Institute of Fisheries Management

Fish Pass Manual:

Guidance Notes On The Legislation, Selection and Approval Of Fish Passes In England And Wales

This manual was first prepared by the Environment Agency. Any questions or queries should be directed to your local Environment Agency Office.

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INTRODUCTION

Definition of a Fish Pass

A fish pass is not defined in the legislation. For the purposes of this manual a fish pass is defined as:

Any form of conduit, channel, lift, other device or structure which facilitates the free passage of migrating fish over, through or around any dam or other obstruction, whether natural or man-made, in either an upstream or a downstream direction.

In the past the provision of fish passes has usually only been concerned with the upstream migration of the diadromous (sea to freshwater cycle) migratory salmonid species. In recent years interest has widened to include the potadromous (within freshwater) coarse fish species, and other diadromous species such as eels and shad. This manual seeks to encourage the consideration of fish passes for the upstream passage of all species.

Until recently downstream migration has largely been ignored in the UK, except in so far as it was covered for migratory salmonids by the legislation on screening water intakes. In 1999 this legislation was strengthened and extended, although still only for the protection of migratory salmonids. Safe downstream passage is an important issue and should not be ignored, however it is outside the scope of this manual. For information on this aspect the reader is referred to the Environment Agency R&D report on Screening for Intake and Outfalls: a best practice guide, Science Report SC030231 O'Keeffe & Turnpenny, 2005), and the Environment Agency training manual on screening of intakes and outfalls (1998).

Recently there has been an upsurge in the use of existing, and sometimes new, obstructions for the purposes of electricity generation by hydropower. It is essential in such projects that account is taken of fish passage needs both in the upstream and downstream directions

Purpose of a Fish Pass

The purpose of a fish pass is to allow the free passage of endemic species of the appropriate developmental stage(s) at the appropriate time(s) of year. It may be necessary to consider the passage of juvenile salmonids (smolts) as well as adult migratory salmonids; the needs of different life stages of freshwater fish species, eels, lampreys and shad. If a barrage is being proposed it may also be necessary to consider the needs of marine species such as mullet and flounder

Whilst the design of fish passes for adult migratory salmonids is well advanced, the requirements of other species, and requirements for downstream migration of all species are not fully understood. This manual seeks to provide a good grounding of our current knowledge but there is still extensive research which needs to be undertaken before we can be fully confident that fish passes will always achieve our design aims.

It is worth bearing always in mind that fish are animals, not automatons, and individuals have a wide range of abilities, just as humans do. Fishways should be designed to allow all individuals in a population to have the chance to pass, and not just the `atheletes` among them.

LEGISLATION

General

Statutory responsibility for the approval of fish passes for migratory salmonids lies with the Environment Agency under the Salmon and Freshwater Fisheries Act 1975 ('SAFFA'). The responsibility was transferred from the Ministers of the Environment, England; Secretary of State, Wales under Section 105 of, and Schedule 15 to the Environment Act 1995 and became effective upon the formation of the Agency on 1st April 1996. Statutory responsibility for the approval of passes for eels also lies with the Environment Agency under The Eels (England and Wales) Regulations 2009, which came in to force on 15th January 2010. This Statutory Instrument implements Council Regulation (EC) No 1100/2007 that established measures for the recovery of the stock of European eel.

In addition when considering construction there are a number of other legislative requirements that need to be taken into account. An appropriate environmental assessment should be undertaken as with all other construction projects. Fish passes are also likely to require Land Drainage Consent under the provisions of the Land Drainage Act 1991 or the Water Resources Act 1991. An impoundment licence may be required under the Water Resources Act. Plannng permission may be required under the Town and Country Planning Act 1990. Extracts of relevant Legislation is given in Appendix II.

Overview of Fish Pass Approval Legislation

The application of fish pass approval legislation is currently confined to watercourses, which are frequented by migratory salmonids (ie salmon, sea trout) and eel. It does not apply to waters, which do not contain migratory salmonids or eel.

Summary of responsibilities and powers in relation to fish passes under the SAFFA 1975 (as amended by Schedule 15 to the Environment Act 1995).

Fish Passes on Fishing Mill Dams

Section 8 of the SFFA refers to fishing mill dams. This section makes it a condition that such a dam cannot be used to take migratory salmonids unless it has an Agency approved fish pass attached to it - S 8(2). In fact in practice the Agency is not aware of the existence of any such structures, and this section is to be repealed by the Marine & Coastal Access Act 2009 with the repeal due to take effect from January 2011.

Fish Passes on New or Rebuilt Weirs

Section 9 of the SFFA allows the Agency to serve notice on the owner or occupier of a dam or obstruction, to install a fish pass where necessary. Where notice is served the owner or occupier of the dam or obstruction has a duty to make a fish pass within a reasonable time as specified in the notice and subject to such form and dimensions as the Agency may approve and thereafter to maintain the pass in an efficient state. The fish pass details are now approved by the Agency, rather than the Minister or Secretary of State as previously - S9(1). This section applies to dams which are either new or have been altered to create an increased obstacle to the passage of migratory salmonids. It is also applicable where dams in a state of disrepair have been rebuilt over at least one half of their length. This section also allows the Agency to enter on any dam or land adjoining, carry out any works necessary to install or maintain a fish pass and gives the Agency powers to recover the costs of these works - S9(3).

The important change within this section of the Act is the transfer of the responsibility for approval of the "form and dimensions" of fish passes for salmon and migratory trout, from the Minister, or Secretary of State, to the Agency. Except for the substitution of the "Agency" for the "NRA", the remainder of this Section is unaltered. It should be noted that this section applies only to waters frequented by salmon and migratory trout and to passes for those species only. (Section 156 of the Water Resources Act 1991 gives the Agency additional powers to purchase land and property associated with dams and fish passes in relation to both this Section, and Section 10 below.)

Fish Passes on Existing Weirs

Section 10 allows the Agency to build or alter fish passes on dams at its own discretion and at its own expense. There is no longer a requirement for the relevant Minister to approve the form and dimensions of fish passes built under this section; this is now left to the Agency to determine - S 10(1). This section also allows the Agency to abolish, alter or restore to its former state of efficiency, any existing fish pass or free gap, or to substitute another fish pass or free gap. Again, there is no longer a need for Ministerial consent for such alterations - the Agency may make its own decisions in such matters - S10(2). Works carried out in this section should not jeopardise the operation of certain specified interests, which may be connected with structures altered by the Agency. The final subsection gives the Agency the power to recover costs incurred in repairing a damaged pass - S10(3). Unlike Section 9, this section contains no caveats referring to ‘waters frequented by salmon or migratory trout’. Arguably, therefore, it provides the Agency with the power to construct fish passes for any fish species in any waters

Powers of Approval

Section 11 gives a number of powers to the Agency which were formerly exercised by the appropriate Minister. As the approving body, the Agency can issue provisional approval for a fish pass, until it is satisfied that the pass is working properly - S 11(1). In a new subsection, the Act makes it a condition that an applicant for fish pass approval will be liable for any costs incurred in determining whether or not a fish pass is working satisfactorily – S11(1A)(b).

This new subsection also makes it a condition that the applicant must supply the Agency with any information or assistance it needs to show that the pass is working properly - S 11(1A)(b). The Agency may revoke any provisional approval, provided that the applicant is given at least 90 days' notice - S 11(2) - and where approval is revoked, the Agency may extend the period within which the fish pass is to be constructed - S 11(3). The Agency may give approval to any fish pass, if it considers such a pass to be operating properly, whether the pass has been built under this Act or not - S 11(4).

Where a pass has received final approval, then it is deemed to be in conformity with this Act, whether or not it was built in the manner or by the person specified in this Act - S 11(5).

Protection of structure and operation of fish passes

Section 12(1)(2) makes it an offence for owners of passes or any person to alter or damage a fish pass, or otherwise do anything that prevents or deters the passage of salmon and trout through a fish pass, or to take fish passing through. It provides powers – S12(2) - for the Agency to serve notice on the owner or occupier of a dam to repair a fish pass. A pass is deemed to be altered if it is damaged, destroyed or allowed to fall into dis-repair.

Compensation to Fishery Owners

Section 17 deals mostly with the restrictions applied to the taking or disturbing of salmonids in the vicinity of dams, obstructions or mill races. This section also makes it a condition that these restrictions will not apply until any necessary compensation has been made by the Agency, to anyone with commercial fishing rights which may be affected by the installation of a pass - S 17(3). This section is to be repealed by the Marine & Coastal Access Act 2009, with the repeal due to take effect from January 2011.

Fish Pass Construction

Section 18 makes additional provisions to the above sections. In particular, this section makes it an offence for anyone to obstruct a legally authorised person from carrying out any act authorised under Sections 9 and 10 - S 18(1). The section also makes it a condition that the Agency must give reasonable notice to the owner or occupier of a dam or other structure, where it intends to construct, abolish or alter any fish pass or free gap under Section 10. The Agency must supply the owner or occupier with a plan and specification of the proposed work, and must take into consideration any objections raised by these people before carrying out the work - S 18(2). If the Agency causes damage to a dam in the process of constructing, altering or abolishing a fish pass or free gap under Section 10, then the person whose interest has been affected may recover compensation from the Agency - S18(3)(a). In the event of a disagreement over compensation under either Section 10 or 17, then a single arbitrator shall be appointed by the appropriate Minister to settle the dispute - S18(4). Where the Agency is liable for compensation under this Part of the Act, proceedings for the recovery of this compensation must be started within two years of the completion of the work which was considered to cause the damage - S18(5).

Fish pass maintenance

Where an owner or occupier has been required to make a fish pass under S9(1) they are also obliged, under the same section, to thereafter maintain it in an efficient state. Failure to do so is an offence - S9(2). The Agency may take remedial action, enter on the structure or adjoining land for the purpose of taking action, and may recover the costs of so doing from the person in default - S9(3).

Summary of responsibilities and powers in relation to fish passes under the Eels (England and Wales) Regulations 2009

This is a Statutory Instrument (SI) 2009 No 3344 made under Section 2(2) of the European Communities Act 1972(b), that came in to force on 15th January 2010.

Application to obstructions and reporting of obstructions

Regulation 12 defines the types of obstruction and circumstances in which the regulations apply. It covers new constructions, maintenance of existing structures, and the construction or maintenance of any structure near waters that may affect passage of eels. Any such works must be notified to the Agency. Regulation 13 requires the Agency to be notified of any new obstructions that come about that may impeded migration (including natural or artificial events).

Eel passes where passage is being impeded

Regulation 14 allows the Agency to serve notice on the responsible person to install a fish pass, make alterations to an existing eel pass structure, operate an eel pass in accordance with conditions, remove an obstruction, or take any other necessary action to improve or maintain eel passage. This regulation also gives the Agency powers to serve notice requiring the responsible person to submit plans for approval of the pass, and to attach conditions regarding operation of the eel pass. Regulation 15 requires eel passes to be maintained, and Regulation 16 makes it an offence to interfere with or obstruct passage of eels through a pass.

Powers of the Agency

Regulation 20 confers powers on the Agency to act in an emergency, if the responsible person cannot be identified, or where the responsible person has not complied with a notice. Costs of any actions may be recovered form the responsible person. Regulation 21 disapplies requirement for abstraction or impoundment licences in respect action required or undertaken under Eel Regulations. Regulation 22 defines 'responsible' persons.

Notices and Appeals

Regulations 23 and 24 cover how notices must be constructed and served on a person. Regulation 25 covers rights of appeal and appeal process.

Additional powers for fish pass construction and approval under the Land Drainage Act 1991 (and Water Resources Act 1991).

As previously noted, the Agency does not have the power under SAFFA to require the provision of fish passes in waters not frequented by migratory salmonids. Even in migratory waters a developer cannot be required to construct a pass, and therefore to go through the approval process, where the barrier to migratory fish passage is not being increased or where a structure has not been taken down for more than half its length.

However, in such waters, land drainage legislation may be used to make sure provision is made for fish passage. S105(3) of the Water Resources Act places a duty on the Agency in exercising its flood defence powers to have due regard to the interests of fisheries and conservation *(important for species such as shad and lampreys),* including sea fisheries (which may be important for species such as *flounder,* mullet etc). This means that, where a Flood Defence Consent is required for a structure, such consent might not be issued if the structure would impede fish migration. The Agency may then seek the installation of a suitable form of fish pass, as an integral part of the Flood Defence Consent process using either:

a) The Land Drainage Act 1991, S 23; applicable to ordinary watercourses[*]

b) The Water Resources Act 1991, S109; applicable to main rivers

However, it should be understood that the primary consideration of flood defence consenting relates to efficient drainage and it is possible that fish passage considerations may not prove determinative. Moreover, conditions cannot be currently imposed on consents under the Land Drainage Act 1991 except in in relation to time and the manner of work being carried out. This is therefore not the most robust means for providing for fish passage.

This route may also be used to ensure the installation of a suitable fish pass if one is proposed by a developer without having been required to do so by the Agency, when it would be otherwise outside the powers of SAFFA.

Water Resources Act 1991

Requiring fish passes or screens with Impoundment, or Abstraction or (Full or Transfer) licences

As noted above the Agency does not have the power under SAFFA to require the provision of fish passes or screens in waters not frequented by migratory salmonids, and there are limitations even in migratory salmonid waters in respect of passes.

However, in any waters where fish passage is an issue, Water Resources legislation (Sections 24 and 25 Water Resources Act 1991) may be used to make sure that provision is made for fish passage as the Agency can impose what conditions it sees fit on abstraction or impoundment licences*. This means that where impoundment or abstraction licences are required, and fish migration would be impeded, conditions can be placed on the licence to install suitable forms of fish pass or screen.

* This is because the Agency has broad powers to impose conditions in abstraction or impoundment licences under Section 38(2)(a) Water Resources Act 1991 i.e. “may grant a licence containing such provisions as the Agency considers appropriate”. In exercising this power the Agency considers its statutory duty under Section 6(6) of the Environment Act, 1995 as amended by the Marine and Coastal Access Act, 2009 to ‘maintain, improve and develop fisheries for salmon, trout, eels, lamprey, smelt and freshwater fish’. It also considers its duty to further the conservation of flora, fauna and geological or physiographical features of special interest under Section 7(1)(a) and take account of effects generally on flora or fauna under Section 7(1)(c)(ii) Environment Act 1995 and its principal aim in relation to attaining objective of achieving sustainable development under Section 4

[*] Note that the Agency will no longer be the consenting authority once the Flood & Water Management Act 2010 provisions are brought into force.

Environment Act 1995. In addition the WFD Regulations 2003 require the Agency to exercise all our functions (powers & duties) including those in WRA 1991 and SAFFA 1975 so as to secure compliance with WFD requirements.

Compulsory Purchase

The Water Resources Act 1991 gives the Agency the ability to acquire land and other properties under compulsory purchase to assist the process of improving fish passage either by the construction of fish passes or by the removal of obstructions. S156 empowers the Agency to purchase or take on lease, either by agreement or compulsorily, any dam, fishing weir fishing mill dam, fixed engine or other artificial obstruction or any fishery connected to the structure (S156(1)(a)) This section also allows the Agency to take land adjoining any dam where we are involved in fish pass construction or maintenance under s10 of SAFFA (S156(1)(b)). Section 156(2) further gives us powers to remove obstructions under certain circumstances.

Impoundment Licences

There may, in certain circumstances, be a requirement for the issuing of an impoundment licence when a fish pass is constructed. This is particularly pertinent where new dams and weirs are being built but is also relevant where fish passes are installed in existing structures. If the pass results in any change in the upstream water regime, essentially water level(s), then an impoundment licence is likely to be required. Section 25 of the Water Resources Act 1991 is applicable here and advice should be sought from the National Permitting Service.

Abstraction Licences

Where a fish pass is constructed on a structure within the river channel, this can be done without the need for an abstraction licence (full or transfer). However, where a fish pass is built to go round a structure and where water is taken out of the river channel upstream of the structure and is then returned to the river channel downstream of the structure, an abstraction (full or transfer) licence will be required. Section 24 of the Water Resources Act is applicable here and advice should be sought from the National Permitting Service.

Environment Act 1995 (and Wildlife & Countryside Act 1981)

Conservation Duties

In carrying out its duties the Agency has a duty to further the conservation and enhancement of natural beauty and the conservation of flora, fauna and geological or physiographical features of special interest under S7(1)(a) of the Environment Act. The Agency is also obliged to have regard to the desirability of protecting buildings and archaeological features of interest, to take into account any impact its activities may have on the beauty or amenity of any rural or urban area or on any such flora, fauna, features, buildings, sites or objects and to have regard to any effect which its activities would have on the economic and social well-being of local communities in rural areas.- S7(1)(c). These responsibilities are particularly pertinent where fish passes are being constructed in weirs of historic interest, or in natural barriers. (While it can generally be argued that the benefits derived for fish species from the construction of fish passes constitutes the furthering of the conservation of fauna, this may not always be the case. An example of the latter might be construction of a pass in a natural barrier that has ramifications in terms of the genetics of fish stocks upstream).

The Agency has a general conservation duty under section 40 of the Natural Environment and Rural Communities Act 2006 to have regard, so far as is consistent with the proper exercise of its functions, to the purpose of conserving biodiversity.

Recreation Duties

The Agency has a general duty under S6(1) of the Environment Act 1995 to promote the conservation and enhancement of the natural beauty and amenity of inland and coastal waters and of land associated with such waters; the conservation of flora and fauna which are dependent on an aquatic environment; and the use of such waters and land for recreational purposes. It has a more specific duty, under S7(4) of the EA 1995, to ensure that water, or land associated with water in the Agency's ownership, is made available for recreational purposes, subject to certain conditions - see S7(4) for details. Land associated with weirs and fish passes may well be used for a variety of recreational activities (walking, picnicking, bird watching, angling etc). Fish passes often make attractive location for canoeists and consideration may be given to making passes safe for canoe passage where feasible. However, the joint design of passes to include fish and canoes is likely to compromise their efficiency for fish passage. Usually it would be better to provide separate facilities.

Sites of Special Scientific Interest

The Agency has duties in respect of SSSIs under S8(3) of the Environment Act and section 28G, 28H and 28 I wildlife and Countryside Act 1981. Where the Agency is either authorising others to do works, or else carrying out its own works, on land designated as an SSSI then it must consult with either NE (Natural England) in England or else CCW (Countryside Council for Wales) in Wales. This must be done before carrying out or authorising any works, operation or activity likely to damage the special interest of the site. These duties have been replicated and supplanted by duties in section 28H (for the Agency’s own works) and section 28I (for activities the Agency authorises) Wildlife and Countryside Act 1981 as amended by the Countryside and Rights of Way Act 2000.

- The Agency also has specific responsibilities, under Section 28H of the Wildlife and Countryside Act 1981, when it is the owner or occupier of an SSSI. It must not carry out any operation likely to damage the features of special interest (OLD) without having notified and received the consent of either NE or CCW. OLD will be specific to each SSSI citation, and will have been notified to the Agency by NE or CCW

The Agency has specific responsibilities under section 28I of the Widlife and Countryside Act 1981 where it is permitting an operation likely to damage an SSSI. It must notify NE or CCW before permitting the operation and await their response before issuing any permit.

The Agency has a general duty under section 28G of the Widlife and Countryside Act 1981 to take reasonable steps, consistent with the proper exercise of its functions, to further the conservation and enhancement of the flora, fauna or geological or physiographical features by reason of which the site is of special scientific interest.

A number of important rivers in England and Wales have been recently designated as SSSIs. Furthermore some of these will become SACs (see below in EC Directives). Any operations carried out by the Agency, or licensed or consented by the Agency, must be covered in formal Consenting Protocols which have been, or will be, drawn up for each site.

Early liaison with NE or CCW is advisable where SSSIs (or SACs) are involved. It is essential that Agency Conservation staff be consulted, since they can provide advice on the location of SSSIs, the existence of particular Consenting Protocols and the normal method of contact with the relevant, local NE and CCW staff.

Sustainable Development

Section 4 of the Environment Act places a duty on the Agency to make a contribution towards attaining the objective of sustainable development. Further, consideration should be given to the fact that the Agency has been directed, as a key component of its contribution to sustainable development under Section 4 to conserve, and where practicable, enhance biodiversity. The Agency is committed to ensuring that the achievement of relevant targets set in the overall UK Plan is recognised in its regulatory, operational and advisory activities. Further information on local biodiversity targets, as applicable to the Agency's work, will be available through the Make it Happen Plans (formerly Local Environment Action Plans or LEAPS).

Regard to Costs and Benefits

Section 39 of the Environment Act places a general duty on the Agency to have due regard to the costs and benefits of exercising its powers. This includes the application of its powers in respect to fish passes. Advice can be obtained from the Agency’s Economic Policy Unit. (page **Error! Bookmark not defined.**).

EC Directives

Formal Environmental Assessments

Where a project is likely to have a significant effect on the environment, developers are required to carry out an Environmental Assessment - EC Directive 85/337/EEC (as amended). The relevant Planning Authority will require such an Assessment under the powers of the Town and Country Planning (Environmental Impact Assessment) Regulations 1999, prior to giving planning permission.

Planning regulations

Where a planning application is required then it should always be accompanied by an Environmental Statement, or if necessary an Environmental Impact Assessment. The relevant Planning Authority should always be consulted to ensure that planning matters are given proper consideration.

Special Areas of Conservation (SACs)

The Agency also has responsibilities under the Habitats and Birds Directives with regards to the Natura 2000 network of sites. This site network is comprised of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). All SACs and SPAs are made up of component SSSIs. The Directives have been transposed into law by the Conservation of Habitatsand Species Regulations 2010. Where a fish pass has the potential to affect a Natura 2000 site, the Habitats Regulations must be applied. Ramsar wetland sites are treated as a matter of policy in the same way as SACs and SPAs.

The stringent tests demanded under the Habitats Regulations are in many ways more demanding than those required for SSSIs, and certainly too complex to outline in any detail here. The legislative position is summarised in Planning Policy Statement 9 (PPS9) and the Biodiversity Circular (Defra 01-05). Detailed internal guidance is also available. Put simply, there is a four stage process to be followed;

Stage 1 - Identifying relevant applications/activities and agreeing the lead Authority

Stage 2 - Assessing likely significant effect

Stage 3 - Undertaking Appropriate Assessment

Stage 4 - Determination of the application

It is important to understand that consultation with NE/CCW is likely to be iterative, and that the applicant should be involved in these discussions from the very earliest stage. If possible, pre-application discussions should be undertaken.

The overall aim of the decision making process is to ascertain whether it can be determined that the fish pass will not adversely affect the integrity of a Natura 2000 site, and record the basis for this decision. In short, the precautionary principle has a statutory basis for the first time. Also, it should be considered that the fish pass need not be constructed within a Natura 2000 site for a significant effect on site integrity to occur, and the significant effects may not necessarily be on fisheries interests.

Other Legislation

Transport & Works Act 1992

On its introduction, this Act provided a new legal and administration system for the authorisation of certain infrastructure projects, which had previously required authorisation by a Private Bill. Under section 3 of the Act, the Secretary of State (SoS) may make an order relating to, or to matters ancillary to:-

- the construction or operation of an inland waterway in England and Wales

- the carrying out of works which interfere with rights of navigation in waters within or adjacent to England and Wales, up to the seaward limit of the territorial sea and which are of a description prescribed by order made under section 4 of the Act. An order under section 3 may not be made if the SoS is of the opinion that the primary object of the order could be achieved by means of an order under the Harbours Act 1964.

Amongst the schemes that may be considered for approval by order under the Act, and of particular relevance here, are those including barrages, whether amenity or energy, river crossings and weirs unless these are proposed for a waterway managed or maintained by a Harbour Authority.

The intention of the Act is to seek to avoid the lengthy Parliamentary process for the promotion of major infrastructure projects, replacing it with a procedure in which an applicant publishes a proposed order which, if it attracts opposition, can be referred by the SoS to public inquiry. It is presumed that appropriate and adequate negotiation between promoter and opponent is carried out prior to public inquiry in order to eliminate as many sources of uncertainty and conflict as possible. The requirements for Environmental Impact Assessment apply (page 19).

The public inquiry is held in front of an inspector, appointed by the Planning Inspectorate, whose role is to preside over and subsequently summarise the proceedings, reporting this to the SoS with a recommendation. Unfortunately the inevitable length of the inquiry, reporting and SoS decision making process means that there is little if any such time saving over the Parliamentary procedure.

If a project also needs authorisation under other Acts, for example an abstraction or impounding licence, or else a discharge consent, then the applicant must also seek this. However section 15 of the Act enables the SoS to assimilate these within the procedures of the works order itself. It should be noted that this could, if deemed appropriate, include the process for fish pass approval.

If a scheme is deemed to be of national significance then the SoS may refer it directly to Parliament, where both Houses must consider it. National significance remains undefined, but is accepted as including schemes that affect a significant part of the country, or have extensive effects on the environment and ecology of an area.

In practice, the Transport and Works Act process can be a long and expensive process. The Usk Barrage was promoted under this Act in 1994 and necessitated a lengthy and expensive consultation process, for which there is no mechanism to seek costs from the applicant. The subsequent public inquiry lasted over 3 months, and the reporting and review process 18 months, after which the scheme was finally rejected on economic and ecological grounds.

Private Bills

Prior to the Transport and Works Act, this was the principal mechanism for substantial infrastructure projects, and was used for the Tawe, Tees and, initially, the Cardiff Bay barrages. Although largely replaced, the method does remain available for future use by potential scheme promoters. Under this process the Bill is drafted and lodged in Parliament by the promoter, where it is then considered by each house prior to examination by a Parliamentary Committee. Opponents to the Bill are able to make representation to the Committee, after which the Committee votes on the scheme and, dependent on a successful outcome the Bill returns to both Houses prior to enactment.

Unless the Acts specifically make provision for an alternative fish pass approval process, then this defaults to the provision for approval set out in SAFFA, as modified by the Environment Act.

As for the T&W Act, it is generally presumed that appropriate and adequate negotiation between promoter and opponent is carried out prior to the drafting of the Bill, so that as many conflicts as possible may be eliminated.

Government Bills

In uncommon circumstances, it is conceivable that the Government might decide that a barrage scheme is nationally significant, warranting promotion by a Government sponsored Bill. This was the case for the Cardiff Bay Barrage after abortive attempts to secure Parliamentary agreement via a private bill, and resulted in relatively rapid enactment.

CAVEAT: The above section contains a summary of the relevant legislation applicable to fish passes and the approval process and is not intended as an exhaustive guide to the interpretation and use of this legislation.

NATIONAL FISH PASSAGE PANEL (NFPP)

Role of Fish Passage Panel

The Fish Passage Panel was set up to consider and make recommendations to the Agency for the formal authorisation of both internal and externally promoted fish passes. The Panel also acts as a centre of expertise and a focus for other issues relating to fish passage, including sceening of intakes and hydropower. These issues include promoting research and development projects to improve the understanding of fish passage requirements, developing and maintaining a comprehensive database of all fish passes in England and Wales, and promoting legislative changes. (Terms of reference are given in Appendix III).

An important role of the Panel is to provide advice and assistance to Agency staff involved in any capacity with fish passes.

It should be noted that the financial authorisation of projects is not part of the role of the Panel but rests with Regional PABs (Project Approval Board).

Rationale

The Agency is responsible for the authorisation of fish passes for migratory salmonids, both those built by external developers and those built by the Agency itself. As a matter of principle it is important that the same standards are applied to the formal Approval of both internal and external projects. It is also important that other National organisations are treated consistently across Regional boundaries. In order to be consistent, fair and equal in the treatment of both internal and external applications for Approval, and provide an appropriate level of independence, an expert Panel was established to advise the signatory (delegated Environment Management Team Leader, EMTL). The EMTL must consult and take advice from the delegated National Fish Pass Officer before issuing any Approval. Exactly the same process and standards are applied to both external and internal projects.

Members of Panel and Reporting Links

The Panel comprises six officers chosen for their expertise and experience in fish pass and fish migration issues. The Panel is currently chaired by a Head Office Senior Technical Specialist with the members each taking responsibility for acting as a first point of contact for one or more Regions (indicated in parentheses below). The Panel includes a Head Office Senior Technical Specialist (Fish Passage) who is also the delegated National Fish Pass Officer (NFPO), which is a dedicated permanent full-time technical post in National Operations Directorate. The current membership is as follows:

J. Gregory (Chairman) (HO)

S. Bailey (NE)

A.Fewings (Southern)

K. Broad (South West)

K. Nash (North West)

Generally technical advice on Fish Passes will be provided initially by the nominated Regional representative (but directly by the NFPO if that representative is not available at the time). Advice on procedures should be addressed to the NFPO.

Overview of Operation

The Fish Passage Panel meets approximately five to eight times a year depending on business demands to consider any concepts (effectively requests for advice about a site), applications for Approval of designs, and other appropriate issues.

Concepts will normally be submitted through the Regional contacts (but may also be submitted to the NFPO), who will describe the challenge to the Panel and obtain some advice about the type of fish pass to use. They will then feed back recommendations to the Area or Region concerned. Hopefully the representative will have been armed with sufficient information and data to obtain robust and detailed advice. Generally, the earlier in a project that the Panel is consulted in a proposal, the more smoothly and efficiently the process runs, and the better the outcome.

Applications for Approvals of the form and dimensions of a pass will normally be submitted to the NFPO (but may also be submitted through Regional representatives), who will make a technical assessment of the proposal prior to the next meeting. This will involve checking the key design features in respect of functionality for fish passage*, and ensuring that the required data have been submitted. Applications will be accompanied by Risk Assment forms (one each for diadromous & potamodromous species, or both as appropriate) that will help determine whether any approval given might be provisional or Final. At the meeting the Regional representative presents and describes the proposal to the rest of the Group for critical appraisal. If there is any contention surrounding an application the representative of the promoting Region is excluded from the decision-making process. In the event of a disagreement the Panel would refer the matter to the Head of Function for arbitration. If proposals are acceptable the NFPO will advise the EMTL that this is the case, and provide the paperwork necessary for the Approval to be issued. Should Provisional or Final Approval not be immediately forthcoming the NFPO will outline to the Area what modifications or further work is necessary to obtain Approval.

*Note that it is not the responsibility of the NFPP to check specifically any health & safety features associated with the pass, nor to ensure that other permissions and consents required are obtained. It is the responsibility of the Project Manager to ensure that all necessary procedures are completed. However, the Panel will comment on any features of the design, health & safety or other matters, that they feel merit attention.

Performance Measure and Standards of Service

The Panel will deal with Fish Pass proposals as swiftly and efficiently as possible. Clearly this is facilitated if all required data have been submitted with the application. The Panel has adopted the following standard of service (SoS) to work to:

$$\text{Determination Rate} = \frac{\text{No. of fish pass applications determined to deadline} \times 100}{\text{No. of fish pass applications}}$$

Definition: Deadline of 4 months with proposed standard of service of 80% to be determined within deadline. Deadline to run from date application registered (ie when all plans and information is complete) to date of decision for Approval.

FISH PASS APPROVAL

Approval Process

Concept

While not strictly part of the Approval process early consultation with the NFPP is to be encouraged, since it will avoid any unwelcome `suprises` later in a project.

This manual should provide sufficient guidance to enable Area staff to select an appropriate pass type(s) for a given situation. The Panel will consider outline proposals (or proposals at any stage of development) and advise on their suitability.

However a fish pass concept form providing an outline of the challenge may be submitted for consideration by the Fish Passage Panel, for them to provide advice in the first instance. The objective of the Panel will be to either, to identify an appropriate design, or else to identify those types of pass, that should be the subject of a feasibility study and then design in the case of a large scheme. In the case of a small scheme it will be to identify a solution that can be easily, and quickly, implemented.

The initial `concept` request to the Panel can comprise a photograph or simple plan, together with an outline of what the current situation is, and what the outcome is intended to achieve. A concept form is included at Appendix IV This should be discussed with and passed to the relevant Regional Representative (see above). Clearly, the more of the information and data that would be used in a full-blown feasibility study that is available at this stage the better.

Treatment of Applications for Approval

In the spirit of modern regulation every endeavour will be made to ensure that the burden placed on applicants for approved passes is not overly onerous. The Environment Agency will take into account the risks associated with any specific scheme when deciding what approval status, if any, will be given to the proposed fish pass. In practice, this means that provided that they follow best practice and offer a low to medium risk to the environment, the vast majority of schemes will be granted Final Approval. Provided that the pass(es) are built to the approved form and dimensions this will relieve the applicant of the burden of monitoring the pass to demonstrate that it is operating effectively and efficiently. Schemes that do not follow best practice or offer high risk to the environment will receive a Provisional Approval, which means that a monitoring programme will be required to demonstrate that the pass is operating effectively and efficiently in all respects before Final Approval can be granted.

At the present time specific legislation in relation to obstructions applies to two groups of diadromous species including migratory salmonids (Salmon & Freshwater Fisheries Act, 1975 as amended by the Environment Act, 1995) and eels (The Eels - England & Wales - Regulations 2009). Formal approval will be required for passes for thse species. Other diadromous species (lampreys and shad) and potamodromous freshwater fish species i.e. brown trout, grayling & coarse fish are not specifically covered by obstructions regulations. Legislation covering obstructions for all species was anticipated to come into effect in 2010, but has been delayed at least until 2012. Where passes have been required by the Environment Agency under broader legislation or are being constructed without obligation proposals will be audited and agreed. In anticipation of legislation covering all species at some future time, a risk-based process to help decide whether a proposal shall receive Provisional or Final Approval has been devised to apply in a smilar way to diadromous and potamodromous species.

Applications for formal approval (or audit) of fish passes will be accompanied by a Risk Matrix form (see Appendix V) to help determine the status granted to a pass. For both diadromous and potamodromous species a simple additive scoring system will indicate the overall risk taking into account proposed pass design, significance of the obstruction in relation to the catchment, whether the obstruction is existing or new, and ecological status of the population. Proposals with scores of ≤ 10 will receive Final Approval, while those with scores of ≥ 16 or not following best design practice will reveive Provisional Approval. Proposals scoring 12 or 14 will be reviewed on their merits with the likelihood that the majority will receive Final Approval, especially those with the lower of the two scores.

Approval Application

A detailed proposal for a new or altered fish pass will be submitted on a pro-forma application form (Appendix VI) to the National Fish Pass Officer, together with any supporting information including a Risk Matrix form(s) as appropriate (Appendix V). This would normally follow both local liaison (with the Area staff and their NFPP contact) and National liaison (with the NFPP). Each application should include two complete sets of plans (three sets if the site is privately owned). These details will be technically assessed and a site visit may sometimes be required.

When approval is given, each plan is initialled, dated, and then `sealed' with the Approval instrument signed by the delegated Environment Management Team Leader or a more senior officer.

One copy of the plans and instrument is sent to the NFPO, one copy is retained by the Area, and if appropriate, one set is sent to the owner of the site of the proposed structure. Construction of the pass can then proceed.

Provisional Approval

Where an approval is Provisional this will be clearly indicated on the instrument of approval and the covering letter (external) or memo (internal).The covering letter or memo will indicate the likely scale of the monitoring programme required to demonstrate that the constructed fish pass is satisfactory in all respects and including effectiveness and efficiency.

It should be noted that a Provisional Approval should also be sought in the case of temporary fish passes/structures.

Modified Approvals & Abolishments

Modifications to a fish pass between provisional and final approval stages will require a modified approval. On agreement of revised plans a new Approval (Provisional or Final) will be issued. At the same time notice will be given of revocation of any original PA, which will be completed after 90 days notice as required by statute. If any changes are proposed to be made to an existing approved fish pass, or else associated structures that may affect the operation of the pass, then a new approval will be required. Application may also be made to abolish a fish pass where it is no longer required e.g. it has been replaced with another, obstruction has ben removed.

Final Approval

As noted above passes receiving Final Approval will require no further action on behalf of the applicant, save meeting the statutory duty to maintain the pass in an efficient state. However, it should be noted that the pass will not be in conformity with SAFFA unless it is constructed precisely to the approved form and dimensions approved.

Final Approval (where PA granted)

At an appropriate stage after construction, usually a minimum of three years, the Agency will require the owner of the fish pass to seek a Final Approval (FA) for the structure. The successful outcome of an application for final approval will depend on the provision of adequate data, drawn from an appropriate monitoring programme, which demonstrates that the fish pass is operating effectively and efficiently. The type of evidence and monitoring programme required is discussed in the section on page 215.

If it is demonstrated to the National Fish Pass Panel that the pass is working satisfactorily then it can receive Final Approval.

If the fish pass is not operating satisfactorily then proposals will need to be made to increase its efficiency and effectiveness. If this requires structural alterations to the pass, or modifications to operating procedures linked to the existing Provisional Approval, then a new PA will be required. The old PA will be revoked.

A Risk Based Approach to Provisional or Final Approval

It is recognised that the costs of monitoring to demonstrate that fish passes are effective and efficient can be very high, and indeed can be significantly very much more than the cost of construction of the asset itself. Recently efforts have been made to find relatively low cost ways of demonstrating the effectiveness (but not efficiency) of fish passes, and to facilitate this by building in to passes standard features that will facilitate this process (Washburn, Gregory & Clabburn, 2008). Notwithstanding this, a risk-based approach to authorisation of future fish passes has been introduced by the Agency that will ensure that in future only high risk sites will be issued with Provisional Approval. This will not only reduce the burden of administration, but will also greatly reduce the costly monitoring burden associated with demonstrating the effectiveness and efficiency of fish pass facilities in order to progress to Final Approval. In the future, proposed fish passes following Best Practice design principles and being in low-medium risk situations will be given Final Approval at one step. Conversely, passes proposed that are novel in form, do not conform to Best Practice, and are in high risk situations for the fishery resource will be subject to a Provisional Approval stage. They will have monitoring needs to demonstrate that they work effectively before Final Approval will be given, and this process will be rigorously enforced.

To aid this process, and to help provide some transparency, a Risk Matrix form will need to be completed to accompany applications for fish pass approval. Separate forms are provided for diadromous and potamadromous fish species (see Appendix V). Risk is assessed based upon four tenants including whether best practice has been used in the design, relative location in the catchment concerned, status of the obstruction, and ecological risk for the population.

Approval Criteria

Each application will be treated according to its merits. Important factors including the proposed design type, current or future status of the river, the location of the obstruction within the catchment and the current and possible future status of migratory salmonid stocks will be taken into consideration. The features out-lined below will be rigorously examined where a new obstruction is concerned, particularly where the impact on fish stocks is potentially high. A distinction will generally be drawn between applications for approval of passes on new obstructions and passes on existing obstructions.

Distinction Between New and Existing Structures

If a new obstruction to fish migration is proposed (e.g. barrage, weir, dam, gauging weir) then the best available design of fish pass for the site must be incorporated within the structure. In some cases interim arrangements will be required to enable fish passage during construction, and these will also require formal approval.

Associated with this will be a requirement to monitor the effectiveness and measure the efficiency of the pass through appropriate pre- and post-construction studies. The granting of final approval will depend on the achievement of an appropriately high efficiency (subject of risk assessment). Where appropriate successful passage past the obstruction via other safe routes will be taken into account in the determination.

The Agency may require a developer to carry out mitigation to fully compensate any adverse effect (e.g. passage efficiency of less than 100%; poor distribution and thus availability of fish for angling and spawning).

It is recognised that the term "new structure" covers a range of structures in terms of their scale and location, and hence their significance and potential impact upon stocks of fish. It will be a matter for Area staff to determine the appropriate scale of monitoring and mitigation required.

In the case of existing structures that impede fish migration, any improvement in potential access to the upstream river is desirable. Although optimum designs will be preferable it is recognised that this may not always be technically or economically feasible. Structures that compromise to some extent some aspects of recognised design criteria will be considered. Monitoring requirements are also likely to be less stringent.

Key Features

Fish passes are invariably site-specific in relation to many factors, and thus each one will represent a unique situation when it is considered for approval.

The following key features will be taken into account at the provisional approval stage, and appropriate information and data must be provided in the application (see Appendix VI):-

- pass type
- pass location within structure
- pass design
- pass hydraulics
- local hydrology and hydrodynamics
- attraction of fish
- fish behaviour
- additional features

Pass Type

The type of pass (e.g. Pool and Traverse; Denil; Borland lift etc) selected at the design stage is dependent upon a number of factors such as type and form of structure where it is to be located, local topography, river characteristics and flow, and species to be accommodated.

While the type of fish pass may be influenced by the range of species to be accommodated the requirements for migratory salmonids will be paramount with respect to applications for approval. The same will be true of any potential Conservation or Recreation opportunities identified at the site.

Applications will be examined to determine that the most appropriate pass type has been identified.

Pass Location

The location of a pass is considered to be one of the most (if not the most) crucial factor in relation its success. It can easily be the case that the hydraulics of a pass is perfectly acceptable to the fish, but they never find the entrance.

Generally, the pass entrance should be located as far upriver at an obstruction as possible, bearing in mind the discharge characteristics of the receiving structure, and avoiding situations where prospective migrants would have to reverse direction to seek the relatively small entrances.

The reasoning behind choice of fish pass location will be assessed.

Pass Design

Guidelines and criteria specific to each particular type of pass are given in the fish pass selection section (page 42). Readers requiring much more detailed information will find many suitable references in the Key References & Bibliography sections.

The following is a list of the important features which will be considered in respect to the different pass types:-

- Pool :- Pool sizes, head differences between pools, pool energy dispersal characteristics, inter-pool traverse details.

- Denil :- Length and angle of flight, baffle design, provision of resting pools, entrance and exit details.

- Lift :- Entrance and exit design, holding capacity, operating cycle, fish clearing mechanism.

Consideration should not only be given to upstream migration but requirements for downstream migration should also be taken into account.

Pass Hydraulics

The volumes and patterns of water flow through a fish pass may determine the success of the structure. It is possible to have an acceptably located pass built to adequate basic design, only for it to fail because of excessive within-structure turbulence or some other behavioural constraint.

The basis for determining dimensions of the structure and calculating hydraulic characteristics of the passes including discharges, velocities, volumetric energy dissipation, etc. is provided in Fish Pass Types (page 62), and also in other source reference documents listed in the key references and bibliography. A description of how the hydraulic parameters vary in relation to changing river conditions (discharge and river levels) will be required, and will be examined as part of the approval process.

It is recommended that, particularly in the case of major schemes, consideration be given to the construction of physical models, in order that the hydraulics characteristics of designs can be thoroughly examined. In some cases this should be a requirement placed upon the developer.

Local Hydrology and Hydrodynamics

Variation in river discharge and local flow patterns (hydrokinetics) in the vicinity of the obstruction and pass will affect fish behaviour and its ability to locate the pass. An effective fish pass is likely to result from a combination of appropriate design, together with an appreciation of the local conditions and an understanding of fish behaviour in relation to those conditions.

Designs will be examined, together with appropriate flow data and other information, to determine whether they take account of local hydrological conditions in order to maximise the success of fish in locating the fish pass entrance.

Attraction of Fish

An important element of attraction of fish to passes is the provision of adequate dedicated attraction flow (volume and plume characteristics) in relation to other competing flows, eg river flow, turbine flow etc. This may vary with river discharge and other factors (eg operation of structures) and will clearly be related to local hydrology and hydrodynamics considered above.

How it is intended to achieve attraction at a site will be assessed.

Fish Behaviour

Fish migration patterns and physical ability will vary according to a number of environmental stimuli and according to the season of the year. Of particular importance will be the swimming abilities (burst speeds, leaping abilities, stamina etc.) as temperature changes. Information on this is provided in the source documents.

For some passes, it is clear that they are only required to work at certain, possibly discrete, times of the year when fish are present. This may be the case in a spawning tributary, which is only entered by pre-spawning fish in October or later.

In order to maximise pass efficiency adequate consideration must be given to the behaviour of fish as they ascend to the obstruction. This may include gaining local knowledge of preferred migration and approach routes (at various times and flow conditions), resting and assembly areas, and any change in these as flow conditions change.

Applications will be examined to see how these factors have been accounted for.

The design of fish passes for multi-species fish assemblages presents particular problems, as behaviour and swimming capabilities are likely to vary. In such a case, criteria will be defined by the most demanding species though other entirely separate fish passes may also be required.

Additional features

Fish passes may be designed to incorporate other fisheries management features such as monitoring devices, for example traps, fish counters etc. It is important that these features are properly designed as integral components of the fish pass so that they do not adversely affect the performance of the pass (e.g. compromise pass hydraulics or negatively affect the behaviour of fish using the pass) whilst at the same time operating efficiently themselves. Retro-fitted additions often fail to work properly or adversely affect the efficiency of the pass to which they are attached.

FISH PASS CONSTRUCTION – THE PROJECT PROCESS

The Project

Any project intended to improve fish passage will follow a logical sequence, which is summarised in Figure 1and 2 below

Figure 1Flow summarising the stages and inputs to a fish passage improvement project part 1

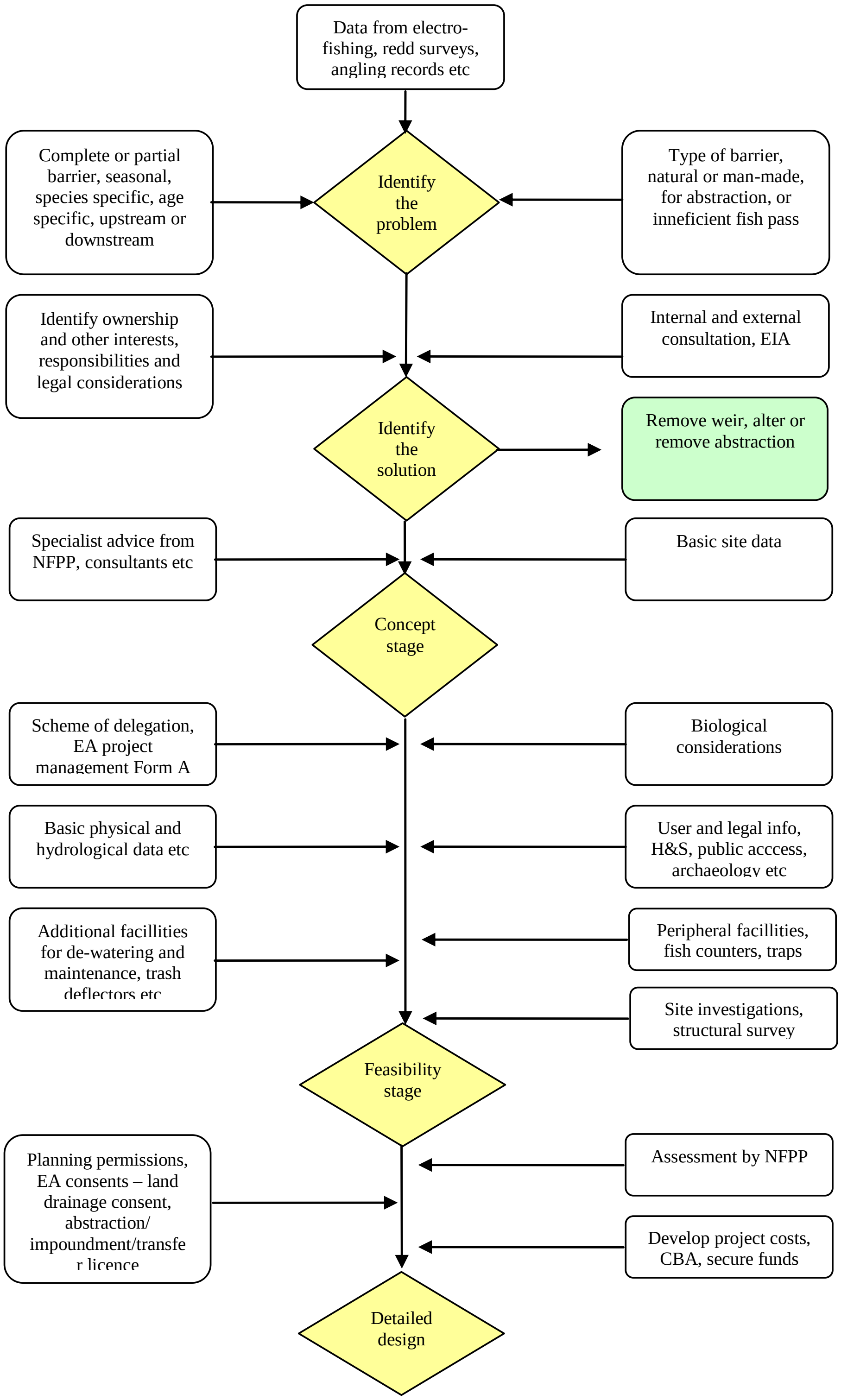
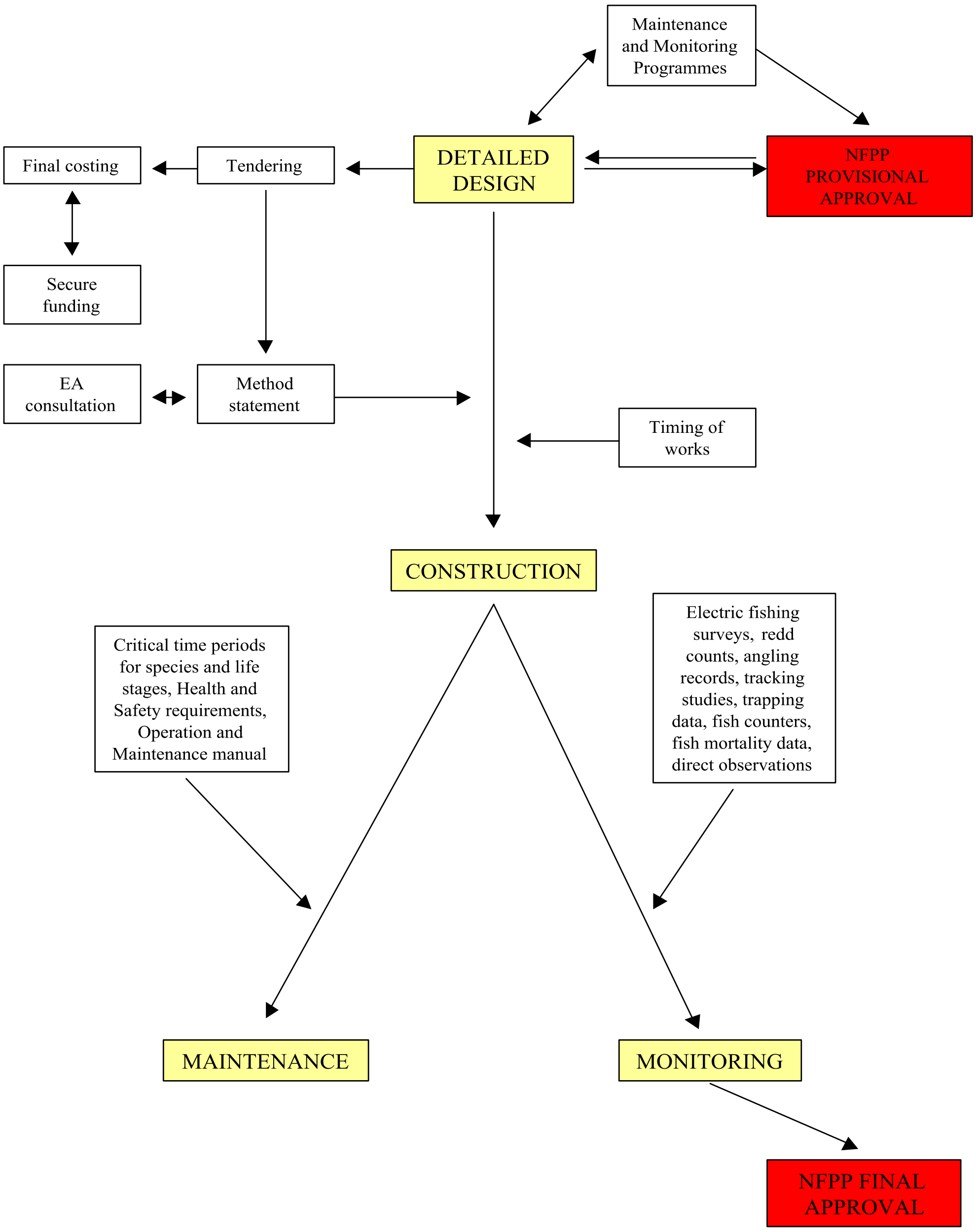


Figure 2 Flow diagram summarising the stages and inputs to a fish passage improvement project part 2



Identify the Problem

The fact that there is a fish passage issue will usually be identified using data from fisheries surveys or studies including population estimates, radio tracking programmes, or angling catch data. Visual clues may also play a part, since the observation of large numbers of leaping fish or accumulations of fish above or below obstructions is a sure sign that the passage of fish is being compromised.

It is important to be clear about what the problem is. For example, it may relate to:

- Upstream or downstream migration, or both
- A complete obstruction or barrier
- A partial obstruction or barrier
- Particular species
- Specific life stages
- Particular (seasonal) river discharges

The type of blockage is important as it may have an important bearing on the chosen solution. For example, barriers can be:

- Natural
- Man-made
- As a result of other activities associated with its use, e.g navigation, abstraction etc
- As a result of an existing fish pass which is ineffective for some reason (poor design, location, built with only a particular species and life stage in mind etc)

In identifying problems for migrating fish the following may need to be considered:

- New structures
- Existing structures
- Physical modifications to existing structures which then cause them to become barriers

- Changes to operating regimes associated with existing structures, eg abstractions, which then form an impediment to fish migration

Identify the Solution

Potential solutions may include:

- Remove or modify barrier
- Remove or modify damaging abstraction etc
- Modify existing fish pass
- Construct low-cost informal solution to assist passage
- Construction of formal fish pass or easement
- Trapping and trucking

If the solution is to be a fish pass or easement, identify and list the precise needs bearing in mind the biological considerations and objectives in relation to:

- Species
- Life stage
- Size range
- Migration period
- Direction of migration

Identify at this stage:

- Ownership of structures, riparian rights, fishery rights, others rights e.g. abstractions etc
- Legal responsibilities - whose responsibility it is to solve the fish passage problems
- Flood risk management, navigation rights, abstraction rights, listed structures and other archaeological and conservation designations
- Poaching, public access, security

Consultation is essential before proceeding beyond this stage in order to clarify these issues. Environmental Appraisal starts at this stage.

Consider funding carefully at this stage. Project costs can be considerable even to reach an outline design stage. Additional costs associated with feasibility and detailed design may include site investigations such as structural, topographical, and hydrometric surveys. Project management, legal, compensation, and construction supervision costs can all add substantial sums to the final total project budget for a fish pass.

Identify the Type of Pass or Easement - The Concept Stage

At the concept stage the range of options that are potentially available are narrowed down to those that are considered practical to investigate in more detail. At this stage it is useful to have the following to hand if possible:

- Plan of the overall layout of the site
- Rough description of the size and nature structure of the obstruction
- Estimate of head difference across the structure
- An estimate of river discharge

The type of fish pass and its location can now be identified having taken account of: the biological objectives; the legal & social objectives; and the available data. Specialist advice at this stage may be obtained from a variety of sources, e.g. EA staff with the appropriate expertise and experience, framework consultants, external consultants but, most importantly the Environment Agency National Fish Pass Panel (NFPP) or any of its members. There is a Concept form (see Appendix IV) that prompts for the basic information required to ask for the advice of the NFPP at this stage, however the better and more comprehensive the information made available the easier it is to provide sound advice. Bear in mind that photographs, particularly aerial ones, are a great help in visualising the site.

Outline Design - The Feasibility Stage

At the feasibility stage the expediency of using any of the practical options identified at the concept stage is investigated in depth, and outline design is prepared for the recommended option(s) chosen for final detailed design.

Take into consideration the biological objectives:

- species
- life stage

- size range
- migration period
- direction of migration

Be aware of the swimming abilities of the target species in relation to expected water velocities in any proposed chosen structure, taking in to account water temperature at the time of migration.

The following basic physical data will be required:

- detailed plans of any existing structure (if none are available, then a topographical survey may be required)
- head difference over the barrier
- hydrograph at the site - preferably over a period of years including typically dry and wet years
- range of water levels upstream and downstream of the barrier over a range of river discharges corresponding with the hydrograph
- water temperature data - particularly during key migration periods

Much of this data and information may be available, but additional surveys may be necessary. **In particular, it is essential to establish the relationship between water level and river discharges, especially downstream since this is not readily estimated (unlike upstream). The downstream level at low river discharge (Q_{95}) is particularly crucial to sound design. Data on water levels must be collected early in the project and in advance of the detailed design.**

The following issues should be considered:

- Health and Safety issues related to the site
- Public access (& Safety)
- Abstractions
- Recreation uses
- Navigation rights
- Fishing rights
- Archaeology
- Landscape
- Conservation
- Flood defence

- Utilities e.g. gas, electric, telecommunications

Additional facilities that will need to be considered at this stage include:

- access arrangements for maintenance
- de-watering mechanisms for maintenance
- trash deflectors

Peripherals that may need to be considered in the design include:

- fish counters
- fish traps
- other monitoring facilities e.g. video

Structural surveys: may be required to confirm the stability of the structure before contemplating modification. This could have a major bearing on the desirability of building a pass directly on the structure, as opposed to building it around the structure.

Site investigations: may be needed to determine the underlying deposits and strata and their suitability for supporting construction works.

Once complete, the outline design can be used:

- for assessment by the NFPP for further advice and guidance
- for formal consultation with all Environment Agency departments (Flood Defence Consent, Water Transfer Licence and Impoundment Licence*) and with external parties
- for Planning Approval requirements

* An abstraction licence or an Impoundment Licence may be required for a fish pass in certain circumstances. Check with the EA Water Resources Licensing section.

Application for Provisional Approval by the NFPP

An application form (see Appendix VI) is designed to summarise the essential features of the pass, to establish the criteria used, to draw out any assumptions and the principles used in the design.

Sufficient copies of the location plans and detailed engineering plans showing the form & dimensions of the pass must be attached. External applications require three copies (applicant's copy, Area copy, National file copy), where internal applications require two copies.

Maintenance and and any monitoring plans will also be required for Approval. Advice on an appropriate monitoring programme can be provided by the NFPP.

The final design will also be used for:

- refining the final project costing to secure funding (using an engineers estimate for the construction cost)
- cost benefit analysis
- final internal and external consultation
- planning permissions and other licences eg abstraction licences, impoundment licences etc where required
- legal and ownership/access consideration, and agreements for formal maintenance and monitoring requirements.

Maintenance

A formal maintenance manual (including operation details) should be produced for the structure, particularly in the case of new passes.

Any maintenance regime should take into consideration the following:

- The period(s) of time when fish pass operation is critical with respect to the life cycle of the target species. For instance, a pass designed for salmon and sea trout located at the bottom of a catchment will need to be operating effectively all year round, while a pass designed for brown trout located at the top of a catchment may need to be operating only during spawning migration periods.

- Health and Safety considerations, which are paramount when undertaking any maintenance work on fish passes

Monitoring

For the final approval of fish passes, information will be required by the Agency to show that the pass is working effectively and efficiently. This takes two parts:

- hydraulic operation

- effectiveness of fish passage itself

It should be ensured that the pass has been built to its specification, and that it operates hydraulically as expected. Gauge boards fixed upstream and downstream, and in any resting pools, can be helpful in ensuring the basic hydraulics are as expected. If present, the operating protocols of any nearby water control structures should also be reviewed to ensure that attraction to the pass is maximised.

The NFPP can advise on the fish monitoring requirements.

Where passes are built which do not need formal approval - easements for instance - best practice dictates that it is still important to monitor the effectiveness of the pass.

The following types of data are typically used to ascertain the effectiveness of a pass:

- electric fishing surveys
- redd counts
- angling records
- tracking studies
- trapping data
- fish counters
- video monitoring (temporary or permanent)
- fish mortality data
- direct observations of fish movement

Where a pass has Provisional Approval a period of three years is usually taken as a standard monitoring period between construction of a pass and application for final approval. However, this period may differ depending on the quantity and quality of the monitoring data. Once sufficient data is available this enables an ***Application for Final Approval to be made to the Agency.***

Fish Pass Costs

In terms of civil engineering most fish pass constructions are small projects, but they are carried out in a high-risk environment (e.g. difficult access, subject to flooding events, water seeping in to the works, unknown or unexpected construction of weirs etc). The latter factors often make a fish pass construction relatively much more expensive than a similar sized civil project in a less risky situation. Significant additional costs may also arise as a result of health & safety requirements. The net result is that the cost of technical fish pass solutions can and does vary very considerably, and is often much higher than initially anticipated. Clearly also, construction of a pass is very much cheaper when it is constructed as part of other works on site so that the mobilisation and other costs can be shared. Engineering construction costs can also vary greatly depending on the state of the economy. Table 1, while based on experience, is given only as a very rough guide.

Table 1 Approximate guide to fish pass costs

Fish Pass Type	Construction Cost(£K)
Baulks	5-25
Single flight, no problems	50-80
Single flight, with complications (difficult access etc)	80-100
Dual flight with resting pool, no problems	100-150
Dual flight with resting pool, with complications	150-400
Pool and traverse fish pass (>1.5m head)	200-500
Vertical slot (>1.5m head)	350-500
Rock ramp	25-500

FISH PASS SELECTION

In selecting fish passes it is important to have an overall perspective and appreciation of the challenges that are presented, and the reasons that drive fish to migrate. This is in addition to knowledge of individual species involved and their particular circumstances. Furthermore, it should always be borne in mind that fish are animals, and that not all animals behave the same!

Biological Factors

Migration and types of migrant

As succinctly put by Northcote (1984) `the migratory behaviour of riverine fishes, and probably all fishes, results from the separation in space and time of optimal habitats used for growth, survival and reproduction during different life-history stages. Therefore, in general, migration up and down rivers involves cyclic alternation between at least two, and more often three or more habitats. The migration may be both passive and active`.

Two major types of migration can be recognised, diadromy (between sea and freshwater) and potamodromy (entirely in freshwater).

Diadromy can be further split into:

Anadromy - adults run up river to spawn, juveniles run down river to the sea to grow, e.g. salmon, shad.

Catadromy - adults run down river to the sea to spawn, juveniles run up river to grow, e.g. eels

Amphidromy - fish run between both spending an appreciable time in each, e.g mullet, flounders.

Potadromy is often associated with spawning and includes, e.g. brown trout, barbel, and many other coarse fish species.

These are simple classifications. It is becoming increasingly clear as we learn more about fish ecology that their life styles are complex, and that migration is an important component of their life plan on both a macro and a micro scale.

It should be noted that it is essential for the fish to move both upstream and downstream, and that very different life history stages, ages and sizes are involved. The significance of which is that they will have a wide range of ability to migrate within a species, let alone between them. For example contrast the abilities of adult salmon, kelts and smolts, or elvers and adult eels. They will also have a wide range of vulnerability at any facilities provided.

Reasons for Migrating and Consequences of not doing so

Fish may undergo migrations for a number of different reasons including:

> **Spawning -** this is the most well known reason for migration. Classic examples are salmon, which migrate many thousands of kilometres including in the sea, and barbel & trout whom can migrate many kilometres in freshwater. However many other coarse fish and other species, e.g. chub, roach, dace etc, also make important spawning migrations.
>
> **Dispersion -** adults of many coarse fish species move upstream to spawn, and the juveniles including pinhead, 0+ and 1+ move downstream to disperse and colonise. Secondary migrations may also take place, e.g. sub-adults moving upstream.
>
> **Feeding -** fish may make regular movements to feed, and this may follow a diurnal pattern, e.g. fish holding in one area at night and moving to another by day to feed.
>
> **Shelter -** fish may move to avoid acute adverse conditions like floods or pollution or other unwelcome physiological challenges. They may move in reaction to more chronic events like summer or winter.
>
> **Displacement -** fish may get moved passively, being displaced downstream by pollution or being washed downstream by floods. They then need to move upstream to re-colonise once the event has passed.

A good example of a single species exhibiting all of these traits at different times and ages comes from dace in the rivers Frome and Hurn (Clough & Ladle, 1997; Anon, 1995). Adults move upstream in spring to spawn, juveniles move downstream in summer to disperse, sub-adults move upstream to disperse and colonise in autumn, fish make diurnal movements between feeding and resting locations, fish move into side-streams to shelter from floods and also to spend the winter months.

If fish of any species are prevented from making any of these movements then it is likely to have adverse consequences for the success and survival of both the individual and the population of that species. It is clear what the immediate consequences are from the reasons given for migration above. A more subtle consequence can be a threat to the population from a reduction in genetic fitness caused by fragmentation.

Species Factors

It is well known that migratory salmonids do not feed while they are in their freshwater migration phase. The fish rely wholly on their reserves of energy. The use of unnecessary energy for migration can only lead to a reduced spawning success and it is therefore extremely important to make it easy for fish to pass obstructions with the minimum of delay. Fish like all animals are individuals with variable ability, and facilities should not be built just with the `athletes` in mind. This is all the more important as fish come towards the end of their journey when they are tired and in spawning condition.

Generally, it is essential that facilities for migratory salmonids, and frequently those for shad, are highly efficient and effective. This is because it is usual for all the fish to need to pass upstream to find their spawning grounds, or to get downstream to reach their growing habitat. This is particularly the case where the facilities are low down the river for upstream migrating fish, and high up the river for downstream migrating fish. These factors are especially important where there are multiple barriers on a watercourse, since the effects are additive. For example, consider the cumulative effect on upstream passage of passes built on six obstructions with a 90% passage rate. Out of a 100 fish arriving 90 pass the first barrier, 81 the second barrier, 73 the third barrier, and so on until passage past the sixth barrier is just 51%, or just half of the fish arriving at the first obstruction. Clearly, diadromous fish populations will not be sustainable in such circumstances. Of course, the same applies where there are obstructions to downstream passage that cause losse of fish or mortalities e.g abstractions, hydropower generation.

An equally important factor is delay, particularly for diadromous species. Fish must be able to locate the passage facilities quickly otherwise they may not reach their destination in an appropriate time frame to spawn successfully or survive the rigours of passage between the sea and freshwater or the reverse. As with upstream passage, the cumulative effects become ever more significant as the number of obstructions on a watercourse increases.

In the case of trout and coarse fish it will not normally be the case that it is imperative to provide highly efficient passage facilities, at least for upstream passage. It will usually be sufficient to ensure a reasonable freedom of passage and mixing between adjacent communities.

The efficiency that is required of any one fish passage facility must be considered in the context of its location in relation to the demography of the particular species in question.

General Considerations

It is important to bear in mind that there is little that is black and white in fish passage terms. The behaviour and swimming performance of both individuals and species over-lap. Any fish may use any pass to some extent. What is important is the efficiency required of the pass, and the efficiency with which it is used.

It is also important to remember that for any one target species or size of fish the idea is to be able to pass all the individuals, and not to add an artificial level of `natural` selection by selecting for only the most athletic individuals.

The desire to build a pass to the minimum specification should always be resisted, though there will always be financial constraints. Use the best possible practice. A pass that does not work and costs money is a total waste of resources, a pass that costs more but works is extremely valuable.

Passes are rarely of the same efficiency for different species, and there may be times when more than one pass are required in order to fully achieve objectives.

Species Applicability

Extensive empirical trials in France and U.S.A. indicate that certain fish passes are particularly suitable for certain species. An example of a species with distinct preferences is that of shad. French experience indicates that few fish pass types are suitable for shad. These fish have been found to require the presence of vertical visual references, and enough free space to accommodate the passage of large shoals of fish at the same time. As such, vertical slot passes with a minimum free gap of 0.45m have been found to be the only truly effective pass apart from fish lifts, although Larinier and Travade (1992) found that additional lighting was also a distinct necessity in dark areas of the pass.

Coarse fish passage can often be accommodated with pool and traverse type fish passes if care is taken to reduce the power density in each pool and to maintain a low head loss between pools. It is recommended to keep the head loss between pools ≤0.3m (Larinier, 1992a) for high swimming performance coarse fish such as chub and barbel. For low swimming performance species of coarse fish (i.e. most cyprinid) a head loss between pools of 0.1-0.2m is recommended. ln particular, barbel appear to prefer pool and orifice or vertical slot passes rather than pool and traverse passes, because of their preference for swimming close to the bottom.

Denil fish passes are generally used for migratory salmonids, lampreys and the largest and most powerful swimmers amongst coarse fish species. Making them small in terms of their baffle dimensions and reducing their slopes means that they can be adapted for many species. Larinier type denils may be the most suitable for broad range of species since there is evidence that even quite small fish can exploit the lower velocity niches that occur in the heterogenous flow patterns in such passes. However Denils are more selective than pool type passes.

Pool type passes, especially deep slot or vertical slot passes, are probably the best solution where several different migratory species are involved.

Fish Behaviour

Time of migration

In any one river system where migratory salmonids, eels and other species are present migration both upstream and downstream may be taking place virtually the whole year round. However for any one species the intensity of migration will usually follow a seasonal pattern. This will vary depending on exactly where in the catchment any obstruction is located, e.g. far up the system or low down it.

Seasonal patterns can clearly be generalised, but it is important to know migration patterns with some precision if passage is to be optimised at any specific location. Migration at some life-stages, particularly for spawning and dispersion can occupy quite small windows of time. It is a significant advantage when planning passes to know precisely the local situation with respect to timing of migration.

Diurnal

Migration patterns may demonstrate a diurnal rhythm. Examples include salmon smolts migrating downstream mostly at night, at least early on in the migration season (later they migrate by day and night). Shad migrate during the day since they require strong visual clues to make passage and also prefer to move as a shoal. Adult lampreys tend to move mostly at night, at least in the early part of their upstream migration.

There is conflicting evidence for upstream movements of adult salmon and sea trout, with some studies demonstrating peak movement at dusk and dawn, while others have shown peak passage during daylight hours. It is likely that movement patterns are changeable being related to other environmental variables like tides in estuaries, river discharge and time of the season. For example peak movements may occur at dusk or dawn during low river discharges, but during the day when river discharge is high. Knowledge of the behaviour of fish in the immediate locality of the intended pass is an advantage when planning the facility.

Sexual maturity / condition

The sexual maturity and condition of the fish will clearly have some effect on the fishes swimming ability. The more mature and the lower the condition of the fish the lower its swimming ability is likely to be. Behaviour may also change in that it is quite likely that maturing fish will lie further downstream of the obstruction and be more reluctant to venture into areas of high velocity. The condition of the fish may be affected adversely by injury, disease or parasites. These factors would be more likely to play a part the further upstream the fish have moved, and appropriate allowances should be made with respect to the demands placed on them in terms of swimming speeds and endurance.

Temperature

Apart from the physiological effects that it has on fish swimming speed, which is covered in more detail below, temperature can also act as a trigger for fish migration. The threshold for active migration upstream of salmon (at least past obstructions) appears to be around 5°C, while for elvers it is 6-8°C, for small yellow eels around 13-14°C, and for many species of coarse fish it is about 9-10°C (Lucas et al, 1998). Conversely, there may also be upper limits above which fish will not migrate. Migratory salmonids will not migrate at temperatures above 21°C, while coarse fish are unlikely to migrate at temperatures over 28°C.

River flow

Fish will tend to move in windows of opportunity that will rarely be in a drought or a flood. Coarse fish, for example, will be moving upstream to spawn in the spring when flows will usually be within a certain range around Annual Daily Flow (ADF). Changes in river flow can act as a stimulus to fish to migrate, so that for example salmon will frequently respond to rising river discharges, and also falling river discharge following a spate. Fish will arrive at different obstructions at different times of the season and under differing hydrological conditions. The conditions in which fish will run may vary both with the season and the location in the catchment. The difficulty of passing any particular obstruction is likely to vary depending on river discharge.

It is important to know the hydrological conditions in which fish are moving so as to define the range of operation of any passage facilities. There is no substitute for knowing or establishing the local conditions for the specific site where it is intended to provide a pass. However, if information on fish migration and flow is not available for the site, then it is suggested that the facility for upstream migration should be designed to operate across a flow range from Q_{90} to Q_{10} for salmon, Q_{95} to Q_{10} for sea trout and brown trout, Q_{50} to Q_{20} for coarse fish and shad, and Q_{99} to Q_{70} for eel.

If data is available on the local migration pattern and flow then it should be used to define the operating limits of any passage facility. If it is available in respect of the specific location so much the better. Where the latter is the case a useful way of assessing the data and the `windows of operation` is given by Solomon in Fish Pass Technology Training Course (Ed Mann & Aprahamian, 1996).

Swimming performance

Swimming Speeds

In the design of any fish pass facility the first question which needs to be considered is what is the swimming capability of the fish. Bell (1984) defined three levels of speeds as follows:

Cruising - a speed that can be maintained for long periods of time (hours).

Sustained - a speed that can be maintained for minutes (≥200 minutes).

Burst - a single effort that is not sustainable (≥20 seconds).

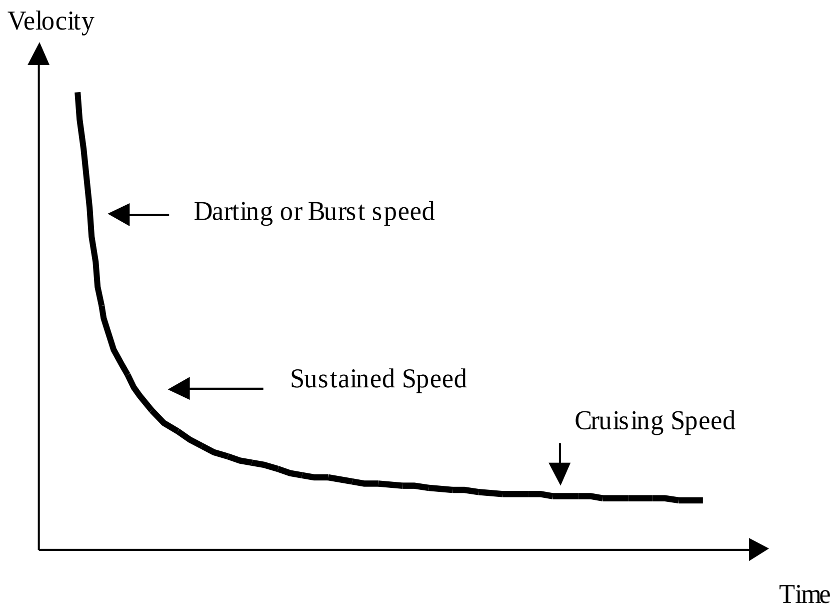
This is a useful principle that permits swimming ability to be sensibly and simply categorised. However it is also useful to modify the definitions a little to include the notion of maximum speed. Thus:

Burst speed is one that can be maintained for ≥20 seconds.

Maximum speed is a swimming speed that is a single effort that can be sustained only momentarily, a single darting movement.

There will of course be very seamless transition between these categories as demonstrated by the generalised Figure 3 (after Clay 1995). Speed attainable is related to endurance: slow speeds can be maintained for long periods while the fastest speeds may only be maintained for tens of seconds or less. The precise relationship for any one species will be different.

Figure 3 Schematic illustration of the swimming speeds of a particular species (After Clay, 1995).



Fish have two types of muscle fibres, red and white. The red fibres are situated just below the skin and cover the main muscle, which consists of white fibres. The red muscles are well vascularised, designed for aerobic activity and are used by the fish for cruising. Most of the mass of a fish consists of white muscles that are poorly vascularised and have few mitochondria. They are designed for anaerobic activity and are used for burst swimming. The length of time the fish can maintain their burst speeds is dependent on how quickly their glycogen store becomes exhausted, which is faster at higher temperatures. Once the glycogen store is exhausted then it takes a significant period of time, up to 24hrs, for it to be restored.

Temperature also effects the rate at which the muscles contract, with the frequency of contractions increasing with increasing temperature (Zhou, 1982), resulting in an increase speed according to the formula:-

$U = 0.7L/2t$ ....(Wardle, 1975)

where:

U = maximum swimming speed (ms^{-1})
L = length of fish
t = muscle twitch contraction time

and where muscle contraction time (t) is equal to:

$t = 0.1700L^{0.4288} + 0.0028\log_e T - 0.0425L^{0.4288} \times \mathrm{Log}_e T - 0.0077$ ....(Zhou, 1982) (1)

where = muscle temperature (°C).

The length of time the fish can maintain their burst swimming speeds can be determined from the equation:-

$t_m = E / (P_c - P_r)$ ....(Beach, 1984) (2)

where:

t_m = endurance time (s)

P_c = Chemical power = $0.9751 \times e^{-0.00522T} \times U^{2.8} \times L^{-1.15}$ (Zhou, 1982)

P_r = Power from oxygen uptake (W) = $4.44 \times 10.836L^{2.964}$

E = Total energy store ($J\ Kg^{-1}$) = $2790 \times 10.836L^{2.964}$

Using equations 1 and 2, Beach (1984) produced two sets of curves one relating maximum swimming speed to fish length and temperature (Figure 4) and the other showing the length of time (i.e. endurance) the maximum swimming speed could be maintained in relation to temperature and size (Figure 5). These factors were combined by Larinier (1992b) to demonstrate the relationship between swimming speed and endurance for different sizes of fish at different temperatures (Figure 6) . It has been assumed in the construction of the graphs that all fish of the same size have the same swimming capability.

Figure 4 Maximum swimming speed in relation to fish length and temperature (After Beach, 1984)

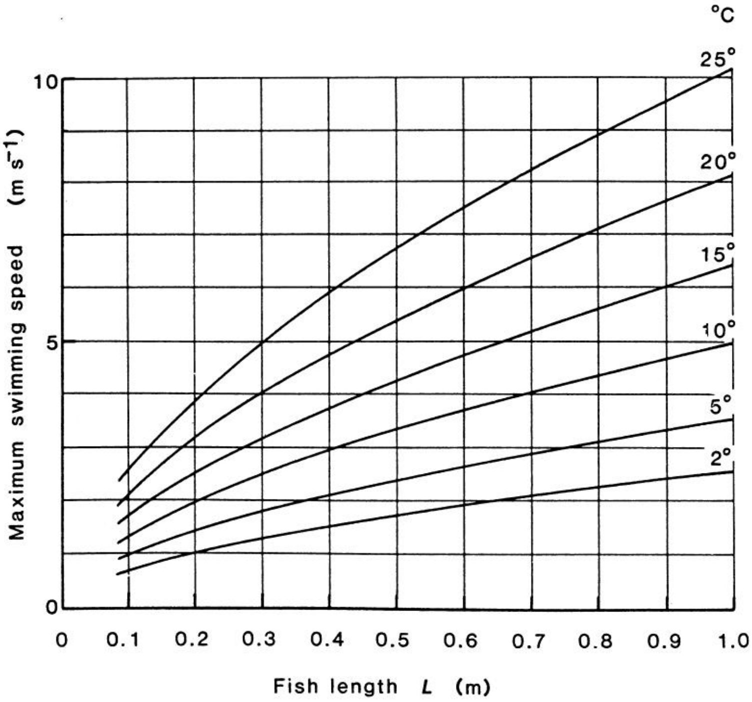


Figure 5 Endurance at maximum swimming speeds in relation to fish length and temperature (After Beach, 1984)

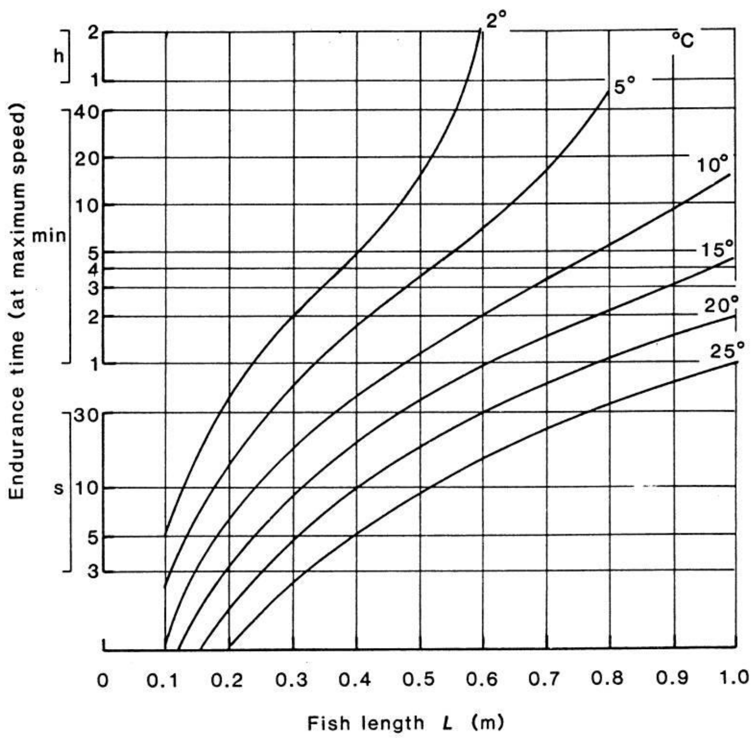


Figure 6 Swimming speed and endurance for different sizes of fish at different temperatures (After Larinier, 1992b)

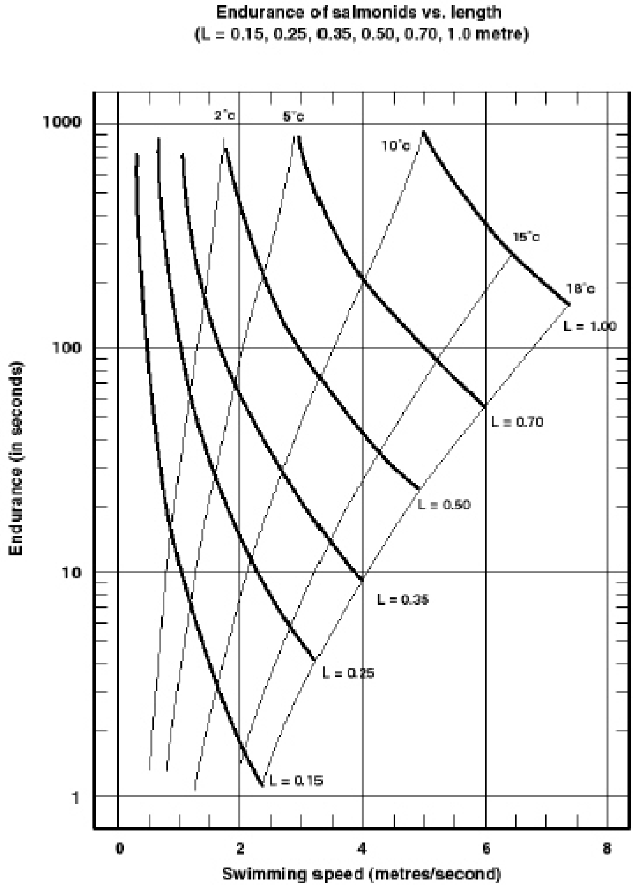
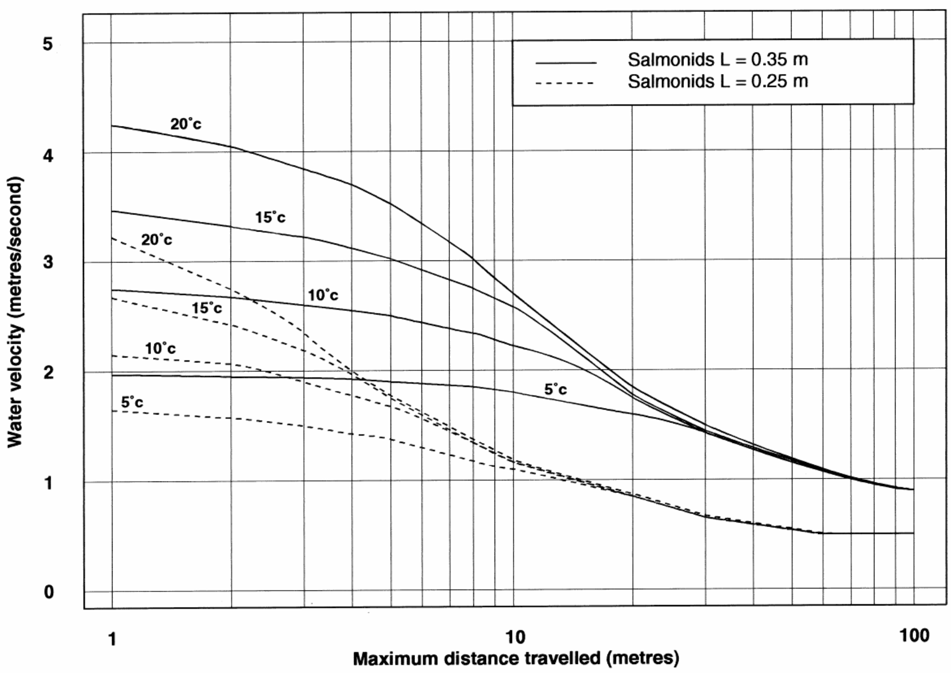


Figure 7 Maximum swimming distance attainable at different water velocities and temperatures for two lengths of salmonid (After Larinier, 1992b)



The estimates of swimming performance, which were reported by Beach (1984) were determined from tail-beat frequency and the physiological relationship with temperature but relates to maximum swimming speed. These estimates are theoretical rather than empirical, but nevertheless the useful relationships derived are widely used to provide the criteria for designing passes for migratory salmonids, including salmon, sea trout and brown trout. Given the nature of the data it is sensible, when considering the capacity of fish to manage the hydraulic conditions in any particular facility, to allow a healthy margin of tolerance. Thus, in pool passes the traverse velocities should be well inside the maximum swimming ability and preferably nearer burst speed, while the resting pool areas should generally have velocities within the sustained or cruising capability of the fish. In passes where fish have to swim a considerable distance, such as baffled type fishways, then the mean water velocities should not usually be higher than the burst speed of the fish. Alternatively fish should be able to swim a net distance some two to three times the length of the flight of pass proposed between resting areas.

