shown clearly that the number of redds is not necessarily a reflection of the number of female fish present on the spawning grounds. In addition, redd numbers may vary greatly from year to year in response to a range of factors. As a result, when assessing the efficiency of a new fish pass, observations of redds may at best be used only to assess changes in the distribution of spawners.

6.2.7 Juvenile densities/distributions

Comparison of fish population surveys conducted by electro-fishing in nursery streams before and after construction of the fish pass, may provide an indication of changes in the number of adult fish successfully reaching the spawning grounds. In the absence of surveys conducted before the construction of a barrier, estimates of the juvenile population can be compared with expected levels using data from other sites or numbers considered to be appropriate based upon systems such as 'Habscore'[9].

6.2.8 Catch statistics

Changes in catches, and more particularly catch per unit of effort, may also indicate changes in the numbers of adult salmon in certain stretches of the river. Thus statistics obtained from fisheries operating immediately downstream of the obstruction may indicate whether fish are being delayed by an obstruction. Alternatively, increases in the catches upstream of the barrier may indicate that more fish are getting past. However, catches and catch rates can be affected by many different factors (e.g. the number of fish returning to the river, river flow, temperature etc.) and only substantial changes over several years are likely to be statistically significant.

6.3 MAINTENANCE OF PASSES

There is a legal requirement that passes be maintained in a manner which will ensure that they perform efficiently. A small reduction in the operational effectiveness of each of a series of passes can substantially increase the loss of fish in a system. Thus it is particularly important that the efficiency of a fish pass is not permitted to deteriorate as a result of poor maintenance. A poorly maintained pass may present a greater obstacle to migrating fish than no pass at all.

Passes may become blocked by debris or be deliberately obstructed by vandals or poachers; they should therefore be inspected regularly for damage and be kept clear, particularly when fish are likely to be migrating. In circumstances where a debris screen is installed it should be kept clean to allow the free passage of fish.

It is important that the cost of maintenance is taken into account when planning a fish pass. It may, for example, be appropriate to incur a greater capital expenditure in order to reduce future maintenance costs.

PART II

7. FISH SCREENS

7.1 BACKGROUND

Fish may be damaged or lost by being drawn into power-generating plants, pumping stations or other intakes, and it is necessary to protect salmon from these and similar hazards. Intakes and discharges should therefore be screened where either juvenile or adult salmon may be at risk. This was recognised as early as 1804 in the Solway Act which contains a provision requiring screens to prevent any fish being drawn into irrigation systems.

More generally, the legal requirement for screens developed from the need to prevent adult fish entering mill lades either on their upstream migration to spawn or as kelts returning to the sea. In these early mills, the speed of rotation of the water wheel was low and the space between each paddle was quite large so that the potential for damage to smolts migrating downstream was low. However, with the development of turbines to generate electricity, the speed of rotation became higher and the water space between the blades much smaller, and, as a result, there is greatly increased risk of damage to smolts. In the extreme case, any smolt entering a Pelton turbine would be killed. The recognition of the need to prevent the access of adult salmon into the area of the mill wheel, where damage could occur to the fish, resulted in the introduction of legislation on the provision of screens.

In Scotland, regulations were made in 1865 which introduced a requirement for screens to prevent access by adult fish from both above and below mill wheels. The screens were required to have bars not more than 3 inches apart if horizontal or 2 inches apart if vertical. There was also a recommendation that the channel be widened at the location of the screens and that the screens be angled or curved across the stream, thereby increasing their length so that the aggregate of the area of the openings in the screens exceeds the sectional area of the lade, thus avoiding any increase in water velocity at the screen. The regulation provided for the redirection of smolts by means of a 'by-wash' sluice with a sill set as low as the bottom of the mill lade which must be operated for at least five hours each week from 15 March to 1 July with not more than six days intervening between each time of opening. These regulations were incorporated as Schedule G of the Salmon Fisheries (Scotland) Act 1868.

In England & Wales, the Salmon and Freshwater Fisheries Act 1923 placed an obligation on operators of mills, water undertakings and canals, which took water from a river with migratory fish, to protect the intake with screens approved by the Minister. The requirement did not extend to mills where the channel or conduit was constructed before 1923.

The development of hydro-electric projects in Galloway in the 1930s, and in the north of Scotland after World War II, resulted in many intakes where it was necessary to provide screens to protect smolts. The then North of Scotland Hydro-Electric Board adopted a mesh size of 1 inch (25 mm) horizontal by ½ inch (12.5 mm) vertical and this has generally been used subsequently where smolt screens were required.

7.2 REQUIREMENTS FOR SCREENS

Screens may be required to exclude fish which may be drawn into intakes or abstraction points and fish which may be attracted into outfalls. Different types of screen may be appropriate in these different circumstances and the design of the screen will also be affected by the size and life-stage of fish to be excluded. There may be different problems excluding fish from intakes and outfalls in tidal waters because of the different migratory behaviour of the smolts and adults in such locations.

7.2.1 Intakes

Downstream migrating smolts or kelts may move or orientate with the current and are thus vulnerable to being drawn into intakes. There is good evidence that significant numbers of smolts can be drawn into intakes to power-generating plants or fish farms. Studies on the River Tummel suggested that in the early 1960s at least 10% of smolts were lost due to acute trauma on passing through Kaplan turbines at each hydro-electric power dam on the river[10]. More recently, trials using hatchery smolts undertaken in the early 1990s at a low-head Kaplan turbine on the River Morar[11] revealed acute loss rates of some three to four times those recorded for wild smolts on the River Tummel[10]. Mortalities of kelts through turbines are likely to be considerably greater[12]. Many smolts may be drawn into some fish farms each year when intakes are inadequately screened[13]. Mortalities of smolts in such situations are generally close to 100% unless action is taken to rescue them. Resident fry may also be drawn into intakes, but the effect of this loss on the population will usually be relatively small.

The likelihood of fish entering intakes will depend to some extent upon the proportion of the river discharge which is taken and the behaviour of the fish. Even a relatively small abstraction point just above an obstruction (e.g. a weir) may entrain a disproportionately large number of smolts. However, it is possible that a well-designed abstraction may not take any smolts.

The main problem of putting gratings on intakes is that they can become clogged with debris. Partial obstruction of a screen will increase the velocity of water through it, resulting in the loss of fish, and may also affect the abstracting facility. Various means may be used to minimise these problems. It may also be possible to restrict the times of year when screens must be in place (e.g. during smolt runs) in order to reduce the impacts on operations. Smolts and kelts may be expected to migrate over a predictable period of the winter and spring and the operation of screens may be restricted while still affording protection. However, in some rivers, there is also a downstream migration of parr in the autumn.

7.2.2 Outfalls

Adult salmonids moving upstream to spawn may be attracted to outfalls because of the nature of the flow (e.g. a strong flow out into a slow-moving stretch of the river). If the facility takes a sufficiently large proportion of the river flow, fish may be attracted to the outflow simply because it appears to them to be the main river channel. Fish might also be attracted to outfalls from fish farms because of some chemical attractant produced by the fish in the farm (e.g. pheromones). Although fish entering outfalls may not always be damaged, they may find it difficult (or be unwilling) to find their way back to the main river channel.

The problem of attraction may be exacerbated at some sites (e.g. fish farms) by the reduced flows in the main stream between the abstraction and discharge points and by weirs used to provide a head of water. The effects will tend to be greatest when river flows are low because a greater proportion of the water is diverted through the farm. As a result the problem may be greatest on chalk streams where fish are more likely to migrate upstream under moderate flow conditions.

One of the risks of putting screens on outfalls is that they may act as a one-way valve for fish of a certain size. That is to say, whatever size of screen is installed there are likely to be some fish, smaller than those that the screen is designed to exclude, that can get upstream through it. These fish will find it difficult to return and may therefore be at risk.

Screens on outfalls are less likely to become blocked than those on intakes, and blockages are less likely to cause operating problems at the facility. For example, screens can be designed to overflow when they become blocked in such a way that they do not allow fish moving upstream to get past.

8. REGULATIONS RELATING TO SCREENS

8.1 LEGISLATION

The legislative requirements for screens are different in England & Wales and in Scotland. The arrangements in each jurisdiction are set out below.

8.1.1 Legislation in England & Wales

The legislation which is applicable to the provision of screens is contained in Sections 14 and 15 of the Salmon and Freshwater Fisheries Act 1975 as amended (see Appendix C). Some of these amendments do not come into effect until 1 January 1999.

Until 1 January 1999, **Section 14** applies in situations where water is diverted by means of a conduit or artificial channel for use for the purposes of a water or canal undertaking or a mill defined in the Act. It requires the owner of the undertaking or occupier of the mill to place and maintain, at his own expense, a grating or gratings across the conduit or artificial channel for the purpose of preventing the descent of salmon. He must also place a grating or gratings across the outfall channel to prevent salmon entering the outfall. In both cases, the grating must be constructed in such manner and placed in such a position as may be approved by the Minister. The obligation imposed on mill channels and conduits by this Section of the Act applies only to those constructed on or after 18 July 1923.

With effect from 1 January 1999, the amended **Section 14** comes into effect. This places an obligation on owners of water and canal undertakings, occupiers of mills and, for the first time, owners or occupiers of fish farms to place and maintain a screen across or within any conduit or channel which diverts water from waters containing salmon and migratory trout. It also requires that screens are placed across any outfall. The new provision specifies that the purpose of such screens is to prevent the descent or entry of salmon or migratory trout into such channels or conduits and, in the case of conduits and channels which divert water for the use of a fish farm, to prevent the escape of farmed fish.

The new provision requires that where screens are placed within a channel or conduit, a continuous by-wash is provided immediately upstream of the screen by which salmon and migratory trout can return to the waters from which they entered the channel or conduit.

The term 'screen' is defined as meaning a grating or other device or apparatus, the operation of which prevents the passage of salmon or migratory trout and, if appropriate, farmed fish. The new provision therefore allows for a wider range of devices to be used than previously.

The Environment Agency has the power to grant exemptions from the requirement to install gratings and to make byelaws specifying the period during which screens need not be placed or maintained.

Section 15 which allowed the National Rivers Authority, with the consent of the Minister, to install gratings at its own expense has also been amended. From 1 April 1996, Ministerial approval will no longer be required and the Environment

Agency can install gratings at its own expense. From 1 January 1999 the term 'grating' will be replaced with 'screen' to bring it into line with the amended Section 14.

We note that the regulations apply only to intakes for mills (except those constructed before 1923), water undertakings and fish farms. In addition, even in circumstances where the law requires intakes to be screened, few screens have been approved. Thus, although there are over 14,000 licensed abstractions from non-tidal waters in England & Wales, few of these have screens. We believe that, in general, all intakes and outfalls on salmon rivers should be screened.

8.1.2 Legislation in Scotland

The Salmon Act 1986 made provision for legislation in Scotland in relation to screens. Section 3 paragraph 2 states that the Secretary of State shall have power to make regulations with respect to:

> 'the construction, alteration and use for the control of the passage of salmon of:
>
> (i) screens in offtakes for inland water; and
>
> (ii) structures associated with such screens.'

Regulations have been made under that power and they apply to all offtakes. These Regulations are reproduced in full at Appendix D. The main provisions are:

- operators of every offtake shall ensure that there is a smolt screen either at the entrance or in the offtake. If it is in the offtake it should be provided with a continuous by-wash through which smolts may return to the river;
- where an offtake returns water to inland waters, the operator must ensure that a screen is provided at the downstream outlet to prevent adult salmon entering;
- a screen may be constructed in a form which prevents adult salmon or smolts, as the case may be, passing through and it must be built to ensure that salmon are not injured or damaged by it; and
- both the construction and maintenance of a screen must be carried out in such a way as to ensure the minimum practicable interruption to the passage of salmon.

Further details of the legislation and procedures are provided in the Scottish Office publication, *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon*[2].

8.2 APPROVAL PROCEDURES

The procedures for obtaining approval for the installation of a screen are different in England & Wales from those in Scotland, as a result of differences in the legislation referred to in Section 8.1.

8.2.1 Approval procedure in England & Wales

The procedures which apply until 1 January 1999 require approval by the Minister for screens covered by Section 14 of the Salmon and Freshwater Fisheries Act 1975. From 1 January 1999, the Environment Agency will take over the responsibility for approving screens. Screens constructed by or on behalf of the Environment Agency under Section 15 do not require approval under the Act.

A typical chain of events leading up to the provision of a screen on a new or existing intake might be as follows:

Consult with the Agency to determine whether an intake or outfall requires or will require an approved screen.

↓

Design a screen for the site.

↓

Submit design to the Minister/Agency for approval.

↓

Submit application to the local planning authority if required.

↓

Construct the screen.

8.2.2 Procedure in Scotland

In Scotland, the Regulations have direct effect and thus there is no provision for official approval of the design or of the completed screen. It is appropriate to consult the Scottish Office publication, *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon*[2].

The chain of events might be as follows:

Determine whether the proposed or existing inlet or outlet needs a screen as required by the Regulations, consulting with the District Salmon Fishery Board and/or The Scottish Office as appropriate.

↓

Design a screen for the site.

↓

Submit application to local planning authority if required.

↓

Construct the screen.

8.3 ASSESSMENT OF PERFORMANCE

There is currently no requirement in the legislation in England & Wales to assess the performance of a screen or to ensure that it is maintained. However, from 1 January 1999 there will be a requirement for screens to be so constructed and located as to ensure, so far as reasonably practicable, that salmon or migratory trout are not injured or damaged by them, and that screens are maintained. Similar requirements apply in Scotland, where any screen or by-wash provided in accordance with the regulations shall be so constructed and located as to ensure, so far as reasonably practicable, that salmon or migratory trout are not injured or damaged by it. In addition, the operator of a dam or offtake must carry out any maintenance in such a manner as to ensure the minimum practicable interruption to the passage of salmon.

9. TYPES OF SCREENS

The subject of screens has been extensively studied and is reported on in the National Rivers Authority R & D Report No. 1, *Diversion and Entrapment of Fish at Water Intakes and Outfalls*[14]. In addition, a useful review of various types of screens is contained in Appendix B of the Scottish Office publication, *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon*[2], and is reproduced in full at Appendix F of this report. This report distinguishes two types of screens: physical screens which prevent the passage of fish by mechanical means (i.e. meshes or bars) and behavioural screens which dissuade fish from entering intakes and outfalls by electrical fields, louvers, sound etc. They are based on quite different concepts and give rise to different design requirements (see Section 10.2).

10. DESIGN OF SCREENS

10.1 APPROACH

The usual approach to designing a screen is to follow a series of steps, broadly as follows.

- Establish the purpose of the screen, determining the size for adult or juvenile salmon to be excluded.
- Determine the layout of the intake or outfall to be screened.
- Obtain information on the hydraulic conditions at the screen location, and the maximum velocity which is acceptable to the life-stage of the salmon being screened.
- Select the type of screen most suitable for the location in accordance with any relevant regulations.
- Design the screen so that it will operate effectively over the full range of expected flows.
- Ensure that there is a safe alternative passage to carry fish past the intake or outfall.

10.2 IMPORTANT DESIGN FEATURES

10.2.1 Physical screens

The most important features of physical screens are:

- the velocity of the water approaching the screen;
- the mesh size or bar spacing of the screen; and
- the design of the bypass facilities.

Swimming speeds and endurance of salmon have been reviewed in Section 5.5. They are particularly relevant to the design of screens to exclude kelts and juveniles from intakes during their migration downstream. It should be remembered that smolts and kelts are less inclined to stem the current and must be able to find a bypass route quickly because of their inability to sustain high swimming speeds for extended periods.

The swimming speed of smolts is dictated by their length, which may be less than 10 cm for the smallest individuals. It is therefore recommended that the velocity of the water passing through a screen should not exceed 0.25 m s^{-1} except in circumstances where fish can quickly and safely move out of the area of influence of the intake. Where a screen is placed across a channel it should be easy for fish to find the bypass. Screens set at an angle to the flow are often more effective because they increase the total screen area and can lead the fish towards the bypass channel. There must, of course, be an adequate flow of water in the bypass channel to return the fish safely to the river.

Appropriate mesh sizes for fish of different sizes are discussed at Appendix F. The choice of an appropriate mesh size may be critical in preventing the intake of fish while still limiting the accumulation of debris. If the screen becomes blocked by debris, this will result in the water velocity increasing close to the screen.

The screen should be oriented so the pattern of flow tends to move fish directly into the bypass channel. The positioning of the bypass channel is also critical. It should be placed as close as possible to the screen in order that the fish move straight into it and are returned to the river as soon as possible.

10.2.2 Behavioural screens

Behavioural screens operate by deterring fish from taking a particular path rather than by imposing a physical barrier to their movements. They are most likely to be effective in deterring upstream migrating fish from entering outfalls. The main ways in which they may fail are, therefore, that:

- their effectiveness varies under different river conditions (e.g. flow or turbidity);
- their effectiveness varies for different groups of fish (e.g. size);
- the fish become acclimatised to the deterrent signal and may ignore it; and
- the fish cannot find the bypass channel sufficiently quickly.

None of the behavioural screens currently available is totally effective. This is particularly true for intakes, where fish may be swept in by the current if they do not respond to the deterrent signal. In higher flows, fish may be moved towards the intake more quickly and a stronger deterrent signal may be required. In addition, if turbidity and ambient noise levels increase at higher flows, both visible and audible deterrents will become less effective. In the case of louver screens, if the flow is reduced or stopped the fish may not be deterred from swimming freely between the louvers; they will then be on the wrong side of the screen when the flow is restarted.

There has been little research on the effectiveness of different behavioural deflectors on different groups of fish. However, recent work on the use of sound to deflect fish suggests that different frequencies or patterns of sound may be appropriate for fish of different sizes or species[15]. It is possible that there may be similar differences for other behavioural deterrents.

The location of the bypass channel is particularly important when behavioural screens are employed. The fish must be moved quickly and easily towards the bypass channel and it is likely that a greater by-wash flow will be required than for a physical screen.

11. EFFICIENCY OF SCREENS

11.1 DEFINING EFFICIENCY

It is possible for significant numbers of migrating salmon smolts or adults to be drawn into intakes, and it is therefore important to ensure that the screens are working effectively. To be considered totally efficient, a screen must permit safe passage past the abstraction or outflow point for all fish that it is designed to exclude. In practice, many screens fail to meet this standard.

Some measure of the efficiency of screens is required for the evaluation of the performance of existing and new screens and for the identification of appropriate remedial work. We recognise that, in addition to excluding fish, a screen will be designed to allow free passage of water through it. In assessing the efficiency of screens, measurement of their performance, both in excluding fish and in allowing free passage of water, will normally be addressed. In this report we consider only their efficiency in excluding fish.

An initial approach to the assessment of the performance of a screen could be based on the proportion of the fish successfully passing a screened abstraction or outflow, and its efficiency can then be described as:

$$\text{Screen efficiency} = \frac{\text{Number of fish passing the area of influence of the screened intake or outflow}}{\text{Number of fish approaching the area of influence of the screened intake or outflow}}$$

However, even if a screen is totally efficient, as measured in this way, it may still have other effects on the fish. Thus, it is also important to assess whether fish are:

- being delayed in finding a bypass channel;
- having to expend extra energy to avoid the intake; or
- suffering trauma or injury which will affect subsequent behaviour or survival (e.g. by predation).

11.2 MEASURING EFFICIENCY

11.2.1 Observations

The first approach to assessing whether a screen is working effectively is to observe whether fish are:

- found on the wrong side of the screen;
- holding position upstream of the screen; or
- being trapped on the screen.

11.2.2 Tagging and telemetry

If losses are observed (e.g. fish impinged on screens), more detailed assessments of the proportion of the population being affected can be made by marking a sample of fish. A large variety of marking methods is now available. The proportion of the marked fish caught on the screen will provide an estimate of the proportion of the whole population that is killed in this way. However, it may be more difficult to estimate the numbers killed in other ways, such as being drawn into turbines or taken by predators. To assess these losses, it will be necessary to make a subsequent estimate of the numbers of tagged fish surviving. This is unlikely to provide an accurate estimate of the total losses.

In order to obtain information on unobserved losses and sublethal effects on fish, it may be necessary to employ more sophisticated methods such as the use of telemetry tags. These may be used to study the behaviour of fish moving past the screen and to see whether their subsequent behaviour is modified. Tags may also relay physiological information about the fish indicating whether, for example, they are having to exert extra energy to avoid the intake.

11.3 MAINTENANCE OF SCREENS

It is important that all screens are maintained in a manner which will ensure that they perform efficiently. They must, therefore, be inspected regularly to ensure that:

- they are being operated correctly;
- debris is not being allowed to accumulate;
- they have not been damaged by debris or vandalism; and
- bypass channels are kept clear.

It will generally be in the interests of the operators of intakes to ensure that screens are kept clear of debris, but this is also essential for the protection of fish migrating past the intake. If debris is allowed to accumulate on a screen, the free area for water to pass through will be decreased. This will result in the water velocity through the screen being increased, making it more difficult for fish to avoid being impinged.

Mesh and bar screens are generally mounted on panels which slide into fixed frames. These frames must be kept clear of debris to ensure that the screens are correctly placed and that fish cannot get around them. Screens must also be inspected regularly for damage; relatively small holes may create an attractant flow that will result in significant numbers of fish being killed.

In the case of behavioural screens and louvers, it is important that operating procedures are observed. For example, if the water flow is reduced or switched off fish may swim straight through louvers and thus be vulnerable to the intake when flow resumes.

PART III

12. FUTURE RESEARCH ON PASSES AND SCREENS

12.1 FISH PASSES

Most passes have been designed to facilitate the upstream movements of migratory fish and little is known of their effectiveness for downstream migrants. Further information is required on the effects of passes, such as denil passes, on fish moving downstream, particularly on adult fish which may be damaged by baffles. Research is also required into the behaviour of smolts and kelts moving downstream into passes and in particular into their responses to the high local acceleration of water as it flows from the deep areas immediately upstream of a dam over the sill of a pass. Studies are needed of the configuration of the entrance to the pass which will provide lower accelerations.

While a considerable amount of work has been conducted on the appropriate hydraulic characteristics of passes, less is known about the way salmon find the upstream or downstream entrance to a pass. More work is therefore required to investigate the detailed movements of fish close to passes.

Fish probably move up river using simple behavioural rules; such as swimming against the water flow and responding to velocity gradients. If the flow regime in the vicinity of a pass entrance is mapped, then the movements of a fish could be simulated by a computer model. Such a model could be tested by comparing the results with careful observations of fish in the wild. A model could be helpful in eliminating some errors in fish pass design and spotting potential problems before construction begins.

The energy usage of a fish passing upstream through a structure could also be modelled using computer techniques. If the flow velocity at different points along the channel is measured then a 'fish' can be started off in a computer model at the bottom of the fish pass. For each time interval, velocity and distance travelled can be calculated and the depletion of white muscle glycogen and build up of lactic acid estimated. In this way, the 'fish' can be allowed to ascend the pass and its point of exhaustion predicted. The simulation exercise would be run for 'fish' of different sizes and at different water temperatures. A criterion could be set that a fish should be able to complete its journey through a pass without depleting its white muscle glycogen reserves by more than a certain amount. This kind of simulation could investigate different pass configurations.

Modelling of the overall passage of fish through a series of obstructions involving passes and screens may assist in taking decisions on making improvements at one or more sites. The costs and benefits of big improvements at one site versus small improvements throughout the system could be compared objectively (remembering always the constraints and assumptions of the model).

12.2 FISH SCREENS

To be fully effective, most screens depend upon the fish being able to find an alternative route past the intake or outfall. More research is required on the design of bypass channels that fish will readily use. There are clear parallels between such research and the studies of fish finding the downstream entrance to fish passes.

More information is required on optimum mesh sizes and bar spacings of physical screens that will exclude salmon. In particular, work is required on the appropriate bar spacings to exclude adult fish. In addition, because upstream migrating fish may be more inclined to force their way through a narrow gap, closer spacing may be required to prevent upstream movement than downstream and this requires further investigation.

There is relatively little information on the effectiveness of most behavioural screens. Where studies have been conducted they generally suggest that, except in the case of louvers, such screens deter a relatively small proportion of the fish or deflect fish only a small distance. However, there may be many circumstances where this would be sufficient to allow fish to avoid an intake and there is therefore considerable scope for their further development for some sites. Nevertheless, further studies will be required on the effectiveness of such screens if they are to gain approval for use under the current legislation in England & Wales or to be considered satisfactory in Scotland.