Laboratory studies on burst and endurance swimming speeds for some UK species including barbel, bream, brown trout, chub, dace, eel & elver, grayling, roach, smelt and twaite shad have been completed in recent years (Clough & Turnpenny, 2001; Turnpenny, Blay, Carron & Clough, 2001; Clough, Lee-Elliott, Turnpenny, Holden, & Hinks 2004a & b; Clough, Le-Elliott, Holden, & Turnpenny, 2003; Clough, Le-Elliott, Holden, & Turnpenny, 2004; Clough, O' Keefffe, & Holden, 2004; Watkins, Liney, & Turnpenny, 2007; and O'Keeffe & Clarke, 2008). Some typical results are given in Table 2 below. Swimming speeds of eel are low particularly in relation to body length, probably because these anguilliform shaped fish lack the caudal fin of carangiforms and therefore cannot generate the same momentum.

Table 2 Examples of Swimming speeds for some UK fish of 15cms fork length at 10°C and eel of 30cms at 15°C (SWIMIT version3_3 Nov 2006)

Species	Mean Burst Speed		Median Sustained Speed		90%ile Sustained Speed	
	ms^{-1}	bls^{-1}	ms^{-1}	bls^{-1}	ms^{-1}	bls^{-1}
Roach	1.27	8.46	0.70	4.67	0.45	3.00
Dace	1.35	9.00	0.58	3.87	0.48	3.20
Chub	1.30	8.67	0.93	6.20	0.53	3.53
Trout	1.35	9.00	1.17	7.80	0.81	5.40
Eel	1.14	3.80	0.25	0.83	0.11	0.37

Data from these empirical studies have been used to generate models for the swimming performance of these species, and these are presented in the program SWIMITversion3_3 Nov06. The program estimates the burst swimming speed and endurance time as well as the sustained swimming speed (i.e. that speed which can be maintained for >200min), dependent on fish size and temperature. The program also allows the operator to select that proportion of the population that can maintain a certain sustained speed. For example it is possible to estimate the speed that can be obtained by 50% of the population (i.e. the median speed), or say 80 or 90% (i.e. percentiles) whatever is desired. This has obvious benefits when looking at the implications of different designs, but essentially it facilitates an approach that permits designs to be produced that we can be more confident will cater for the majority of the population, rather than an average one. In addition it is also possible to calculate how long the fish can maintain their burst swimming speed in relation to water velocity. For more information see the series of Environment Agency R&D reports referenced above.

It must be recognised that while empirical data, the swim speeds have been compartmentalised in the sense of creating discrete windows or periods of time in which any described speed can be sustained. Clearly, actual performance of speed and endurance has a continuously inverse relationship. In particular the Critical Burst Speed (CBB) methodology used for swimming speed trials in laboratory conditions probably provides a conservative estimate of the actual ability of fish in the wild. For example, migratory fish are often forced to swim at speeds that are greater than their maximum sustained speed (defined as sutainable for 20 seconds), can volitionally sustain faster speeds for short durations, and can change gait to maximise distance travelled against a particular water velocity (Peake 1998, Castros-Santos 2005). Nevertheless, the swim speeds generated by SWIMIT for example, provide robust guidelines for designing fish passage mitigation devices in most cases.

Preceding the work by Clough et al, 2003 there was very limited information about the swimming ability and endurance of *Alosa alosa* and *Alosa fallax*. Litaudon (1985) estimated that the burst swimming speed of *Alosa alosa* ranged from 3.1 ms-1 to 4.7 ms-1 at temperatures of 16 to 17°C. At these temperatures the fish could maintain such speed for approximately 6.5s. The maximum speed was estimated at between 4.1 ms-1 and 6.1ms-1, but could only be sustained for a few seconds. Table 3 summarises the swimming capabilities of shad measuring 0.30 to 0.50 m in length (Larinier, 1996), and Table 4 gives some examples of swimming capability of Alosa fallax from SWIMIT version3_3Nov06.

Table 3 Swimming capabilities of shad (0.30 to 0.50 m in length) from Larinier (1996).

Temperature (°C)	Maximum speed (ms^{-1})	Endurance at maximum speed (sec)	Cruising speed (ms^{-1})
10	2.75 – 3.30	15 – 60	0.8 – 1.5
15	3.50 – 4.30	10 – 25	
20	4.40 – 5.40	5 – 10	

Table 4 Examples of swimming speed of shad (Alosa fallax) at 15 -20°C from SWIMITversion 3_3 Nov06

Size (cms)	Mean Burst Speed ms^{-1}	Median Sustained Speed ms^{-1}	90%ile Sustained Speed ms^{-1}
30	1.52	0.44	0.35
40	2.06	0.59	0.47

There is not a great deal of swimming performance data available for the anguilliform lampreys. Huun and Young (1980) reviewed the literature and noted that adult sea lamprey were capable of burst speeds up to $3.9ms^{-1}$ that could be maintained for a few seconds. It might be expected that the smaller river lampreys would more than likely only attain about half of this burst speed. However, in the specific case of lamprey what may be more important to successful passage at obstructions may be their ability and behaviour in using their suckers (see later section on lamprey passage).

Swimming performance can depend on the prevailing environmental conditions. The level of dissolved oxygen can affect prolonged and sustained swimming speed since these depend on using the red muscles aerobically. Once oxygen levels are below a certain threshold level swimming performance declines rapidly. Above the threshold concentration of dissolved oxygen level does not limit swimming performance. Beamish (1978) showed that the sustained swimming speed of Atlantic salmon (@15°C) was lower at $4mgl^{-1}$ at approximately $50cms^{-1}$ than at $5mgl^{-1}$ when the fish could swim at nearly 80 cms^{-1}.

Similarly, pollutants can cause a reduction in swimming performance. Carling & Dobson (1992) reported that a change in swimming behaviour occurred at concentrations of toxicants of less than 16% of the average concentration that caused mortality. The presence of parasites may also reduce swimming performance (Sprengel & Luchtenberg, 1991) although clearly it is difficult to take any account of this in pass design.

It is important not only to ensure that the water velocity is within the swimming capability of the fish but that the fish can migrate the distance required before becoming exhausted. The distance a fish can migrate can be calculated as follows:-

$D = (U-V)/t_m$ ....(3)

where:-

D = distance travelled (m)
U = maximum swimming speed of the fish
V = water velocity (ms^{-1})
t_m = endurance time (secs)

As swimming performance is dependent on temperature such estimates need to be made for the range of temperatures the migrating fish might experience. Examples of the distances that might be covered by relatively small salmonids of two different size is shown in Figure 7 (After Larinier, 1992b).

Some Simple Swimming Speed Criteria for Fish Passes

While more detailed consideration can be given to specific species and sizes of fish using the various sources outlined above to match to the individual site, some general guidelines can be provided. Table 4 below gives some guidelines for maximum water velocities and head drops in pool passes, and mean water velocities and maximum flight lengths in baffle fishways.

Table 4 Some simple guidelines for basic parameters of pool, and baffle, fish passes

Pass Parameters		*SPECIES*			
		Coarse fish	*Brown trout*	*Sea trout*	*Salmon*
POOL PASS	*Max Vel (ms^{-1})*	*1.4-2.0*	*1.7-2.4*	*2.4-3.0*	*3.0-3.4*
	Head drop (m)	*0.1-0.2*	*0.15-0.3*	*0.3-0.45*	*0.45-0.6**
BAFFLED PASS	*Mean Vel (ms^{-1})*	*1.1-1.3*	*1.2-1.6*	*1.3-2.0*	*1.3-2.0*
	Length (m)	*8-10*	*8-10*	*10-12*	*10-12*

*It would only be in exceptional circumstances that a head drop of >0.45m would be used, for example for a pre-barrage or else a single jump amongst many others.

Location and Attraction

There are many different types of fishway which are known to provide hydraulic conditions that fish can pass through readily. Several of these are outlined in this manual. However, in many respects the most significant problem in passing fish, either upstream or downstream, is that of attracting the fish into the fish pass facility. For species such as migratory salmonids where it is necessary to provide passage for all fish waiting to move upstream (which can be the whole or a significant part of the migrating population) this is clearly an onerous requirement. For species such as coarse fish it may be acceptable for only a proportion of fish to move upstream and location and attraction is less critical.

The reader is directed to the excellent description of the factors applying to the location and attractivity of fish passes is given by Larinier, 2002 in Chapter 4 of the BFPP supplement on Fishways. This concisey examines factore influencing choice of location of fishawys and the hydraulic coditions required at the fish pass entrance(s).

Choice of Location at an Obstruction

Fishways should be located where migrating fish are observed either to congregate, or else attempt to pass, when actively trying to move upstream. The observation may be direct visual means or else by means of a monitoring study employing, for example, radio-tracking or acoustic tracking techniques. The value of such information cannot be over-stated and every effort should be made to collect it before committing to pass design. This should be possible where a migratory population is present but is clearly not possible when one is not, eg. in a river subject to a restoration programme, or when a new obstruction is being constructed. In the latter case the experience of the fishway designer has to be relied upon.

The general principle i.e. best practice should be to locate the entrance to the fishway at the most upstream point which migrators can reach at an obstruction since this is where they will tend to move too. The topography of a pool might suggest where holding areas or approach locations may be. In some cases the topography might be altered by using rip-rap etc to create shallower areas that deflect approaching fish into correspondingly deeper areas that lead them to the fish pass entrance(s).

A location near one or other banks should be favoured since this is where many species tend to migrate and especially salmonids and shad. Generally location at the bank also facilitates monitoring and maintenance of the facility. In some cases, particularly on large watercourses consideration may need to be given to installing facilities on both banks. Mid-river locations should be avoided unless this is clearly where fish move to, are led to or attracted by existing configurations which cannot easily be changed. Siting of a pass where significant active aggregation of alluvial material is taking place, often on the inside of bends, should generally be avoided.

It is recommended that the entrance to the fishway is not located more than 2m downstream of the edge of the barrier unless conditions are such that entrance to the facility is masked by other hydraulic conditions e.g. significant turbulence, standing wave. If the entrance is located too far downstream, and especially if it is without sufficient attraction, then fish are unlikely to find it since they will tend pass the entrance and congregate immediately below the obstruction. These fish will be reluctant to search downstream for an alternative route. In these circumstances the very least that will occour is that fish will be delayed, and it will almost certainly reduce the passage rate efficiency of the facility. If the entrance has to be well downstream of the obstruction because of site constraints, then this should be compensated for, by increasing the attraction flow significantly.

In the case of low-head hydropower developments the associated fish pass(es) should have entrances that are co-located and co-terminus with the turbine discharge, and preferably the pass jet will discharge parallel to that from the turbine outflow.

The upstream exit of a pass should not be located where there is a danger of fish being immediately swept back downstream.

If the river bed downstream can be modified to lead fish to the entrance of the pass, or else control structures can be managed to lead fish, then this should be taken account of in deciding the fishway location.

Flow Conditions at the Entrance

The jet of water issuing from a fishway must be discernible to the fish amongst all the other competing flows and from as far away as possible. Attractivity will depend on the direction and the momentum (discharge x velocity) of the pass entrance jet. The greater the momentum of the jet the further the entrance jet penetrates the tailwater and the more attractive is the fish pass (Larinier, 2002 c). Exit velocity must be in excess of $1ms^{-1}$ for all species and preferably be of the order of $2\text{-}2.4ms^{-1}$ for large salmonids (corresponding to head drops of 0.2 – 0.3m). In order to maintain a high velocity the occurrence of hydraulic jumps must be avoided since this will dissipate the energy. Where a pass entrance is located competing with the flow from low-head hydro turbines the velocity of the pass jet should be at least twice that of the turbine outflow.

Care should be taken to avoiding the attraction jet from a fishway being masked by cross-flows or by injecting it into an area of high turbulence. Every effort should be made to align the jet issuing from the fishway with the other local velocity lines. It is also good practice to avoid a situation where the issuing jet is not in the vicinity of a re-circulation eddy where fish may take up orientations which do not facilitate their finding the entrance.

Given a choice in the construction of a new structure, or refurbishment of an old one, it is better to have overshot water-control structures adjacent to the fishway rather than under-shot ones. Radial gates or double-leaf sluice gates that drop a little to permit fine control are far better than bottom-only opening gates. This is because the high velocity jets that issue from such structures at low to medium river discharges is both highly attractive to fish, and impassable. They thus draw fish away from the fishway, to areas where they have no hope of passing. While there will be a limit to the period of the river hydrograph over which over-shot conditions can be maintained, it is likely that it will include the whole or the greater part of the migration window of flow. The overshot condition can attract fish because of the noise it generates but the velocity away from the structure is low and does not compete unduly with the exit jet from the fishway.

Discharge from the Fishway

Deciding upon the discharge through a fishway is not an easy or clear-cut decision. Clearly a major part of the attraction to the facility is the volume of flow and the larger the proportion of flow in the fishway compared to that in the watercourse, the better. Where fish passes are not positioned optimally then much greater discharges may be required to compensate and maintain pass efficiency. The problem of deciding just how much flow is exacerbated on large watercourses of tens m^3s^{-1} because of the increasing size and cost of the facilities involved.

French guidelines for larger (>100 m^3s^{-1}) watercourses are for the fishway to take between 1-5% of the competing flow at the obstruction, during the migration period (Larinier, 1992c). On some of the large French rivers such as the Garonne and Dordogne with discharges of several hundred cumecs, attraction flows are taken of about 10% of minimum flow, equating to around 1 – 1.5% of highest design flow (twice ADF)(Larinier, 2002c). In the western USA with recommended design pass flows are taken as 5 – 10% of 'design high flow', where design high flow is taken as that flow exceeded for 5% of the time during the migration season (NMFS, 2008). In practice the Columbia River Dams, with discharges around 3,500 – 5,000 cumecs, usually have around 3% of design high flow. For example, the Bonneville Dam has a pass attraction flow split between several entrances of nearly 350cumecs (J. Williams, pers com).

On watercourses in England & Wales a minimum target discharge of 5% of annual daily flow (ADF) is recommended, and if possible considerably more (≥10%), in order to provide a sensible size of fishway with good attraction. Ten per cent or more of ADF is generally achievable on rivers with an ADF less than about $15m^3s^{-1}$. Some types of pass, eg. super-active baffle type, lend themselves to situations where a large attraction flow can be provided. However, there can be no prescriptive definition of discharge because the range of flow hydrographs in different types of watercourse is very variable. In addition there may be other significant constraints and competing factors, e.g. space, navigation, water abstraction etc. It is critical that flows during the known migration period of the target species are taken into account.

Where hydropower facilities are being developed on obstructions the discharge from the hydro may attract migrating fish to the area where the turbine discharge is situated. Here it is recommended that pass discharge (at Hands off Flow, HoF) is between 5 – 10% of maximum turbine discharge, the larger % applying at smaller facilities and those where the location of the fish pass entrance does not follow best practice and is not optimally located.

Where constraints mean that insufficient attraction flow can be accommodated in the pass itself, then the provision of auxiliary attraction flow should be considered. This might be discharged immediately adjacent to the pass, but is better discharged in to the final pool or fishway entrance after appropriate dissipation of energy.

Fish Pass Selection Matrix

The fish pass selection matrix provides a simple method by which some initial criteria can be used to reduce the number of fish pass types that could be considered for a particular site. These criteria have been broken down into five features that generally have the greatest influence in the selection of suitable fish pass designs. It should be stressed that this method can only form a starting point in the iteration process towards the goal of an optimal design. The process does not however take account of cost and in reality a number of designs may be equally suitable for a given site.

The five main criteria are listed in the leftmost column. They comprise fish species category, fish pass slope, the resilience of the fish pass to debris, the capacity of the fish pass to operate under conditions of high bed load, and the ability of the fish pass to function under a range of upstream water level.

Fish species category groups species by their ability to overcome the challenge of high water velocities, or sometimes the ability to leap. It also takes into account some factors such as the likely size of the fish as for example adult chub would be considered high performance coarse fish but adult dace are generally too small to fall into this category. Lampreys are not particularly fast swimmers but have the ability to rest by attaching to fixed objects.

The slope of the structure is important for two reasons. The first is that some pass designs will only operate over a small range of slopes. The second is that most fish pass projects are spatially confined in some way, and this often precludes the use of some types of pass.

Many rivers carry substantial amounts of debris due to the nature of the catchment and the hydrology of the catchment. In some catchments the proximity of a supermarket is as important as the area covered by forest in terms of the amount of debris the fish pass is challenged by. Some fish passes are much more resilient to debris than others.

For some rivers the resilience to bed load movements could be a major factor influencing the final design. For example, some pool and traverse passes have been known to fill up with gravel where they have been built on rivers with a high bed-load movement. In contrast, side baffle Denil fish passes do not have bottom baffles, and therefore do not accumulate bed material.

Under many circumstances the range in upstream water level limits the choice of fish pass. The super active baffled pass is an excellent fish pass in many respects but is limited in the range of upstream water levels that can be accommodated before the pass is drowned. In contrast, the side baffle Denil pass requires fish of relatively high swimming performance but can accommodate a large range in upstream water level whilst remaining operative.

A simple procedure is included below in a selection matrix.

Fish Pass Selection Matrix

Requirement		Pool Fishways: Pool & Traverse (plunging)	Pool & Traverse (streaming)	Vertical (pool &) Slot	Pool & Orifice	V' Notch Weirs	Ice Harbor	Pool & Chute	Preliminary Weirs	Fish Locks	Fish Lifts	Baffled Fishways: Plain Baffle Denil	Fatou Denil	Alaskan 'A' Denil	Super Active Baffle (Larinier)	Chevron Baffle	Side Baffle Fishway	Notes
Species	Salmonid sp.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	ND= NO DATA AVAILABLE
	Hi perf coarse sp.	Y	Y	Y	Y	Y	ND	ND	Y	Y	Y	Y	ND	Y	Y	n	n	
	Lo perf coarse sp.	n	Y	Y	n	Y	ND	ND	Y	Y	n	n	ND	n	Y	n	n	
	Alosa sp.	n	Y	Y	n	Y	Y	ND	Y	Y	n	n	ND	n	Y	n	n	
	Eel sp.	n	n	Y	n	n	n	ND	Y	Y	n	n	ND	n	n	n	n	
Slope	<5%	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Excludes resting pools in the case of baffled fishways
	>5%<10%	Y	Y	Y	Y	n	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
	>10%<20%	n	n	Y	n	n	n	n	n	Y	Y	Y	Y	Y	Y	Y	Y	
	>20%<25%	n	n	n	n	n	n	n	n	n	Y	Y	n	Y	n	n	Y	
	>25%	n	n	n	n	n	n	n	n	n	Y	n	n	n	n	n	n	
Debris resilience	High	n	n	n	n	Y	n	n	Y	Y	n	n	n	n	Y	Y	n	Relates to basic properties of the pass type
Bed Load Capacity	High	n	n	n	n	n	n	n	Y	n	n	n	n	n	n	n	Y	Some passes can clog with gravel etc.
Range in upstream head capacity	Large	n	n	Y	n	n	n	n	Y	n	Y	n	n	n	n	n	Y	
Total																		

Operation of fish pass selection matrix

Step

A Photocopy the matrix sheet

B On the copy use a highlighter pen to select the important rows for the desired installation

EG. High light the Salmonid and Alosa sp. rows along with the range in upst. head capacity

C For each fish pass column add all of the highlighted cells with a Y in them and place the numerical result in the Total row for that column

D The highest scoring fish passes should be good options with which to start actual calculations for the site

FISH PASS TYPES

There are many different types of fish pass, which are generally variations on the themes of steps, slopes or lifts. The `step` approach involves splitting the height to be passed into a series of small drops with various forms of traverse separating resting pools. The `slope` approach involves spilling water down relatively steep slopes where various forms of baffles are used to dissipate energy and slow down the water velocity. Lifts involve attracting fish into confined spaces and then lifting them either mechanically or hydraulically and depositing them upstream.

To these can be added diversion or by-pass channels that may vary from the totally artificial to the `natural stream-mimicking` type, and many forms of `easement`.

In England and Wales the vast majority of fish passes are installed in `low-head` situations and this has tended to limit the type of passes considered. In recent years the range of passes being used has begun to expand. For completeness most types are covered in this section, although some are rarely if ever used.

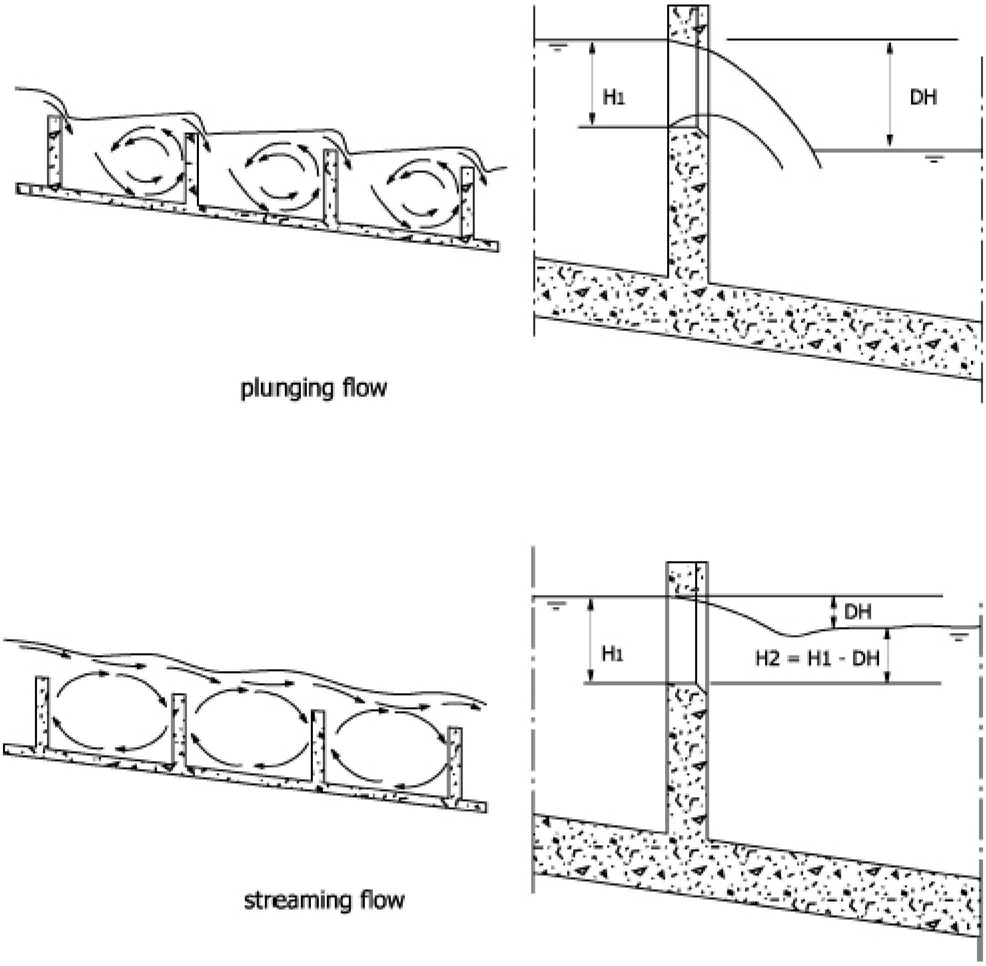
Pool Passes

General

Pool passes are perhaps the oldest type of pass in use. They are generally applicable for most fish species, are extensively used throughout the world and in most cases require low maintenance. They can frequently change direction, even very sharply, and therefore may be integrated into some locations much more easily than some other types of pass.

Pool and traverse fish passes largely fall into two categories distinguished by the type of flow between pools (Figure 8). When the lower pool water level is substantially above the level of the notch between the pools (i.e. $H2 \geq 0.5\text{-}0.6H1$) then the pool pass is of the `streaming flow` type (Larinier, 1992). Energy is dissipated by large re-circulation eddies in the downstream pool. When the lower pool water level is below, or not far above the level of the notch between the pools, then the energy is dissipated by turbulent mixing and a hydraulic jump at the bottom of the fall. This type of pass is of the `plunging flow` type. The transition between plunging and streaming flow is associated with instability and hysteresis. In pool passes with notches the notch flow, particularly at the downstream entrance, may in some cases become streaming while the flow over the adjacent overfall may remain plunging.

Figure 8 Plunging and streaming flow passes (After Larinier, 1992a).



The connection between the pools may take one of several forms including simple over-falls, a variety of notches, vertical slots, or orifices. There may also be a combination of these. Pool & traverse or Pool & Weir passes are not suitable for benthic species such as barbel, which will require a Vertical Slot or Orifice pass i.e. with openings extending to the bottom of the cross-walls, to be effective.

The following guidelines are generally adopted for the head loss between the pools, for the size of the traverses, slots and orifices, and for the power density in each pool. These apply to all the major types of pool pass detailed below.

A maximum head loss of 0.3-0.45m for migratory salmonids and non-migratory trout, 0.20-0.30m for the more powerful swimming coarse fish (Chub) and shad, and 0.10-0.20m for other cyprinids and piscivorous fish. Maximum head drop between pools will generally occur at the minimum design flow in the pass, corresponding with the minimum river discharge for which the pass is designed to be operational.

The maximum water velocity occurring in the drop between the pools, which the fish have to `burst` or jump through approximates to:

$$V = (2g\ DH)^{0.5}\ ms^{-1}$$

As a guide this gives the following velocities:

Head Drop (m)	Velocity (ms^{-1})
0.10	1.4
0.15	1.7
0.20	2.0
0.25	2.2
0.30	2.4
0.45	3.0
0.60	3.4

When considering the design of pool passes and the distribution of head drops it is often sensible to put a maximum head drop at the fish pass entrance at lower flows, and to distribute smaller head drops in the remaining pools. This is because tail-water levels often rise more rapidly than head-water levels, which results in reduce head drops, water velocity, and therefore attraction at the pass entrance on rising fows. If it facilitates smaller head drops in the remainder of the structure it will also help constrain power densities in the pools, resulting in easir passage and an extension of the operational window for the pass.

The traverses (notches, slots etc) in `streaming flow` passes must be at least 0.30-0.40m wide for large migratory salmonids, 0.45m for shad, 0.20m for trout and 0.15m for small coarse fish. In `plunging` flow passes they should be wider and a minimum of 0.6m is usually taken for large migratory salmonids and 0.3m for trout and coarse fish.

The traverses should usually be a minimum of 300mm thick, with well-rounded nappes in order to ensure that flow adheres to its surface. An adherent nappe is important since flow breaking away from the traverse and creating an air gap is not conducive to the passage of fish, and especially the smaller individuals. Fish are forced to jump and this means that they can easily be dis-orientated. This is a particularly important consideration in plunging flow type passes. Thinner walls, with chamfered or specially angled shapes may be employed in vertical slot type passes.

Power densities (strictly power dissipation per unit volume) up to 150-200Wm^{-3} are suitable for migratory salmonids dependent on the number of pools and the discharge in the pass. Maximum values at the lower end of this range should be used as the number of the pools increases, and for smaller passes with modest discharge (<1.0m^3s^{-1}). Power densities of up to 100-150Wm^{-3} are suitable for trout, shad, and coarse fish species, but maximum values at the lower end of this range are recommended, especially for coarse fish. These recommended maximum power densities should be achieved for the smallest pool at the highest discharge for which the pass is designed to operate (usually at Q_{10} river discharge). Pools at sharp turns i.e. approaching 180° in a fishway should normally have significantly lower power density values e.g. 100Wm^3 for large migratory salmonids

Power density is a measure used to describe the turbulence in a volume of water. It is the potential energy per unit time spread throughout a known volume of water in a pool. The potential energy entering a pool per second may be calculated using the following formula:

$$PE = Q . p . g . DH$$

Where:

PE	= the potential energy entering the pool per second
Q	= the water flow in the fish pass (m^3s^{-1})
p	= the density of water (1000kgm^{-3})
g	= acceleration due to gravity (9.81 ms^{-1})
DH	= the drop between pools (m)

This has units of energy per unit time, in this instance Joules per second or Watts, a unit of power. To calculate the power dissipation or density value this figure is divided by the volume of the receiving pool, i.e. the volume of water throughout which the input power is spread or dissipated:

$$Pv = \frac{PE}{V}$$

where

Pv = the power dissipation per unit volume or power density [Wm^{-3}]

V = the volume of the receiving pool [m^3]

Put more simply:

$$Pv\ (Wm^{-3}) = \frac{9810 \times Q \times DH}{L \times W \times Dm}$$

where

L = length of pool (m)
W = width of pool (m)
Dm = mean depth of pool (m)

Pool dimensions for these estimates are applied using the precautionary principle. Guidelines for length of pool are 7-12 times the head loss between pools (width of slot in slot fishways, diameter of orifice in orifice fishways). The minimum length can be taken as three times the length of the largest fish expected to pass. In the case of large migratory salmonids a minimum length of pool recommended is 3m. Guidelines for width of pool are set by the length and power density constraints but a normal minimum for large migratory salmonids is 2m. The minimum depth must be at least twice, and preferably three times, the head drop in plunging flow passes. A minimum depth of 1.2m is generally used for large migratory salmonids. For trout and coarse fish the pool sizes may be reduced subject to satisfactory power densities being present, however lengths and widths less than 1.8m & 1.2m respectively and depths less than 0.6m would not normally be satisfactory.

It should be borne in mind that a failure to dissipate power satisfactorily would lead to the transfer of residual power to the next pool, thus creating a tendency for conditions in subsequent pools to worsen incrementally.

A problem that can occasionally occur in long pool passes is a phenomenon known as surge or seiche. An oscillating transverse wave or clapotis is formed that can reach a height of several feet. It was observed in a long fishway at the McNary Dam on the Columbia River, USA, where after a series of tests it was resolved by bevelling the tops of the weirs (Clay, 1995). Clay also describes how a better solution for preventing oscillation waves was found by laboratory testing using a combination of bevelled crests at each side of a higher centre section, and short wing or stub-walls projecting upstream. This is the Ice Harbor type of pool pass described later in this section. This phenomenon has been observed in several other locations (Larinier, pers comm), including a long pool pass – the Deep Navigation Cascade- on the R. Taff-Bargoed in South Wales. In the latter case a solution for this problem, which occurs at low to medium flows, has yet to be developed but is expected to include the provision of stub-walls in some of the pools.

Pool & Weir or Pool & Traverse

In Britain pool and traverse passes have typically been based on the plunging type form shown in Figure 9, which gives the minimum recommended dimensions for a pass for large migratory salmonids, i.e. salmon & most sea trout (Anon, 1942). In the case of populations of smaller sea trout, or non-migratory salmonids and coarse fish, there is some potential for reducing these minimum dimensions a little. Of course, passes may also be very substantially bigger.

The notches are effectively designed to provide effective communication and passage between pools at low flows. However, they may also serve to constrain flows as river discharge rises if the cross-wall(s) beside it are increased in height i.e. forming a tall notch, so that as river discharge rises flow in the pass is constrained by what can pass the notch width only. When head is allowed to rise on the cross-walls as well, then the total pass discharge rises very quickly and power densities soon exceed the guidelines.

Suitable Species: Plunging flow passes, requiring fish to swim in the nappe formed from pool to pool are more suited to salmonids, but can be used by coarse fish (except the more benthic species)provided that the head difference and energy densities are limited. Streaming flow pool passes are essential for shad, and generally more suitable for coarse fish. Pool & Weir or Pool & Traverse passes are not particularly suitable for eel or lamprey though they may be adapted to be partly effective (see relevant sections on eel & lamprey).

Head difference: A maximum head loss of 0.3-0.45m for migratory salmonids, 0.20-0.30m for brown trout and the more powerful swimming coarse fish (e.g chub,) and shad, and 0.10-0.25m for other cyprinids and piscivorous fish.

Length & Width of pools: Minimum length and width of pools is 3m & 2m respectively for large migratory salmonids. Minimum length is 3 x length of largest fish requiring passage for other species. Minimum width is 3 x notch width. Notch widths and depths are not generally <0.6m x 0.25m for large migratory salmonids, 0.3m x 0.25m for other species. However, the depth of the notch might be reduced to say 0.2m where head drops are <0.45m, e.g. 0.3m drop.

Gradient: Should not exceed 10% but may be further influenced by the pool dimension and power density guidelines above.

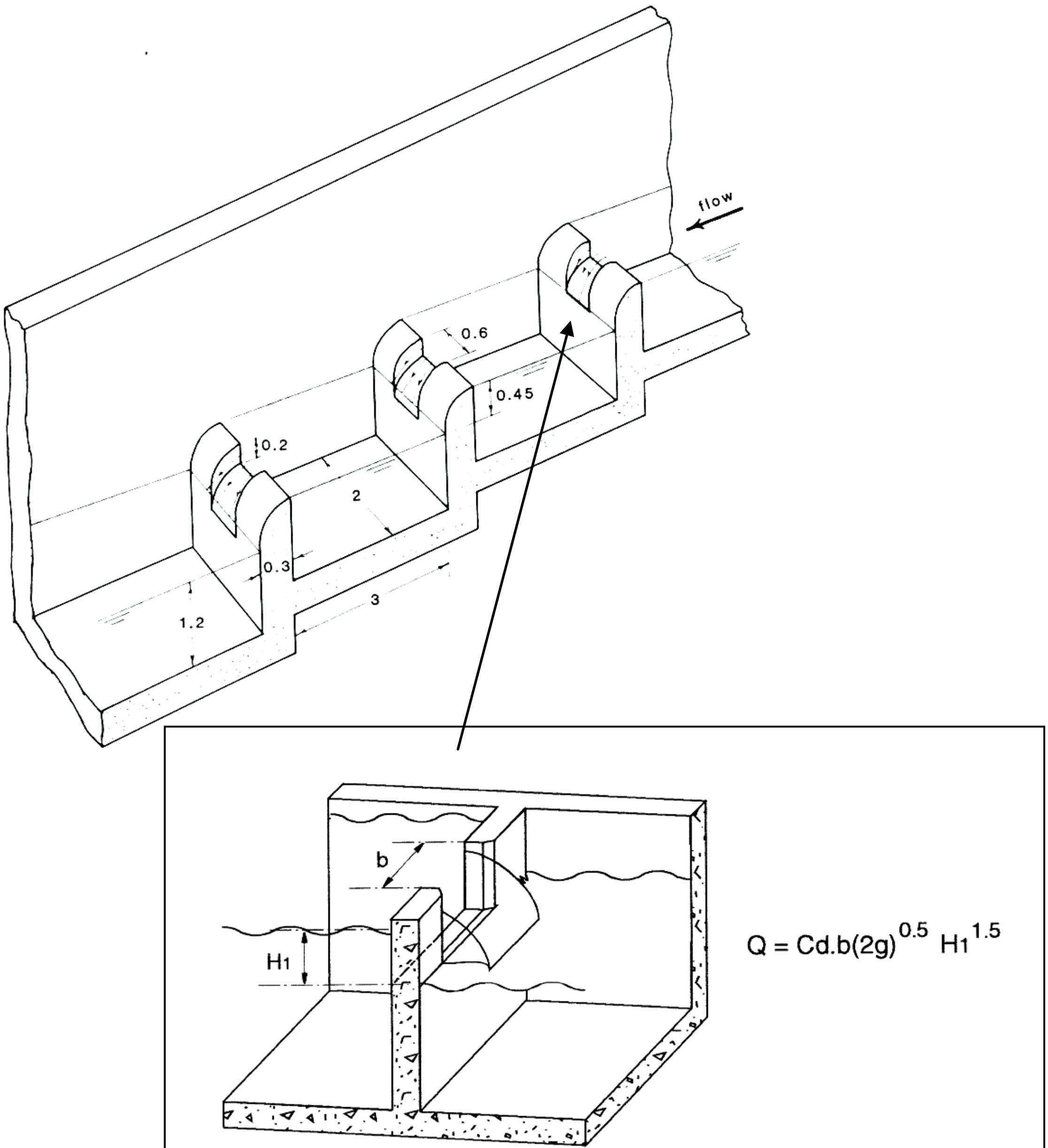
Flow: The flow in the minimum sized pass for large migratory salmonids, illustrated in Figure 9, is $0.13m^3s^{-1}$. It may vary substantially. Pass discharge (m^3s^{-1}) in this contracted notch is best estimated using the Francis equation (Beach, 1984) $Q = 1.84. [b - 0.2h]. h^{1.5}$. For the rounded traverse $Q = 1.85. b. h^{1.5}$. A more generalised diagram of a Pool & Traverse pass and an equation for estimating flow is also given in Figure 8 (After Larinier, 1992a). The coefficient C_d is determined mainly by the thickness of the wall and the profile of the notch. C_d may vary from 0.33 for a sharp broad-crested weir type to 0.50 for a profile shaped to achieve an adherent nappe (ogee profile). Usually it is near to 0.40.

Velocity: 1.4 to 3.0 ms^{-1}

Strengths: Extensively tried and tested, applicable to many species, low maintenance requirements.

Weaknesses: The overall slope of this type of pass is generally low at 10-12.5%, thus costs are generally high. Generally an inability to cope with large increases in upstream head because total flow and thus energy transfer becomes very large very quickly. Can be prone to debris blockage & sedimentation where there is movement of large material such as cobble. Not suitable for the more benthic coarse fish species such as barbel.

Figure 9 Schematic diagram of a typical Pool & Traverse fish pass with notched traverse and plunging type flow. Dimensions given are the recommended minima for large migratory salmonids (After Beach, 1984 & Larinier 1992a).



$$Q = Cd.b(2g)^{0.5}\ H_1^{1.5}$$

Generalised geometric characteristics and discharge equation for a pool and traverse pass *(downstream pool level lower than invert of the notch)*

(After Larinier, 1992a)

Vertical Slot

Vertical slot fish passes (Figure 10) consist of a rectangular channel with a sloping floor. Pools are formed by partitions between the pool with either one or two vertical slots. A water jet is formed at each slot and the energy dissipated in the pool below. Normally a projection is incorporated on the upstream edge of the slot, which is considered important to maintain a stable flow through the slot. If the flow becomes unstable fish may become disoriented.

A number of different configurations for single slot passes (Nos 1-7, Figure 12) were model-tested by Rajaratnam, Van der Vinne & Katopodis (1986) and they commended the designs 1 & 2 (same configuration but with or without a sill). Later, Rajaratnam, Katopodis & Solanki (1992) carried out further tests and recommended three designs (Nos 6, 16 & 18,), for practical use that had good overall performance, and the virtue of simplicity of design and construction when compared to the earlier configurations. Descriptions of other tried and tested configurations may also be found in R&D Note 110 and Larinier (1992a).

In single slot passes a small sill of approximately 0.2-0.3m has often been included at the bottom of the slot to stabilise and direct the water jet issuing into the pool where its energy is dissipated, and also to limit the flow in the fish pass. This is because single slot passes are not as effective as dissipating energy as paired slot passes, and because otherwise there is a tendency for the flow to direct itself directly from slot to slot down the pass, effectively by-passing the pool. It is particularly important to include the sill if the pools are <1.7m deep, or if the head drops are more than the usual 0.3m. On the other hand, there are advantages for the slot to be full depth with substrates used on the bed to ensure roughness and good connectivity for the more benthic and the smaller fish species, and also for invertebrates. This latter approach is much more likely where passage is being considered for a wide variety of species including potamodromous ones

Vertical slot passes can be considered to be ubiquitous and cater for a wide variety of species and sizes of fish, offering the full range of depth for passage, and are capable of functioning effectively across a wide range of water levels.

The Fitzroy River fishway in Queensland, NE Australia was adapted to pass a wide range of non-salmonid fish species, some as small as 40-120mm, by reducing the slot width to 0.15m, and the head difference between pools to 0.10m (Stuart & Mallen-Cooper, 1999). Slot velocities were around 1.4ms^{-1} and pool energy dissipation values around 40W/m^3. Pools were 1.95m long x 1.83m wide x 1.3m deep. The pass slope was 5%.

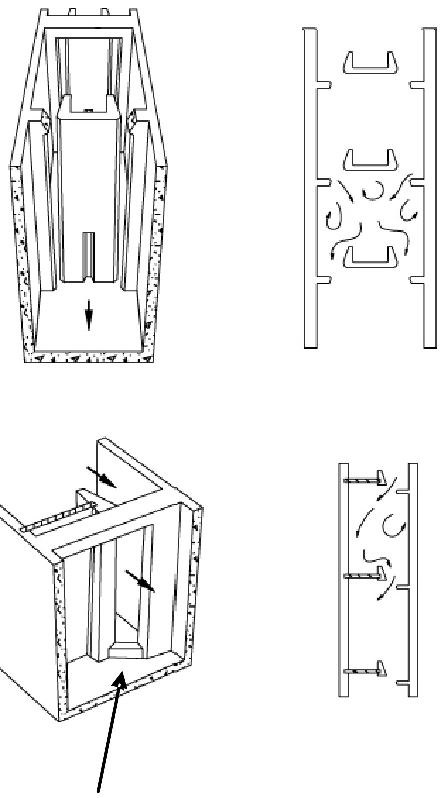
Manipulation of the dimensioning and hydraulic characteristics particularly in terms of energy dissipation can modify the performance of these passes (Tarrade, Texier, David, & Larinier, 2008). Modifying the length to width ratios of vertical slot passes and introducing energy dissipating devices near the slots helped improve energy dissipation and reduce re-circulation eddies, both of which features tend to limit the use of passes by small fiss.

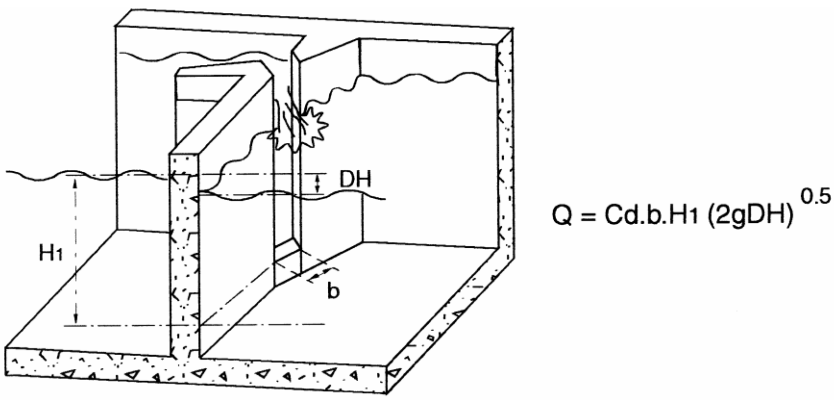
On the Murray River several vertical slot passes have been constructed at 3 – 5% slopes that pass small fish, but at 5% slopes are not effective for fish <100mm, which excludes several species that do not grow that big. Recently trials have been conducted to increase the range and size of species using such passes by increasing bed and wall roughness, introducing middle sills that partially block the vertical slot, and reducing head drops at the entrance (Mallen-Cooper, Zampatti, Stuart & Baumgartner, 2008). The wall roughness consisietd a secondary wall at a twenty degree angle to the side-wall, consisting an array of 30cm perforated pipes set at a forty five degree angle in a frame. The reduced turbulence resulting from these measures permitted much smaller fish down to 25mm to pass, and increased passage rates by up to four times with wall roughness and six to thirteen times for middle sills. However, the method was selective with some species still not able to pass.

It should be borne in mind that adapting such a pass for less able swimmers, or to cater for small fish, by reducing head drops between pools can have a significant effect on attraction velocity at the downstream entrance – perhaps greatly reducing attraction for migratory salmonids for example.

In some cases the bottom of slots has been adapted for species such as lamprey by providing brushes on the sill (Laine, Kamula & Hooli, 1998). More recent evidence has shown that adapting slots, by for example making them rounded rather than having sharp edges, can improve lamprey passage characteristics because lampreys can use their suckers to aid passage (Moser, pers com).

Figure 10 Single and paired vertical slot passes (after Larinier, 1992a)





Generalised geometric characteristics and discharge equation for a vertical slot pass (After Larinier, 1992a)

Figure 11 Details of designs of vertical slot pass tested by Rajaratnam, Katapodis and Solanki (After Rajaratnam et al 1992) (a)

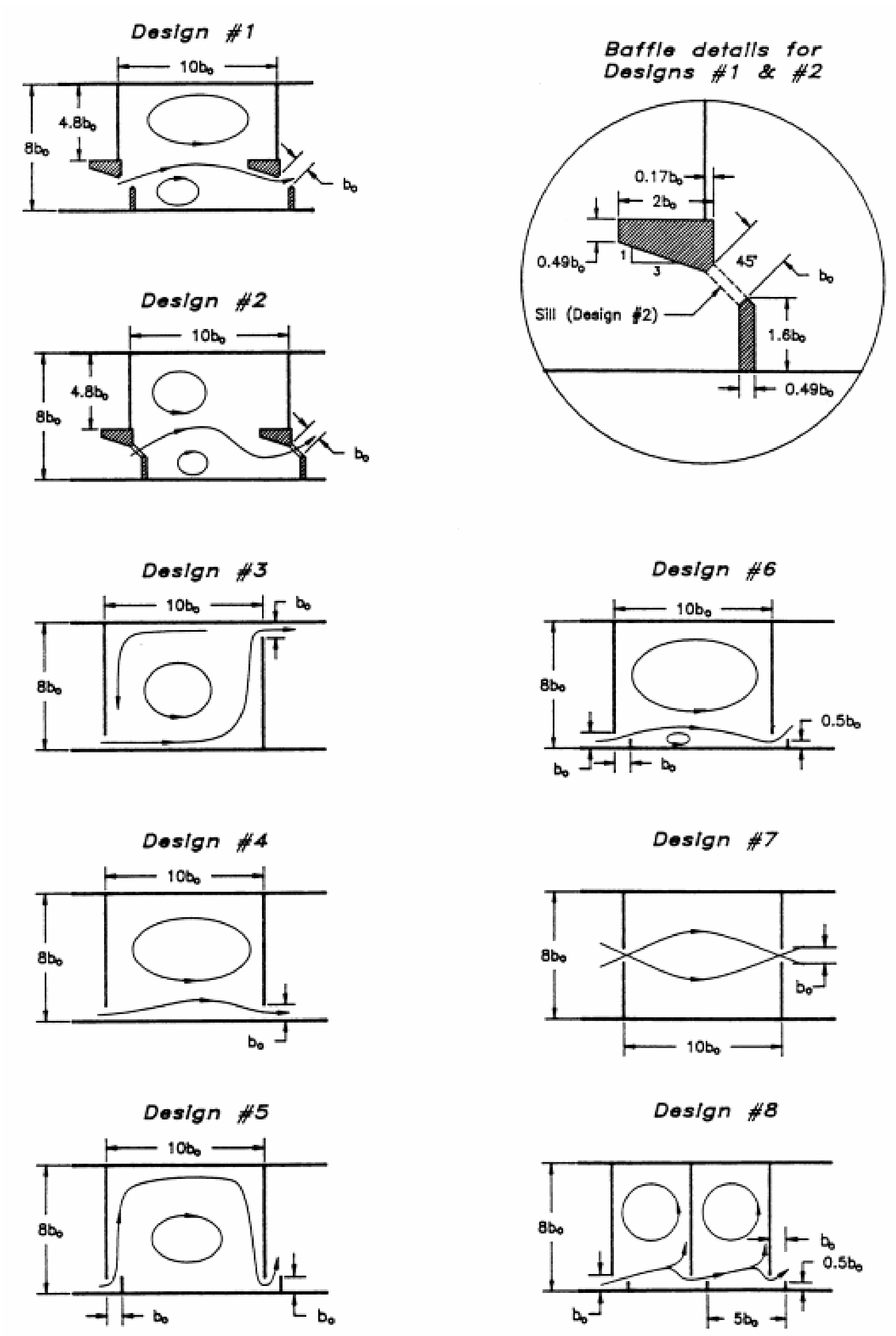
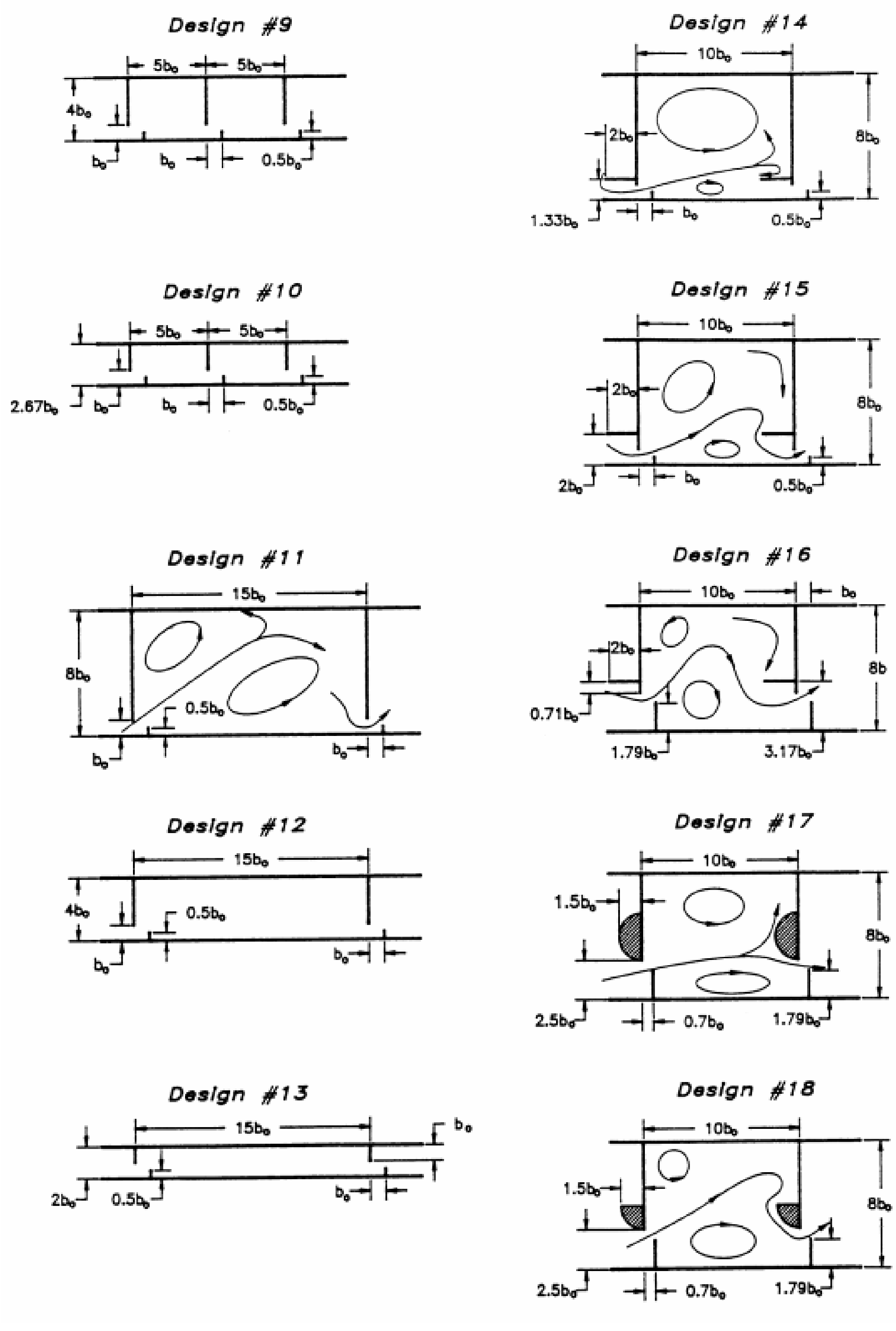


Figure 12 Details of designs of vertical slot pass tested by Rajaratnam, Katapodis and Solanki (After Rajaratnam et al 1992) (b)



Suitable Species: Most fish species. Shad require specific additional features relating to their preference for migrating as a shoal (sufficiently wide slot) and a need for visual cues (pass must be lit).

Head difference: Approximately 0.3m for large salmonids, <0.2m for coarse fish

Length & Width of pools: Usually 10 and 8 times the slot width respectively. Slot width generally from 0.2-0.6m, but can be less for non-salmonid species (Larinier, 1992). Minimum must be 0.2m for trout, 0.3m for migratory salmonids, and 0.45m for shad.

Flow: Not generally suitable for large migratory salmonids unless discharge ≥0.7 m^3s^{-1}, but may be used for other species using lesser flows.

Discharge (m^3/sec): An approximation of discharge is given by Q = 3.32. b. H1. $h^{0.5}$. Where H1 is the depth of water on the upstream side of the slot (Andrew, 1991). More exact flows for any design may be found in original references (e.g. Rajaratnam et al, 1992; Larinier, 1992; FAO/DVWK, 2002). Generalised geometric and hydraulic parameters for determining flow are given in Figure 10 (After Larinier 1992a). The shape and form of the slot affect the discharge coefficient, which may vary from 0.65 (slot sharply bevelled) to 0.85 (slot rounded).

Gradient: Usually 10%, but have been built at slopes between 5-12.5%.

Velocities: 1.4-2.4 ms^{-1}

Strengths: Capable of accommodating large changes in upstream water level provided that the downstream level varies in a similar manner. Provides a large range of water depth within the slot at which fish may choose to pass from one pool to another. Can cope with large bed load. Suitable for a wide range of fish species and fish sizes, especially with full depth notch(es) and bed roughening material utilised to create lower velocity boundary and refuge areas. With bed roughening may also pass some invertebrates.

Weaknesses: The overall slope of this type of pass is generally low at 5-12.5% thus costs are generally high. Can be prone to debris blockage. Shad can become trapped or exhibit fall-back behaviour if dead or re-circulation zones are excessive.

Pool & Orifice

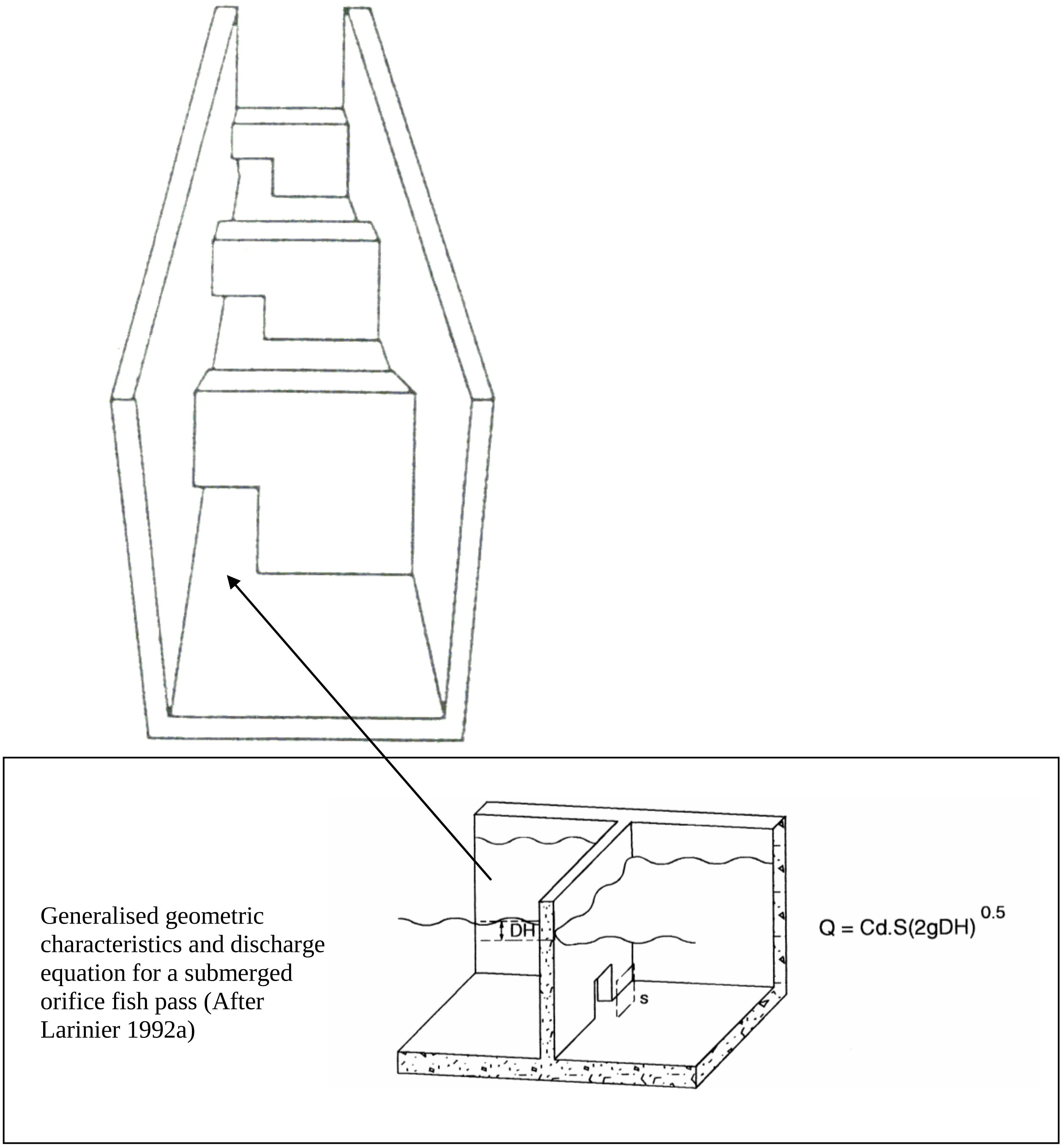
Pool and orifice passes (Figure 13) comprise a series of pools formed by partitions in a rectangular sloping channel. Water flows from pool to pool through submerged orifices. Discharge and velocity is relatively stable compared to a weir type pass (discharge varies in proportion to square root of the head as opposed to weir where it varies in proportion to 1.5 power of head).

Fishways consisting wholly pool & orifice units are rare, although some classic examples exist, e.g. Pitlochry Dam Fishway (orifice 0.84m diameter, 0.45m head drop, pass discharge 1.4 m^3s^{-1}), and a very specific small orifice pass that has found use in Holland (Boiten & Dommerholt, 2005) for passing coarse fish (discharge only 0.05-0.15 m^3s^{-1}, orifice 0.2m wide x 0.3-0.6m high, head drop 0.05m) . Most often they are found as control sections at the head of other types of pass, because a considerable increase in head pond level affects discharge in an orifice section very little. If all orifices are the same size throughout a fishway then the head differences will even themselves out over all the pools. However, if overall head difference reduces, the attraction to the pass becomes weak, and it is then not easy for fish to find the orifices.

Orifice-only passes are rarely used but, because of the stabilising influence on pass flows and the fact that they offer an alternative route between pools, they are frequently used in combination with other types of traverse.

The small Dutch Orifice pass has a hydrometric standard discharge relationship and may be used as part of an ISO Standard compound flow gauging & fish pass structure (Boiten & Dommerholt, 2005).

Figure 13 Pool and orifice fishway (After Rajaratnam, Katopodis & Mainali, 1989 and Larinier 1992a)



Suitable Species: Salmonids including grayling and some coarse species such e.g. roach and perch. Not very suitable for eel or lamprey, though passes with very small heads might be passable by either, and orifices might be adapted for lamprey by rounding the orifice x-wall section. Not suitable for shad or pike.

Head difference: Usually ≤ 0.30m, but up to 0.45m for salmon

Length & Width of pools: Usually 7-12 x orifice diameter. Minimum length and width of pools is 3m & 2m respectively for large migratory salmonids. Minimum length is 3 x length of largest fish requiring passage for other species. Minimum width is 3 x notch width.

Orifice dimensions: Orifices may be square or circular, with minimum dimensions for migratory salmonids of 0.45m x 0.45m if square, or a cross-sectional area of $0.20m^2$ if round. If used in combination with other forms of traverse the minima may be reduced to 0.3m x 0.3m for large migratory salmonids, and 0.2m x 0.2m for trout and coarse fish.

Gradient: ≤10%

Flow: up to 1.35 m^3s^{-1} in large passes

Discharge (m3/sec): $Q = C_d\ S\ (2gDH)^{0.5}$, where DH is the head drop, S is the area of the orifice (m^2), and C_d is a coefficient of discharge that may vary depending on the width and x-section of the orifice. C_d may vary between 0.65 and 0.85 or more, being larger the more the edges of the orifice are bevelled or rounded.

Velocities: up to $3ms^{-1}$

Strengths: Potentially suitable for a wide range of species, may be suitable for bottom swimming species such as barbel.

Weaknesses: The overall slope of this type of pass is generally low at 10% thus costs are generally high. Can be very prone to debris blockage. Considerably reduced effectiveness where head differences are reduced as a result of increasing river discharge. Relatively limited discharge for attraction compared to other pass types.

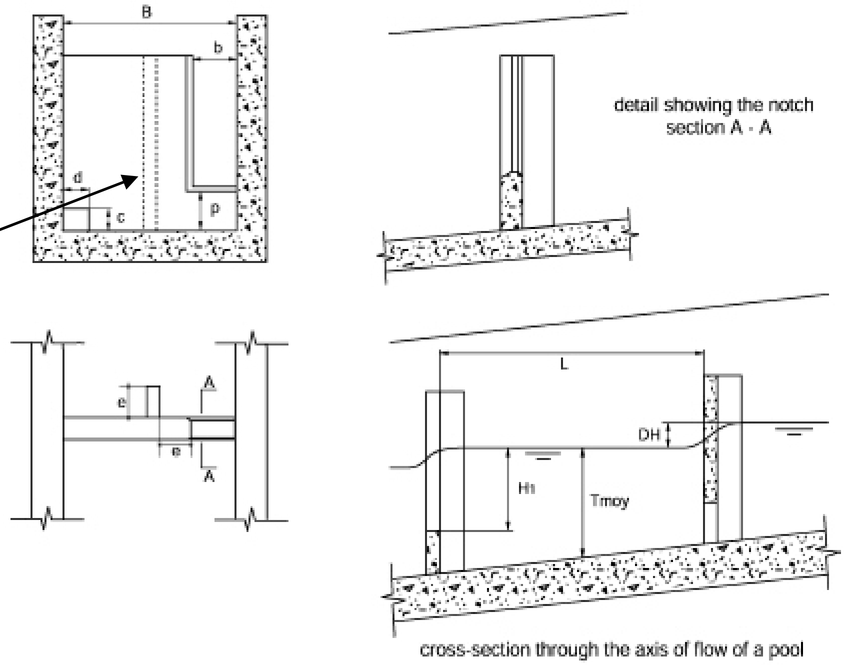
Deep Notch & Submerged Orifice

These passes have been much studied and used in France. Again on a sloping floor, the rectangular channel is separated into pools with walls equipped with a combination of deep slot or notch and an orifice located at the floor on the other side of the partition. The position of these traverses is alternated from pool to pool. The upstream side of each wall is equipped with a baffle to straighten the flow and reduce the turbulence in the slot or notch.

The pass must have streaming flow and the minimum head in the notch must be around twice the head drop between pools. Energy is not expended very efficiently in this type of pass because the jet tends to be perpetuated, and it is better to make the pools relatively longer rather than wider.

The head drop between pools is generally ≤0.3m. It cannot be used for flows less than 0.15m^{3}s^{-1}, and typically has flows from 0.18-0.70 m^{3}s^{-1}. The parameters used for several sizes of pass are shown in Figure 14 below. They can cope with a large range in upstream level and are simple to construct.

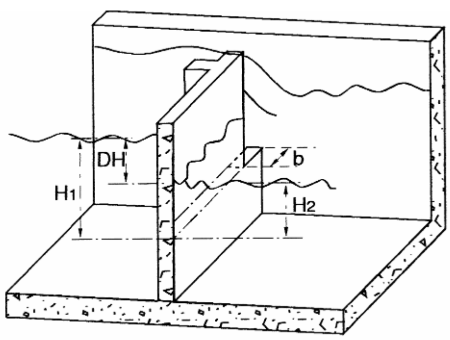
Figure 14 Characteristics of some deep slot and orifice passes used in France (After Larinier, 1992a).



Q (*) (m³/s)	L (m)	B (m)	Tmoy (m)	b (m)	cxd (mxm)	e (m)	P (m)	H1 (*) (m)
0.175	2.20	1.25	1.15	0.20	0.15x0.15	0.15	0.70	0.60
0.300	2.70	1.50	1.30	0.30	0.20x0.20	0.25	0.80	0.65
0.500	3.15	1.80	1.50	0.40	0.30x0.30	0.35	0.925	0.725
0.700	3.50	2.00	1.65	0.45	0.375x0.375	0.40	0.95	0.85

(*) design head and flow discharge

Generalised geometric characteristics and discharge equation for deep slot fish pass (After Larinier 1992a)



$$Qn = K.Qd$$

$$K = [1-((H1-DH)/H1)^{1.5}]^{0.385}$$

$$Qd = Cd.b(2g)^{0.5} H1^{1.5}$$

$$H2 = H1 - DH$$

Suitable Species: Most fish species. Shad require specific additional features relating to their preference for migrating as a shoal (sufficiently wide slot) and a need for visual cues (pass must be lit). Might be made passable by lamprey by adapting slots, by for example making them rounded rather than having sharp edges.

Head difference: Generally 30cms.

Length & Width of pools: Generally 8-10 and 4-6 x the notch width respectively. Notch width generally from 0.2-0.6m, but can be less for non-salmonid species. Minimum must be 0.2m for trout, 0.3m for migratory salmonids, and 0.45m for shad.

Gradient: ≤10%

Flow: Not less than $0.15m^3s^{-1}$

Discharge: Where the slot is moderately drowned (defined by the ratio of head upstream and downstream of the notch H1-DH/H1 <0.9), the discharge $Q_n = K\ Q_d$. Where Q_d is the flow through a free-flowing notch, and K is a discharge reduction coefficient induced by submergence.

$Q_d = C_d\ b\ (2g)^{0.5}\ H1^{1.5}$, where H1 is the head of water in the slot, and C_d can vary depending on the thickness and shape of the traverse between about 0.33 and 0.5, but is generally about 0.4. While $K = [1- (H1- DH/H1)^{1.5})]^{0.385}$.

Velocities: 2-0-2.4ms^{-1}

Strengths: Well tried and tested in France. Suitable for most species of fish, relatively easy to construct, and accommodates significant variation in water levels upstream.

Weaknesses: The overall slope of this type of pass is generally low at 10%, thus costs are generally high.

Ice Harbor

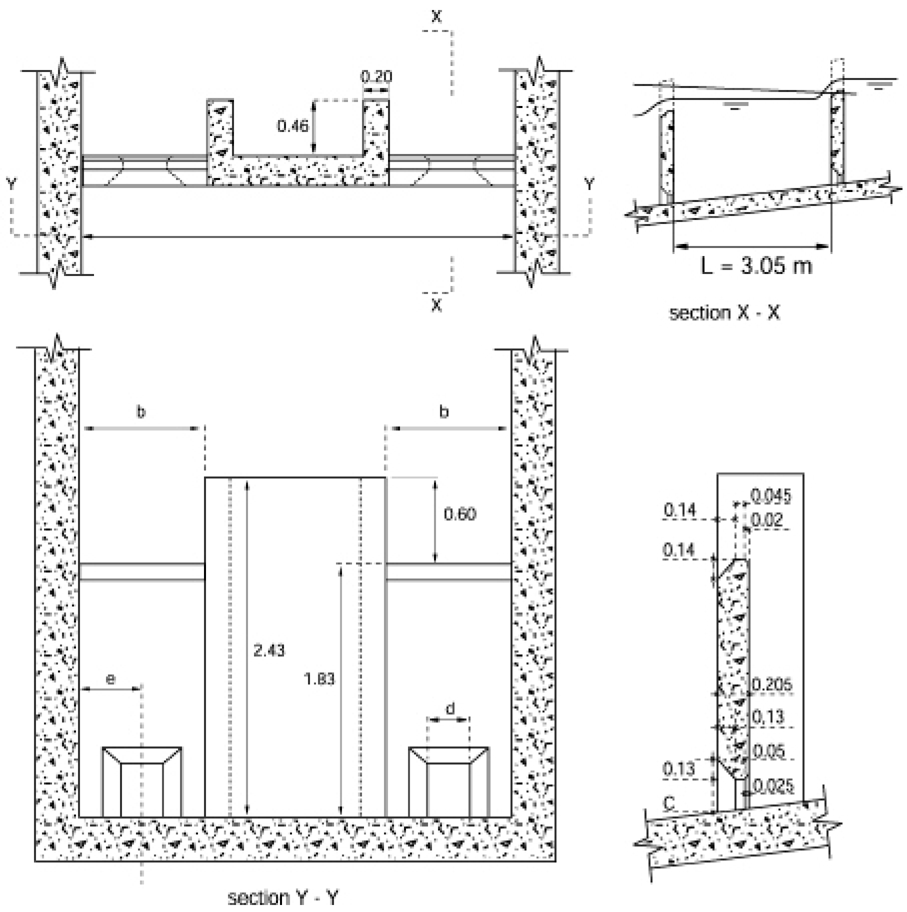
The Ice Harbor type pass is effectively a combined `plunging-flow` over-spill weir and submerged orifice pool pass (Figure 15). It has been the subject of many model studies in the USA. (Rizzo, 1969; Bell, 1986). Examples of this type of pass have been built to discharge flows of between 1- 6 m^3s^{-1}, with widths of channel ranging from 2 to 10m. Those with widths less than 5m are usually built as Half Ice Harbor passes, split along the centre line.

The width of each of the side notches is 0.312B, where B is the width of the pass. Orifices vary from 0.3m x 0.3m in passes < $2m^3s^{-1}$, to 0.46m x 0.46m in passes ≥$2m^3s^{-1}$.

Power is dissipated by the combination of plunging water from the over-spill and recessed notches. Power dissipation is of the order 150-200 Wm^{-3} and therefore marginal for shad and excessive for most coarse species.

Modifications to the format of the pass have been incorporated at sites in the USA to improve performance for the passage of shad. These included an increase in head loss to 0.45m to create a more streaming flow, a reduction in the size of the submerged orifices to reduce turbulence, and closing of alternate staggered notches to prevent by-passing (Rideout et al, 1985).

Figure 15 Characteristics of an Ice Harbor pass (after Larinier, 1992a)



Q (*) (m^3/s)	B (m)	b (m)	e (m)	cxd (mxm)	pv (*) (watts/m^3)
1.0	3.05	0.95	0.55	0.30x0.30	160
1.6	4.26	1.32	0.79	0.46x0.41	180
2.0	5.20	1.63	0.91	0.46x0.46	180

(*) flow and volumetric dissipated power for a nominal head of 0.30 m

Suitable Species: Migratory salmonids, Shad with some modifications. There are no data available on use for coarse species. Turbuence and velocities make them not particularly suitable for lampreys.

Head difference: 0.3-0.45m

Length & Width of pools: Length of pools generally between 3-5.4m, (minimum 3m), widths 2-10m, average depth ≥2m.

Gradient: 5-7% (Orsborn 1985), ≤10% (Larinier, 1992)

Flow: A 5m wide Ice Harbor passes about $2m^3s^{-1}$

Discharge: In the notches $Q = 0.45\ b\ (2g)^{0.5}\ H1$, where H1 is the depth of water on the notch; while in the orifices $Q = 0.85\ S\ (2gDH)^{0.5}$, where S is the area of the notch and DH the head drop between the pools (Rizzo, 1986).

Velocities: Normally $2.4m^3s^{-1}$ at the overfalls, but up to $3m^3s^{-1}$ for head drops of 0.45m. Orifice velocities up to $3m^3s^{-1}$.

Strengths: Well used and tested for large passes for salmon in North America

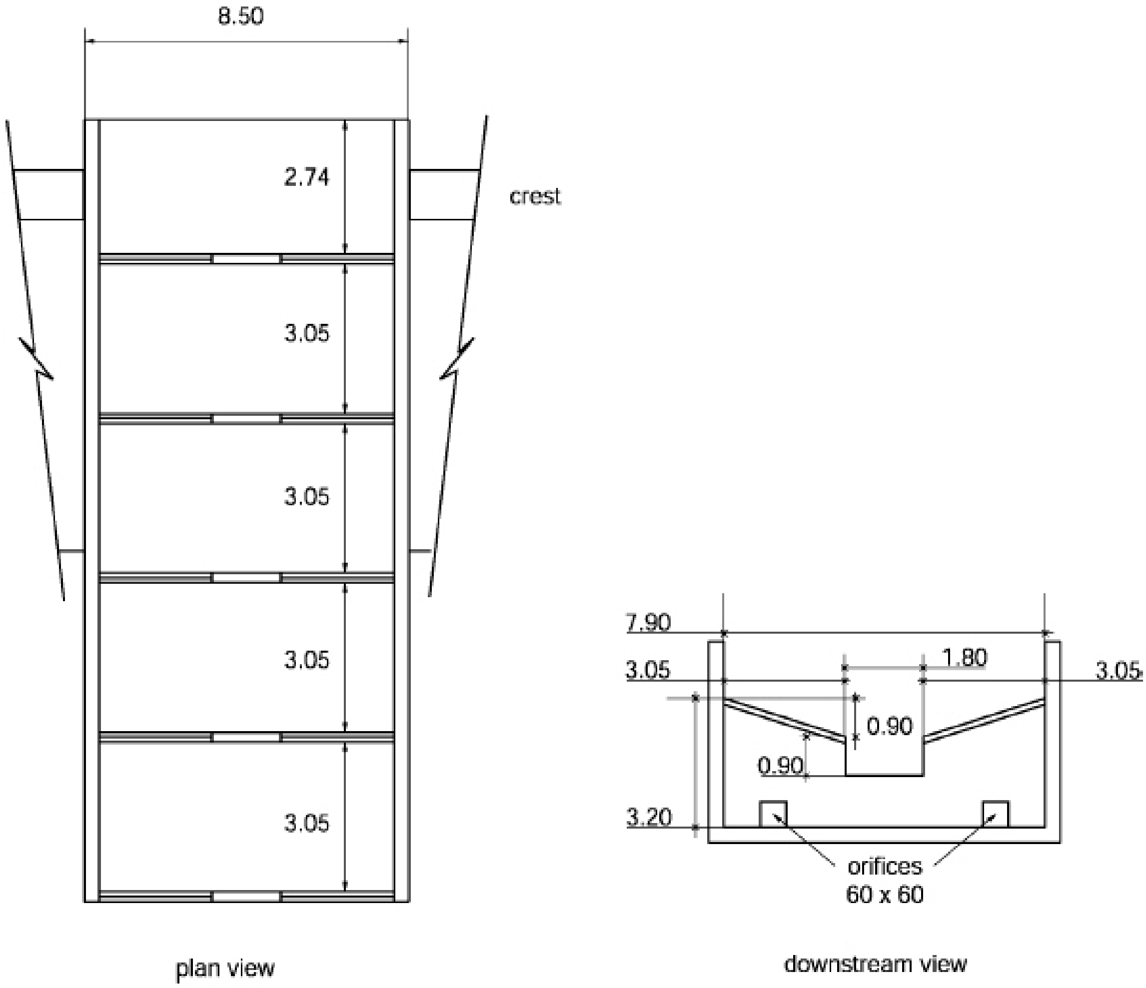
Weaknesses: Withstands only small increases in head, requiring control sections upstream if head is variable. The overall slope of this type of pass is generally low at 10% thus costs are generally high.

Pool & Chute

The pool and chute fish pass is a hybrid pool type fish pass with the dividing partitions shaped to form a 'v', the invert of which is modified to form a rectangular slot. The partitions may also include a submerged orifice on each side of the pass (Figure 16).

At low flows the pass operates as a pool and traverse type pass, with plunging flow. At high flows the pass operates as a roughened chute, with streaming flow down the centre of the fishway, but with plunging flow at the sides. For these reasons power dissipation estimates are only relevant under pool and traverse type operation. Bates (1990) describes the use of these fishways on the West Coast of the USA.

Figure 16 Characteristics of a Pool & Chute fishway (after Bates, 1990)



Suitable Species: Migratory salmonids, no data on other species

Head difference: Usually 0.15-0.30m

Length: ≤3.1m [7.9m wide = discharge $10m^3s^{-1}$]

Gradient: ≤10%

Flow: Up to $10m^3s^{-1}$

Discharge: As pool & traverse at low flow, criteria not available for high flow

Velocities: Similar to plunging flow passes at low flows, probably similar to V notch weirs at high flows

Strengths: Designed to operate across a wide range of river discharges and upstream levels, high energy dissipation values allowable at high flows

Weaknesses: As yet poorly documented. Not suitable for sites with drops >2m.

Shallow 'V' Notch Weirs

These pool passes have been used throughout Holland with some success, especially in small rivers (Boiten, 1990). Sometimes in the river itself, but most often in by-pass channels parallel to the main river. In essence these weirs form a series of pools where power is expended near each drop and throughout the majority of the lower pool. Power dissipation per unit volume is generally low at <$100Wm^{-3}$.

The fishway channel normally has a gradient around 3.33% to a maximum of 5.0%, however they may be designed with lower gradients to accommodate higher flows (Larinier, 1992a). The low gradients employed mean that these passes are effectively artificial rivers.

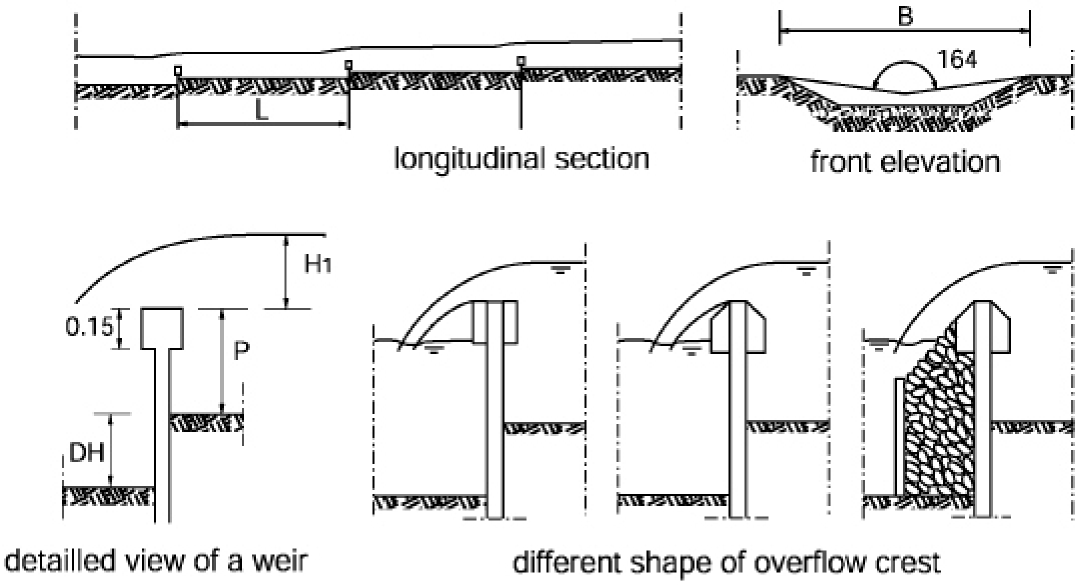
This type of pass has a limited ability to function at other than very modest changes in upstream level. They are however particularly suitable for species of modest swimming performance, and, since they can span the width of the river channel as artificial rivers, they can also exhibit very high measures of efficiency.

In locations where they form only part of the river flow they are limited in their performance by their attractiveness, and particularly the location of the downstream entrance if it is not immediately below the obstruction.

These passes have a hydrometric standard discharge relationship and may be used as part of an ISO Standard compound flow gauging & fish pass structure (BS ISO 26906:2009).

Example characteristics of the pools for several design flows are given in Figure 17 (after Larinier 1992a). These are applicable provided that the fishway operates at flows between 0.5Q and Q (i.e. head between 0.75H1 and H1). The standard design can be scaled down or up to cater for discharges between $0.35m^3s^{-1}$ and $5.50m^{3-1}$. For precise hydraulic characteristics the reader should refer to the original reference material.

Figure 17 Characteristics of a V-shaped pool fishway used in the Netherlands (after Boiten 1990).



Flow (m^3/s) Q ($9.8\ H_1^{2.5}$)	Drop DH ($0.475\ H_1$)	Dimensions (m) L ($14.2\ H_1$)	B ($18.8\ H_1$)	P (m) ($0.76\ H_1$)	Head H_1 (m)
1.14	0.20	6	8	0.32	0.42
2	0.25	7.5	10	0.40	0.53
3.15	0.30	9	12	0.48	0.63
5.51	0.375	11.25	15	0.60	0.79

Suitable Species: Migratory salmonids, coarse species at low head loss (<0.25m), generally all surface swimming species. Not suitable for benthic species of coarse fish, eel or lamprey.

Head difference: 0.125-0.375m

Length: 3.75 - 11.25m pool width 5-15m

Gradient: normally 3.3% (max 5%)

Velocities: maximum behind the crest 1.74-3.02ms^{-1}, maximum in pool 0.53-0.92ms^{-1} both dependent on gradient.

Strengths: Applicable to a wide range of fish species and sizes dependent on drop between pools. Not prone to blockage. Tested designs shown to operate with relatively shallow pool depths of as little as 0.2m.

Weaknesses: Relatively low gradient therefore potentially high construction costs if not incorporated into an existing structure. Capable of operation under only a very restricted range of upstream water levels (generally range of 0.1-0.2m) since the maximum useful flow is set by the power dissipation in the pools.

Baffle fishways

General

A Belgian engineer named Denil developed the first `baffle` fishway, in 1908 (Denil, 1909). Baffle fishways consist of a straight sloping channel fitted with specific geometrically shaped deflectors which cause helical currents to be developed thus dissipating the energy in the flow and reducing velocities in a relatively large main through channel. The energy is very effectively and continuously dissipated along the entire length of the pass. Fish can then swim straight up them provided that their swimming capabilityis adequate.

Several different types of baffle are known to be effective in practice. Geometric characteristics of baffles are given in a dimensionless form related to the width of the channel or else the height of the baffle, and these should be rigidly adhered to since any amendment may cause substantial change to the flow characteristics. Each type has a hydraulic operating range where the minimum flow provides sufficient depth for helical currents to form (i.e. for the pass to charge), and the maximum is the flow and/or gradient above which the helical structure breaks down and streaming flow develops.

This form of fishway is known not to be especially suitable for some species like shad, which do not like the aeration in the water column because it obscures their vision of their compatriots, and consequently are only ever likely to use them with low efficiency. It is also not especially suitable for poor swimmers or small fish because of the relatively high velocities. However, some types of pass are more adaptable than others, and velocities in all types can be restrained by using shallow slopes.

Apart from velocity another consideration is the size of the helical currents that are formed. The larger the fish, the larger the helical current dimension (and thus baffle spacing/channel width) that it can manage without being disorientated. Thus, small fish need small, closely spaced baffles.

Fish must pass the length of any one flight in a single attempt. Therefore the length of passage must be limited to 10-12m (1.8m-2.4m) of drop, except for Alaskan ‘A’ type where up to 3m may be considered for large migratory fish (i.e. salmon, sea-trout), and 6-8m (1.2-1.5m of drop) for trout and cyprinids. Resting pools between lengths of pass must be provided to extend the overall height of obstruction capable of being passed. Any one individual flight of baffled fishway must be in a straight line, and the direction changed only at a resting pool.

Guidelines for suitable power densities and the calculation of power inputs and dissipation in rest pools is given in the section on Additional Facilities – Resting facilities, page 180.

To avoid local acceleration in the vicinity of the entrance, or else the formation of a hydraulic jump at this point, the downstream end of the fishway should be drowned equivalent to the depth (h) within it.

With the exception of Alaskan and Chevron type baffle passes the baffles are normally fabricated from 10-12mm steel, and should not be thinner than 8mm. At a thickness less than 8mm the baffles can vibrate, especially in plane baffle Denils, and this can dissuade fish from entering the pass. Thinner baffles are also likely to be more abrasive for the fish. To avoid any prospect of injury should fish bump into the baffles they should always be fully rounded on their edges. Galvanised mild steel is usually adequate for most pass applications, particularly Super-active baffle passes that are always drowned, however stainless steel may be necessary if the design life of the pass is more than 60 years or if the pass is located in a salt water environment. Thicker baffles have been used, for example wood, concrete and plastic (GRP). However they have generally been found to be unsatisfactory because of limited durability. If employed maximum thickness should be L/20, where L is the unit pass width.