12.3 TAGGING AND TELEMETRY

Many studies of passes and screens will depend upon tracking and telemetry techniques. There have been rapid developments in this field in recent years. However, in relation to the studies outlined above, there is a particular need for tags which provide more information on the physiological status of the fish and its detailed behaviour. This will require the development of improved sensors and more precise tracking methods.

13. CONCLUSIONS

We have noted that there have been substantial changes to the regulations relating to fish passes and screens made by the Salmon (Fish Passes and Screens) (Scotland) Regulations 1994 and under the Environment Act 1995. These have extended the requirements for installing passes and screens in Scotland and in England & Wales.

13.1 FISH PASSES

We consider that, in general, there should be a fully effective fish pass on each existing or new man-made obstruction on a salmon river. The objective for the design and operation of all fish passes for salmon is that they will ensure the safe and successful passage of all the fish at whatever stage of the life-cycle migrating either upstream or downstream.

An environmental assessment will generally be required when any new obstruction is proposed. This should include a detailed assessment of the expected performance of any pass. We acknowledge that there will be locations where extending the range of salmon by installing a pass on natural obstructions or existing man-made barriers is not appropriate in order to avoid interference with established ecosystems and natural fisheries. As a result, the impacts of any such plan should be fully assessed.

People considering the installation of a pass should be aware that there are a large variety of different types. They should therefore consider which of these is most appropriate to their particular site bearing in mind the nature of the river and the salmon population.

We note that in England & Wales, the Environment Agency will be called upon to approve all new fish passes. This will include passes in any proposed barrier to which the Agency itself may have a conflicting interest as the main objector or promoter of the proposal. We consider that some means of arbitration may be required to resolve potential conflicts of interest in such circumstances.

We consider that there is insufficient definition of the required standards for the performance of fish passes in the legislation in England & Wales and recognise that in Scotland it depends ultimately on an uncertain decision of the courts. It would be helpful to have a practical definition of the efficiency of passes. We suggest that efficiency should be measured by the ratio of the number of fish approaching the obstruction to the number getting past. We recognise the difficulty or impracticability of measuring efficiency in many circumstances but consider that the efficiency of passes could be most effectively assessed by the use of fish counters or appropriate tagging or tracking studies.

When assessing the efficiency of passes, we recommend that operators should also assess whether:

- the upstream or downstream movements are delayed;
- the passage through the pass may affect the vulnerability of fish, particularly smolts, to predation;

- the behaviour or spawning success of the adult salmon is affected; and

- the pass is selective.

We recommend that, wherever possible, the efficiency of all fish passes, both existing and newly installed, should be assessed.

We wish to emphasise the need for all fish passes to be regularly inspected to ensure they are operating efficiently.

13.2 SCREENS

The objective for the design and operation of screens for the exclusion of salmon should be that they will ensure the safe and successful passage of all these fish migrating either upstream or downstream.

We note that the Environment Act 1995 has introduced a new requirement to place screens on the intakes and outfalls of all fish farms in England & Wales but we are surprised that there is no screening requirements for industrial and agricultural abstractions and for mill channels constructed prior to 18 July 1923. We recommend that, in general, all intakes and outfalls on salmon rivers should be suitably screened as required under the Scottish regulations.

We suggest that the efficiency of screens should be measured on the same basis as suggested for passes, namely the ratio of the number of fish approaching the area of the intake or outfall to the number safely passing it.

When assessing the efficiency of screens, we suggest that operators should also assess whether fish are:

- being delayed in finding a bypass channel;

- having to expend extra energy to avoid an intake; and

- suffering injury which will affect their subsequent survival (e.g. by predation).

We recommend that, wherever possible, the efficiency of all fish screens, both existing and newly installed, should be assessed.

We emphasise the need for screens to be regularly inspected, cleaned and maintained to ensure they are operating efficiently.

APPENDIX A

MEMBERSHIP OF THE SALMON ADVISORY COMMITTEE

Chairman: Mr R M Clerk

Mr G H Bielby	Mr I Mitchell
Mr C G Carnie	Mr M Owens
Mr J H Ferguson	Mr D R Paton
Mr D Heselton	Dr D J Solomon
Dr L M Laird	

PREVIOUS REPORTS BY THE SALMON ADVISORY COMMITTEE

- *Information on the Status of Salmon Stocks* published in September 1988. Ref. No. PB 2021, price £3.
- *The Effects of Fishing at Low Water Levels* published in March 1989. Ref. No. PB 0176, price £3.
- *Factors Affecting Natural Smolt Production* published in May 1991. Ref. No. PB 0535, price £3.95.
- *Assessment of Stocking as a Salmon Management Strategy* published in September 1991. Ref. No. PB 0641, price £1.50.
- *Factors Affecting Emigrating Smolts and Returning Adults* published in May 1993. Ref. No. PB 1270, price £4.
- *Run Timing of Salmon* published in June 1994. Ref. No. PB 1797, price £4.95.
- *The Effects of Predation on Salmon Fisheries* published in July 1996. Ref. No. PB 2514, price £4.
- *The Anti-poaching Measures Contained in the Salmon Act 1986* published in July 1996. Ref. No. PB 2515, price £4.

Copies of these reports may be obtained from:
MAFF Publications, London, SE99 7TP

APPENDIX B

GLOSSARY OF SCIENTIFIC SYMBOLS USED IN THIS REPORT

Measurement	Units	Symbols
Distance/length	Metre	m
Velocity	Metres per second	$m\ s^{-1}$
Flow/discharge	Cubic metres per second	$m^3\ s^{-1}$
Volumetric power dissipation	Watts per cubic metre	$W\ m^{-3}$
Temperature	Degrees Celsius	°C

APPENDIX C

SALMON AND FRESHWATER FISHERIES ACT 1975: SECTIONS RELATING TO FISH PASSES AND SCREENS MARKED UP AS AMENDED BY THE ENVIRONMENT ACT 1995

Changes enter into force on 1 April 1996 unless otherwise indicated.

N.B. In the following:

underlining = text inserted by the 1995 Act

text struck through = text deleted by the 1995 Act

italics = text to be deleted on 1 January 1999

square brackets = parts of Act entering into force on 1 January 1999

all references to 'water authority' are to be construed as references to the Environment Agency

Duty to make and maintain fish passes.

9.-(1) Where in any waters frequented by salmon or migratory trout-

(a) a new dam is constructed or an existing dam is raised or otherwise altered so as to create increased obstrution to the passage of salmon or migratory trout, or any other obstruction to the passage of salmon or migratory trout is created, increased or caused; or

(b) a dam which from any cause has been destroyed or taken down to the extent of one-half of its length is rebuilt or reinstated,

the owner or occupier for the time being of the dam or obstruction shall, if so required by notice given by the water authority and within such reasonable time as may be specified in the notice, make a fish pass for salmon or migratory trout of such form and dimensions as the Agency ~~the Minister~~ may approve as part of the structure of, or in connection with, the dam or obstruction,and shall thereafter maintain it in an efficient state.

(2) If any such owner or occupier fails to make such a fish pass, or to maintain such a fish pass in an efficient state, he shall be guilty of an offence.

(3) The water authority may cause to be done any work required by this section to be done, and for that purpose may enter on the dam or obstruction or any land adjoining it, and may recover the expenses of doing the work in a summary manner from any person in default.

(4) Nothing in this section-

(a) shall authorise the doing of anything that may injuriously affect any public waterworks or navigable river, canal, or inland navigation, or any dock, the supply of water to which is obtained from any navigable river, canal or inland navigation, under any Act of Parliament; or

(b) shall prevent any person from removing a fish pass for the purpose of repairing or altering a dam or other obstruction, provided that the fish pass is restored to its former state of efficiency within a reasonable time; or

(c) shall apply to any alteration of a dam or other obstruction, unless-

(i) the alteration consists of a rebuilding or reinstatement of a dam or other obstruction destroyed or taken down to the extent of one-half of its length, or

(ii) the dam or obstruction as altered causes more obstruction to the passage of salmon or migratory trout than was caused by it as lawfully constructed or maintained at any previous date.

Power of water authority to construct and alter fish passes

10.-(1) Any water authority may, ~~with the written consent of the Minister~~ construct and maintain in any dam or in connection with any dam a fish pass of such form and dimensions as it may determine, ~~as the Minister may approve~~ so long as no injury is done by such a fish pass to the milling power, or to the supply of water of or to any navigable river, canal or other inland navigation.

(2) Any water authority may, ~~with the written consent of the Minister~~ abolish or alter, or restore to its former state of efficiency, any existing fish pass or free gap, or substitute another fish pass or free gap, provided that no injury is done to the milling power, or to the supply of water of or to any navigable river, canal or other inland navigation.

(3) If any person injures any such new or existing fish pass, he shall pay the expenses incurred by the water authority in repairing the injury, and any such expenses may be recovered by the water authority in a summary manner.

Approvals for fish passes

11.-(1) Any approval given by the Agency to or in relation to a fish pass may, if in giving it the Agency indicates that fact, be provisional until the Agency notifies the applicant for approval that the pass is functioning to its satisfaction.

(1A) The applicant for any such approval-

(a) shall be liable to meet any costs incurred (whether by him or by the Agency or any other person) for the purposes of, or otherwise in connection with, the performance of the Agency's function of determining for the purposes of subsection (1) above whether or not the fish pass in question is functioning to its satisfaction; and

(b) shall provide the Agency with such information or assistance as it may require for the purpose of performing that function.

~~(1) Any approval or consent given by the Minister to or in relation to a fish pass may, if in giving it he indicates that fact, be provisional until he notifies the applicant for approval or consent that the pass is functioning to his satisfaction.~~

(2) While any such approval ~~or consent~~ is provisional, the Agency ~~the Minister~~ may, after giving the applicant not less than 90 days' notice of its ~~his~~ intention to do so, revoke the approval ~~or consent~~.

(3) Where the Agency ~~the Minister~~ revokes a provisional approval given to a fish pass forming part of or in connection with a dam or other obstruction, it ~~he~~ may extend the period within which a fish pass is to be made as part of or in connection with the obstruction.

(4) The Agency ~~the Minister~~ may approve and certify any fish pass if it ~~he~~ is of opinion that it is efficient in all respects and for all purposes, whether it was constructed under this Act or not.

(5) Where a fish pass has received the approval of the Agency, ~~the Minister~~ and the approval has not been revoked, it shall be deemed to be a fish pass in conformity with this Act, notwithstanding that it was not constructed in the manner and by the person specified in this Act.

Penalty for injuring or obstructing fish pass or free gap

12.-(1) If any person-

(a) wilfully alters or injures a fish pass; or

(b) does any act whereby salmon or trout are obstructed or liable to be obstructed in using a fish pass or whereby a fish pass is rendered less efficient; or

(c) alters a dam or the bed or banks of the river so as to render a fish pass less efficient; or

(d) uses any contrivance or does any act whereby salmon or trout are in any way liable to be scared, hindered or prevented from passing through a fish pass,

he shall be guilty of an offence, and shall also in every case pay any expenses which may be incurred in restoring the fish pass to its former state of efficiency; and any such expenses may be recovered in a summary manner.

(2) The owner or occupier of a dam shall be deemed to have altered it if it is damaged, destroyed or allowed to fall into a state of disrepair, and if after notice is served on him by the water authority he fails to repair or reconstruct it within a reasonable time so as to render the fish pass as efficient as before the damage or destruction.

(3) If any person –

(a) does any act for the purpose of preventing salmon or trout from passing through a fish pass, or takes, or attempts to take, any salmon or trout in its passage through a fish pass; or

(b) places any obstruction, uses any contrivance or does any act whereby salmon or trout may be scared, deterred or in any way prevented from freely entering and passing up and down a free gap at all periods of the year,

he shall be guilty of an offence.

(4) This section shall not apply to a temporary bridge or board used for crossing a free gap, and taken away immediately after the person using it has crossed.

Gratings

14.-(1) Where water is diverted from waters frequented by salmon or migratory trout by means of any conduit or artificial channel and the water so diverted is used for the purposes of a water or canal undertaking or for the purposes of any mill, the owner of the undertaking or the occupier of the mill shall, unless an exemption from the obligation is granted by the water authority, place and maintain, at his own cost, a grating or gratings across the conduit or channel for the purpose of preventing the descent of the salmon or migratory trout.

(2) In the case of any such conduit or artificial channel the owner of the undertaking or the occupier of the mill shall also, unless an exemption is granted as aforesaid, place and maintain at his own cost a grating or gratings across any outfall of the conduit or channel for the purpose of preventing salmon or migratory trout entering the outfall.

(3) A grating shall be constructed and placed in such a manner and position as may be approved by the Minister.

(4) If any person without lawful excuse fails to place or to maintain a grating in accordance with this section, he shall be guilty of an offence.

(5) No such grating shall be so placed as to interfere with the passage of boats on any navigable canal.

(6) The obligations imposed by this section shall not be in force during such period (if any) in each year as may be prescribed by byelaw.

(7) The obligations imposed by this section on the occupier of a mill shall apply only where the conduit or channel was constructed on or after 18th July 1923.

[Screens

14.-(1) This section applies in any case where –

(a) by means of any conduit or artificial channel, water is diverted from waters frequented by salmon or migratory trout; and

(b) any of the water so diverted is used for the purposes of a water or canal undertaking or for the purposes of any mill or fish farm;

and in this section "the responsible person" means the owner of the water or canal undertaking or (as the case may be) the occupier of the mill or the owner or occupier of the fish farm.

(2) Where this section applies, the responsible person shall, unless an exemption from the obligation is granted by the Agency, ensure (at his own cost) that there is placed and maintained at the entrance of, or within, the conduit or channel a screen which –

(a) subject to subsection (4) below, prevents the descent of the salmon or migratory trout; and

(b) in a case where any of the water diverted is used for the purposes of a fish farm, prevents the egress of farmed fish from the fish farm by way of the conduit or channel.

(3) Where this section applies, the responsible person shall also, unless an exemption from the obligation is granted by the Agency, ensure (at his own cost) that there is placed and maintained, across any outfall of the conduit or channel a screen which –

(a) prevents salmon or migratory trout from entering the outfall; and

(b) in a case where any of the water diverted is used for the purposes of a fish farm, prevents the egress of farmed fish from the fish farm by way of the outfall.

(4) Where a screen is placed within any conduit or channel pursuant to subsection (2) above, the responsible person shall ensure that a continuous by-wash is provided immediately upstream of the screen, by means of which salmon or migratory trout may return by as direct a route as practicable to the waters from which they entered the conduit or channel (and accordingly nothing in subsection (2) or (3) above applies in relation to a by-wash provided for the purposes of this subsection).

(5) Any screen placed, or by-wash provided, in pursuance of this section shall be so constructed and located as to ensure, so far as reasonably practicable, that salmon or migratory trout are not injured or damaged by it.

(6) No such screen shall be so placed as to interfere with the passage of boats on any navigable canal.

(7) Any exemption under subsection (2) or (3) above may be granted subject to conditions.

(8) If any person who is required to do so by this section fails to ensure that a screen is placed or maintained, or that a by-wash is provided, in accordance with the provisions of this section, he shall be guilty of an offence.

(9) In any proceedings for an offence under subsection (8) above, it shall, subject to subsection (10) below, be a defence for the person charged to prove that he took all reasonable precautions and exercised all due diligence to avoid the commission of the offence by himself or a person under his control.

(10) If in any case the defence provided by subsection (9) above involves the allegation that the commission of the offence was due to an act or default of another person, or to reliance on information supplied by another person, the person charged shall not, without leave of the court, be entitled to rely on that defence unless –

(a) at least seven clear days before the hearing, and

(b) where he has previously appeared before a court in connection with the alleged offence, within one month of his first such appearance,

he has served on the prosecutor a notice in writing giving such information identifying or assisting in the identification of that other person as was then in his possession.

(11) Any reference in subsection (10) above to appearing before a court includes a reference to being brought before a court.

(12) The obligations imposed by subsections (2) to (6) above, except so far as relating to farmed fish, shall not be in force during such period (if any) in each year as may be prescribed by byelaw.

(13) The obligations imposed by subsections (2) to (6) above on the occupier of a mill shall apply only where the conduit or channel was constructed on or after 18th July 1923.

(14) Any reference in this section to ensuring that a screen is placed and maintained includes, in a case where the screen takes the form of apparatus the operation of which prevents the passage of fish of the descriptions in question, a reference to ensuring that the apparatus is kept in continuous operation.

(15) In this section "by-wash" means a passage through which water flows.]

Power of water authority to use *gratings* [screens] etc. to limit movements of salmon and trout

15.-(1) A water authority, with the written consent of the Minister

(a) may cause a *grating* [screen] or *gratings* [screens] of such form and dimensions as they may determine to be placed and maintained, at the expense of the authority, at a suitable place in any watercourse, mill race, cut, leat, conduit or other channel for conveying water for any purpose from any waters frequented by salmon or migratory trout; and

(b) may cause any watercourse, mill race, cut, leat, conduit or other channel in which a *grating* [screen] is placed under this section to be widened or deepened at the expense of the authority so far as may be necessary to compensate for the diminution of any flow of water caused by the placing of the *grating* [screen], or shall take some other means to prevent the flow of water being prejudicially diminished or otherwise injured.

(2) If any person –

(a) injures any such *grating* [screen]; or

(b) removes any such *grating* [screen] or part of any such *grating* [screen], except during any period of the year during which under a byelaw *gratings* [screens] need not be maintained; or

(c) opens any such *grating* [screen] improperly; or

(d) permits any such *grating* [screen] to be injured, or removed, except as aforesaid, or improperly opened;

he shall be guilty of an offence.

(3) A water authority, with the written consent of the Minister may adopt such means as in its opinion are necessary as the Minister may approve for preventing the ingress of salmon or trout into waters in which they or their spawning beds or ova are, from the nature of the channel or other causes, liable to be destroyed.

(4) Nothing in this section shall-

(a) affect the liability under this Act of any person to place and maintain a *grating* [screen]; or

(b) authorise a *grating* [screen] to be so placed or maintained during any period of the year during which under a byelaw *gratings* [screens] need not be maintained; or

(c) authorise any *grating* [screen] to be placed or maintained so as to obstruct any conduit or channel used for navigation or in any way interfere with the effective working of any mill;

and nothing in subsection (3) above shall authorise the water authority prejudicially to interfere with water rights used or enjoyed for the purposes of manufacturing or for milling purposes or for drainage or navigation.

[(5) In this section "open", in relation to a screen which consists of apparatus, includes the doing of anything which interrupts, or otherwise interferes with, the operation of the apparatus.]

Provisions supplementary to Part II

18.-(1) If any person obstructs a person legally authorised whilst he is doing any act authorised by section 9, 10 or 15 above, he shall be guilty of an offence.

(2) The Agency shall not-

(a) construct, abolish or alter any fish pass, or abolish or alter any free gap, in pursuance of section 10 above, or

(b) do any work under section 15 above,

unless reasonable notice of its intention to do so (specifying the section in question) has been served on the owner and occupier of the dam, fish pass or free gap, watercourse, mill race, cut, leat, conduit or other channel, with a plan and specification of the proposed work; and the Agency shall take into consideration any objections by the owner or occupier, before doing the proposed work.

~~(2) The Minister shall not give a water authority his consent-~~

~~(a) to the construction, abolition or alteration of a fish pass or the abolition or alteration of a free gap in pursuance of section 10 above; or~~

~~(b) to the doing of any work under section 15 above,~~

~~unless reasonable notice of the authority's application under the relevant section has been served on the owner and occupier of the dam, fish pass or free gap, watercourse, mill race, cut, leat, conduit or other channel, with a plan and specification of the proposed work; and the Minister shall take into consideration any objections by the owner or occupier, before giving his consent.~~

(3) If any injury is caused –

(a) to any dam by reason of the construction, abolition or alteration of a fish pass or the abolition or alteration of a free gap in pursuance of section 10 above; or

(b) by anything done by the water authority under section 15 above,

any person sustaining any loss as a result may recover from the agency compensation for the injury sustained.

(4) The amount of any compensation under section 10, 15 or 17 above shall be settled in case of dispute by a single arbitrator appointed by the Minister.

(5) In any case in which a water authority is liable to pay compensation under this Part of this Act in respect of injury or damage caused by the making or maintaining of any work, compensation shall not be recoverable unless proceedings for its recovery are instituted within two years from the completion of the work.

Interpretation

41.-(1) In this Act, unless the context otherwise requires –

"the Agency" means the Environment Agency

"dam" includes any weir or other fixed obstruction used for the purpose of damming up water;

["fish farm" has the same meaning as in the Diseases of Fish Act 1937;]

"grating" means a device approved by the Minister for preventing the passage of salmon or trout through a conduit or channel in which it is placed;

"immature "in relation to salmon means that the salmon is of a length of less than 12 inches, measured from the tip of the snout to the fork or cleft of the tail, and in relation to any other fish means that the fish is of a length less than such length (if any) as may be prescribed by the byelaws applicable to the water in which the fish is taken;

"inland water" means any area of inland waters within the meaning of the Water Resources Act 1991;

"migratory trout" means trout which migrate to and from the sea ;

"mill" includes any erection for the purpose of developing water power, and "milling" has a corresponding meaning;

"the Minister" means, the Minister of Agriculture, Fisheries and Food;

"occupier" in relation to a fishery or premises includes any person for the time being in actual possession of the fishery or premises;

"owner" includes any person who is entitled to receive rents from a fishery or premises;

"river" includes a stream;

"salmon" means all fish of the salmon species and includes part of a salmon;

["screen" means a grating or other device which, or any apparatus the operation of which, prevents –

(a) the passage of salmon or migratory trout, and

(b) if the screen is required in connection with a fish farm, the passage of any fish farmed at that fish farm, or any combination of devices or apparatus which, taken together, achieve that result.]

"trout" means any fish of the salmon family commonly known as trout, including migratory trout and char, and also includes part of a trout;

APPENDIX D

STATUTORY INSTRUMENTS

1994 No. 2524 (S.119)

RIVER, SCOTLAND

The Salmon (Fish Passes and Screens) (Scotland) Regulations 1994

Made - - - -	*23rd September 1994*
Laid before Parliament	*6th October 1994*
Coming into force	
For the purposes of regulation 1(2)(a)	*1st January 1998*
For the purposes of regulation 1(2)(b)	*1st January 2000*
For all other purposes	*1st January 1995*

The Secretary of State, in exercise of the powers conferred upon him by section 3(2)(c) and (f), (4) and (5) and section 10(2) of the Salmon Act 1986(**a**) and of all other powers enabling him in that behalf, and after having consulted such persons as he considers appropriate, hereby makes the following Regulations:

Citation, commencement and application

1.—(1) These Regulations may be cited as the Salmon (Fish Passes and Screens) (Scotland) Regulations 1994 and shall, subject to paragraph (2) below, come into force on 1st January 1995.

(2) These Regulations insofar as they apply–

(a) to an off-take the construction of which commenced before 1st January 1995, shall come into force on 1st January 1998, and

(b) to a dam the construction of which commenced before 1st January 1995, shall come into force on 1st January 2000.

(3) Subject to paragraph (4) below, these Regulations shall apply to dams in and off-takes from inland waters which ordinarily contain upstream migrating salmon.

(4) Regulations 3 to 7 hereof shall not apply to any dam or off-take–

(a) the construction, extension or operation of which has been authorised, approved or consented to by the Secretary of State (or by any other Minister of the Crown) under the Electricity (Scotland) Act 1979(**b**), or any enactment repealed by that Act, or under the Electricity (Scotland) Act 1989(**c**); or

(b) used for the abstraction of water for the purposes of providing a water supply in accordance with the approval of the Secretary of State granted in the exercise of any power requiring him to secure so far as practicable the rights of riparian owners and of other owners of land or salmon fishings.

(**a**) 1986 c.62.
(**b**) 1979 c.11; the Act was repealed by the Electricity (Scotland) Act 1989 (c.29), Schedule 18.
(**c**) 1989 c.29.

Interpretation

2. In these Regulations–

"fish pass" means any fish pass, ladder, fish way or lift or other device which facilitates the free passage, upstream or downstream, of salmon around, over or through any dam;

"off-take" includes a lade;

"operator" in relation to a dam or off-take means its owner or, where another person is in occupation or control of it, that person.

Dams

3. Every–

(a) dam the construction of which commenced on or after 1st January 1995,

(b) mill dam constructed after 28th July 1865, and

(c) portion, of any other mill dam, renewed or repaired at any time after 28th July 1865,

shall be made and maintained watertight by the operator so that no water, which can reasonably be prevented, shall run through it except when necessary to maintain the stability of the dam.