To provide stable and smooth approach conditions a slope should be provided away from the invert of the bed of the pass channel at the upstream end. A slope of 1:2 is recommended, though it may be as little as 1:20. It is also beneficial to round the upstream ends of the side-walls of the pass channel to retain a laminar flow pattern.

Idealised profiles for the head and intermediate resting pools are shown in Figure 18.

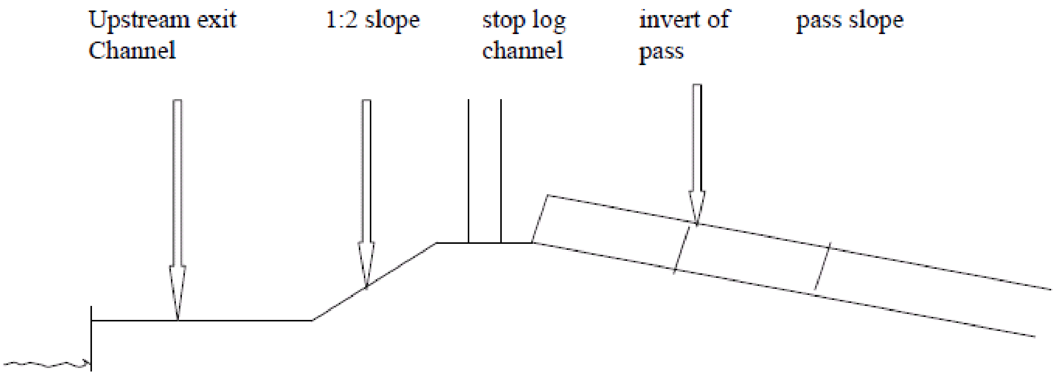
At the downstream entrance of the pass it will be an advantage, particularly for the more benthic species of fish such as Barbel, to provide a slope that is contiguous with the river bed. This may also be an advantage if applied, where space and volume for appropriate power densities to be maintained allows, in the rest pools of those passes that have multiple flights.

The mean water velocity in any upstream exit channel should be between 0.3-0.5m/sec for coarse fish and trout, and 0.3-1.0m/sec for migratory salmonids and shad.

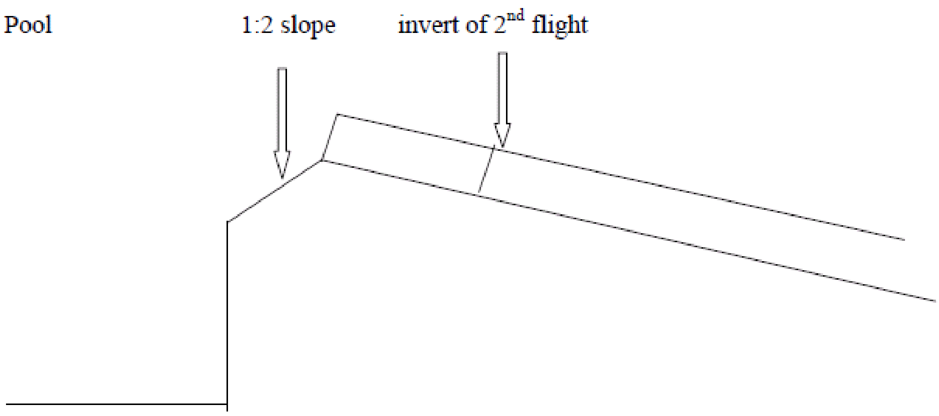
Stop-log channels, or preferably a penstock, should be provided at the upstream end of the fishway to facilitate closure for maintenance. Stop log channels may also be of benefit at the downstream end of the pass.

Figure 18 Idealised profile for the head of the pass and intermediate rest pools for baffle passes

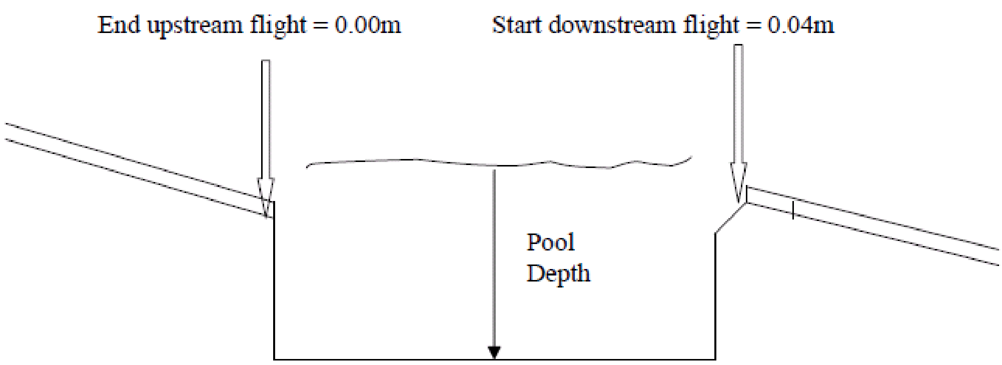
Upstream head arrangement:



Rest pool and 2nd flight arrangement:



Rest Pool Arrangement (concrete inverts):



There are three different characteristic types of baffled pass:

- baffles fitted on the sides and bottom of the channel;
- baffles fitted only on the bottom of the channel;
- baffles fitted on the sides of the channel only.

Side & Bottom Baffle Fishways

Plane Baffle Denils

This is the most common type of baffle fishpass. It is used extensively in Europe and on the East Coast of America. The baffles are in a single flat plane and set at 45° to the channel slope, which generally varies between 10% and 20%. The width of the channel generally varies between approximately 0.6 and 1.2m. The characteristics of plane baffle passes are shown in both cross-section and isometric view in Figure 19 & Figure 20. The characteristic dimensions of the baffle and the spacing between baffles are related to the channel width L.

Figure 19 Cross-section and geometric characteristics of a plane baffle Denil fishway (After Larinier 1992d)

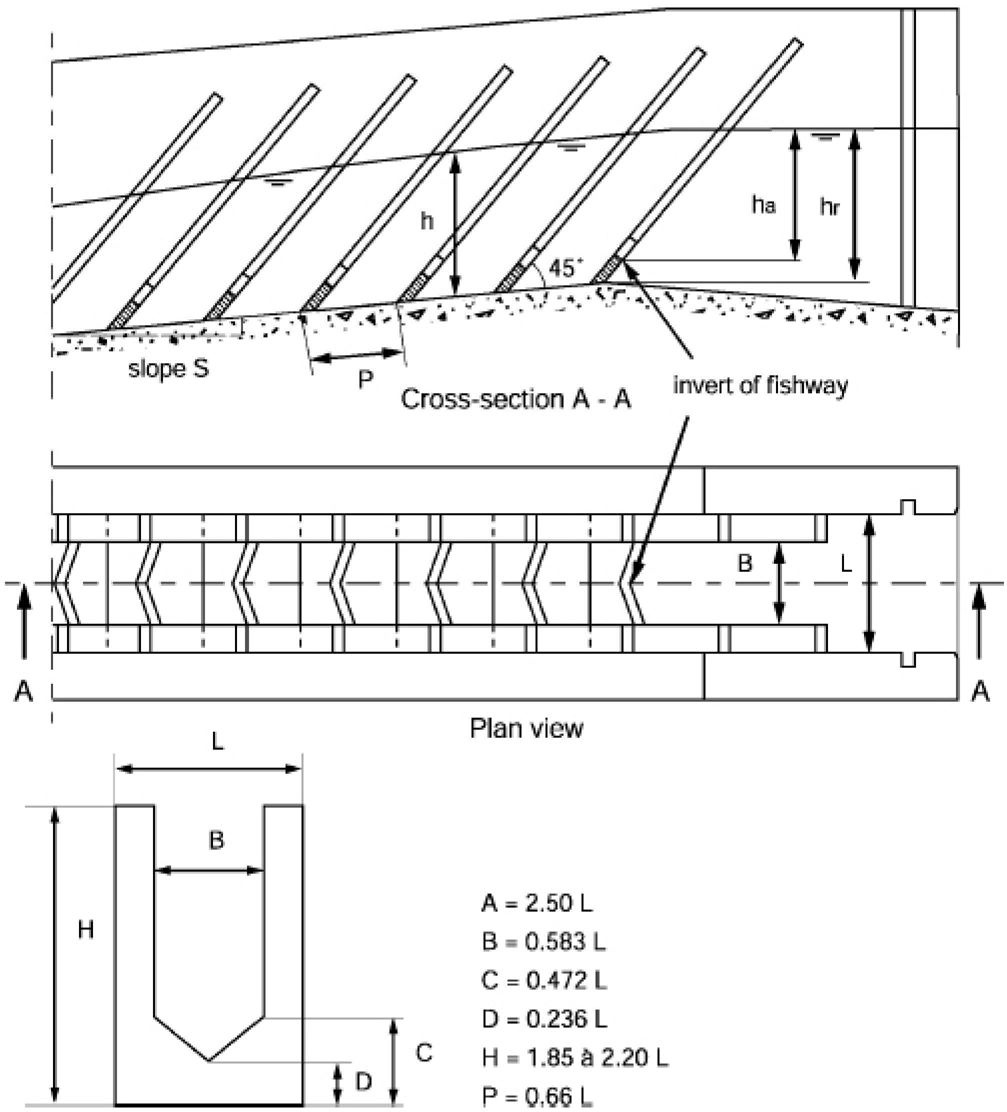
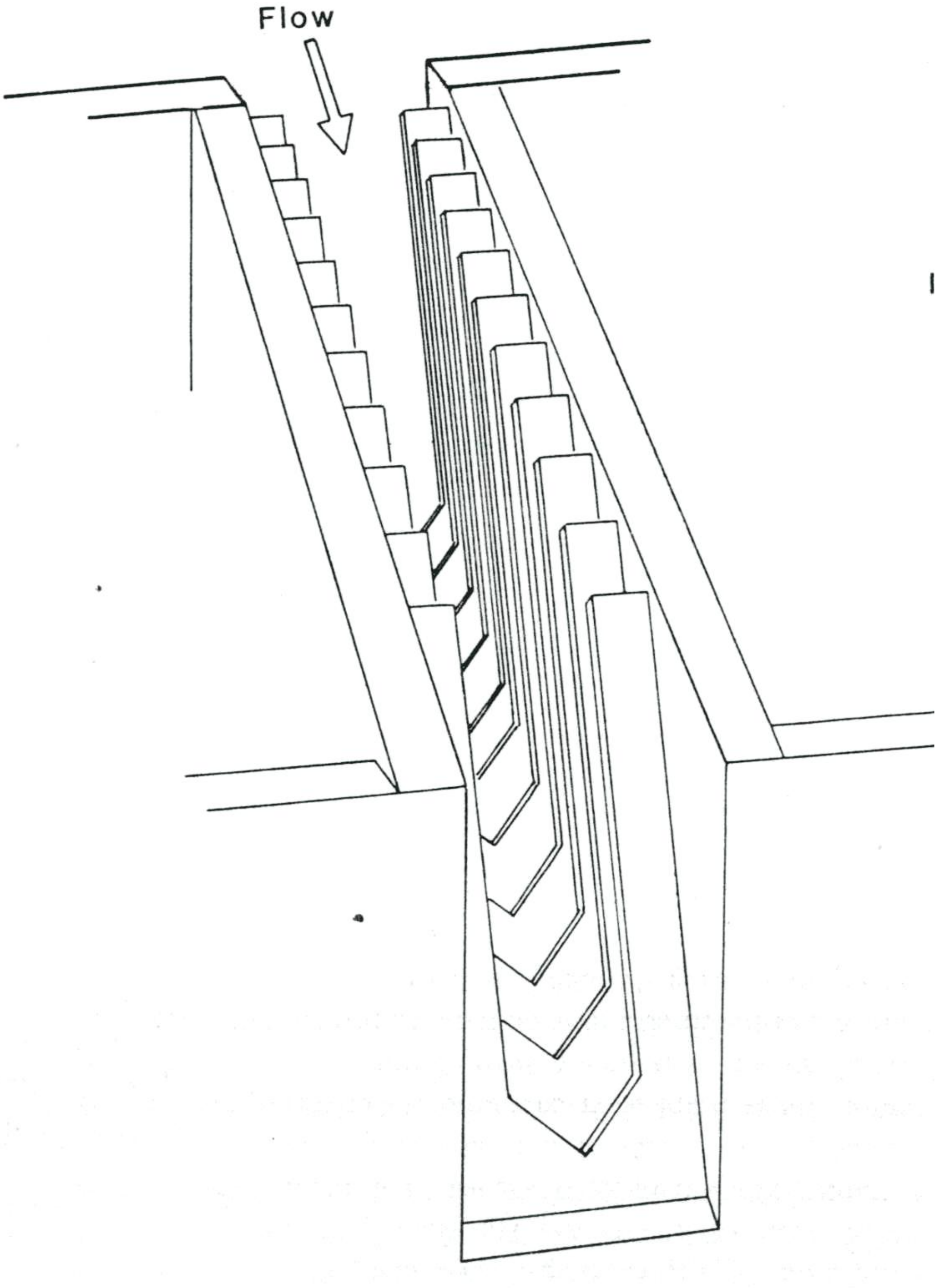


Figure 20 Isometric view of a plane baffle Denil fishway (After Beach, 1984)



The invert of the pass is determined from the lowest point of the ‘V’ of the most upstream baffle (Figure 16). The upstream head on the pass (h_a) is the difference between the pass invert and the water level upstream before any acceleration of flow. This should not be confused with hr, which is the difference in level between the invert of the concrete slope on which the baffles are placed and the upstream water level:

$$h_r = h_a + 0.236L \ \sin(45° + \arctan s)$$

where:

s = slope.

In short, for a slope of 10% $h_r = h_a + 0.183L$ and for a 20% slope $h_r = h_a + 0.196L$.

The relationships between head, discharge and velocity in a plane baffle pass for three gradients are shown in a dimensionless form in Figure 21. The actual relationships for the two most common widths at the most common gradient are shown in Figure 22.

Plane Baffle Denils are usually deployed for migratory salmonids, however they can be used by a variety of rough fish and shad (USA), coarse fish and lampreys (Europe,) and other native (Australia) species by using shallow slopes around 10 – 12% or even less.

Fish of 45 – 630mm were shown to be able to utilise a PB Denil, and the whole size range of Bony Herring, 45 – 350mm fork length were able to pass when the pass was at an 8.3% slope. Some 88% of herring were able to utilise the fishway at the 8.3% slope, reducing to 31% when the pass was at a 20% slope. Performance was in between in thepass at a 14.3% slope. This paper, Mallen-Cooper & Stuart, 2007, provides a useful review of the performance of Denils at different slopes and sizes.

Sea lampreys appear to be able to use PB Denils and certainly they have been trapped and sucker marks are obvious at times on the baffles at the top of the Tees Barrage pass, R. Tees, UK (pers com Richard Jenkins, personal observation). Sea lamprey passage in PB Denil passes in Ireland has also been seen in videos on U-tube. While large numbers of river lamprey are seen in PB Denils in Normandy, France when lowered to inspect traps (personal observation) it is not clear that they could migrate under normal hydraulic operation.

Figure 21 Dimensionless relationship between upstream head (h_a), mean depth in pass (h), discharge (Q), and velocity (V) in a plane baffle fishway at 10, 15 & 20% slopes (After Larinier 1992d)

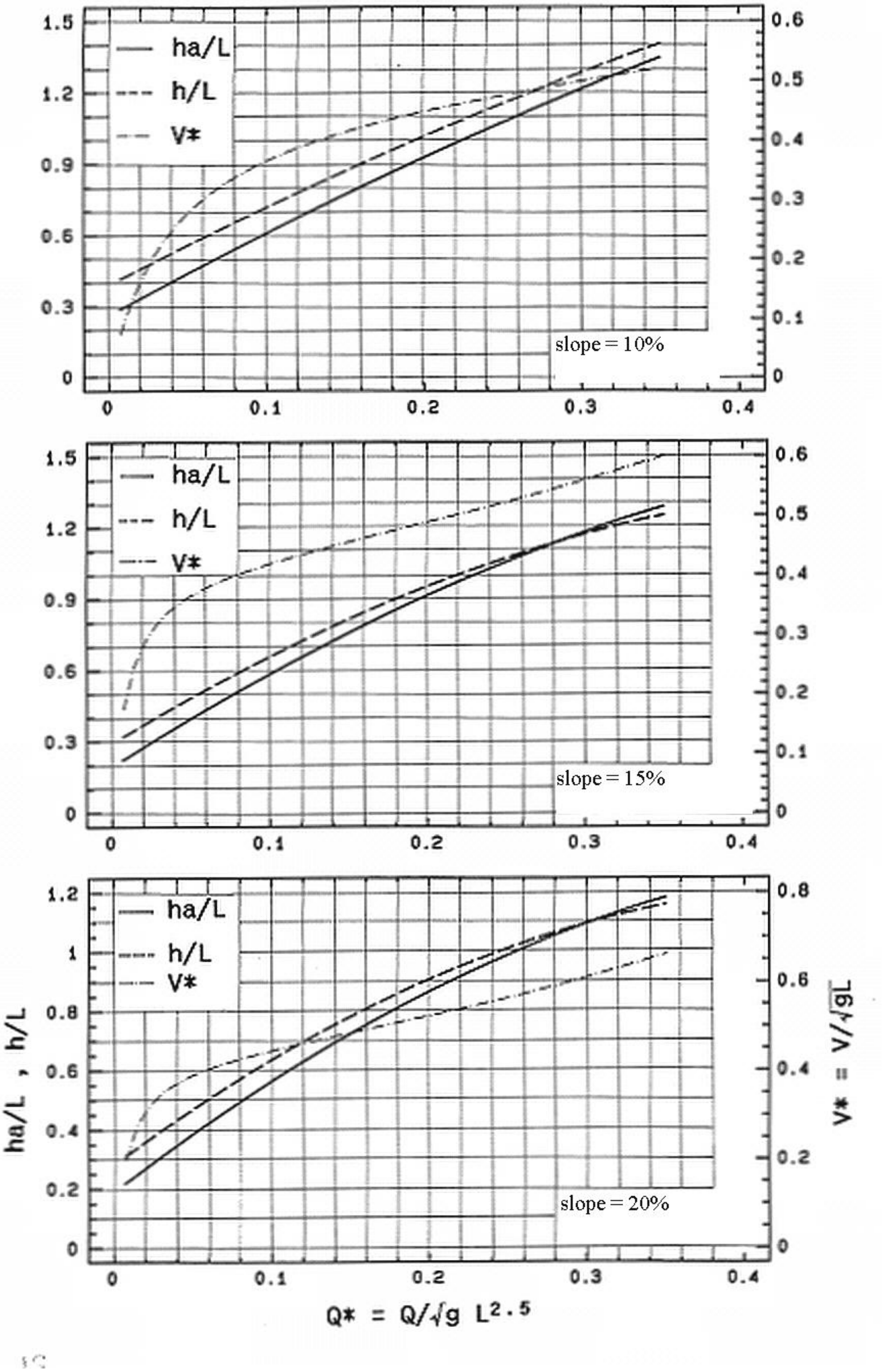
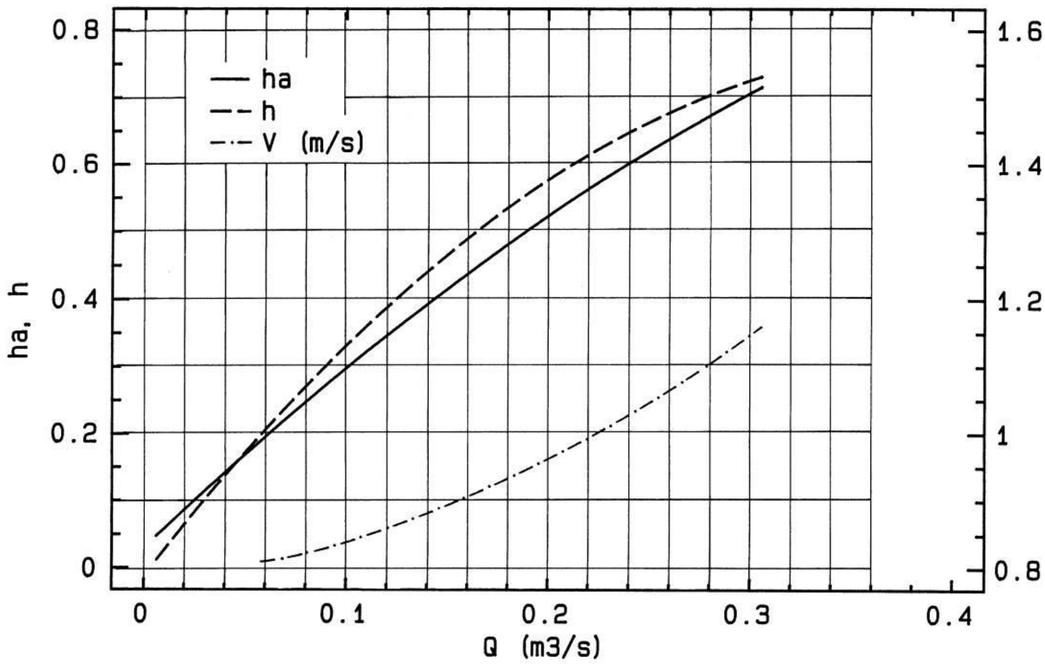
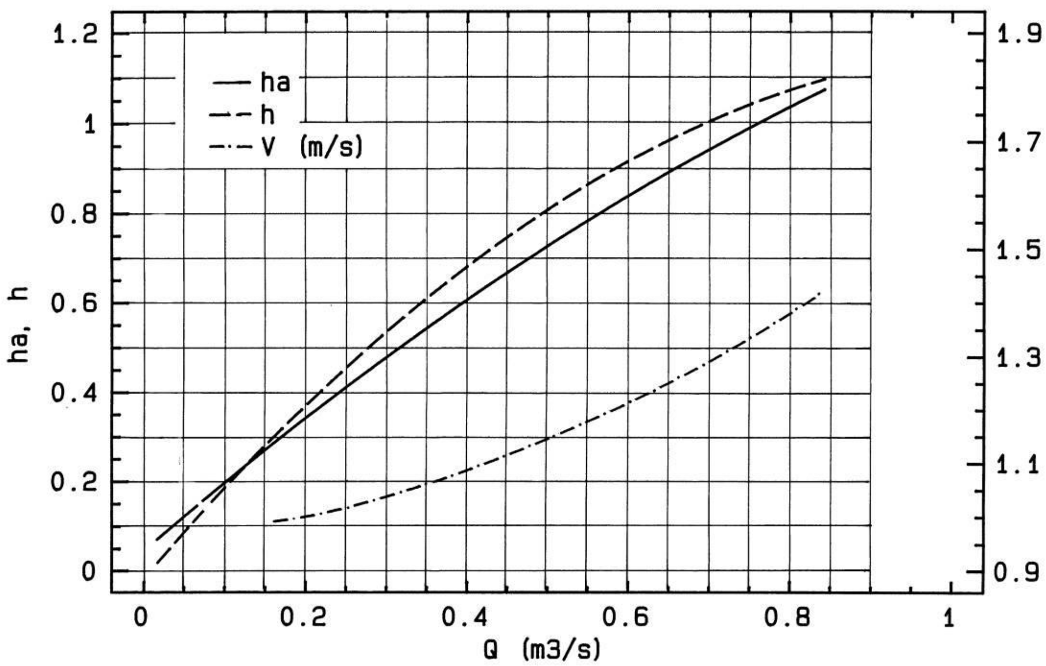


Figure 22 Relationship between between upstream head (h_a), mean depth in pass (h), discharge (Q), and velocity (V) in plane baffle fishways 0.6 & 0.9m wide at 20% slopes (After Larinier 1992d)



Plane Baffle 20% slope L=0.60m



Plane Baffle 20% slope L=0.90m

Suitable species: This type of pass is regarded as very suitable for large migratory species such as salmon, sea-trout, and sea lamprey, and good swimmers such as trout and some of the larger riverine coarse fish species. It is not regarded as very appropriate for small fish, which become disorientated by the relatively large helical currents. Short lengths of shallow sloping channel 6-8m, 10-12% gradients have been found to be fairly effective for "rough" species (can be translated as non-salmonid species) in the north east of the USA and Canada.

Head difference: Single flights may be used to accommodate a head difference of up to a maximum of 2.4m for large migratory salmonids, and 1.6m for other species.

Length & Gradient: Maximum gradient 20%. The length of any one flight should be limited to 12m for migratory salmonids, and 8m for other species.

Width: Usually 0.8-1.2m for large migratory fish (salmon and sea trout), and 0.5-0.7m for smaller migratory species (trout).

Depth: The lower operating limit is generally taken as h/L = 0.5 (where h = the depth in the pass from the bed). This depth is necessary for the pass to develop the helical currents and to provide sufficient space for fish to swim. The upper limit is not easily defined but a level of h/L of 1.1 is regarded as reasonable.

Discharge: Would normally vary between about $0.25m^3s^{-1}$ and $0.75m^3s^{-1}$ for large migratory salmonids in a 0.9m wide pass. Larger discharges have been used in both 0.9m wide passes (up to $1m^3s^{-1}$) and wider units. For other species discharges of $0.1m^3s^{-1}$ to $0.3m^3s^{-1}$ in narrower passes would be more typical. The discharge Q in the pass is given in a dimensionless form for head to pass width ratios at various slopes in Figure 24, where $Q^* = Q/ (\sqrt{g}.L^{2.5})$.

Velocity: Mean velocities are generally constrained between 1.0-1.8m/sec dependent upon dimensions, slope and discharge selected. Velocity profile in the pass in the vertical plane is variable sinusoidally, being lowest at the bottom of the pass (approx. 80% of mean) and most rapid at the water surface. The velocity V in the pass is given in a dimensionless form for head to pass width ratios at various slopes in Figure 25, where $V^* = V/ (\sqrt{gL})$.

Strengths: Relatively simple to design and to construct, well understood and proven to be effective. They can accommodate a modest range in upstream head, and provide a reasonable attraction flow in many circumstances.

Weaknesses: Their major disadvantages are that they are very limiting in terms of the range of species which they can effectively pass, and that they can be costly to maintain in an operational condition because of the ease with which they can block with debris.

Fatou Denils

This type of fishpass has been used in France and is very efficient from a hydraulic point of view. It is effectively an alternative to a plane baffle pass, and in most respects the limits of application are similar. However, the baffles are difficult to construct because of their shape and the pass is very prone to blockage. In addition, because of its hydraulic efficiency the relatively low water velocity and discharge at the entrance limit its attractivity to fish. The characteristics of Fatou baffle passes are shown in Figure 23.

The relationships between head, discharge and velocity in a Fatou baffle pass for three gradients are shown in a dimensionless form in Figure 24. The actual relationships for the two most common widths at the most common gradient are shown in Figure 25.

Figure 23 Cross-section and plan view of a Fatou baffle fishway (After Larinier, 1992d)

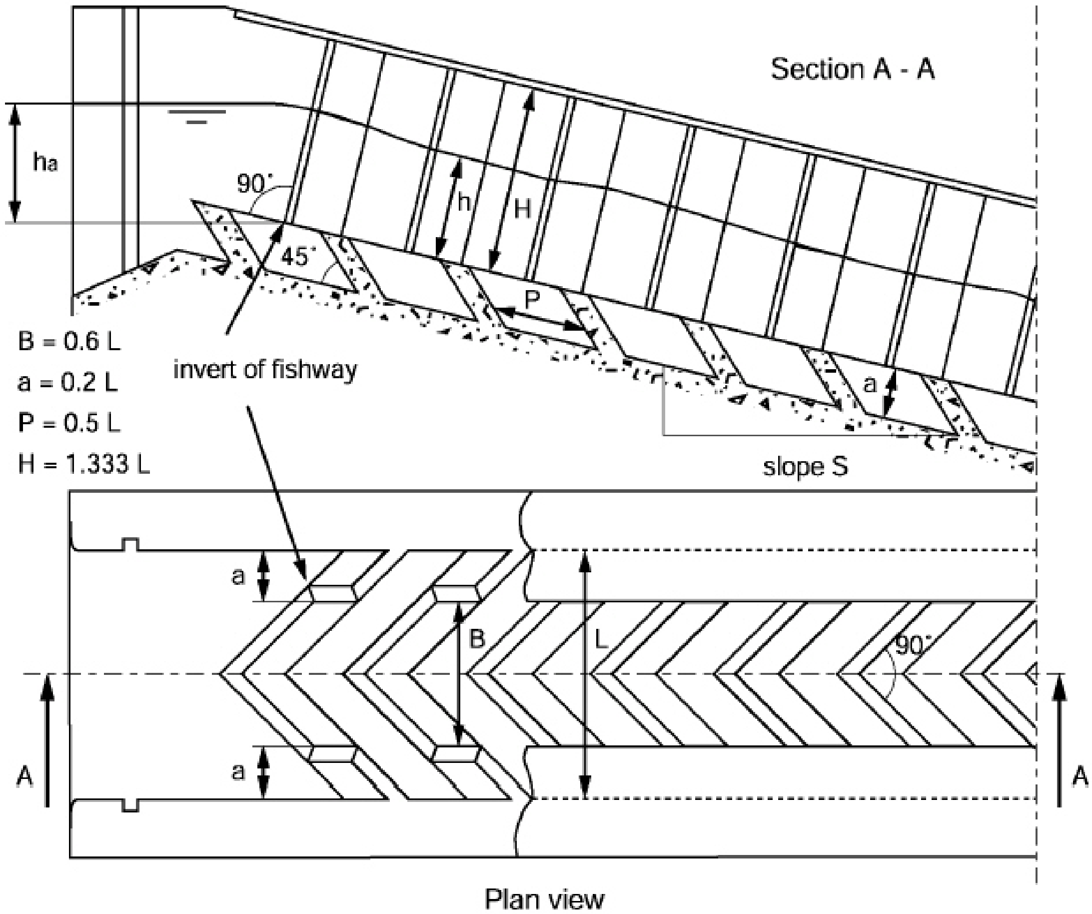


Figure 24 Adimensional relationship between upstream head (h_a), mean depth in pass (h), discharge (Q*), and velocity (V) in a Fatou baffle fishway at 10, 15 and 20% slopes (After Larinier, 1992d)

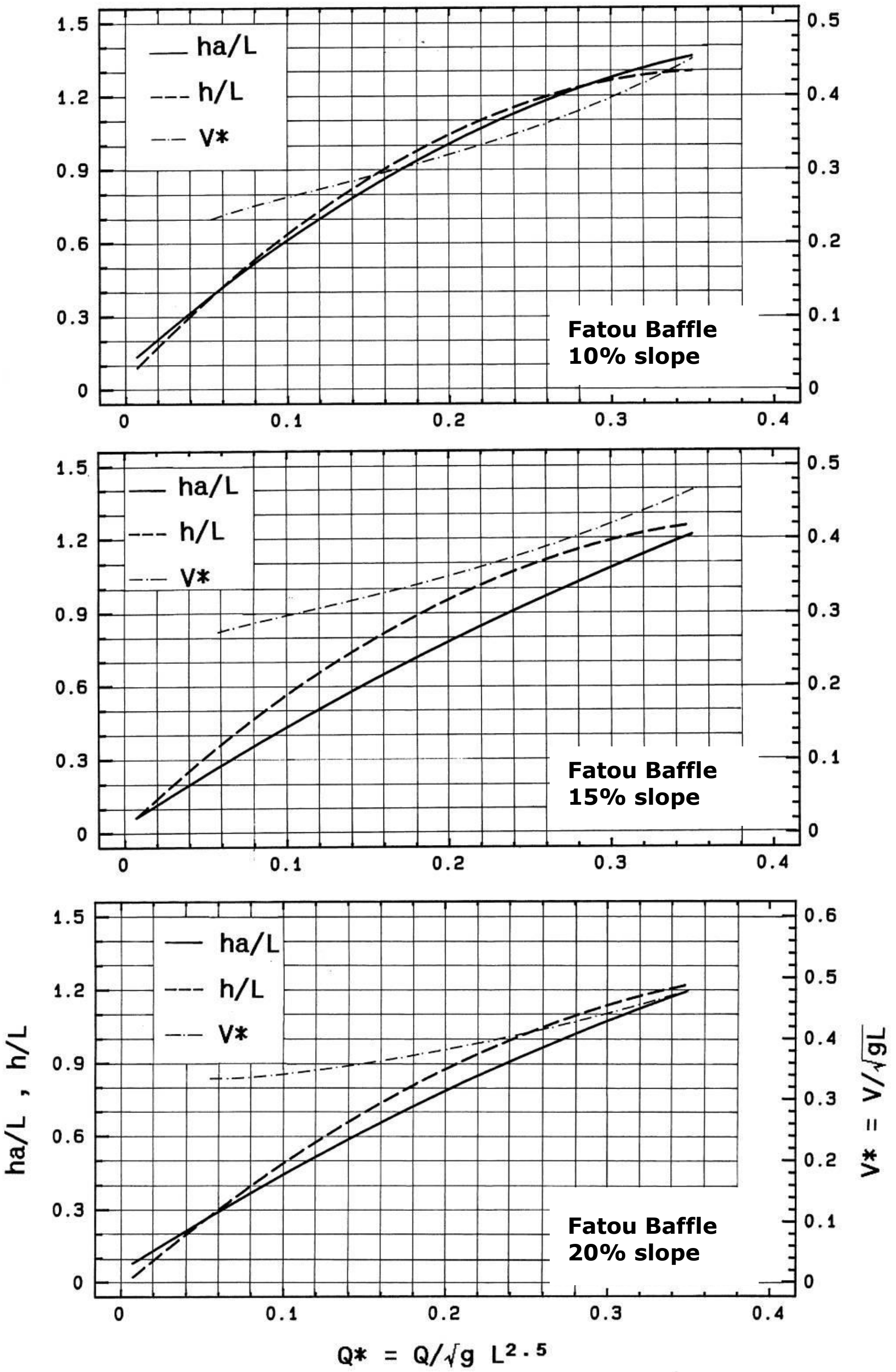
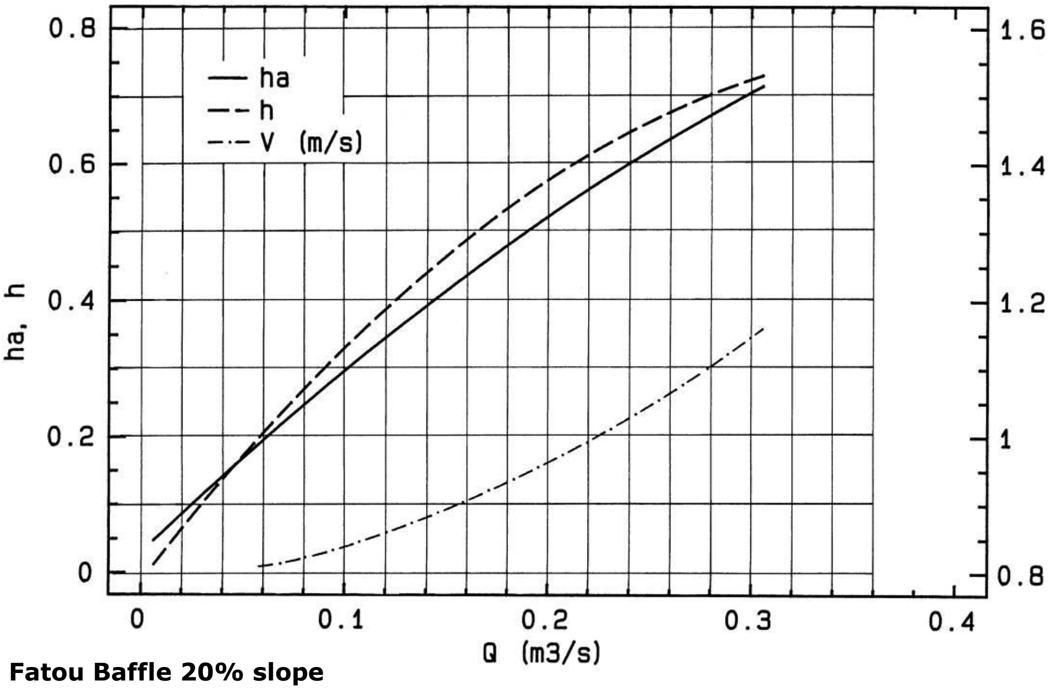
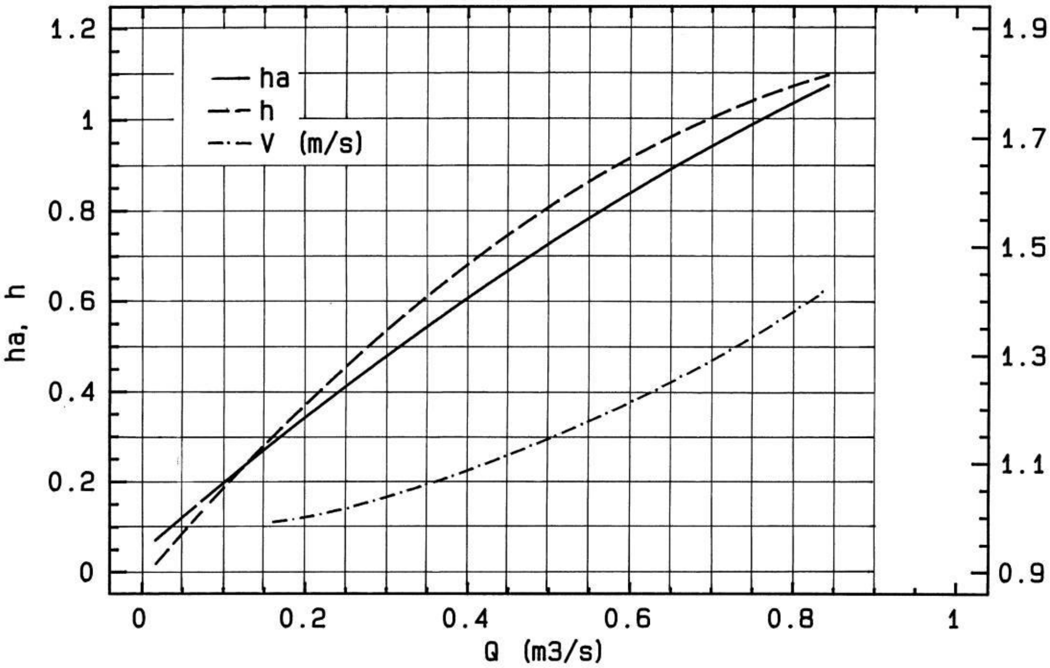


Figure 25 Relationship between between upstream head (h_a), mean depth in pass (h), discharge (Q), and velocity (V) in Fatou baffle fishways 0.6 & 0.9m wide at 20% slopes (After Larinier, 1992d)



Fatou Baffle 20% slope

L= 0.60m



Fatou Baffle 20% slope

L= 0.90m

Suitable species: Suitable for migratory salmonids, sea lamprey, trout and some larger coarse fish species. Probably less suitable for migratory salmonids and more suitable for coarse fish than a plane baffle Denil.

Length & Gradient: Maximum gradient 20%. The length of a flight should be limited to 12m for migratory salmonids, and 8m for other species.

Width: Usually 0.8-1.0m for large migratory fish (salmon and sea trout), and 0.5-0.7m for smaller migratory species (trout).

Depth: The lower operating limit is generally taken as h/L = 0.4 (where h = the depth in the pass from the bed). This depth is necessary for the pass to develop the helical currents and to provide sufficient space for fish to swim. The upper limit is not easily defined but a level of h/L of 1.0 is regarded as reasonable.

Discharge: Would normally vary between about $0.25m^3s^{-1}$ and $0.65m^3s^{-1}$ for large migratory salmonids in a 0.9m wide pass. For other species discharges of $0.1m^3s^{-1}$ to $0.24m^3s^{-1}$ in narrower passes would be more typical. The discharge Q in the pass is given in a dimensionless form for head to pass width ratios at various slopes in Figure 24, where $Q^* = Q/ (\sqrt{g}.L^{2.5})$.

Velocity: Mean velocities are generally constrained between $0.85\text{-}1.25ms^{-1}$ dependent upon dimensions, slope and discharge selected. The velocity V in the pass is given adimensionally for head to pass width ratios at various slopes in Figure 24, where $V^* = V/ (\sqrt{gL})$.

Strengths: Hydraulically efficient and can withstand a modest increase in upstream head.

Weaknesses: Very prone to blockage with debris, limited attractivity especially for migratory salmonids because of the low kinetic energy of the jet at the pass entrance.

Alaskan 'A' Denils

This type of fishpass with 3-dimensional baffles is a very specific type of pass originally developed for passing Pacific salmon in remote areas. Its box-like construction from 6mm aluminium made it strong and light for air-lifting, and thus facilitated fitting to remote natural barriers. Sections, usually 1-3m, long were prefabricated and then bolted together on site.

The channel has fixed dimensions in terms of width and baffles and is narrow (0.56m) with a small free passage width (0.35m). It is used in depths from 0.7 to 1.4m. Modular units in 1m lengths and heights of 0.7m, 1.0m and 1.4m are available commercially in the UK.

It is more effective hydraulically than a similarly sized plane baffle pass operating at a similar depth, passing less flow at a lower velocity. The baffles are closely spaced making the size of helical currents in the pass relatively small. The characteristics of the Alaskan `A` pass are shown in figures Figure 26 & Figure 27 .

Figure 26 Plan and cross-section, giving the geometric characteristics of an Alaskan `A` fishway (After Larinier, 1992d)

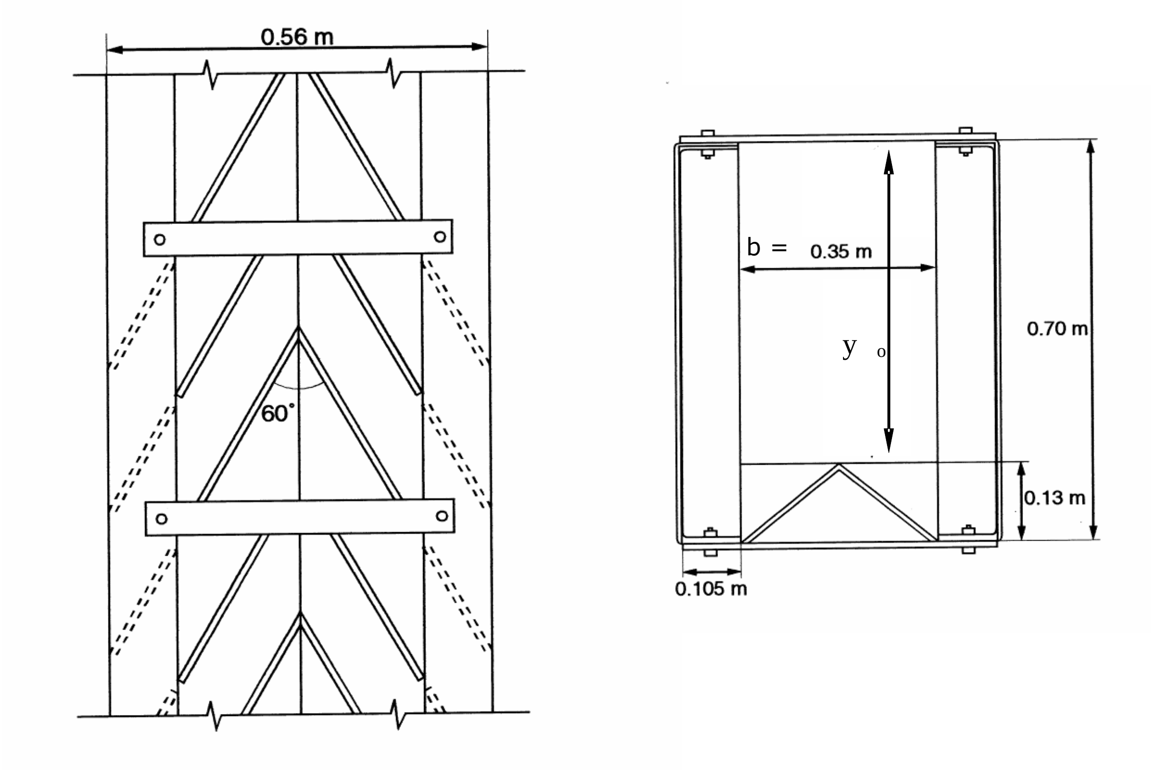
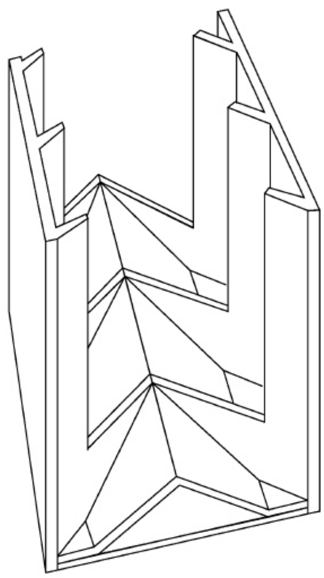


Figure 27 Isometric view of an Alaskan `A` fishway (After Larinier, 1992d)



Steepasses with lengths from 9.1m to 27.4m and slopes ranging from 19.7% to 26.2% have been used to successfully pass coho, pink, and sockeye salmon in Alaska, and the same species together with steelhead for length sup to 20.1m in the Columbia River, USA (Slatick & Basham, 1985). Model A Alaskan passes with lengths ranging from 9.1 – 20.1m, slopes 23.3 – 28.7% passed a range of non-salmonid species though some species were restricted by the challenge, so that for example carp could only manage lengths less than 15m lengths, while northern sqawfish, American shad, and suckers could not manage 20m. Adult Pacific salmon, Pacific Sea lamprey, and steelhead could manage 27m.

American shad (Alosa sapidissima) and White Sucker (Catostomous commersoni) could pass a Model A40 Alaskan Steeppass (upto 90cm deep, 45cm free gap) at a 12.5% slope with more than 50% efficiency provided it was a single straight run and around 12m long. However, if a turning pool was introduced (curve same width as channel turning through 180 degrees) the efficiency was more than halved. There were also indications of damage suffered by the fish, especially where fallback behaviour occurred (Haro, Castros-Santos, & Noreika, 2004).

Athough likely to be useable by coarse fish, particularly at slopes ≤ 20%, apart from a site at the Dog-and-Doublet, Anglian Region which is tidally influenced and passed by a range of species and sizes of coarse fish, there is little documented information on passage of coarse fish in Alaskan As.

Suitable species: They are very suitable for migratory salmonids and trout, probably suitable for sea lamprey, and for some larger coarse fish species. The relatively low velocities and small helical currents also makes these passes useful for larger coarse fish species, provided that gradients ≤20% are used.

Head difference: In exceptional circumstances single flights may be used to accommodate head differences up to 3.0m for migratory salmonids, and 1.6m for other species.

Length & Gradient: Gradients used for this type of pass can be steep (hence it is often called a steeppass), and slopes up to 33% have been used. However, it is not recommended to use a gradient steeper than 25% for migratory salmonids and 20% for other species. A single flight should not exceed 12m for salmonids and 8m for other species.

Width: The channel has fixed dimensions in terms of width and baffles, and is narrow (0.56m) with a small free passage width (0.35m).

Depth: The lower operating limit of depth y_o (Figure 23) for large migratory salmonids is generally taken as about $0.1m^{3-1}$ or 0.325m for a pass at a 25% slope. The upper limit is not easily defined but should certainly not exceed 1.27m.

Discharge: Can range between $0.1m^3s^{-1}$ and $0.81m^3s^{-1}$, most often being around 200-450ls^{-1}. Discharge $Q = 0.97.\ b^{0.95}.\ s^{0.5}.\ y_o^{1.55}.g^{0.5}$, or for a pass of standard width 0.35m (Figure 23) $Q = 0.3578.\ s^{0.5}.\ y_o^{1.55}.\ g^{0.5}$. Where s = the tangent of the angle between the slope and the horizontal.

Velocity: Mean velocities are usually between 1.1-1.4 ms^{-1} (for slopes between 20-33% and depending on depth). Velocity varies in the vertical plane, being highest at the bottom and slowest at the surface for depth values $y_o/b \leq 1.20$. For values greater than this the maximum velocity drifts away from the bottom towards the mid-depth line. Mean velocity $V = Q/b.\ y_o$

Strengths: Well-tried and tested and commercially available as pre-fabricated modular units. Accommodates a modest increase in upstream head, provides passage at relatively low flows, and at slightly lower velocities than other Denils. May be considered for head differences up to 3m without a rest pool, and for gradients up to 25%.

Weaknesses: The disadvantages of this type of pass are the likelihood of blocking, and the relatively limited discharge that reduces its attractivity because of the low kinetic energy of the jet at the pass entrance. In many watercourses augmentation of attraction flow would frequently have to be considered.

Bottom Baffle Fishways

Super-active baffle (Larinier) pass

This type of pass, developed by Larinier and Miralles in the early 1980's (Larinier & Miralles, 1981) is coming to be widely used in Europe and Britain. There is increasing evidence that this type of pass is suitable not only for large migratory salmonids such as salmon and sea trout, but also for an extensive range of other species including brown trout, grayling, and coarse fish. For example some sixteen different species, ranging from salmon to gudgeon, have been recorded using such a pass in the Thames catchment. This includes many small coarse fish 11-20cms in length, that must have been exploiting low velocity areas within the fishway. It is therefore quite clear that fish are very clever at exploiting the heterogeneity of micro-velocities in this type of fishway.

It is a relatively wide and shallow type of fish pass (by comparison with Denils), and only has baffles on the bed of the pass. Channel width is only limited by site conditions and not by hydraulic operating characteristics as is the case for other types of baffled fishpass. A significant advantage of this type of fishway is that major attraction flows can be created, by juxtaposing multiple `units` of pass in to a very wide channel.

Baffle height is variable between 0.08-0.20m with recommended heights between 0.075-0.10m for trout and coarse fish, and 0.10-0.20m for salmon and sea trout. The characteristics of Larinier passes are shown in plan & cross-section in Figure 28, and isometric view in Figure 29. The characteristic dimensions of the baffles and the baffle spacing are a function of the baffle height, so that the width of one baffle unit = 6.a and the space between baffles = 2.6.a, where a = the height of the baffle.

Baffles are generally fabricated from 10 – 12mm thick galvanised mild steel, sometimes stainless steel, with fully radiused top edges. Other materials have also been used, including for example, green oak baffles where the wood has been obtained from sustainable sources – though this has usually been at sites regarded as easements rather than where expensive permamnent technical solutions are being employed.

Figure 28 Geometric characteristics of a Super-active baffle (Larinier) fish way (After Larinier, 1992d)

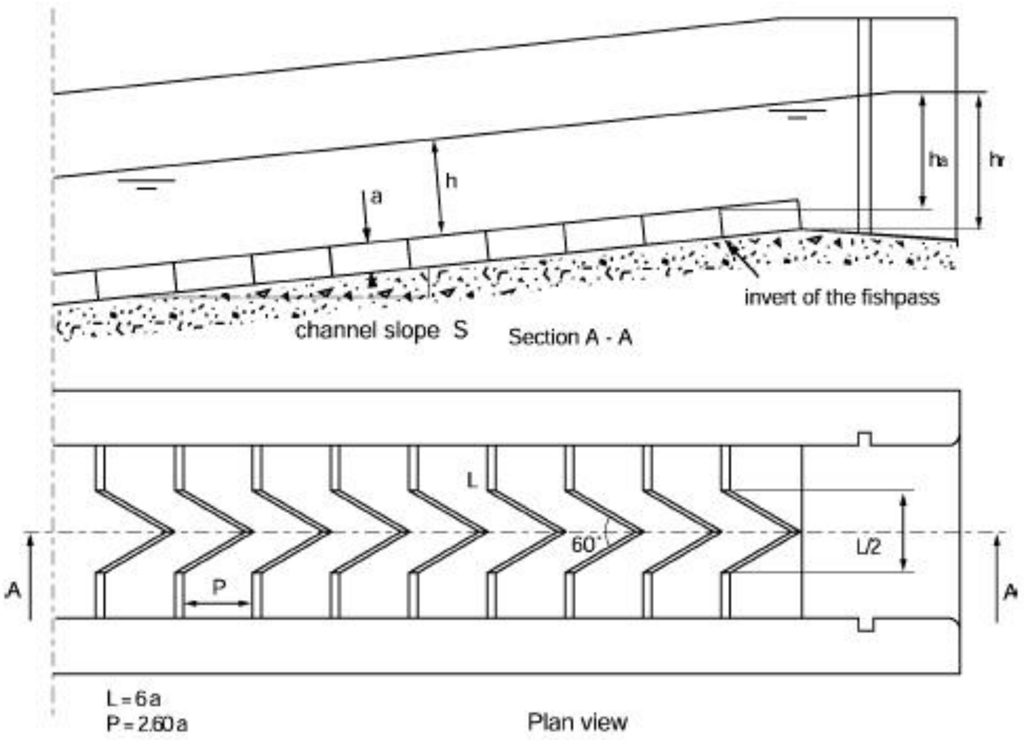
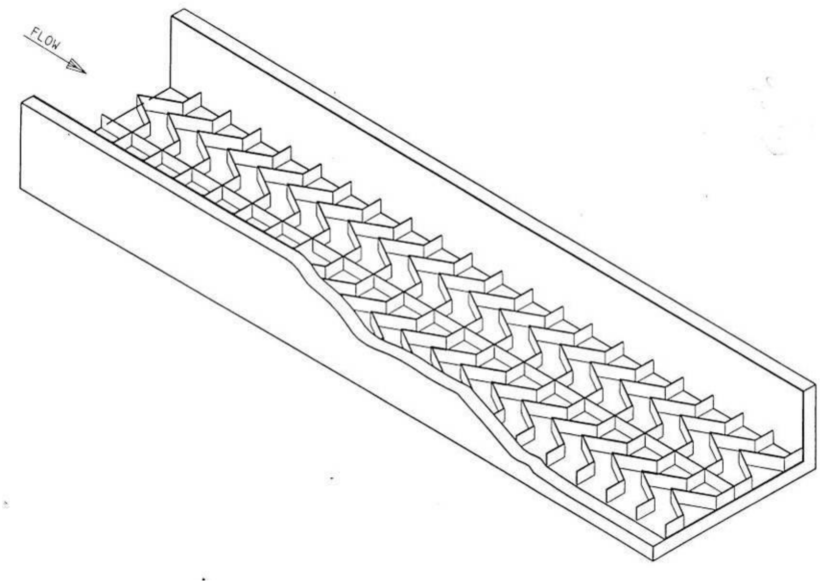


Figure 29 Isometric view of a Super-active baffle (Larinier) fishway



The invert of the pass is determined from the straight lateral piece of the most upstream baffle. The upstream head on the pass (h_a) is the difference between the pass invert and the water level upstream before any acceleration of the flow.

$$h_r = h_a + a - 2.6. a. s$$

where:

s = slope = the tangent of the angle between the slope and the horizontal.

The mean depth of water in the pass (h) is the depth above the baffles.

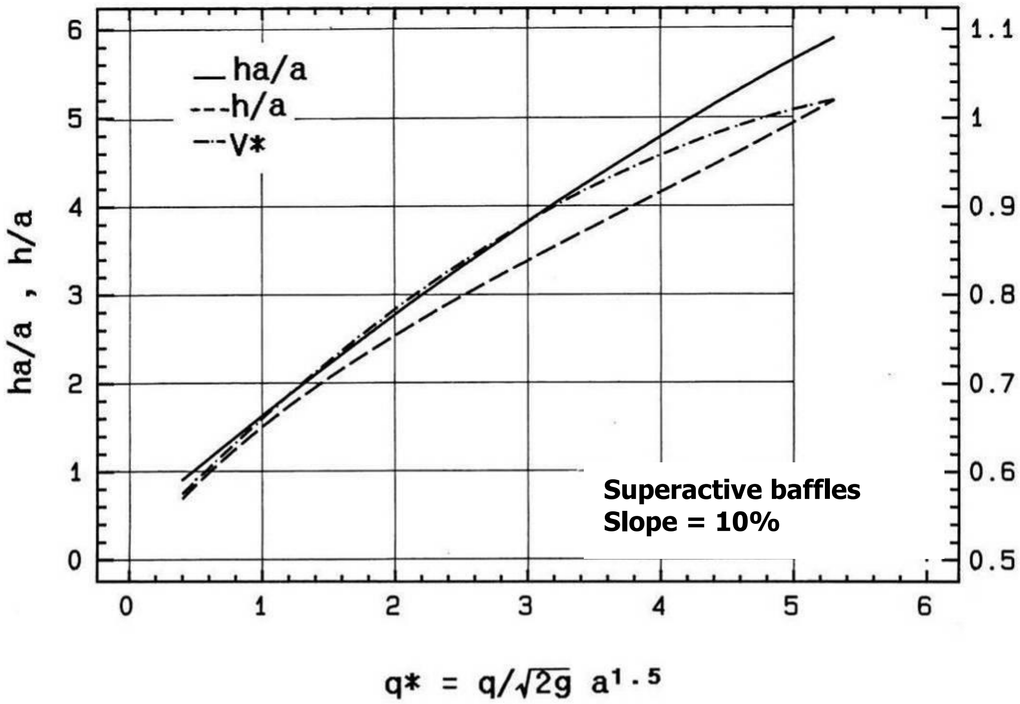
The relationships between head, discharge and velocity in a Super-active baffle pass for two gradients are shown in a dimensionless form in Figure 30. The actual relationships for the two most common baffle heights at the most common gradient are shown in Figure 31. Since the width of the fishway may vary considerably the latter figure gives discharge as a unitary measure ($m^3/s/m$), total discharge is obtained by multiplying by the actual width.

Lariniers may be adapted for joint use by canoes by modifying some of the construction details. The following adaptations were agreed with the British Canoe Union (BCU) and employed for a fish pass on Haverfordwest Town Weir, R. Western Cleddau, Wales (constructed in 2003):

- Pass to be a minimum of 1.4m wide
- Baffles to be 20mm thick and fully rounded profile on their tops (normally 10 -12mm fully rounded)
- Minimum depth Ha on the pass to be 300mm
- Tops of pass side-walls to be rounded
- Side-walls of pass at upstream to rake down into the (minimum) head water level at an angle of 45° or less
- Grab chains to be provided at the upstream end of the pass
- Preferably the pass to consist of an odd number of units juxtaposed, minimum three, so that the middle of the pass offers a higher velocity lead for the canoe.

This pass consisted of a single flight of Larinier. Where multiple flights are used and rest pools are required, particularly if they are used to turn the pass, consideration will need to be given to the length of the pool. Although not especially adapted for canoes, paddlers are known to enjoy using the large Larinier (3.6m wide with 6m rest pool used to turn the pass) on the River Dove in Midlands Region.

Figure 30 Dimensionless relationship between upstream head (h_a), mean depth in pass (h), unitary discharge (q*), and the average water velocity (V*) in a Super-active baffle fishway at 10% and 15% slopes (After Larinier 1992d)



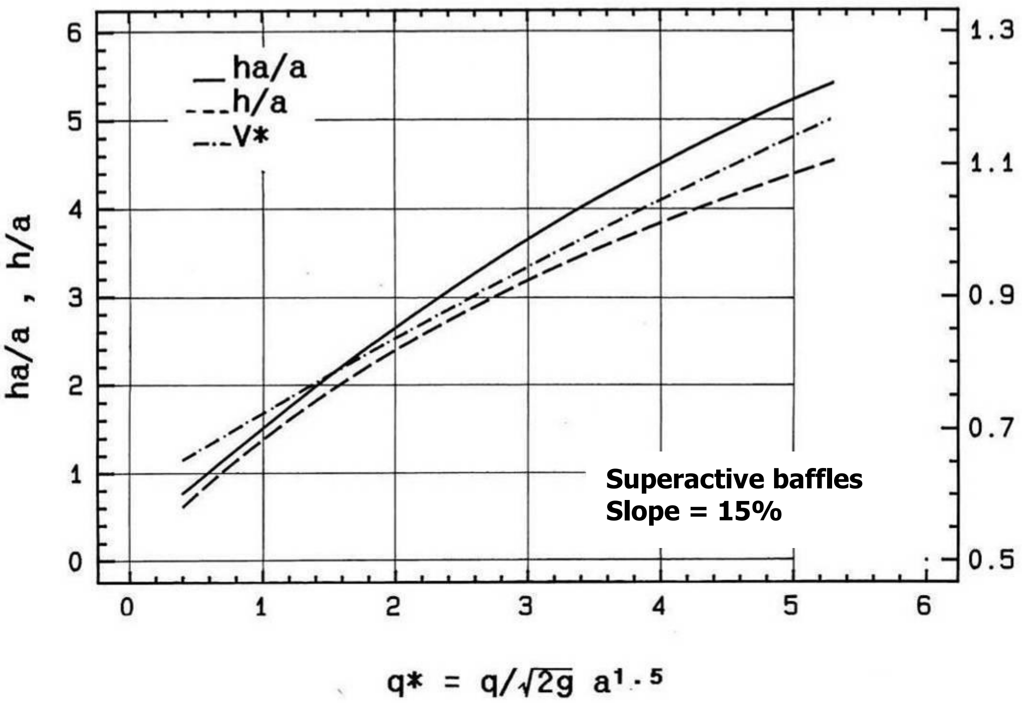
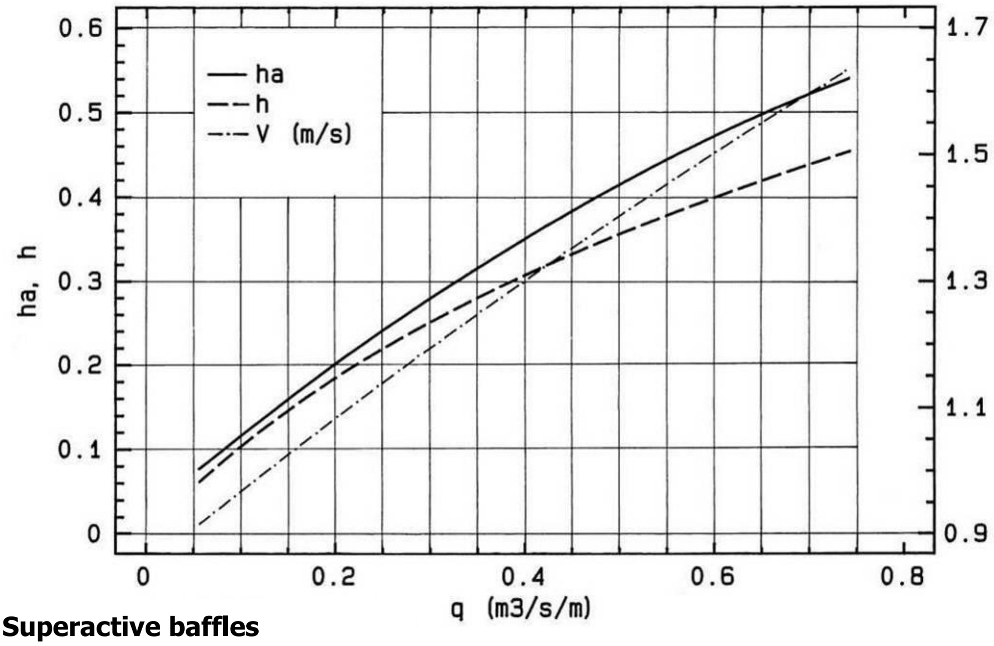
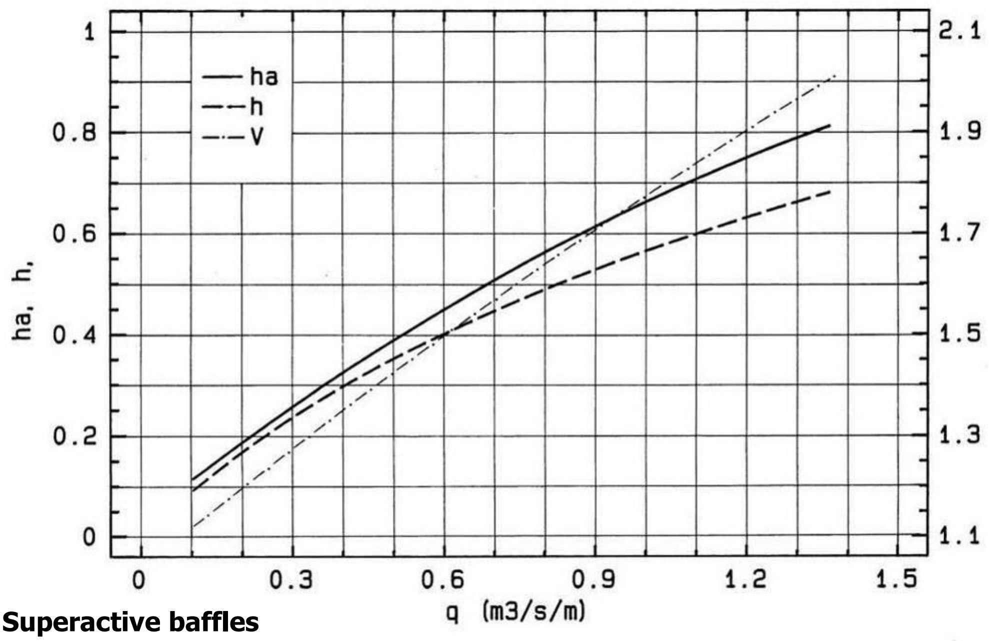


Figure 31 Relationship between upstream head (h_a), mean depth in pass (h), unitary discharge (q), and velocity (v) for 0.10m & 0.15m high super-active baffle fishways at 15% slope (After Larinier 1992d)



Superactive baffles
Slope = 15% a=0.10m



Superactive baffles
Slope = 15% a=0.15m

Suitable species: This type of pass is regarded as suitable for a wide range of species including salmon, sea trout, sea lamprey, trout, grayling, and coarse fish.

Head Difference: Single flights may be used to accommodate head differences up to a maximum of 1.5-1.8m for large migratory salmonids and a maximum of 1.2-1.5m for coarse fish species.

Length & Gradient: Maximum gradient 15%. Generally the gradient used is between 10% and 15%, although it can be less. The length of any one flight should be limited to 12m for migratory salmonids and 8-10m for other species.

Depth: The lower operating limit is generally taken as h/a = 1.15 (where h = mean depth over the baffles in the pass and a = the height of the baffle), which depth is necessary for the fishway to develop the necessary hydraulic characteristics. Minimum depths h in the pass for large migratory fish and trout/coarse fish to swim should be taken as 15-20cm and 10-15cm respectively. The upper limits of operation in terms of h_a (head on top baffle) are approximately 0.5m for trout and coarse fish (100mm or 150mm baffle) and 0.6m & 0.9m for large migratory salmonids (100mm & 150mm baffle respectively).

Width: The width of any one unit of pass is a function of the chosen baffle height (L = 6.a). Passes are not normally less than 0.6m wide (i.e. 100mm high baffle, single unit), but smaller ones might be considered where available flows and head ranges are very low.The most commonly used baffle heights are 100mm and 150mm, with pass widths typically 0.6-1.8m. Half widths of unit may be used, thus a fishway might be 1.5 or 2.5 units wide etc. The largest passes currently in the UK are 3.6m wide i.e. 6 juxtaposed units of 100mm baffles, or 4 juxtaposed units of 150mm baffles.

Discharge: It is recommended that operating range is taken as between 0.15-0.65$m^3s^{-1}m$ for trout and coarse fish and 0.25 - 1.50$m^3s^{-1}m$ for migratory salmonids (where $m^3s^{-1}m$ is cubic metres/second/metre width of pass). Significant discharges can be attained in the fishway by juxtaposing several units of pass together. The overall width of the fishway is limited only by; the flow available to be used, the physical limits of any structure that it is in, the increased difficulty of shutting a wide pass for maintenance, and the cost. If pass units are juxtaposed then a plate, the same height as the baffles, must be inserted between each one. The unitary discharge in the pass is given adimensionally for head to baffle height ratios at two different slopes in Figure 30, where $q^* = q/(\sqrt{2g}.a^{1.5})$. Total discharge Q = 6 a N q, where N = number of juxtaposed units, and q = unitary discharge per metre of pass.

Velocity: Mean velocities are generally constrained between 1.0-1.5ms^{-1} for coarse fish species and non-migratory trout and 1.3-2.0ms^{-1} for migratory salmonids dependent on dimensions, slope and discharge selected. The velocity in the pass is given adimesionally for head to baffle height ratios at two different slopes in Figure 30, where $V^* = aq^*/h$.

Strengths: Suitable for a relatively wide range of species and sizes of fish. Major advantages over other types of Denil are that they are much more unlikely to block (because they have only bottom baffles) and therefore less of a maintenance risk, and that major attraction flows can be provided by juxtaposing multiple units of baffles to create wide fishways. With suitable modifications to design details may be used by canoes.

Weaknesses: Their main disadvantage is the sensitivity to change in head level which means that they will not generally remain effective if head rises more than about 200-300mm above normal operating level in 100mm baffle passes, or 400 – 500mm above normal operting level in 150mm passes.

Chevron baffles

This type of pass has been used in France as a dual-purpose fish and canoe way (Larinier, 1984). Thick wooden baffles are used on the bottom of the pass in place of the thinner metal baffles used in a super-active fishway. This is in order to make the pass more 'boat-friendly'. Owing to the high velocities in this type of pass, which also increase rapidly as a function of depth, these type of fishways are only suitable for large salmonids, sea lamprey, and very large coarse fish such as barbel.

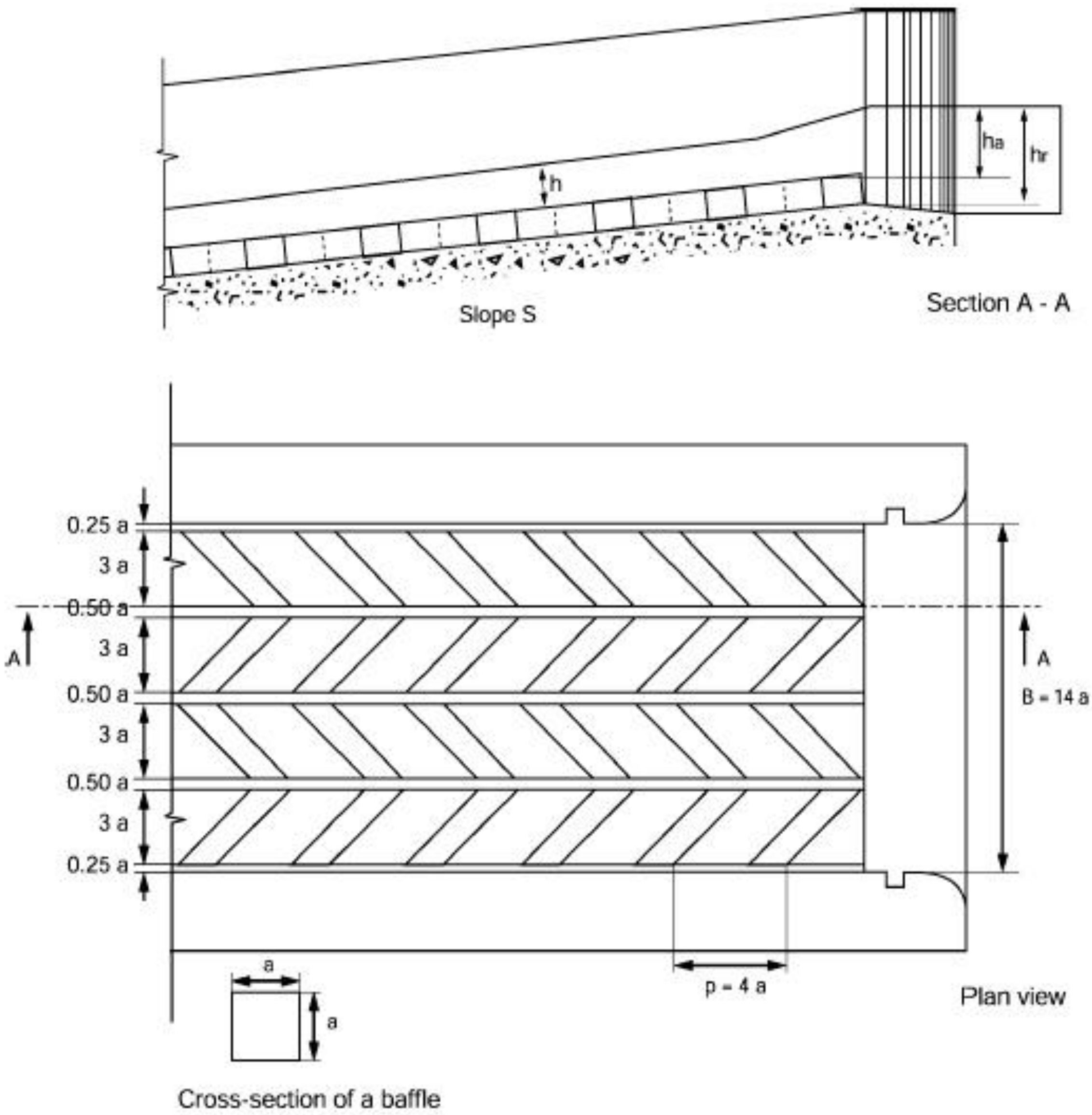
The baffles are arranged in 'arrow shaped' sections that are juxtaposed across the bottom of the fishway. They are generally constructed of 10-12cm (minimum 8cm, maximum 15cm) square section timber. Longitudinal strips between each chevron are used to help stabilise the flow and increase the `boat-friendliness` of the facility. Where the facility is only to be used by fish it is possible to exclude all the longitudinal strips except for the central one along the axis of the pass, which is required to stabilise the flow pattern.

For boat passage the arrangement of the chevrons is revised so that the centre of the passage facility corresponds to the upstream point of the V. This facilitates boat passage by ‘guiding’ them in to the centre of the fishway.

Like the Larinier Super-active type of pass, many units can be juxtaposed to increase total fishway discharge. If boats are to use the pass then it must have a minimum width of 1.4-2.1m.

The characteristics of Chevron baffle fishway are shown in plan & cross-section in Figure 32.

Figure 32 Geometric characteristics of a Chevron baffle fishway (After Larinier 1992d)



The invert of the pass is determined from downstream side of the uppermost point of the first baffle. The upstream head on the pass (ha) is the difference between the pass invert and the water level upstream before any acceleration of the flow.

$$h_r = h_a + a - 3a\ s$$

where:

s = slope

The mean depth of water in the pass (h) is the depth above the baffles.

The relationships between head, discharge and velocity in a Chevron baffle pass for two gradients are shown in a dimensionless form in Figure 33. The actual relationships for at baffle height of 0.1m, at the most common gradient of 15%, is shown in Figure 34. Since the width of the fishway may vary considerably the latter figures provide discharge as a unitary measure ($m^3s^{-1}m^{-1}$), total discharge is obtained by multiplying by the actual width.

Figure 33 Dimensionless relationship between upstream head (h_a), mean depth in pass (h), unitary discharge (q*), and velocity (V*) in a Chevron baffle fishway at 10% and 15% slopes (After Larinier, 1992d)

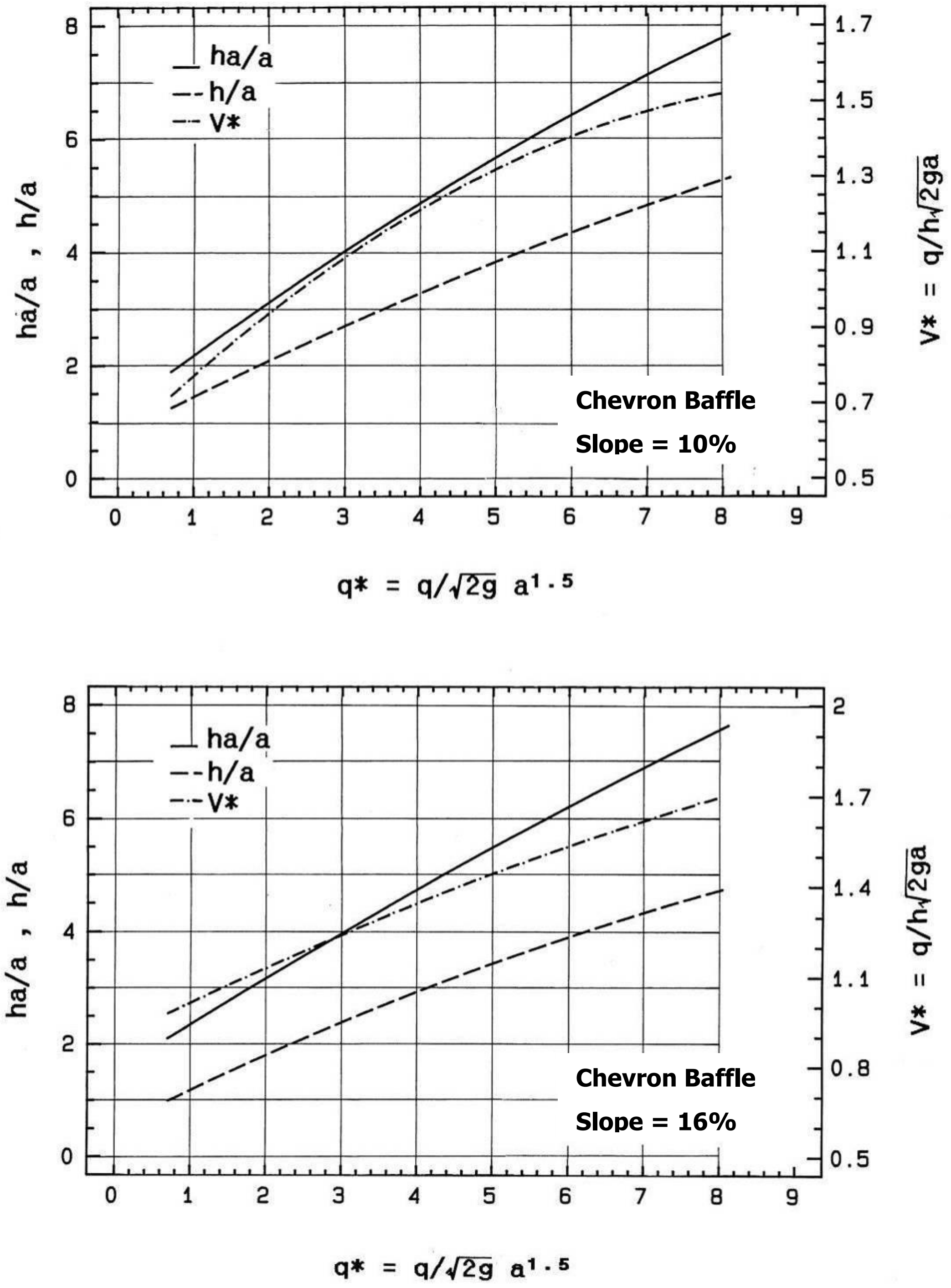
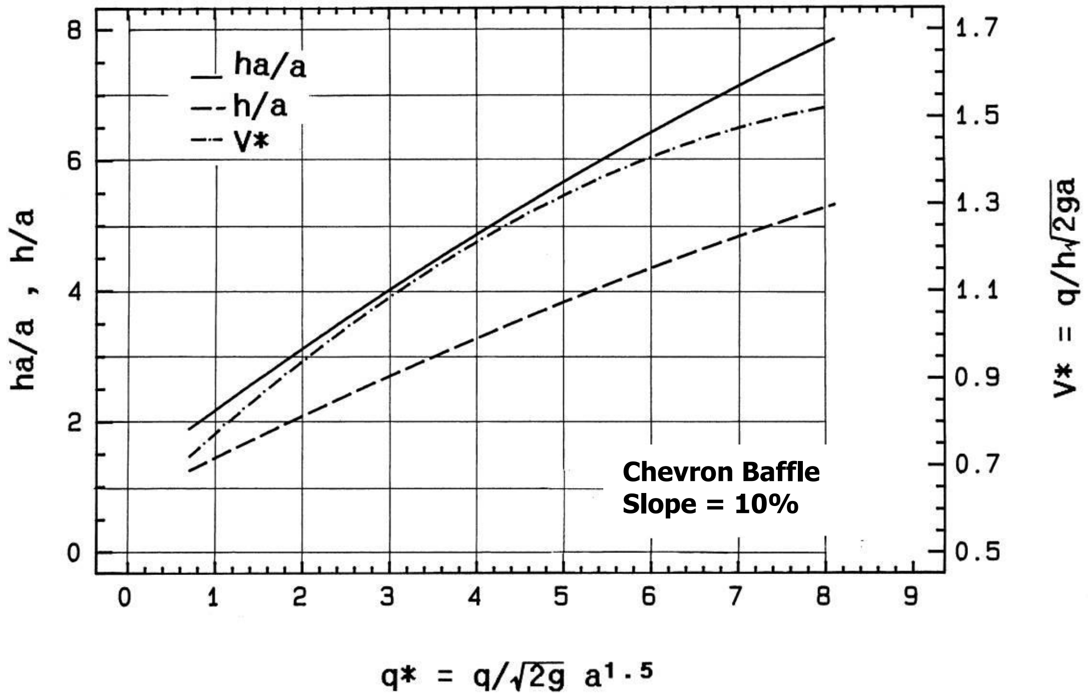
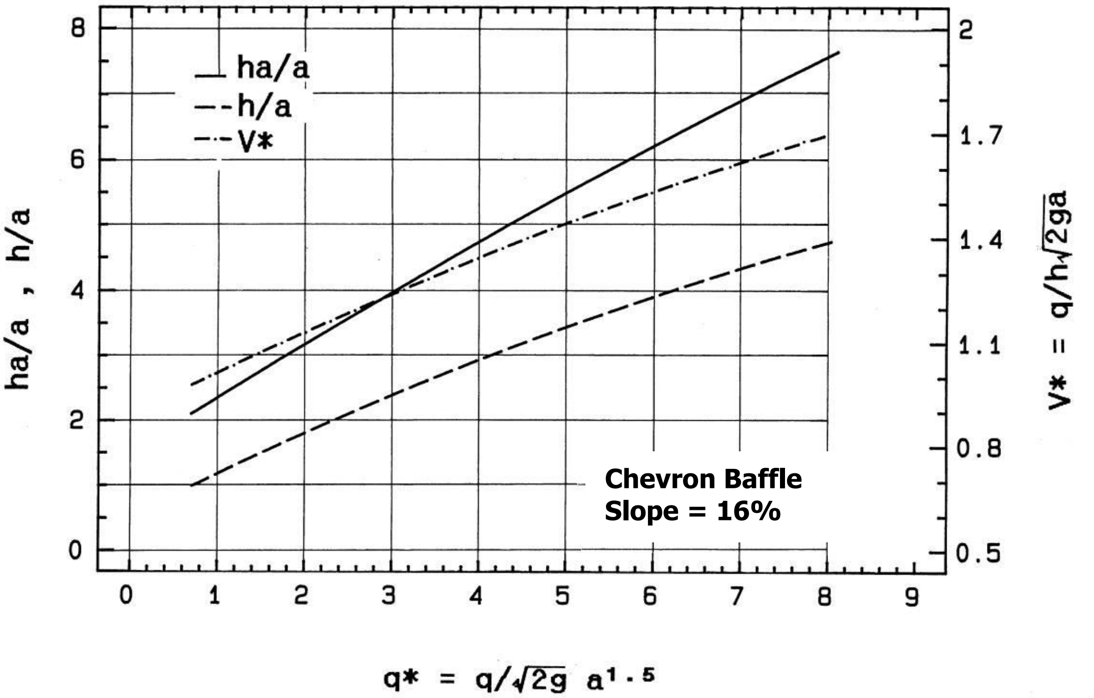


Figure 34 Relationship between upstream head (h_a), mean depth in pass (h), unitary discharge (q*), and velocity (V*) for a 0.10m high chevron baffle fishway at a 15% slope (After Larinier, 1992d)





Suitable species: This type of pass is generally only suitable for large salmonids >40cms in length. May accommodate sea lamprey and very large coarse fish.

Head Difference: Single flights may be used to accommodate head differences up to a maximum of 1.5-1.8m.

Length & Gradient: Maximum gradient 15%. Generally the gradient used is between 10% and 15%, although it can be less. The length of any one flight should be limited to 12m.

Depth: The minimum operating depth for large migratory fish should be taken as 30cms. The upper limit of operation in terms of h_a (head on top baffle) is approximately 0.65m.

Width: The width of the pass is a function of the chosen baffle height. Passes would normally be a minimum of 1.4m wide (i.e. minimum of 100mm high baffle),but may be substantially wider.

Discharge: The unitary operating range is between 0.25 – 0.90m^3s^{-1}m for migratory salmonids. Significant discharges can be attained in the fishway by juxtaposing several units of pass together. The overall width of the fishway is limited only by; the flow available to be used, the physical limits of any structure that it is in, the increased difficulty of shutting a wide pass for maintenance, and the cost. The unitary discharge in the pass is given adimensionally for head to baffle height ratios at two different slopes in Figure 33, where $q^* = q/ (\sqrt{2g}.a^{1.5})$. Total discharge is given by multiplying the width by the unitary value.