Fish passes

4.—(1) The operator of every dam shall ensure that it is provided with a fish pass which facilitates the free passage of salmon at all times except during any period when, for natural reasons, the flow of the river at the point where the dam is located is so low that salmon would not reasonably be expected to seek passage.

(2) In this regulation "natural reasons" means any reason which is not related to–

(a) the operation of the dam, or

(b) the abstraction of water from the river by the operator of the dam or for a purpose for which the dam was constructed or is being used.

Lades

5.—(1) The operator of every lade shall ensure that it is provided with a sluice to control the flow of water.

(2) The operator shall ensure that the lade and sluice are so constructed as to secure that the quantity of water passing into the lade shall not exceed that which is required for the purpose for which abstraction is made except when it is necessary to do so to prevent damage during high water flow.

Screens

6.—(1) Subject to paragraph (6) below, the operator of every off-take shall ensure that a screen, which prevents salmon smolts from passing through it, is provided at its entrance or within it.

(2) Where the screen is situated within the off-take, the operator shall ensure that a continuous by-wash is provided immediately upstream of the screen, by means of which salmon smolts may return by as direct a route as practicable to the river from which they came.

(3) Where an off-take returns water to inland waters the operator shall ensure that a screen is provided at the downstream outlet which prevents adult salmon from entering the outlet of the off-take.

(4) A screen may be constructed in the form of a heck or grating or in the form of any device which prevents the passage through it of adult salmon or salmon smolts (as the case may be).

(5) Any screen and any by-wash provided in accordance with this regulation shall be so constructed and located as to ensure, so far as reasonably practicable, that salmon are not injured or damaged by it.

(6) This regulation shall not apply to–

(a) any off-take which conveys or channels water to ponds or pools and returns it directly to the river from which it was abstracted, provided that the passage of salmon through the off-take until return to the river is, at all times, unobstructed and the water is not subject to any process, contamination or disturbance which might cause injury or damage to the salmon, or

(b) overflow outlets or spillways used to discharge excess water from reservoirs.

Installation, maintenance etc.

7.—(1) The operator of a dam or off-take shall carry out any work necessary to comply with these Regulations in such manner as to ensure the minimum practicable interruption to the passage of salmon.

(2) The operator of a dam or off-take shall carry out any maintenance of it or of any fish pass, sluice, by-wash or screen in such manner as to ensure the minimum practicable interruption to the passage of salmon.

Revocation and saving

8.—(1) Subject to paragraph (2) below, the regulations with respect to the construction and use of mill dams or lades, or water wheels made by the Commissioners, by byelaw dated 29th April and 19th July, 1865, under section 6(6) of the Salmon Fisheries (Scotland) Act 1862(**a**) are hereby revoked.

(2) The said byelaw shall–

(a) in relation to lades to which it applies and whose construction commenced before 1st January 1995, continue to have effect until 1st January 1998; and

(b) in relation to dams to which it applies and whose construction commenced before 1st January 1995, continue to have effect until 1st January 2000.

Hector Monro
Parliamentary Under Secretary of State,
Scottish Office

St Andrew's House, Edinburgh
23rd September 1994

(a) 1862 c.97 (25 and 26 Vict.). The byelaw was subsequently enacted as Schedule G to the Salmon Fisheries (Scotland) Act 1868 (1868 c.123 (31 & 32 Vict.)) by section 10 of that Act. Schedule G was amended by the Salmon and Freshwater Fisheries (Protection) (Scotland) Act 1951 (c.26) Schedule 1 and by the Electricity (Scotland) Act 1979 (c.11) Schedule 11 and revoked by section 41 of and Schedule 5 to the Salmon Act 1986 (c.62). The 1862 Act was revoked by section 41 of, and Schedule 5 to, the said 1986 Act. The byelaw was retained in effect by sections 3(1) and 10(1) of the said 1986 Act.

EXPLANATORY NOTE

(This note is not part of the Regulations)

These Regulations make provision for the construction and alteration of certain dams and lades, and the construction, alteration and use of screens and associated structures in off-takes.

The Regulations apply to dams in and off-takes from inland waters which ordinarily contain upstream migrating salmon (regulation 1(3)) but do not apply to certain dams or off-takes constructed, extended or operated for the supply or generation of electricity (regulation 1(4)(a)) or the provision of a water supply (regulation 1(4)(b)).

The Regulations come into force–

(a) on 1st January 1995 for all dams or off-takes the construction of which commenced on or after that date (regulation 1(1));

(b) on 1st January 1998 for all off-takes the construction of which commenced before 1st January 1995 (regulation 1(2)(a)); and

(c) on 1st January 2000 for all dams the construction of which commenced before 1st January 1995 (regulation 1(2)(b)).

All dams the construction of which commenced on or after 1st January 1995, all mill dams constructed after 28th July 1865 and any portion of an earlier constructed mill dam which has been renewed or repaired after that date, require to be maintained watertight (regulation 3).

All dams which obstruct the passage of salmon require to be provided with a fish pass (regulation 4). "Fish pass" is defined in regulation 2.

A sluice requires to be provided in every lade (regulation 5).

A screen which prevents salmon smolts from passing through it requires to be fitted in every off-take (regulation 6) except off-takes which return water unobstructed to the same river or which are overflow outlets or spillways used to discharge excess water from reservoirs (regulation 6(6)).

Construction and installation required by these Regulations and any maintenance, must be carried out so as to ensure the minimum practicable interruption to the passage of salmon (regulation 7).

The existing byelaw relating to the construction and use of mill dams or lades, or water wheels (formerly enacted by section 10 of the Salmon Fisheries (Scotland) Act 1868 as Schedule G to that Act) is revoked (regulation 8) subject to its being retained in force–

(a) until 1st January 1998 in relation to mill lades the construction of which commenced before 1st January 1995, and

(b) until 1st January 2000 in relation to mill dams the construction of which commenced before 1st January 1995.

Breaches of these Regulations will be dealt with as offences under section 15 of the Salmon Fisheries (Scotland) Act 1868 punishable on summary conviction in accordance with section 6 of, and Schedule 2 to, the Freshwater and Salmon Fisheries (Scotland) Act 1976 (c.22) by a fine not exceeding level 4 on the standard scale.

The Compliance Cost Assessment relating to these Regulations is available in the library of each House of Parliament. A copy of it can be obtained from the Scottish Office Agriculture and Fisheries Department, Division K2, Room 408A, Pentland House, 47 Robb's Loan, Edinburgh EH14 1TW.

APPENDIX E

The following is an extract from the Scottish Office publication *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon*

TYPES OF FISH PASS

Passes without pools

The most elementary type of pass for a simple weir is a plain cut or gap in the crest and apron of the weir which allows a concentration of water flow at a particular point. [The old Schedule G of the Salmon Fisheries (Scotland) Act 1868 stated that the notch in the crest of the weir should be 6 inches deep and not less than 4, 5 or 6 feet wide respectively in dams of width less than 100, 100–200 and more than 200 feet]. These passes appear to work satisfactorily in dams up to about 1 metre high where ascending fish require some assistance in negotiating the dam because of the length of downstream face or the nature of the take-off. The provision of large stones embedded in the floor of the gap, thus helping to break the flow of water, was preferred to a smooth concrete facing.

The dished channel (Figure 8) comprises a wide shallow trough on the downstream face of the weir from the top of a weir to the toe. This type of pass is suitable only for gently sloping weirs and, to operate properly, the bottom end must be submerged in the pool below at all tailwater levels.

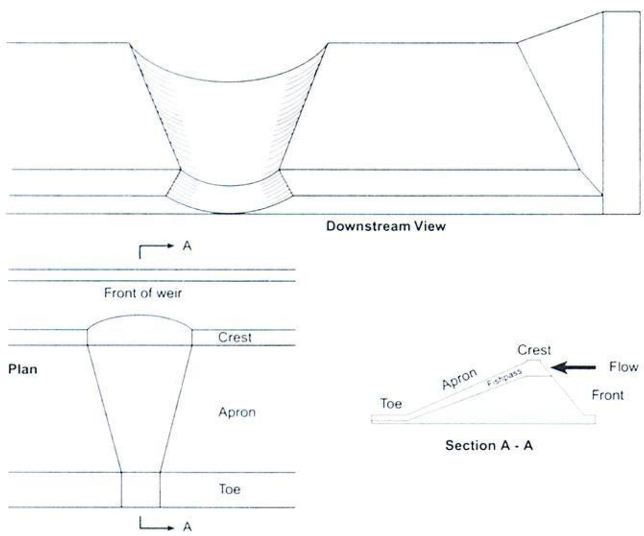


Figure 8 The dished-channel fish pass ('King's gap'). (after Fort and Brayshaw, 1961).

The diagonal baulk fish pass (Figure 9) has also been used with some success at low sloping weirs. Basically, a rectangular timber or concrete baulk runs at an angle across the face of the weir from the crest to the toe. A notch is formed in the crest adjacent to the upstream end of the baulk and this passes water from the headpond downstream along its length to the base of the weir. Upstream migrants negotiate the weir via the channel created by the baulk.

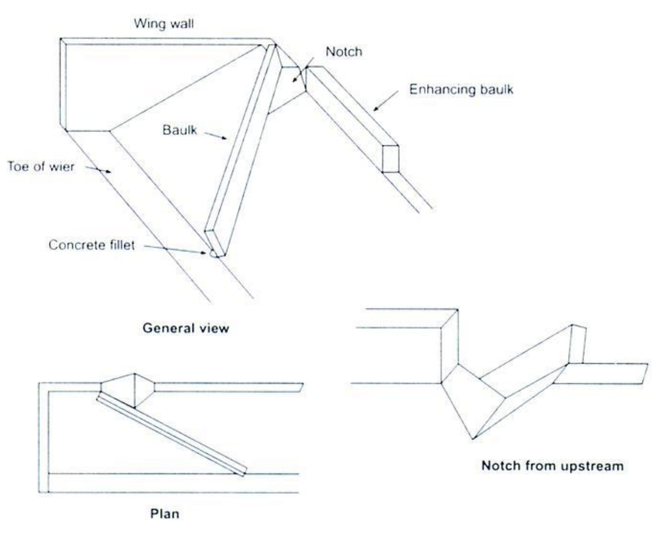


Figure 9 The diagonal baulk fish pass. (after Fort and Brayshaw, 1961).

The uniform gradient pass is another early fishway used in Scotland; an example is the Deanston Pass on the River Teith, originally installed about 1828, and considered a success. Its main features were a very gentle gradient (1:38); the diversion of excess water away from the pass to maintain suitable flow conditions for fish; and the provision of cross-walls spanning more than half the width of the pass and alternating from side to side. In another type of uniform gradient pass, rows of upright stones, suitably spaced, are placed across the width of the pass to break up the flow and dissipate energy (Figure 10). Some of those passes still exist in Scotland eg on the Thurso at the outfall from Loch More, and in the Tay catchment on the Ordie Burn, near Perth, and at the Linn of Tummel.

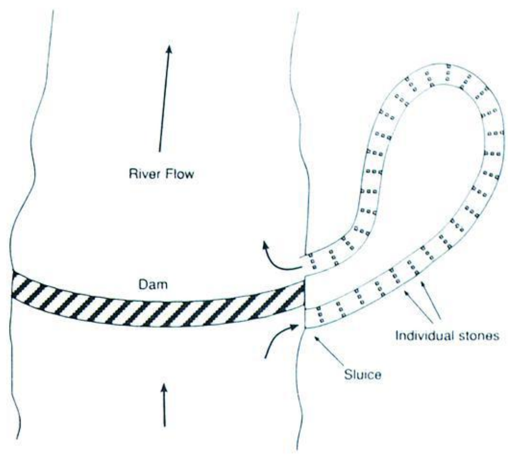


Figure 10 Diagrammatic plan view of a uniform-gradient fish pass with rows of upright boulders/blocks at regular intervals to break up the water flow.

Pool and weir passes

Pool-and-weir passes are among the commonest type of fishway and consist of a number of pools, arranged in a series of steps, separated by cross-walls. Longer passes are usually provided with larger rest pools positioned at regular intervals along the length of the pass (see Figure 5). In the original design, the cross walls extend across the total width of the pass (Figure 11). Water spills over the cross-walls, creating either a "plunging" or "streaming" flow pattern which upstream migrants negotiate by leaping or swimming respectively.

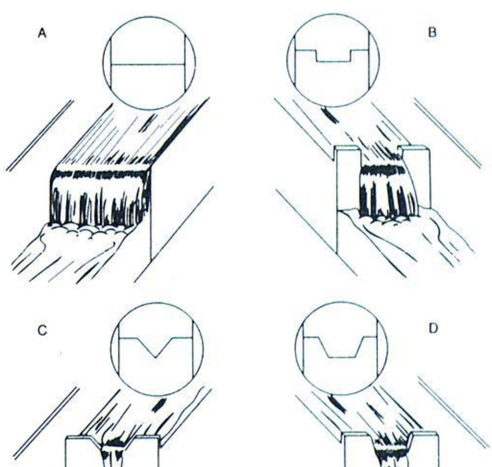


Figure 11 Weirs and notches : A, broad spillway; B, rectangular notch; C, triangular notch; D, trapezoidal notch. (after Stuart, 1962)

A variation of the overspill pass is the notched pass where water passes through a rectangular, triangular, trapezoidal notch, in the top of each cross-wall (Figures 11 and 12).

The Committee on Fish Passes (1942) recommended the following design requirements for a pool-and-weir pass:

- the drop in water levels between adjacent pools should not exceed 0.45 m;
- pools should have minimum dimensions of 3 m length, 2 m width, and 1.2 m depth. Failure to satisfy those dimensions proportionately results in the water energy not being dissipated efficiently, thus causing excessive turbulence;
- the downstream edge of both the notch and the traverse should be curved so as to reduce turbulence and provide an adherent nappe ie water flowing down the face of the cross-wall, rather than a free-spurting jet.

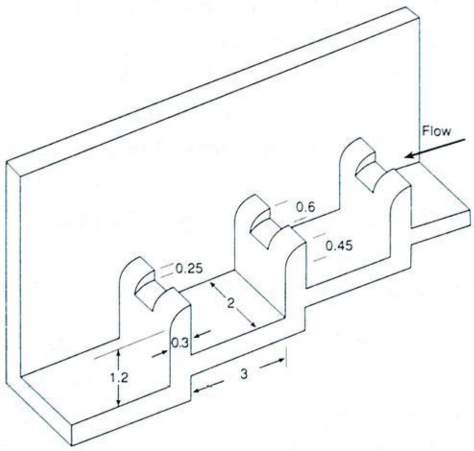


Figure 12 Schematic diagram of a pool-and-traverse fish pass with notched traverses. Dimensions (metres) are recommended minima. Head difference between pools should not exceed 0.45 m. (after Beach, 1984)

These criteria have been generally adopted and are considered to be satisfactory. However it should be noted that the specified minimum dimensions for pool size may not be sufficient if a large flow of water is allowed to enter the pass.

Submerged Orifice Passes

Submerged-orifice fish passes (figure 5) were first used in Scotland in the Galloway Hydro-Scheme in the mid-1930s. They are also installed at Pitlochry and Clunie on the Tummel-Garry hydro-electric scheme.

Submerged orifices can be square or circular, and it is recommended that they should have a minimum cross-sectional area of 2.25 ft^2 (0.68 m^2). The length of the orifice should be not less that 2–3 times the width or diameter (Fort and Brayshaw, 1961). Pools should be not less that 3 m long, 1.2 m wide, and 1.2 m deep. In Scotland, the orifices are bevelled at the upstream end, preferably with a bell-mouth to reduce turbulence. However, in the United States, the recommendation is that the orifice be bevelled at the downstream end (Bonnyman 1958)

These fish passes are not suitable for very small flows. In a large fish pass at Pitlochry, the orifices were originally 3' 3" (1 m) in diameter, but these were subsequently reduced to 2' 9" (0.83 m). The corresponding reduction in flow, from 1.8 m^3/s to 1.35 m^3/s, resulted in more-acceptable hydraulic conditions within the pools. To reduce water energy within the pools, the orifices are inclined at an angle of 20° to the horizontal and the water discharges into a dish-shaped depression in the bottom of each pool. Velocity through the orifices is about 2.4 m/s. Each of the standard pools is 7.8 m long, 4.2 m wide, and 2.1 m deep.

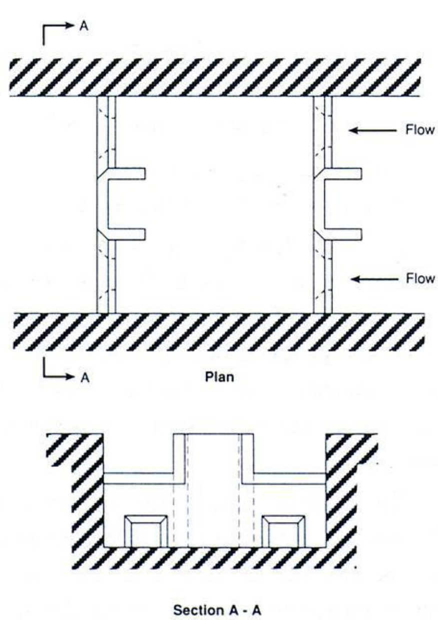


Figure 13 Diagrammatic plan view and section of the Ice Harbour fishway, showing notches and submerged orifices. (after Orsborn, 1987)

Combined overfall and submerged orifice pass

This type of pass, commonly called the Ice Harbour fishway (see figure 13), has been developed over many years in North America where it is used for larger passes with substantial migrations of salmon. Fish can pass over the notches on the cross-wall or through the orifices at the base of the wall.

Denil passes

Named after its inventor, the Denil pass is a development of a roughened channel and consists of a rectangular chute with closelyspaced baffles or vanes along the sides and bottom. Like the pool-and-weir pass, various versions have been developed to improve efficiency and to meet the differing requirements of different fish species. Three main types of Denil are used at present: they are illustrated at Figures 14–16.

The Plain or Standard Denil (Figure 14) contains a series of planar baffles pointing upstream at an angle of 30–40° to the fishway floor. Total channel width varies from 0.5–1.0 m, with a central gap of 0.36–0.53 m between baffles, and the baffles spaced from 0.25–0.6 m apart. Gradient of the channel varies from 10–25%. Typical water velocities (0.6–1.8 m/s) are within the swimming capability of most upstream-migrating salmon and sea trout.

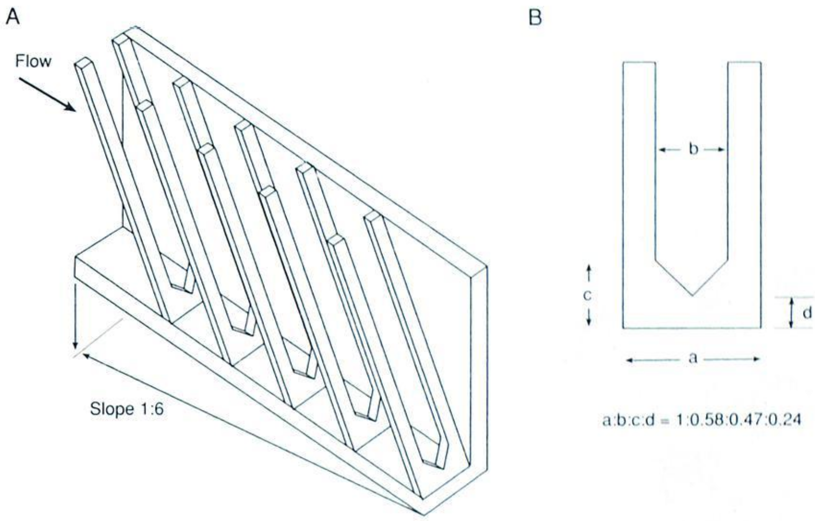


Figure. 14 A. Schematic diagram of a Standard Denil fish pass with single plane baffles. (after Bell, 1986)
B. single baffle with recommended proportions. Distance between consecutive baffles = 0.67 x a. (after Lonnebjerg, 1980)

In the Alaskan Steeppass (Figure 15) the baffles are angled away from the walls of the channel and the floor is ridged. Velocities of less than 1.0 m/s in the main channel are achieved. Gradients of up to 1:3 (33%) have been reported as successful.

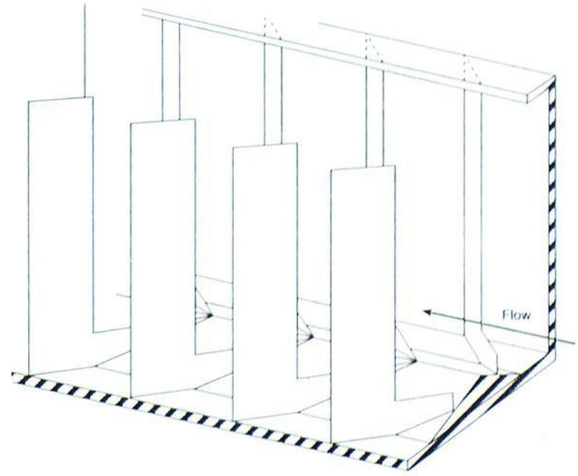


Figure 15 Cut-away sectional diagram of the Alaskan 'Model A' Denil fish pass (Steeppass). (after Beach, 1984)

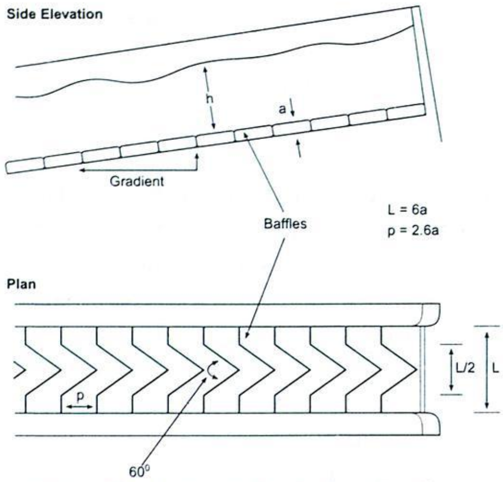


Figure 16 The Larinier Pass (after Harpley, 1989)

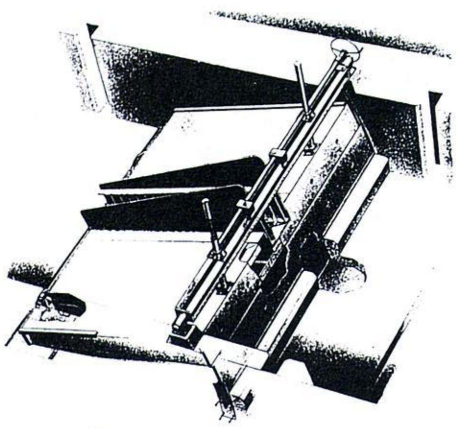


Figure 17 The Fishway Gate is a tilting gate which contains an integral fish pass. It permits upstream water levels to be controlled while providing an ascent for migratory fish, all within a single mechanism. (from Fishway Service)

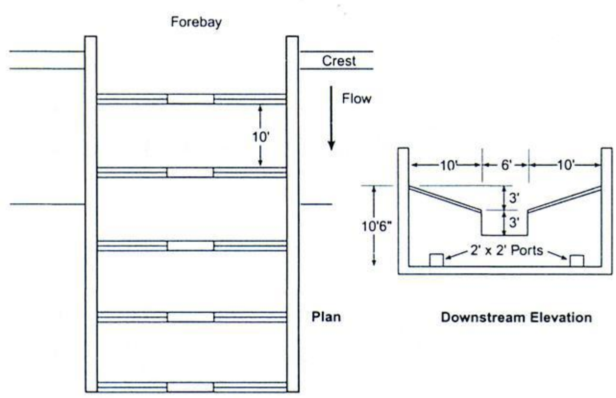


Figure 18 The pool and chute fishway. (after Bates, 1991)

The Larinier Pass (Figure 14) has no side baffles, but is fitted instead with chevrons along the bottom of the channel. Optimum gradients range from 10–20%.

The Fishway Gate

The Fishway Gate (Figure 17), a unique design of tilting gate, which incorporates a Denil type fish pass. The gate permits control of upstream water levels while simultaneously providing access for migrating fish.