Velocity: Mean velocities are generally constrained between 1.5-2.2ms^{-1} for large migratory salmonids, dependent on dimensions, slope and discharge selected. The velocity in the pass is given adimesionally for head to baffle height ratios at two different slopes in Figure 33, where $V^* = aq^*/h$.

Strengths: Capable of dual use as fish pass and canoe/kayak pass. Unlikely to block and therefore low maintenance risk. Significant attraction flows can be provided, by juxtaposing multiple units of baffles.

Weaknesses: Significant disadvantages of only being suitable for large migratory salmonids (>40cm length) or very large individuals of some of the very fastest swimming riverine species, and only operating effectively over a very limited range in head.

Side Baffle Fishways

Side-baffle only fishways have had very limited use and little is known about their performance or characteristics. It is unlikely that they would be suitable for any species other than large migratory salmonids. While many configurations of baffle may be possible from simple bands (Anon, 1942) to complex shapes (Larinier & Miralles, 1981), it is only the latter that would be considered for use in modern times. These are described below.

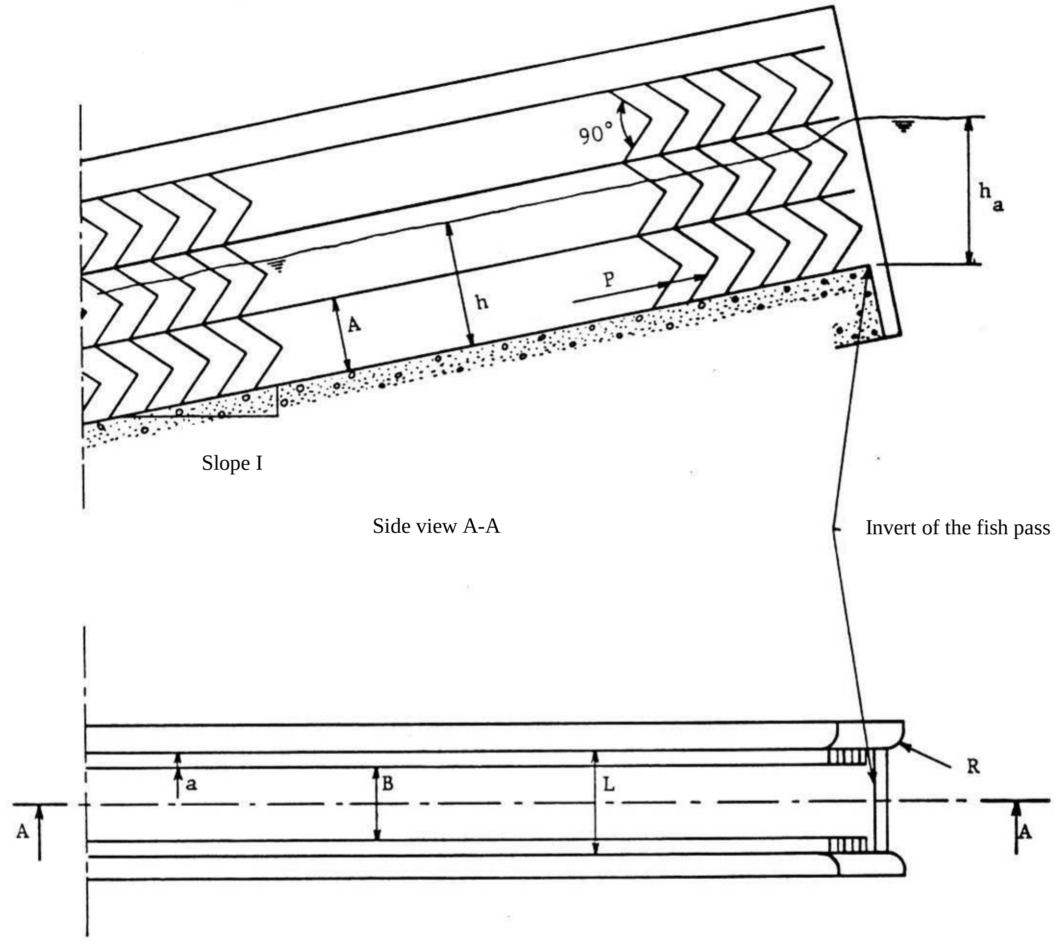
Chevron Side Baffles

A relatively simple design, consisting of rows of chevron shaped baffles on the sides of a relatively narrow channel, was described and tested hydraulically by Larinier & Miralles (1981). Average water velocities are relatively high (>$2ms^{-1}$) in this type of pass, and they are therefore unsuitable for species other than large migratory salmonids. However, the velocity in the water column remains fairly constant, at least up to a depth equivalent to twice the width of the pass, and this hydraulic behaviour may be advantageous at sites where a large range in upstream water level is expected during the period of fish pass operation.

Passes of this type has been used at Radyr Weir on the River Taff in Cardiff and Stoke Lock on the River Itchen. Although velocities range from about $2ms^{-1}$ (low discharge) to as high as $3ms^{-1}$ (design discharge), the passes appear to work well for salmon and sea trout (P. Gough, A. Fewings pers comm).

The characteristics of Chevron Side-Baffle fishway are shown in plan & cross-section in Figure 35.

Figure 35 Geometric characteristics of a Chevron Side Baffle fishway (After Larinier & Miralles, 1981)



Plan view

A = 5 a

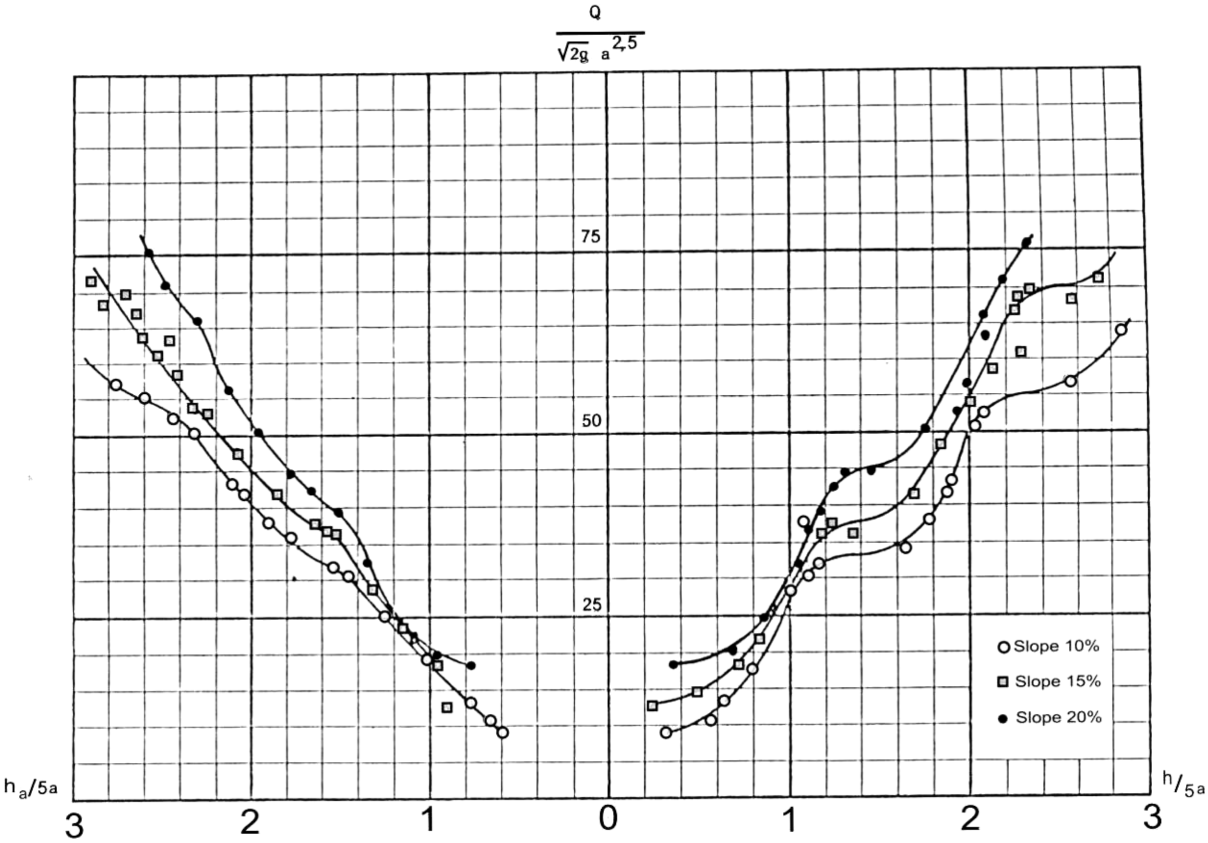
B = 5 a

L = 7 a

P = 2,50 a

R = 1,50 a

Figure 36 Dimensionless relationship between upstream head (h_a), mean depth in pass (h), and discharge (q) in a Chevron side baffle fishway at 10%, 15% and 20% slopes (After Larinier & Miralles, 1981)



Suitable species: Large migratory salmonids.

Head Difference: Up to a maximum of 1.8-2.4m.

Length & Gradient: Not more than 12m in length at gradients not exceeding 20%.

Width: Not well known but it is suggested that they might vary between say 0.08-0.2m, thus widths would probably be within the range 0.56-1.40m.

Depth: The minimum depth for charging of the pass to develop the typical hydraulic condition is equivalent to the height of one chevron, i.e. $h/5a > 1$. Maximum operational depth is unknown, but probably up to more than twice the width of the pass (L).

Discharge: Fairly substantial discharges can be accommodated. Discharges might range form a minimum of $0.5m^3s^{-1}$ to $>5m^3s^{-1}$. The discharge Q in the pass is given adimensionally for head to baffle width ratios at various slopes in Figure 36, where $Q^* = Q/ (\sqrt{2g}.a^{2.5})$.

Velocity: Mean velocities are relatively high, typically in the range of 1.7- $2.5ms^{-1}$.

Strengths: Potential strengths include an attractive flow (substantial discharge at high velocity), ability to cope with both large fluctuations in head level and significant bed load movements.

Weaknesses: Relatively high velocities suitable only for large migratory salmonids, relatively high risk of blockage by woody debris.

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Brush-furnished Fishway & Canoe-Fishway

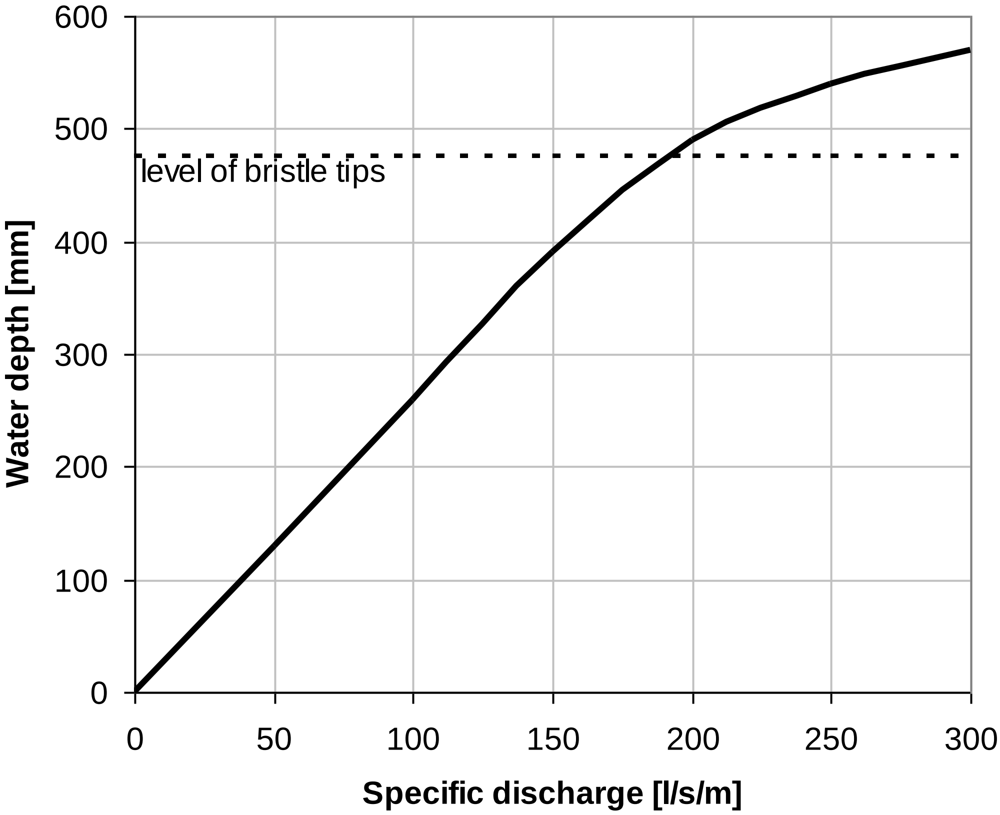
In the last eight years a new type of sloping fishway has enjoyed increasing use in Germany, Switzerland, & Austria, and more recently in England. Developed by Hassinger in Germany around 2002, more than thirty five examples are in use in Continental Europe and two have recently been constructed in Southern England at sites on the River Medway. This brush-furnished fishway can be designed for use either exclusively for fish (about half of the examples in Europe) or jointly for boats including canoes and kayaks, and fish.

Large numbers of thin and pliable roughness elements are used to dissipate energy while also being suitable to facilitate the passage of boats. The pass consists a shallow sloping channel in to which bristle brushes are fixed. Maximum slope is 8% (1:12.5), and while there is no specific minimum width about 0.6m is recommended for ecological purposes, and a minimum 0.5m wider than the largest boat expected where it is a dual-purpose facility.

Brushes consist of bundles of five or six individual polyethylene bristles, up to 600mm long and about 5mm thick, welded together and fixed in blocks to a plate that can in turn be fixed readily in various ways to the channel bed. The brushes are spread evenly over the channel with gaps of 20 – 40cms between them depending on the species and sizes of fish to be accommodated. The channel bed can be natural or artificial, but the us of natural river substrates such as stone, cobble, and gravel is recommended in order to increase roughness and habitat heterogeneity even further. In this way the channels can accommodate passage of fish, other vertebrates, and invertebrates, while also harbouring invertebrate and fish populations as well.

The mean velocity is constant for different depths of water column up to the level of the tips of the bristles, after which velocities will increase with increasing drowning. Mean velocity among the bristles is very low, and a function of the density of the bristles and slope of the channel, while that in the gap between brushes follows the conventional equation where $V_{max} = 2gDH^{0.5}$. Given that the slope is low and the head drop between series of brushes only typically about 4 – 5cms, maximum velocity is usually ≤1.0ms^{-1}, while mean velocity across the fishway as a whole is about 0.5ms^{-1}.

Figure 37 Head discharge relationship for a fishway with 47cm long bristles (after Hassinger & Kraetz, 2006)



(bristle length 470mm, bristle density 1110 m^{-2}, dimeter 4-6mm overall, slope 1:25)

Clearly, total discharge is related to the size of the structure constructed but will be lower than a conventional pass in terms of the equivalent cross-section. Using 0.5ms^{-1} average water velocity discharge can easily be approximated e.g. a 0.5m deep x 1.2m wide pass will discharge 0.30m^{3}s^{-1}, whereas a 0.3m deep x 0.6m wide pass will discharge 0.09m^{3}s^{-1}.

While probably unnecessary biologically, resting pools can effectively be created if desired by having zero gradient (flat) sections of channel.

For use by canoes minimum water depths should exceed 40 – 50 cms, and there should be a minimum 1.2m of clear head space above the water level if a pass is enclosed[2]. It is also advantageous to ensure that the gaps between brushes are concentrated towards the centre of the channel, and maybe to use more flexible bristles here as well. When used as a combined fish and canoe pass canoes can pass in both directions. The low water velocities mean that such facilities are mainly for conveyance of canoes rather than as a canoe “play” feature.

Maintenance of these facilities is not a great issue due to the flexible nature of the bristles and because light organic material such as leaf detritus etc are consumed over time by the macro-organisms inhabiting the bristles. Non-organic debris and large organic debris may be a problem and require regular cleaning, especially in urban areas.

Life-time of the bristles is expected to be around 10 – 20 years. Since there are presently relatively few suppliers of these specific brushes the cost and lead time of supply should be considered in new designs.

Suitable species: This type of pass is regarded as suitable for a wide range of species & sizes including salmonids, lampreys, eels, and coarse fish. However, it may have limitations in terms of attracting migratory salmonids because of the low velocities at the entrance.

Head difference: No limit to the head drop that can be accommodated, likely to be limited by the space available.

Length & Gradient: No limit to minimum gradient, maximum gradient 8%, 1:12.5 slope. No limit to flight length.

Depth: Lower limit taken as 0.10m (coarse fish, small trout, eel etc) to 0.30m (large migratory salmonids) depending on fish size to be accommodated. Minimum depth 40 – 50cms for boats. Upper limit unknown and probably dependent on other factors once above bristle tips.

Width: Any maximum width possible, minimum usually 0.6m.

Discharge: Discharge taken as about half the cross-sectional area of the water column i.e. $1m^2 = 0.5m^3s^{-1}$, $0.5m^2 = 0.25m^3s^{-1}$.

Velocity: Maximum velocity generally constrained to $\leq 1ms^{-1}$ between brushes, much lower within bristle brushes.

Strengths: Suitable for a wide range of species & sizes of fish, conjunctive use with boats, passage for vertebrates & invertebrates, provides habitat for fish & invertebrates.

Weaknesses: Limited attraction discharge and velocity provides poor attraction properties for migratory salmonids, thus may be inefficient for these species.

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[2] CDM and confined space legislation should be consulted on such matters

Active Fish Elevators

Fish Locks

A fish lock operates on the same principle as a navigation lock in order to secure the passage of fish over an obstruction. Fish locks in use are almost invariably of the Borland lift variety, which was first tried out in Ireland and Scotland in the 1940's and 1950's. Borland lifts are now installed at several hydropower dams in Scotland and at a smaller number of sites in Wales. They usually consist of a sloping or vertical cylinder constructed as an integral part of the dam structure (or in a few instances as a later addition to the structure), which connects two pools, one located at the upstream level and one at the downstream level. The pools are each provided with a sluice gate that controls the operation of the structure. Fish are encouraged to accumulate in the lower pool before they are trapped and lifted to the higher level by filling the connecting conduit. Most Borland lifts have been installed in dams of 6m to 18m in height, although some examples are on dams of up to 42m high (Aitken et al, 1966), or as little as 4-5m high (Travade & Larinier, 1992). There are four distinct operational stages:-

- **an attraction stage** in which the upper and lower control gates are both open and water flows through the lock structure to attract fish into a holding chamber. The conditions for fish attraction are those used conventionally for pool passes.

- **a filling stage** in which the fish entrance gate is closed and the incoming water, either directly from the headwater gate or indirectly into the lower part of the chamber via a valve, causes the water level within the lock to raise and equilibrate with the upstream level. Fish are required to rise up through the body of the lock chamber in this stage

- **a fish exit stage** during which the lower gate is partially opened and the upper water inlet gate is manipulated to provide an attractive flow of water to entice fish to leave the lock. The fish then have the opportunity to leave the lock chamber and enter the upstream water body.

- **an emptying stage** during which the upstream gate is raised above the upstream forebay water level, allowing the lock to empty slowly.

The characteristics of a typical fish lock and its operational cycle are shown in Figure 38 & Figure 39.

Figure 38 The plan and cross-section of a typical fish lock (after Aitken et al, 1996)

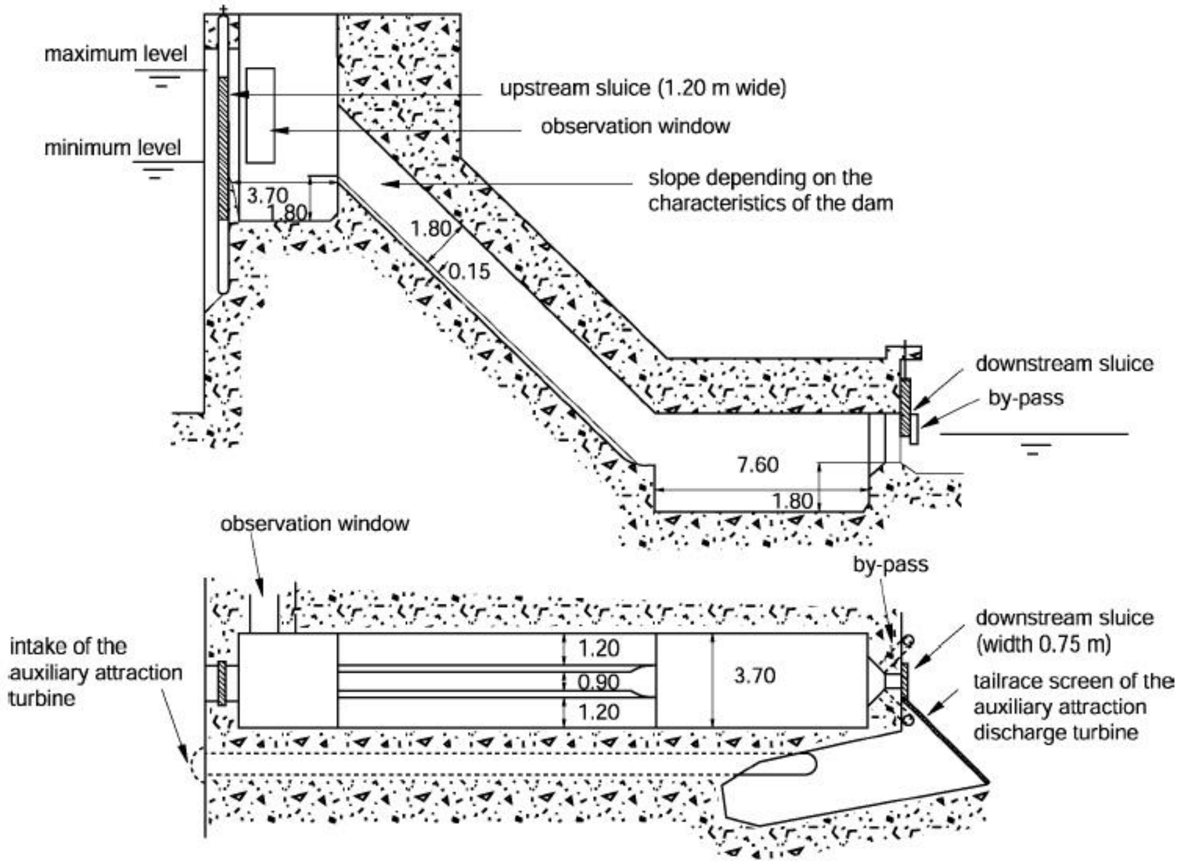
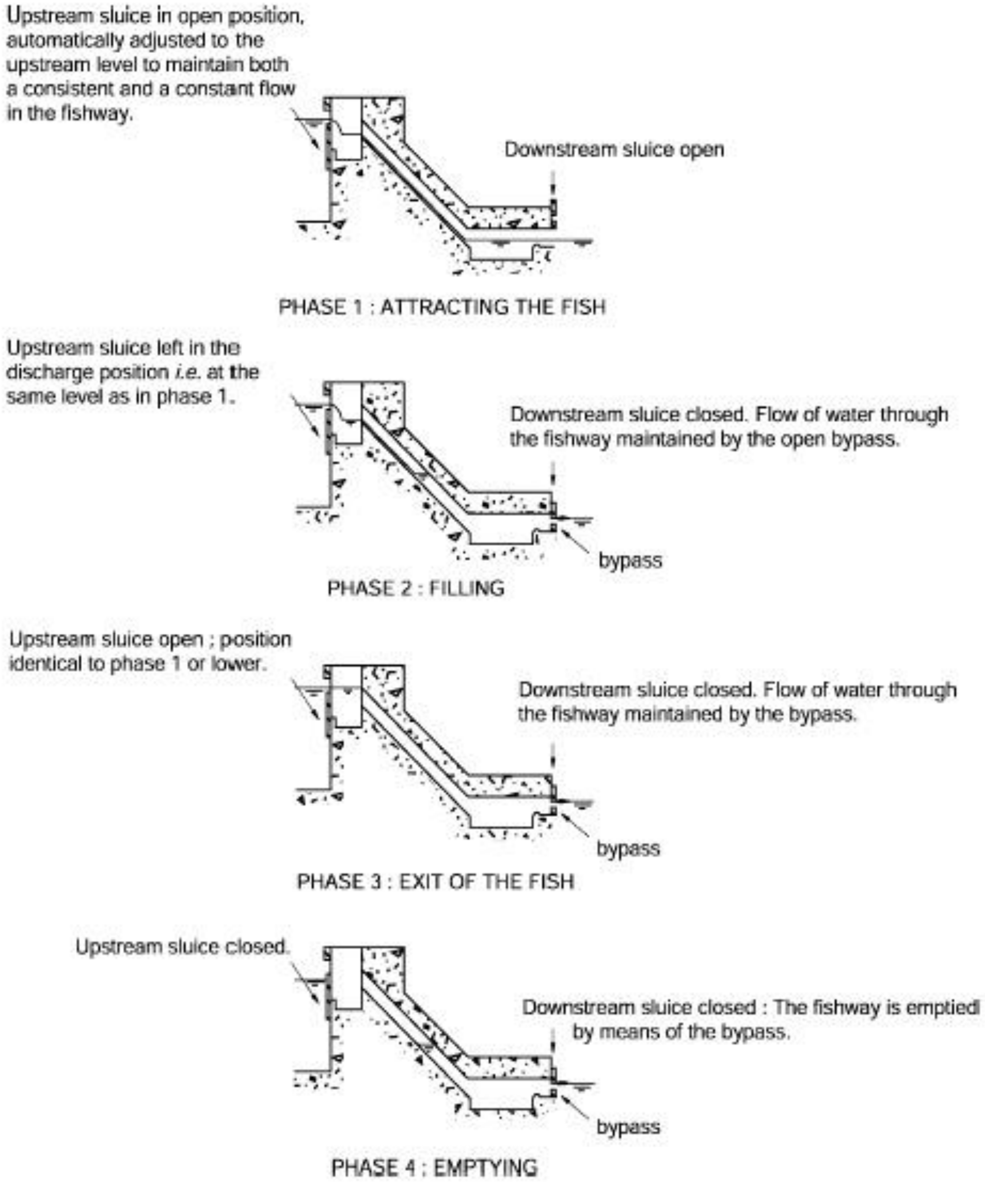


Figure 39 The operating cycle of a fish lock (after Travade & Larinier, 1992a)



The timing of the operating cycle should be adapted to enable it to correlate closely with the number and species of fish wishing to ascend, and the timing and pattern of their migration. Typically this may involve fishing stages of about two hours, followed by appropriate length of time filling and a fish exit stages of about one to two hours. Operating practice has also indicated that the hydraulic conditions during the fish exit stage are crucial to passage effectiveness, and that fish must be encouraged to leave the chamber by carefully manipulating flows and relative water levels. A head difference of up to 15 inches has been quoted as optimum (Aitken et al, 1966). There can be a tendency in practice for the number of cycles to be reduced, for example to as few as two automatic cycles per day. However it should be noted that failure to optimise the timing of the cycle is frequently the cause of reduced operating efficiency.

Monitoring of the effectiveness of fish locks has been carried out at one of the Borland Lifts in the Beauly and the Conon system, Scotland (Forbes et al, 1996, 1999, 2000 & 2002; Gowans et al, 2003 respectively) . In the Beauly, the behaviour of 10 radio tagged salmon was examined immediately below a functioning Borland lift. Fish were found to make series of brief visits to the vicinity of the pass, sometimes entering the holding chamber. However only 5.3% of such visits into the chamber resulted in fish ascending the lift during the fill cycle. Of these, 80% successfully left the pass and entered the headwater. The later studies were carried out with the objective of recommending improved operating practices (Johnstone, pers.comm.). Adjusting attraction flow upwards, provided it was not too high, increased numbers of fish entering the lower chamber. Efforts to increase passage by making the upstream exit more visible to fish, and increasing the number of lift cycles form three to four a day made no significant difference to performance. On the Conon fish passage efficiency in the Borland Locks was very modest at around 63%, and fish were delayed by up to 52 days.

The difficulty of encouraging fish to exit the chamber after the filling stage, noted by Larinier (1990), is one reason why locks are now rarely considered for use in France. Larinier & Travade (1992) have demonstrated other problems associated with the difficulty of establishing optimum hydraulic conditions and in maximising the efficiency of passage for fish which do enter the holding chamber. These include lack of attraction and the need for augmentation flow, excessive turbulence in the downstream pool, poor lighting conditions, insufficient residence time in the lower pool, and the possibility of fish being washed away from the vicinity of the entrance to the pass during the emptying stage. Furthermore it is evident that no fish can enter the structure during the filling and fish exit stages - this is the main reason why two parallel locks were proposed for the Usk barrage.

Strengths: Overall, fish locks clearly offer a partial solution to fish passage issues related to high head dams, where more conventional pool passes are not feasible.

Weaknesses: Disadvantages include: modest efficiency, the relatively high capital cost, their sensitivity to head water level variation, the difficulty of establishing optimum operating protocols, and the discontinuous nature of their operation.

Fish Lifts

A fish lift operates on the principal of a conventional elevator. There are three distinct operational stages:-

- **an attraction stage** in which water flows through a holding pool part of which forms a transport tank, or else from which fish can be crowded into a tank further along a channel. In practice this often involves the use of guide screens and re-entrant devices to maximise retention of fish which enter the structure. The conditions for fish attraction are those used conventionally for pool passes.

- **a lifting stage** in which the transport tank ascends on guide rails to the top of the dam

- **a fish exit stage** in which the tank is tipped so that fish are discharged either directly in to the headwater, or else into a channel to carry them a safe distance upstream thus helping prevent passage back downstream.

Effectively there are two types of facility, the choice of which depends on the number and species of fish that are being moved. Lifts with integral tanks are used for robust species that tend to arrive at the facility in relatively low numbers at any one time, such as migratory salmonids. Lifts that employ mechanical crowders and large holding pool areas are used where fish arrive in large numbers, or else for the more delicate species, such as shad.

An excellent description of the design features and principles of such facilities is provided by Travade & Larinier (1992). This includes selection of type of lift, siting, water supply, dimensioning of the holding pool and the lifting tank, crowding device, fish emptying and transfer, size and operation, and care and maintenance.

There is no known example of a fish lift in the UK, however they are widely used in France and the USA (Travade and Larinier, 1992), particularly where large numbers of shad are involved.

Strengths: Fish lifts have the advantages that, compared to other facilities at high head obstructions, they take little space, are cheaper to construct, are relatively insensitive to head water level variations, and can easily be adjusted for any dam height. They are also suitable for a wide range of species, including some like pike that have difficulty using other conventional types of fishway.

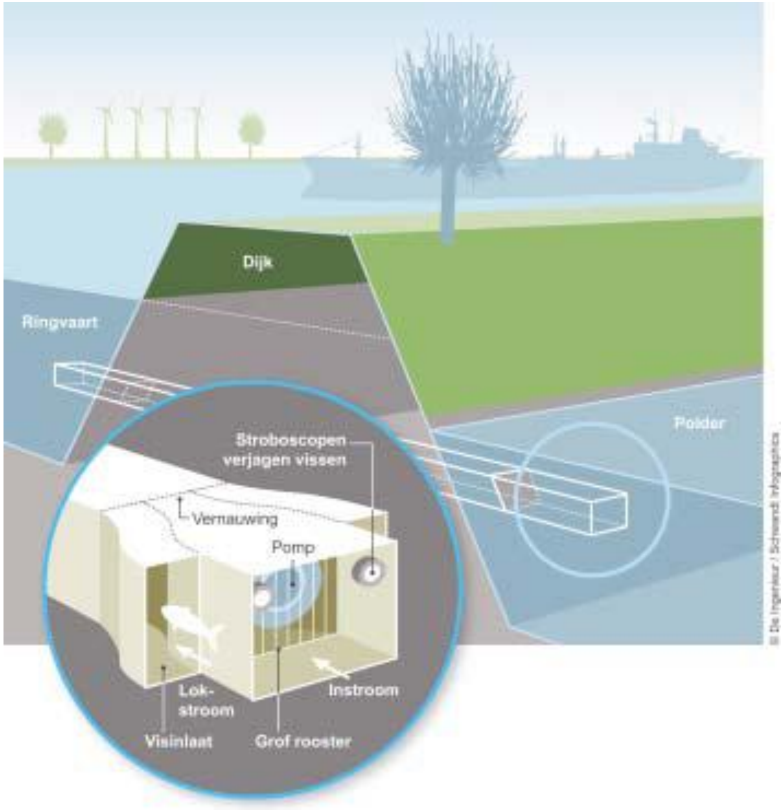
Weaknesses: The reliance on mechanical systems means that the costs of operation and maintenance are relatively high, and that a programme of ongoing maintenance is essential to avoid restricting availability. Availability is anyway limited by the operational cycle.

Venturi Pump Fishway

Venturi fish pass pumps are an innovation designed by Gerard Manshaden c. 2005. In the Netherlands more than 3000 pumps are used operationally to manage land drainage, pumping water from lower-lying polders to higher water channels. These pumping operations can be responsible for the mortality of virtually all of the fish passing the pump, which millions of fish naturally do as part of their ‘downstream’migrations in these channels.

In essence the FishFlow Fishway is a venturi system applied to conventional pumps in pumping stations. The venturi is located behind a conventional pump where the discharge is forced through a narrow aperture inducing a high velocity jet that creates a vacuum, and this in turn draws flow around two side channel pipes connected to the discharge pipe ‘downstream’ of the narrow aperture. The two side channels are completely unobstructed, and stretch back either side of the main inlet pipe to the intake area where fish naturally accumulate. The intake chamber to the main pump is provided wih a stroboscopic lights to discourage fish from entering, and to divert them instead to the side channel by-passes. Fish entering the side-channels then bypass the pumps altogether, see Figure 40.

Figure 40 Typical layout of the FishFlow venturi pass (after FishFlowInnovations)



Trialled at the Meerweg pumping station, R.Oude Aa between 2005 and 2007 it was concluded that when the venturi was in operation in combination with the strobe lights 100% of a wide variety of coarse fish species and sizes were diverted and passed without damage. Species included those found in typical lowland rivers, and included many eels. The only mortalities of fish were of those taking refuge in the pump chamber when the pumps were switched on.

Such systems are likely to be very useful in low-lying Levels and Fens areas, especially when used during normal pumping operations (as opposed to flood water pumping). They may also be useful in potable water supply reservoirs that have ‘land-locked’ populations of adult eel introduced as elvers and small eels when pumped in with abstracted water from sourse rivers.

FishFlow venturi fishways are marketed by FishFlow Innovations, www.fishflowinnovations.nl

NON-TECHNICAL FISH PASSAGE SOLUTIONS

A variety of works and modifications may be carried out on existing weirs and similar structures which, although designed to ensure fish passage, do not necessarily fall within the scope of the formal authorisation process. Whilst some may be only minor in scale, others may be considerable engineering undertakings (see examples below). These "informal" passes are, for the purposes of the authorisation process, termed easements, and do not usually require authorisation. (Although they will still constitute "fish passes" for the purposes of the SAFFA, 1975 - Section 12 for example). However, the Fish Passage Panel should be informed of the details of such passes so that their status in relation to authorisation can be confirmed. Further, the Panel can give guidance on best practice and design, maintain a database of such structures and circulate information on application and design throughout the Agency for the benefit of those wishing to construct easements.

Where any of these features are included in new structures that are being built on migratory salmonid rivers, then formal authorisation will be required. Formal authorisation will also be required where such structures are required to be included at sites on migratory salmonid rivers where proposed to an existing structure would increase the difficulty for fish to pass.

Easements fall into the following general categories:

- Streaming flow and heterogeneous conditions
- Adherent (Non-aerated) nappes
- Notches and gaps
- Baulks
- Baffle Systems
- Preliminary Weirs (Pre-barrages, Check Weirs)
- Modifications to the Natural Bed

Streaming flow and Heterogeneous conditions

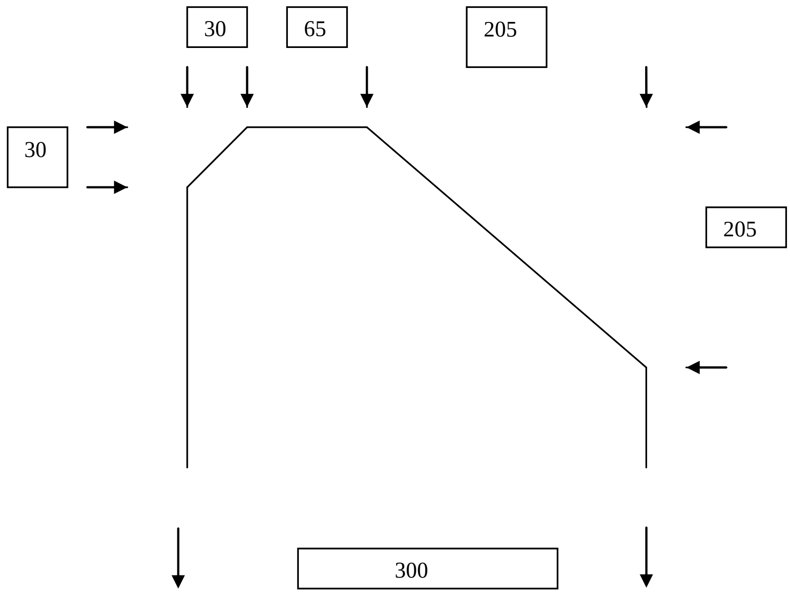
In general terms the best flow conditions for fish passage are those where streaming flows are present, making the easiest conditions for fish to swim. The conditions that provide streaming flow, as opposed to plunging flow, are described earlier in the Pool Passes section. In simple terms the depth of flow over the invert of a gap on the downstream side should be more than half (preferably 60% to avoid hysteresis, or alternation between the two states) of the depth on the upstream side of the notch (see Figure nn). When low structures are put in streams for pre-barrage, habitat enhancement, or other objectives such as bed stabilisation it is worth considering using free gaps (or full depth notches) or other connections that will maintain streaming flow conditions.

On many occasions where blockstone or other weirs have been inserted into streams for bed stabilisation or a variety of flood defence and other purposes, they are constructed with a level invert across the entire stream. This should never be done, and free gaps, notches, and or lateral variations of the structure should be included in the works to ensure that a wide variety of flow and velocity conditions occur across the structure an any one flow condition. These heterogeneous conditions offer fish of different species, sizes, and abilities the greatest prospect of surmounting obstructions.

Adherent (non-aerated) nappes

Sharp edges on structures, including notches intended for fish passage, cause water plumes to leave the face of the structure creating an air gap between the plume and the structure i.e. an aerated or ventilated nappe (see Appendix XI, Fig 1). This prevents fish from swimming up and through the plume, and causes them to have to jump. Fish are essentially designed to swim, and while they can clearly jump, especially salmonids, jumping fish is a sign that they are in difficulty. To surmount an obstacle successfully a jumping fish has to locate the right spot form which to jump, get its trajectory correct, land safely, and pointing in a direction that enables it to succeed in swimming away upstream. Jumping is thus uncertain advertising the fish's prescence to preadators, risking collision damage with structures, with high risk of failure to achieve the correct height and trajectory, and with every risk of being swept back downstream if it does not land with head pointing upstream (because of the large forces on its side if it is in any way across the flow).Aerated nappes, especially on fish pass notches, must therefore be avoided in favour of adherent nappes (e.g. see Appendix XI, Fig 7) that fish can simply swim through. In pool passes this is normally achieved by having sufficient thickness of cross-wall and providing a curved or 250 -300mm radiused profile (see pool passes). An alternative means of creating an adherent nappe can be to use a chamfered profile, which is sometimes easier to attain. Chamfered notches are used in some forms of pool pass e.g. deep slot and pool & chute. Scaleing up the profiles in these structures gives possible profiles for use in other thicknesses of cross-wall, for example that shown in Figure 41 below for a typically 300mm thick wall.

Figure 41 Chamfered profile for an adherent nappe



(measurements in mm)

In some cases, such as when constructing blockstone weirs or pre-barrages using natural materials, it may be difficult to achieve satisfactory profiles. However, the same effect can often be achieved by ensuring that the stones put in the notches are sloped.

Notches and Gaps or Slots

This is perhaps the simplest form of fish pass, and can be effective in low head weirs.

Notches or slots can be applicable in a variety of situations, often in conjunction with other forms of easement (for example, see Baulks below). Two main types of application are considered here: use in weirs with a downstream glacis of low gradient; and use in narrow crested, vertical faced weirs. It should be borne in mind that a fish will be required to use a speed between maximum and burst swimming speed to pass these facilities. Since the time for which the fish can sustain the effort is very limited, the distance to be covered by it is also very limited. Each situation must therefore be assessed on its own merits. Essentially, the distance to be covered cannot be excessive.

In weirs with a low-gradient, ≤10%, downstream glacis, notches can be effective for the passage of salmon, sea trout, brown trout and faster swimming cyprinids provided that the head difference is small (≤1m for salmonids, ≤ 0.5m for coarse fish). Here the notches can act to concentrate the flow, and provide a passable depth of water over the face of the weir. Flow can be further concentrated below notches using channels in the glacis. . In order to be effective the apron of the weir must not be perched (i.e. above the level of the downstream water level), and the technique will be most useful where the downstream water level rises more rapidly than the upstream level on increasing flow thus reducing the head drop to less challenging values. Notches can also resolve problems associated with the up-stands or lips that are frequently encountered on the crests of such weirs, and which frequently prevent passage that otherwise would have been perfecty possible.

Notches are effective in narrow crested, vertical weirs where the head difference is ≤0.5m and there is a suitable depth of water below the weir - a depth of at least twice the head difference is required. As in pool and traverse passes, it is advantageous if the weir is of a sufficient thickness to allow the provision of a curved downstream edge in order to provide an adherent nappe of water, and to reduce turbulence. Flow and fish passage characteristics can be considered to be the same as in pool and traverse passes, with streaming and plunging flow, depending on the height of the weir, downstream water level etc. Where the head difference is >0.5m (0.3m for trout and coarse fish) preliminary weirs (see below) can be used to reduce this so that a notch then becomes effective.

In `streaming flow` situations the gaps, notches must be at least 0.30-0.40m wide for large migratory salmonids, 0.45m for shad, 0.20m for trout & large coarse fish, and 0.15m for small coarse fish. In `plunging` flow situations they should be wider and a minimum of 0.6m is usually taken for large migratory salmonids and 0.3m for trout and coarse fish.

In narrow crested, vertical weirs a simple gap can be employed to ease passage. This may be any width subject to the minimum given above, depending on the requirement to maintain water levels upstream (for aesthetic or ecological reasons, for instance). Typically, a simple gap would be cut from the crest to the base of the weir. Narrow gaps, generally ≤1m, used where there is a need to maintain water levels upstream of the existing weir, can be designed to operate in a similar way to deep notch or vertical slot passes. In this case there may be a need to have a preliminary weir to help reduce velocities and ensure adequate water depths through the gap. Wide gaps may be used in situations where there is not a critical need to maintain the water level immediately upstream of the structure.

Suitable species:

Notches - generally for salmonids if plunging flow, but streaming flow notches in vertical weirs will be suitable for most surface-swimming or mid-water-swimming species.

Gaps - can be designed to accommodate most species

Head difference:

Notches - ≤1m. in broad weirs, ≤0. 5m. in vertical weirs

Gaps - ≤0.5m

Velocity: 1.4-3.1ms^{-1} (see velocities in pool passes, section sterting page 62) in notches or slots, or where there is a head drop at a gap

Strengths: Cheap, and easy to maintain. Can be simple to fit in existing weirs

Weaknesses: Notches - limited head differences, limited range of operation. Gaps - may lead to loss of head above the weir. May compromise the integrity of the weir.

Baulks

Baulks are a form of low-cost easement that may be considered for existing weirs, however it is likely that they are only useful for salmonids. They should therefore be regarded in many cases as interim solutions to achieving fish migration prior to full resolution (eg under the WFD driver) with a more efficient and effective technical solution.

Baulks should not be considered for new structures, where more robust solutions to promote passage of all species of fish should be sought.

Baulks are effective in weirs with a low gradient downstream glacis and especially for weirs oriented diagonally across the river (typical of old weirs). The purpose of the structure is to gather water over-spilling the crest of the weir and concentrate it in a diagonal run across and down the glacis. This acts both to provide an attractive jet at the toe of the weir, and to provide a suitable depth of water to allow fish to swim up the plume of water created.

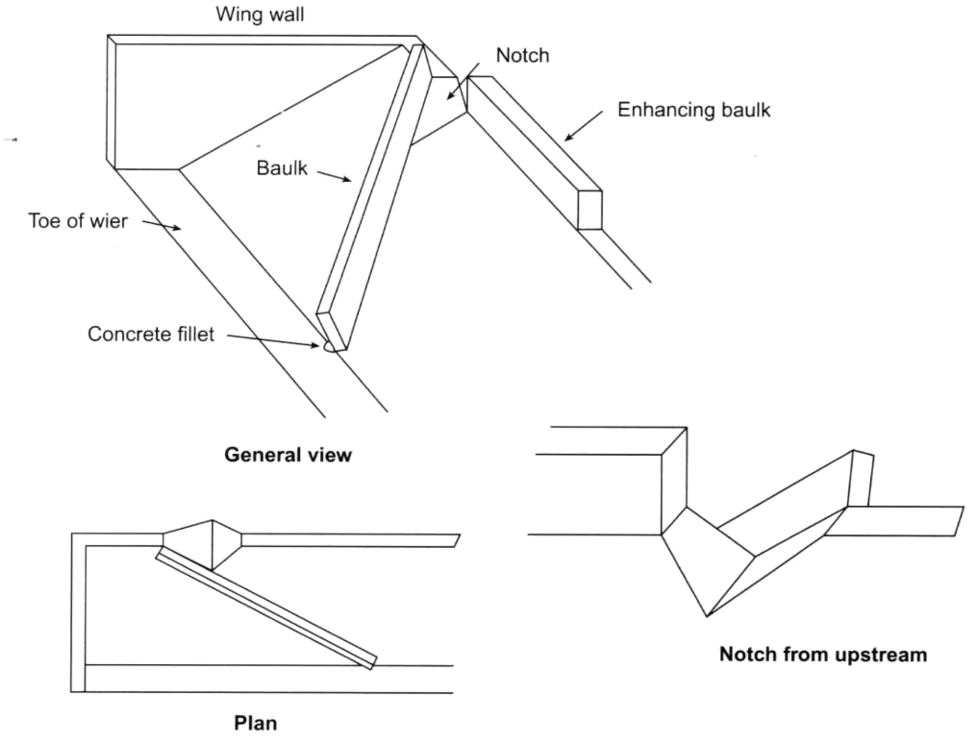
There are a number of ways to construct a baulk. Most are constructed using a set of timber beams or a fillet of concrete or other material, placed diagonally down the face of the weir, extending the full distance from the crest of the weir to the toe. They also work best if the the crest is notched at the top of the baulk, to facilitate fish exit, and also if the toe of the weir is locally lowered to broaden the range of downstream water levels at which the baulk will operate. The upstream notch also permits operation of the structure in low flows and tends to reduce the risk of debris accumulation.

Total flow along the baulk and the water velocity in various flows should be assessed prior to build. This can be assessed empirically, and by observing conditions at existing baulks. In some cases this may lead to control of the volume of water collected by raising the elevation of part or all of the baulk i.e. the baulk takes the form of a wedge being taller at the tail than at the head, or by reducing flow by raising part of the weir crest with an enhancing baulk immediately above the baulk (see Figure 42). It is preferable to avoid the baulk being over-topped by water as this may lead to disruption of fish ascending the structure and even to risk of fish being washed sideways over the baulk and back downstream. The toe of the baulk should ideally be constructed so that it is drowned at all times, allowing fish to enter the pass without having to negotiate a drop or step.

In practice it may not be possible to notch the weir, to lower the toe, nor to ensure the lower end of the baulk is drowned (due to local considerations including cost). While these are all desirable features it is sometimes pragmatic to simply “do the best you can” in order to achieve some gain for migration.

The characteristics of a baulk type fish pass are shown in Figure 42.

Figure 42 Schematic diagram of a Baulk pass (after Fort & Brayshaw, 1961)



Baulks became quite widely used in the late nineteenth and first half of the twentieth Century (Pryce-Tannatt, 1938) but have seldom been used more recently. However, in seeking affordable solutions at the many hundreds of sites requiring fish passage improvement several have been built over the past 10 years in Herefordshire (P. Gough, pers observation). These have been built in the River Lugg sysem, intended to improve access for salmon and brown trout, and have met with some qualitative success.

The solutions used have included the use of timber sections (approximately 30cm square in cross-section and up to 2m long, arranged in up to 3 layers). These have been bolted to a galvanised steel base plate which is itself attached to the weir with specialist Cintec anchor bolts. This arrangement resolves the difficulty of attaching any structure to a weir of uncertain provenance, whilst minimsing the risk of the baulk turning-motion pulling the bolts out of the weir – possibly leading to initiation of a progressive weir erosion and collapse.

An alternative has been the casting of a concrete fillet – with or without a steel mesh framework – directly onto the weir surface. This has worked acceptably well, however the effect on weir structure remains a concern.

An alternative not yet used is the deployment of pre-cast concrete sections (perhaps some form of kerb-stone) secured on the weir with anchor bolts. This promises to be cheaper, and when combined with anchors designed to sheer when subjected to excessive forces during especially high flood flows in order to prevent damaging occurring to the weir, a more sustainable solution.

Costs for each variant have been modest (£5 - 20K). Those at the higher range have been more expensive because of the challenge of ensuring adequate fixing mechanisms. This has necessitated the use of structural assessments, pull-tests, and a very careful specification of the licenced Cintec anchoring system..

Although there is still a lack of information available giving guidance on the design and installation of baulks to ensure effective operation. Some information, based largely on empirical experience, is given by Pryce-Tannatt (1938), as follows:

- Optimum head difference:................................ c. 2m
- Maximum glacis gradient:................................ 1 in 4
- Maximum length of baulk:............................... c. 20m
- Angle of baulk in relation to weir crest:........... between 25º and 45º

Suitable Species: typically used for larger salmonids, but may be effective for some coarse species, depending on head differences, lengths and gradients.

Strengths: cheap and easy to construct and maintain. Relatively simple to retro-fit to existing weirs.

Weaknesses: limited application for fish species. Limited range of operation. Lack of sound design criteria.

Observations of performance of a network of nine baulks in the Lugg system, amongst other fish passes and some partially passable structures indicates that the baulks have expanded the range of salmon along the river. In several cases salmon and trout have been observed to use them, although this clearly does not represent strong evidence (P.Gough, pers. observations).

Baffle systems

A variety of baffle types and configurations, constructed from a range of materials, have been used to improve fish passage, particularly over low head difference weirs. These are designed to retain water depths, reduce velocities and create heterogeneous flow conditions on the structure in question. Because of the range of applications and the paucity of standard design criteria available for such devices, it is often most practical to undertake hydraulic modelling studies to ascertain the most effective design for the specific weir under consideration and for the species and size range of fish involved.

Typically, baffle systems are located on the downstream glacis of weirs, although examples have been described in channels set into the weir face, in drowned notches at the weir crest, or in purpose-built channels built below the weir.

Systems have been used in Japan (Nakamura, 1995) and New Zealand (Mitchell, 1995) incorporating the use of either natural boulders or purpose-built concrete blocks embedded in the downstream glacis. Whilst instinct would tend to dictate that these boulders should be set randomly to increase turbulence and reduce water velocities, trials have shown that they are most effective if arranged in ranks in line with the water flow. These materials have also been deployed in shallow channels set into the weir face. Again, hydraulic modelling can be used to determine the precise characteristics of such systems, allowing for fish species and size, weir characteristics and prevailing flow regimes.

Two baffle systems have been the subject of recent development in England & Wales. The first was the Hurn-type baffle system developed for Flat V gauging weirs, and the second was the Low Cost Baffle solution (LCB) developed for Crump type and sloping weirs.

Hurn-type baffle system for Flat V weirs

A particular baffle system (known as the Hurn-type baffle system) was developed and installed in England on a small, (10m wide) Flat V gauging weir in Dorset (Walters, 1996a). Hydraulic modelling determined the configuration and location of the baffle system which was intended to allow passage of dace of 200-300 mm length over the weir, (a burst speed of $1.5ms^{-1}$ was used as design flow criterion) whilst still retaining its properties as a gauging structure. The device was finally constructed using bars made of recycled plastic with dimensions of 100mm wide and 150mm high (Walters, 1966b). Initial hydraulic trials suggest that it would restrain velocities that enable dace to pass the structure, where previously they failed to do so. However, when used in practice at Hurn weir trials dace seemed to be incapable of exploiting any low velocity areas created on the weir face because the turbulence that is created on the structure at field scale appeared to confuse and disorientate the fish and they could not discern any routes to the upstream. On the other hand, where the system was employed at (four) sites in SE Wales in streams supporting salmonids (salmon and brown trout) it was considered (Gough pers comm) that fish were able to exploit them (though no definitive tagging trials have ever been completed).

In view of experience to date the system is no longer considered suitable for coarse fish, but is still considered suitable for salmonids.

The geometric characteristics of the Hurn-type baffles on a Flat V weir are shown in Figure 43, while a velocity profile is given in Figure 44.

Figure 43 Characteristics of the Hurn-type baffle system (After Walters, 1996)

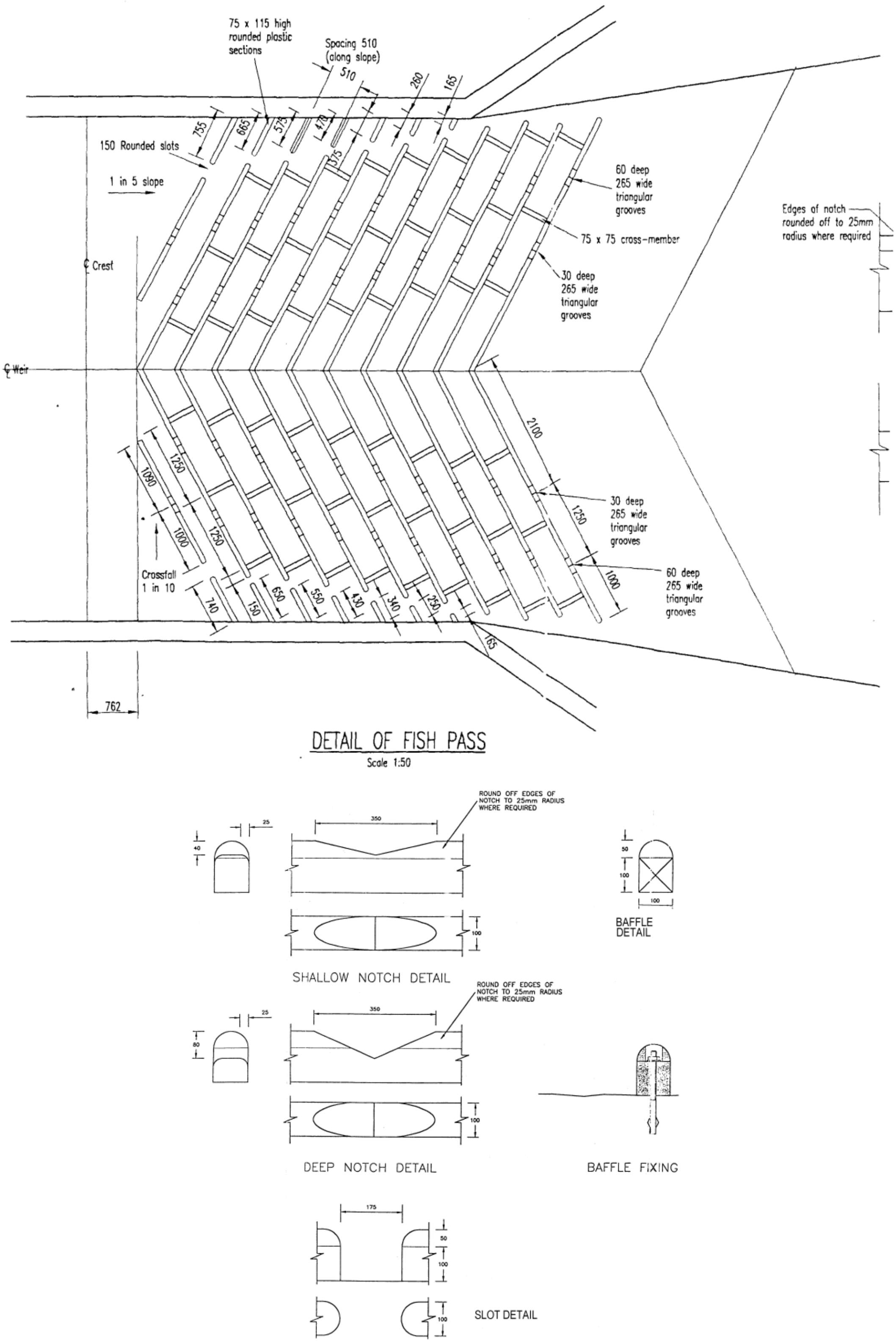
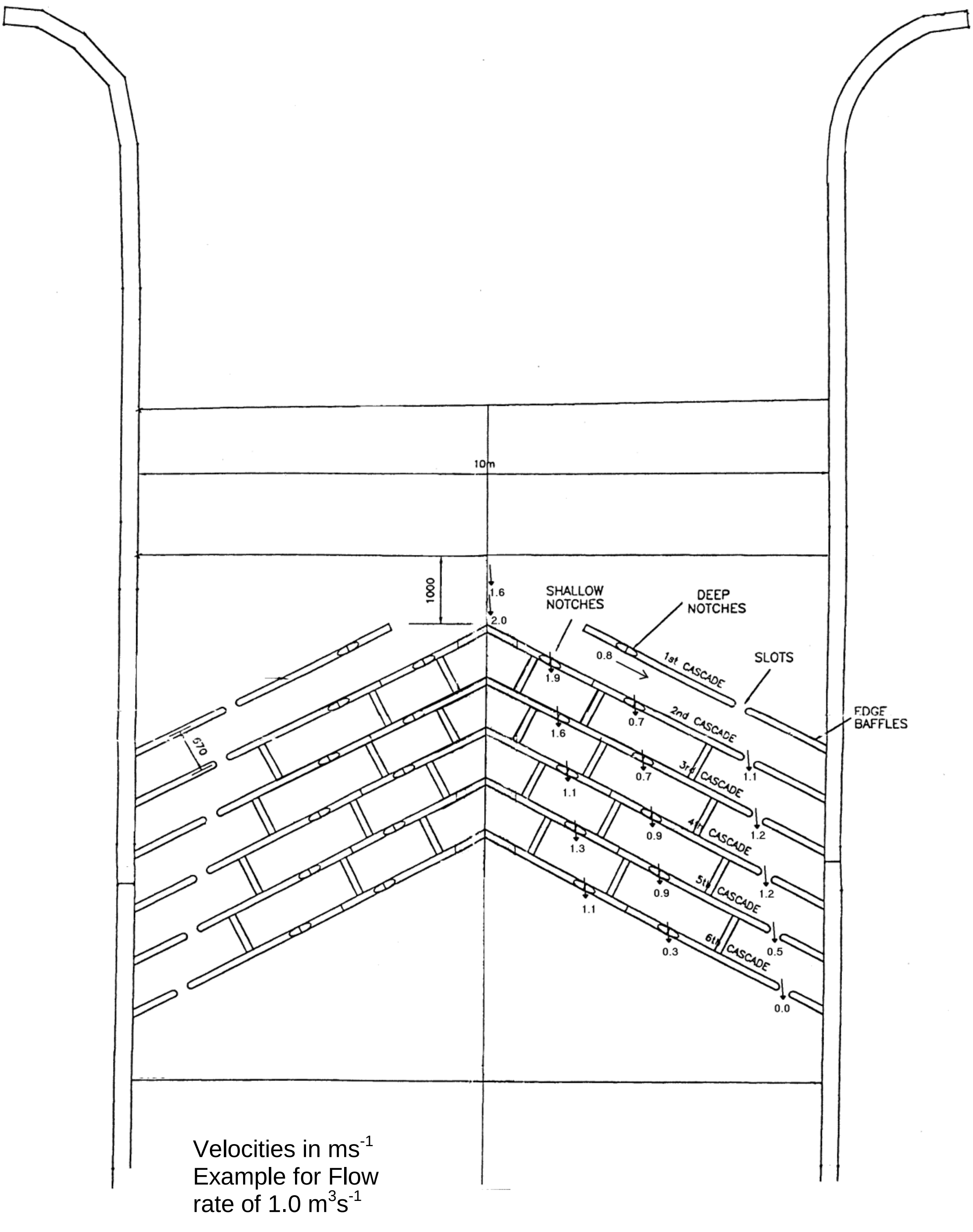


Figure 44 Velocities on a Flat V gauging weir fitted with Hurn-type baffles



The Hurn baffle system is specific to the particular configuration of the Flat V weir in terms of weir slopes and width. In order to apply it to other similar weirs of different widths, then the baffle dimensions would have to be adjusted to scale. The dimensions of the baffles, slots etc are scaled linearly, while the water velocities and discharge are scaled according to non-linear functions.

The scaling of baffles is simple since the dimensions are in linear proportion to the width of the weir, taking the Hurn model as the starting point. For example, consider the application of baffles to a weir of 7.62m width. Hurn Weir is 10m wide and the baffles are 0.1m wide, 0.15m high and are spaced at 0.67m apart. For the new weir, 7.62m wide, each of these dimensions requires scaling by multiplying by 7.62/10 or 0.762. This yields baffle dimensions of 0.76m, 0.114m and 0.511m for width, height and spacing respectively.

To calculate a water velocity relative to that shown for Hurn Weir the scale factor must first be calculated, i.e. Hurn Weir width/new weir width. In the case of the new weir 7.62m wide, then the ratio is 1:10/7.62 or 1:1.31. The reciprocal of the square root of this ratio must be taken to find the velocity-scaling factor: $1/(1.31^{0.5}) = 0.874$. Thus, a velocity marked on the diagrams given in the July 1966 Supplementary Report (Walters, 1966b) for a known discharge, should be multiplied by this velocity-scaling factor.

To calculate a discharge relative to that at Hurn Weir, an appropriate scale factor must then be calculated. In this case, use is made of the width ratio as above, modified by raising it to the power of 5/2 and then using the reciprocal of this figure: $1/(1.31^{5/2}) = 0.51$. Therefore, a discharge of $1.00m^3s^{-1}$ at Hurn would be scaled to $0.51m^3s^{-1}$ for the new weir.

Some examples of scaling for different sites are given in Appendix IX.

When used on gauging weirs the coefficient of discharge of the Flat V weir is not to be altered by more than 1%. Thus, the position of the top baffle should be checked. The methodology for deciding where the most upstream baffle may be placed is described in Chapter 5 of White, Bowker & McGahey, 2005, Flow measurement structure design to aid fish migration without compromising flow data accuracy, Science Report SC020053/SRS.

Suitable species: only suitable for salmonids.

Head difference: generally ≤1m.

Gradient: ≤20%.

Velocities: target dependent on species but $\leq 3.0ms^{-1}$ for migratory salmonids.

Strengths: Relatively cheap, and simple to retro-fit to existing structures.

Weaknesses: gauging weirs need re-calibrating after installation, since the installation of baffles is likely to reduce the modular operational range of the station.

It should be noted that where Hurn type baffles are fitted to existing structures there is no requirement for formal fish pass authorisation, however the details should be made known to the NFPP for auditing purposes. In the case of a new structure being built that incorporates this system, then the formal authorisation process must be completed.

Low Cost Baffle (LCB) solution for Crump-type and sloping weirs

A recent solution has been the result of a three year PhD study (Servais, 2006; Rhodes & Servais, 2008) in the hydraulics laboratory to find a low-cost means of retarding velocities and retaining depth on sloping weirs in a way that is suitable for fish to pass. Without baffles water flow on a sloping weir simply accelerates in a region of super-critical flow resulting in very high velocities and very thin depths, before returning to sub-critical flow metres down the slope in a hydraulic jump near the downstream water level. The high velocities and thin flow depths make it difficult or even impossible for fish to pass.

In the idealised version (

Figure 45) the first two baffles have inverts level with the crest of the weir, the first baffle being smaller (120mm) and the second and subsequent baffles being 200mm. Baffles down the weir slope are placed parallel, at right angles to the flow direction, and are equally spaced down the weir at 400mm intervals. A free gap in each baffle, starting at the upstream bank, runs successively across and down the weir forming a channel with consistent depth and low velocity. On wider weirs this channel could form one diagonal run, but on narrower weirs the channel is reflected across the weir forming a V-shaped run. Where the channel is reflected the slots are particularly arranged to ensure a water jet cannot by-pass straight down to the next slot.

The design was very much aimed at coarse fish species and the slot is 250mm wide. Fish are expected to exploit the low velocity oblique channel in low discharges. Comparison of modelled depths of flow and water velocities suggests that the solution creates conditions that most species of fish will be able to exploit over a wide range of flows. In high discharges it is also expected that fish might both exploit this low velocity channel, and the retarded velocities and retained depth of water above the baffles i.e run straight up over the baffles.

For large migratory salmonids it is proposed that the free gap be increased to 350mm, while ensuring that the same horizontal distance is maintained between successive slots to avoid any increased chance of water jets by-passing straight to the next slot downstream.

The design can be adapted for Crump gauging weirs, and in fact the system was developed on the model of such a conventional Crump gauging station – see section on fish passes and gauging weirs (page 192).

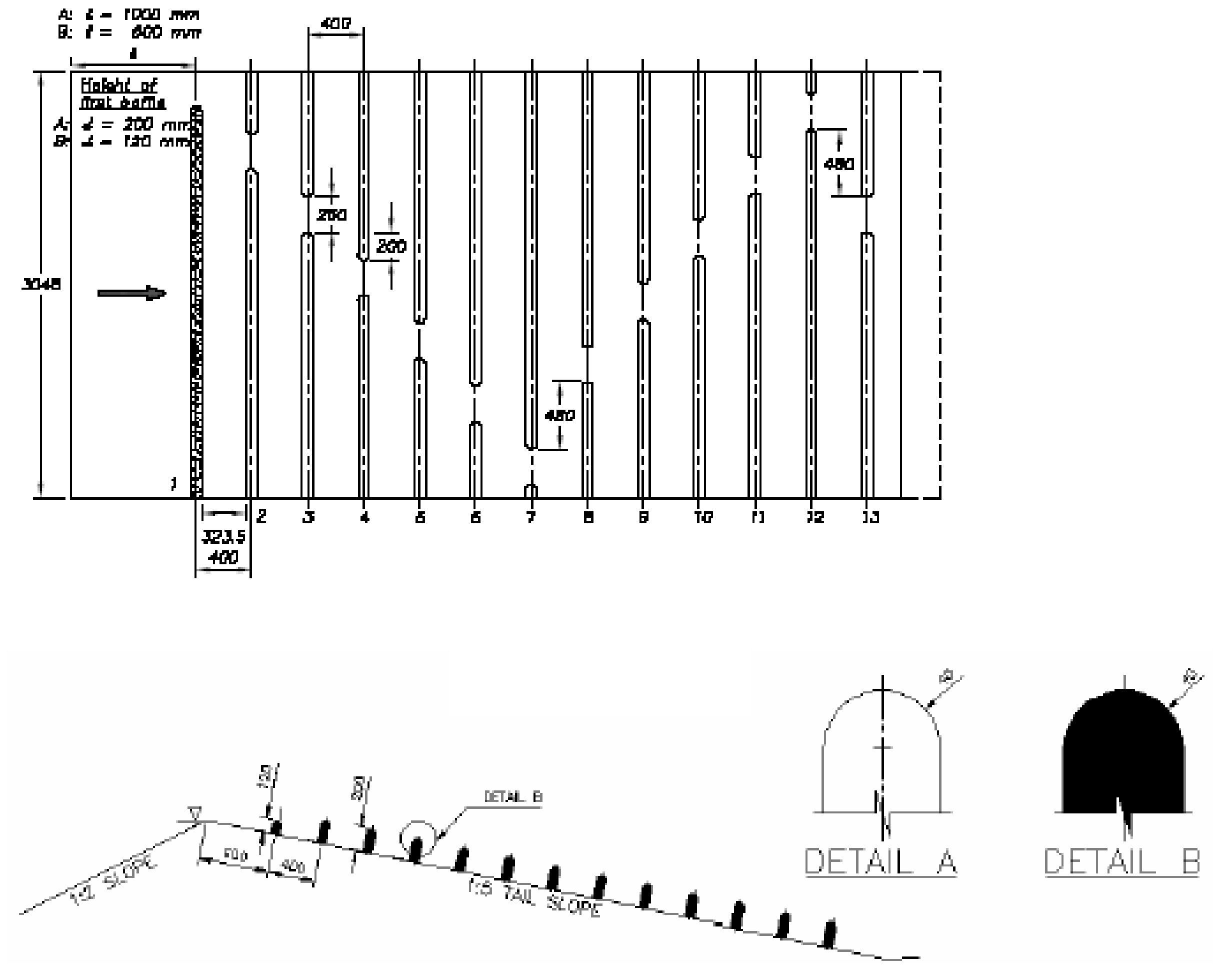
The system could be adapted and deployed on wide weirs where a single diagonal run reaches the tailwater level by isolating the section of weir with the LCB from the rest of the structure. A longitudinal baulk high enough to act as a side-wall and retain flow in the system to a sensible depth (say 0.3 -0.5m above the baffles) would create a passable section of weir.

The system has yet to receive any widespread use. However, a field trial has been carried out at the Crump gauging weir (Brimpton GS, R.Enborne) that was used as the basis for the hydraulic modelling. Of 61 fish electrofished from reaches upstream of the weir and displaced downstream a minimum of 36% made it back upstream, and 63% of those individuals that actually made an attempt to move back upstream were successful. Sample size included 45 chub (23.7-51.0cms) of which 18 were successful, 9 dace (18.5-24.0cms) of which 3 were successful, and two roach (24-24.4cms) one of which was successful. The most optimistic assessment of efficiency was for the group of chub, of which 27 attempted the weir, putting efficiency at 67%.

Some of these fish moved back upstream under relatively low flows when the free gap would have been available only, but many under higher flows when they might have used the free gap or swum over the tops of the baffles. These trials were encouraging since the baffle system had to be compromised form the ideal by moving it down the weir slope (as outlined below), thus a high velocity zone still occurred between the topmost baffle and the weir crest. A trial at a non-gauging weir site where the system has been modified for migratory salmonids as above is ongoing (first season will be 2010).

Hydrometric trials are still onging at Brimpton, but so far the gauge with baffles has performed as expected in relation to the discharge characteristics and is thus regarded as satisfactory in terms of measuring flow. It has also been satisfactory in operational terms with little problem with trash or debris being retained on the structure to interfere with gauging continuity.

Figure 45 General arrangement of the Low Cost Baffle solution at field scale, in plan and elevation & showing cross-sectional details



When used on gauging weirs the coefficient of discharge of the Crump weir is not to be altered by more than 1%. Thus, the position of the top baffle should be checked. The methodology for deciding where the most upstream baffle may be placed is described in Chapter 5 of White, Bowker & McGahey, 2005, Flow measurement structure design to aid fish migration without compromising flow data accuracy, Science Report SC020053/SRS. This results in the most upstream baffle being some distance downstream of the crest, which is likely to compromise its performance as a pass.

Suitable species: potentially might accommodate most species.

Head difference: generally ≤1m.

Gradient: ≤25%.

Velocities: target dependent on species but ≤ $3.0ms^{-1}$ for migratory salmonids and ≤ $1.5ms^{-1}$ for coarse fish species.

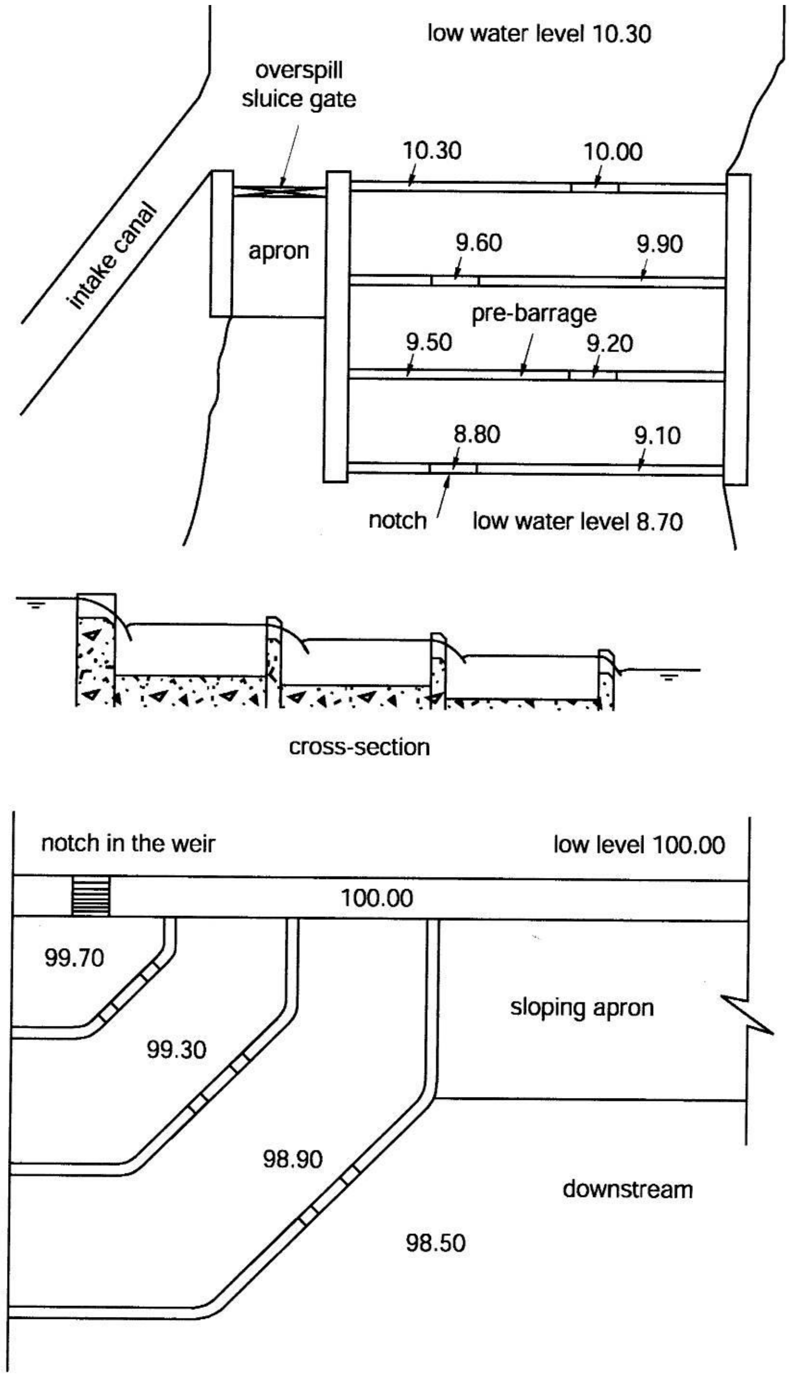
Strengths: Relatively cheap, and simple to retro-fit to existing structures.

Weaknesses: gauging weirs may need some re-calibrating for higher discharges after installation, since the installation of baffles is likely to reduce the modular operational range of the station. Enhanced risk of gauge downtime through trash/debris collection.

Preliminary Weirs (Pre-Barrages, Check Weirs)

To effect fish passage at low head obstructions preliminary weirs (Figure 46) can often provide a low cost but effective solution. They are placed downstream of the main obstruction in order to reduce the head loss across it. Typically may also be located below culverts, road bridges and similar structures to maintain passable water depths through the channel conduit. They would also be found below other larger weirs, where they have been used to raise the water level in the weir pool to allow either sufficient depth of water for fish to leap, or else to assist in drowning out the weir to allow fish passage. They are commonly used in conjunction with a notch or gap in the primary structure, and can even be used as a device to ensure proper drowning of the entrance to a formal fish pass. A series of such weirs can be installed over a length of channel depending on the overall head difference that is to be overcome.

Figure 46 Schematic plans illustrating the use of pre-barrages across the whole, or part of the width, of a stream in front of a barrier (after Larinier, 1992a)



Normally of simple construction, e.g. blockstone or natural stone drilled and cemented to bedrock, they can span the whole channel in relatively narrow streams, or else form a pool in front of the intended area of passage in a wider structure. Generally it is best to locate them near to the banks, where fish are most likely to be moving and to facilitate maintenance. There should be sufficient depth of water on the crest of the structure to ensure that fish can swim over, and this will usually mean that there is a notch or slot somewhere that will ensure this condition prevails at low river discharges. Wherever it is expected that fish may pass, the crests of the weirs should be shaped to ensure an adherent nappe.

The head at individual weirs should not exceed 0.3 – 0.5m for migratory salmonids 0.15-0.3m for coarse fish, and the downstream water depth should be at least twice the head. The length of the pools should usually be a minimum of 3m, but in practice they will often be longer because mean power dissipation values will tend to rise rapidly with increasing river discharge.

Guidelines for the minimum length of pools and for power dissipation values are generally the same as those for pool passes. In cases where there is a modest discharge in the facility then volumetric power dissipation values should be $\leq 150 Wm^{-3}$ for migratory salmonids, and $\leq 100 Wm^{-3}$ for trout and coarse fish at all times when they are expected to be migrating. If only a few preliminary weirs are required for migratory salmonids then higher than normal power dissipation limits may be used for large installations, for example where discharge is $>10m^3s^{-1}$, perhaps up to $500Wm^{-3}$.

Suitable species: any species if streaming flow, otherwise only salmonids and larger surface and mid-water swimming coarse fish. Plunging flows are not suitable for shad, eels or benthic species of coarse fish.

Head difference: up to maximum 0.5m for migratory salmonids, 0.30m for coarse fish, but preferably ≤ 0.35m and ≤ 0.20m respectively.

Length: generally unconstrained except for dependence on power dissipation limits, and ensuring an effective entrance location if the facility does not span the whole stream. It is not sensible to have pools less than the minimum lengths quoted for pool passes.

Gradient: ≤10%.

Strengths: generally cheap and easy to construct and maintain.

Weaknesses: can be problematic for fish passage at low flows if not designed well.

Modifications to the Natural Bed

Fish passage can be effected at natural obstructions by a variety of pragmatic modifications, depending on the nature of the obstruction and the species of fish involved. Notches, channels and pools cut into bedrock can all be used to ease passage and may be deployed with a combination of other easements (baulks, preliminary weirs, baffles). Such obstructions may even be removed completely where circumstances and management policy allow (see Environment Agency Salmon & Sea trout Strategy, and Brown trout & Grayling Strategy). It should be noted that such removals often carry some risks associated with deconstruction and potential changes in water level upstream. Where percussive methods are used for deconstruction care should be taken to consider the immediate environmental impact of such methods. Design criteria are difficult to define for such modifications and a pragmatic approach based on experience is required.

In the absence of directly applicable designs, guidance can be drawn from conventional types of fish pass or easements. For example, minimum depth criteria can be drawn from guidance relating to easement of fish passage at culverts and bridge footings. Guidance for pool and traverse fish passes relating to pool dimensions, swimming depth, pool head-loss and energy dissipation can suggest if potential modifications are likely to be effective. One often used rule of thumb is to consider the proportion of "white water" in any plunge pools. Ideally pools should have less than 75% "white-water" and be deep enough for fish to swim through rather than leap over any traverses or transition points.

Suitable species: typically carried out in upland streams where salmonids are the target species.

Head difference: generally low, ≤1m, for any one traverse, but may be considerable overall.

Gradient: variable depends on location.

Velocities: usually within burst speed capability of the target species, but may approach maximum swimming capability.

Strengths: cheap, and often easy to carry out. Can be unobtrusive in a natural setting.

Weaknesses: Vague design criteria. May not be effective at all flow ranges.

Rock Ramps

Rock ramps have been used extensively and relatively successfully in Britain, Europe and Australia to provide or improve passage at obstructions of a modest height. They are perhaps specially suited to use at vertical fixed weirs. They have the benefits of very wide species applicability, low maintenance and high operational availability in addition to the avoidance of fish attraction problems (at full width). With suitable design they can operate over a wide discharge range and can achieve high value to cost ratio when species diversity is incorporated in the analysis. Ing and Gebler (2007) provides guidelines for key rock ramp designe parameters in relation to more than 20 european fish species.

A ramp of bedrock and mixed bed material is located on the downstream side of an existing weir, to create a semi-natural river bed of reasonable gradient (≤5%) to allow fish passage over a low head (≤1m) structure (Figure 47 & Figure 48). Typically, the ramp covers the whole width of the river channel - where ramps have been built over only part channel width, difficulty has been experienced in retaining satisfactory water depths over the ramp, when water merely percolates sideways through the material. Part width channels have also lead to difficulties in fish finding the entrance to the pass although modifications to invert of the weir at the head of the ramp can ensure preferential flow to the rock ramp. To ensure operation over a wide range of flows, the ramp may have one or more low flow, dished channels. To accommodate higher heads, ramps have been constructed over a 2m head with the incorporation of a resting pool at half height. Pool and traverse design criteria could be used for such a resting pool. Full width rock ramps can accommodate higher head structures given suitable space and conservative design.

Normally the ramp is constructed in a downstream to upstream direction. Care must be taken to secure the downstream end of the ramp to prevent the toe from being removed in high flows. Similarly, it is critical that any settling that may occur does not lead to a gap developing between the upper end of the ramp and the crest of the weir. Transverse rows of large boulders may be set into the design at regular or irregular intervals, to assist with the stability of the structure and to help retain water depths over the ramp. It may be advisable to create notches in the weir crest or lower the crest in whole or part to ensure that fish can negotiate the transition from the ramp over the crest. Alternatively, the ramp can be finished at a slightly higher level than the crest, with the subsequent back-watering of water over the crest. Simpler structures involving the random placement of coarse rock in a channel can provide fish passage benefits but care must be taken that the slope is sufficiently low to retain the new material under flood flow conditions.

A continuum exists between the low slope loose bed ramps to the locked in place large rock ramps at high slope that are stabilised with deep anchors such as sheet piles. Low slope loose ramps can be built without river diversion leading to a trade off between the size of the structure and the ease of build (low slope). Where rock has to be anchored and accurately placed diversion of river flow is often necessary. Some of the largest fish passage facillities in Europe are being built with significant rock ramp components (Ing and Gebler, 2007), with some suffuciently large to be significant habitats in their own right. In some cases it is possible to use such relatively high energy habitats to provide rare habitat in heavily modified rivers. In particular, for rheophilic species or species that require coarse substrate in which to spawn the riffles and pools that can be designed into large ramps may be very important for local fish populations.

Studies in Germany (Gebler, 1998) and Australia (Harris et al, 1998), have shown that small fish and even invertebrates are able to move upstream using rock ramps, making use of the interstitial system between the boulders and cobbles to effect migration.

Figure 47 The general design layout of experimental rock-ramp fishways in New South Wales, Australia (after Harris et al, 1998)

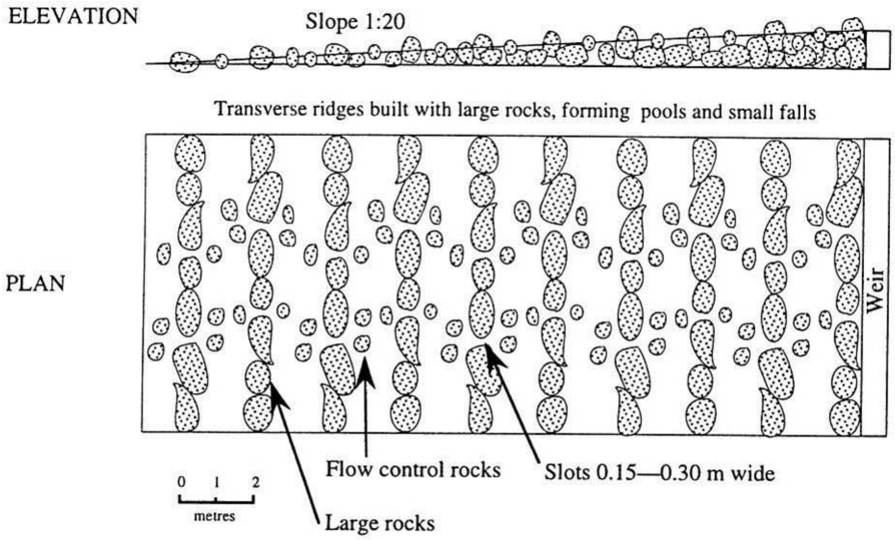
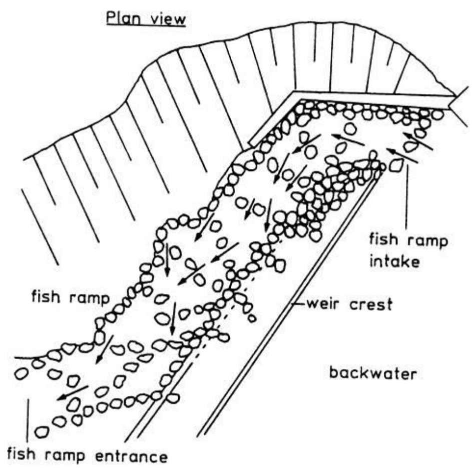


Figure 48 Plan view of a fish ramp in the corner of a weir on the Elz River, Germany (after Gebler, 1998)



In Wales a rock ramp with a gradient approaching 10% has had some success in permitting passage of sea trout in a naturally steep gradient river. A wide central section of a 1.5m high bed-check weir above a new passable culvert was removed. While re-grading was planned, a modest flood event succeeded in completing this naturally. Large rocks were added to help stabilise the resulting ramp, which extended over some 30m at a mean slope of 9.8% (the length of stream above was already at a steep gradient). Sea trout have subsequently spawned above this formerly impassable structure (Armstrong, pers comm).

Typically, large rocks that are used either to stabilise the structure or retain water depth on the ramp must be substantially embedded in the ramp. An often used rule of thumb is to embed the rocks by two thirds, in other words for each unit of height exposed two units must be embedded. In practical terms this can lead to rocks of substantial dimensions. It is also normal to include a wide range of rock sizes to "lock" the substrate rock together which also tends to reduce leakage through the bed during periods of low flow.

Where the rock ramp forms only part of the river width at an obstruction it may be necessary to artificially concentrate the flow ejected from the ramp to encourage some species to locate the ramp. In such cases a compromise is often required between the effectiveness of the attraction jet and the reduction in range of species that may be able to ascend the jet.

Where a wide range of species are required to pass extra features that increase heterogeneity of water velocity can be incorporated to aid the poor swimming species. These additional features may include a cross slope in the ramp as well as at the entrance to the facility which introduces a range of water depths and velocities. The lowest velocities being at the edges in the shallowest water.

Whilst most rock ramps are associated with large rocky structures, it is possible to construct rock ramps on rivers and streams using small rocks where the slope and limited flow range allows a stable structure to be formed. In such cases the effective slope can be reduced by the introduction of in-stream meanders created by the formation of alternating gravel/flint bankside projections. Structures such as these can be introduced in less than a day even using manual labour and a ready supply of substrate. Great care must be taken regarding the range of flow and velocity likely to be experienced as this will dictate the size of substrate required.

Suitable species: can potentially accommodate a wide range of aquatic fauna.

Head difference: normally ≤1m but can be used up to 2m with the use of resting pools.

Gradient: normally 1-5%.

Velocities: maximum heterogeneity desirable.

Strengths: suitable for a wide range of fish species and sizes. Relatively cheap and easy to install, operate and maintain. Can be adapted to a wide range of flow regimes. High aesthetic value.

Weaknesses: may settle or disintegrate in high flows if not constructed robustly.

Sweeps

In Denmark (Hyldegaard and Peterson, 1999) a novel approach to the problems of fish passage at existing dams has been developed, effectively combining a wide gap with a rock ramp. A large gap is created in the dam, and then parallel vertical double-pile walls are built either side of the gap back up through the entire impounded section of river (Figure 49) and until the head is lost over the previous natural channel slope. This effectively creates a channel within a channel (a low level ramp and a high level impoundment). The inner central channel (though it might also be made on one side or other of the river) is then re-formed with a low natural gradient in a similar way to a rock ramp, using natural materials that ensure a suitable ruggedness and heterogeneous velocity conditions. This approach has been taken at many relatively large barriers where there was a need to retain both parts of the original dam and the water level immediately upstream of the existing dam, for continued industrial activity.

The fishway channel is designed to give a minimum water depth of 0.2m, with maximum, mean cross-sectional water velocities of $<1ms^{-1}$ for 90% of the time during the main migration period. The sloping bed of the sweep channel has a gradient of <10‰ (i.e. <1%). The channel can be several hundred metres long, e.g. 350m long at Stora Dalum Paper Mill dam, Fyn County, Denmark. Sweeps and by-pass channels are now the only fishways used in Fyn County, Denmark on the basis that they are more efficient than other technical solutions, and also accommodate all species of fish.

Figure 49 Schematic diagram of a `through dam sweep` (after Hyldegaard & Peterson, 1999)

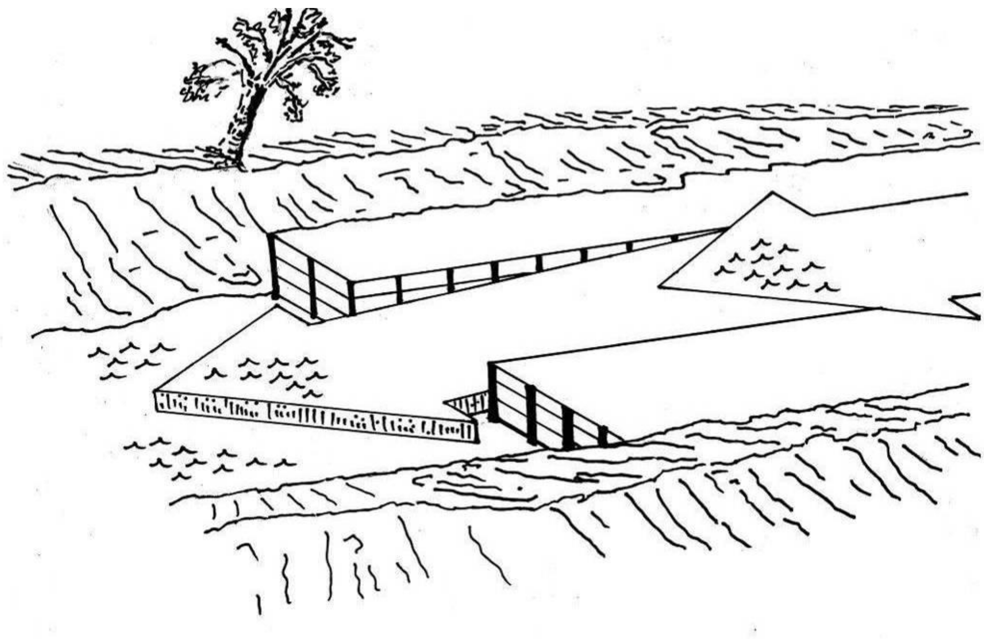
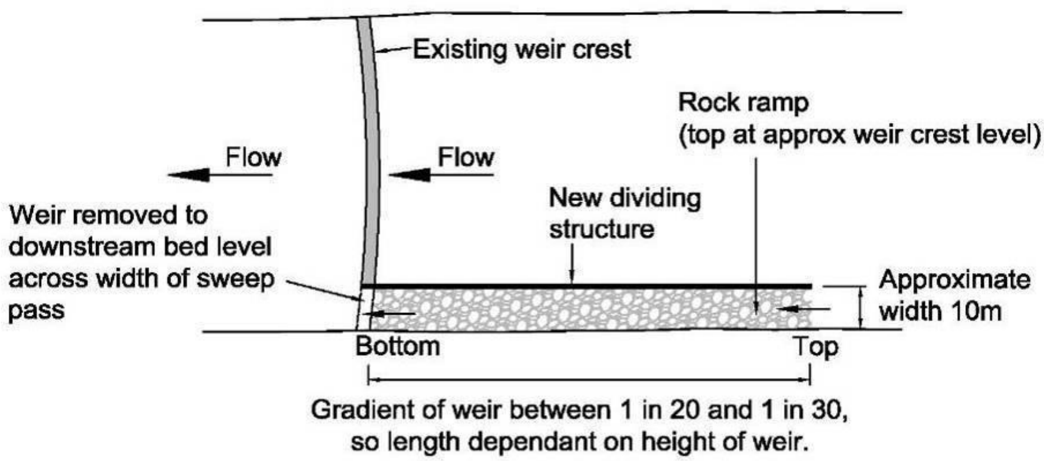


Figure 50 Asymetric arrangement of a sweep fishpass (courtesy of Atkins plc.)



Suitable species: all species.

Head difference: up to several metres.

Length & Gradient: up to several hundred metres long at a 1% gradient (might be steeper where large discharges are available).

Width: suitable to maintain the target depths and velocities specified below.

Depth & Velocity: Minimum depth of 0.2m and velocity (1.0 ms^{-1} during 90% of the relevant migration period(s).

Strengths: Efficient for a wide range of species, not prone to blockage.

Weaknesses: Significant aesthetic impact, that is not necessarily pleasing.

Artificial River Channels

Artificial river channels are widely used in Europe and in North America to overcome passage problems, frequently in relatively large rivers and at obstructions of considerable height (many metres). A continuous riverine link is formed round the barrier using a channel that can be more or less natural, depending on the specific site requirements. Energy is dissipated within the channel by means of informal structures (blockstone weirs) placed at regular intervals or by the unevenness of the channel bed, achieved using either natural materials (boulders) or purpose built blocks etc, or by mimicking pool/riffle sequences. Such channels can have a variety of uses, not solely related to fish passage. In some cases, the channel can be constructed to allow the spawning and subsequent development of fish, thus creating additional habitat in a river, or for the compensation for loss of habitat resulting from barrier construction. Channels can also be designed to accommodate recreational activities such as canoeing.

Where the design of the channel is more formal or semi-natural, with regular cross walls creating symmetrical pools, the structure can be designed with the normal energy dissipation characteristics and fish swimming abilities in mind.

Where more natural channels are envisaged, relying on bed roughness to reduce water velocities, physical modelling may be the most appropriate method of ensuring that the design achieves its objectives. Adjustments both during and after construction may be necessary.

Near natural artificial channels should be of a more gentle gradient (usually 0.03-2.5%) and can be made to accommodate the migration needs of most freshwater fish, both for upstream and downstream movements. If the channel is built to mimic a pool/riffle sequence, with a heterogeneity of flow characteristics, then a range of species not normally considered for fish passage can use the facility eg bleak, gudgeon, bullhead, loach etc. In the case of near natural channels, it is very important to monitor channel morphology changes after construction and make modifications if necessary.

A useful summary of design criteria, developed from a classification of channel widths and slopes originally proposed by Huet (1949), that can be used for planning natural type fishways is given by Parasiewicz et al (1998). This text also provides pertinent conceptual guidelines for the design and construction of this type of passage facility and is recommended as a reference source when planning them (Table 5).

Table 5 Framework used in the initial planning phase to describe the approximate dimensions in terms of slope, discharge and maximum mean velocities in nature like by-passes in Austria (After Parasieewicz et al, 1998)

Parameter	Upland	Upland	Lowland	Lowland
Mean river discharge (m^3s^{-1})	<20	20-100	<20	20-100
Bypass Discharge (m^3s^{-1})	0.25-1.0	1.0-5.0	0.25-1.0	1.0-5.0
Maximum pass slope (%)	0.3-2.5	0.2-1.75	0.1-0.3	0.05-0.2
Maximum mean x-section velocities (ms^{-1})	0.5-1.3	0.5-1.3	0.3-0.5	0.3-0.5
Mean by-pass channel width (m)	1-5	5-25	1-5	5-25

Whilst these channels can be used to overcome fish passage problems at structures which are already in existence, they have the disadvantage that they can often be quite long and require a relatively large amount of land for construction. Further, it is often difficult to locate the downstream end close to the barrier in question or to divert significant flows in to them, thus leading to difficulties in attractiveness for upstream migrants. The latter problem may not be so significant in small rivers where a high proportion of the river discharge can be used in the fishway.

Generally the by-pass channels can only provide suitable conditions over a limited flow range, and thus a limited range in upstream head. If the upstream head varies greatly then it will be necessary to have some form of formal control structure, more akin to a formal technical fish pass solution.

Suitable species: can be designed to accommodate even the poorest of swimmers.

Head difference: can be used to by-pass a wide range of heads - space is usually the limiting factor.

Gradient: ≤5% for low weir type fishways, ≤2.5% for near-natural channels.

Velocities: heterogeneous, natural stream channel velocities can be modelled in near natural channels.

Strengths: can accommodate virtually all species over a wide range of head differences. High aesthetic, and environmental value.

Weaknesses: require a large amount of land for construction and therefore may not be cheap. Can often be difficult to arrange to have the entrance immediately downstream of the barrier thus severely restricting attractivity and therefore efficiency.

In some instance channels intended for migratory salmonids may require formal approval.

Passage in Culverts and Other River Crossings

General

Wherever there are river crossings, for whatever purpose, the best solution from the environmental viewpoint is a clear span bridge that allows the original characteristics of the channel to be preserved. This ensures that there is no impediment to migration. These conditions might also be achieved using, for example, a bottomless-arch culvert of sufficient width, or an over-sized box culvert set well below bed level (≥0.5m), that allows natural sediment to form the the bed of the channel.

Environment Agency Culvert Policy (March 1999) makes a presumption against the use of culverts, since their use for any purpose causes a loss of open channel, a reduction of aquatic diversity, impinges on river corridor migrations of many different species, and also presents a flooding risk through blockage.,. However, culverts tend to be a cheaper option than constructing a clear span bridge and therefore tend to be the preferred option for developers. Where their construction is unavoidable, account needs to be taken of fish migratory requirements to ensure that the culvert does not present an obstruction to fish migration.

Generally culvert design for fish passage does not require formal fish pass approval and should be controlled through other appropriate legislation, principally land drainage consents. However, where technical structures are required within the culvert barrel to ensure satisfactory conditions for passage of migratory salmonids, then formal approval will be required in some cases.

In the past culverts, may well have been constructed which cause either delay or total exclusion of migrating fish. The common reasons for these problems include, excessive water velocities, inadequate depth or culvert diameter, perching of the downstream inlet, rapid change in stream hydraulics at the upstream inlet, lack of resting places, and debris accumulations causing physical blockage or creation of any of these factors. In such instances there are a number of structures that can be retro-fitted to improve fish migration, provided that the reduction in channel capacity does not pose an unacceptable increase in flood risk.

New Culverts

If, for whatever reason, it is not possible to use a clear span bridge and a culvert must be used, then the approach should be to ensure that the channel is as close to the original stream bed in terms of slope, bed material and wetted width, as is practicable. Only in the last resort should the environment in the culvert be an artificial one.

The problems listed above that impede passage in many existing culverts need to be avoided. Essentially the conditions in the culvert for successful fish passage must include adequate swimming space, adequate depth of water, appropriate water velocity, and no physical or behavioural barriers. In addition suitable resting areas may need to be provided below, and sometimes above the culvert. These conditions need not exist at all times or all flows, but must prevail during times (both seasons and flow windows) when fish are actively migrating. If the latter is not known precisely, it is suggested that these conditions are present for river flows between Q_{90} and Q_{10}.

Following an extensive review of the literature, appropriate design criteria for culverts for salmonids, are recommended by the Scottish Executive (Anon, 2000). These criteria, with some modifications, to include coarse fish, to increase minimum screen sizes, and to provide contiguous fish sizes, are reproduced in Table 6

If a culvert is screened the minimum screen gap quoted in the table should only be used where it is essential i.e. it should not be a presumption to use the minimum gap. Where a screen is provided to exclude trash wider gaps than these should be employed, preferably at least 250 or 300mm. Through-screen water velocities should not exceed the criteria applicable to the length of culvert being used, and a margin (e.g. 25%) should be allowed for increases in the through-screen velocity caused by the partial blockage of the screen brought about by accumulating trash.

In some cases conflict may arise between the need for screen gaps sized to allow fish passage and those required to safely prevent unauthorised or accidental access. In this case the reader is referred to the section entitled, Screening of Culverts and Other Openings (page 161), which describes the approach to be taken.

Table 6 Design criteria for culverts to enable fish to pass (Adapted after Scottish Executive, 2000)

Parameter	Notes	Coarse Fish Roach, Dace, Chub etc <25cms	Brown trout <25cms & large coarse fish 25-50cms	Small Sea trout & brown trout 25-50cms Large coarse fish >50cms	Salmon & large Sea trout >50cms
Maximum acceptable water velocity through culvert and any screen fitted (ms^{-1}):	*a,b,c,d*				
Culvert Length <20m		1.1	1.25	1.6	2.5
Culvert Length 20-30m		0.8	1.0	1.5	2.0
Culvert Length >30m		0.5	0.8	1.25	1.75
Minimum Diameter of Pipes (m)		0.3	0.3	0.3	0.5
Minimum Depth of Water (m)	*e*	0.1	0.1	0.15	0.3
Maximum water Level Drop (m)	*f*	0.1	0.2	0.3	0.3
Trash Screen (minimum gap)(m)	*gh*	0.10	0.10 (trout) & 0.15 (c/f)	0.15 (trout) & 0.15 (c/f)	0.2

Notes:

a) *Mean velocity of cross-section (there will be areas of lower and higher velocity) and through any screens fitted*

b) *The velocities for the shorter culverts approximate to the burst speed achievable by salmonids at 5 ℃, and the velocities for culverts >30m approximate to the cruising speed. For coarse fish they equate to mean burst speed and the median cruising speed achievable at 10 ℃.*

c) *These velocities should not be exceeded at any flow within the passage design flow range*

d) *Where screens are fitted the culvert entrance may need to be over-sized to enable the trough-screen velocity criteria to be met, and to allow a margin for the accumulation of trash that will cause the velocities to rise*

e) *Minimum depth acceptable at the lower end of the passage design flow range*

f) *Maximum drop at either intake or outlet*

g) *Where occasional horizontal bars are used on vertical screens they should be spaced at least 400mm apart*

h) *Screens should be constructed from square, oblong, or wedge-wire section materials, not round section materials (which more easily lead to gilled and trapped fish)*

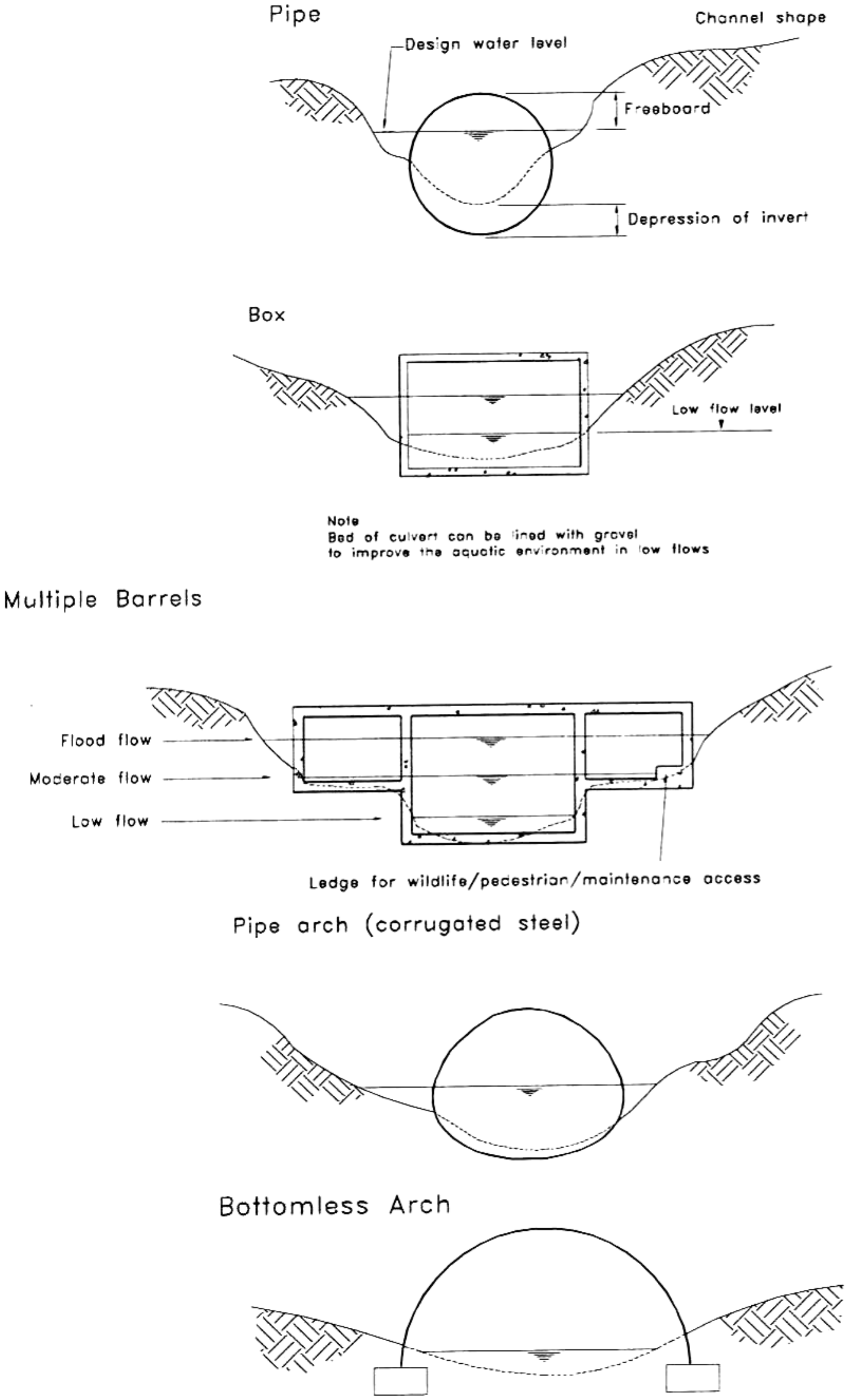
Many of the potential problems with culverts can be avoided by doing the following:

- matching the culvert gradient to that of the existing stream. Any changes are likely to cause unacceptable hydraulic conditions at the head or tail of the culvert. The most common problem is at the downstream end where excessive erosion occurs, resulting in perching of the culvert.
- drowning the downstream end of the culvert to a depth of at least 0.15-0.30m.
- providing a resting pool of sufficient size and depth immediately downstream of the culvert. Sometimes one may also be required upstream as well. The minimum depth should be 30cms for trout and coarse fish, and 45cms for salmon. An area of deeper water with adequate cover for cover and resting should also be included.
- aligning the culvert with the water course, i.e. no immediate change in direction at the head or tail of the structure. This minimises the length of culvert and provides a more stable hydraulic regime at inlet and outlet. It does not necessarily prevent moving the watercourse.
- ensuring that the approach conditions are within the cruising, i.e.sustained, swimming speed of the fish
- ensuring that if the use of trash screens cannot be avoided then they have adequate free gap for fish to pass unimpeded (see section on debris protection).
- avoiding sharp light/dark interfaces at the culvert entrance and exit. Fish can be reluctant to pass a sudden change, and this can be avoided, for example, by the judicious planting of vegetation.
- providing at least one barrel at a low enough level to permit passage at low flow where multiple -barrel culverts are used.
- using culverts with a high roughness coefficient to encourage boundary layer effects

Where culverts are used there are various configurations (Figure 51) that may be considered, in order of preference for fish passage these are:

- bottomless-arch culvert retaining the natural stream bed;
- culvert with a depressed invert to permit natural stream-bed materials to lie on the bed and sufficient depth of water in which fish can swim etc;
- provision of a low flow channel within the barrel and;
- provision of baffles within the culvert.

Figure 51 Examples of culvert types



It is possible that appropriate conditions may result simply from design considerations for flood flow, however it is far more likely that the culvert will need to be over-sized.

Existing Culverts

In the case of existing culverts where there are problems these can generally be ameliorated by using the combined effects of increased water depth and reduced water velocity. This is achieved by increasing roughness, in the form of some type of baffle or other structure, or else by back-watering the culvert using a pre-barrage, or by a combination of these. Since all of these will reduce, sometimes very dramatically, the discharge capacity of the culvert a very careful consideration of the risks of doing so is required. Where it is intended to retro-fit baffles to a culvert (s) the flood defence impacts must be assessed and any works agreed with and consented by the relevant Authority (usually Flood & Coastal Risk Management, FCRM, Environment Agency).

In designing baffles for a culvert a distinction should be drawn between baffles designed to increase roughness and dissipate energy continuously, and weirs that dissipate energy in a concentrated area. Baffles are relatively low and spaced closely together, with streaming flow over them and/or between in any gaps between them where they are paired. If large enough to constitute weirs then designs would follow the principles used in pool passes. Bates (1997) gives a succinct description of culvert baffles, and further detailed information can be found in a series of papers by Rajaratnam and Katopodis with others, 1988, 1989, 1990a and b, 1991.

Simple Baffles

Various simple baffle designs have been described may be applied to any of the typical culvert cross-sections (most usually round or square). Various examples of these are shown in Figure 52 and Figure 53.

Figure 52 Baffle designs for barrel culverts (After Bates, 1992)

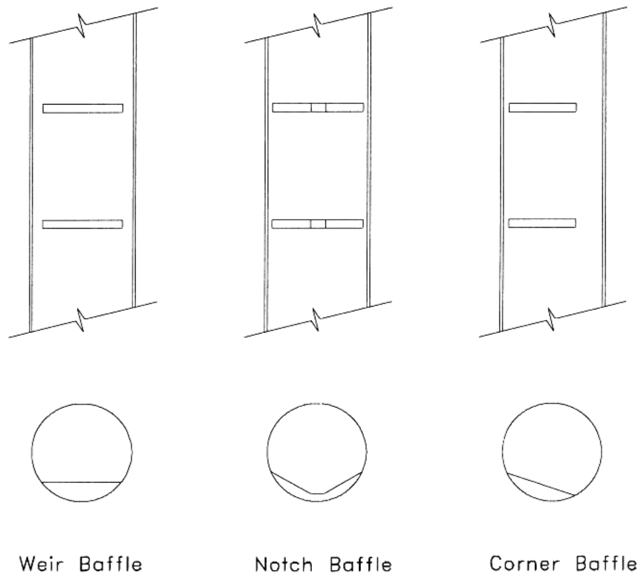


Figure 53 Rectangular, triangular, and slotted baffle systems (After Larinier, 2002).

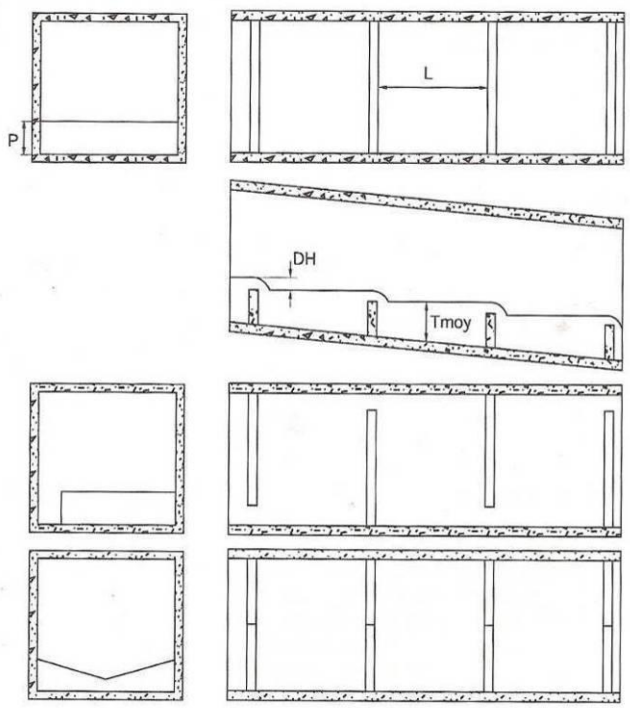
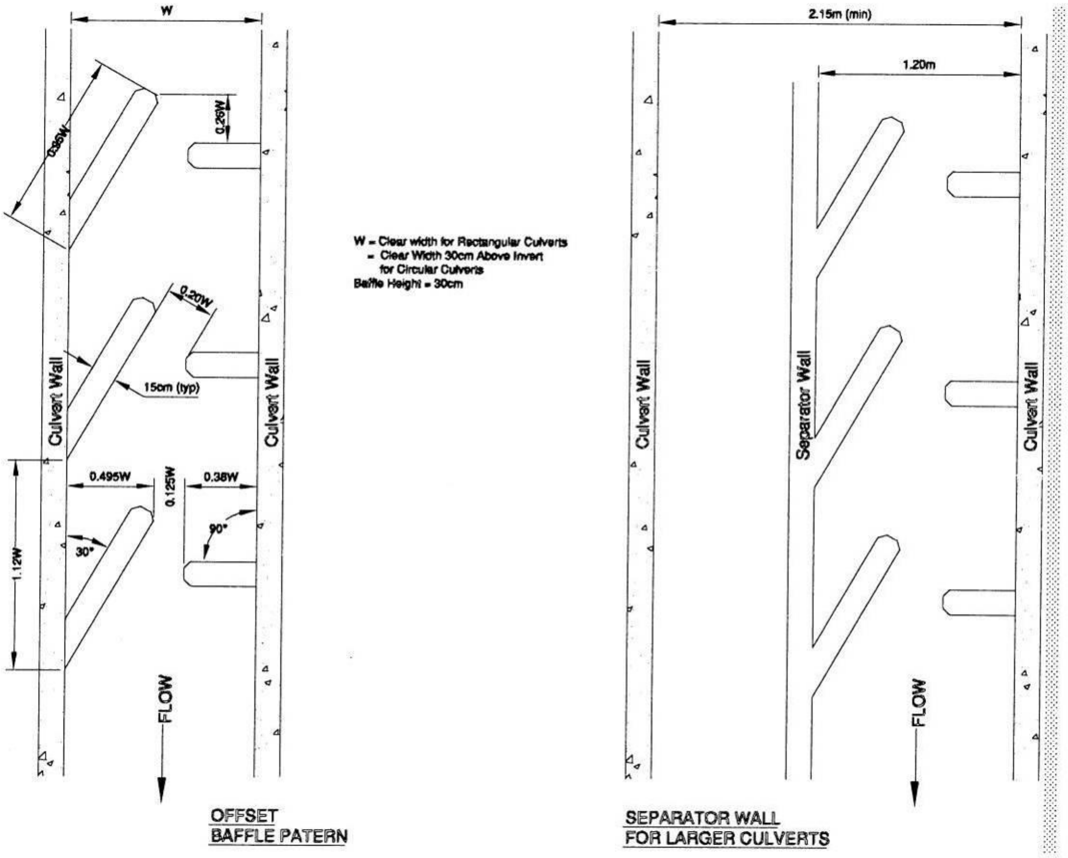


Figure 54 Geometric characteristics of the off-set baffle (After McKinley & Webb, 1956)



Weir baffles in pipes, usually between 0.15-0.45m in height, are used to create roughness. They are not recommended for slopes over 1%.

Corner baffles in pipes are used typically in culverts with slopes between 1-2.5%.

Notch baffles in pipes are particularly useful in wide (e.g. pipe-arch) culverts where the slope is between 2.5-5%. The height of the central length of notch can be zero i.e. effectively two corner baffles. Where the height of the central notch is zero and depending on the culvert dimensions, baffle may be considerable up to a metre or more.

Horizontal baffles with notches or slots used in flat cross-section or box culverts essentially mimic the pool pass, and ay be designed using similar criteria. Baffle heights should be sufficient to retain the appropriate depth for the target species (see earlier guidelines Table 6) at the point immediately downstream of each baffle. Depth of water at this point should be 2-2.5 times the head drop across the baffle. Power dissipation in each 'pool' should be acceptable following the same criteria for pool passes. The spacing of the baffles should ensure that flow does not become surging. Useful guidelines are provided in the form of a simple formula (Larinier & Chorda (1995), Larinier (2002e)). They suggest that the requirements outlined mean that the height of weirs (p) will generally vary between 0.15 – 0.40m with weir spacings (L) such that the value (S x L/p) lies between 0.20 and 0.30, where S is the slope of the structure:

$$0.20 \leq (S \times L/P) \leq 0.30$$

Triangular- crested baffles in box culverts create more heterogeneous flow conditions than simple horizontal baffles, providing variation in depths that fish can choose at any particular discharge. The slopes on the sides of the triangle are generally between 1:5 to 1:7. The formula for horizontal baffles above applies for baffle spacing.

Off-set Baffles

Another baffle system developed for use in culverts of box, circular or arch section is the off-set system developed by McKinley & Webb (1956). It was designed for use in culverts with a slope between 2.5-5%. These baffles are more hydraulically efficient acting as energy dissipators. Where bed-load movement is a consideration care, should be taken not to make notch widths too small (can occur in culverts <1.8m wide), and the spacing should ensure a minimum hydraulic drop of at least 0.06m in order to prevent gravel from inundating the baffles (Bates, 1992). Model tests by Larinier & Chorda, 1995 showed that baffle spacing could be increased if desired to help reduce the number of baffles required with the spacing (L) varied according to the height of the baffles (p) and the slope of the culvert (s) as follows:

$$0.25 \leq S \times L/p \leq 0.35$$

The off-set baffle system has been successfully employed in SW Wales (see examples below).

This baffle system can be adapted for shallower sloping culverts (between 1-2.5% slope) by shortening or removing the stub baffle. In very wide culverts, >2.15m, an off-set baffle system can be confined to one side of the structure.

Figure 54 shows the characteristics of the off-set baffle.

Some examples of baffle use in culverts

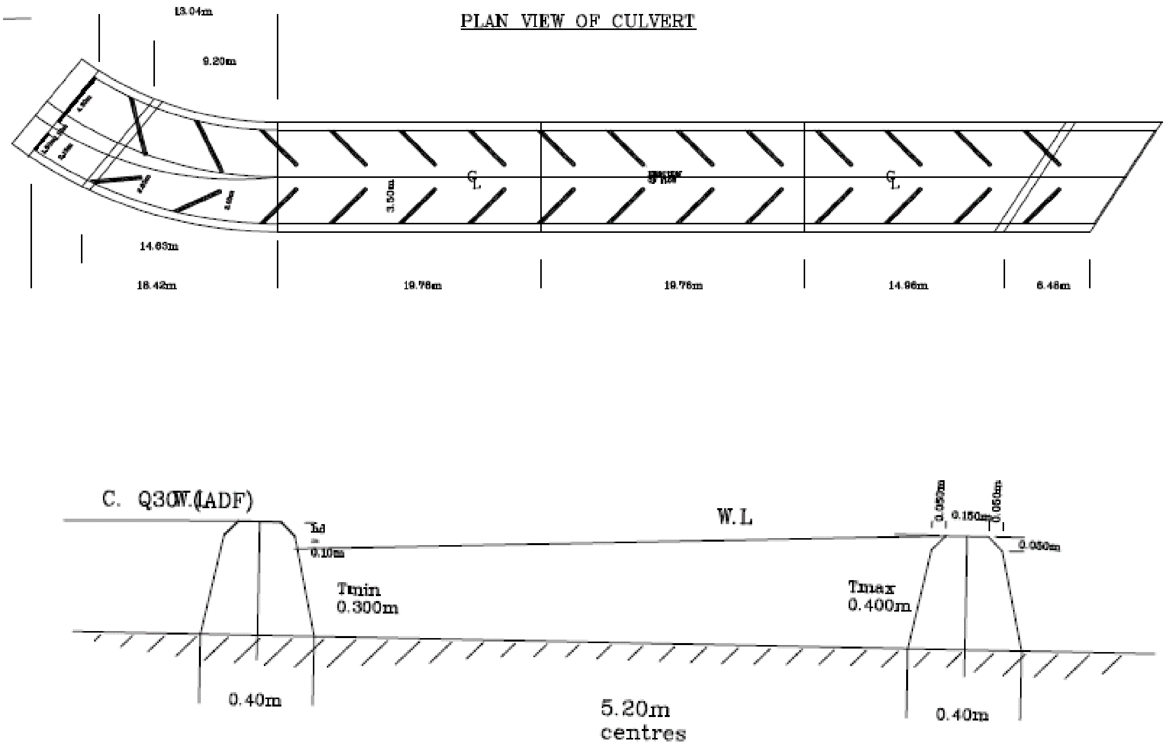
Notched baffles 0.20m high, and at 1.48m centres, were successfully deployed in one barrel of a 1.8m diameter culvert about 30m long, 4.7% slope, at Llwydarth, Nant Sychbant, SW Wales. The other barrel of this twin culvert had a slightly shallower gradient of 4.1% and here off-set baffles 0.3m high, again at 1.48m centres, were deployed (see below). Baffles were fabricated from a sustainable source of (green) oak. Despite the fact that the perching of the culverts was not addressed, migratory salmonids passed them the first spawning season after installation.

In a typical box culvert, usually a relatively wide oblong section, a simple Chevron baffle system with paired baffles (one each side of culvert) set facing upstream at an angle of 45° to the culvert wall and with a free gap have been used successfully in a number of culverts in locations in SW Wales, UK and France (pers comm., Michel Larinier). These culverts have usually had a slope < 2.5%. Baffles have consisted various materials including concrete, but are generally fabricated from sustainable sources of (green) oak. Spacing between baffles has taken account of the culvert slope and the need to maintain a head drop of 0.06m (as below) between successive baffle pairs. The height of the baffles has varied, generally between around 0.20 – 0.40m, following a maxim of preserving 0.30m depth in the free gap between baffles for salmon and a minimum of 0.15m for sea trout (for brown trout 0.10m would suffice). Given that many of these applications were on small tributaries or else well up catchments, the width of free gap was designed generally to be full at river discharges around Q_{30}. A drowned flow equation like that for the deep slot passes was used to roughly estimate the hydraulic condition.

At Grwylech culvert carrying a road by-pass in the River Neath catchment, concrete baffles were used in a perched (by 0.7m) 7m wide, 80m long culvert, of 2% slope, that had been impassable for migratory salmonids ever since its construction. The baffles were very large, 400mm high and set in pairs at 5.20m centres with a 1.60m free gap, maintaining a depth of 0.30m at the free gap in the next baffles upstream (see Fig nn) at around Q_{30} river discharge. Despite the fact that the perching was not addressed, nor was making the flow over the downstream culvert edge adherent (usually accomplished by using a nappe plate bolted on), and in fact, the two baffles creating a water depth and notch (1.10m wide) at the front of the apron actually increased the hydraulic head drop, fish were able to pass the culvert the first spawning season after installation.

Best practice dictates that the upper edges and ends of the baffles be at least chamfered so that there are no sharp edges for fish to damage themselves, and a tendency to promote adherent and less turbulent (aerated) flows. However, in the more rustic approaches with sustainable wooden baffles this has not always been carried out.

Figure 55 Chevron culvert baffle design detail for Grwylech Culvert, Afon Grwylech, SW Wales.



Fixing Baffles to Weirs and other Surfaces

Fixing baffles to weirs, aprons, and culvert floors requires some care since the quality and integrity of the structure the baffles are being fixed to can be very uncertain, and is often in a poor condition sub-surface e.g. containing voids, consisting loose material etc. Voids and loose material in the structure being fixed to weaken the structure and inappropriate fixings used with the baffles may lead to catastrophic failure that includes damaging the structure itself as well as losing the baffles. Each site must be treated on its own merits, depending on the size, fabrication material, and weight of baffle together with the severity of forces acting on it. The following approach to fixing has been developed in South West Wales as experience has been gained providing baffle easements, using timber baffles (green oak from sustainable sources) typically 200 – 300mm high:

- Carry out some experimental drillings to help identify any issues e.g. voids, nature and depth of sound material for fixing to, depth of loose material etc
- For large timbers (200-300mm high), use 25mm or larger threaded high tensile bar (stainless steel, galvanised) for fixing.
- Place the pre-drilled baffle in position and drill through the baffle fixing holes and into the accommodating surface. For a 300mm baffle a minimum of 200mm depth of fixing is required. Where the baffle will experience significant lateral forces this should be increased. Drill holes in the baffle should be countersunk to accommodate a top nut fixing.
- Place baffle in position on a bed of proprietary bedding mortar such as ROTAFIX, especially where the receiving surface is uneven. Threaded bar should be in location to ensure correct positioning of baffle.
- Fix the threaded bar in the receiving base hole using a proprietary anchor grout and activator such as ZEROSET. Both bedding mortar and anchor grout will then "go-off" together. If there are voids, fill with an injected proprietary CEMBOND product such as ROTAFIX, allow to harden and then re-drill the fixing hole.
- The top nut should then be tightened just by hand in the first instance. When the oak baffle takes on water it will swell and an over tightened fixing has the potential to "pop" by pulling out the fixing as the baffle increase slightly in width and height.
- Once the baffle has been immersed in water and has had sufficient opportunity to take on water (a few days) then the fixing can then be tightened with a torque wrench and any excess bar cut above the top nut. For both security and hydrodynamics, the counter sunk voids can then be filled with bedding mortar to form a continuous surface.
- It is not recommended to use mechanical fixings such as thunder bolts or rawl plugs. These put pressure on the accommodating surface and can cause cracking and compromise overall integrity. This is of particular concern when the original structure is in poor condition.
- For extra robustness, where required, the baffle can be haunched with bedding mortar to help resist lateral pressure. This may affect the hydraulics so technical guidance should be sought before this is carried out.

Increasing Bed Roughness

A simple bed-load collector has been used to increase roughness of culverts in Montana, USA. A pre-fabricated steel frame (Figure 56) of an appropriate length is constructed to install on the channel bed. Two or three large rocks are placed against each cross-member and used to increase roughness, thus increasing depth and lowering velocities. The rebar loops are set at an angle upstream so that the rocks set against them act to hold down the frame.

Figure 56 Detail of a Montana bed-load collector (After Belford & Gould, 1989)

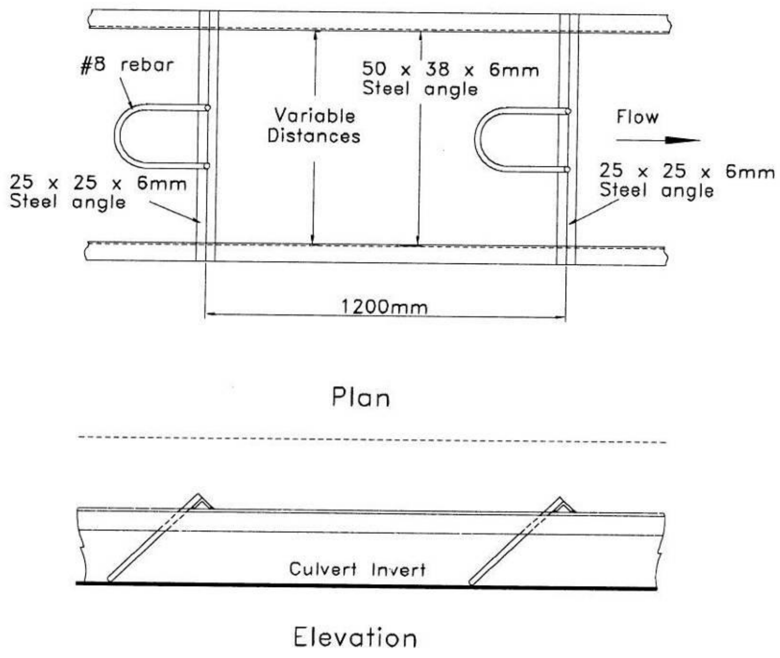


Figure 57 Typical configuration of a culvert pre-barrage

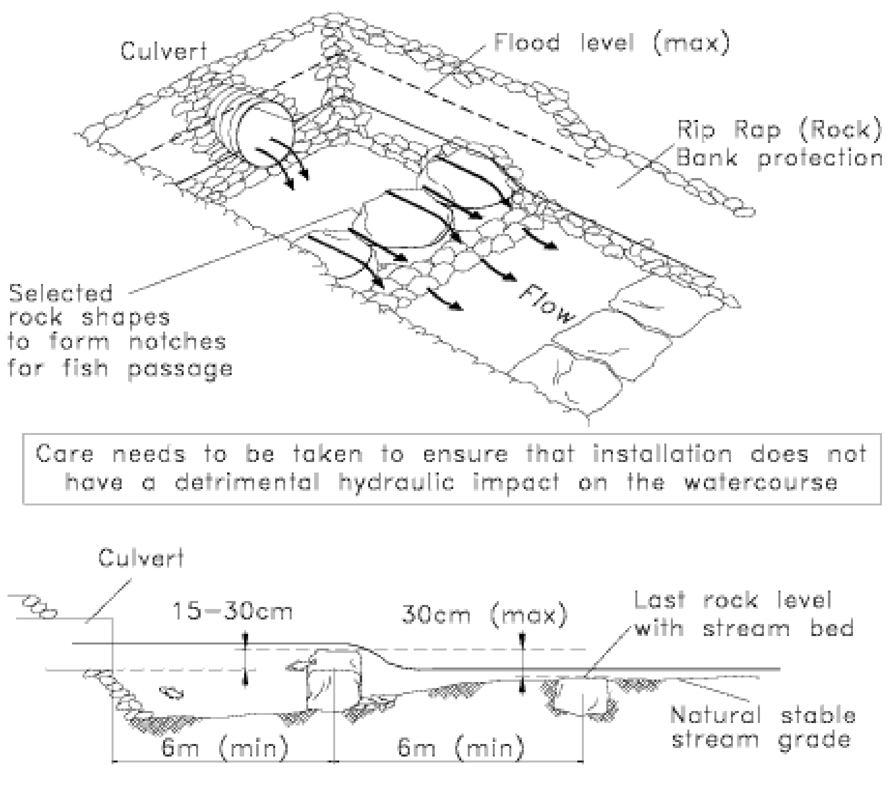


Figure 7.1 Typical Dimensions for a Low Stone Weir

Raising Tail-water levels

As with other obstructions a simple solution to problems is often the installation of a weir or pre-barrage downstream of the outlet (Figure 57). This can be used to cure perching, and to improve the water depth in the culvert. Low weirs can be constructed of stone or other materials. They should have head drops of not more than 0.3m, and be not less than 6m apart if possible. Where necessary, notches should be provided to ensure a sufficient width and depth in which fish can traverse the weir. Depth below the traverse should be at least twice the head drop. The most downstream structure may benefit from having a free gap, rather than consisting of a notch. Care should be taken to ensure that any pre-barrage used will not result in erosion, and become perched itself. Specifically raising tail-water levels and the conditions required in stilling basins for gauging weirs are discussed in a later section (see Fish passage at gauging stations, page 192).

Screening of Culverts and Other Openings

Background

There is a potential for conflict between the need to maintain free passage of migrating fish in watercourses and, where required, to exclude waterborne debris, unauthorised entry by humans, or accidental access by humans or other mammals. In such cases careful consideration has to be given to the design of any screens.

The Environment Agency's approach to best practice for the design and installation of screens is detailed in the Trash Screens: A Design and Operations Manual (R&D Publication 5A, Version 1, 2001). This document is also referred to in the Flood Defence Information Sheet No10 (Wales) which gives guidelines for external applications. The manual provides a detailed method for carrying out a risk assessment and making the decision whether a screen is required or not.

A screen should be designed and installed where there is a high risk of culvert blockage where that blockage would result in serious consequences (e.g. flooding of property), and where there are no other economic alternatives for removing the risk or minimising the risk to an acceptable level. Additionally they should be installed where there is an unacceptable risk of a fatality occurring as a result of unauthorised entry into the culvert. In summary, key independent reasons for screening include the prevention of blockage, the prevention of unauthorised or accidental entry, and the prevention of damage to the infrastructure of the culvert by debris. Clearly the risks and the need for a screen will be generally higher in urban areas than in rural ones, and this may help reduce the potential conflict with fish passage issues in the latter areas.

The most frequent reason for screening will be to exclude trash. This is not likely to be a particular conflict with fish passage issues since screens with small gaps will block quickly, and this will generally mitigate against using the size of free gaps that will create problems for migrating fish. The conflict will arise where the screens are installed for security reasons to prevent unauthorised access. Where security is an issue the guidelines recommended free gap in the screens is ≥75mm≤150mm. Screens should be a minimum of 75mm because of the increased risk of blockage with smaller gaps. Generally a gap of 150mm is regarded as sufficient to exclude children, although in areas of very high risk it might be considered appropriate to reduce this.

Guidelines

Criteria to be used in designing screens for culverts, while at the same time providing for fish passage are included in Table 6. Attention needs to be paid to the free gap dimensions, minimum depths and maximum through-screen velocities.

Where security is not an issue and it is simply a case of protection from water-borne debris, then the free gap used for screens should err on the generous size and not be limited to the minimum gap specified in the table. Thus, the size of free gap employed in the screen should be 250-300mm.

Conflicting needs for screen gaps will generally arise where large migratory salmonids are present and where the risk of unauthorised or accidental access is high. They may also occur where fish >25cms are present and there is considered to be a need to use a screen gap <150mm because the risk of unauthorised or accidental access is exceptionally high. These occasions should be identified as the result of a rigorous and appropriate application of the EA Screening Guidelines. In these cases a section of the screen adjacent to the culvert bed should be provided that meets the criteria for fish passage. It should occupy a minimum depth of 400mm, but should extend to be near to the normal water surface where the water is deep. The remainder of the screen may then consist of whatever smaller gap is considered appropriate for security purposes.

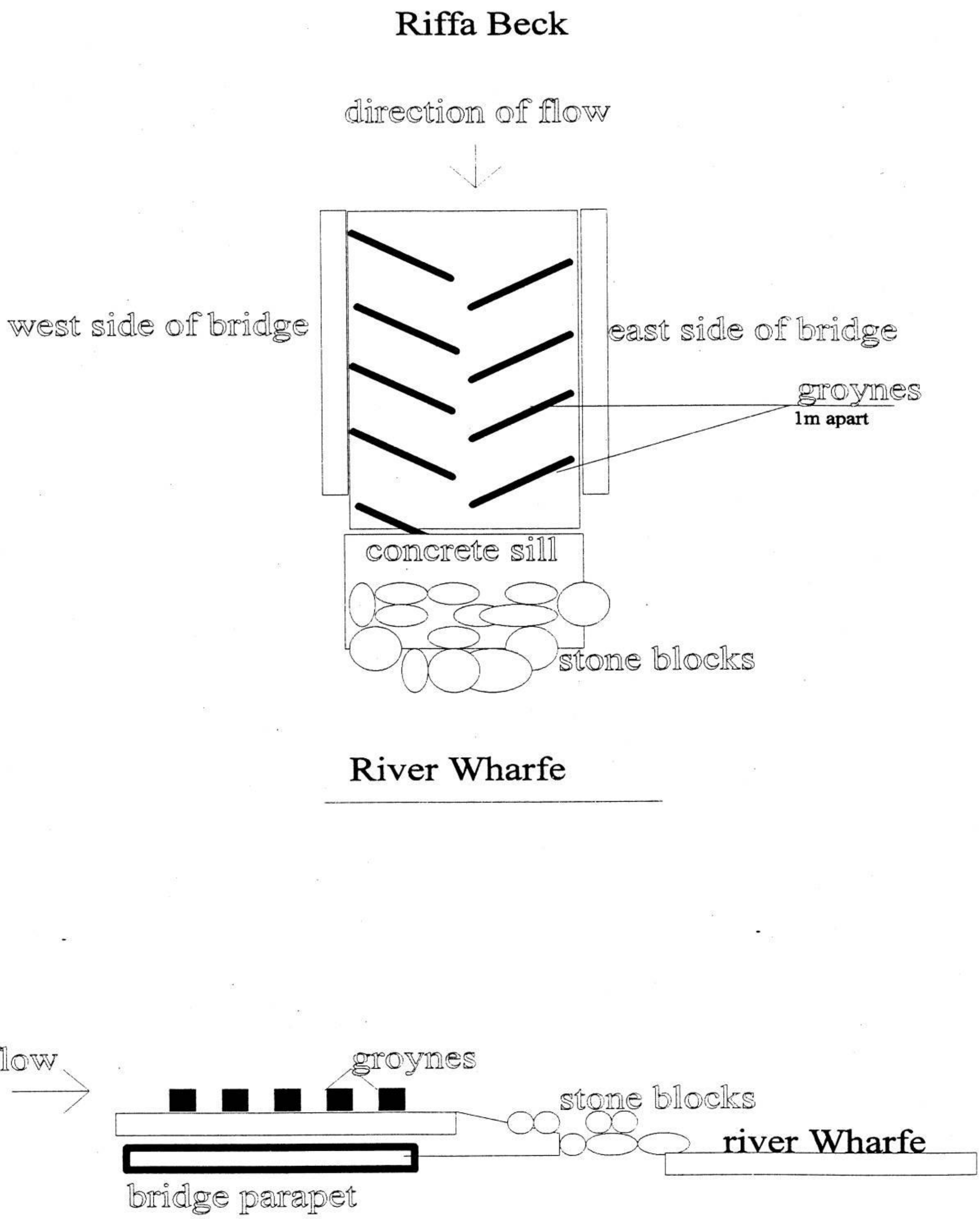
Bridges

New bridges should be clear span, or else have foundations of in-river piers and abutments of sufficient depth to avoid the problems from scour that would require aprons and weirs to be provided (see BA 59/94 in Volume 2, Design manual for Roads and Bridges, 1993). If the latter features are absolutely necessary then the criteria, conditions and solutions used above for culverts apply. At least some part of the structure must provide adequate depths, and low enough velocities for fish to migrate during the appropriate times and river discharges.

In the case of existing bridges any of the retro-fit solutions involving baffles or pre-barrages described for culverts might be used, although in the worst cases technical fish pass solutions may be required.

Other simple designs, using baffles between 0.15-0.35m high, can be envisaged for use on bridge aprons. Such systems are presently being used at various sites in the Regions, and an example is shown in Figure 58.

Figure 58 Baffle system in use at road bridges in North East England



Fords

Problems with fords are the same as for culverts and bridge aprons, though often the magnitude of the problem is less since the crossing is not so wide. A problem with inadequate depth may be resolved by constructing a central deeper channel, or else a small conduit or culvert through the ford to act as a low flow channel. The design criteria for culverts given above can be applied to the specification of a conduit or culvert option. However, a draw-back of such an approach is that the resulting small culverts are easily blocked, and this may result in excessive maintenance requirements.

Where small fish are the sole concern then a novel solution may be to construct the ford using blocks with a gap between them that is large enough to permit fish passage (perhaps 0.15-0.2m), but small enough to allow vehicular passage.

More radical solutions include the replacement of the ford with a free span bridge, or more often a box culvert of large enough dimensions to ensure that culvert passage conditions as previously outlined are met.

Tidal Flap Gates

Flap gates are normally, but not exclusively, used for the purposes of flood protection and prevention of saltwater incursion in tidal areas. Often these purposes are mutually inclusive. Conventionally gates are hinged at the top and hang over a conduit to act as a one-way valve. A force, i.e. a head differential, on the upstream side will open the gate, while one on the downstream side will close it. The stream can drain in a normal direction for part of a tidal cycle, how long depending on the level it is set at and the tidal range. Regardless of how long it drains because of the height that it is set at, it will only permit fish passage, if at all, over a very limited part of the tidal cycle. This is because the gate is firmly shut over much of the tidal cycle. Even if open a lot of the time because it is set high relative to tidal range, it will then probably be perched thus effectively preventing fish entry.

Traditionally, the gates are made of cast iron, hardwood, or some other heavy-duty material. As a result these heavy gates have a relatively high inertia, openings are minimal, and often the gate(s) never opens far enough to permit fish passage at all. When they are open water velocities in the culvert behind the flap are often high, and this is exacerbated if the gate is perched.

Before attempting to improve a situation where fish access is poor, consideration has to be given to the wider ramifications of permitting more tidal incursion and inundation. This is because it may not be environmentally or socially acceptable for reasons not associated with fish migration. Presuming that it is acceptable then potentially there are a number of possible solutions, or at least improvements that can be made to enhance fish passage.

In most cases it is best to limit any improvement to just one of the control gates. If all gates were to be improved, sharing flow between them all, then little benefit would accrue. Having one (or more) designated gate to take most of the flow most of the time, provides the largest benefit. Often the gate or gates designated for fish movement will be set at a lower elevation than the others.

Side-hung Gates

The hinges hanging the gate may be rotated from the horizontal to near the vertical, but not entirely vertical since otherwise the weight of the gate would not help to shut it. The hinge needs to be modified in order to cope structurally with the weight of the gate, and to physically prevent the gate from opening so far that it cannot be shut by the downstream forces. The gate will open far more easily, much further, and stay open longer. In addition fish can enter from the side more easily than they can from below.

Counter-balanced & Light-weight Gates

Heavy gates can be modified by providing counter-balances on the fluvial side so that it is just closes, but is capable of having a large opening when circumstances permit because of the reduced forces needed to open it. Alternativly, the use of light-weight materials like plastic (GRP) or aluminium, formed into a thin dome shape, will also permit the gate to open very much further for any given differential head. In either case, it also means that the gate at least stays open for a longer period during the tidal cycle.

The gate needs to open at least 0.3m for a head differential of ≤0.3m (Bates, 1997). The opening is defined as the point where the gap is at its maximum i.e. usually the point directly opposite the hinge. The theoretical benefits of using light-weight gates was clearly demonstrated by Bates by considering the differences in hydraulic characteristics of cast iron and aluminium gates. Bates produced curves plotting the maximum opening of cast iron and aluminium gates against head differential and discharge (Figure 59 & Figure 60). These were derived from a theoretical static, hydraulic model that accounted for specific weight and submergence of the gate and pressure head. They demonstrate that for a 1.2m diameter gate, a cast iron one has no condition where it meets the above opening criteria. In contrast, the aluminium gate is open wide. For example at a head differential of one foot and no submergence, the aluminium gate is open over 0.75m and the cast iron gate is open about 0.15m.

Figure 59 Gap and flow for a 4-foot (1.2m) cast iron flap gate (After Bates, 1997)

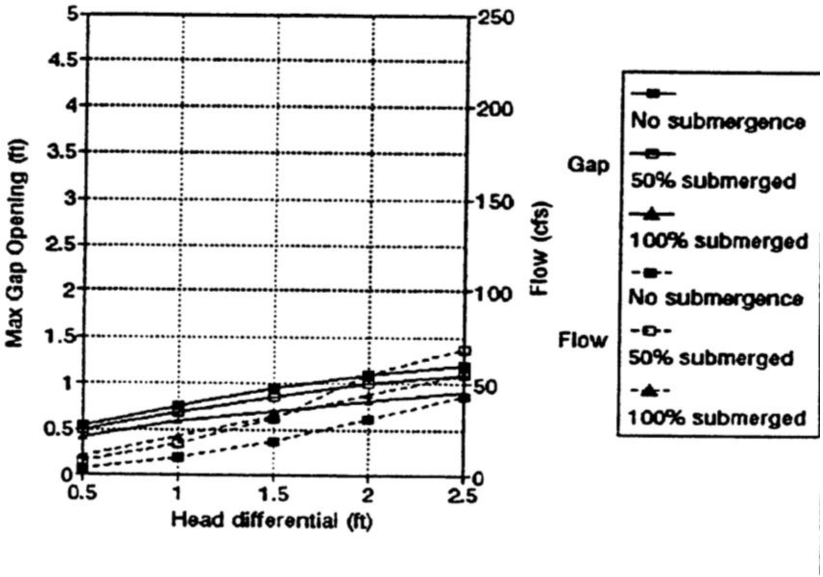
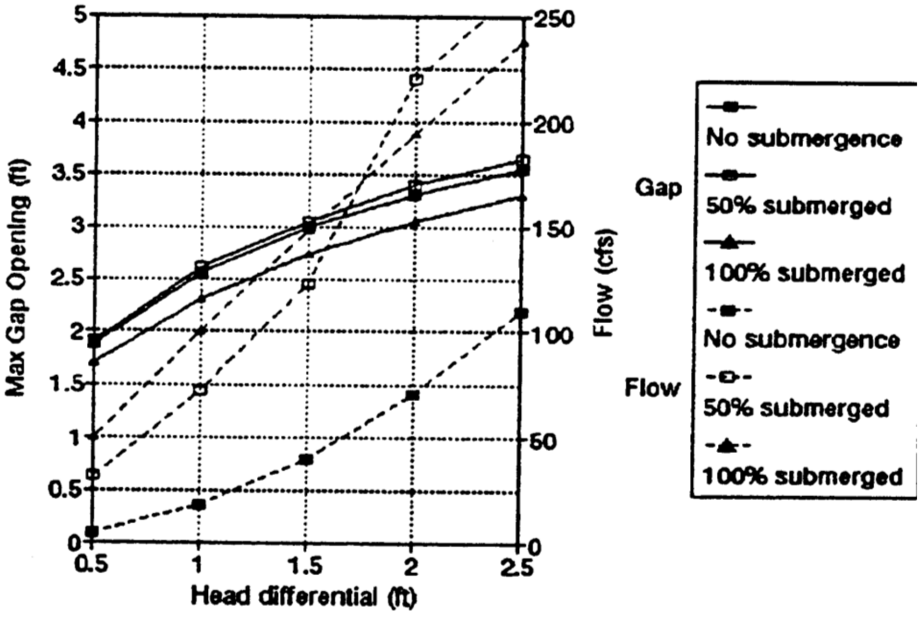


Figure 60 Gap and flow for a 4-foot (1.2m) aluminium flap gate (After Bates, 1997)



An additional benefit of a light-weight gate is the resulting additional discharge capacity, that drains the upstream impoundment more quickly thus equalising levels more swiftly. This ensures that optimum passage conditions are achieved and maintained longer in any one tidal cycle. This helps maximise the time available for migration.

Automated gates

Another solution is electrically powered automated sluices, with their operation linked to the tidal cycle. The benefits of these are that the sluices can be open fully, and the time that they remain open can be maximised. The disadvantages are that they are expensive to install, operate, and maintain. The requirement for electrical power may also seriously compromise the feasibility of such an alternative.

Self Regulating Gates (SRT Gates)

A solution that is novel to Europe, but which has been used in the USA for 15-20 years, is the Self-Regulating Tideway gate (SRT Gate*). The gate has many attributes including that it; requires no electrical power supply, can be adjusted manually to operate over a specified range, and it is robust requiring little maintenance. The gate uses a system of floats to operate it, and generally stays open across a wide part of the tidal range. However, it is versatile enough to be set just to prevent tidal surges or be limited to opening across only a small part of the tidal range. The very significant advantage that this gate has over other types is that when it is open it is fully open, with the gate floating on top of the water, thus making fish passage easy. Because it is in a free flowing state any species of fish can pass. In many ways it is an ideal solution where there are no social or other environmental reasons for preventing tidal incursion. Indeed, in many situations it may provide a safe means of re-estuarising areas of habitat thus having a much wider ecological and conservation value[3].

Figure 61 shows the principles of operation of the SRT Gate.

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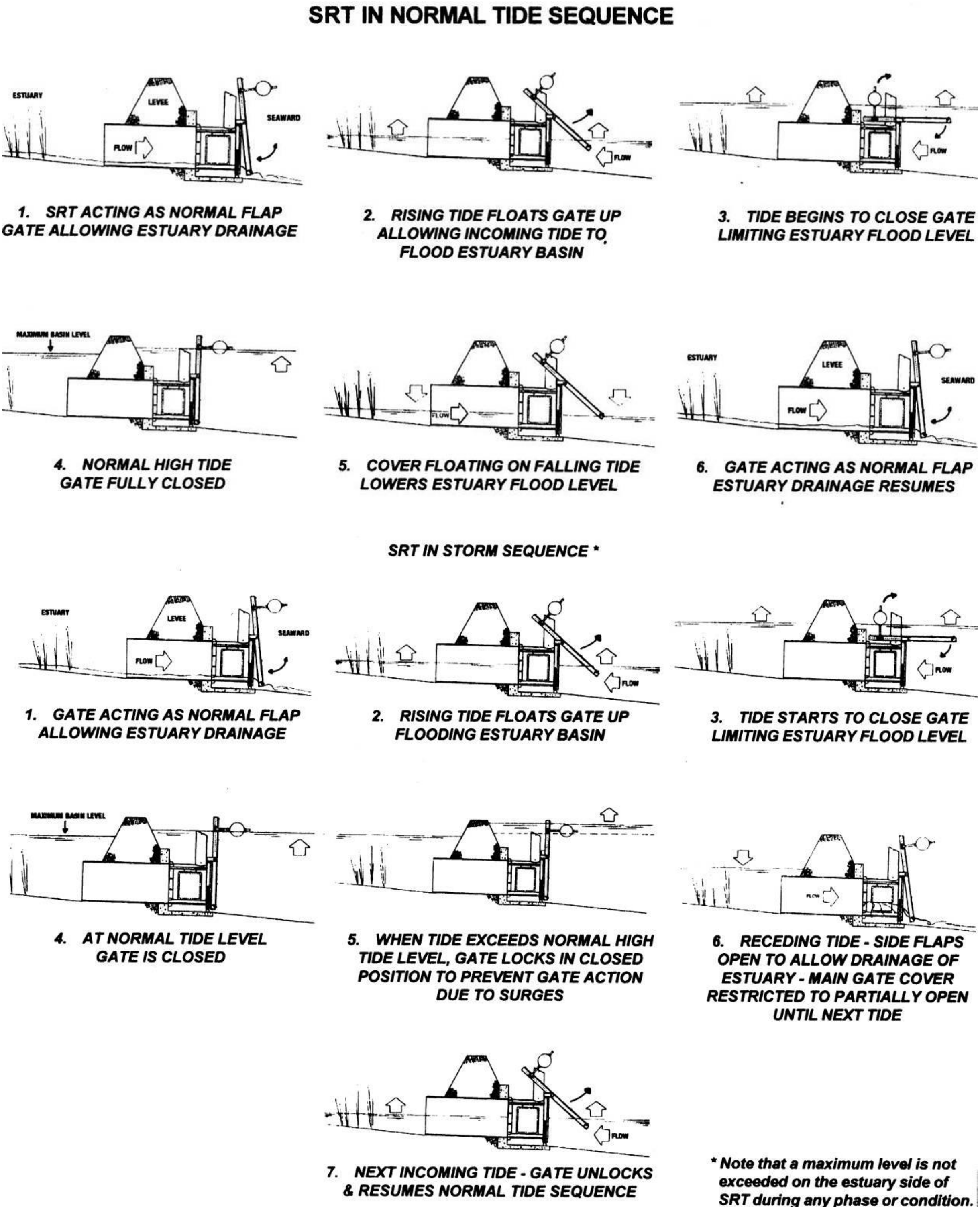
[3] SRT Gates are manufactured by Waterman Industries Inc., Exeter, California, USA and can be procured through their agents Anthony Timms, Water Control Products International, Villa Farm, Isle Brewers, Taunton, TA3 6QL.

Figure 61 Operating sequence of the SRT Gate (courtesy of Waterman Industries Inc)



ANGUILLIFORM PASSES

General

Eels present a special case in terms of arranging free passage. Elvers and small eels, which are the stages that it is essential to pass upstream, are very poor swimmers compared to the adult stages of other fish that migrate upstream. Eels are not capable of jumping. While elvers can be good climbers in appropriate circumstances, once a vertical barriers is greater than the equivalent of 50-60% of their body length then it becomes impassable (Knights & White, 1998). Eels, especially females, can actively migrate for a number of years during which they can occupy a considerable range in size between ≤10cm to >50cm.

Because of their morphology it can probably be expected that the larger eels are adept at using lower water velocity areas associated with boundary layers or turbulence in order to progress. As such it is likely that fish over about 30cm are capable of using some types of conventional type fishways provided that they do not have to jump. For example, larger eel have sometimes been monitored successfully negotiating Larinier Super-active baffle passes. However, recent observations (Andy Don, pers comm.) of migrating eels on the River Parrett in SW England have demonstrated quite clearly that, given the choice of a conventional Larinier pass and a bristle ramp, all sizes of eel (10 – 50cms) almost exclusively chose the ramp. It is therefore suggested that separate fishway should therefore be provided for eels in all circumstances where their passage is a requirement.

In the recent past two principle types of passage facility have been provided for elvers and small eels – open or closed channel (media occupying part or the whole of the channel respectively). Both types rely on providing a wetted medium (e.g bristles, brushes, bosses), which the eels can readily gain purchase and wriggle through. The pass need only be provided with a very small flow of water of sufficient volume to keep the medium well wetted – for example, recent evidence is that for pump fed facilities a flow of only $0.5ls^{-1}$ is sufficient for effective passage. It can be beneficial to provide an additional attraction flow at the downstream entrance. An attraction flow may be available because the eel pass is located adjacent to a facility for other species, or else separate arrangements may be made to inject additional flow at a low velocity near the pass entrance, or else sprayed on to the water surface near the entrance.

The downstream entrance should be located in an area where eels are observed to congregate. This will usually be in an area where there is a positive but weak and low velocity flow away from the obstruction, not an area where velocity is high. The upstream exit from the pass must be sufficiently far upstream and preferably in a low velocity zone in order to avoid migrating fish being washed back downstream. It is essential to extend the pass, or at least the media used in the pass, extend down to the upstream and downstream river beds.

Careful consideration should be given to screening the upstream entrance to help avoid blockages from accumulating debris, and also to providing access points to facilitate regular maintenance of the medium in the pass. Consideration should also be given to covering the pass to prevent predation on the fish using it e.g. from piscivorous birds, rodents such as rats etc, and sometimes to shading it to prevent either elevated temperatures in, or drying of, the facility.

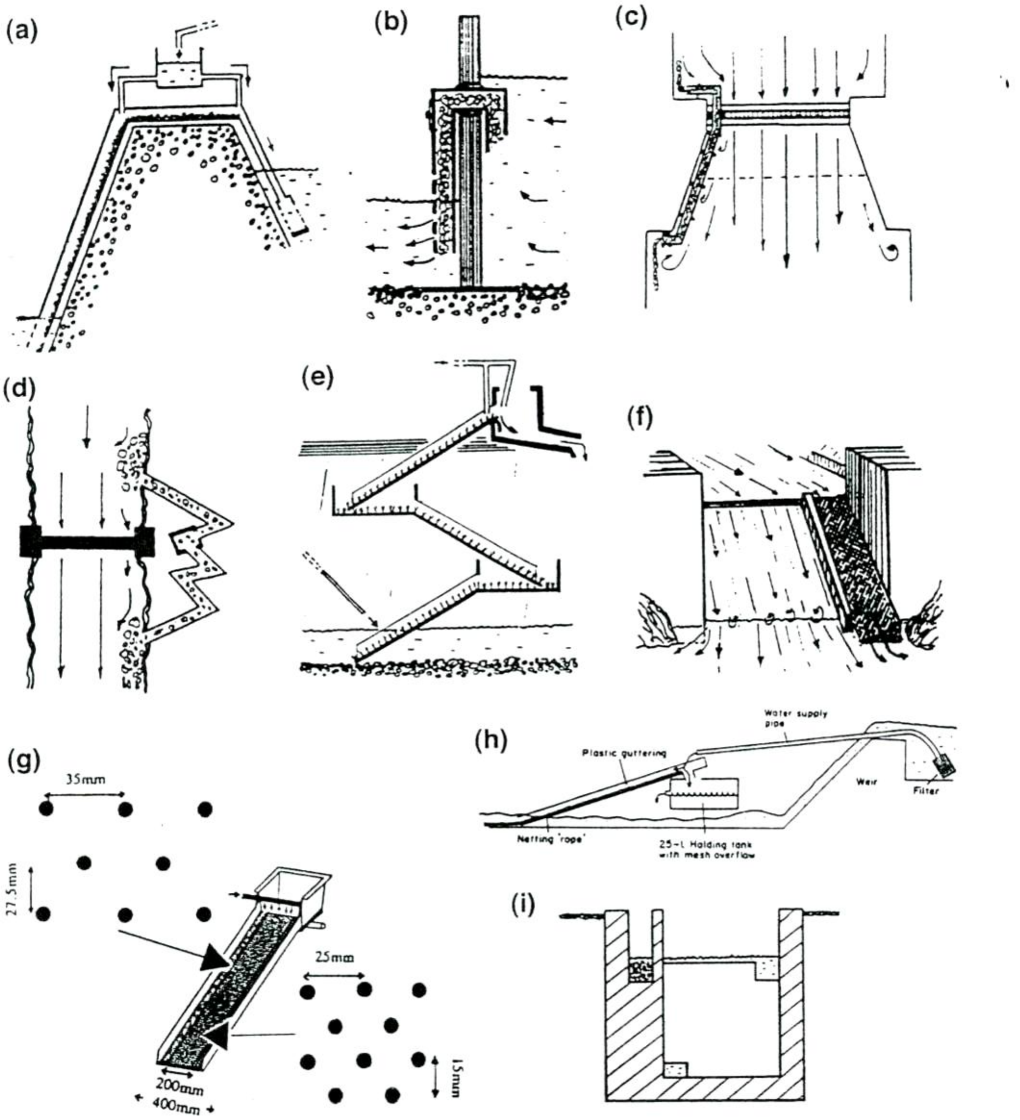
Considerable progress on the design of eel passes has been made in the last twenty years. Many configurations of pass have been used over this time with some success, and several examples are given by Knight & White (1998), see Figure 62. Others are given by Dahl (1991), and by Porcher (1992). More recently a world-wide review of best practices was carried out by Solomon & Beach[1]

(2004), and this was condensed in to a Manual for provision of upstream migration for Eel & Elver (Solomon & Beach[2], 2004). Since then the Environment Agency has recently held an international workshop (October 2009) to draw together more recent experiences, and is presently engaged in further updating the manual, including describing some standardised designs of pass. Most eel passes are likely to feature bristle type media with either a gravity fed or pumped water supply. However, some other types of media such as ABS plastic bosses (material Anguillette, Larinier pers comm.) have also been developed and are in use in France and England.

The bristle ramp eel passes described in the manual can be built at modest cost although these are generally made of materials and in configurations that are less permanent (more at risk from flooding etc). The small flows required to operate pump fed passes has led to the development of systems that can be sustained by renewable energy sources such as solar and wind power (see updated manual for further information). All eel passes require regular maintenance because of the risks of blocking from waterborne debris.

In any one location it should be borne in mind that many different sizes of eel may want to actively migrate, typically any fish from 100 – 400 or 500mm. Typically maximum migration will occur on low flows, and designs of pass should operate over a river exceedance discharge between say Q_{99} and Q_{70}.

Figure 62 Various configurations of eel pass (after Knights & White, 1998)



Closed type eel passes

In a closed type of pass, typically a pipe or trough of 10-25cm diameter or width, but sometimes a wire cage (Dahl, 1991), a medium such as rolled geotextile or horticultural mesh (20mm) mesh, or bottle-brushes, is provided that fills the channel and through which is passed a small volume (several ls^{-1}) of water is passed. The Danes (Dahl, 1991) recommend Enkamat type 7020 as a particularly suitable medium and this has received much use. There have been concerns expreseed recently that geotextile type materials they are too aggressive, and although eels easily pass they lose a great deal of mucus in the process and this may reduce their survival (Larinier, pers comm). For this reason, this type of media is generally no longer favoured.

The entrance of these facilities is placed tight against the foot of the dam or obstruction and extends very closely to the bed of the watercourse. Several entrances may be made into the conduit at different levels below the downstream water surface. The conduit may be fixed at angles up to 90°, i.e. vertical, but shallower angles (15-30°) are probably preferable to ease the climb. Several lengths of conduit may be used to overcome very high obstacles. In such cases it is probably sensible to provide resting areas every 2-3m of height.

These types of facility can can be easily made to follow the contours of low obstructions. It is important to ensure that the medium is extended to the upstream and downstream river-bed, and that it remains wetted throughout its entire length.

A major difficulty with closed type facilities, where the media fills the channel, is that they are easily clogged with debris and are very difficult to access for maintenance.

Head difference: there is little data to go on, but it is suggested up to 2-3m per flight of pass.

Length: probably not more than 4-5m per flight before a rest pool.

Gradient: up to 90° but preferably 15-30°.

Velocities: $<0.2ms^{-1}$.

Strengths: Well tried, relatively cheap to construct, fish safe from predation.

Weaknesses: Very prone to blockage and require very regular maintenance, can be prone to flood damage.

Open type eel passes

In open types of eel pass a ramp covered in a medium similar to those mentioned above, but more typically now bristles, is provided for eels to wriggle through or over (Figure 63 & 55). Other types of media involving various configurations of different types of material, but more usually plastic based, have also been found to be successful (see manual referred to above).

Ramps may be 0.2-1.0m wide and have a gradient between 5-45% (typically 20-30%). Bristle type substrates consist of tufts of bristles that are spaced apart at distances suitable to meet the size of migrant expected. For elvers and small eels up to 20cm in length spacing is 14mm apart, and for eels >20cm spacing is ≥21mm apart. Often a ramp will have a strip of each (spacing) of materials side by side. Typically the brush substrate comprises 1mm thick, 40-70mm long polyester bristles mounted in tufts in 5mm holes on 1m long boards, often made of polypropylene (see Figure 64). Other boss type materials include Akwadrain, Anguillette etc (see Figure 64).

Generally, the ramp will be self-contained and installed as a retro-fit in some form of plastic or metal trough that is provided with a hinged lid to provide both easy access for maintenance and protection from predators.

In order to provide for some limited range in head water level in gravity fed facilities the ramp can be graded laterally, or else several units may be fitted side by side at different levels (see inset Figure 63).

There has been limited evidence from video monitoring that some minor species including Bullhead and Stoneloach can use thse types of passes (Andy Don, *pers com*). Despite that fact that there is no known evidence, it also seems likely that Brook lamprey may be able to exploit tem through either thigmotropic behaviour or the potential to us their suckers.

Figure 63 Schematic plan of a fishway for elvers and small eels (after Porcher,1992)

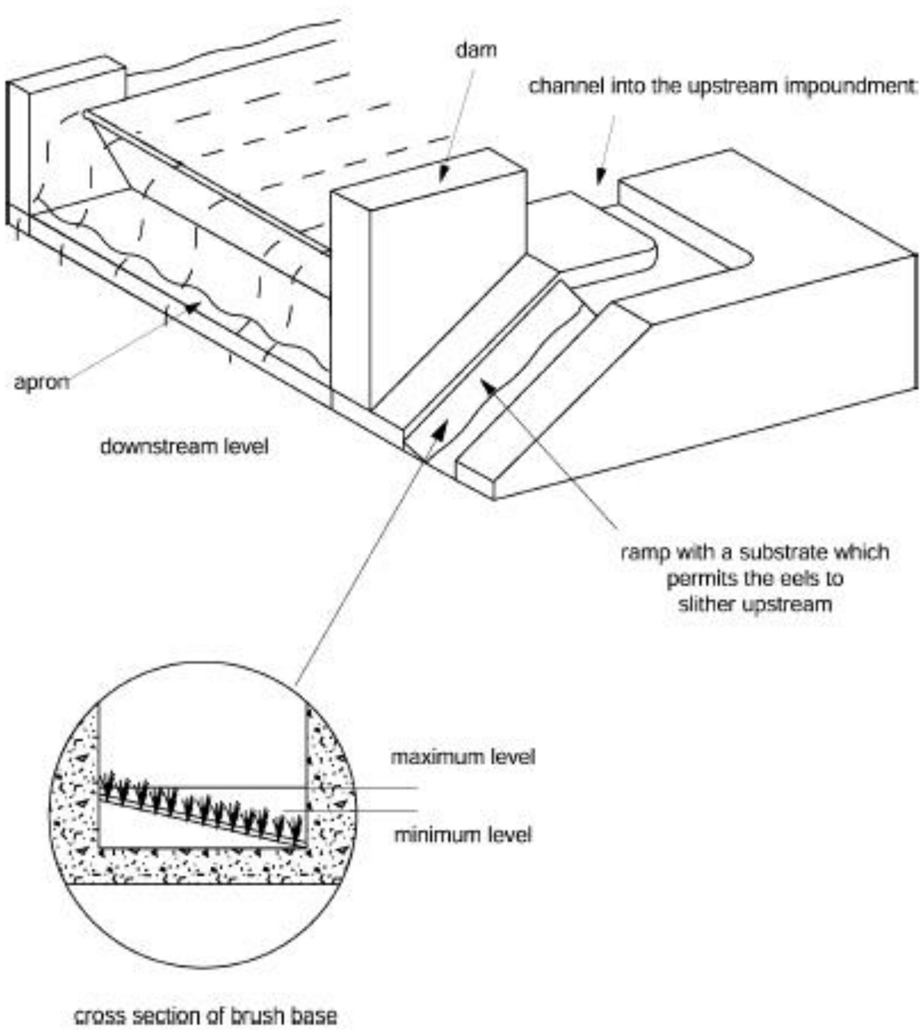


Figure 64 Typical specification of brush boards for eel passes

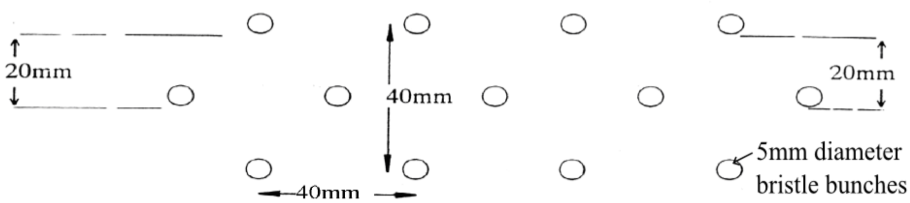
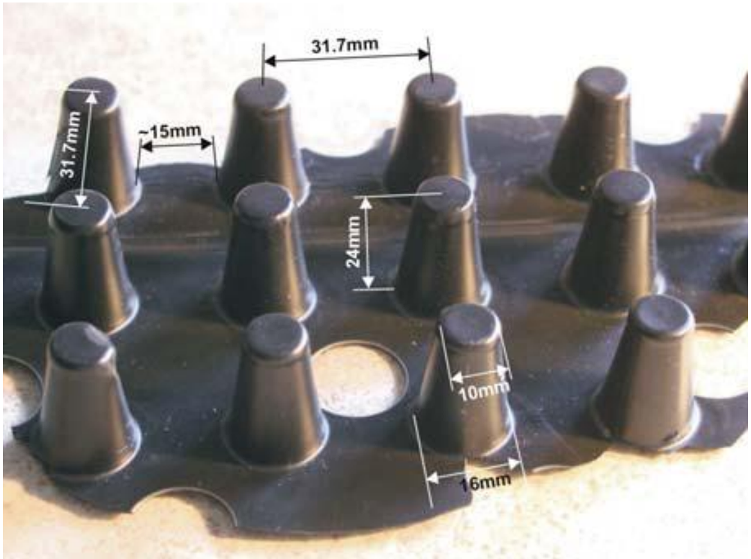


Figure 65 Examples of typical eel media (a, brushes, b, Akwadrain, c, Anguillette)

(a, standard bristle medium)



(b, Akwadrain medium)

(c, Anguillette or Boss medium)

Head difference: there is little data to go on, but it is suggested up to 2-3m per flight of pass.

Length: several metres depending on slope.

Gradient: 5-45%, preferably <30%.

Velocities: $<0.2ms^{-1}$ in area of passage.

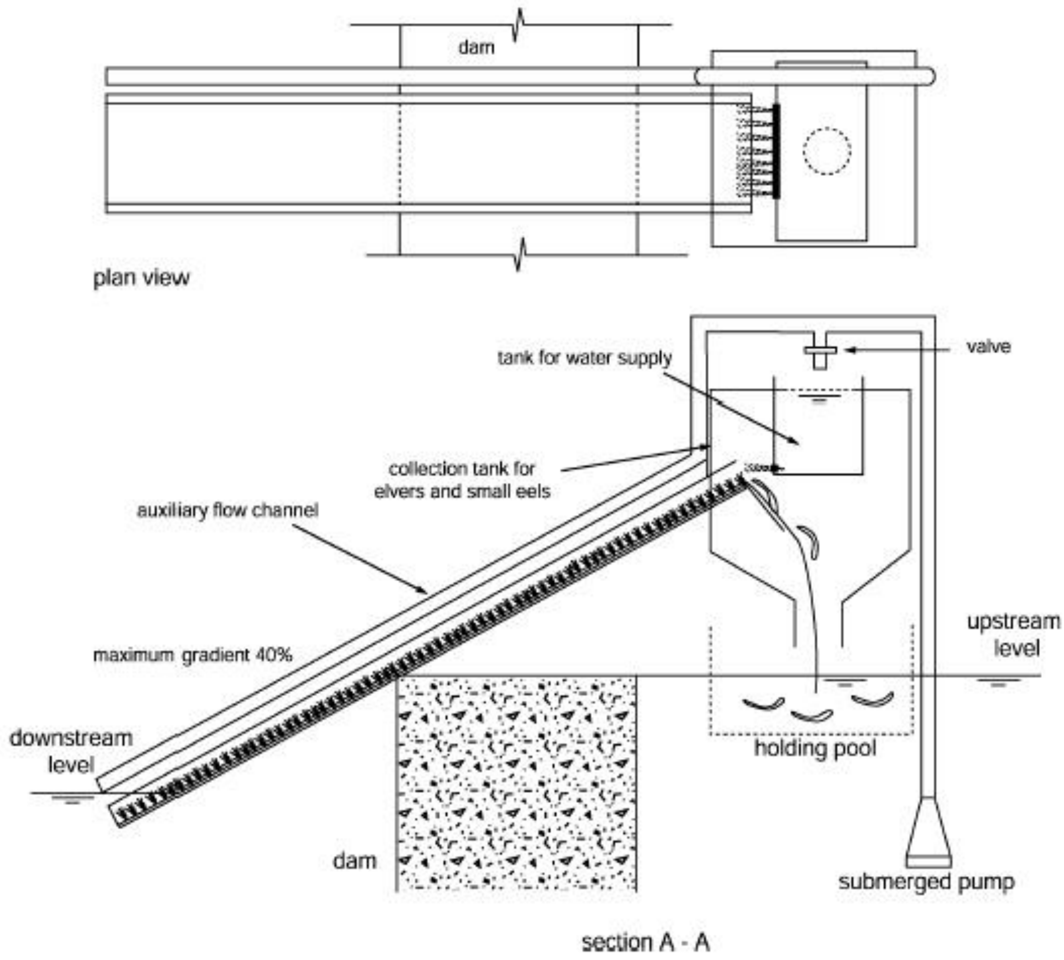
Strengths: Well tried, relatively cheap to construct especially standardised retro-fit trough units, fish safe from predation.Require small flows and/or can cope with some variation in water level, known to work well. Can often be de-mounted. May pass some minor fish species such as bullhead, stoneloach, and brook lamprey.