Pool-and-chute Pass

The Pool-and-chute fishway (Figure 18) is a combination of a pool-and-weir (low flow) and Denil (high flow) pass. It has been designed to accommodate a wide range of stream flows without the need for an adjacent spillway for excess flow. This type of pass is considered suitable for barriers where the total head is up to 1.5 m. Chinook salmon *(Oncorhynchus tshawytscha)* have used a test fishway without apparent problems or delay. A similar fishway, 3.4 m wide, with 1.7 m long pools, and a slope of 11%, was observed to pass flows up to 2.2 m^3/s.

Vertical Slot Pass

The Vertical Slot Pass (Figure 19), which operates at a gradient of about 1 in 8 comprises a rectangular channel separated into a series of pools by cross-walls along its length. Water passes from pool to pool through vertical slots, 0.3–0.6 m wide, at one or both the ends of each cross-wall. In standard Vertical Slot passes, each slot extends from top to bottom of the cross-wall (but a low cill at invert level may improve flow conditions in the pools). It is recommended that the width and length of each pool should be 8 and 10 times the slot width respectively. Energy is dissipated by the slot directing water at an appropriate angle into the pool downstream. In addition, each cross-wall has an upstream projection which further reduces water velocity. Single slot passes do not dissipate energy as readily as those with double slots and, consequently, require larger pools. The recommended drop between pools for adult salmon is 0.3 m. Water velocities through the slot are more-or-less similar at all levels. This kind of fish pass has not been much used in Britain but may be particularly useful in some circumstances (eg where there is enough water, and headwater and tailwater heights vary together).

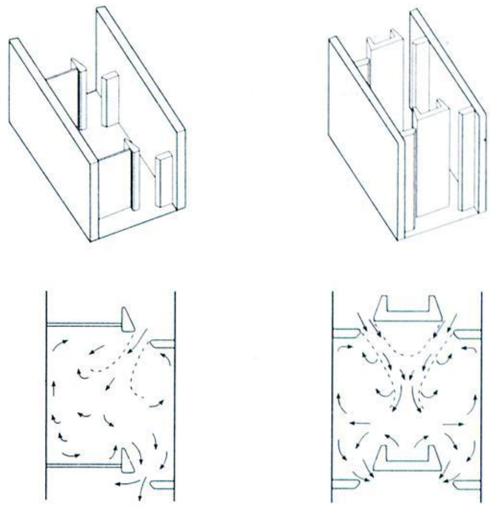


Figure 19 Single and double jet vertical slot fishways, with plan view to show flow patterns. (after Andrews, 1991)

Fish lifts and locks

A fish lock operates on the same principle as a navigation lock: water at a lower level is raised by temporary impoundment until it equalises the headwater level. A fish lift or elevator also incorporates mechanical devices to lift the migrating fish from the collecting chamber at tailwater level – it may discharge into the reservoir or to a transporting facility.

The Borland Lock (Figure 20), first used in Scotland in the 1950s, comprises, basically, two chambers, one in the base of the dam at tailwater level, the other at reservoir level, with a sloping or vertical shaft connecting them. During the "fishing" phase, water flows through the pass and attracts upstream migrants into the lower chamber. At set intervals this chamber is closed at its downstream end and the water rises in the lock (the "lifting" phase) until it reaches the upper chamber. Fish in the lock can move up through the shaft into the upper chamber and from there into the reservoir. The length and frequency of the phases can be varied and, typically, might be 3 hours fishing, 1 hour lifting. Recent investigations at a Borland lock at a Scottish hydro-dam indicate that, at that site, adult salmon are more likely to exit the upper chamber if there is a small waterfall over the upper gate rather than no obstruction between the upper pool and headpond.

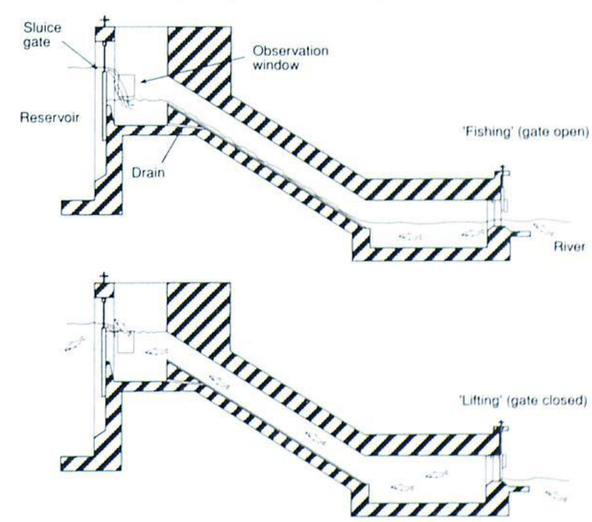


Fig. 20 Borland fish lock showing 'fishing' and 'lifting' phases.

The Warner Fish Lift has an upper and lower chamber, connected by a vertical shaft. Additionally, during the filling phase, the fish are shepherded from the bottom to the top chamber by a horizontal mesh screen. This ensures that fish ascend to the upper chamber, increasing the likelihood of their leaving the lift.

The Holyoke Fish Elevator (Figure 21) operates on a similar principle to the Warner Fish Lift. A large fish-collecting pool is situated at the base of the dam. A travelling screen herds the fish into the bottom chamber which is then closed off and the fish raised within the shaft.

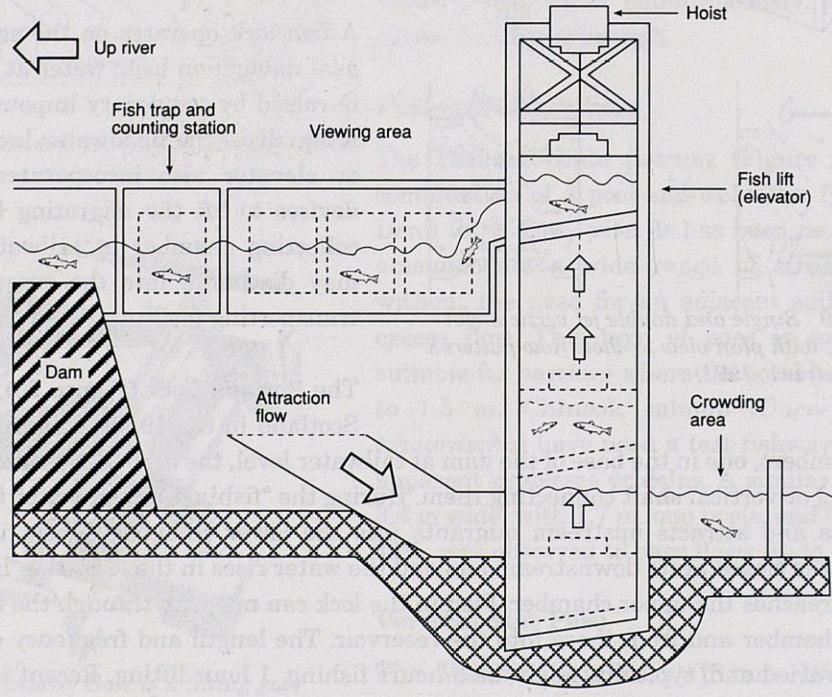


Figure 21 The Holyoke fish elevator. (after Woolnough, 1988)

APPENDIX F

The following is an extract from the Scottish Office publication *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon*

TYPES OF FISH SCREENS

The most common method of excluding fish from water abstraction intakes and outfalls in Scotland is physical screening, which as the term implies, prevents the passage of fish by mechanical means, ie meshes, bars etc. It is possible to prevent passage using devices which do not physically block the fish, ie they can be dissuaded from entering intakes and outfalls by electric fields, louvers, sound etc. These are generally called behavioural screens. Physical screens, although described separately below, also affect the behaviour of fish which may attempt to take evasive action to avoid them.

Physical screens

Fixed mesh or bar screens. The simplest and commonest form of screen that has been used to keep salmon from intakes is a fixed mesh or bar screen. Smolts are excluded from intakes at hydro-electric power stations using vertical woven or weld-mesh screens with a rectangular mesh of internal measurements 25 mm (horizontal) x 12.5 mm (vertical). All smolts over 11.5 cm would be expected to be kept out by such a screen but a smaller mesh is sometimes used to exclude smaller fish. Total exclusion of smaller parr down to 8 cm requires a mesh of about 10 mm x 10 mm. The dimensions can be established from a relationship between fish length and mesh size (see Figure 22). It is important that all screens are properly seated in their support frames to prevent escape around or under them. The screens may be vertical, sloped or horizontal. The use of "wedgewire" (Figure 23) is believed to have potential in new designs, especially in horizontal screens. Curved wedgewire panels have been tried with apparent success, although problems have been met under low flow conditions if all the water is abstracted.

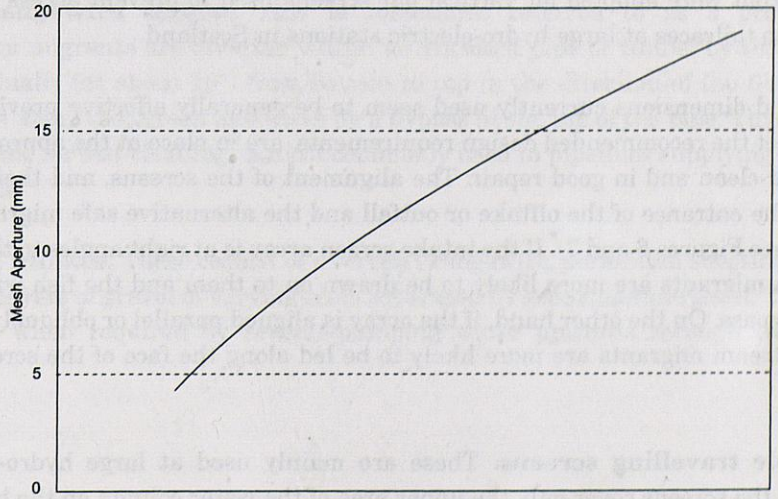


Figure 22 Mesh size required to exclude juvenile salmon based on formula proposed by Turnpenny (1991). (from Solomon 1992)

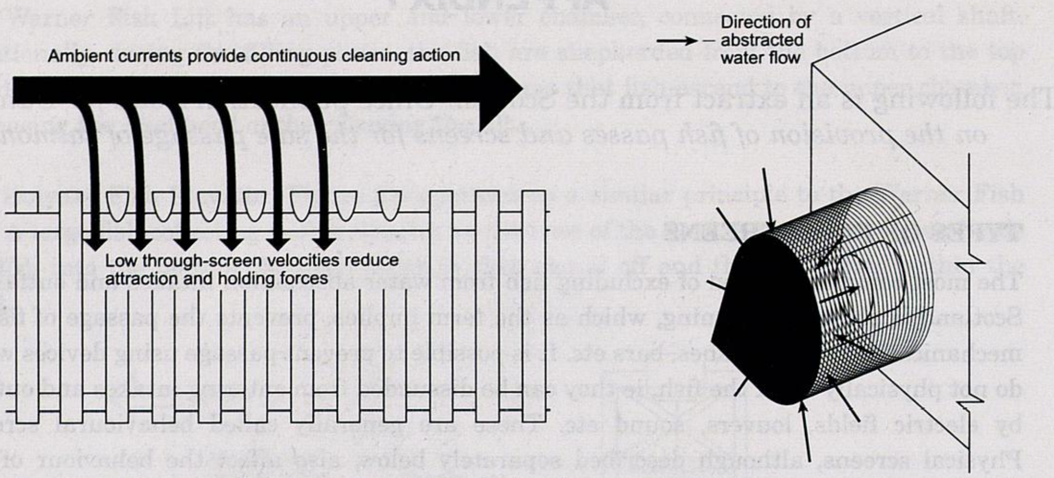


Figure 23 Section of wedgewire screen demonstrating flow patterns and cleaning principle (Johnson Filtration System) (after Solomon 1992). Diagrammatic representation of a cylindrical Johnson passive intake screen. (from Solomon 1992)

To prevent the passage of downstream-migrating adult salmon or sea trout, barred screens are generally preferred to mesh, mainly because they are less likely to trash with small debris and are more easily cleaned. Vertical barred screens with maximum spacing in between bars of 5 cm have been used at mill lade intakes in Scotland for over 100 years. More recently, Scottish hydro-electric power stations have been fitted with heavy vertical round or flat barred screens with spacings between 3.8 cm and 5 cm between the bars. Although these gaps may prevent the majority of adult salmon passing through the screens, finnock and small adult sea trout kelts are unlikely to be protected to the same extent. Approach water velocities not exceeding 0.75–0.9 m/s at the screen array are recommended to prevent the fish being pinned to the screen.