Weaknesses: Require regular maintenance.

Monitoring

When monitoring is required it is usual to be employing pump fed facilities and to facilitate trapping by raising the exit of the pass well above the obstruction, and then washing migrants down into a collection chamber. In this case the pumped supply of water is necessary to both collect migrants and to provide flow in the pass itself (see Figure 66).

Figure 66 Typical configuration of a pass and trap for elvers and young eels (After Porcher, 1992)



Lamprey Passage

Like eels the lampreys (Sea, River, & Brook) present a very specialised case when considering passage arrangements. Unlike eel, they probably do not necessarily require a totally separate facility to achieve acceptable rates of passage efficiency, but rather can be passed in many of the more conventional fish pass types – provided that they are adapted to suit the very specific capabilities and behaviours exhibited by lamprey. However, because of their very specialist skills in surmounting obstructions separate facilities for lampreys can also be considered. Indeed specific facilities are currently being researched and developed in the Columbia River basin to compliment passage in the existing fish pass facilities.

Sea lamprey can attain a size over one metre in length, and for an aguilliform can achieve a surprisingly high turn of speed - having a reported maximum swimming speed of $3.9ms^{-1}$ that can be maintained for a few seconds – and also appear to recocver relatively quickly from their exertions. They migrate into rivers form about February onwards, but mostly in the spring and early summer upto early July when they spawn and then die. River lampreys migrate much later in the autumn and winter, and are smaller, perhaps attaining 50-60cms maximum, and maximum swimming speeds and endurance are likely to be around half that of sea lamprey. Both species are negatively photactic, migrating at night to begin with (probably to help avoid predators) but also migrating during the day later on in the run when their eye sight is failing because of on-coming senescence. They are likely to be migrating in the higher range of the hydrograph, sea lamprey most likely around Q_{50} to Q_{20} experienced in spring, and the upper range perhaps Q_{30} to low flood flows for river lamprey. Like migratory salmonids they do not feed in freshwater, and generally will spawn in the middle reaches of larger rivers and their lower tributaries.

Lampreys appear to be attracted by high velocities, while on the other hand can be obstructed by high velocities and turbulence. Outside of providing suitable low velocities the key to providing effective and efficient passage robaly lies in exploiting the peculiar ability of lampreys to use their mouth parts to create and control suction (Adams & Reinhardt, 2008). Lampreys can attach to suitably smooth substrates and then use an active creeping behaviour where they release, or artially release with areduced vacuum – burst swim – re-attach & rest before making another attempt to progress. In this way they are able to exploit their maximum speed to make short progressive burst of progress, rather than a more limited burst speed that has to be maintained for seconds at a time to pass an obstruction. Pacific sea lampreys (Petromyzon tridentate) are even capable of climbing smooth vertical surfaces with a very thin skim of high velocity flow (Moser, pers com). While this same behaviour has not yet been demonstrated in Atlantic sea lamprey (Petromyzon marinus) it seems very likely that they must have learnt the same behavioural tricks, and anyway they certainly exhibit the same traits of exploiting their sucker to enhance the ability to locomote in high velocity zones.

There appears to be conflicting evidence about the ability of lampreys to pass various types of pass, but this is probably due to the very specific features of a specific site in terms of velocities and the availability and continuity of areas of smooth substrate where lampreys can successfully attach themselves to aid progress. Lampreys attained unexpectedly high passage rates in Vertical Slot passes on the Columbia River, USA, wher velocities exceeded $2.4ms^{-1}$. Passage rates of 38-82% were achieved in Bonnevile and Dalles dams, although in three passes now including John Day Dam overall passage rate was only 3% (Moser et al, 2002). At smaller Vertical Slot passes in the Great Lakes system, Cananda passage rates up to 100% were reported (O'Connor et al, 2003, 2004). Despite not being ken on turbulence Pacific lampreys were found to pass Alaskan A Denils with slopes of 23% to near 29%, lengths of 8 - 20m and flows around $0.16m^3s^{-1}$ i.e modest depth (Slatick & Basham, 1985). Sea lampreys are known to pass some Plane Baffle (PB) Denils with video of fish passing a PB Denil on U-tube in Ireland and fish monitored passing Stamford Bridge and the Tees Barrage Denils in the UK for example. On the other hand, while making some progress through the Isohaara combined Vertical Slot and Denil pass, river lamprey could not manage the whole fishway even apparently with modifications designed to help (Laine et al, 1998).

Apart from using specific passes for lamprey, designed along the lines of those currently being developed in the Columbia River basin using sloping stainless steel chutes with a skim of water and transitional facilities of a vertical steel plate on which the ramp sits to aid location and entry to the pass, the key to improving lamprey passage is to adapt existing facilities. This can be done by providing smooth, preferably stainless steel plate, surfaces for the lampreys to grip and ensuring that those surfaces have rounded or shallow angle surfaces at notches, slots, downstream and upstream transition areas so that fish can progress to areas where they can safely detach once attached in the first place. So the lateral urface of a notch in a Pool & Traverse pass would be rounded on the upstream and downstream face, the vertical side-walls of a Vertical Slot pass will have a rounded cross-section rather than sharp edges, a Crump Gauging Weir or sloping V-shaped weir would have a stainless steel plate at one side against a wall (low velocity zone) leading from the river bed downstream to the river bed upstream, and so on. And in any fishway, clearly, thought has to be given to the continuity of arrangements to facilitate passage throughout the length of the pass.

Even less is known about the ecology and ability of Brook Lamprey in terms of migration. While it is much smaller, up to may be 15cms, there seems no reason why it too might exploit its sucker. Also like other anguilliforms it may exploit thigmotropism, so for example, it might be expected to be ale to exploit bristle ramp fish passes provided for eels and elvers?

ADDITIONAL FACILITIES

Resting facilities

It should be recognised that fishways can often represent a physical challenge to ascending fish in terms of endurance. Therefore flights of baffle fishways, or in some circumstances sequences of pools, cannot be extended indefinitely without providing suitable areas where fish can take a rest between exertions.

Where resting pools are required fish must be able to reside in areas of low turbulence and aeration. The resting pools must have sufficient length and volume to dissipate the kinetic energy of the water entering the pool before it enters the next flight or pool. The presence of residual turbulence, energy, or currents carried over to the next downstream flight or pool will adversely affect the hydraulic performance of the fishway thereafter. Care should be taken to ensure that exit flows from the upstream pool or baffle flight do not strike an opposite wall with undue force, since this will generate conditions that are uncomfortable or impossible, for fish to rest in. In addition it is useful to round the corners of the rest pools to help prevent the formation of vertical currents that can encourage fish to jump out of the fishway.

Power dissipation values in resting pools should be more conservative than the values used for the standard pools in pool passes (page 62), the lower end of the range 100-150Wm^{-3} for migratory salmonids and shad, and 50-100Wm^{-3} for other species. In general, while resting pools tend to be larger and to have modest power dissipation values some care may be needed not to over-size them when sedimentation may prove to be a problem (because of insufficient turbulence).

In pool passes the power dissipation values are calculated in the normal way. In order to calculate the energy input from a length of baffle pass, an approximation to the difference in head in the energy dissipation equation can be made from the average velocity as follows:

$$DH_{Equiv} = V^2 / 2g$$

Where:

DH_{Equiv} = equivalent difference in head (m)

V = the estimated average exit velocity (ms^{-1})

g = gravitational acceleration (9.81ms^{-1})

Since this is only an approximation it may be sensible to allow a margin for error of up to 50% for Plane Baffle passes and 25% for Alaskan A and Super-active Baffle passes (Larinier, pers comm).

The minimum length of pool for large migratory salmonids should be 3m, but may be less, say 2.5m for sea trout and smaller still for other species. A good guide is that the pool should be at least three times the length of the largest fish expected to be using it. Pool depths should not generally be less than 1.0-1.5m. While pools must not be too shallow, it should also be borne in mind that over-deepening them can encourage fish to rest indefinitely, thus delaying migration or making the fish vulnerable to predation or poaching. Pool widths may vary, usually being equal to or greater than 2m for pool passes, greater than twice the width of a plane baffle pass, and equal to or greater than the width of a Larinier Super-active or Alaskan A baffle pass. Within these guidelines the pool dimensions are adjusted to provide a suitable volume to achieve the desired dissipation value for the species concerned.

In the case of baffle fishways resting pools should be provided every 1.8-2.4m (10-12m run) of fall in head for large migratory salmonids (>0.6m long), and every 1.2-1.5m of fall in head (6-8m run) for small salmonids (<0.6m) and for coarse fish. Resting pools must also be placed at any changes in direction of the fishway. In the circumstances where a baffle pass changes direction, the wall(s) opposite to the exit from any flight(s) should be at least 3m away.

With pool type passes resting pools should be provided at changes in direction of the axis of the fishway. A deeper resting pool is often an advantage because it provides more cover for resting fish and provides less opportunity for illegal fishing.

Protection from Debris

The need for protection from trash at any one site is clearly dependent upon the nature of the water course and the type and quantity of debris which it carries, particularly during the migration period(s). It is also dependent upon the type of pass since some are more inclined to block than others. Some form of protection is always to be recommended for side or side and bottom baffled fishways which block easily, however some pool type passes and particularly the bottom-baffle-only type fishway may be considerably less vulnerable and not require protection at all. If there is any doubt a protective device should be fitted.

Protection may take many forms including floating booms, screens with bars (minimum free gap 200mm, preferably spaced 250 - 300mm apart to allow passage of salmon), solid surface deflectors, rows of rails or piles upstream of the facility, or combinations of these.

Bar screens should be designed in such a way that the velocity through them does not exceed 0.3-0.4ms^{-1} to avoid clogging quickly. If vertical bars are used then any additional horizontal bars for strengthening the screen should be at least 500mm apart. Solid screens should be designed in such a way that velocities under or around them do not increase to values in excess of that entering the pass (ie. cause no head drop across them nor associated acceleration of flow). Apart from potentially interfering with the ability of fish to exit the pass, accelerating flow under shields may draw debris collected on or near the suface underneath and in to the pass. Screens or shields should also be sufficiently far away from the exit of the pass so as not to interfere with fish leaving it, at least 1.5-2.0m away from the last traverse or most upstream baffle. Where surface mounted a deflector or trash screen should have a minimum gap underneath of 40cm. Positioning of the screen should take account of flow patterns in the vicinity to enable debris to wash away rather than back into the fishway during cleaning. Careful consideration should also be given to access arrangements for the maintenance operations.

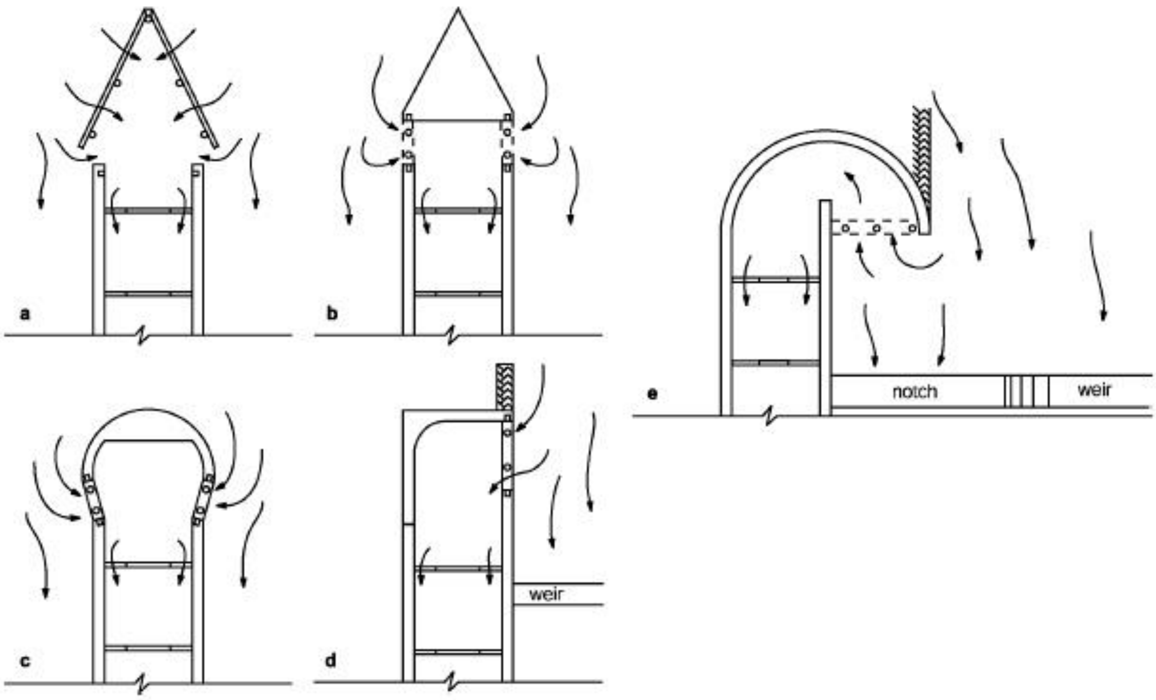
The lateral siting of fish pass exits is recommended (Larinier, 1992c), since this encourages trash to by-pass the entrance and also helps ensure that it is washed away downstream during the cleaning process. Examples of laterally sited exits are shown in Figure 67. Note that the exit must not be sited in any zone where a re-circulation eddy is formed, and any exit but especially a downstream facing one, must have a flow away from it and over the weir or obstruction sufficient to carry debris away.

It may also be useful to ensure that the exit to the pass finishes a little above the upstream river bed, to help avoid sediment and demersal debris being rolled or carried in to the pass. In combination with a surface deflector or screen across the exit, effectively creating an orifice, both floating and demersal debris can be largely excluded from the pass. It is next to impossible to keep all debris out, especially neutrally buoyant debris.

Pool passes are unlikely to block with light debris alone, but generally require protection against heavy and longer material such as tree branches and floating timber. Where larger mobile sediments such as rocks, cobbles, and gravel may be encountered they may need protection from sedimentation and/or an easy and safe means of being cleared. Vertical slot passes are vulverable to blockage by materials wider than the slot, but not vulnerable to mobile sediments that should pass through.

Denil side & bottom (Plane baffle, AkaskanA) or side only passes are relatively deep and narrow and block very easily with ant debris that is wider than the free gap between the baffles. Once one piece of material is lodged forming a bridge, other material soon builds up. Deflectors and screens may not always keep out material effectively, especially if not optimally designed. Provision for safe and easy clearing of screens and pass channel are advisable.

Figure 67 Schematic examples of laterally sited fishway exits to help avoid trash problems (after Larinier, 1992c)



Bottom baffle passes such as Lariniers and baffle easements are generally wide in nature with up-welling and turbulent currents that carry material through and reduce the risk of blockage. The roughness reated by the baffles can nevertheless catch heavy sediments (rocks & cobbles) and large angular materials such as tree branches and trunks. Defelectors that will divert such debris are advantageous.

A useful review of trash accumulation and ways to miminise it at fish passes is given by White, Bowker & McGahey, 2005 (Chapter 3, Flow Measurement structure design to ai d fish migration without compromising flow data accuracy).Completely effective trash protection is virtually impossible to achieve. In order to facilitate easy and cost-effective structural (infrequent) and operational (frequent) maintenance, careful consideration should be given to fitting a penstock, or some other means of shutting-off the flow, at the head of the pass. The minimum provision should be stop log slots.

It may also be worth considering remote surveillance to detect problems with trash, or poaching, and to reduce the operational necessity to make overly frequent visits to the site. See section on Remote Surveillance (page 228).

Lighting

Where possible the best situation for a fishway is to be in the open and subject to natural lighting conditions. Where this is not possible and the pass has to be covered, or else lies within a structure, then some consideration needs to be given to lighting conditions.

There is conflicting evidence about the effects of light levels on passage. Salmonids are known to use fishways in both light and dark conditions. A recent study of the migration of salmon past thirty one obstructions on the Pau River in France (Chanseau et al, 1999) showed that nearly 86% of passage at obstacles took place during daylight, and that only natural by-pass channels enabled a significant proportion of migrants to pass at night. Fish approaching the hydro-electric dam at Baights on the Pau River (Chanseau & Larinier, 1999) mainly did so at dawn, and fish rarely stayed in the immediate vicinity for more than an hour.

On the other hand shad will definitely not move through a fishway in darkness. They require strong visual clues, not least of which is other shad since their behaviour is very much to move in shoals. A shad fishway must therefore be illuminated, preferably with natural light.

Both adult and juvenile (i.e. smolts) salmonids are very reluctant to cross a sudden transition between light and dark. A gradual transition between light and dark can be provided by using artificial lighting inside the tunnel or fishway entrance, or perhaps by creating a natural light gradient through the prudent use of vegetation at the entrance or exit.

Should there be any problem with fish being reluctant to move through a fishway, then lighting may provide a solution.

Where lighting is used it will need to meet appropriate electrical safety standards. This will impose maintenance and monitoring costs in addition to the normal operating costs for power.

Auxiliary Flow

Where it is necessary to provide auxiliary attraction flow then it should be injected at low velocity, <0.30-0.40 ms^{-1}, into the downstream section of the pass, or at the entrance itself. Power must be dissipated and aeration removed before it is fed into the pass or entrance pool. Usually this is accommodated in a separate pool (power dissipation 1000-1500Wm^{-3}) or an area behind the screens that are used to guide the flow gently into the pass. The injection of the auxilliary flow can take place from the bed of the pass, but more likely will be from the side because the former is more liable to create maintenance problems from clogging with debris.

The gaps between the bars of the injection screen must be small enough to prevent passage or impingement of the fish using the pass. Larinier (1992c) suggests 25-35mm for fish >30cms, 20-25mm for trout, 25mm for lampreys and 5mm for eels. The screens may be used to help guide fish to the pass entrance, or else to the next traverse.

Maintenance of these screens is highly demanding, and their use would normally be avoided at remote sites. Mounting short widths of screen on vertical pivots can be a benefit since, they can then be cleaned by turning them through near 180°, effectively using the reversal of water current to wash the debris from the screen.

Traps

Trapping fish at the exit of a fish pass has been carried out at many sites throughout the world. At such sites fish ascending the pass enter a screened and confined space from which it is difficult to escape. The entry route to the trapping area generally consists of an in-scale or funnel formed from metal mesh or bars.

The advantages of including a trap in a fish pass development are that the installation costs are often low if incorporated at the design stage, and that a high level of monitoring of the fish using the pass can be achieved including counting, species identification, sexing, measuring, marking & tagging, checking for marks & tags etc. With very careful configuration of the trapping facility many of these tasks may be achieved by direct observation without even handling the fish.

The disadvantages of using traps in a pass include the potential interference and reduction in fish passage efficiency, high labour costs of maintenance, and the risk of injury to fish.

There are many examples of both good and bad design of traps associated with fish passes. Well-designed trapping areas need to be comfortable for fish to remain in, otherwise they are likely to damage themselves trying to escape. They will generally have a generous volume, good exchange of water with no areas of stagnation, and have low levels of light intensity being well shaded and protected from bright sources of illumination whether natural or artificial. Water velocities must be well within the cruising speed of the target species, and this will usually be in the order of 0.3ms^{-1}. Power dissipation values will be low, certainly <100 Wm^{-3}.

Well designed traps also need to be comfortable for operators to work in so that fish can be easily and safely handled. Safe and easy access to enable equipment to be taken in and out is essential. Where work is required at night then adequate lighting arrangments are clearly required, and preferably ones that will not disturb migrating fish nearby.

The conditions for capturing, handling, and transferring fish during processing need to be well designed to minimise stress and ensure efficient and rapid processing. Processing takes time, and especially if large catches are anticipated this can disrupt migration at the site. Ideally, a parallel two-chamber system capable of independent use and isolation may be the ideal. Fish, especially large ones or where there are large numbers, may hurtle around causing damage to themselves. Fish-friendly materials within the trap chamber (netting, foam, plastic for example) may help avoid damage, while crowding devices or stepped floors to confine fish as the trap is progressively de-watered may be helpful.

Good arrangements, including infrastructure and procedures, are required for releasing fish after processing. Fish will probably have to recover after anaesthetising during processing before being released in a safe area. Dedicated recovery and release areas, say with a chute to a recovery area that fish can leave volitionally are recommended.

No matter how well designed the trapping area, it must be visited very regularly when it is in operation. It is not sensible to leave any species of fish, but particularly migratory salmonids, in a trap for more than 24 hours, especially in the peak of the migration season.

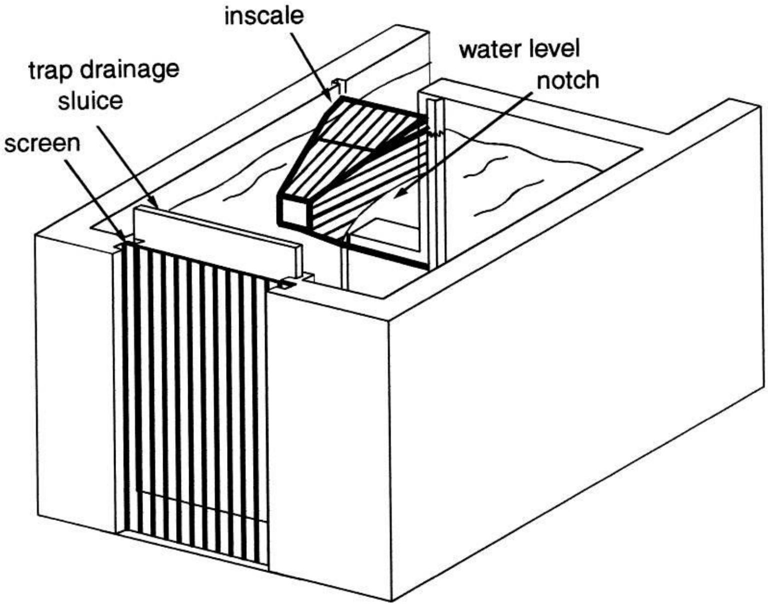
Useful guidelines for the design of traps for salmon, trout and shad are given by Travade & Larinier (1992a) and are outlined below in Table 7:

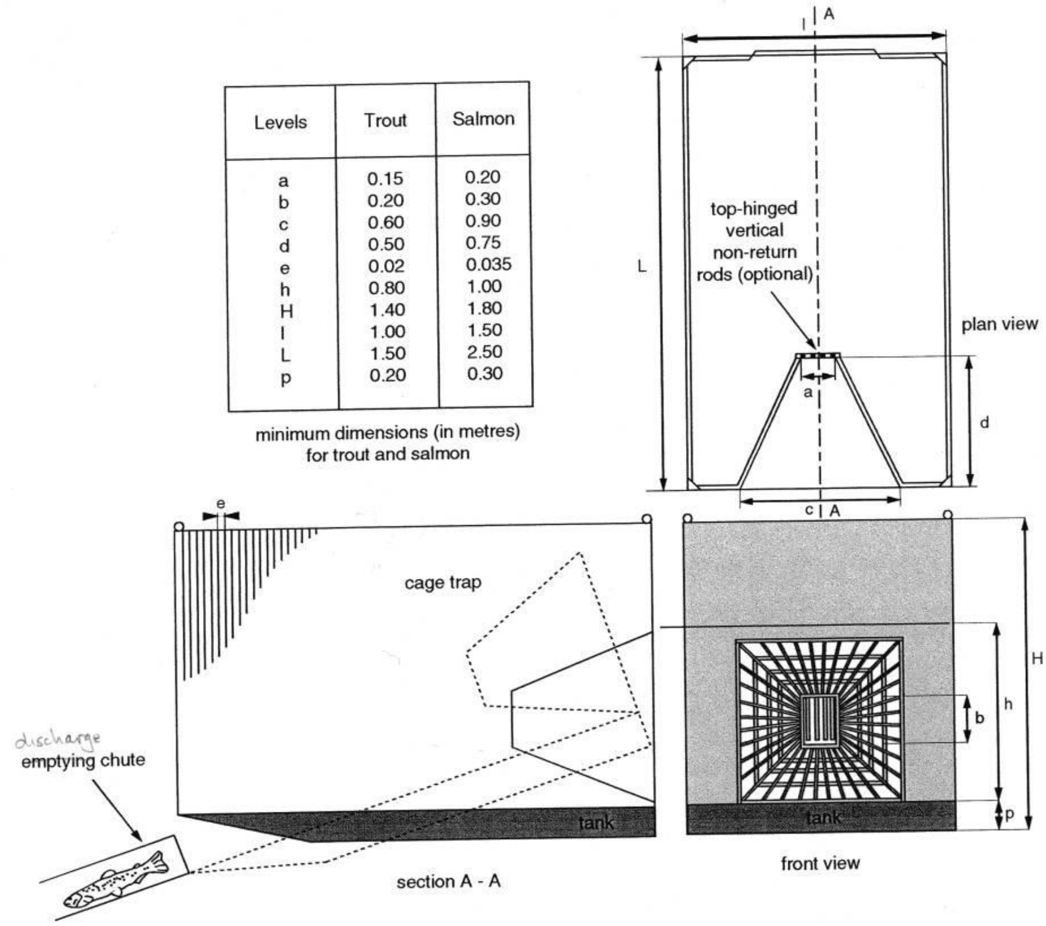
Table 7 Guidelines for the sizing of trapping areas

Measure	*salmon*	*trout*	*shad*
Holding volume (l/kg of fish)	*80-150*	*5-15*	*30*
Minimum dimensions of pool or cage (L x W x D)(m)	*2.5 x 1.5 x 1.0*	*1.5 x 1.0 x 0.8*	*5.0 x 2.5 x 1.5*
Minimum water velocity at entrance (ms^{-1})	*0.6-1.0*	*0.6-1.0*	*0.6-1.0*

These and other minimum size criteria for the sizing of inscales are given in Figure 68.

Figure 68 Schematic plan of a trapping area showing minimum dimensions (adapted after Travade & Larinier, 1992a)





Levels	Trout	Salmon
a	0.15	0.20
b	0.20	0.30
c	0.60	0.90
d	0.50	0.75
e	0.02	0.035
h	0.80	1.00
H	1.40	1.80
l	1.00	1.50
L	1.50	2.50
p	0.20	0.30

minimum dimensions (in metres)
for trout and salmon

The free gap between the bars used to confine the fish to the trapping area should be about 5mm less than the width of the head of the smallest fish to be trapped (Travade & Larnier, 1992a). They also advise that to help avoid fish becoming stuck, square or rectangular section bars should be preferred to round ones. The following free gaps (e) were recommended:

e = 25-35mm for fish > 300mm

e = 20-25mm for trout and small sea trout

e = 25mm for lampreys

e = 5mm for small yellow eels

A neat alternative method for deciding the free gap in mesh or bar screens, which gives similar values to those above, is to use the fish exclusion formula proposed by Turnpenny (1989) for excluding fish from intakes:

$$M = L/(0.209L + 0.656 + 1.2F)$$

Where:

M = the free gap (cms)

L = the standard length of the fish (snout to caudal peduncle) (cms)

F* = a ‘fineness’ ratio (maximum of depth or width)

Thus for:

eel ....F = 16
salmon ....F = 4.7
dace ....F = 4.5
roach ....F = 3.8

* Note that this value may change slightly depending on the size group of fish used.

This formula is used to determine required free gap sizes for fish screening applications under Section 14 of the Salmon And Freshwater Fisheries Act, 1975 (as amended by the Environment Act, 1995).

In practice, for salmon and large sea trout, not less than 500mm in size, a free gap of 40mm (10mm bars @ 50mm centres) has been found to be sufficiently small at Molesey and Sunbury traps on the River Thames (G Armstrong, pers comm). At Black weir on the river Taff a trap with a free gap of 30mm (10mm bars @ 40mm centres) works well, but rarely will gill the very smallest sea trout (P Gough, pers comm). The trap at Chester Weir on the river Dee has a free gap of 30mm (12mm bars @ 42.5mm centres) and effectively takes sea trout down to 35cms. However, a square mesh of 20 x 20mm has to be used to efficiently capture the small sea trout between 21-35cms that make up a very large proportion of the run (R Cove, pers comm).

A free gap size of 18mm square has been found to capture coarse fish down to about 100mm in fork length at Blakes trap on the river Kennet, and it is therefore suggested that a free gap of 10-18mm is suitable for most coarse fish traps (Armstrong, pers comm).

Some examples of successful trapping areas include:

- Molesey Weir (R.Thames), Holme Head Weir (R. Caldew) and Chester Weir (R.Dee), which are all pool traps (top pool of Pool & Traverse passes)

- Forge Weir (R.Lune), which is a pool trap at the head of a crump fish counter weir:

- Blakes Weir (R. Kennet) which is a cage trap (top of a Larinier pass)

- Black Weir (R. Taff) trap (trap area at top of an Alaskan A Denil)

- Gunnislake Weir (R. Tamar), which is a pool trap at the downstream end of a composite pass.

Plans of all of these traps may be obtained from the Regions where they are located.

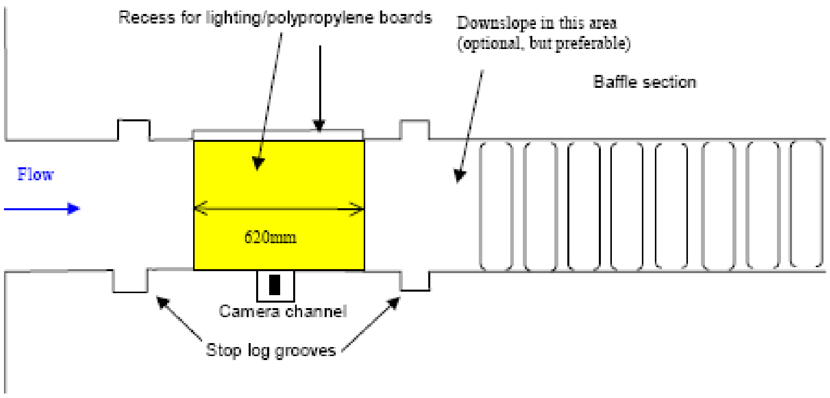
Robust measures will need to be included to prevent unauthorised access to the trapping area. Risk assessments and safe systems of work will be required for trapping operations, and the design and operation of the trapping facilities should be carefully considered.

Facilitating Monitoring

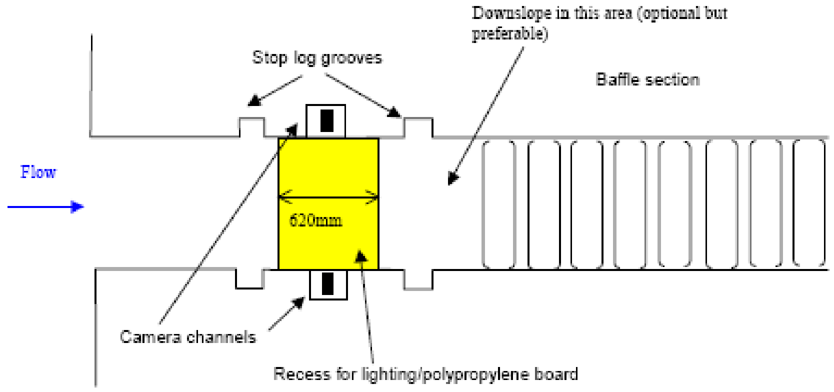
Unless space is limiting it can be relatively easy to design in to a project at low cost structures that will facilitate future monitoring by a variety of methods. Generally, only a very short space of 1– 2m s required, often less. Typical monitoring techniques include video, infra-red, resistivity, and PIT tag technology. Each method has its own limitations that affect the quality and therefore use of the data, particularly where they are deployed in fish passes when they are not usually in their optimum (performance) environment.

A recent R&D report (Washburn, Gregory & Clabburn, 2008) details processes for monitoring various types of pass (Pool including Vertical Slot, Larinier, and Denil) by deploying video-monitoring equipment. This can be very effective at least for determining the species and size range of fish that are capable of using the pass under a variety of flow conditions. The use of movement detection technology, data-logging hardware, and appropriate data handling software can provide good data that can be quickly assimilated and analysed efficiently. The report provides standardised approaches for designing the head of passes to receive the necessary equipment such as cameras, white or lighting boards, data logging gear etc. For example see Figure 69 which gives some typical examples of setups for various pass types.

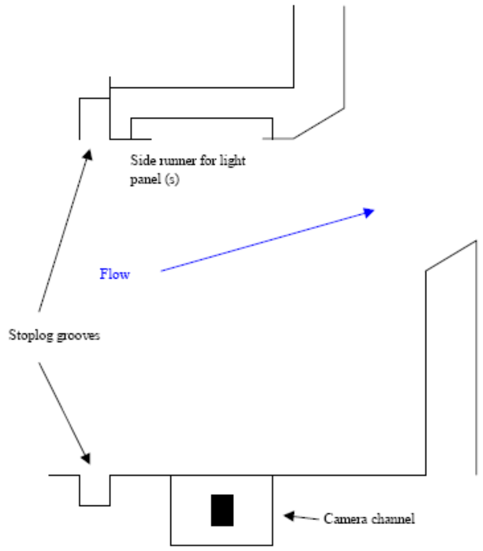
Figure 69 Some typical configurations in plan view of video monitoring arrangements in Larinier, Denil, and Vertical Slot passes



a) Denil or Larinier up to 900mm wide



b) Denil or Larinier more than 900mm wide



c) Vertical slot pass

It is als possible to combine techniques or to make them inter-changeable. For example, the recess for a lighting board might be used for a resistivity counter or a (Full Duplex) Flat Bed PIT tag detector instead. Any of them might be located on the downslope, or the video monitoring might follow immediately upstream of restivity or PIT tag detectors mounted on the downslope. The camera slot might be used for a (Half Duplex) PIT tag detector loop. Common to each approach would be the provision of multiple stop log slots to facilitate installation, de-installation, and maintenance of the gear.

Where normally employed on the downslope away from the head of baffled passes, or immediately thereafter, it may be possible to install any of these gears on the upstream end of the upslope of the pass. In the case of resistivity or PIT tag technologies the upslope would be better since the flow here is going to be laminar still and relatively shallower. While this can be accomplished by removing some baffles this would affect pass performance, and it would be better to use non-metallic baffles over the detection equipment.

Fish counters

Many types of fish counter can be applied to the task of enumerating the passage of fish through a fishpass. All require to be operated in relatively non-turbulent water, which is generally to be found at the exit of the fishpass, but may also be found in the laminar flows of orifices or slots. Each type can offer differing characteristics of accuracy, species identification, manpower costs, volume of water sampled per second and individual fish measurement. It is outside the scope of this document to discuss each counter type in detail and therefore the reader is directed to Fewings (1994 & 1998) Nicholson et al (1996).

Conjunctive use by canoes

Fish passes can be a significant attraction to canoeists, and indeed in some circumstances may be specifically designed (Bristle Ramp Canoe/Fish pass) or else modified for conjunctive use. However, there is considerable scope for a conflict between the two uses. The hydraulic characteristics are intended to be the most ideal and efficient for the passage of the fish. This means choosing a pass that is the most efficient at dissipating energy and lowering water velocity, and frequently also one that operates over the widest range in headwater level. In turn this leads to structures that use fairly aggressive means to accomplish this, with relatively narrow gaps, small head differences across them, or relatively thin and sharp baffles.

Normally, substantial efforts are made to avoid blockage of the pass by trash since clearly this would compromise pass efficiency, if not prevent fish migration altogether. Accumulations of trash also represent a potentially very expensive maintenance problem. Fish pass facilities are therefore usually provided with a form of protection that precludes the entry of canoes or kayaks.

While some types of pass, like very large pool and traverse passes or chevron bottom-baffle passes, may be suitable for canoes or similar small boats, and some types adapted eg. Larinier, the choice of one type over another may well compromise the efficiency of the structure as a fish pass (higher water velocity, smaller operating range with head). On an individual site basis it may or may not have significant consequences, however, if compounded by the use of a number of similar facilities along the river continuum then for migratory fish (especially diadromous species) the cumulative effect would almost certainly be significant .

Fish may use fish passes at different times of the day and night depending on flow, season, local conditions and the nature of the passage facility. Migrating fish often exhibit crepuscular activity during low flows (i.e. active at dusk and dawn). In general, activity patterns are not very predictable and may be very specific to a particular site. There is clearly a potential conflict for the disturbance of migrating fish if any one facility was in constant or very frequent use by boats at a time when fish wanted to migrate.

For the reasons given above a facility designed for conjunctive use is not normally recommended, and it is best to provide separate facilities. While conjunctive use is not discounted altogether, a careful assessment needs to be made on an individual site basis and quite possibly in a catchment context. There are likely to be more opportunities for conjunctive use where `natural ` by-pass channels can be employed. See earlier Sections (page 17) on Recreation Duties and Area Administration (Canoe Passage page **Error! Bookmark not defined.**).

FISH PASSAGE AT GAUGING STATIONS

The accurate gauging of river flow requires very precise hydraulic conditions to be met, and this means the equally precise engineering of structures used to carry out the measurements. The stringent conditions imposed are frequently at odds with the requirements for fish passage.

Non-intrusive methods, leaving a clear unobstructed channel, are clearly the best ones from the point of view of fish passage. Non-intrusive methods of gauging such as ultra-sonic or electromagnetic have been used infrequently in the past because of lack of accuracy at low river discharges, physical topography of the site or else the cost. However, in recent years, great strides have been taken particularly in respect of ultrasonic time of flight or doppler technology and these types of stations are seeing a welcome and rapidly increasing use in the UK (see for example Non-invasive techniques for river flow measurement. Science Report SC030230/SR. Environment Agency. March 2008).

The most common approach historically has been to use some form of in-river structure that creates a head loss in a highly regularised situation. While this may now be changing with the advent of more reliable non-invasive technologies, there is a considerable and valuable legacy of existing gauging assets that will remain in use for many years. Of the many types of structure that have been used historically, by far the most common in the last 40 years have been Crump and Flat V weirs.

These triangular weir structures need not necessarily compromise fish passage very greatly, provided that the dimensions and in particular their height, are not excessive. Given that on occasion some new Crump and Flat V gauging structures are still likely to be built, and that many continue to be re-furbished and maintained in use into the foreseeable future, the following sections describe their typical construction, operation and means of mitigating their affects on fish migration. Some of the methods, for example reducing affluxes or utilising Compound Gauging & Fish Pass principles, may also be used to mitigate fish passage at other types of intrusive gauging structures.

Crump Weirs (including compound Crump weirs)

Crump weirs are two-dimensional triangular profile structures that generally have a 1:2 slope on the upstream side and a 1:5 slope on the downstream side. Upstream and downstream of the weir the river channel is engineered to have very regular features in order to help provide stable hydraulic conditions for precise flow measurement. A comprehensive description of the design and hydraulic function of a crump weir is given by Herschy et al (1977). Figure 70 shows a typical Crump weir.

Figure 70 Schematic diagram of a crump flow gauging weir with upstream and downstream slopes of 1:2 and 1:5 respectively (After Crump,1952)

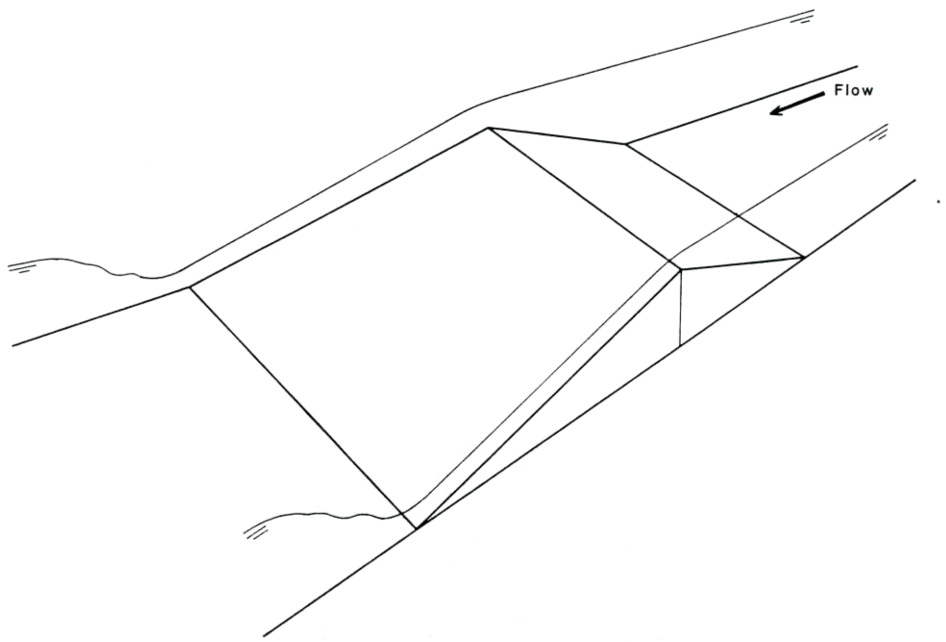
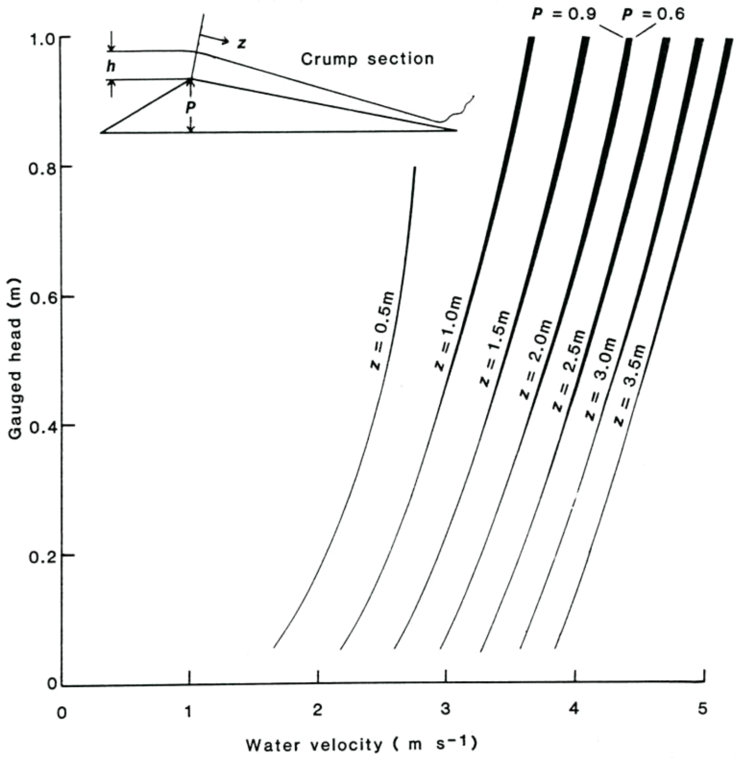


Figure 71 Mean water velocity at various distances Z from the crest of a Crump weir plotted against upstream head (After Beach, 1984)



As water approaches the weir it accelerates smoothly as a result of the upstream sloping face, then flows over the crest to accelerate rapidly under the influence of gravity on the 1:5 downstream slope. As it accelerates the depth of water naturally decreases, and the flow and depth in this region are referred to as being `super-critical`. On reaching the downstream water level the flow has to return to the sub-critical state, and this occurs rapidly in the form of a `hydraulic jump`.

Fish have difficulty passing the structure because they have first to negotiate the highly turbulent area in the hydraulic jump itself, and then to traverse the long and sloping face of the weir on which there is a very shallow depth of water travelling at high velocity.

The turbulence caused by the standing wave can potentially cause serious erosion downstream of the structure. As a result, erosion is usually prevented by using a hard concrete bed immediately downstream, which is generally in the form of a stilling basin. There can be a tendency to reduce construction costs by truncating the slope of the weir, and this can create another difficulty since, if it is not drowned, it will cause fish to leap from a highly turbulent area on to a weir face with a high velocity water layer. The need to leap compounds the difficulty for fish attempting to cross the weir. This is because they often land in a disorientated fashion, and are subsequently easily and rapidly swept back downstream. On the other hand, provided that a truncated weir is drowned it can be an aid to fish passage since it can reduce the distance over which the fish will be challenged.

Guidelines for the construction of crump weirs suitable for fish passage began to be developed for migratory salmonids by Beach (1984), and they provide the foundation for the present more robust Agency guidance (see page 198). He proposed the following: ` the recommendations for the design of a Crump weir to allow fish passage derive from a consideration of the water velocity on its downstream face and require the submergence of any downstream truncated edge. Hence the stilling basin should be so designed that the hydraulic jump always forms on this downstream face. Figure 71 shows water velocity as a function of gauged head h for a range of weir heights P, and the distances Z downstream from the crest. Four weir heights are considered (P = 0.6m, 0.7m, 0.8m and 0.9m) and the water velocity is calculated at seven distances from the crest (Z = 0.5m, 1m, 1.5m, 2m, 2.5m, 3m, and 3.5m) using the appropriate coefficient of approach velocity for each value of P`.

'The maximum water velocity on a Crump weir, which occurs in the region of super-critical flow just above the hydraulic jump, should not exceed $3.5ms^{-1}$. This swimming velocity can be achieved, for example, by a fish of length 0.54m in water of temperature 10°C and maintained for about 90 seconds before exhaustion. From Figure 71 it can be seen that this velocity occurs at about 2.5m from the weir crest for a gauged head of 0.2m (equivalent to a flow of $0.18m^3s^{-1}m^{-1}$ of weir), or at about 1m from the weir crest for a gauged head of 0.8m (equivalent to a flow of $1.56m^3s^{-1}m^{-1}$ of weir). A sloping distance of 2.5m corresponds to a vertical distance of 0.5m, so, since the zone of super-critical flow extends slightly below the downstream water level, the difference between the Crump weir crest level and the downstream water level must not exceed 0.5m'.

This guideline lacks any reference to an acceptable minimum depth that should occur on the weir face. In addition the velocities quoted would clearly provide extremely challenging, if not impossible, conditions for coarse fish species that are both smaller and poorer swimmers. There is great uncertainty about the minimum acceptable depth, though quite clearly fish must establish some purchase and thrust to successfully secure passage after emerging from the hydraulic jump. It is suggested that the minimum depth in the super-critical region immediately above the standing wave should be ≥50mm. For coarse fish it is probably sensible to have a difference between downstream water level and the weir crest of <0.3m.

The above conditions, and those outlined below for approach conditions, need to pertain during the periods of time when fish are migrating. Compound Crump structures (Figure 72) may help provide an area of the structure where fish can pass at low river discharges, while still retaining the accuracy of flow measurement.

Where it is absolutely necessary to construct a new Crump gauging weir with a crest height >0.5m above the downstream water level for migratory salmonids or >0.3m for other species, then they may only be used where they are part of a BS ISO Standard Compound Gauging & Fish Pass structure (see page 200).

Where existing Crump gauging stations that have conditions outside of the agreed guidelines are refurbished and retained then arrangements should be made during the works for modification to ensure the guidelines are met e.g. reduced afflux, improved approach conditions; or to retro-fit a fish pass to form a Compound Gauging & Fish Pass structure; or else to fit either the Low Cost Baffle solution (Crump Weirs, any species) or Hurn Solution (Flat V Weirs, salmonids only), see pages 131 & 135).

Figure 72 Schematic diagram of a compound Crump weir showing the low flow section that provides a fishway and a high crest section for high flows. Note the automatic fish-counting electrodes on the weir face (after Beach 1984 & Bussell, 1978).

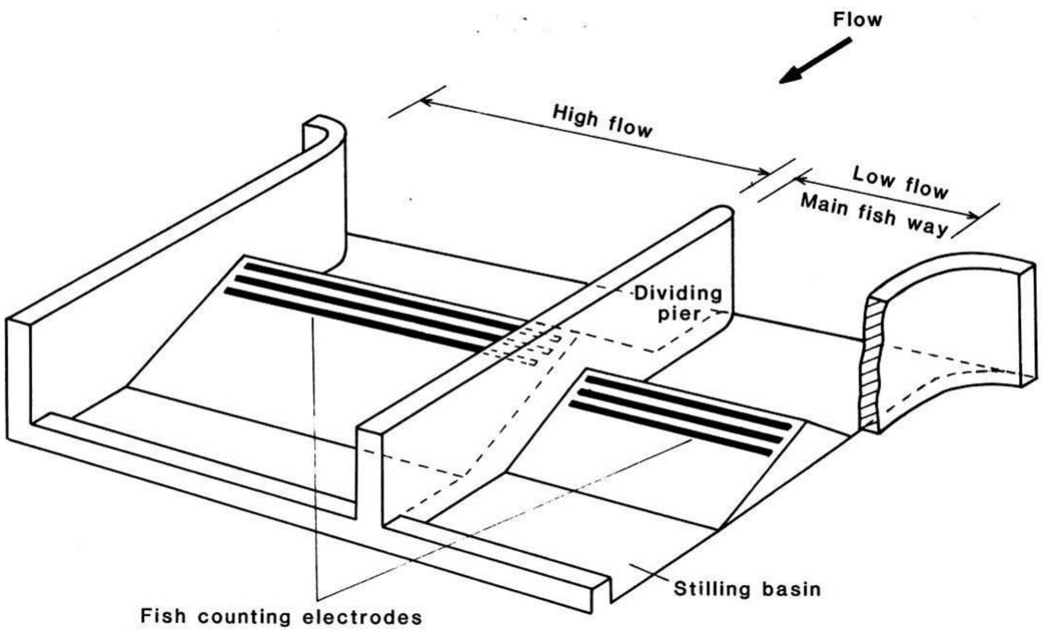
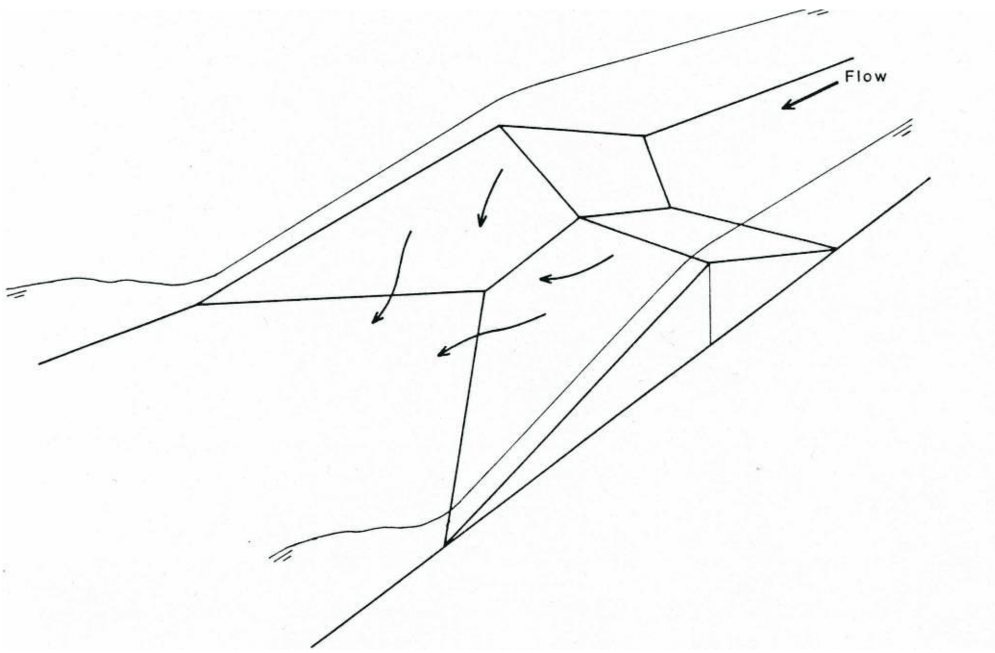


Figure 73 Schematic diagram of a Flat V gauging weir (After Beach, 1984)



Flat V Weirs

Flat V weirs became a popular tool for gauging flow during the 1960s, and have remained so until recently. They usually have a long-section profile of 1:2/1:5 with cross-slopes of 1:10 to 1:40. The characteristics of a Flat V weir are shown in Figure 73.

The advantage from the hydrometry point of view is that they maintain gauging accuracy across a broad range of flow, but since a reasonable depth is maintained in the centre they are particularly suited to accurate low flow measurement. However, despite the original thinking to the contrary they are not weirs that are very suitable for fish passage. In addition to the high water velocities on the downstream face, fish have to contend with highly turbulent and converging flow patterns that make it extremely difficult for them to orientate themselves appropriately. Also, fish easily find themselves in a situation where they have a side force acting on their body, which quickly ensures that they are washed back downstream.

For these reasons it is now recommended that new Flat V structures only be used where there are no reasonable alternatives. From the Fisheries perspective the use of Compound Crump weirs with a low crest meeting the guidelines would be preferable to a Flat V for measuring low discharges. Where they must be used the head difference between the crest of a Flat V and the downstream water level should be ≤0.3m, given mean daily flow conditions as set out in the guidelines that follow at page 198. Flat V weirs may only be used with a head difference >0.3m where they are part of a BS ISO Standard Compound Gauging & Fish Pass structure (see page 200) or else for salmonids where the Hurn type baffle solution (see Baffle systems, page 130) is employed. In both these cases the structure will require fish pass approval.

Where existing Flat V gauging stations that have conditions outside of the agreed guidelines are refurbished and retained then arrangements should be made during the works for modification to ensure the guidelines are met e.g. reduced afflux, improved approach conditions; or to retro-fit a fish pass to form a Compound Gauging & Fish Pass structure; or else, in the case of salmonids, to fit the Hurn solution (see page 131).

Approach Conditions to Gauging Weirs

Since fish crossing Crump and Flat V weirs are certain to have to use burst speeds to do so in all but conditions when the weir is drowned, they will be swimming anaerobically and building up an oxygen debt. In order to have the best chance to cross the weir they need to approach the area immediately downstream of the hydraulic jump using aerobic, preferably cruise speed, swimming performance. The water velocity in this area needs therefore to be very modest, and conditions must also not be excessively turbulent. The downstream area and the approach conditions that it generates thus need to be considered carefully. These factors have been taken in to account in the guidelines outlined below.

Guidelines for new Crump and Flat V Gauging Stations

Guidelines for new constructions of these types of gauging weir were developed and agreed by the Agency Joint National Hydrometry and Fish Passage Panel, and were adopted informally in December 2001. The guidelines were subsequently formally adopted as Agency policy in December 2004.

The following design criteria relate to the mean daily flow condition for the period of the year when upstream fish passage is required. These periods will vary locally and be specific to the site location, the river and the species concerned. The relevant periods should be confirmed with Fisheries, Ecology or Biodiversity staff as appropriate. In the absence of good information the relevant inclusive periods of the years will normally be:-

Coarse fish: ....March - June
Trout: ....September - November
Eel: ....April - August
Salmon & Sea trout: ....April - December

The following design criteria relate to the more common fish species, special considerations may apply in the case of rare or SAC listed species (e.g. shad, bullhead, lamprey, etc).

1. The maximum difference in level between crest level and the downstream tail water level is to be not greater than 0.5m for Crump weirs and 0.3m for Flat V's.
2. The maximum velocity should be no more than $3.5ms^{-1}$ on the downstream face of the weir immediately upstream of the hydraulic jump.
3. The mean approach velocity in the stilling basin must be no more than $0.7ms^{-1}$ for migratory salmonids (including trout) or $0.3ms^{-1}$ for coarse fish.
4. The stilling basin should have a minimum depth of 300mm below tail bed level[4].
5. The hydraulic jump is to form on the face of the weir, not in the stilling basin.
6. It is desirable to truncate the downstream face of the weir. Where it is truncated the toe of the weir must be drowned, and the hydraulic jump must form up-stream of the truncation.
7. The tail stilling basin must be a minimum of 3.0m in length downstream of any truncation, or of the bottom of the weir slope.
8. The designer must produce the necessary calculations[5] to show that the requirements above are met, and these should be included in the Environmental Impact Assessment that is carried out for the site[36].
9. Where particular design features other than those above need to be included to accommodate fish passage, consultation with the National Fish Passage Panel will be required.

Other Gauging Structures

Other types of gauging structure may be used, and certainly many built in the past are still in use today. Where they are structures involving vertical head drops then the guidelines given in the Pool pass section regarding maximum drops, energy dissipation and pool depths apply. In particular head drops must be ≤ 0.45m for migratory salmonids and ≤0.30m for coarse fish.across the range of river discharge Q_{95} to Q_{10} exceedance. Pool depths should be at least twice the height of the drop.

Where thin plate weirs are used conditions are more difficult for fish to pass and the above guidelines should be reduced by a third to ≤0.30m and ≤0.20m respectively. If V notch plates are used then the bottom of the V should be the minimum possible height above the downstream water level at times of low discharge. It is preferable for the bottom of the V notch to be drowned when fish need to migrate, and this condition must be engineered for migration flows..

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[4] *explanatory diagrams can be provided if required*
[5] *see Herschy, R.W, White, W.R, & Whitehead, E,. `The Design of Crump Weirs`, Technical Memorandum No 8, February 1977, Department of the Environment, Water Data Unit Report, ISBN 0 904871 08 8. Page 43*
[6] *via the National or Area Environmental Assessment Staff as appropriate*

In the case of flume type gauges mean water velocities should not exceed $3ms^{-1}$ for migratory salmonids, $2ms^{-1}$ for trout, and $1.5ms^{-1}$ for coarse fish, across the range of river discharge Q_{95} to Q_{10} exceedance.

There is a special case for ultrasonic gauging stations where shad are present. The audio response of shad extends to a low frequency range, and they are alarmed by sounds in the range around 200kHz. They do not appear to be alarmed by frequencies > 420kHz. Thus low frequency sound, <450kHz should be avoided at ultrasonic gauging stations where shad are present since they will be actively deterred from migrating past.

International Standard (ISO) & British Standard (BS) Compound Gauging & Fish Pass Structures

Any new intrusive gauging structures constructed would almost certainly be of either Crump or Flat V construction. There may be occasions where Hydrometric needs require that intrusive gauging structures be constructed that have larger affluxes across them than 0.3m (Flat V) or 0.5m (Crump Weir). There are also many intrusive gauging structures in place that have affluxes that lie outside of the 0.3 – 0.5m guidelines.

In April 2009 International (ISO) & British Standards (BS) were published for Compound gauging & fish pass structures that facilitate the construction of accurate gauging facilities that pass fish while not compromising flow gauging measurement standards. These Standards ISO 26906:2009 Hydrometry – Fishpasses at flow gauging structures specify the requirements for integrating fish passes with flow measurement structures, and methods for computing combined flow uncertainties. Three fish pass types that have hydrometric standard discharge relationships are included – Dutch Pool & Orifice, Pool type with V shaped overfalls, and the Larinier super-active baffle pass with 100mm high baffles. The type favoured for compound facilities in the UK will generally be the last of these – the Larinier pass since this enables good attraction flows to be generated while taking limited longitudinal space. These standards can be applied to new constructions, or to retro-fit situations where it is necessary to improve fish passage at existing sites.

The standard sets out the conditions that require to be met in respect of the structure including site selection, installation, upstream channel, downstream channel, maintenance, head measurement, and pass location, attraction flow, downstream entrance, upstream exit, fish pass performance and limitations. Also set out are the computation of discharges and uncertainty measurement. It is not intended to go into the details here, but they may be found in the standard. Further guidelines on the juxtaposition of gauging and fish pass elements may be found in White, Bowker & McGahey, Chapters 6 & 7 of Flow measurement structure design to aid fish migration without compromising flow data accuracy, Science Report SC020053/SR2, Environment Agency, January 2005.

Because the baffle geometry is quite complex the coefficient of discharge for the pass in its modular flow range follows a distinctive changing pattern. It is recommended that the pass element generally be designed to have a minimum head ≥ 0.20m that suits both gauging and fish passage ideals. However, values less than this may be used especially for small fish (10 - 20cms) with the pass working hydraulically for depths > 12cms. Maximum design head for fish passage Ha = 0.60m, though for coarse fish species, brown trout & grayling it is probably better to restrict it to Ha = 0.50m.

A typical suggested layout of a new-build compound gauging and fish pass structure is shown in Figure 74. The discharge relationship for a 100mm baffle pass and head to Ha = 0.70m is shown in Figure 75 and Table 8 below.

Lariniers may be built with different baffle heights but the only size accredited currently for compounding with a gauging structure is 100mm. It is intended to establish hydrometric standard discharge relationships for other sizes of baffle in the near future. In the meantime other baffle size Larinier passes would rely on having a separate means of flow measurement in the pass channel such as a transit time ultrasonic station.

Figure 74 General arrangement of a compound gauging structure with Larinier fish pass alongside a Crump Weir

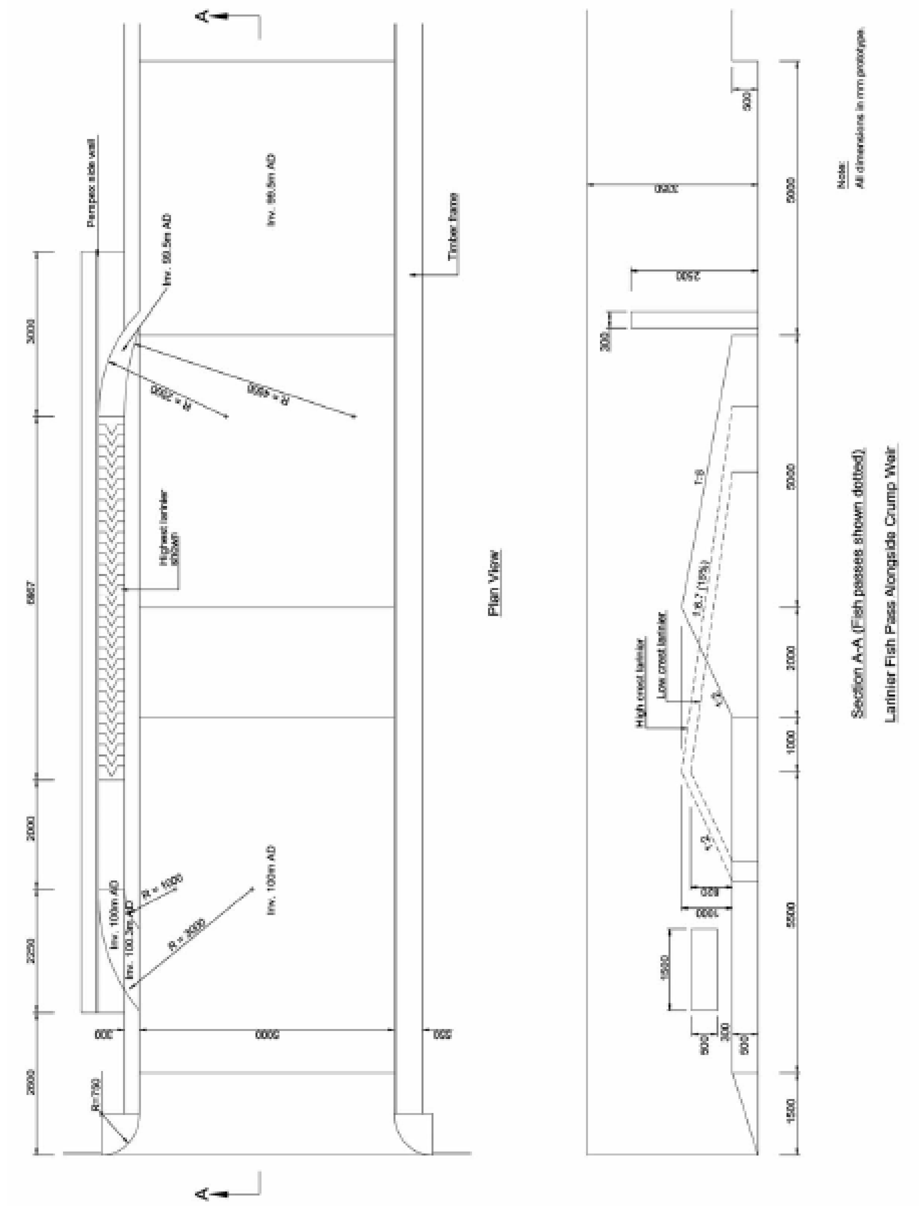


Figure 75 Hydrometric standard discharge relationship for a Larinier super-active baffle pass with 100mm baffles.

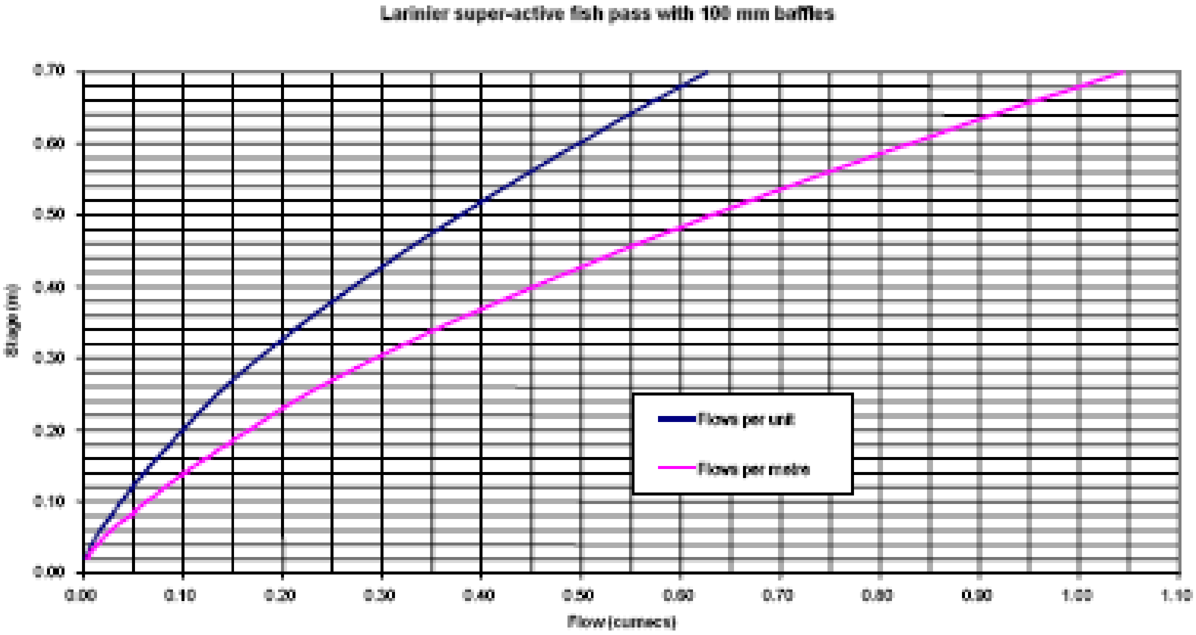


Table 8 Numerical values for hydrometric standard discharge relationship for a Larinier super-active baffle pass with 100mm baffles

Larinier flows - numerical values

Upstream gauged head (m)	Flow per Larinier unit (cumecs)	Flow per metre Width (cumecs)
0.020	0.003	0.004
0.030	0.005	0.009
0.040	0.008	0.014
0.050	0.012	0.021
0.060	0.017	0.028
0.070	0.022	0.037
0.080	0.028	0.047
0.090	0.033	0.055
0.100	0.038	0.063
0.110	0.044	0.073
0.120	0.049	0.082
0.130	0.055	0.092
0.140	0.061	0.102
0.150	0.067	0.112
0.160	0.074	0.123
0.170	0.080	0.133
0.180	0.087	0.145
0.190	0.093	0.155
0.200	0.100	0.167
0.220	0.113	0.188
0.240	0.127	0.212
0.260	0.142	0.237
0.280	0.159	0.265
0.300	0.176	0.293
0.320	0.194	0.323
0.340	0.212	0.353
0.360	0.231	0.385
0.380	0.251	0.418
0.400	0.271	0.452
0.420	0.292	0.487
0.440	0.313	0.522
0.460	0.334	0.557
0.480	0.356	0.593
0.500	0.379	0.632
0.520	0.402	0.670
0.540	0.425	0.708
0.560	0.449	0.748
0.580	0.473	0.788
0.600	0.498	0.830
0.620	0.523	0.872
0.640	0.548	0.913
0.660	0.574	0.957
0.680	0.601	1.002
0.700	0.627	1.045

Improvements at existing structures

Salmonids & Coarse fish

Clearly, it may be possible to apply a retro-fit solution that uses the ISO Standard outlined above to modify an existing structure to become a compound gauging and fish pass facility. On the other hand, other improvements to passage at existing gauging stations may well be possible utilising some of the methods described in more detail in earlier sections. In the first instancea comparison of existing conditions against the those outlined in the gauging & fish pass guidelines above may identify features that can be readily modified to improve the situation e.g. reduction of afflux across the structure, or improvement to approach conditions.

In some instances a fish pass solution such as a Larinier might be located in a by-pass channel with a conventional gauging weir such as a Crump Weir located immediately upstream of it to gauge flow accurately. The gauge weir would need a small afflux across it that meets the agreed guidelines. The conditions required for a flow gauging adaptation at the head of a Larinier pass are described in Chapters 4.6 of Flow measurement structure design to aid fish migration without compromising flow data accuracy, Science Report SC020053/SR2, Environment Agency, January 2005.

The retro-fitting of a conventional fish pass solution other than those specifically included in the ISO Standard is possible, including retro-fitting to non-standard gauges. In such cases the pass channel would have to be fitted with an additional suitable flow gauge such as ultrasonic time of flight or Doppler technology.

A relatively simple improvement may be the reduction of afflux, effectively the head difference between crest of the gauge weir and tail-water level, by the provision of notched pre-barrages (notch with streaming flow or adherent nappe as per examples in pool passes). This may be particularly attractive where approach conditions are not less than acceptable at the moment sine it would help address that issue as well as make passage over the structure easier, and where only one or two pre-barrages have to be used. It would be helpful if the most downstream pre-barrage as a free gap rather than a notch. The disadvantage of reducing afflux is that this will compromise i.e. reduce the range of flows over which the station remains in the modular range. However, this may not be critical where the station is a low flow device.

Although not yet accepted for widespread use a technique for Crump type weirs is a modification of the Low Cost Baffle solution (LCB - see Easements section). This is currently the subject of ongoing field-based R&D, but early indications suggest good potential –see LCB section. The LCB system has to be compromised from its idealised form by placing the nearest baffles to the weir crest further down the weir slope, such that the coefficient of discharge of the Crump weir is not altered by more than 1%. The methodology for deciding where the most upstream baffle may be placed is described in Chapter 5 of White, Bowker & McGahey, 2005, Flow measurement structure design to aid fish migration without compromising flow data accuracy, Science Report SC020053/SR2, 2005.

Another baffle solution, the Hurn baffle solution, has been used for Flat V Weirs in a small number of locations. This has been described in the Baffles section, page 131. The solution has not proved to be effective for coarse fish species that appear to be disorientated by the turbulence and cannot find a passage route. However, they are considered to help passage of salmonids. The same methodology for locating the most upstream baffle would apply as described above for the LCB solution on Crump Weir.

Eels

Eels are a particular challenge because, especially in their early most migratory phases as elver & small eel, they are very poor swimmers. Eels require separate fish pass facilities from salmonids & coarse fish. Various of the techniques briefly outlined in the earlier eel pass section might be used at gauging stations, however in practice these are currently limited to the non-invasive techniques that do not impair gauging station accuracy. Guidelines have been agreed between Fisheries & Hydrometry and put in place as policy in November 2009. Non-invasive solutions for eel/elver passage at gauging stations may be used as follows:

Definition of non-invasive: An eel pass that is located above and beyond the area bounded by the wing walls of a gauging structure.

These may be installed subject to agreement between local fisheries and hydrometry teams

Provided that the design of non-invasive eel passes meets the following general principles then it is expected that they will be an acceptable solution for use at gauging sites. In some cases invasive eel passes may be acceptable at gauging stations, but the general presumption is they will not. The following guidance should permit the identification of sites where the provision of eel passes is more immediately possible e.g. these will usually be pipe or channel "up and over" type passes with elver-friendly substrate and a pumped flow.

General Principles

1. Both entrance and exit need to be sited in a manner that is acceptable for eel passage[1] while not compromising the performance of the gauging structure[2]. The lower entrance to the pass should be placed downstream of the end of the gauging weir wing wall. For hydrometric reasons, the eel pass should be fed by water pumped from downstream of the structure wherever possible.
2. The pump should abstract no more than 0.5 litres of flow / second[3.] This assumes that at least half of the 0.5 litre per second is discharged back downstream. Less than half to be discharged upstream of the structure.
3. Such passes can only be installed where minimum dry weather flow of the watercourse exceeds 25 litres/ second.
4. The siting of the pass entrance and exit should be near the margins of the stream and not mid – channel.
5. At a site where a high flow rating exists for the channel outside of the wing walls, the hydrometry team will need to consider the impact of the eel pass on that high flow rating.
6. Agreement will need to be achieved between local fisheries and hydrometry and telemetry teams on the design of the eel pass.
7. The hydrometry team can object to the installation of an eel pass if it considers it has justifiable reasons. Adjudication of disputes will be resolved by the Regional Hydrometry and Telemetry Client Panel.

Notes:

[1] Near the toe of the obstruction

[2] Avoids snagging debris or interfering with flow lines

[3] Experience has shown that if correctly sited eels will find a very small attraction flow. The nominated flow is sufficient for a bristle pass 200 mm wide that will allow thousands of eels to pass per night. The pump only

needs to be operating from dusk till dawn. Key months for use of pass: April-September with some Regional variation.

The full temporary guidelines document can be found in the Appendix XVI.

It is expected that guidelines for a specific ‘invasive’ type of eel pass will shortly be agreed, and this is the subject of ongoing R&D to confirm acceptance and agree detailed specific structural and operational guidelines. This comprises a tall, narrow vertical structure with horizontal bristle media at one or both banks of a gauging station. It may be suitable for many gauge structures but particularly broad-crested and Crump Weirs for example. It is not especially suitable for some structures, such as Flat V weirs.

Lampreys

Like eels, lampreys (sea & river lamprey) are not particularly good swimmers and require specific arrangements to enhance passage. Given their unique ability to use their sucker mouthparts to augment locomotory capability, a simple means of enhancing passage without interfering with gauging accuracy is to provide a continuous stainless steel plate, say 0.3 – 0.5m wide up one or both sides of the weir from the weir base on the downstream side to the river bed on the upstream side. The crest should not form a sharp edge that might cause the lamprey to lose the vacuum created with the villi in their sucking mouthparts.

Brook lampreys are a special case being very small (<15cms). It is quite possible that passage solutions provided for eel & elver may be used by brook lamprey as well.

FISH PASSAGE AT WATER CONTROL STRUCTURES & NAVIGATION LOCKS

Sluices and radial gates

Conventional water control structures are rarely designed with fish passage in mind. However, when new structures are being installed or perhaps replacements during maintenance it is possible for them to be constructed sympathetically. Modifications that can help improve the chances of fish passage are discussed below.

It should never be forgotten that changes in the operating regime or defined protocol(s) for control structures at existing sites might be used to bring about substantial improvements in fish passage.. By moving the areas where the majority of the flow is discharged, or by creating different velocities and flow patterns, the behaviour of the fish can be influenced and they may be dissuaded from entering some areas while being guided or attracted to others. Careful observation of, or an understanding of, fish behaviour in relation to the hydrodynamics at a site may facilitate the use of tactics that can improve the effectiveness and efficiency of passage, for example to attract fish to an area where fish can pass such as the location of a fishway.

Undershot Sluices

Undershot sluices control discharge by restricting the flow to a limited area under the gate. The mean water velocity through the gate is related to the head difference across it and is the same as for head differences in pool and traverse type fishways. The velocity is approximately equal to $(2gh)^{0.5}$ for a free flowing gate, while the discharge is roughly equal to velocity multiplied by the open area of the gate. While these are only approximations because they ignore coefficients of discharge and contraction, approach velocities, and also roughness, they are good enough for fishery purposes.

In the right circumstances undershot sluices can pass fish. As with orifices in pool passes, the open aperture of the gate must be a minimum size of 0.3m x 0.3m, and the velocity through it should not exceed $3ms^{-1}$ for migratory salmonids. A velocity of $3.0ms^{-1}$ would be generated by a head difference of about 0.45m if the gate is free flowing. If the sluice opening is well submerged i.e. drowned, then a head difference of 1m results in a velocity of about $2.7m^{-1}$ (see Appendix XI, Examples 9 & 10).

To improve the likelihood of achieving passable conditions it is better to regulate flow at such structures by using multiple small gates that can be well open, as opposed to small numbers of very large ones (see Figure 76 & Figure 77. Wide gates open by a small amount have attractive high velocity jets that are impassable, and distract fish from finding more beneficial routes.

Ideally the sluice should discharge in to a stilling basin designed to bring the formation of the hydraulic jump close to the structure, and to dissipate energy and the water velocity rapidly. Extending the sill in to the basin and avoiding the use of base blocks is also an advantage. These principles are demonstrated in Figure 78 & Figure 79.

Figure 76 Undershot sluices with flow regulated by multiple gates, permitting low discharges to be achieved while providing suitable conditions for fish passage (After Beach, 1984)

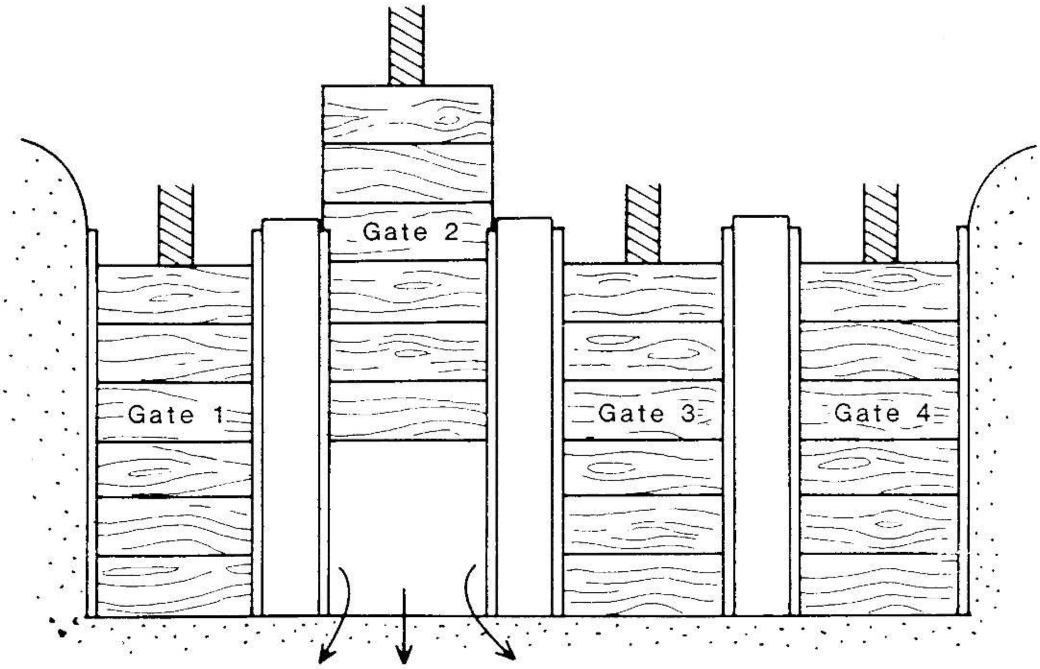


Figure 77 A single large undershot gate controlling flow (often automated).A low discharge results in an impassable high velocity jet (After Beach, 1984)

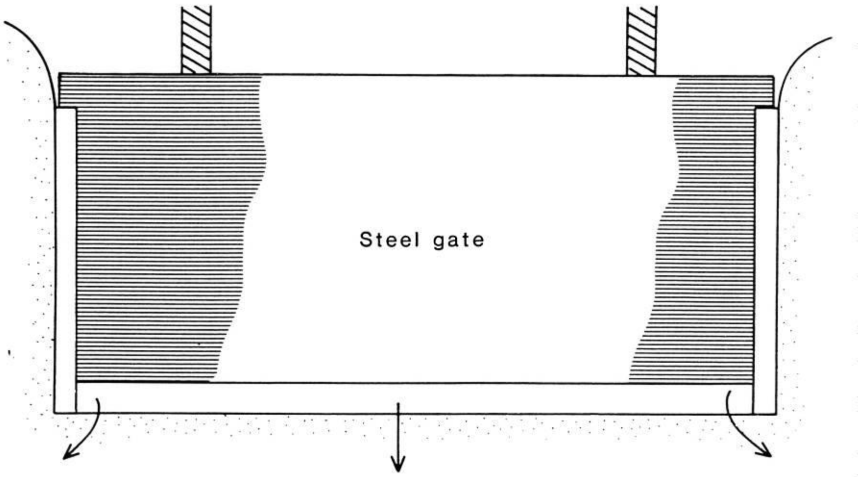


Figure 78 This form of undershot sluice is very unsuitable. The base block enables a water jet to form, while the flat base allows the high velocity to persist over a considerable distance (After Beach, 1984)

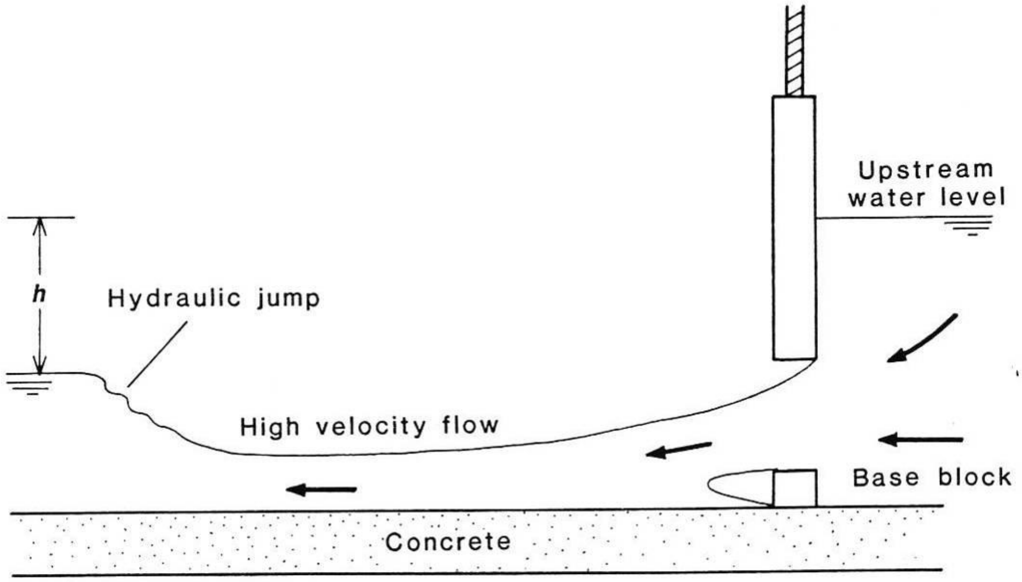
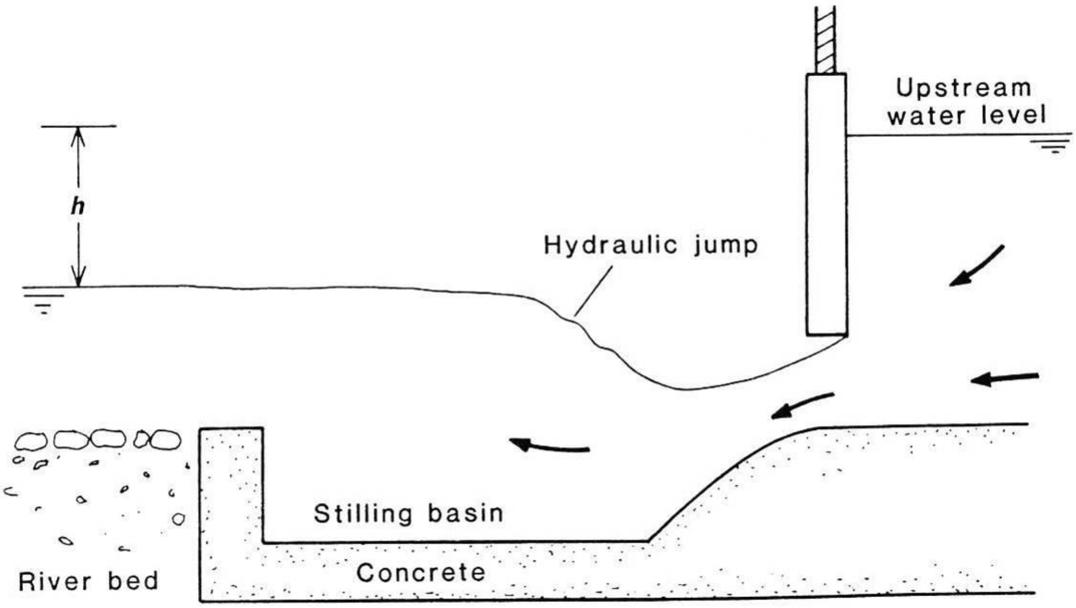


Figure 79 Fish passage at this form of undershot sluice is much easier. The lack of obstruction below the sluice gate and graded approach to the stilling basin allow rapid attenuation of water velocity (After Beach, 1984)



Overshot Sluices

Overshot sluices (Figure 80 & Figure 81) can permit fish passage provided that most of the conditions required for pool type passes are mimicked. The head difference across the gate should not exceed 0.45m for migratory salmonids, less for other species. Velocities are calculated in the same way as for undershot sluices or pool passes. The gate should have a rounded profile to ensure an adherent nappe, and the pool below should be sufficiently deep - at least twice the head difference. Like the undershot sluice it is preferable to have a stilling basin, and to regulate flow with a number of smaller sluices that allow the appropriate conditions to be maintained at one or more of them.

The disadvantage of overshot sluices when compared to undershot is that the overshot sluice will generally have the additional hazard for the fish of a solid spindle in the passageway. However, it is possible to avoid this by having sluices with side-actuating spindles

Figure 80 Overspill sluice with sharp edge and shallow water over concrete apron; this produces difficult approach conditions for fish because of insufficient downstream water depth (After Beach, 1984)

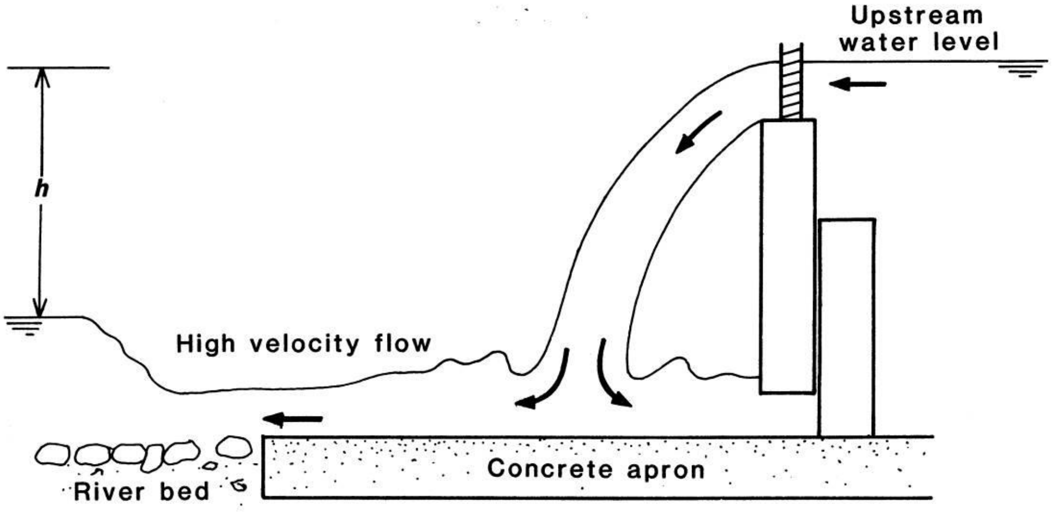
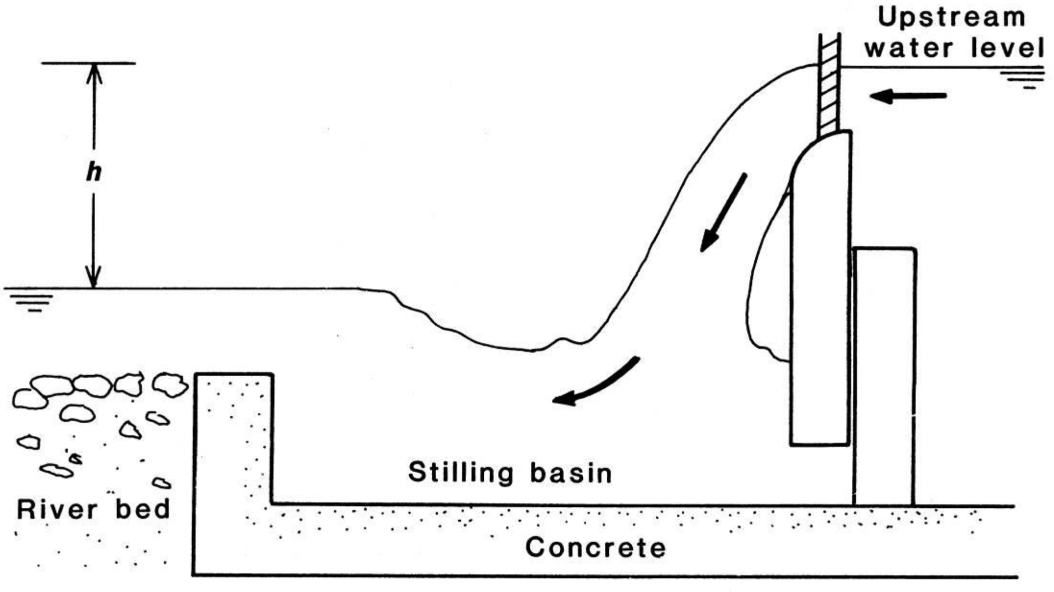


Figure 81 Overspill sluice with curved edge and stilling basin; this produces sufficient water depth for an easy approach and a smooth crest flow (After Beach, 1984)



Radial gates

Radial gates are only likely to be passable when they are drowned out during high river discharge events. In normal circumstances there is a high velocity under partly open gates, with extreme reverse-rolling turbulence that makes them unapproachable.

Navigation Locks

Navigation locks, by definition, are not intended for passing fish and are not usually located in a position that would make them attractive to fish. Despite this the emptying phase of lockage can attract fish in to the lock chamber. As a result fish can be accidentally, or even deliberately lifted upstream (Klinge, 1994; Moser et al, 2000). Locks would not be considered as the principle means of moving fish upstream, but nevertheless may be exploited to considerable advantage to augment more conventional arrangements.

There are numerous examples from around the world of locks being used to enhance fish passage. In the USA sites where locks are used include Bonneville Dam on the Columbia River, USA (Monan et al 1970), Chittenden Locks on the Lake Washington Ship Canal, Seattle, USA (P. Gough, pers comm), and the Cape Fear River (Moser et al, 2000.) All feature locks used with some success in this way. Sites are also known in France (Jolimaitre,1992; Zylberblat & Mainali, 1996), Switzerland (Kreitmann, 1925), and the USSR (Kipper & Mileiko, 1962). In the UK the technique has been used with some success, although not as a regular operation, at the navigation lock at the River Tees Barrage (R. Jenkins, pers comm). Early observations also suggest that fish might use navigation locks associated with the Cardiff Bay Barrage on the River Taff (P. Gough, pers comm). Thus, while by no means a primary means of providing fish passage it has been proved to be a useful ancillary one at some locations.

There are a number of changes to the operational protocol for navigation locks that can be used to increase their ability to act as a fish passage device. For example, in the USA passage of American shad through locks on the Cape Fear River (Moser et al, 2000) was greatly enhanced by:

- Operating the lock as a fish pass (i.e. a specifically designed protocol) during appropriate periods
- Increasing attraction flows from the lock entrance
- Conducting as many lockages as possible in a day
- Adjusting the position of the lock gates and local flow patterns to attract and retain fish better.

At the Chittendon Locks (Lake Washington Ship Canal, Seattle), the large lock is regularly left in a part open position (with a gap of perhaps 0.5m), creating a through-flow that successfully promotes the migration of sockeye salmon (P. Gough, pers comm).

On the Cape Fear River (Moser et al, 2000) the locks were originally operated over one cycle per day during the shad migration period. Fish were attracted in to the lock over a 24hr period by opening the sluices on the upstream gates, while leaving the downstream gates open. At the end of the 24hr period the downstream gates were shut and the lock filled. Once full the upstream gates were opened, and at the same time the sluices on the downstream gates were opened in order to create a flow that encouraged the shad to leave the lock. Modifications to this protocol included increasing lockages to three times per day, shutting one of the downstream gates to help prevent fish leaving the lock, and opening the sluices that directed flow down the lock wall where the downstream gate was open. These adjustments were carefully made after observation of the behaviour of the shad in the lock.

A typical operating protocol might be:

- Lock empty, crack top gate sluices, run flow through cracked lock gates (if the design will stand this) or else say one gate open (increases attraction, re-directs fish back up the lock rather than swimming back out) developing a small head drop (attraction velocity) and streaming flow entrance.

- Run for a period of time to attract fish in

- Close downstream gates and fill lock

- Open upstream gates, and crack downstream gate sluices to generate a current that encourages fish to leave the lock

This protocol is precisely similar to the operation of a Borland Lift.

FISH PASS EVALUATION AND MAINTENANCE

The need for monitoring the performance of a fish pass

The approval of fish passes is dealt with under section 11 of the Salmon and Freshwater Fisheries Act 1975. This can be a two-stage process; the first being to submit detailed proposals and obtain Provisional Approval, the second stage being to submit details on how the fish pass is performing in order to obtain Final Approval. There is thus may be a requirement to monitor the performance of a fish pass.

When considering an application for Provisional Approval, the Environment Agency expects information to be supplied not only on the design and operation of the fish pass, but also on how it is intended to assess the performance of the pass. The aim of this section and Appendix XIV is to outline how such data might be obtained.

Introduction

The performance of a fish pass will vary with the type of pass, species and specific site conditions (Katapodis, 1992). There is a considerable amount of information both published and unpublished which indicates that fish passes can be effective in that they are known to pass fish (Beach, 1984; Clay, 1995; Katapodis, 1992). Similarly there is considerable evidence that fish passes have been constructed which have proved to be ineffective in passing their target species; mainly as a result of poor/unsuitable design.

While there is a considerable literature on the effectiveness of fish passes, there is not a great deal of information on fish pass efficiency. This is largely because of the considerable resource requirement required to complete such studies. Table 9 summarises the estimates of efficiency for some fish passes for salmon.

Table 9 Efficiency of various fish passes for salmon

Type of Pass	Location (river)	Efficiency	Reference
Denil	Blackweir (Taff)	25 - 39%	Gough (pers.comm)
Denil	Pau River	34%	Chanseau & Larinier (1999)
Submerged Orifice	Pitlochry (Tummel)	45.5% 86 - 100%	Webb (1990) Gowans et al.(1996)
Various (31 sites)	Pau River	35 – 100%	Chanseau, Croze & Larinier (1999)
Borland Fish Lift	Kilmorack (Beauly)	40%	Smith et al.(1996)
Various(6 sites)	River Conon	63 - 100%	Gowans et al (2001)
Various (21 sites)	River Thames	65 – 100%	Clifton-Dey (pers. comm.)

The three-year study carried out on the Pau River tracked 114 salmon, and looked at thirty-one sites equipped with fishways varying from natural by-pass channels, to technical constructions. Overall efficiencies of passage varied from 35.3% to 100%. Those sites with 100% efficiency were characteristically those that caused delays to passage of no more than two weeks, while those with efficiencies less than 100% were characterised by significant numbers of fish being delayed for periods longer than this. Those fishways that were efficient were also those that cause the least delay, and there was an inverse relationship between the two factors.

The Pau River tracking study also demonstrates clearly that when considering the efficiency of a pass it is not simply the proportion of fish approaching the obstruction that subsequently get past that has to be considered, but also the time that it takes. This becomes a particularly important consideration when the fish absolutely must pass in order to achieve their objective, foe example when all the spawning grounds for migratory salmonids lie upstream of the obstruction. In France, a fish pass for migratory salmonids would generally be expected to achieve an efficiency of >80% and to delay fish for less than two weeks to be regarded as acceptable.

The study on the River Thames took place over several years (1995 - 2004) and reflects passage past the weir with fish pass as opposed to the fish pass alone. This is because these low weirs, generally 1.5 - 2m high, are not wholly impassable and some fish can pass either over the weirs or else through flow and head regulation structres at elevated river discharge. However, they mostly remain impassable and often for long periods without the passes.

Some estimates of efficiency exist for other species, including shad and grayling. For shad on the River Garonne, the percentage passing through the Golfech lift and the pass at Bazacle (pool pass with vertical slots) ranged from 17 - 32% (Larinier & Travade,1992) and at Ramier the fish pass was estimated to be >70% efficient (Dartiguelongue, 1990 in Larinier & Travade,1992). On the Dordogne at Mauzac the efficiency of the pool pass, for shad, ranged from 0.5 - 30% (Larinier & Travade, 1992). For grayling, Linlokken (1993) estimated the efficiency of pool and weir and a Denil fish passes to be <2%. No estimates of fish pass efficiency are known for cyprinids and eels.

For species not indigenous to Europe, estimates of efficiency have been reported for *Micropterus dolomieui* and *Catostomus commersoni* using a Denil fish pass, of 50% and 33% respectively (Bunt et al, 1999).

Some reasons for undertaking evaluation

The scope of any monitoring programme will depend on the nature of the fish pass and its potential impact on the fish stocks. The reasons for an evaluation programme fall into three main categories as follows; to improve operational efficiency of the fish pass, to assess the level of any mitigation that might be required for a poorly performing pass, and to to improve future designs.

To appraise operation

To confirm the functioning of the pass for the target fish species over the range of environmental conditions in which migration occurs. For example, the upstream migration of salmonids can occur throughout the year and it is important that a fish pass is able to facilitate their passage at all times, without undue delay.

To confirm the functioning of the pass for each component of the fish stock. For example, it is important that the ability of the pass to assist passage of each age class or length class of the target fish species is confirmed and that the pass is not size selective.

To provide information to enable improvements to be made to the operation of the fish pass if required.

To collect information and data (qualitative and/or quantitative) to support a future application for Final Approval under the SAFFA, 1975 (as amended by the Environment Act, 1995).

To determine the proportion of the target migrating stock which succeeds in ascending the pass (or descending a downstream pass).

To assess mitigation

To provide data for the assessment of any mitigation required. For example, a Fisheries Compensation Scheme associated with a major new obstruction to migration may require information on the efficiency of the fish pass in order to quantify the required level of mitigation.

To improve future designs

To enhance the overall sum of knowledge on the functioning and performance of fish passes in order to promote future improvements in design and construction.

The requirements for monitoring

Types of assessment

In principle there are two ways of monitoring and judging the performance of a fishway.

Detecting changes in the upstream population

The detection of change in the upstream population indicates whether or not the pass is effective i.e. is it "capable of passing fish in the desired direction". It may be either a quantitative or quailitative assessment of the performance of the fish pass.

Assessing the efficiency of the pass

The proportion of available fish using the pass is the efficiency of a fish pass and is a quantitative measure of its performance. In its simplest form Efficiency (E) is that proportion (n) of the available stock of fish (N) which succeed in ascending/descending a fish pass.

$$E = n/N \qquad (1)$$

Where it is obligatory that all fish must pass, such as a migratory salmonid population arriving at a barrier downstream of any potential spawning habitat, then this is a simple scenario. Where not all fish arriving at or near an obstruction need to pass, the efficiency might better be assessed relative to the numbers of fish that approach the barrier or pass that intend to move upstream.

Further complexity is added when considering the element of delay. An efficient fish pass is not necessarily one that simply passes a high proportion of the fish. It is one that passes a high proportion of the fish without undue delay. How important the latter is depends on the context. A single obstruction near the lower end of a long river catchment, or a number of obstructions on even a short river catchment, clearly mean that the element of delay becomes an important issue.

Factors affecting the required precision

The potential magnitude of the impact of any development on the fish population is an important consideration. Two primary situations can be recognised. The situation where a new obstruction is being created that imposes a new constraint on the fish population, and the situation where the existing effects of an obstruction are being mitigated by the installation of a fishway.

Existing structures

On an existing structure, the criteria to be fulfilled are lower than for new structures, as any improvement in potential access to the river upstream is desirable. As long as fish are witnessed to pass over or through the structure then it is evident that the fish pass has made a difference. However, it is important when applying for final approval that some assessment of the effectiveness of the pass is presented. In these cases the quality of the data required to assess effectiveness does not usually need to be as robust as when a pass on a new structure is being considered.

New structures

For a fish pass on a new structure the actual efficiency of the pass must usually be determined. In circumstances where there is a significant risk that the new structure will have a detrimental effect on the migratory salmonid population, a quantitative monitoring programme capable of determining passage efficiency will be required.

In this case the context of delay will be much more likely to be an important issue. There is evidence that fish delayed for more than one to two weeks from entering a river may disappear never to return (Solomon et al, 1999). The work on the Pau River (Chanseau & Larinier, 1999) showed that highly efficient passes in terms of both proportion of fish passing and short delay were associated with delay periods of less than two weeks.

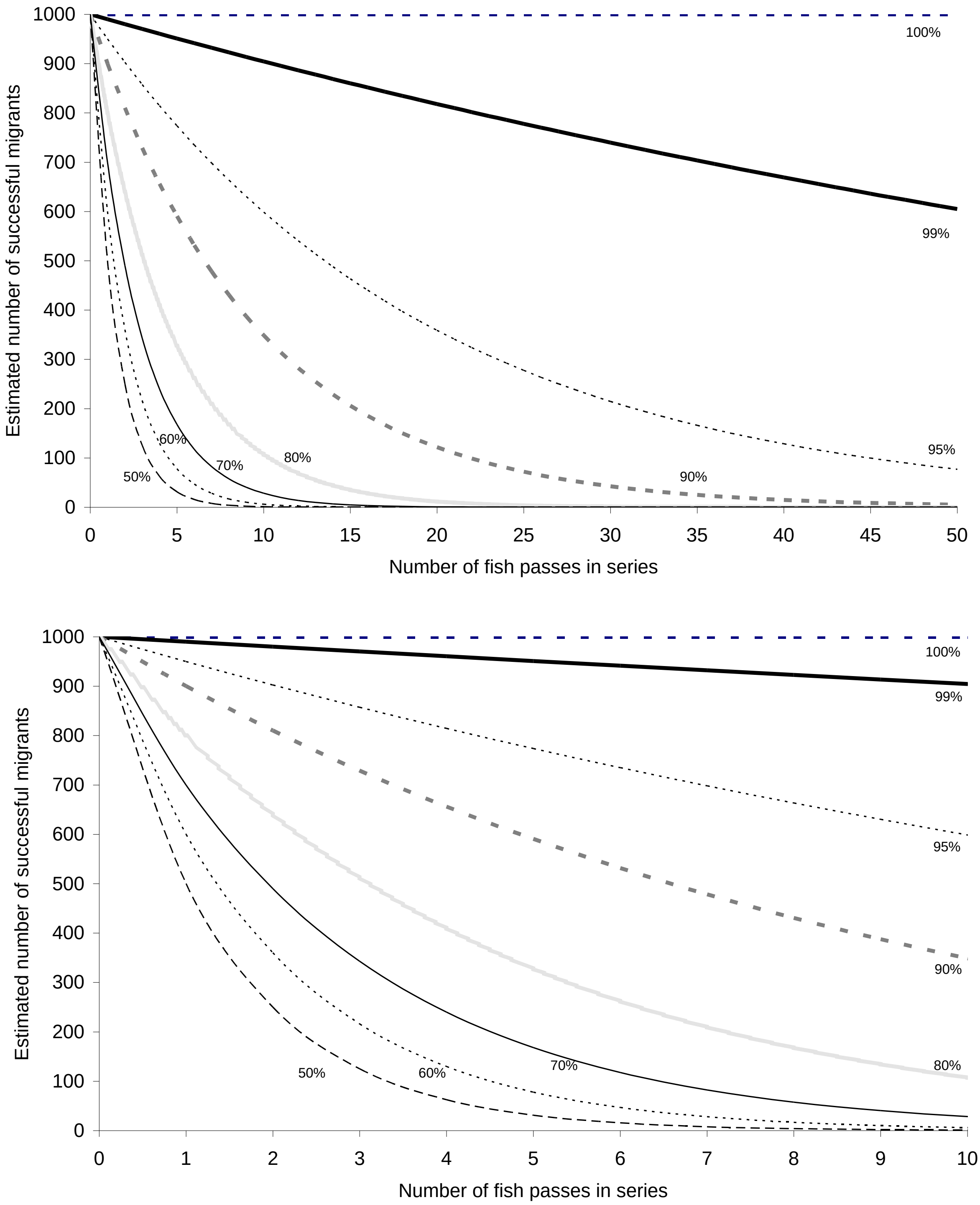
The intensity of the required monitoring programme will depend on the risk that a structure poses to the population. An intensive monitoring programme is likely to be required for a development in the estuary or lower reaches of a major migratory salmonid river where risk to the population is high. On the other hand the programme can be less intensive for a new development on a tributary in the upper reaches of a river where the perceived risks are low.

Cumulative effect of a number of structures

The importance of monitoring is particularly apparent in the case of rivers where multiple obstructions to migration exist. If each of a series of ten fish passes on a river operated at an efficiency of 50%, then the migrating stock of fish ascending the whole series would be reduced to only 0.1% of its initial number. An alternative way of looking at this from the point of view of a fishery manager is to imagine that a spawning escapement of 100 fish is required to reach the uppermost stretch of the river. Even with the greater fish pass efficiency of 80%, a stock of 1000 fish would need to arrive at the first obstruction to achieve the target escapement above the top one. Clearly, on watercourses with diadromous fish populations and multiple obstructions it is essential for fish passage facilities to be highly efficient, near 100%.

The rapid decline in the number and proportion of fish reaching the spawning area as the number of obstructions increases, and the efficiency of passes declines is demonstrated in Figure 82. The initial number of migrating fish is assumed to be one thousand, and the lines represent different mean efficiencies between 100% and 50%.

Figure 82 Effects of fish passage efficiency in river systems where a series of passes are constructed along the migratory route for salmonids (After Gowans, 1998)



Relative position and importance of the obstruction within the catchment

The monitoring associated with a pass on an existing structure in a tributary which improves the potential for migration will not require as robust a programme as a pass within a major new obstruction in the lower reaches of a river. The former may require simple operational or observation data only (eg. redd counts, lack of accumulation of potential migrants downstream), whilst the latter may require a major monitoring programme requiring pre and post-construction monitoring programmes involving the collection of quantitative data, and the accurate assessment of pass operating efficiency.

Criteria for evaluation

Fish pass performance is likely to vary between fish species and also according to the size and condition of the fish. It is also likely to be affected by flow, and the relationship between pass performance and flow may mean that it varies both throughout the run of fish (e.g. different for spring and summer components of the stock), and from year to year. As an example, Larinier & Travade (1992) reported that river flows often had a marked effect on fish pass efficiency for Alosa spp, with low flows being optimal for shad to use the fish passes. In these cases the relative attraction flow from the passes was higher at times of low river discharge.

It is essential that the estimation of performance of a pass should take account of the variability in environmental conditions, but particularly flow, as well as the timing of the fish migration and other factors. For this reason it is important, when dealing with species such as salmon or eel that have relatively large windows of migration, to stratify the sampling programme. In practice this will usually mean that monitoring needs to extend not only throughout a season, but also usually over more than one season. This is to ensure that actual variation in the conditions a species might be expected to experience as well as their physiological state (i.e. how close the fish is to spawning) are taken into account.

Different species and life stages

The criteria for monitoring may be different for different species, and even life stages of the same species. For example, for those species which have a relatively short migration period (eg. *Alosa spp*.), or a late running population of salmon say, it is imperative that any delay to their migration be kept to a minimum. In the case of migratory salmonids it is frequently the case that the whole of the spawning population is obliged to cross an obstruction in order to reach the spawning grounds that are located upstream. However, in the case of cyprinids, where the main biological objective is to avoid the population becoming isolated, it is not necessary to ensure that the whole population migrate pass the obstruction, as long as a reasonable proportion of the population can do so (Porcher & Travade, 1992).

Hydraulic factors and flow

Monitoring should also include measurement of the hydraulic conditions in the pass under a variety of flows. This is to ensure that the pass meets the original design criteria, and thus its suitability for the particular target species. Also to ensure and confirm that the facility operates effectively across the expected range of river discharge and levels.

Methods for determining the effectiveness of fish passes

The effectiveness of a pass is a qualitative description of the performance of a pass. It simply demonstrates that some fish are able to use the pass and, even though numbers of fish recorded using the facility may be very high, it cannot necessarily be taken as an indication of good performance of the fishway. The effectiveness of a pass can be determined either directly or indirectly (see below).

The relative merits of the main methods (both direct and indirect) that can be used to monitor the effectiveness of a fish pass are shown in Table 10.

Table 10 The relative merits of the main methods that can be used to monitor the effectiveness of a fish pass

Method of Assessement	Effectiveness
Visual Inspections	+
Rod Catches	++
Redd Counts	++
Fishery Surveys	+++
Telemetric Surveys PIT tag,Radio tag etc	++++
Fish Counter - in pass Resistivity, Video, Infra-red	++++
Fish Counter - in pass with information on population d/s	++++
Counter + Photo/Video	++++
Trapping and tagging	++++

Direct assessment of effectiveness

Confirmation that fish are using a fish pass can be accomplished through direct means including visual inspection, photography, trapping in the fish pass, or from recordings on a fish counter (see Fewings 1994 for various types). Design criteria for resistivity counters can be found in Nicholson et al. (1995), and for automatic video recording systems in Travade & Larinier (1992b). One of the limitations of using methods such as fish counters is that they need a power supply. In those instances where no power source is available other methods of assessing effectiveness will be required, and these include indirect methods.

Indirect assessment: Detecting changes in the upstream population

These methods involve the assessment of the status of juvenile and/or adult stocks pre and post-construction of the fish pass. If data on the juvenile and/or adult population are to be used to assess the effectiveness of the pass then the study must be based on a statistically robust experimental design (see Wyatt & Lacey, 1994). Some worked examples of assessing effectiveness are given in Appendix XIV.

Methods for determining the efficiency of a fish pass

The efficiency of a pass is a quantitative measure of its performance. It is the proportion of the fish that approach the facility that successfully pass. It is a sound indicator of performance, although then effects of delay may also need to be taken in to account in some instances.

The relative merits of the main methods that can be used to monitor the efficiency of a fish pass are shown in Table 11.

Table 11 The relative merits of the main methods that can be used to monitor the efficiency of a fish pass

Method of Assessement	Efficiency
Telemetric Surveys	++++
Fish Counter - in pass with information on pop. d/s	++
Trapping and tagging	++

A monitoring programme designed to determine efficiency would clearly be significantly more intensive than one designed simply for the assessment of effectiveness.

To calculate the efficiency of the fish pass it is necessary to determine the number of fish wishing to migrate past the obstruction and the proportion of these fish which actually do so. The known number of fish can be determined in a number of ways:

Fish can be tagged, either with traditional tags or with radio, PIT or acoustic tags (the latter if the pass is in saline waters), and the proportion that migrate through the fish pass determined from the recoveries. Recoveries can be obtained by either trapping in the fish pass or, if the obstruction is a complete barrier, by more traditional methods such as electric fishing, netting and/or angling. In the case of the latter methods it is important to consider sampling efficiency and as such the estimate of fish pass efficiency is likely to be a minimum value.

Alternatively there may be an estimate of the number of fish available to migrate from a fish counter (Fewings 1994) downstream, which may be compared with a count of fish obtained for the new pass. This approach has been used to estimate efficiency on the Dordogne at Mauzac (Larinier & Travade, 1992) and on the Garonne at Ramier (Dartiguelongue, 1990 in Larinier & Travade, 1992b).

The preferred method is telemetry as this technique can provide information on fish behaviour; of particular relevance is the behaviour of fish in relation to the entrance of the pass and the effect of flow. The method can also provide information on any delay in their migration (Baril & Gueneau, 1986; Webb, 1990). This can be an important consideration for those species with a relatively short migration period, such as shad.

From tagging studies efficiency can be estimated as follows (Travade & Larinier, 1992b):

$E = n_p/ANm$ .... (2)

where:

E = efficiency as a proportion

n_p = number of marked fish that migrate through the fish pass

N_m = number of marked fish

A = proportion of fish which die as a result of tagging and handling.

The level of precision and confidence that can be attached to measures of efficiency of fish passes by using different sample sizes of fish is addressed in APPENDIX XIV Monitoring Programme Examples.

Conclusion

Though the methods are well understood on how to assess the effectiveness and determine the efficiency of a fish pass, there are still important questions to be answered. Namely what level of efficiency should a fish pass achieve and should this affect whether a fish pass receives Final Approval? For example, if a fish pass does not achieve a pre-determined level of efficiency should mitigation be requested, or should modifications to the structure, or the operating regime be compulsory? Obviously some of this will depend on the nature of the problem and whether the pass is placed on a new or existing structure, as discussed in section 6.3.2. Consideration should also be given to the level of precision and confidence that the study aims to achieve, as these have a significant impact on the resource requirement. It is also important that the monitoring programme is commensurate with the benefits that the installation of the pass aims to achieve. To enable comparison between the costs of monitoring and the benefits of constructing a fish pass the benefits need to be determined in monetary terms (see Milner & Power, 1996, Appendix VIII).

When assessing effectiveness using population change there will be usually little pre construction data on the particular river which can be used to design the sampling programme. Therefore it will be necessary to use data, ideally from similar river systems in order to help determine the number of sites and the duration of the study. At present there is a paucity of such data, and it would be useful to construct a database relating the various components of variance to river type and species. This database could then be used to assist with the development of a monitoring programme.

When determining the effectiveness and efficiency of a particular type of fish pass it is important to record all the relevant conditions. These include the local hydrological conditions, the hydraulic conditions within the pass, the target species and size of fish, and the location of the pass (particularly the entrance in relation to the obstruction and the flow).

Consideration should also be given to the measurement of the delay to migration, which in certain instances can be considerable (Baril & Gueneau, 1986; Webb, 1990, Chanseau & Larinier, 1999). The effect of delaying fish on their spawning migration could result in fish spawning on or in sub-optimal habitat, which may lead in turn to a decline in recruitment. Therefore it is important to ensure that delay is minimal.

Fish Pass Maintenance

Legal Position

There is a legal duty under Section 9(1) of SAFFA, 1975, for fish passes for migratory salmonids to be maintained in an efficient state, and it is an offence under the Act not to do so. Responsibility rests with the legal owner or occupier of the structure or land on which the fish pass is constructed. Where passes are constructed by the Agency, responsibility for maintenance of the pass would normally be transferred to the Agency by a legal agreement. Where any person fails in this duty, the Agency may carry out any necessary works to ensure compliance and recover the costs of the works in summary manner.

To ensure that this aspect of fish passage has been considered, the Agency Fish Pass Approval Process requires the owner of the fish pass, and the site where it is constructed if different, to be identified. It also requires confirmation of whom will be responsible for carrying out the maintenance, when and how. These details should be submitted with the application for Provisional Approval.

Generally we should be aiming to ensure that the pass achieves at least 90% availability during the required period of operation. The required operating period should be clearly defined.

Inspection

Clearly there is no point in investing in a fish pass structure to improve fish passage if it is not checked to ensure that the pass has not been rendered ineffective through temporary blockages from trash or bed load movement, or by damage to the structure itself. This is potentially an onerous task that can consume considerable resources. Careful selection of the type of fish pass itself, anticipation of the needs for maintenance, and the incorporation in to the design of structures such as penstocks and trash screens can minimise the risk of obstructions to migration occurring and facilitate ease of maintenance.

Where the pass has no moving parts it is recommended that structural maintenance, ensuring that the fabric of the structure is in good repair, should be carried out not less than every 3-5 years. Checks should be made to ensure that the pass still mets its specification, for example, in the case of Plane Baffle Denils the baffles themselves should be replaced when they become <8mm thick.

Operational maintenance, that is ensuring that its function is not impaired, should be carried out on an `as needs` basis. The plan for operational maintenance thus needs to be subject to some form of risk analysis as the pass is commissioned, but in time will reflect experience at the specific site. Both structural and operational maintenance will clearly be much more onerous in terms of required frequency where the fishway has moving parts.

It should not be forgotten that an important aspect of maintenance is to ensure that the pass is, and continues to, operate in the way that it was intended. The fact that the pass has been constructed correctly according to the design specifications should be checked before the pass is commissioned. It is also very useful to install water level gauge-boards, bearing the design operating ranges of the pass, both upstream and downstream of the structure. This will help ensure that the pass is operating within the expected limits of river discharge and water levels.

Where attraction to the pass relies to some extent on the operating procedures for other nearby structures, then the operating practices for those structures should be reviewed from time to time to ensure that they are:

- operating as expected, and
- do indeed maximise attraction to the pass.

The programme of maintenance and inspection is left to local management to determine, but should comprise a schedule of frequency of visits that should be tailored to the period when the pass needs to operate. A number of factors will influence the decision about frequency of maintenance visits. These will include, for example: whether the obstruction is total or partial, type of pass, relative location in the catchment, hydrographic regime in the river, geology of the catchment in respect of sediments, and type of plant growth in the river and on the banks. Take for example a fish pass high up in a catchment, it may need to be checked weekly during the spawning season but only quarterly at other times of the year. On the other hand, a pass low down a catchment with plenty of woody debris may need to be checked weekly or more frequently throughout the period when fish are running.

In the case of migratory salmonids, wild brown trout, and shad populations a simple initial risk assessment might take the following form. The two main risk factors are the position in the catchment (P) and vulnerability to blockage (B).

Then creating a table to take the combination of the two factors in to account gives:

Table 12 Risk assessment for maintenance requirement of a fish pass

PB	Pb
pB	pb

PB = Low down catchment, High risk of blockage = weekly inspection

Pb = Low down catchment, Low risk of blockage = fortnightly inspection

pB = High up catchment, High risk of blockage = fortnightly inspection

pb = High up catchment, Low risk of blockage = monthly inspection

The frequency of inspection and operational maintenance would follow the guideline during the relevant period of migration, with the latter needing to be carefully defined. After a suitable period during which experience is gained it should be possible to adjust the programme of visits to suit the individual site.

In the case of fish passes for coarse fish it is suggested that monthly inspection and maintenance during the spawning season, i.e. March to June inclusive, is good enough for most species, most of the time.

Outside of the relevant migration period(s) it is clearly unnecessary to visit the site. However, a first visit should be made a suitable period before the anticipated start of migration to ensure that there is sufficient time to rectify any problems. Should a pass be conjunctively used for canoe passage or other public amenity purposes, or if any Public Safety Control Measures PSCMs) are an issue, then this may affect the frequency of inspection required.

Remote Surveillance

An alternative that may be worth considering is the installation of remote video surveillance. If the site is not very remote from human development then power and data communications may be available. Modern ADSL lines are commonly available within 4 km of a communications substation and many providers can assess the availability from the postcode of the nearest dwelling. With at least an ADSL line and AC power remote monitoring by network video camera is possible. This technique allows any personal computer with an ADSL connection and a web-browser or proprietary software to view the video output of the site camera(s) on the computer from <u>any</u> remote location. Additional features allow the camera to be controlled remotely for actions such as zoom, pan, tilt and focus. For suitable sites, a routine visual inspection for debris blockage could be carried out in a few minutes as often as required.

For sites where power and cable communications are not available it is possible to employ the mobile phone short message service features to relay detected blockages at remote sites. This does of course depend on mobile phone network coverage, but where suitable coverage is available this system is able to run the communications and water level sensors for extended periods of time. The blockages can be detected by a number of means, but perhaps the simplest is the detection of a large increase in the difference in water level between that of the water upstream of the fishway, and that in the pass near the discharge point.

For very remote locations it is possible to employ similar means to the water level difference/mobile phone scheme described above, but using the alternative of satellite based mobile phone networks. Unfortunately they are not only more expensive and bulkier but also generally have larger power consumption. As a result power from solar and or wind generators may be required.

In summary, there are many ways in which fish pass sites may be routinely checked for blockages and other problems without the need for a site visit. As technology improves and becomes cheaper, while labour costs escalate, this is increasingly attractive option.

Inspection Records

A basic form is included in Appendix XII Maintenance inspections for fish passes constructed by external developers should also be made available to the Agency as and when local management requires. Where appropriate, inspection will need to include monitoring of PSCMs and Safety systems.

Remedial Action

Where a blockage is identified we should aim for it to be removed within three working days during the defined period when the fish pass should be in operation, subject to a safe system of work being feasible. This standard of service can be relaxed outside the defined period, to a time-scale considered reasonable by local management.

It is recommended that, in the case of an external developer a written requirement for remedial works to be undertaken should be faxed to them, identifying the legal requirement and a reasonable time-scale for completion of works. Failure to comply should result in formal action, the severity of which should clearly take into account any extenuating circumstances.

Where the fish pass has suffered structural damage repair is very unlikely to be feasible within the 3 day standard. Therefore repairs should be completed as soon as practically possible, always bearing in mind that we should aim for an overall standard of 90% availability during the defined operating period.

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APPENDICES

APPENDIX I Manual Feedback Form

FISH PASS MANUAL FEEDBACK FORM

1. Document reference including version & publication date

2. Your name & title

3. Your position

4. EA Region & Area

5. Organisation (if not EA)

6. Date of comments

7. Full postal address

8. Telephone Number

9. Generic comments

10. Specific comments (please give specific section & page number)

APPENDIX II Legislation

The Salmon and Freshwater Fisheries Act 1975 as modified (bold text) by the Environment Act 1995

Source Her Majesty's Stationery Office (HMSO)

Fishing Mill Dams

Section 8.

(1) No unauthorised fishing mill dam shall be used for taking or facilitating the taking of salmon or migratory trout.

*(2) A fishing mill dam shall not be used for the purpose of taking salmon or migratory trout unless it has attached to it a fish pass of such form and dimensions as may be approved by **the Agency** and unless the fish pass is maintained in such a condition and has constantly running through it such a flow of water as will enable salmon and migratory trout to pass up and down the pass.*

(3) If any person:-

(a) uses an unauthorised fishing mill dam as mentioned in subsection (1) above: or

(b) uses or attempts to use a dam in contravention of subsection (2) above,

he shall be guilty of an offence.

(4) If a fishing mill dam has not a fish pass attached to it as required by law, the right of using the fishing mill dam for the purpose of taking fish shall be deemed to have ceased and be for ever forfeited, and the water authority for the area may remove

from it any cage, crib, trap, box, cruive or other obstruction to the free passage of the fish.

Part II

(5) In subsection (1) above "unauthorised fishing mill dam" means any fishing mill dam which was not lawfully in use on 6th August 1861, by virtue of a grant or charter or immemorial usage.

Duty To Make And Maintain Fish Passes

Section 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 obstruction 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 Agency*** *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*** *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 Agency** 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 The Agency To Construct And Alter Fish Passes

Section 10.

(1) ***The Agenc****y may construct and maintain in any dam or in connection with any dam a fish pass of such form and dimensions as it may determine, 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) ***The Agency*** *may 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 Agency*** *in repairing the injury, and any such expenses may be recovered by* ***the Agency*** *in a summary manner.*

Approvals for fish passes

Section 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.

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

(3) *Where* ***the Agency*** *revokes a provisional approval given to a fish pass forming part of or in connection with a dam or other obstruction,* ***it*** *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*** *may approve and certify any fish pass if* ***it*** *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****, 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

Section 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 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 maybe 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 Agency*** *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 wherby salmon or trout may be scared, deterred or in any wayprevented from freely entering and passing up and down a free gapat 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.

Restrictions on taking salmon or trout above or below an obstruction or in mill races

Section 17.

(1) Any person who takes or kills, or attempts to take or kill, except with rod and line, or scares or disturbs any salmon or trout -

a) at any place above or below any dam or any obstruction, whether artificial or natural, which hinders or retards the passage of salmon or trout, being within 50 yards above or 100 yards below the dam or obstruction, or within such other distance from the dam or obstruction as may be prescribed by byelaw; or

b) in any waters under or adjacent to any mill, or in the head race or tail race of any mill, or in any waste race or pool communicating with a mill; or

c) in any artificial channel connected with any such dam or obstruction, shall be guilty of an offence.

(2) Nothing in this section shall apply to any legal fishing mill dam not having a crib, box or cruive, or to any fishing box, coop, apparatus, net or mode of fishing in connection with and forming part of such a dam or obstruction for purposes of fishing.

(3) Where a fish pass:

(a) ***approved by the Agency, or***

(b) ***constructed and maintained by the Agency in accordance with section 10(1) above****.*

is for the time being attached to a dam or obstruction, this section shall not be enforced in respect of the dam or obstruction until compensation has been made by ***the Agency*** *to the persons entitled to fish in the waters for that right of fishery.*

Provisions supplementary to Part II

Section 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.

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 Agency*** *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 ***the Agency 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.*

Note: Section 15 concerns screening

Water Resources Act, 1991

Source Her Majesty's Sationary Office (HMSO)

PART VIIII LAND AND WORKS POWERS

I POWERS OF THE AUTHORITY

Provisions in relation to land

154 Compulsory purchase etc

(1) The Authority may be authorised by either of the Ministers to purchase compulsorily any land anywhere in England and Wales which is required by the Authority for the purposes of, or in connection with, the carrying out of its functions.

(2) The power of each of the Ministers under subsection (1) above shall include power—

(a) to authorise the acquisition of interests in, and rights over, land by the creation of new interests and rights; and

(b) by authorising the acquisition by the Authority of any rights over land which is to be or has been acquired by the Authority, to provide for the extinguishment of those rights.

(3) Without prejudice to the generality of subsection (1) above, the land which the Authority may be authorised under that subsection to purchase compulsorily shall include land which is or will be required for the purpose of being given in exchange for, or for any right over, any other land which for the purposes of the [1981 c. 67.] Acquisition of Land Act 1981 is or forms part of a common, open space or a fuel or field garden allotment.

(4) Subject to section 182 below, the Acquisition of Land Act 1981 shall apply to any compulsory purchase under subsection (1) above of any land by the Authority; and Schedule 3 to the said Act of 1981 shall apply to the compulsory acquisition under that subsection of rights by the creation of new rights.

(5) Schedule 18 to this Act shall have effect for the purpose of modifying enactments relating to compensation and the provisions of the [1965 c. 56.] Compulsory Purchase Act 1965 in their application in relation to the compulsory acquisition under subsection (1) above of a right over land by the creation of a new right.

(6) The provisions of Part I of the [1965 c. 56.] Compulsory Purchase Act 1965 (so far as applicable), other than sections 4 to 8, 10, 21, 27(1) and 31 and Schedule 4, shall apply in relation to any power to acquire land by agreement which is conferred, by virtue of any provision of this Act (including section 4 above) or otherwise, on the Authority as if—

(a) any reference in those provisions to the acquiring authority were a reference to the Authority; and

(b) any reference to land subject to compulsory purchase were a reference to land which may be purchased by agreement under that power.

156 Acquisition of land etc. for fisheries purposes

(1) Without prejudice to section 4 above, the powers conferred on the Authority by that section and section 154 above include power to purchase or take on lease (either by agreement or, if so authorised, compulsorily)—

(a) any dam, fishing weir, fishing mill dam, fixed engine or other artificial obstruction and any fishery attached to or worked in connection with any such obstruction;

(b) so much of the bank adjoining a dam as may be necessary for making or maintaining a fish pass for the purposes of section 10 of the [1975 c. 51.] Salmon and Freshwater Fisheries Act 1975; and

(c) for the purpose of erecting and working a fixed engine, any fishery land or foreshore together with any easement over any adjoining land necessary for securing access to the fishery land or foreshore so acquired.

(2) Without prejudice to section 4 above, the Authority may—

(a) either alter or remove an obstruction acquired in the exercise of the powers mentioned in subsection (1) above; or

(b) by itself or its lessees use or work in any lawful manner the obstruction for fishing purposes and exercise the right by any fishery so acquired,

subject, in the case of an obstruction or fishery acquired by way of lease, to the terms of the lease.

(3) Expressions used in this section and in the Salmon and Freshwater Fisheries Act 1975 have the same meanings in this section as in that Act.

The Eels (England and Wales) Regulations 2009

Source Her Majesty's Stationery Office (HMSO)

Part 4 Passage of eels

Construction, alteration etc of obstruction
12.—(1) This regulation applies to—

(a) the construction of a new dam;

(b) alterations or maintenance made to an existing dam that are likely to affect the passage of eels around, over or through the dam;
(c) the construction or maintenance of a structure in or near waters that amounts to, or is likely to amount to, an obstruction.

(2) Any person who constructs, alters or maintains a dam or structure must first notify the Agency.

(3) An application for, or variation of, a licence to abstract water or for impounding works under section 24 or 25 of the Water Resources Act 1991(**c**) is deemed to be notification for the purposes of this regulation.

(4)Failure to comply with paragraph (2) is an offence.

Reporting an obstruction

13.—(1) A responsible person must immediately notify the Agency of any obstruction occurring since the coming into force of these Regulations.

(2) Failure to comply with paragraph (1) is an offence.

Eel passes

14.—(1) This regulation applies where the Agency determines that the passage of eels is impeded or likely to be impeded by—

(a) a dam or obstruction in or near waters to which these Regulations apply;
(b) any works notified to the Agency under regulation 12; or
(c) any obstruction notified to the Agency under regulation 13.

(2) The Agency may, by service of a notice, require a responsible person, at their own cost, to—

(a) construct an eel pass;
(b) make alterations to an existing eel or fish pass;
(c) operate an existing eel pass in accordance with any conditions stated in the notice;
(d) remove an obstruction; or
(e) take any other action specified in the notice.

(3) The notice—

(a) may not require anything that interferes with any statutory right of navigation;
(b) may require the responsible person to submit plans for an eel pass or for alterations to an existing eel pass or fish pass to the Agency for approval;
(c) must give the date by which such plans must be submitted;
(d) may require the construction of an eel pass, or alterations to an existing eel or fish pass, to be carried out in accordance with plans approved by the Agency.

(4) The Agency may, by service of a further notice, require the responsible person—
(a) to operate any eel pass constructed or altered, or any fish pass altered, under this regulation in accordance with any conditions stated in the notice;
(b) to make any alterations to an eel pass constructed or altered or to any fish pass altered under this regulation.

(5)Failure to comply with a notice served under paragraph (2) or (4) is an offence.

Maintenance and repair of eel pass

15.—(1) A responsible person must, at their own cost, maintain an eel pass in an efficient state.
(2) Failure to comply with paragraph (1) is an offence.

Damaging or obstructing eel pass

16.—(1) A person must not damage, interfere with, obstruct or do anything that impedes the passage of eels through an eel pass.

(2) Failure to comply with paragraph (1) is an offence.

Sections 17 – 19 deal with Eel screens and By-washes

Part 5 Notices and Appeals

Notices

23.—(1) A notice served under these Regulations must—

(a) be in writing;
(b) describe the action required;
(c) give reasons for the action required;
(d) specify the date by which the action must be taken or any designation will take effect; and
(e) except for a notice served under regulation 8 or 11, inform the person on whom the notice is served of the right of appeal under regulation 25.

(2) A notice may be amended, suspended or revoked, by service of a further notice, at any time.

Service of notices

24.—(1) A notice served under these Regulations may be served on a person by—

(a) delivering it to the person;
(b) leaving it at the person's proper address; or
(c) sending it by post or electronic means to that person's address.

(2) Where the person on whom a notice is served is a body corporate, the notice is duly served if it is served on the secretary or clerk of that body.

(3) For the purposes of this regulation and section 7 of the Interpretation Act 1978(**a**) (service of documents by post) in its application to this regulation, the proper address of any person to whom a notice is to be given is—
(a) if the person has given an address for service, that address; and
(b) if no address has been given—

(i) in the case of the secretary or clerk of a body corporate, the registered or principal office of that body;
(ii) in any other case, the person's last known address at the time of service.

(4) If the notice is transmitted electronically, it is to be treated as duly served if—

(a) the person upon whom the notice is required or authorised to be served ("the recipient") has indicated to the person serving the notice the recipient's willingness to receive notices transmitted by electronic means and has provided an address suitable for that purpose; and

(b) the notice is sent to the address provided.

Appeals

25.—(1) A person must notify the Secretary of State in England and Welsh Ministers in Wales ("the appropriate authority") of an intention to appeal against a notice served under regulation 14(2) or (4), 17(2) or (5)(b).

(2) Notice of appeal must be served—
(a) within 56 days of the date of a notice served under regulation 17(2) or (5)(b); or

(b) within 28 days of the date of a notice served under regulation 14(2) or (4).

(3) The time limit may be extended by the appropriate authority.

(4) Procedures for the appeal are set out in the Schedule.

(5) The appointed person may confirm, amend or quash the notice, and must give written notification of the final decision and the reasons for it, and may, if appropriate, add further requirements necessitated by the lapse of time since the notice was served.

(6) A notice need not be complied with pending determination of an appeal unless the appropriate authority directs otherwise.

(7) The appellant may withdraw an appeal by notifying the appropriate authority and any person appointed to deal with the appeal.

For Regulation 25 a Schedule - Appeals covers details of the appeals process

APPENDIX III National Fish Passage Panel Terms of Reference

Purpose

To provide a thorough technical appraisal of all fish pass proposals and to make recommendations in conjunction with Area Staff for the formal approval of all fish passes in the Environment Agency Area. To act as a focus for all matters relating to fish passage issues, including screening and hydropower developments. To ensure that consistent standards of approach and design are achieved Nationally.

Terms of Reference

- To consider and thoroughly appraise all fish pass design proposals and to make recommendations to the EMTL for formal approval of migratory salmonid passes, and to quality assure the design of all other fish passes.
- Identify fish passage issues to input to the Functional Business Plan and to provide co-ordination and consistency of fish pass and screen construction and approval throughout the Agency.
- To provide advice on the development of National Policy & Process relating to fish pass approval, hydropower and screening issues, to help ensure that these are practical and meet operational needs.
- To develop and maintain an effective database of all fish passes in the Environment Agency area.
- Identify and prioritise R&D Projects for refining fish passage development and to co-ordinate the implementation of output from that programme.
- To provide a focus for advice to Agency staff on all matters relating to fish passage and the fish pass design and approval process, and on design of screens and measures associated with hydropower developments where they impinge on fish passage or the operation of fish passage devices
- Provide a forum for dissemination of information on fish passes, fish screens and hydropower passage issues, and to contribute to the National training programme.
- Make recommendations on any changes to legislation needed.
- Identify and promote best practice and common operational solutions and contribute to the development of National input and output measures and the delivery of service level agreements.

Membership

Senior Technical Specialist – Fisheries Technical Services, National Operations (Chair)
Senior Technical Specialist (Fish Passage) & designated National Fish Pass Officer, National Operations
Regional Fish Pass experts (5)

APPENDIX IV Concept Form

FISH PASS CONCEPT Date:

(Please complete as much as possible)

1.Region

2.Area

3.Site Name & Type of Obstruction

(Preferably as site location & nearest town, eg Blakes Weir, Reading, map reference XYnnnnnn, describe the structure)

4.Watercourse

(Preferably as river hierachy, i.e. Brook, Stream, R iver, Catchment)

5.Internal or External Project

(If external identify promoter)

6.List species passage required for & others present:

7.River Discharge

(*ADF, Q_{10} & Q_{90} and other exceedance figures if available as* m^3s^{-1})

8.Head Difference (m)

(Maximum difference between upstream & downstream water levels across structure at low flow or target design flow if known)

9.Attach photos and/or plans of location & give context

(Context = single or multiple channels, flow splits etc)

10.Known constraints and/or other info

APPENDIX V RISK MATRICES

Guide to decision making for Fish Pass Approval:

A Risk Matrix for fish pass proposals for diadromous species

	High Concern (5)	Medium Concern (3)	Low Concern (1)
Fish Pass Design e.g. Novel/Conventional Siting Design Approach Attraction Detailing	Not Best Practice, novel or unconventional approach	Deviation from best practice	Current Best Practice, no obvious issues
Relative location in Catchment	Tidal barrier, or lower catchment/river where migration critical, no spawning downstream anadromous), no recruitment upstream (catadromous)	Middle – lower catchment/river, some spawning downstream (anadromous), some recruitment upstream (catadromous)	Standard river environment, Upper catchment/river, limited spawning upstream (anadromous), good recruitment upstream (catadromous)
Obstruction	New or significantly increased	Marginal increase	Existing
Ecological Risk	1. Failing SAP river (Salmon & Sea Trout?) 2. Failing SAC (Salmon, Lamprey, Shad) 3. Failing EU plan escapement target (Eel) 4. Failing to meet GES/GEP*	1. SAP or Recovering River 2. SAC in good status 3. Meeting EU plan escapement 4. At risk of failing to meet GES/GEP	1. Presence of migratory salmonids 2. Presence of migratory salmonids, shad, lamprey 3. Presence of eel 4. Meeting GES/GEP

Notes:

1. The risk matrix will be applied as an additive score. Those sites with a score ≤10 points will be given FA.

Scores of 12 & 14 will be reviewed on their merits by the NFPP, with the likelihood that most in 12 will be FA and most in 14 will be PA.

Scores ≥ 16 will be PA.

Any sites scoring as' Not Best Practice' will only receive PA at best

2. Failing SAP sites scoring 5 includes 'At Risk' and 'Probably at Risk' of failing (2013)Management targets.

Sites scoring 3 include 'Not at Risk' and 'Probably Not at Risk' of failing to meet (2013) Management Targets. This category also includes recovering rivers that may be failing SAP targets but are not mature enough to anyway hope to pass the (future) MT.

3. Please append any comments to the reverse of this sheet.

* In relation to the migratory species present

Guide to decision making for Fish Pass Approval:

A Risk Matrix for fishpass proposals for potamodromous species

	High Concern (5)	Medium Concern (3)	Low Concern (1)
Fish Pass Design e.g. Novel/Conventional Siting Design Approach Attraction Detailing	Not Best Practice, novel or unconventional approach	Deviation from best practice	Current Best Practice, no obvious issues
Relative location in Catchment	Demonstrably restricting ecological status Prevents altogether colonisation/re-colonisation of substantial suitable habitat Prevents adults reaching significant spawning areas Populations discontinuous	Potentially restricting ecological status Colonisation/recolonisation is restricted & slow	Unlikely to restrict ecological status Upper limit of distribution, limited availability of habitat upstream Limited spawning area upstream Populations continuous
Obstruction	New or significantly increased	Marginal increase	Existing
Ecological Risk	Failing to meet GES/GEP*	At risk of failing to meet GES/GEP Recovering river	Meeting GES/GEP

Notes:

1. The risk matrix will be applied as an additive score. Those sites with a score ≤10 points will be given FA.

Scores of 12 & 14 will be reviewed on their merits by the NFPP, with the likelihood that most in 12 will be FA and most in 14 will be PA.

Scores ≥ 16 will be PA.

Any sites scoring as' Not Best Practice' will only receive PA at best.

2. Please append any comments to the reverse of this sheet.

* In relation to the potamadromous species present

APPENDIX VI Draft Application For Fish Pass Approval Form

Application for fish pass approval

ENVIRONMENT AGENCY

Introduction

Please read through the guidance notes FP003 and the application form carefully before you fill this form in.

Please contact us if you are unclear about anything in this form. The general enquiries number is **08708 506 506**.

This form is designed to get the information that we require in order to understand and approve the design and dimensions of a proposed fish pass design. However, please note that fish pass design is a highly specialised and technical discipline and you are advised to refer to the Environment Agency Fish Pass Manual (or other similar publications) and/or use specialist consultants in the field to help ensure that an appropriate design and adequate details are provided.

Contents

1 Site details

1.1 What is the name of the site?

____

1.2 National Grid Reference of the site (10 figure)?

____

1.3 Environment Agency region and area (If known)

Region_________________________________

Area__________________________________

1.4 Name of watercourse

____

1.5 Watercourse Order or Hierarchy

Please give the watercourse name and then as appropriate each successive river until the primary watercourse reaches the sea as watercourse/tributary of 1/tributary of 2/……./tributary of n/Sea.

____

2 Obstruction details

2.1 What is the nature of the obstruction to fish passage that the pass is designed to overcome?

____

2.2 What is the purpose of the obstruction?

____

2.3 What is the configuration of the obstruction?

____

2.4 What is the overall crest length(s) of the obstruction that the pass is located in or beside (m) and what is its (their) invert level (mAOD)

____

2.5 What is the maximum head difference across the structure (m).

____

2.6 Who owns the obstruction and river banks?

Title ______________

Forename ____

Surname ____

Position ____

Flat/Building Name/Number ____

Street ____

Town ____

County ____

Postcode ______________________ Country ______________________

Phone ______________________ Mobile ______________________

Fax ______________________ Email ______________________

3 Fish pass design & ownership details

3.1 Who has designed the fish pass

Title ______________

Forename ____

Surname ____

Position ____

Company name ____

Flat/Building Name/Number ____

Street ____

Town ____

County ____

Postcode ______________________ Country ______________________

Phone ______________________ Mobile ______________________

Fax ____________________ Email ____________________

3.2 Who will own the fish pass?

☐ As in question 2.6

☐ As below

Title ________

Forename ______________________________

Surname ______________________________

Position ______________________________

Flat/Building Name/Number ______________________________

Street ______________________________

Town ______________________________

County ______________________________

Postcode ____________________ Country ____________________

Phone ____________________ Mobile ____________________

Fax ____________________ Email ____________________

3.3 Name of the lead Environment Agency officer involved with this pass, if applicable?

____

4 Fish species

4.1 Provide details of species for which the pass is designed. Indicate a size range for each fish species.

Species	Designed For Range (cms)
Salmon	
Sea Trout	
Brown Trout	
Eels	
Shad	
Lamprey*	
Grayling	
Coarse Fish*	
Others*	

*List Species in each group

____

4.2 Identify any other species present at this site (for which passage would be desirable) and include the size of the fish?

____

4.3 Is there a need for the pass to operate 12 months of the year?

Yes Continue to section 5

No

If you intend to operate over shorter periods that coincide with the relevant species movement patterns, name the species groups (as above) and state the periods when it is expected to operate for them below:

Species	Months of year

5 River discharge data and water level information

5.1 Please provide the annual river discharge hydrograph as a graph and/or table showing flow as cubic metres per second (m^3s^{-1}) against percentile exceedance value. Identify the gauging site from which the data originates, and if not at the structure itself state distance removed up or downstream and describe any interpolation used. If not gauged, state how it was estimated such as "generated from hydrometric software `Low Flow 2000`"

Annual discharge summary for river given as m^3s^{-1} to two decimal places:

%tile exceedence	Annual Discharge (m^3s^{-1})
5	
10	
50	
90	
95	
ADF*	

* Annual mean daily flow

5.2 Range of river discharge over which pass is expected to operate

	Percentile	m^3s^{-1}
Lowest Flow	Q	
Highest Flow	Q	

5.3 River water levels above ordinance datum (mAOD) corresponding with the flows identified in the previous question.

	Upstream Level	Downstream Level	Estimated or measured*
Lowest Flow			
Highest Flow			

* Describe how the were recorded or estimated.

5.4 Is the fish pass for eel only?

Yes (please go to question 8)

No (please go to question 7)

6 Description of fish pass, operating flows, and intended operating periods

Please include plans and sectional elevations of all relevant parts of the pass and adjacent structures. (see guidance)

6.1 Type of fish pass

____

6.2 Description of fish pass

____

6.3 Describe why the pass was positioned at its proposed location and identify any constraints restricting the choice of location?

____

6.4 How is the pass location and operation designed to ensure that fish are attracted to the fish pass across the intended river discharge operating range.

River Discharge (m^3s^{-1})	Exceedance Value (percentile)	Pass Discharge (m^3s^{-1})	Augmentation flow (if any) (m^3s^{-1})	Total attraction flow as % of river discharge

6.5 Describe any operating regime(s) or protocols for those nearby water control structures that may in any way affect operation of the pass.

____

6.6 Does the fish pass include a pool pass?

Yes
No (please go to question 7.10)

6.7 Describe how it is intended that the pool pass will operate to pass fish efficiently and effectively including the changing hydraulic conditions that will exist within it over the range of river discharge (window of fish migration) when is the pass is expected to operate.

____

6.8 Summarise the operating conditions at the limits of operation in the following table;

Pool Number[a]	Length and Width (m)	Min mean depth (m)[b]	Max mean depth (m)[c]	Head difference Max (m)[b]	Head difference Min (m)[c]	P/V Min (Wm^{-3})	P/V Max (Wm^{-3})
1							
2							
nn							
Tailwater*							

* Drop from last pool to prevailing tailwater level

6.9 Does the fish pass include a baffle pass?

Yes

No (please go to question 7.14)

6.10 Describe how it is intended that the baffle pass will operate to pass fish efficiently and effectively including the changing hydraulic conditions that will exist within it over the range of river discharge (window of fish migration) when is the pass is expected to operate.

____

6.11 Give details of the operating conditions at the limits of operation in the following table:

Parameter	Flight 1	Flight 2	Flight 3	Flight 4
Upstream Pass Slope Invert Elevation (mAOD)				
Upstream Pass Hydraulic Invert Elevation (mAOD)				
Downstream Pass Slope Invert Elevation (mAOD)				
Downstream Pass Hydraulic Invert Elevation (mAOD)				
Head Difference (m) slope				
Length slope (m)				
Slope %				
Head Ha on top baffle (min)(m)				
Head Ha on tail baffle (min)(m)				
Head Ha on top baffle (max)(m)				
Head Ha on tail baffle (max)(m)				
Mean Velocity (min)				
Mean Velocity (max)				

*Ha is the hydraulic head over the invert of the baffle

6.12 Where resting pools are required please summarise details of the operating conditions in the table below:

Pool Number[a]	**Length and Width (m)**	**Depth (min) (m)[b]**	**Depth (max) (m)[c]**	**Equivalent head(min) (m)[d]**	**Equivalent head(max) (m)[d]**	**P/V Min (Wm^{-3})**	**P/V Max (Wm^{-3})**
1							
2							
nn							
tailwater							

6.13 For combined passes and passes other than pool passes or baffle passes, please follow the principles outlined above in 7.7 – 7.12 to provide details of the proposal. See guidance notes for description of application requirements.

7 Eel passes

This section is only to be used for passes specifically designed to pass eels and elvers.

7.1 Type of eel pass?

____

7.2 Description of eel pass?

____

7.3 For pump feed passes only. Give details of the pump and associated infrastructure?

____

7.4 Describe why the proposed pass is planned to be installed at the location indicated and identify any constraints restricting the choice of location?

____

7.5 Describe any operating regime(s) or protocols for nearby water control structures that may in any way affect operation of the pass.

____

7.6 Provide a summary of the operating conditions at the limits of operation in the table below.

	Flight 1	**Flight 2**
Upstream pass invert elevation (mAOD)		
Downstream pass invert elevation (mAOD)		
Head difference (m)		
Length (m)		
Slope %		

8 Monitoring and maintenance

This section to be filled in for all types of pass and intended species

8.1 Outline any proposals for monitoring the hydraulic and biological performance of the pass after construction.

____

8.2 Outline the procedures that will be put in place to ensure the structural and operational maintenance of the pass.

____

9 Supporting documentation

Please include with this application the following:

☐ a map or plan (1:50,000) with this application

☐ the annual river discharge hydrograph

☐ detailed engineering drawings of the existing obstruction and the proposed design for the fish pass. List Drawings and their reference numbers: ____

☐ If available the engineering drawings of the existing obstruction and the proposed design for the fish pass

If essential documentation has not been provided we will not be able to assess your proposal and all documentation will be returned without further processing.

Application for fish pass approval
Guidance notes

ENVIRONMENT AGENCY

INTRODUCTION

Please read through the guidance notes and the application form carefully before you fill the form in.

Please contact us if you are unclear about anything in this form. The general enquiries number is **08708 506 506**.

This form is designed to illicit the information that we require in order to understand and approve the form & dimensions of a proposed fish pass design. However, please note that fish pass design is a highly specialised and technical discipline and you are advised to refer to the Environment Agency Fish Pass Manual (or other similar publications) and/or use specialist consultants in the field to help ensure that an appropriate design and adequate details are provided.

Contents

About the form

Fish pass facilities designed to aid the upstream passage of fish are specialised structures. Where they have been required on rivers inhabited by migratory salmon, sea trout, and eels the form and dimensions of the pass must be approved by the Environment Agency.

This is so we can ensure that an appropriate type and construction of pass is provided.. We will require pass designs for other fish species (such as coarse fish) to be compatible with approved status for the same reasons of consistency and quality and therefore ask for this form to be filled in for all fish passes, regardless of the intended species.

Q1 Site details

We need to be able to easily identify the location of the proposed fish pass, please provide:

- Site name - Provide name of site including alternative local names (if any).
- Site location - National Grid Reference (10 figure).
- Environment Agency Region and Area - Include the Environment Agency Region and area, if known
- Name of watercourse
- Stream order or hierarchy –

Q2 Obstruction details

2.1 Nature of obstruction

Give a description of the type of obstruction, for example: vertical weir, sloping weir, stepped weir, weir & control structures, control structures only (mixed), sluices, radial gates, dam, estuary barrage, tidal exclusion, bridge footings, ford, culvert, natural falls, other (please specify).

2.2 Purpose of obstruction

Give a description of the purpose of obstruction, for example: navigation, abstraction, hydrometric/gauging weir, bed/bank stabilisation, fish counter, fishing weir, flood defence, hydroelectric, milling, recreational, transport crossing, other (please specify)

2.3 Configuration of obstruction

Provide a description and plan at 1:2500 or 1:10,000 showing the general site layout including any relevant control structures, associated channel bifurcations or braiding. Where there are multiple channels at an obstruction describe how the flows are currently distributed.

2.4 Length of the crest of the structure(s) that the pass is beside

Provide the overall length of the existing structure, including separate details for fixed crest overfall and other water control structures. Please also ensure that the inverts of the structure(s) are noted on the plans accompanying this application.

2.5 Maximum head difference (m)

State the maximum head drop expected between upstream and downstream water levels. The maximum head difference at a structure will normally occur at low flow, but this may not always be the case. Please state at what exceedance flow the maximum head drop is expected, such as Q_{95}. If the maximum head drop does not occur at low flow please explain how and why it occurs at a different flow.

Q3 Fish pass details

3.3 Lead Environment Agency Officer

If it is a non-Environment Agency pass please give the name and location of any Environment Agency Officer who has been consulted during the design process. If it is an Environment Agency pass development please provide details of the Officer leading the project including name, office base, and contact details.

4 Fish species & period of operation

4.1 Species

Please indicate for what species the pass is designed to operate.. For the species groups asterisked please list the individual species in those groups under separate headings, for example, Lamprey = Sea lamprey, River lamprey Brook lamprey; Coarse fish = Barbel, Chub, Dace, ………; Others = Bullhead, minnow, ………

4.3 Period of operation

If expected to work for all species or over all 12 months enter ALL. Otherwise, please use the species groups in 4.1, expand the number of boxes as necessary, and enter details separately.

5 River discharge and water level information

5.1 River discharge

River discharge exceedance data can be obtained by Environment Agency Hydrometric Officers (a charge may be made). For example, Q_{95} is a low discharge exceeded for 95% of the time, Q_{10} is a higher discharge exceeded for 10% of the time.

5.2 Range of river flow

Where specific widows of migration are known please use these, recording them separately for each target group of species (as per 5.1 above). Where windows of migration are not specifically known for the site, then it is expected that the pass will operate over the following ranges: Q_{90} to Q_{10} for salmon, Q_{95} to Q_{10} for sea trout, Q_{95} to Q_{20} for coarse fish, and Q_{99} to Q_{70} for eels.

5.3 River water levels

Please indicate how these levels have been established. Were they monitored over a range of flows, measured at specific flows, or estimated. If the latter describe the methodology used. You may need to take account of differences during different seasons of the year for example weed growth in summer months may cause water levels to be higher than in winter months.

Where different flow migration widows and water levels apply to different species groups it will be useful to give these separately, and also to indicate them on the drawings supplied.

6 Description of fish pass, operating flows, and intended operating periods

The details provided in this section must accurately describe the form & dimensions of the pass, and how the fish pass is intended to operate effectively over the range of river flows (migration window) when the target species are expected to be migrating.

Plans and sectional elevations

Include plans and sectional elevations of all relevant parts of the pass and adjacent structures. The levels of all relevant crests, inverts of elements of the pass, and the upstream and downstream water levels under the range of river water levels over which the pass is expected to operate should be marked on the drawing using Ordnance Survey datum. Should a local datum be used please identify the location and height of the temporary bench mark used. Three copies of the final plans will be needed for Approval to be issued: one each for the owner, the Environment Agency Area file, and the Environment Agency National file. Please list the drawing number(s) including revision number(s) and date of revision (if any).

6.1 Type of pass

For example, fish pass types include: Pool & Traverse, Pool & Orifice, Pre-barrage(s), Vertical Slot, Deep Notch & Orifice, V Notch Weir , Plane Baffle Denil, Alaskan A Denil, Larinier (Super-active Baffle), Chevron Bottom Baffle, Chevron Side Baffle, Hurn Type Baffle, Low Cost Baffle, Bristle Fish & Canoe, Combination of these (Specify), Other (please specify).

6.2 Description of pass

Please describe very briefly the general layout of the pass for example single flight of Plane Baffle Denil, two flights of Larinier pass with rest pool, x pool Vertical Slot pass, x pool Pool & Traverse pass, Alaskan A Denil with pre-barrages.

6.3 Position of pass

Please describe where the downstream entrance of the pass is in relation to the toe of the obstruction and why it is located there. Typically the location of the downstream entrance is critical for a pass for upstream migrants. For example, it may be the most upstream location, it may be where fish are observed to collect, or else where tracking studies have identified that they approach the obstruction. The opposite will be the case for downstream passes. If it is relevant describe the relationship or juxtaposition of the pass downstream entrance with the discharge from a hydropower station.

6.4 Pass location and operation design

The ability to attract fish in to the fish pass entrance is absolutely critical to efficient fish pass performance. Please describe how the pass has been designed and located in order to attract fish efficiently in to the pass. This will include, for example, location of the pass entrance, relative proportion of attraction flow compared with river discharge, hydrodynamics including exit jet velocity and direction, any augmentation flows, any operational procedures used to increase attraction, and how these features may change over the expected range in river discharge & water levels when the pass is expected to operate effectively. Describe any changes proposed to flow distributions in any braided channels at the site, including identifying any depleted reaches.

Information on critical breakpoints in flow distribution should be provided in the table e.g. Q_{95}, Q_{mean}, Q_{10}, $Q_{max\ turbine\ discharge}$.

6.5 Effect of other control structures on operation of the pass

Spills of water at or from other parts of the structure, and particularly varying ones from water control structures may alter the performance of the pass by altering the water level regime, flows in the pass, and relative attraction of the pass. For example, manipulation and sequence of opening of sluice gates (undershot & overshot), separate flood discharge channel arrangements, abstractions, hydropower operating regimes, or extraneous discharges.

6.7 Details of pool passes

This section, with the aid of the drawings, should demonstrate how the pool pass is designed to meet the guidelines laid out for pool passes in the Environment Agency Fish Pass Manual

For Pool Passes the following details <u>must</u> appear either in the detailed drawings, or else be separately described:

- Elevations and dimensions of all relevant inlet or outlet channels and control structures at the site that are likely to affect operation of the pass e.g. adjacent weir crest, inverts(s) of water control structures etc
- Elevations of side walls and the bases of pools
- Elevations and dimensions of all overfalls, notches, orifices and sills
- Thickness of traverses in notches or on overfalls
- Length and width of all pools
- Expected water levels in pools at minimum and maximum range of intended operation
- Geometry of vertical slots if present
- Dimensions and elevations of debris shielding arrangements, including the free gaps between bars if any are fitted
- Volumetric power dissipation (power density) values in the pools at minimum and maximum range of intended operation given as Wm^{-3} (see table below)
- Details of any ancillary structures such as traps or counters in so far as they may affect pass characteristics or operation
- Details of any coverings or lighting arrangements

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6.8 Operating conditions for pool passes

This section summarises the hydraulic conditions expected in the fish pass at the limits of its intended (river discharge) operation

Power dissipation per unit volume (power density) is a measure of turbulence in the pools, it may be calculated using:

$$P/V\ (Wm^{-3}) = (9810 \times Q \times DH) / (L \times W \times D_m) \qquad (1)$$

Where:

Q = flow m^3s^{-1}

DH = difference in head between pools (m)

L = length of pool (m)

W = width of pool (m)

D_m = mean depth of pool (m)

The table should be filled in using the following conventions:

[a] Pools numbered from upstream to downstream

Pools may be aggregated together where the various parameters are similar e.g. 2+6, 2-6

[b] Depth occurring at lowest discharge

[c] Depth occurring at highest discharge

6.10 Details of baffle passes

This section, with the aid of the drawings, should demonstrate how the baffle pass is designed to meet the guidelines laid out for baffle passes in the Environment Agency Fish Pass Manual

For Baffle Passes the following details <u>must</u> appear either in the detailed drawings, or else be separately described:

- Elevations and dimensions of all relevant inlet or outlet channels and control structures at the site that are likely to affect operation of the pass e.g. adjacent weir crest, invert(s) of water control structures etc
- Elevations of side walls
- Elevations of upstream & downstream ends of the slopes of each flight
- Elevations of the baffle inverts at the upstream & downstream ends of each flight
- Elevations of inlet & outlet channels
- Length of each flight (m)
- Slope of each flight (%)
- Baffle height, thickness and design geometry including spacing
- Expected water levels at the upstream & downstream ends of each flight at the minimum and maximum range of intended operation
- Elevations of the side walls and bases of any resting pools
- Length and width of any resting pools

- Volumetric power dissipation (power density) values in any resting pools at minimum and maximum range of intended operation as Wm^{-3} (see table below)
- Dimensions and elevations of debris shielding arrangements, including the free gaps between bars if any are fitted
- Details of any ancillary structures such as traps or counters in so far as they may affect pass characteristics or operation
- Details of any coverings or lighting arrangements

6.11 Operating conditions for baffle passes

This section summarises the hydraulic conditions expected in the fish pass at the limits of its intended (river discharge) operation

6.12 Resting pools for baffle passes

Power dissipation per unit volume (power density) is a measure of turbulence in the pools, it may be calculated using:

$P/V\ (Wm^{-3}) = (9810 \times Q \times DH) / (L \times W \times D_{m})$ (1)

Where:

Q = flow m^3s^{-1}

DH = difference in head between pools (m)

L = length of pool (m)

W = width of pool (m)

D_m = mean depth of pool (m)

The table should be filled in using the following conventions:

[a] *Pools numbered from upstream to downstream*

[b] *Depth occurring in pool at lowest discharge*

[c] *Depth occurring in pool at highest discharge*

[d] *An approximation of the difference in head (DH) to substitute in Equation (1) above for baffle passes can be calculated using:*

$DH \equiv V^2/2g$

Where

DH = an equivalent head in (m)

V = mean velocity in the pass

g = acceleration due to gravity ($9.81 ms^{-2}$)

6.13 Other fish passes

This section, with the aid of the drawings, should demonstrate how any other form of pass other than a pool pass or baffle pass is designed to meet the guidelines laid out for that type of pass in the Environment Agency Fish Pass Manual (Version 1.1 February 2004).

All details relevant to describing the efficient & effective operation of the pass should be provided. These may, where relevant, follow the outlines provided for pool and baffle passes. They should include for example:

Elevations and dimensions of all relevant inlet or outlet channels and structures that are likely to affect operation of the pass.

Relevant hydraulic conditions in the pass including flows, velocities, head drops, pool sizes, and volumetric power dissipation (power density) values as Wm^{-3} across the range of river discharge when the pass is expected to operate.

For composite Baffle and Pool & Traverse passes please also use the principles outlined separately above for these types of pass.

7 Eel passes

The details provided in this section must accurately describe the form & dimensions of the pass, and how the fish pass is intended to operate effectively over the range of river flows (migration window) when the target species are expected to be migrating.

7.1 Type of pass

Please identify the type of pass by selecting appropriate features from the following list of descriptors:

Open or Enclosed; Gravity Fed or Pump Fed; Bristle Ramp, Boss Ramp, Other Ramp (please identify media); With Lateral slope or Without Lateral Slope; Fabricated Channel e.g. GRP, Aluminium, Steel etc or In-situ Channel e.g. cast in concrete; Bristle Media on sidewall; Tidal Flap Modification; Eel Lift; Other (specify); With Monitoring Facility or Without Monitoring Facility.

7.2 Description

Please provide a description of the pass/easement through inclusion of a photograph, drawings or written description, manufacturer and model number, specification of substrate including type & spacing. The entrance and exit of the pass are key areas in respect to fish finding and accessing the pass, and exiting safely. Please state the number of flights and rest areas, and what, if any, trapping or other monitoring facilities are provided.

7.3 Pump fed passes

Please provide details of the following: Pump Capacity (litres/minute) at the target head level; details of the pump installation (drawings) to showing the pump in relation to the channel and the eel pass; show any screening or protection from debris and the facilities for cleaning/maintenance. Indicate how water is fed into the head of the pass and any flow-splitting arrangements (to upstream ramp/trap and downstream ramp. State how the pump will be powered e.g. mains voltage, battery array, solar power, wind power, or other.

7.4 Location details

The ability for eel to find the fish pass entrance is absolutely critical to efficient eel pass performance. Please describe how the pass has been located in order to for eel to efficiently find the pass.

7.5 Operating regimes

Spills of water at or from other parts of the structure, and particularly varying ones from water control structures may alter the performance of the pass by altering the water level regime, flows in the pass, or the areas that eel may congregate in. For example, manipulation and sequence of opening of sluice gates, separate flood discharge channel arrangements, abstractions or extraneous discharges etc).

7.6 Operating conditions

This section summarises the hydraulic conditions expected in the eel pass at the limits of its intended (river discharge) operation.

8 Monitoring and maintenance

8.1 Hydraulic and biological performance

A full monitoring programme would demonstrate that the fish pass is functioning as anticipated both hydraulically and biologically. The use of gauge boards upstream & downstream of the pass to help establish that the pass is operating within the expected range of head levels is highly recommended as part of the physical monitoring of the pass. Biological monitoring should aim to demonstrate that the target fish species use the pass effectively and efficiently.

8.2 Structural and operational maintenance

It is an offence not to maintain the pass in an effective and efficient state. How often will the structural integrity of the pass be checked, and by whom. How often will the pass be checked to ensure that it is operating correctly and is not compromised by debris collection, and who will be responsible.

APPENDIX VII Typical List Of requirements For A Feasibility Study

The contents of a feasibility study might look like the following:

Introduction

The Brief

The Site

Fish Species

Data Sources

River Flows

Consultations

Existing Obstruction

History

Type & Construction (including plans)

Use & Operation

Visual Inspection & Condition

External Influences

Hydraulic Assessment

Constraints

Topography of Existing Obstruction

Structural Condition of Existing Obstruction

Upstream & Downstream Water Levels

Access & Working Environment

Ownership

Conservation Matters

Planning Matters

Utilities

Feasibility Options

Required Operating Range

Option Types

Assessment of Options (1 to nn)

Recommended Option(s)

Budget Cost Estimate(s)

Outstanding & Miscellaneous Issues

Conclusions

Appendices

APPENDIX VIII Examples of Cost Benefit Analysis

IX.A Cost benefit analysis for the fish pass construction on the Garth Dulas, a tributary of the R. Irfon.

Tech. Memo: SE/EAU/96/11. M. Clyde. Environmental Appraisal Unit (S.E.), National Rivers Authority - Welsh Region, St. Mellons, Cardiff. March 1996.

1. Introduction

The NRA in conjunction with the Wye Salmon Fishery Owners Association (WSFOA) are considering ways of increasing the spawning area available to migratory salmonids, particularly in the Upper Wye. These include:

i) gravel clearing/raking of impacted spawning areas

ii) removal of temporary blockages

iii) alteration of natural permanent barriers

iv) removal of man-made barriers/construction of fish passes.

The Garth Dulas is one of the main tributaries of the R. Irfon, a sub-catchment of the Upper Wye. It enters the Irfon at SN 955494, 11km upstream of the Irfon/Wye confluence. The Upper reaches of the Irfon are impacted by acidification, a problem not apparent in the Garth Dulas.

Access of migratory salmonids to the upper Garth Dulas is restricted by a concrete weir at SN 945516, 4km from the confluence with the R. Irfon. Construction of an effective fish pass would increase the accessible stream area by 51,750m2.

2. Objectives

The aims of this simple cost benefit analysis were to assess the benefits, in terms of salmon smolt yield and adult return, of constructing an efficient fish pass on the Garth Dulas, and the costs associated with this undertaking.

3. Methods

Historical fisheries, water quality and biological data for the Garth Dulas were collated to assess the general state of the catchment.

3.1 Water Quality

Water quality data for the period 1990-1995 were retrieved for the only sample point on the Garth Dulas (SN 949494), downstream of the weir.

3.2 Fisheries

2 sites on the Garth Dulas have been routinely electrofished as part of the RJSMP since 1985. One site has been fished quantitatively and the other semi-quantitatively. Both are below the weir.

A third site on the Gwynfel, a tributary of the Dulas above the obstruction has been semi-quantitatively surveyed since 1991.

3.3 Biology

One site on the Garth Dulas below the weir has been surveyed in 1991, 1992 and 1995 as part of the General Quality Assessment (GQA) programme/River Quality Survey (RQS).

3.4 Habitat

An extensive habitat assessment was undertaken by NRA bailiffs following the methodology listed in Betts et al (1994).

The method entailed a simple mapping exercise, dividing the river and tributaries into sections depending on their suitability as salmonid spawning/rearing habitat. Habitat was classed as either:

i) non-salmonid,

ii) moderate salmon rearing or

iii) good salmon rearing habitat.

The good habitat consisted of glides/riffles with gravel as the main substrate and moderate habitat mainly cobbles. Bedrock/deeper water formed the majority of non-salmonid rearing habitat.

Width measurements were taken in each section to allow an estimation of the area of each habitat type.

3.5 Smolt production

The river area available for salmonid spawning/rearing above the weir was calculated from the habitat mapping undertaken by the bailiffs. Areas of non-salmonid habitat were not included in the smolt production estimates.

In areas of good juvenile habitat a smolt production output of 5 per 100m2 (Symons, 1979) was assumed and in areas of moderate juvenile habitat a lower output of 3 per 100m2 was assumed. Age of fish at smoltification was not considered in the smolt output estimates.

95% mortality of wild smolts was used in the estimate with a rod recapture rate of returning adults of 20%. Again the age of fish on return to freshwater

has not been taken into account in calculating the potential adult return rate/economic benefit.

The value of increased smolt production from the Garth Dulas was calculated solely on the potential increase in the annual salmon rod catch with 2 different values used to calculate the potential economic benefit:

i) Harris and Stokes (1994) estimated the value of a salmon to the R. Wye fishery to be £3000. Harris and Stokes are Commercial Property Specialists based in Hereford.

ii) Radford and Hatcher (1991) estimated the per capita value of each salmon to the average annual rod catch of a Welsh river to be £5647.

4. Results

4.1 Water quality

Summary of data (1990-1995) from sample site on the Garth Dulas.

Determinand	Number of samples	Minimum	Maximum	Mean	Standard Deviation
pH	78	5.9	7.8	6.9	0.33
Conductivity	15	58	104	78	13.6
Temperature	73	0.6	20	9	4.2
Diss. Oxygen	73	75	111	95	6.7
BOD mg/l	73	0.4	3.8	1.1	0.6
NH4 mg/l	73	0.01	0.17	0.02	0.02
TON mg/l	12	0.24	1.1	0.62	0.33
Alk4.5 mg/l	27	6.9	20.6	11.8	3.5
Total Hard.	54	9.5	76.3	23.6	9.7
Total Zn mg/l	51	<2	72	11.2	10.8
Diss. Mg mg/l	54	1.1	4.9	1.9	0.5
Diss. Ca mg/l	54	1.8	22.5	6.4	3.2
Diss. Al mg/l	16	0.004	0.22	0.06	0.05

There was no evidence from the routine water quality data available that low pH events occur on the Garth Dulas, or that spawning of migratory salmonids is limited by the prevailing water quality. This is unlike the situation in the upper reaches of the Irfon that are impacted by acidification due to extensive afforestation, exacerbated by the poor buffering capacity of the underlying substrata. The upper Garth Dulas is not heavily afforested.