Barred screens, usually vertical or gently sloping, are also the main means of preventing the entry of ascending adult salmon and sea trout at outfalls. The maximum dimensions of gap in the regulations of the 1860s were considered too large for more recent hydro-electric developments. Consequently a maximum gap of 4.2 cm for salmon and between 3.2 and 3.8 cm for sea trout were adopted for vertical bar screens used to prevent access of salmon or sea trout into tailraces at large hydro-electric stations in Scotland.

The sizes and dimensions currently used seem to be generally effective provided that the facilities meet the recommended design requirements, are in place at the appropriate times, and are kept clean and in good repair. The alignment of the screens, and their position in relation to the entrance of the offtake or outfall and the alternative safe migration route is important (see Figures 6 and 7).* If the intake screen array is at right angles to the main flow, downstream migrants are more likely to be drawn on to them and the fish will less easily locate the bypass. On the other hand, if the array is aligned parallel or obliquely to the main flow, downstream migrants are more likely to be led along the face of the screens towards the bypass.

Submersible travelling screens. These are mainly used at large hydro-electric dam intakes and the screens cover only the upper area of the water column on the basis that the migrating smolts tend to swim near the surface. The fish are diverted into gatewells in the dam and are attracted into a suitable bypass which carries them to the downstream side of the obstruction.

---

*Refers to Figures 6 and 7 in *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon.*

Drum screens. These are designed to be self-cleaning and thus to reduce trashing problems and blockages. The "Econoscreen" (Figure 27) is a rotating water-driven drum screen which requires no power supply. It is sited in a lade or channel and requires that at least 25% of the flow is not abstracted. This provides space for fish to bypass the screen. Any fish pinned on the mesh are released as the drum rotates but, as with all screens, physical contact of the fish with the screen should be avoided wherever possible as the fish may be damaged by de-scaling.

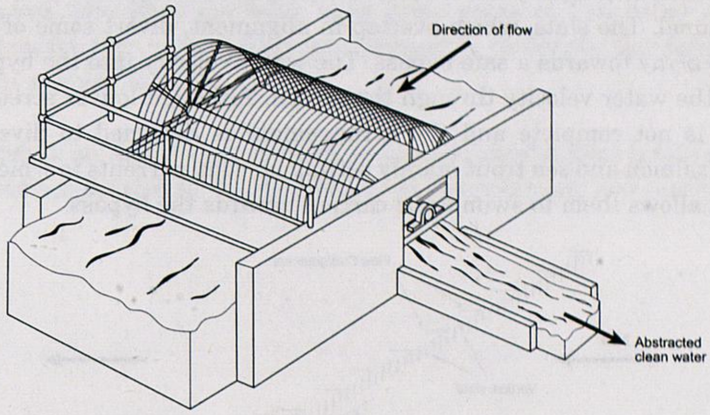


Figure 24 Diagram of the "Econoscreen". (from Solomon 1992)

Johnson passive intake screens. These are considered a significant advance on previous fixed screens because they reduce risks of fish being pinned on the screen. The screens are usually cylindrical and made of wedgewire (see Figure 23). A slot width of 6 mm is considered adequate to completely exclude large parr and smolts. The screens require to be installed in sufficient water to allow a free water space all round. A low approach velocity (15 cm/s) ensures that the fish are not pinned on the screens, and their smooth external surface causes minimal abrasion to any fish which might come in contact with them. Where the river or channel flow velocity exceeds the velocity of water flow through the screen, it is largely self-cleaning. Alternatively, debris can be cleared by discharging compressed air from behind the screen.

Eicher wedgewire screen. This is sometimes referred to as a pressure screen. Downstream migrants are diverted within an enclosed pipe or tunnel by the screen which slopes gradually (at about 19°) from bottom to top in the direction of the flow in the pipe. Fish are led along the screen and leave by a bypass at the top of the pipe. This screen which can be rotated for self-cleaning, is most commonly used in pipelines supplying hydro-electric installations.

Subgravel intakes. These consist of a screen (wedgewire, perforated sheeting etc) which is covered by layers of gravel of varying sizes separated by geomembrane sheet. The intake can be cleaned when required by reverse-pumping water upwards through the screen and gravel.

Behavioural exclusion and diversion systems

Louver screens. These consist of an array of vertical slats set at right angles to the flow and spaced at regular intervals, eg 5 cm, 10 cm etc (Figure 25). The screens operate best in a channel and can cover part or all of the water column depending on the depth at which the fish usually swim. Covering only part of the depth may be less effective but could be appropriate where the cost of total screening is very high and the likelihood of fish being in the unscreened area is very low. The screen array is best angled at 10°–15° to the axis of flow in the channel. The slats, which overlap in alignment, divert some of the water along the face of the array towards a safe bypass. The water velocity into the bypass should be about 1.5 times the water velocity through the screen. Although louver screens create a physical barrier it is not complete and the arrangement is designed to divert the downstream-migrating salmon and sea trout mainly setting up eddy currents to which the migrants react and which allows them to swim or be carried towards the bypass.

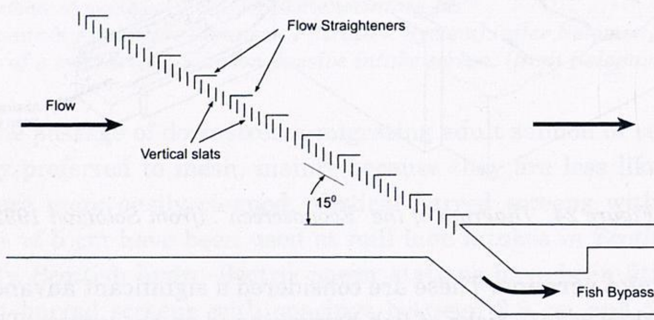


Figure 25 Diagrammatic plan view of louver screen array with bypass for diversion of downstream migrants.

Bubble screens. These operate on the principle of creating a curtain of bubbles by passing compressed air through perforated pipes placed across the bed of the intake or channel. Results from experiments over the last 50 years have been largely inconclusive and further research and development is necessary to establish whether bubble screens can effectively exclude salmon from intakes. There is some evidence to suggest that bubble screens may be more effective if combined with strobe lights.

Lighting. During darkness, smolts tend to be displaced due to an inability to relate their movements to stationary objects around them. Under these conditions, artificial lighting has been used at abstraction intakes to enable fish to avoid becoming pinned on screens and, where appropriate, to attract them towards a safe alternative bypass. Light may therefore be useful in guiding salmon or sea trout provided that factors such as water temperature, turbidity and velocity are appropriate. Strobe lights have been found to repel salmonids, including Atlantic salmon. However further research is needed to examine the potential of light as an effective means of excluding or diverting fish from hazardous areas.

Sound. Although early investigations into the use of sound as a means of diverting fish from intakes were not encouraging, recent work suggests more positive results. Various underwater sound sources have been tested, including "poppers", from which high-pressure air bubbles are produced, "pulsers" or "hammers", which emit repetitive pulses, and "drones", which can produce a range of frequencies from 20 to 1,000 Hz. Responses to these sounds vary with fish species but the pulser seems to be generally most effective as a repellant. Sound with fish-repelling characteristics is at present under investigation for diverting salmon smolts at hydro-electric stations. This has included the use of low frequency sound (10 Hz) which may be effective for juvenile salmon.

Electric screens. Electric fields have been used to discourage the entry of salmon into tailraces. An array of electrodes is set across the outfall and energised. These are effective in some circumstances (though there have been some cases of fish being damaged by electrocution). Reliability has to be taken into account – obviously the screen becomes ineffective if there is a power failure.

Laboratory experiments on using electric fields to exclude smolts from intakes gave some promising results but application in the field has been disappointing and ineffective.

APPENDIX G

SOURCE REFERENCES

1. Calderwood W L (1930). *Salmon and Sea Trout* (on Hydro-Electric Schemes, Fish Passes etc.) Edward Arnold & Co, London. 242 pp.

2. Anon. (1995). *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon*. The Scottish Office Agriculture and Fisheries Department. 38 pp.

3. Katapodis C (1992). *Introduction to Fishway Design*. Freshwater Institute, Central and Arctic Region, Department of Fisheries and Oceans, 501 University Crescent, Winnipeg, Canada, R3T 2NG.

4. Beach M H (1984). *Fish pass design – criteria for the design and approval of fish passes and other structures to facilitate the passage of migratory fish in rivers. Fish Res Tech Rep*. No. 78. MAFF Directorate of Fisheries Research, Lowestoft No. 78. 46 pp.

5. Larinier M (1992). Location of fishways at barriers. *Bull Fr Peche Pisciculture*, 326–327, 30–44.

6. Webb J (1990). *The Behaviour of Adult Atlantic Salmon Ascending the Rivers Tay and Tummel to Pitlochry Dam.* Scot Fish Res Rep No. 48. 27 pp.

7. Dunkley D A and Shearer W M (1982). An assessment of the performance of a resistivity fish counter. J Fish Biol, 20, 717–737.

8. Webb J and Hawkins A D (1989). *The Movements and Spawning Behaviour of Adult Salmon in the Girnock Burn, A Tributary of the Aberdeenshire Dee, 1986.* Scot Fish Res Rep No. 40, Department of Agriculture and Fisheries for Scotland, Pitlochry. 42 pp.

9. Milner N J and Wyatt R J (1991). HABSCORE *Software Manual (Version 2.1).* National Rivers Authority (Welsh Region).

10. Munro W R (1965). *Effects of passage through hydro-electric turbines on salmonids.* ICES/C.M., Salmon and Trout Committee 1965, No. 57. 5 pp.

11. Black A, personal communication.

12. Solomon D J (1988). *Fish passage through tidal energy barrages*. Department of Energy, Energy Technology Support Unit, 63 pp. plus appendix 13pp.

13. Lightfoot Dr G, personal communication.

14. Solomon D J (1992). *Diversion and entrapment of fish at water intakes and outfalls*. National Rivers Authority R&D Report 1. 51 pp

15. Loeffleman P H, Van Hassel J H and Klinect D A (1991). Using sound to divert fish from turbine intakes. *Hydro Rev*, October 1991, 30–43.

APPENDIX G

SOURCE REFERENCES

1. Calderwood W L (1930). *Salmon and Sea Trout (on Hydro-Electric Schemes, Fish Passes etc.)* Edward Arnold & Co. London. 242 pp.

2. Anon. (1995). *Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon.* The Scottish Office Agriculture and Fisheries Department. 38 pp.

3. Katopodis C (1992). *Introduction to fishway design.* Freshwater Institute, Central and Arctic Region, Department of Fisheries and Oceans, 501 University Crescent, Winnipeg, Canada, R3T 2N6.

4. Beach M H (1984). *Fish pass design – criteria for the design and approval of fish passes and other structures to facilitate the passage of migratory fish in rivers. Fish Res Tech Rep.* No. 78. MAFF Directorate of Fisheries Research, Lowestoft No. 78. 46 pp.

5. Larinier M (1990). Location of fishways at barriers. *Bull Fr Peche Pisciculture* 326–327, 30–44.

6. Webb J (1990). *The Behaviour of Adult Atlantic Salmon Ascending the Rivers Tay and Tummel to Pitlochry Dam.* Scot Fish Res Rep No. 48. 27 pp.

7. [illegible]. An assessment of the performance of a [illegible] fish [illegible]. J Fish Biol, [illegible].

8. Webb J and Hawkins A D (1989). *The Movements and Spawning Behaviour of Adult Salmon in the Girnock Burn, A Tributary of the Aberdeenshire Dee, 1986.* Scot Fish Res Rep No. 40. Department of Agriculture and Fisheries for Scotland, Aberdeen. 42 pp.

9. [illegible]. *HABSCORE Software Manual (Version 2.1).* [illegible] Region.

10. [illegible] turbines on [illegible], No. 57. 5 pp.

11. [illegible]

12. [illegible] energy barrages. Department of Energy [illegible]. 39 pp. plus appendix 15pp.

13. [illegible]

14. Solomon D J (1992). *Diversion and entrapment of fish at water intakes and outfalls.* National Rivers Authority R&D Report 1. 51 pp.

15. Loeffelman P H, Van Hassel J H and Klinect D A (1991). Using sound to divert fish from turbine intakes. *Hydro Review*, October 1991. 30–42.

MAFF Publications, London SE99 7TP
 PB 3001. £5.00