The water quality data is however from a site on the lower Dulas.

4.2 Fisheries

RJSMP results for sites on the Garth Dulas and its tributary the Gwynfel

RJSMP Site 8, SN 947497, Garth. Quantitative survey, downstream of weir.

Year	Salmon 0+	Salmon >0+	RJSMP Class	Trout 0+	Trout >0+	RJSMP Class
1985	121.4	1.6	A	-	-	D
1986	300	16.1	A	-	0.9	C
1987	187.3	3.7	A	-	3	C
1988	162.6	12.8	A	0.5	1.3	D
1989	333.8	22.5	A	10.4	5.8	C
1990	319.6	13.2	A	-	1.2	D
1991	262.6	10.5	A	1.9	-	D
1992	301.6	2.3	B	0.6	0.6	D
1993	79.9	2.6	B	-	-	E
1994	319.6	4	B	2	0.8	D
10 yr ave	238.8	8.9	A	1.5	1.4	D

RJSMP Site 44, SN 946514, Semi-quantitative survey, downstream of weir.

Year	Salmon 0+	Salmon >0+	RJSMP Class	Trout 0+	Trout >0+	RJSMP Class
1985	152.4	3.2	A	-	-	D
1986	22.3	2.3	B	-	-	D
1987	69.2	3.2	A	-	0.6	C
1988	70.3	0.8	B	7.2	0.8	D
1989	41.7	2.1	B	-	0.5	D
1990	109.9	2.1	B	-	-	E
1991	-	-	-	-	-	-
1992	131.3	1.2	B	-	-	E
1993	72.4	2.9	A	O.4	-	D
1994	85.4	1.8	B	1.8	0.7	D
10 yr ave	83.9	1.9	B	1	0.3	D

RJSMP Site 44a, SN 930538, Nant Gwynfel. Semi-quant survey, upstream of weir.

Year	Salmon 0+	Salmon >0+	RJSMP Class	Trout 0+	Trout >0+	RJSMP Class
1991	-	-	E	-	15.4	C
1992	-	-	E	16.5	9	B
1993	-	-	E	9.2	21.1	B
1994	-	-	E	3.4	23.2	B
4 yr ave				7.3	17.2	B

4.3 Biology

Biological quality results for sample site on the Garth Dulas downstream of weir (from GQA/RQS surveys)

Year/sample	Season	Invertebrate BMWP Score	Diversity Class
1990	Spring	150	A
1990	Autumn	181	A
1992	Spring	140	B
1992	Summer	166	A
1995	Spring	139	B
1995	Autumn	135	B

4.4 Habitat and smolt production estimates

River Section	Length (m)	Width (m)	Area Total	Habitat Good	m^2 Mod	Poor	Est Smolt Prod (100 m^2)	Number Smolts	Number Adults
Dulas A	1500	12	18000	18000	-	-	5	900	45
Dulas B	1500	11	16500	16500	-	-	5	825	41.25
Dulas C	250	6	1500	-	-	1500	-	0	0
Dulas D	250	8	2000	-	2000	-	3	60	3
Dulas E	500	5	2500	-	-	2500	-	0	0
Dulas F	1000	4.5	4500	-	4500	-	3	135	6.75
Gwynfel G	1000	3	3000	-	-	3000	-	0	0
Gwynfel H	1500	2.5	3750	-	3750	-	3	113	5.65
Total			51750	34500	10250	7000		2033	102

Assuming 20% of returning adults caught by anglers	20
Therefore number of adults using pass	82
Increased value to Wye fishery according to Harris & Stokes, 1994:	£60,000
Increased value according to Radford & Hatcher, 1991:	£112,940

5. Discussion

The water quality and biological data available is restricted to the lower Garth Dulas and is therefore limited in terms of assessing the status of the upper reaches. However the current fisheries data classifies the juvenile salmon populations as 'good' at sites below the weir, and although juvenile salmon are absent at the site above the weir the juvenile trout population is classed as 'good'.

The water and biological quality of the Garth Dulas is suitable for migratory salmonids as neither appears to limit the successful spawning and rearing of juvenile salmonids in the lower catchment.

Juvenile salmon densities at sites below the weir have consistently been amongst the highest recorded annually on the Wye. Given these present densities it is possible that the smolt output in parts of the catchment above the weir could exceed 5 smolts $100m^2$, with a resulting potential increase in the number of returning adults.

Apart from the economic value, other benefits would result from opening up the upper Garth Dulas to migratory salmonids. These include:

i) increase in good quality spawning/juvenile habitat

ii) increase in smolt production

iii) increase in number of returning adults with a subsequent increase in spawning potential.

However offset against the benefits are costs/problems which need to be considered if a fish pass is constructed.

i) the costs of building a fish pass. These are currently estimated at £30,000 (pers com J. Gregory).

ii) ongoing maintenance of the fish pass structure i.e to keep the structure free of riverborne debris and functioning efficiently

iii) enforcement requirements to cover the extended spawning area available

iv) monitoring to assess fish pass efficiency, either a count of returning adult spawners or juvenile survey to estimate spawning success and juvenile survival.

v) there may be a requirement to initially stock the area above the weir to prime the catchment and boost the salmon populations whilst natural regeneration of returning adults occurs.

6. Conclusions

1. The Garth Dulas is of suitable quality to support juvenile salmonids in the area below the weir and the fisheries data for the area above the weir falls within the 'good' category so salmonid spawning and survival there does not appear to be impacted by the prevailing water quality.

2. $51{,}750m^2$ of river area would become available with the capacity to produce 2033 smolts.

3. An increase in rod catch produced by the added smolt yield could increase the value of the salmon fishery to the owners by £60,000 (Harris & Stokes, 1994) or £112,940 (Radford & Hatcher, 1991).

4. A fish pass would open up good quality spawning area with the potential to boost the numbers of adult salmon returning to the Wye to spawn.

IX.B Retrospective evaluation of Conwy Falls fish pass

SELECTION OF FISHPASS OPTIONS

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Summary

Evaluation of fishpass options requires their economic costs and benefits to be assessed. However, the benefits of fishpasses (and many other fisheries management options) are difficult to assess because of errors in predictions of the biological consequences and in the estimation of their economic value. This paper offers an approach to incorporate this uncertainty into a fishpass evaluation, using the Conwy Falls fishpass, North Wales, as an example. The basis of the method is that the range of likely values, derived using best judgement where poor data restrict formal statistics, is used to construct a probability distribution that describes the probability of the outcome, expressed here as Net Present Value. This is considered to be more helpful to managers than a single benefit-cost ratio value. The Conwy scheme is shown to be cost-effective, principally because of pump-priming stocking, which brought benefits forward by several years. The assumptions behind the method are briefly discussed and areas for further work identified.

1. INTRODUCTION

Fishpasses can be very expensive to build and maintain. It is therefore essential that the best design is used and that the decision on whether or not to build is based on the best available information.

Cost-benefit analysis of fishpasses is often a simple comparison between some discounted value of returning fish versus construction and maintenance costs. Such analysis is probably acceptable for many assessments, but gives no insight into the likely outcomes or risks involved and as costs increase so too do the risks associated with failure.

Not only are the stakes higher with more expensive schemes, but their chances of working effectively and realising their investment may be more complex to determine because of, for example, problems over efficiency of attraction velocities, flow control systems etc. Moreover, larger schemes may have wider implications for other users of the river, with associated values that are sometimes even more difficult to estimate than fisheries benefits.

Fishpass benefits are normally based on the fishery value of predicted catch increases. This introduces two problems; firstly the considerable difficulty in predicting future returns of fish, and secondly the attribution of economic value to these fish, as well as the evalaution of a host of other benefits that have no directly measurable economic value.

In the face of so much uncertainty how can we be sure that a correct decision has been taken over selecting either a scheme option or whether to build at all? We can never be certain of course, but there are ways to ensure that the full range of information has been evaluated and presented to managers in ways that facilitate decisions.

There is at present little experience of such analysis in the Agency, although methods for benefit - cost analysis methods have recently been developed for water quality improvement schemes (Environment Agency, Benefit Assessment Manual). This paper sets out some principles and approaches that might be useful, and is intended as a catalyst for further thought rather than a recipe of procedures. The following is from the salmonid management perspective, using the Conwy falls fishpass in North Wales as an example, but the principles should apply to other species and to other types of schemes.

2. RETROSPECTIVE EVALUATION OF CONWY FALLS FISHPASS

2.1 General description

The Conwy Falls scheme was enabled by a Welsh Office grant as mitigation for the A55 Conwy estuary-crossing scheme, with further contributions from the National Rivers Authority. The decision to build was made after review of other options, including hatchery and trapping and trucking, and estimation of the fishery benefits based on predicted catches (not translated into monetary value). The scheme would open up an additional 40% of wetted rearing area for salmon and sea trout (Fig 1), estimated to increase smolt output by at least 18%.

An initial proposal was for a pool and traverse pass up the face of the falls on the sites of a previous, but never-functioning, pass built in the last century. This was rejected on visual grounds because the sight is a noted tourist attraction. The option of tunnelling around the falls was then considered and an initial proposal was rejected on cost grounds (~ £1m).

A cheaper tunnel design, which later won the British Construction Industry (Small Projects) Design Award was devised by Donaldsons Associates. The site is situated in a steep, torrential gorge where the Conwy has an ADF of 8 cumecs. The pass comprises 25 pools spanning a 12m elevation. Three penstocks control exits and regulated flows through the pass to a nearly constant 2 cumecs. Flow was a particular issue because it was essential to protect the flow over Conwy Falls as an important visual amenity and the pass closes at flows below the 95%ile.

2.2 Methods to estimate Fishery benefits

Table 1 Summary data for fishery evaluation, Conwy Falls (salmon only)

FEATURE	downstream	upstream of fishpass		Total	% change
Accessible wetted area (m2)	687490	272380		959872	40
		"worst"	"best"	"worst"	"worst"
Smolt output	15464	2815	3786	18279	18
Run to estuary	1546	282	379	1828	18
Commercial catch	129	17	32	146	13
Rod catch	422	57	104	479	14
Spawning escapement	995	208	243	1203	21

Fishery benefits were estimated as changes in catches based on predictions of smolt output in the newly accessible area. These were obtained from basic habitat and juvenile surveys throughout the Conwy system. A particular concern was the potential for acidification in part of the upper river to limit survival of eggs or young stages of salmon and sea trout, which would reduce the effectiveness of the pass. Estimates of available rearing areas and smolt numbers were corrected to allow for this.

Smolt outputs were converted to catches by applying ranges of marine survival and freshwater exploitation rate values. A range of catches was therefore established bounded by "worst" and "best" cases (Table 1). This involved subjective judgement and educated guessing, and the interpretation of these limits is discussed below.

2.3 Economic Assessment

When undertaking a monetary appraisal all of the values used should be adjusted to current prices, that is the price level pertaining to the year when the appraisal is carried out (in this case 1991/2). This is done by applying an adjustment factor (being the difference between current and original Retail Price Index) to the raw values. The largest correction required is the adjustment for discount rate to give Present Values (PV) for each item of cost and benefit (see Agency Benefits manual for a full explanation). Two options for assessment are then possible.

1) Benefit-cost ratio (BCR).

BCR = **PV**benefits / **PV**costs

A positive value normally signifies a viable scheme. BCRs are used to compare between different schemes faced with a capital constraint.

2) Net Present Benefit (NPV)

NPV = **PV**benefits **- PV** costs

This describes the value level of benefit, allows assessment of a single or multiple schemes and provides a means to compare non-monetary benefits.

2.4 Estimation of Net Present Values for Conwy falls fishpass

Net Present Values which were initially calculated over two time periods, 25 and 100yrs, and for two scenarios:

- **A)Natural colonisation, without stocking**, (with two alternative colonisation models)
- **B) Colonisation artificially boosted by stocking**

In both cases the worst case predicted rod catch of 57 fish (Table1) was initially used and the costs and benefits have been referenced to the first year of construction (year 1). Fishpass construction costs were phased over three years as follows:

year 1 (1992)	£155,000
year 2 (1993)	£313,000
year 3 (1994)	£32,000

In both scenarios annual running costs, made up of maintenance, counter use and post scheme monitoring, are assumed to be £14,000. The calculations are made for salmon only, but sea trout are also expected to use the pass. NPVs for salmon were multiplied by 1.5 to allow for an assumed equal number of sea trout having half the fishery value of salmon.

Benefits have been assumed here to comprise two main components:

- **Fishery capital value.** This is a capital benefit to the fishery owners only. A value of £6,000 per rod caught fish has been assumed for illustrative purposes (Radford and Hatcher, 1991).

- **Revenue income** This represents an annuity benefit to the economy (the geographical allocation of this is complex matter and is not relevant to the present calculations). A value of £1,000 is assumed here (Humphreys and Partners, 1991)

Benefits were calculated with the following assumptions.

Scenario A1:

- spawners first use pass in year 4 (first clear year after construction)
- smolts are all 2 yr old and adult salmon are all 2 sea winter
- spawners increase linearly (Fig 2) from year 9 up to saturation (maximum equivalent to 57 rod caught fish Table 1) after 10 years
- the predicted rod catches (Table 1) are realised without error

Scenario A2:

- As A1, but assume that stock (and rod catch) increase exponentially (Fig...) between year 9 and year 25

Scenario B:

- stocking of fry begins in year -4 (8 years before the pass opens to spawners)
- stocking costs are based on standard unit production rates (based on fed fry unit cost of £0.3) and do not assume that a hatchery is purpose built
- stocking level is assumed to ensure that saturation escapement is possible in the first year of pass operation
- the predicted rod catches from the saturation spawning return in year 9 (57 fish)
- benefits exclude the rod catches derived from fry stocked before returns from natural spawning began (in year 9)
- NB the value of fish derived from the priming stocking, but caught before the pass opens, is included in these calculations. For illustrative purposes, survival of fed fry to adult returning to the river was assumed to be 0.001. No capital value was attributed to these fish, because of the short time they were present, but annual income @£1k per fish (see above) was counted as benefit.

The one-off capital benefit (E) arising from increased value of the fishery, was converted

to Present Day Value (PV) in 1993 by:-

$$PV(E) = E \times (1 + r)^{-n}$$

(where r = discount rate (currently 6%) and n = number of years)

Construction capital costs were similarly adjusted.

The annual "income"(C) to economy was converted to PV by:-

$$PV(C) = C \times [1 - (1 + r)^{-n}] / r$$

Annual maintenance and monitoring annual costs were similarly adjusted.

In summary, the costs and benefits are:

COSTS (£)

1. Construction yrs 1992-4...500k (capital)
2. Maintenance ....10k (pa)
3. Monitoring..4k (pa)
4. Stocking ....range 2-45k (pa)

BENEFITS (£)

1. Capital fisheries value..6k (per rod caught fish) (capital)
2. Annual income to local economy.................................1k (per rod caught fish) (pa)
3. value of net catch...£25/fish
4. value of rod-caught fish, derived from stocking, prior to pass opening (variable pa)

Note that the correction of PV to NPV can be made using the above equations or by reference to most economics textbooks or to the Agency's Benefit Assessment manual, where tables give correction factors. Use of the equations allows trials with varying interest rate or time horizon.

2.5 The effect of assumptions on NPV

Effect of stocking

The two alternative scenarios, natural colonisation and pump priming produce different financial assessments (Table 2). In the former, the time lag between pass opening and full realisation of the spawning potential substantially reduces the NPV, giving values of £13k (A1) and -£111k respectively when construction costs are discounted over 25 years , although the relative differences decrease over longer time horizons.

In contrast, when stocking is carried out before pass opening, the financial benefits are realised early and the NPV becomes positive (£177.4k). The Benefit-cost ratios vary similarly, being <1 (0.81) for the exponential colonisation (A2) and >1 (+1.21) when stocking is applied.

Table 2 Summary of Cost, Benefits, Present value and Net Present Values for different colonisation scenarios

SCENARIO		25 YRS		50YRS		100YRS	
		PV	NPV	PV	NPV	PV	NPV
A. (natural)	COST	593.2		634.9		646.9	
linear A1	BENEFIT	606.2	13.0	862.8	227.9	936.5	289.6
expon.A2		482.2	-111.0	738.8	103.8	812.5	165.6
B. (stocking)	COST	831.3		873.0		885.0	
	BENEFIT	1008.7	177.4	1428.4	555.4	1758.7	873.7

Effect of colonisation rate

The rate of colonisation has a significant effect on the outcome. A linear rate produces a higher NPV than an exponential rate, because the time of return on the investment is delayed with the latter (Fig 2). The exponential pattern is probably a more accurate description of the natural process. The assumption that full saturation was reached by year 9 is optimistic and other scenarios could be assessed.

Effect of rod catch estimate

NPV values were calculated over a range of predicted rod catches (Fig. 3). The relative differences between the scenarios described above for a rod catch of 57 fish alter with increasing catch. Thus break-even point (NPV = 0) occurs at rod catches of 56, 71 and 44 fish for A1, A2 and B respectively.

2.6 The basic economic assessment

The above account has outlined a basic estimation and comparison of NPVs. Alternatively, the benefit-cost ratios (BCR) can be calculated. Values of =<1 implying that a scheme fails. Note that, as a ratio, a high BCR does not automatically mean a high NPV. In all cases the decision on what and whether to build will need to incorporate other, non-monetary, factors.

The Conwy fishpass, when stocking takes place, meets the decision rule for BCR and also indicates a large NPV. Without stocking the decision is more marginal, and non-monetary benefits need to be considered (they should be in all cases).

In Fig. 3 the "worst" (pessimistic) and "best" (optimistic) estimates are shown to mark boundaries on the likely NPV. Whilst this provides a frame of reference to make a decision it does not take into account the uncertainties in the estimates of either catches or the economic benefits attributable to them. The former are considered below, but first an approach to deal with non-monetary values is outlined in section 2.6.

2.7 Unvalued and non-monetary benefits and costs

In addition to the major economic components several other benefits and costs can be identified to which it is more difficult to assign economic value. These fall into two main categories:

Unvalued benefits/costs - these are either very difficult to put costs to or are beyond current techniques

Non-monetary benefits/costs - these are completely outwith the realm of economic definition.

Examples of these are given below:

Unvalued benefits

- possible increased spawning in the Lledr, an adjacent tributary (could be a cost, but unlikely)
- net catches. These can be valued easily now, but the future catch rate and level of netting are hard to predict, and in any event the amounts are very small (<1%)compared with the rod catch benefits.
- increased incidence of salmon jumping at falls, enhancing visual amenity

Unvalued costs

- possible damage to brown trout populations and fishing in upper Conwy, through interactions with migratory salmonids
- increased antipoaching work - although, as a staff time, this can be costed easily, it is very difficult to predict the amount to account for at this stage.

Non-monetary benefits

- increased diversity in Conwy salmon and sea trout stock composition
- increased stability in run size
- increased "feel good" factor because salmon running up the falls into upper catchment
- increased educational and public relations opportunities (NB these would require further investment to take forward properly)

Non monetary costs

- reduced genetic diversity in N Wales non-migratory "brown trout stock"

Although the benefits above cannot be reliably estimated, if at all, it is possible to compare them subjectively against any shortfall in NPV that may arise from the analysis of the quantifiable values. In this case the NPV shortfall (i.e. a negative NPV) can be translated into annual payments over the scheme lifetime and this value compared with a judgement of the non-quantified benefits. The appropriate ***Annual Equivalent Annuity*** (AEA) is calculated from:

$$AEA = NPV \times r / [1 - (1 + r)^{-n}]$$

In the case of "worst" catch of 57 fish (Table 2) the AEA over 25yrs with scenario A2 (natural, exponential colonisation) is £8.7k, indicating a likely judgement that the economic appraisal of the scheme was highly favourable, even with a nominal shortfall in NPV.

2.8 Uncertainty and errors in the assessment

There are many areas of uncertainty surrounding the estimates of scheme cost-effectiveness, including poor knowledge of processes leading to compounded errors in original predictions and the future states of nature that may obtain during the pass's lifetime. The following were all considered, although in most cases not quantified, in the Conwy context.

Fishpass design

- Can fish find the pass entrance?
- Can they move up: velocities, gradient, resting areas?
- Can they exit the pass?
- Will they stray to or from adjacent catchments?

Environmental factors

- Are habitat and water quality suitable, now and in future?
- Has rearing area been estimated properly?
- Area there further obstructions between pass and spawning areas?

Biological factors

- Have predators been estimated properly?
- Have freshwater mortality rates been correctly estimated, what errors?

- Have Marine mortality rates been correctly estimated, what errors?
- Have population characteristics been correctly estimated, what errors?
- What are the conservation implications? (competition with indigenous species, effects on other species, changes in ecotone)

Exploitation

- What are the exploitation rates (+ errors) in component legal fisheries?
- Will illegal fishing level change?
- Will fishermen take advantage of catch opportunities?
- What will the future catch level and variability be?

A number of these issues and variables are now becoming better understood and described, especially those relating to survival and exploitation rate. However, it may not be realistic or practicable to build all the factors listed above into the assessment.

In Fig. 3 the "worst" (pessimistic) and "best" (optimistic) estimates mark boundaries on the likely NPV. "Worst" is not strictly correct - no fish at all is worst! Similarly, "best" does not convey an absolute upper limit. These terms were subjectively used to mean that there was only a low chance of catch values below or above them, so they are analogous to confidence limits. The midpoint catch is more likely to occur than the extremes and this can be described by a probability distribution (Fig 4) . This provides a pragmatic way to incorporate uncertainty into the predicted catches.

2.9 Stages and assumptions in calculating Probability Density Function (PDF) and Cumulative Density Function (CDF) for predicted catch

Stage 1. The "worst" and "best" catches are assumed equivalent to 5 percentile probability limits, encompassing 90% of the probability distribution for catch. Reference to tables of a normal curve show that this corresponds to 1.645 x 2 = 3.29 standard deviations, allowing the standard deviation (SD) to be calculated. Catch data are often lognormally distributed. Therefore the exercise should be carried out on log-transformed data. In the Conwy data this caused only a small change in the distribution function, but was felt to be a better representation of the truth.

Stage 2. The midpoint of the "worst" and "best" is an estimate of the mean catch, assuming a normal curve.

Stage 3. Given the mean and SD derived as above, the PDF and Cumulative Density Functions (CDF) can be calculated (using e.g. Minitab, Lotus 123 or other) over a range of catch data, and NPV plotted against CDF (Fig.5)

Using CDF/NPV graphs allows the risk associated with each scenario to be displayed as a probability. This should be an improvement on the acceptance of predicted rod catch and its associated NPV at face value. In the case of the Conwy Fig 5 shows that with stocking there is a <1% chance that the scheme will at least break even, whereas the no stocking option, although cheaper, has only a 65% chance of a positive NPV. The graphs can be used to identify the likelihood of reaching any economic outcome or, by altering the parameters that determine the curves, assess the risks of other management scenarios.

3. HEALTH WARNINGS AND FUTURE DEVELOPMENTS

The probabilities are dependent on the catch PDF. This is subject to many assumptions (see above) and it would be prudent to test the sensitivity of the analysis to these. In particular the translation of "worst" and "best" into standard deviations from the mean, and acceptance of the mean as the midpoint of these is subject to error. A family of curves can be produced for different assumed PDFs that encompass different proportions (e.g. 80 or 70%) of the distribution, to demonstrate the effect of the assumptions.

Discount rate, and time horizon, have large effects on the economic appraisal. The 6% rate is set by the Treasury and must be applied to Agency schemes, however it is worth noting that this rate may not be the most applicable to environmental schemes such as fishpasses, where the benefits accrue over long (20yrs+) periods. Some NPVs for example lower rates are shown below. Even a 1 % cut reduces the A2 shortfall by half.

Colonisation Scenario	**Discount Rate**		
	0.06	***0.05***	***0.03***
A1 natural/linear	13.0	87.7	288.2
A2 natural/ expon.	-111.0	-47.3	129.0
B stocking	177.4	270.2	507.3

The values of individual fish have been taken without error. These too will vary, but the theory behind these estimates is still the matter of research and debate, again alternatives should be tried. A fuller account of economic descriptors and their applications is given in The Salmon Action Plan Guidelines (Environment Agency, 1996).

This approach brings the basics of decision theory into the scheme assessment. The rod catches (or the various parameters determining it, and trends in the same) can be interpreted as "states of nature" having specified probabilities (specified in the PDF). If a number of management decision options are available then the results could also be presented in a decision table (e.g. Black, 1994 and many others). They can also be taken further, by incorporating utility in order to look at the risk aversion (caution) that managers might want to apply to such a large financial investment.

Further development is required in the estimation of the various parameters which lead to catch predictions and this is part of current Fisheries R&D, but more is also urgently required to improve the incorporation of risk across the range of fisheries management decision making.

Figure 1 Map of the Conwy catchment showing areas accessible to migratory fish

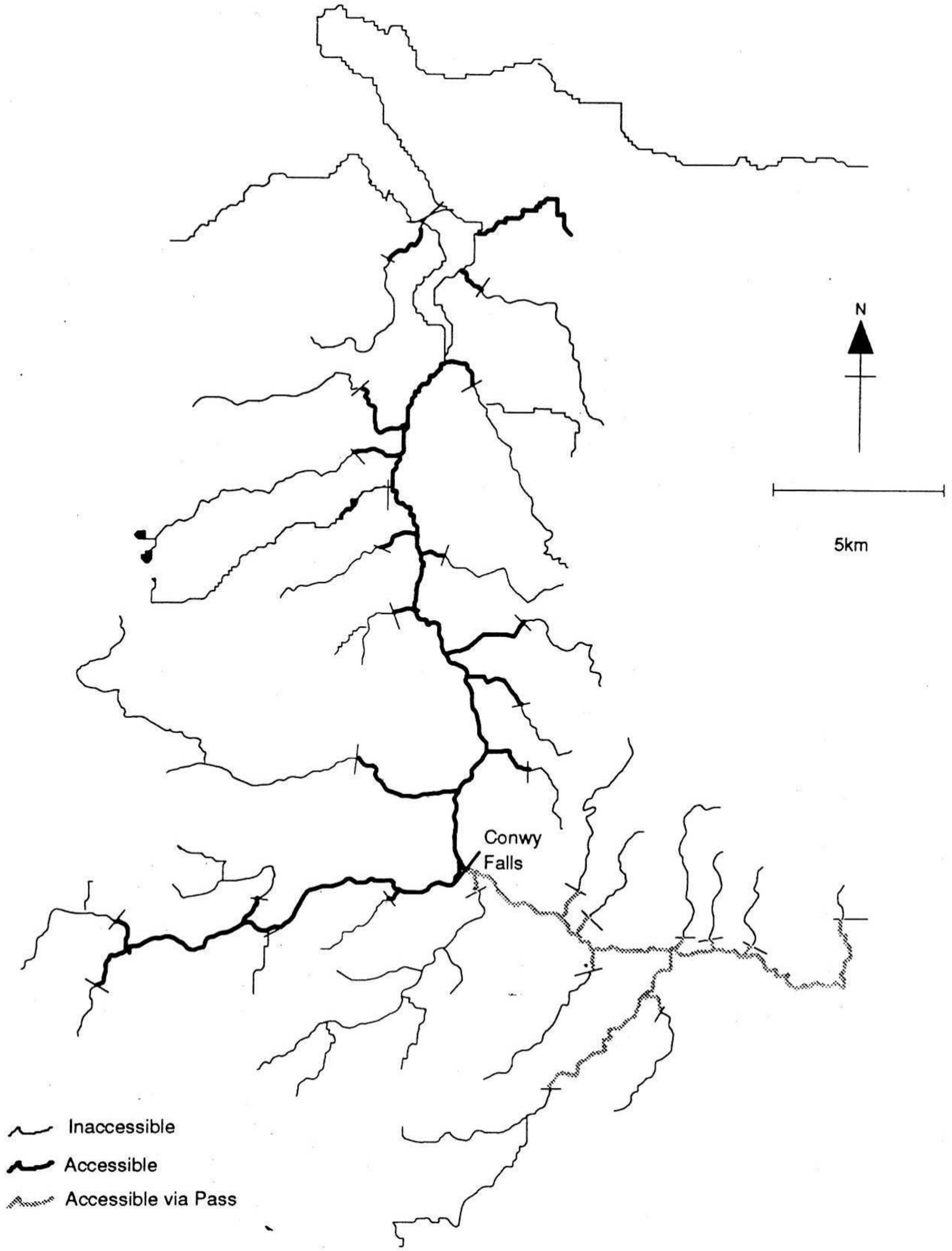


Fig 3 Effect of salmon rod catch on NPV

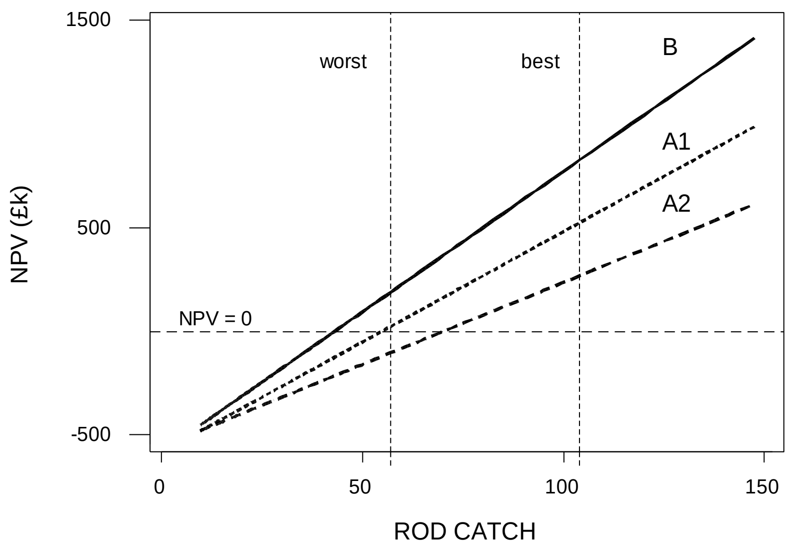


Fig 2 Salmon rod catch under 3 colonisation scenarios

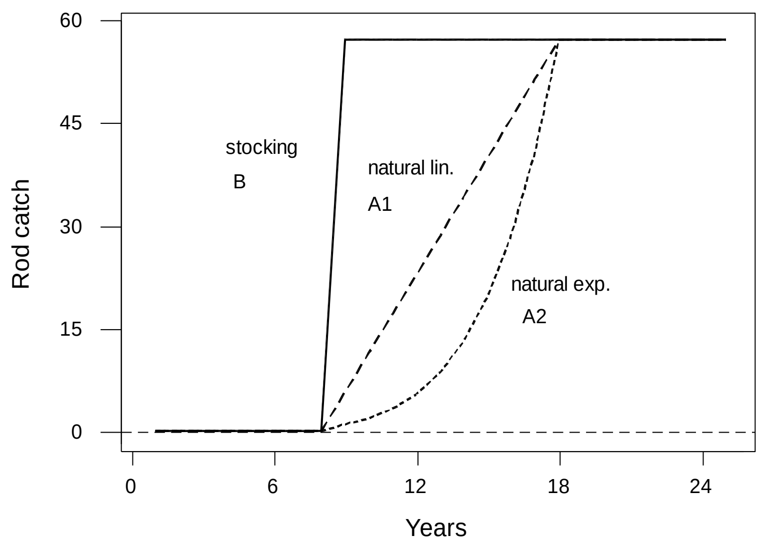


Fig 4 NPV and PDF for different catches

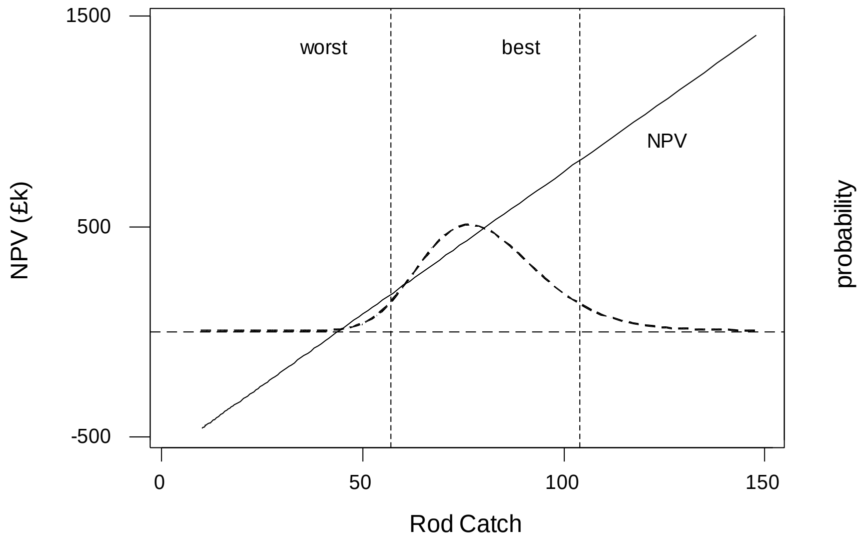
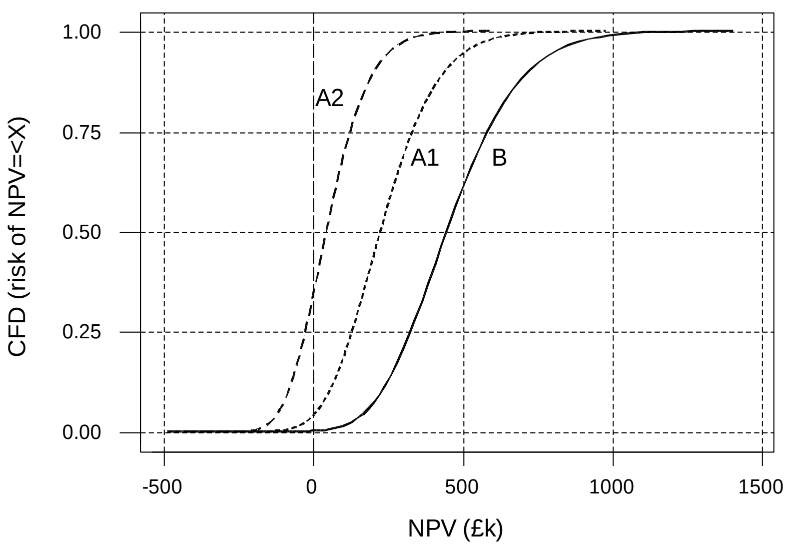


Fig 5 Probability of achieving NPV



APPENDIX IX Scaling Factors For The Hurn Baffle Solution For Flat V Weirs

When considering the scaling of flat V weirs for fish pass approval the different parameters need to be scaled appropriately. The main parameters to be scaled are the linear dimensions of baffles, slots etc. and the non-linear scaling of water velocities and discharge. The scaling of the baffles is simple since the dimensions are in linear proportion to the width of the weir, as shown in the baffle-scaling sheet.

By way of example, the Hurn weir was 10m wide and the baffles were 0.1m thick, 0.15m tall and spaced 0.67m apart. A weir built on the river Uck was 7.62m wide, and therefore each of these dimensions required scaling by multiplying by 7.62/10 or 0.762. This yielded baffle dimensions of 0.76, 0.114 and 0.511m for thickness height and spacing respectively.

To calculate a water velocity relative to that shown for Hurn weir the scaling factor must be calculated (Hurn width / new weir width). In the case of the Uck this was 10/7.62 or 1:1.31, which must then be square rooted and the reciprocal taken to obtain the velocity scaling factor, or $1/(1.31^{0.5}) = 0.874$. Thus a velocity marked on the Hurn Weir diagram, for a known discharge, should be multiplied by this velocity-scaling factor. For a discharge of $2m^3s^{-1}$ at Hurn, the corresponding discharge at Uck is calculated at $1.04\ m^3s^{-1}$ (see later). Therefore at a discharge of $1.04m^3s^{-1}$ the Hurn velocity of $3.6ms^{-1}$ should be scaled to 3.6 x 0.874 for the Uck, giving a velocity of $3.15\ ms^{-1}$.

To calculate the discharge-scaling factor the width ratio should be raised to the power of 5/2, and then the reciprocal taken i.e. $1/(1.31^{2.5}) = 0.51$. Therefore a discharge of $1m^3s^{-1}$ at Hurn should be scaled to $0.51m^3s^{-1}$ for the Uck.

Examples of scaling:

Example of scaling Flat V sites with 1:10 cross slope

Site Name	weir width	baffle thickness	baffle height	baffle spacing	slot width	groove1 depth	groove1 width	groove2 depth	groove2 width	width scale factor	velocity scale factor	flow scale factor
Hurn	10.000	0.100	0.150	0.670	0.200	0.040	0.350	0.080	0.350	1.000	1.000	1.000
Mislingford	6.600	0.066	0.099	0.442	0.132	0.026	0.231	0.053	0.231	0.660	0.812	0.354
Uck	7.620	0.076	0.114	0.511	0.152	0.030	0.267	0.061	0.267	0.762	0.873	0.507

APPENDIX X Glossary Of Terms

Acoustic tag	a tag which emits regular pressure variations vibrations that can be detected with a hydrophone
Adherent nappe	a nappe which remains in contact with the weir surface, usually arranged by having a curved weir profile
Agency	The Environment Agency
Alluvial	derived from the action of rivers
Amphidromy	describes the activity of fish which regularly move from the sea to freshwater and vice versa, not for breeding, but for some other purpose, eg feeding, overwintering etc Adjective: amphidromous
Anadromy	in fish, a life cycle in which adults migrate from the sea into freshwater to spawn. Adjective: anadromous
Average daily flow	average discharge in a watercourse for a 24-hour period (ADF)
Attraction flow	water exiting a fish pass, acting to attract fish to the entrance of the pass
Augmentation flow	water used to enhance the attraction flow from a pass, not flowing through the main body of the pass itself, but typically being injected at low velocity into the final pool or pass entrance orrouted alongside or under the pass and injected into the tailwater
Barrage	a dam or other such water control structure situated in tidal waters
Baulk	a squared or oblong timber, typically of large dimension >0.3m high
Bed-load	material moved along the bed of a river during elevated flows, gravel, cobbles etc
Bifurcation	a forking or division of a stream into two branches
Birds directive	Council Directive 79/409/EEC on the protection of wild birds
Boom	a floating device to prevent water-borne debris from entering a fish pass
Bottomless arch culvert	a culvert in which the natural river bed is retained
Burst speed	a swimming speed that can be sustained for ≤20 seconds
Catadromy	in fish, a life cycle in which adults migrate from freshwater into the sea to spawn. Adjective: catadromous
Clapotis	a standing wave phenomenon caused by the reflection of a non-breaking wave train from a structure with a vertical or near vertical face. Also known as a Seiche.
Coefficient of discharge	a coefficient used in discharge equations: a factor which accounts for viscous effects, turbulence, non-uniform velocity distributions, and centripetal accelerations. Describes the actual discharge compared with he theoretical discharge.

Compound Crump	a Crump weir split into sections of different crest height to improve measurement precision at low river discharge. Different sections are isolated from each other by dividing walls
Crepuscular	active at twilight or in the hours preceding dawn
Crib	trap with inscale for catching salmon
Cruising speed	a swimming speed that can be maintained for long periods of time - hours
Cruive	weir constructed with gaps to take traps for catching salmon
Crump	a gauging weir with triangular cross-section and horizontal crest, typically with a 1:2 upslope and 1:5 downslope
Cyprinid	fish of the carp family
Dam	SAFFA 1975 - any weir or other fixed obstruction used for the purpose of damming up water
Diadromy	a life cycle which involves the migration of fish between the sea and freshwater. Adjective: diadromous
Discharge	the rate of flow of a fluid - in this manual –flow is expressed as volume per unit time, usually cubic metres per second (m^3s^{-1}) (also cumecs)
Diurnal rhythm	at daily intervals
Easement	pragmatic solutions to fish passage which generally fall outside the formal fish pass authorisation process
Endemic	prevalent or regularly found in a district, confined to a particular area
Enkamat	proprietary geotextile material consisting of UV-stabilised synthetic fibres, looped and bonded in three-dimensional form to form open-weave mat
Entrance	the downstream end of a fish pass, out of which water flows and into which fish migrating upstream enter the pass
Environmental appraisal	sometimes used to refer to a less formalised process than EIA (see below) where an assessment is not required by legislation
Environmental Impact Assessment	at the project level, a process intended to ensure that environmental impacts of schemes are identified prior to the work being carried out so that proposals can be modified or managed in such a way that adverse impacts are avoided or minimised
Environmental report	produced for projects which do not require an Environmental Statement
Environmental statement	the document produced when environmental impact assessment is formally required under the EIA Regulations
Exceedance value	see percentage exceedance value
Exit	the upstream end of a fish pass, into which water flows, and out of which fish migrating upstream leave the pass

Fish pass	any form of conduit, channel, lift, other device or structure which facilitates the free passage of migrating fish over, through or around any dam or other obstruction, whether natural or man-made, in either an upstream or a downstream direction
Fishing mill dam	SAFFA 1975 - a dam used or intended to be used partly for the purpose of taking or facilitating the taking of fish, and partly for the purpose of supplying water for milling or other purposes
Fishway	fish pass
Fixed engine	any fixed device used for the purpose of taking or catching fish
Flat V	a gauging weir with triangular cross section and a shallow V-shaped crest and cross-slopes
Flight	a discrete length of fish pass cf flight of stairs
Flume	an artificial open channel used for flow gauging
Fork length	fish length measured from the tip of the snout to the fork of the tail
Form A	Agency internal form used for project approval
Free gap	any opening in a weir or other obstruction to allow fish passage
Gauge board	a measuring board set at an arbitrary level in a river and used for indicating water level height
Glacis	an inclined slope, the sloping face of a weir
Glycogen	polysaccharide; a compound found in the muscles and liver of animals which is broken down to form glucose
Habitats directive	Council Directive 92/43/EEC on the conservation of natural habitats of wild flora and fauna
Head of function	designated Agency National Head of Function - in this case the Fisheries Function
Head	depth of water above a specific invert
Head difference	the vertical difference - typically measured in metres - between upstream and downstream water levels across a structure (e.g. a weir) in a watercourse or between consecutive pools in a fish pass
Head drop	see Head difference
Head level	water surface level on the upstream side of a structure in a water course - typically measured in metres above Ordnance Datum or else referred to a local temporary bench mark (TBM)
Head loss	see head difference

Heterogeneity	Composed of parts of different kinds. Adjective: heterogeneous
Hydraulic jump	a standing wave or roller below a weir, sluice, or spillway where water at super-critical velocity reverts to su-critical velocity
Hydrodynamics	that branch of dynamics which studies the motion produced in water by applied forces
Hydrographic regime	seasonal discharge characteristics of a watercourse
Hydrokinetics	Motion and movement of water
Hydrology	Local water resources, quantity and availability in time
Invert	the lowest point of a cross section of a culvert, flume, notch, fish pass entrance, etc
Joule	System International (SI) unit of work, energy (joule/sec^2) and heat (joule/sec); equal to the work done when a force of one newton advances its point of application by one metre
Kelt	a salmonid fish that has just spawned
Laminar flow	smooth flow as opposed to turbulent flow, or the intermediate state, transitional flow
Low Flow 2000	a hydrometry software programme that estimates river discharge in defined catchment areas by using average annual rainfall and making statistical comparisons, involving various characteristics, with other known catchments
Maximum speed	a swimming speed that is a single effort which can be sustained only momentarily, a single darting movement
Mitochondria	energy producing bodies present in living cells
Nappe	the sheet or jet of water that forms as water has passes over a weir crest or other invert
NFPP	National Fish Passage Panel
NFTG	National Fisheries Technical Group
Natura 2000	a network of sites (SACs and SPAs) across Europe set up under the Habitats Directive
Null hypothesis	a statistical term, "a proposition that the difference between statistical samples does not imply difference between populations" i.e. any observed differences are merely due to fluctuations in sampling from the same population.
Ordnance datum	average sea level at Newlyn in Cornwall. Heights on Ordnance Survey maps are referenced to this level.
Orifice	an opening with closed perimeter, through which water flows- usually submerged in fish passes

Overfall	action of water passing over a wall, weir or other obstruction, e.g. typically the cross-wall of a fish pass
Penstock	a sluice gate, generally operated by a mechanical lift mechanism, for instance a screw system
Percentile exceedance value	the flow exceeded for a given percentage of time (graphically x-axis flow, y-axis % exceedance)
Perched	Weir or culvert apron higher than the downstream water level such that it forces fish to jump on to it to gain passage
Piscivorous	an animal that eats fish, includes fish eating other fish
Pit tags	Passive integrated transponder tags, each have a unique code that responds to an interogating signal received and does not require to be powered itself
Planning supervisor	engineer responsible for ensuring that CDM regulations are adhered to in capital works schemes
Plume	a jet of water emanating from the downstream entrance of a fish pass, or other discharge
Plunging flow	in a pool pass, flow that plunges towards the bottom or bed of a pool, energy is dissipated by turbulent mixing and a hydraulic jump at the base of the fall
Potadromy	a life cycle in which fish undertake regular migrations solely within freshwater systems. Adjective; potadromous
Power density	Energy released per second per unit volume, estimated in fish passes as watts/cubic metre
Power dissipation	see volumetric power dissipation
Precautionary principle	defined at the Rio Earth Summit (1992): 'where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'
Prolonged speed	a speed that can be maintained for 20 seconds to 200 minutes
Radio tags	fish tags which emit a radio signal, allows a fish to be tracked in freshwater with the use of an appropriate radio receiver (not suitable for use in saline conditions)
Ramsar site	site designated under the 1971 Ramsar Convention on Wetlands of International Importance. These are Wetlands considered to be of international importance, particularly as habitat for wildfowl.
Rectilinear	in a straight line, bounded by straight lines
Redd	a spawning nest made in gravel by salmonid fish
Restistivity counter	a device for counting numbers of migrating fish utilising the fact that fish have a different electrical resistance to the surrounding water.

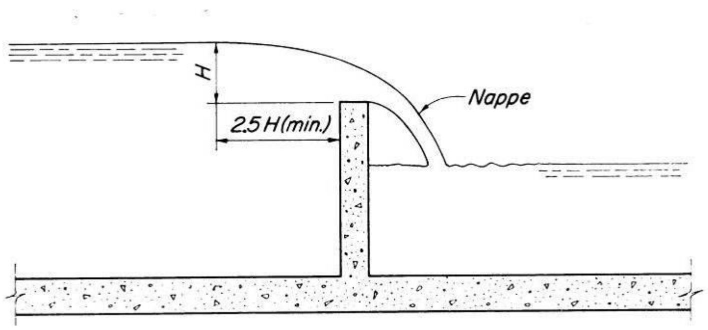
Resting pool	a pool provided between flights in a fish pass, to allow fish to rest before progressing through the next flight
Retro-fitted	a fish pass or easement fitted to an existing structure – e.g. a weir- after that structure has been built, rather than being included as an integral part of the original design of the structure
Reverse-rolling turbulence	Condition induced by squirting flow from undershot gates where water rolls and tumbles back on itself in a reverse direction to the normal downstream direction of flow
Riparian	relating or situated on the bank of a watercourse
Rugosity	roughness of a surface or the river channel
Salmonid	fish of the salmon family
Scabbling	the operation of roughening a surface to obtain a key to for adhesion
Seiche	See Clapotis
Sinusoidal	'S'-shaped curve
SAC	Special Area of Conservation, i.e. site designated under the Habitats Directive
cSAC	candidate SAC
SPA	Special Protection Area, i.e. site designated for the protection of birds under the Birds Directive
Stilling basin	section of artificially deepened channel – typically a concrete lined pool below a dam or gauging weir - to dissipate energy, reduce water velocities, and prevent bed erosion
Stank	a colloquial term for a small coffer dam; to make an area watertight
Stop log	board, usually made of timber, inserted in an artifical channel to stop the flow, facilitate de-watering, maintenance or other operational activities
Streaming flow	in a pass, water flowing at or near the surface, energy is dissipated by large re-circulation eddies in the downstream pool
Super-active baffle	a particular form of baffle designed (by Larinier & Miralles) to efficiently dissipate energy when laid on the bed of a channel
Super-critical	The ‘critical’ depth of flow is where energy is least. At depths greater than ‘critical’ depth, the flow is said to be slow, tranquil, or ‘sub-critical’. At depths les than critical depth, the flow is said to be fast, shooting, or ‘super-critical’
Sustained speed	a swimming speed that can be maintained for ≥ 200 minutes
SWIMIT	“Swimming Information Technology” An Excel software programme that generates estimates of swimming speeds for various fish species using empirical data

Tail-water	area immediately downstream of a structure in a watercourse
Thalweg	The longitudinal profile of a river, often used to denote the return distance between river meanders
Thin plate Weir	gauging weir, usually made from a metal plate set vertically in the channel
Topographical survey	survey of an area defining dimensions of features and their heights above Ordnance Datum
Traverse	cross-wall in a pool pass
Utilities	water, electricity, gas companies etc
Ultrasonic gauging station	a gauging station which measures flow discharge in a watercourse using the time of flight of sound waves with frequencies above the audible range for humans
Volumetric power dissipation	a measure of the power dissipation per unit volume in a pool of a fish pass, usually estimated as watts per cubic metre (Wm^{-3})
Wayleave	permission to pass over another's ground or property
Watt	SI unit of power; 1 watt is equivalent to 1 Joule per second

APPENDIX XI Some Typical Hydraulic Equations

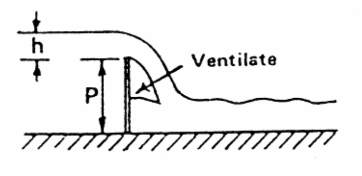
The following equations give approximations of discharge for a variety of different control structures, including pool pass traverses. A variety of things will modify these relationships including for example roughness (or friction) of the material, shape of the crests, inverts or orifices, and approach velocities etc. However, for the purposes of estimating flows and depths over various structures during fish pass design, these equations are perfectly satisfactory.

Note that in measuring values of h (or H in the diagram below) for head on a weir, these should always be taken sufficiently far upstream of the weir before the water begins to accelerate over the crest. A guide is that h (i.e the difference between the actual water level and the weir crest) should be taken at a distance equivalent to at least 2.5 x the value of h upstream of the weir.



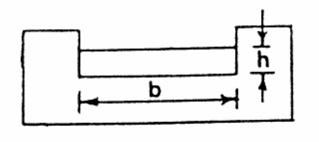
(After Clay, 1995)

1. Rectangular thin-plate weir, full width b, with no side contractions



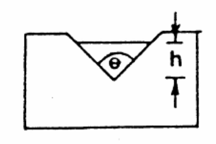
$Q = 0.59\ b\ \sqrt{g}.\ h^{1.5}$ or $= 1.85\ b\ h^{1.5}$

2. Rectangular thin-plate weir with side contractions



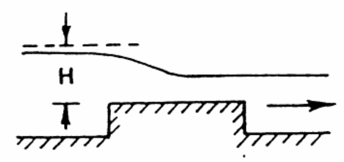
$Q = 0.56 (b + 0.003) \sqrt{g}. h^{1.5}$ or $= 1.75 (b + 0.003) h^{1.5}$

3. Vee-notch thin-plate weir



$Q = 0.58 \sqrt{g}. \tan\theta/2\ h^{2.5}$ or $= 1.82 \tan\theta/2\ h^{2.5}$

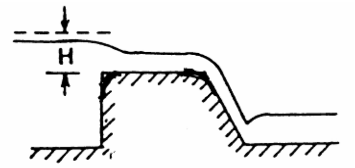
4. Rectangular profile weir



$Q = 0.46 b \sqrt{g}. h^{1.5}$ or $= 1.44 b h^{1.5}$

Note also that h = the gauged head on the weir i.e. to the actual water surface, whereas H in the diagram above is the total head on the weir that includes approach velocity

5. Broad horizontal-crested weir with rounded edges

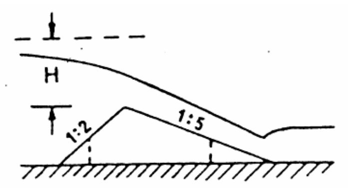


Q = 0.544 b √g. $h^{1.5}$ or = 1.70 b $h^{1.5}$

Note that most broad or narrow-crested weirs with no shrap edges and a will have a multiplying factor i.e Cd √g in the range 1.5-1.7

Note also that h = the gauged head on the weir i.e. to the actual water surface, whereas H in the diagram above is the total head on the weir that includes approach velocity

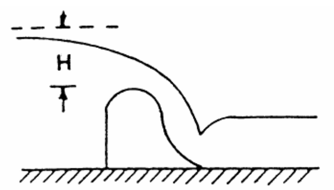
6. Triangular profile Crump weir



Q = 0.633 b √g. $h^{1.5}$ or = 1.98 b $h^{1.5}$

Note also that h = the gauged head on the weir i.e. to the actual water surface, whereas H in the diagram above is the total head on the weir that includes approach velocity

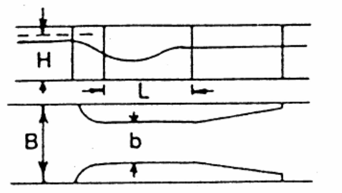
7. Ogee weir



Q = 0.67 b √g. $h^{1.5}$ or = 2.10 b $h^{1.5}$

Note also that h = the gauged head on the weir i.e. to the actual water surface, whereas H in the diagram above is the total head on the weir that includes approach velocity

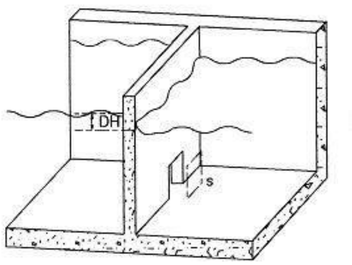
8. Rectangular flume



$Q = 0.544\ b\ \sqrt{g}.\ h^{1.5}$ or $= 1.70\ b\ h^{1.5}$

Note also that h = the gauged head on the weir i.e. to the actual water surface, whereas H in the diagram above is the total head on the weir that includes approach velocity

9. Submerged orifice (which would include a submerged vertical sluice gate)



The general equation for the discharge is $Q = Cd\ A\ \sqrt{2gh}$

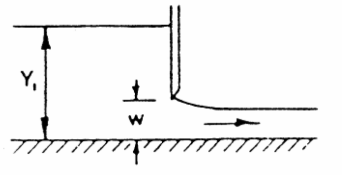
where Cd is a coefficient of discharge, and

A is the area (m^2) of the orifice (b x d)

For a typical sharp edged sluice or orifice we can take $Q = 0.61\ A\ \sqrt{2gh}$

Note that any bevelling or rounding of the edges of the orifice will increase its discharge coefficient, which can then vary the from about 0.65-0.85

10. Vertical gate not obstructed by the tail-water



The free discharge below a sluice gate is a function of the upstream water depth and the gate opening.

$Q = C_d\ bw\sqrt{2gY_1}$

Where $C_d = \sqrt{(C_c / 1 + w/Y_1)}$, and $C_c = 0.61$

11. Accounting for approach velocity

The equations for weirs above ignore the approach velocity of the water to a weir. If the mean velocity of the water approaching the weir is known then this can be reflected in the calculation of flow. It is only of real significance if approach velocities are high, say more than 1m/s.

Say discharge over a weir is say $Q = 1.7\ b\ h^{1.5}$

Where h = static head a distance at leat 2.5h upstream of the leading edge of the structure

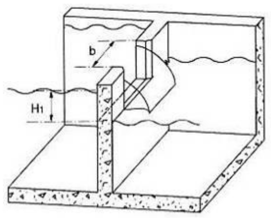
Given that the theoretical velocity of falling water $V = \sqrt{2gh}$ by squaring it and transposing it we can estimate a value for its equivalent velocity head h_1 thus

$$h_1 = V^2/2g$$

by combining this with the equation above discharge becomes

$$Q = 1.7\ b\ [(h + h_1)^{1.5} - h_1^{\ 1.5}]$$

12. Pool pass – pool & notched traverse



The general equation for free-flowing rectangular notch

$$Q = Cd\ b\ (2g)^{0.5}\ h^{1..5}$$

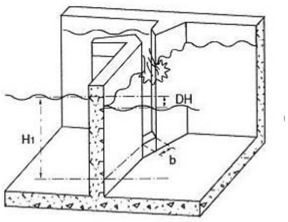
Where Cd is a coefficient of discharge that can vary between 0.33 for a gap forming a broad-crested weir, to 0.5 for a notch with an ogee weir shaped traverse. In most cases it will be about 0.4.

Alternatively for the typical profiled notch used in a conventional P&T fish pass the Francis equation is used

$$Q = 1.84\ (b – 0.2h)\ h^{1.5}$$

Where b = notch width (m)

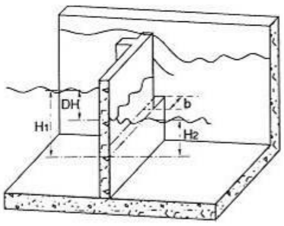
13. Pool pass – vertical slot



$Q = Cd\ b\ H_1\ (2gDH)^{0.5}$

Where Cd is a coefficient of discharge that can vary between 0.65 for a sharply bevelled slot to 0.85 for a well-rounded slot

14. Pool pass – deep slot



Flow in the pass Qn = K. Qd

where $Qd = Cd\ b\ h_1\ (2gDH)^{0.5}$

while $K = [\ 1 – ((H_1 - DH)/H_1)^{1.5}]^{0.385}$

15. Flow in open channels

Q = A. V.

where A = cross-sectional area

and $V = (1/n)\ R^{o.667}\ S^{0.5}$ (Manning formula)

where R = mean hydraulic radius = A/ wetted width

S = gradient or slope of the channel

n = roughness coefficient for the channel

Typical values for the Manning constant are as follows:

Channel Type	**Surface material and alignment**	**Manning's constant 'n'**
river	earth, straight	0.02 - 0.025
	earth, meandering	0.03 - 0.05
	gravel (75-150mm), straight	0.03 - 0.04
	gravel (75-150mm), winding or braided	0.04 – 0.08
unlined canals	earth, straight	0.018 – 0.025
	rock, straight	0.025 – 0.045
lined canals	concrete	0.012 - 0.017

APPENDIX XII Fish Pass Inspection Form

FISH PASS INSPECTION FORM

NB: Before carrying out a fish pass inspection, make sure that you have read and understood the relevant safe system of work for the site.

NAME OF RECORDER:	DATE:
FISH PASS NAME:	RIVER:
FISH PASS TYPE:	FISH PASS OWNER:
GRID REF:	FREQUENCY OF INSPECTION Specify:

1. IS PASS FUNCTIONING AS EXPECTED? (Considering questions below)	Y/N
2. IS FISH PASS TOTALLY BLOCKED?	Y/N
3. IS FISH PASS PARTIALLY BLOCKED?	Y/N

4. IF Y TO EITHER (2) or (3) ABOVE DESCRIBE PROBLEM:

(Take photos if possible)

5. ANYTHING U/S AFFECTING FLOW INTO PASS? Y/N

IF Y DESCRIBE PROBLEM:

(Take photos if possible)

6. ANYTHING D/S AFFECTING APPROACH INTO PASS? Y/N

IF Y DESCRIBE PROBLEM:

(Take photos if possible)

7. IS PASS DAMAGED IN ANY WAY? Y/N

IF Y DESCRIBE PROBLEM:

(Take photos if possible)

8. ANY OTHER COMMENTS :

Eg: If this pass is on a spawning tributary you may want to record number of redds up and downstream over a measured reach

You may consider that there is too much/ too little water in the pass even though it's not blocked.

You may consider that there is something wrong with the fish pass design, perhaps there are fish jumping on the weir and not going into the pass or the water drops a long way so difficult for fish to get into the pass.

If the fish pass is equipped with a gauge board(s), enter the reading(s).

DATE REMEDIAL ACTION COMPLETED: COST :

DESCRIBE REMEDIAL ACTION:

APPENDIX XIII List of Abbreviations

ADF	Annual Daily Flow
AFER	Area Fisheries, Ecology and Recreation (Manager)
BCU	British canoe Union
CCW	Countryside Council for Wales
CDM	Construction, Design and Management Regulations for planning
CROW	Countryside and Rights of Way Act 2000
cSAC	Candidate Special Area of Conservation
EA	Environment Agency
EC	European Community
EN	English Nature
EWF	Emergency Work Force
FA	Final Approval
H&S	Health and Safety
NCPM	National Capital Programme Management
NFPP	National Fish Passage Panel
NFPO	National Fish Pass Officer
NRA	National Rivers Authority
ODN	Ordnance Datum Newlyn
OLDSI	Operation Likely to Damage features of Special Interest
PA	Provisional Approval
PAB	Project Approval Board
PI	Policy Instruction
PID	Project Implementation Document
PPG	Planning Policy Guidance
Q	Discharge (m^3s^{-1})
Q90	Percentile Exceedance Value (in this case a value exceeded for 90% of the time, i.e. a low flow)
R&D	Research and Development

SAC	Special Area of Conservation
SAFFA	Salmon and Freshwater Fisheries Act 1975
SI	Statutory Instrument
SoD	Scheme of Delegation
SoS	Standard of Service
SPA	Special Protection Area
SRT	Self Regulating Tideway (gate)
SSSI	Site of Special Scientific Interest
SWIMIT	Swimming Information Technology
TBM	Temporary Bench Mark
UK	United Kingdom

APPENDIX XIV Monitoring Programme Examples

Examples of detecting change in upstream populations to demonstrate the effectiveness of a fish pass

Sources of information and data, and their relative value, have been outlined in section entitled 'Methods for determining the effectiveness of fish passes' (page 223). At the very beginning of the process a management decision needs to be made regarding what level of change in the chosen parameter (e.g. a doubling, trebling etc) would indicate that the pass is effective. The approach that follows utilises the overall variance including temporal, spatial, random and movement.

The duration of the study and the number of sites sampled post-construction will depend on the management decision of the level of change that is to be detected. It will also depend on the overall variability of the data, the number of sites sampled, and the number of years of data available prior to the construction of the fish pass.

Statement of required precision

Proof of effectiveness can be derived from a statistical determination of whether there has been a significant improvement in the population following the construction of a fish pass. For example, the hypothesis (null hypothesis, H_o; a statement of no difference) would be that the study aims to test whether the size of the population before the construction of the pass was different to the size of the population post-construction (H_o: population before = population after). Alternatively the study could aim to test whether the size of the population before the construction of the pass had increased by a fixed amount (H_o: population before = population after + difference). If the null hypothesis is false then the alternative hypothesis is deemed to be true, for example the population after construction is significantly different from the population post-construction (i.e. H_a: population before = population after construction).

In any such test there are two types of error:

Type I - H_o is rejected when H_o is true. The probability of this occurring is denoted by the significance level α [eg setting $\alpha = 0.05$ means there is a 5% chance of rejecting H_o (the size of the population pre and post construction are not the same) when if fact they were the same].

Type II - H_o is accepted when the alternative hypothesis (H_a) is in fact true (eg. the size of the population pre and post construction are the same when in fact they were different). This probability is denoted by the value β. Therefore 1- β (= power) is the probability of accepting Ha when Ha is true.

The two types of error are inversely related. A decrease in a Type I error will increase the probability of a Type II error, for any given sample size. The only way of reducing both sets of error is by increasing sample size. The ideal statistical test is one that has a small probability of rejecting H_o when it is true and a large probability of rejecting H_o when it is false.

The effect of different values of alpha (α) and beta (β).

Let it be assumed that the monitoring programme aimed to determine whether the population post construction (P_2) had increased by a certain amount (d) of the pre construction population (P_1).

Let the actual change in the population be X (= P_2 / P_1; or = P_2 - P_1) and therefore the null hypothesis being tested is whether

H_o: X ≤ d against the alternative hypothesis H_a: X ≥ d.

The influence of alpha and beta and the minimum difference (d) in the population level pre and post construction can be examined through their effect on the standard error of the difference pre and post construction (X).

The standard error (SE) of the observed change in the size of the population (X) is:

$$SE(X) \leq d / (u_{\alpha/2} + u\beta) \qquad \text{equation *1}$$

Where $u\alpha/2$ is the upper 100(1- $\alpha/2$) percentage point and $u\beta$ the upper 100(1 - β) percent point of the Standard Normal distribution (Appendix Table 1) The difference (d) can be either a specific amount or a multiple of the pre construction level. In the case of the former the actual value is substituted into equation *1, while if a multiple of the pre construction is being considered the Logarithm (Log d) is used.

Appendix Table 1 Values of alpha and beta for different levels of probability

Probability	$u_{\alpha/2}$	u_β
0.01	2.576	2.326
0.05	1.960	1.645
0.10	1.645	1.282
0.20	1.282	0.842
0.30	1.036	0.524

By substituting various values into equation *1 it is possible to determine the standard error for different levels of alpha, beta and the detectable difference in the population level pre and post construction. The smaller the standard error the more intensive the monitoring programme needs to be to detect the difference in the population level post construction of the fish pass.

For example, where the monitoring programme is being used to determine whether the population had increased post construction by a certain multiple of the pre construction level, tables can be created to examine the implications of changing the various parameters (Appendix Table 2).

Appendix Table 2 Standard error to achieve a particular detectable difference (multiple) in the population level pre and post construction at various levels of alpha and beta

Alpha	0.05	0.05	0.05	0.10	0.10	0.10
Beta	0.10	0.20	0.30	0.10	0.20	0.30
Detectable difference(multiple)						
0.67 / 1.5	0.13	0.14	0.16	0.14	0.16	0.19
0.50 / 2.0	0.21	0.25	0.28	0.24	0.28	0.32
0.40 / 2.5	0.28	0.33	0.37	0.31	0.37	0.42
0.33 / 3.0	0.34	0.39	0.44	0.38	0.44	0.51
0.29 / 3.5	0.39	0.45	0.50	0.43	0.50	0.58
0.25 / 4.0	0.43	0.49	0.56	0.47	0.56	0.64

The multiple column contains two numbers because the standard error would be the same whether the population halved or doubled its size pre construction.

Assessment of required sampling effort

This will depend on the method being used and whether historic data exists to make comparisons. The issues can become quite complex and only relatively simple cases with temporal comparisons at one site where historic data are available are given as examples below. Where things become more complex, for example temporal comparisons involving more than one site where no historic data is available, then the statisticians in the National Salmon & Trout Centre should be consulted.

Examples of temporal comparisons involving one site where historic data are available.

The method proves a quantitative assessment of effectiveness and involves a comparison of the population, catch and/or the number of redds, pre and post construction of a fish pass.

The variance of the minimum detectable difference can be calculated as follows (Note: in all calculations the variance is the variance of the data following transformation by using logarithms (Log_e or Log_{10}):

$$V(X) = (V_t + (V_r + V_e)/n)\ (1/M_2 + 1/M_1) \qquad \text{equation *2}$$

Where:

V(X) = variance of the minimum detectable difference pre and post construction as a multiple of the pre construction level

V_t = temporal variance

V_r = random variance

V_e = variance associated with measurement error

M_n = number of years of data pre construction (1) and post construction (2)

n = number of sites

Details on how the various sources of variance can be determined can be found in R&D Note 292 (Wyatt and Lacey, 1994).

The standard error is estimated using:

$$SE(X) = \sqrt{V(X)} \qquad \text{equation *3}$$

And 95% confidence intervals calculated by doubling the standard error:

$$\text{Confidence limits} = 2SE(X) = 2\sqrt{V(X)} \qquad \text{equation *4}$$

A Worked Example using Catch Data

Appendix Table 3 contains catch-data from a hypothetical fishery. In this example it was not possible to identify the various components of the total variance and the variance calculated represents the combination of all three, ie (V_t +(V_r+V_e)/n).

Appendix Table 3 Ten years of catch data from a hypothetical fishery (pre construction)

Year	1	2	3	4	5	6	7	8	9	10	Var.
Catch	267	139	304	252	342	511	332	207	747	938	
Log_e Catch	5.587	4.934	5.717	5.529	5.835	6.236	5.805	5.333	6.616	6.844	0.3356

The minimum detectable difference in population level pre and post fish pass construction can be determined by substituting the variance pre construction (0.3356) into equation *3. It is then possible to estimate the standard error for the minimum detectable difference for various time periods post construction.

Appendix Table 4 Standard error for the minimum detectable differences in the population level pre and post construction for different periods of study post construction

Years Post construction (M_2)	Standard Error
1	0.61
2	0.45
3	0.38
5	0.32
7	0.29
10	0.26

These standard errors can then be compared with those calculated in Table IV.ii. It is then evident that with only two years post construction sampling the increase in population level pre and post construction would have to be at least 3.5 times the pre construction level to be regarded as significantly different for $\alpha = 0.05$, $\beta = 0.20$, or 3.0 times pre construction level for $\alpha = 0.10$, $\beta = 0.20$.

Alternatively, if post construction sampling was carried out for 10 years, the minimum detectable difference in the population would be an approximate 2 fold increase (or decrease) in the size of the population pre construction $\alpha = 0.05$, $\beta = 0.20$.

A worked example using survey data

In many instances there is no information on variance of the population available. In this case information needs to be taken from a different river, ideally as close as possible in terms of its physical and biological characteristics. Appendix Table 5 contains the components of variance for two age classes of trout from two systems, one in the upper reaches (Lledr) and the other a small stream close to the mouth (Nant-y-Goran).

Appendix Table 5 Components of total variance for two rivers (Lledr and the Nant-y-Goran) for two age-classes of trout. (Spatial variance, though not required in the analysis has been included for completeness)

Variance	Lledr O+ trout	Lledr >O+ trout	Goran O+ trout	Goran >O+trout
Spatial (V_s)	0.068	1.151	0.170	0.216
Temporal (V_t)	0.173	0.103	0.251	0.224
Random (V_r)	0.529	0.379	0.222	0.350
Measurement (V_e)	0.011	0.008	0.011	0.008

Using the data from the Nant-y-Goran O+ trout, as an example, it is possible estimate the population difference which could be detected. To do this V_t and V_e are substituted into equation *6 and the number of sites sampled and the duration of the pre and post construction survey period varied until the required standard error is achieved.

However, it is evident from Table IV.v that random noise was significant and in some instances was the major component of the overall variance. Therefore it is important to evaluate the effect of including it in the monitoring programme. It is therefore suggested that the study should aim to determine whether there has been a change in the population throughout the reach affected. This would be based on a sub-sample (n) of the total number of sites available (N).

Using the Nant-y-Goran O+ trout data, including random error (V_r) and assuming 5 sites were sampled out of a potential of 100 sites, the standard error of the population shows a relatively small increase (Appendix XIV Table 6).

Appendix Table 6 Standard error for the minimum detectable difference in the population for various periods pre and post construction when 5 sites were sampled (n) out of 100 (N) sites

M_2 / M_1	1	2	3	5	7	10
1	0.77	0.67	0.63	0.60	0.58	0.57
2		0.54	0.50	0.45	0.44	0.42
3			0.44	0.40	0.38	0.36
5				0.34	0.32	0.30
7					0.29	0.27
10						0.24

However, in reality it is hoped that the installation of a fish pass would make a substantial difference to the population, possibly by an order of magnitude, thus reducing the duration of the sampling period. Of course, if the obstruction was impassable prior to the construction of the fish pass then a qualitative assessment would be adequate as only the presence of the fish would indicate that the fish pass was effective. Though a more intensive programme would be required if the benefits of constructing the pass were to be quantified.

Analysis of results

The standard error can then be calculated and compared with the aims of the study in a similar way as above using equation 3. Likewise the 95% confidence limits are obtained using equation 4.

Determining the efficiency of a pass - precision and confidence in the measure

Assessment of required precision

The size of the sample required to make an estimate of efficiency is dependent on both the precision with which the parameter is to be estimated, and the confidence with which the desired precision is to be achieved. Precision is generally referred to in proportional terms (±0.10). Associated with the desired precision, is the percentage confidence (C) with which the desired precision is to be achieved. For example, if a fish pass efficiency of 0.70 is to be determined with an error no greater than ±0.10 with 95% confidence, there is a 1 in 20 chance that the true efficiency will be outside the range 0.60 to 0.80.

The use of precision and confidence to develop a monitoring programme is outlined in section 10.5.1.

Assessment of required sampling effort

Estimates of fish pass efficiency to a given level of precision with C% confidence can be calculated using the following formula:

$$N = u^2 p(1-p)/\delta^2 \qquad \text{equation *5}$$

where:

N = number of fish to be marked and available to migrate (=AN_m)

p = prior estimate of fish pass efficiency

u = Standard Normal deviate corresponding to a cumulative probability of (100-C)/2

δ = desired level of precision

If prior information exists on the efficiency of a particular type of fish pass (p) this should be substituted into equation 5. If no information exists then a value 0.5 should be used. Using a prior estimation of efficiency avoids overestimating the sample size needed to determine efficiency for the required precision and confidence. For example, if the true proportion is known to be around 0.8 (i.e about 80% of fish successfully use the fish pass), then ignoring this information will prescribe a sample size nearly 50% greater than that calculated using the default value of 0.5, i.e. 61compared with 96 @ C = 95%, δ = 0.10.

The sample sizes needed to estimate efficiency at various levels of precision are presented, for three levels of confidence in Appendix Table 7. For example, a sample size of 166 fish is required to ensure with 99% confidence the estimated efficiency will be within ±0.10 of the true estimate.

Appendix Table 7 Sample size required in order to meet various levels of precision and confidence (value of u in brackets), assuming an estimate of fish pass efficiency (p) of 0.5

Confidence level	90% (u = 1.645)	95% (u = 1.960)	99% (u = 2.576)
Precision			
0.01	6765	9604	16590
0.05	271	384	664
0.10	67	96	166
0.20	17	24	42

It is suggested that the monitoring programme should aim to estimate the efficiency of the fish pass with an error no greater than ±0.10 with 90% confidence. **A sample size of 67 fish is required to achieve this** (note that this means having a determinable result from this number of fish, either positive or negative. For example, many more fish may need to be tagged in a tagging programme where tags are lost, fish are not seen again, they never approach the obstruction or pass, there are several components of the stock etc).

Analysis of results

Determination of confidence limits.

The upper and lower 95% confidence limits (CL) for the true efficiency can be determined as follows:

Upper 95% CL = $(n_p + 1)F_{v1',v2'}/(AN_m - n_p + (n_p + 1)F_{v1',v2'})$ equation *6

Lower 95% CL = $n_p / (n_p + (AN_m - n_p + 1)F_{v1,v2})$ equation *7

where:

$v1' = 2(n_p + 1)$

$v2' = 2(AN_m - n_p)$

$v1 = 2(AN_m - n_p + 1)$

$v2 = 2 n_p$

$F_{n1,n2}$ denotes the 5% point of the F distribution with n1 and n2 degrees of freedom. (For example, $F_{12,10} = 2.91$).

APPENDIX XV Symbols Used In The Text

The notation used is not unique; the same symbol may be used to denote more than one quantity or variable, but the context will make it clear which applies in a particular section of the manual

Symbol	Description
a	Height of baffles in a Super-active bottom baffle or Larinier fishway
A	Number of fish which die as a result of tagging and handling
b	Weir width
b	Notch or slot width
b	The open width in an Alaskan A Denil fish pass
B	Width of pass (Ice Harbour)
C	Percentage confidence with which a desired precision is to be achieved
C_d	Coefficient of discharge
d	Increase in fish population following pass construction
D	Distance travelled by swimming fish
DH	Head drop between pools in a fish pass
DH_{Equiv}	Equivalent difference in head (estimated figure used to help calculate power input to a pool from a flight of Denil pass)
D_m	Mean depth of fish pass pool
e	Free gap between bars (of a fish trap, or screen)
E	Estimated fish pass efficiency (%)

Symbol	Description
E	Total energy store
F	A fitness ratio (maximum of depth or width)
g	Acceleration due to gravity (ms^{-1})
h	Mean depth in pass from bed (Plane Denil,)
h	Gauged head at gauging weir
h	Mean depth in pass – depth above bottom baffle (Fatou, Larinier)
h	Water head or depth on a weir or in a notch
h_a	Operating head on a baffle fishway (difference in level between the effective invert of the pass and the water level upstream before it accelerates towards the pass)
h_r	Water depth over concrete invert on which baffles are set in baffle pass (difference in level between the concrete invert and the water level upstream before it accelerates towards the pass)
H_a	Alternative hypothesis
H_o	Null hypothesis
H1	Depth of water in a vertical slot or deep notch (upstream side)
H2	Depth of water in a vertical slot or deep notch (downstream side)
K	Discharge reduction coefficient (induced by submergence)
L	Length of fish
L	Length of pool in fish pass
L	Standard length of fish (snout to caudal peduncle)
L	Width of channel in a baffle fishway (note single unit width in the case of a Super-active baffle or Larinier fishway)

Symbol	Description
M	Free gap in mesh or bar screens
M_n	Number of years data pre construction(1) and post construction(2)
n	Number of fish that actually ascend a fish pass
n	Number of sites
n_p	Number of marked fish that migrate through pass
N	Number of fish to be marked
N	Available stock of fish to go through pass
N	Number of juxtaposed units of Super-active baffle or Larinier pass
N	Number of potential sites
N_m	Number of marked fish
p	Density of water
p	Prior estimate of fish pass efficiency
P	Weir height (gauging weir)
PE	Potential energy entering fish pass pool per second
P_c	Chemical power
P_v	Power dissipation per unit volume or power density
P_r	Power from oxygen uptake
P1	Fish population pre pass construction
P2	Fish population post pass construction

Symbol	Description
q	Discharge in Denil pass
q	Unitary discharge per metre width of pass Larinier
q*	Dimensionless characteristic of discharge (unitary discharge per metre width)
Q	Discharge
Q_d	Discharge through a free flowing notch
Q_n	Discharge through a moderately drowned notch or slot (H1-DH/H1 <0.9)
Q*	Dimensionless characteristic of discharge (total discharge)
u	Standard normal deviate
s	Slope as a decimal fraction of 1
S	Cross-sectional area of orifice in pool and orifice pass
t	Muscle twitch contraction time
T	Muscle temperature
t_m	Endurance time, fish swimming
U	Maximum swimming speed for fish
v	Mean water velocity in a baffle fishway
V*	Dimensionless velocity in Denil pass
V	Estimated average exit velocity
V	Mean water velocity in baffle fishway
V	Volume of receiving pool in fish pass

Symbol	Description
V	Water velocity
V_e	Variance associated with measurement error
V_r	Random variance
V_t	Temporal variance
$V(X)$	Variance of the minimum detectable difference pre and post construction as a multiple of the pre construction level
W	Width of pool in fish pass
y_o	Depth of water above the invert (bottom baffle) of an Alaskan A fishway
Z	Distance as measured downstream from crest of gauging Weir
α	Level of significance
β	Probability
δ	Desired level of precision

APPENDIX XVI Draft Guidance Note: Eel passes at Gauging Structures

GUIDANCE NOTE

Installation of eel passes at River Flow Gauging Structures

The Eels (England and Wales) Regulations 2009 require that all obstructions that may impede the passage of eels have eel passes fitted. This is mandatory for both new and legacy structures, including gauging structures. The Regulations also apply to the maintenance or alteration of the structure and stipulate that the 'responsible person' must install and maintain the pass at their own cost.

Currently an asset matrix tool is being trialled to prioritize the roll-out of eel passes to Environment Agency owned structures.

The 'Eels (England and Wales) Regulations 2009' are available at:

http://www.opsi.gov.uk/si/si2009/pdf/uksi_20093344_en.pdf

National Fisheries and Hydrometry and Telemetry (H&T) functions have agreed the following guidance on the type of eel pass that is acceptable for installation at river flow measurement structures. They are divided into two categories - non-invasive and invasive eel passes.

Non-invasive eel pass

Definition: An eel pass that is located above and beyond the area bounded by the wing walls of a gauging structure.

These will be pipe or channel "up and over" type passes with elver-friendly substrate and a pumped flow. Suitable design solutions are already available. Point of contact for design type is Andy Don. Contact point for head office fisheries is Greg Armstrong, and for head office H&T is Richard Iredale.

General design principles

1. Both entrance and exit need to be sited in a manner that is acceptable for eel passage[1] while not compromising the performance of the gauging structure[2]. The lower entrance to the pass should be placed downstream of the end of the gauging weir wing wall. For hydrometric reasons, the eel pass should be fed by water pumped from downstream of the structure wherever possible.
2. The pump should abstract no more than 0.5 litres of flow / second[3]. This assumes that at least half of the 0.5 litre per second is discharged back downstream. Less than half to be discharged upstream of the structure.

3. Such passes can only be installed where minimum flow of the watercourse exceeds 25 litres/second.
4. The siting of the pass entrance and exit should be near the margins of the stream and not mid – channel.
5. At a site where a high flow rating extends beyond the top of the wing walls, the H&T team will need to consider the impact of the eel pass on that high flow rating.
6. Agreement will need to be achieved between local fisheries and H&T teams on the design of the eel pass.
7. The H&T team can object to the installation of an eel pass if it considers it has justifiable reasons. Adjudication of disputes will be resolved by the Regional H&T Client Panel.

Notes

[1] Near the toe of the obstruction at the d/s; at the u/s where migrants are safe from risk of wash-back

[2] Avoids snagging debris or interfering with flow lines

[3] Experience has shown that if correctly sited eels will find a very small attraction flow. The nominated flow is sufficient for a bristle pass 200 mm wide that will allow thousands of eels to pass per night. The pump only needs to be operating from dusk till dawn. Key months for use of pass: April-September with some Regional variation

The agreement between Fisheries and H&T will principally cover the design requirements but will also cover -

- ✓ Health and safety including public access issues at the site.
- ✓ Electrical issues around any pump installation. Every effort should be made to use 'green energy' where practicable for powering the pump. Where possible pumps should be non mains powered.
- ✓ The local fisheries department will own the eel pass and be responsible for its maintenance.

Essential elements of the eel pass design include:

- ✓ Covering the channel to prevent desiccation and predation (desiccation includes, at night time, protection from prevailing winds)
- ✓ Capacity to fit monitoring equipment either as part of the installation or retrospectively e.g. CCTV/webcam
- ✓ Suitable eel substrate choice for the site.

<u>Invasive eel pass</u>

Definition -Eel passes that are located within the area bounded by the wing walls of a gauging structure

Two methods are approved.

1. Pipe or channel "up and over" type passes with elver-friendly substrate and a pumped flow
2. Vertical bristle board eel passes.

1. Pipe or channel "up and over" type passes

These will be pipe or channel "up and over" type passes with elver-friendly substrate and a pumped flow but whose layout and configuration brings it within the area bounded by the gauging structure's wing walls at some point. Agreement will need to be achieved between both local and national Fisheries and H&T functions Suitable design solutions are already available. Point of contact for design type is Andy Don. Contact point for head office fisheries is Greg Armstrong, and for head office H&T is Richard Iredale.

General design principles

The same general design principles and requirements set out above for Non Invasive eel passes are to be followed with the addition of the following -

1. Passes within the walls of a flow gauging weir may be acceptable at some sites if the entire installation is mounted above the level of modular limit for the weir.
2. Where high flows need to be accurately gauged, passes mounted in the weir-channel at high level are not acceptable
3. In rivers where trash and debris could be a significant problem, eel passes mounted within the gauging channel wing wall will be especially vulnerable to damage during high flow events and should be avoided where possible.

2. Vertical bristle board eel passes on crump weirs

Vertical board eel passes are designed to be installed on crump type weirs. The eel pass is constructed of boards that are supplied in 1mt long and 0.4m wide sections with bristle tufts 70mm long spaced at 30mm intervals set on a backing board 10mm thick. They are mounted vertically along one side of the crump weir adjacent to the wing wall.

General design principles

1. The base of the board will make a smooth joint with the upstream and downstream slopes of the crump weir.
2. The boards shall run parallel to the wingwall and be mounted so that the end of the bristle touches the wingwall and that the outer face of the backing board is set 80mm out from the wingwall.
3. The board shall extend downstream sufficiently far enough to ensure that the end of the board is always below the lowest downstream water level expected at the site. This would normally be at or beyond where the downstream 1 in 5 slope of the crump weir terminates.
4. The board shall extend sufficiently far enough upstream to at least the point where the upstream slope of the crump meets the river bed. Where possible it is desirable to extend the board upstream as far as possible. In practical terms this is usually restricted to where the wingwall return curves back into the bank. It is important not to impede the stilling well inlet pipe.
5. The board shall extend to the top of the wingwall or 1.2m above the weir crest which ever is the lesser.
6. The outer face of the board will be smooth with no external fixings or fastenings protruding into to the flow of the river.
7. It should be mounted in such a manner that it can be taken off for cleaning if required.
8. The boards can only be installed on crump weirs that are wider than 4mts in width. The installation ofthe board has the effect of reducing the flow calculated over a 4m wide weir of between 1.2 to 1.5%. This reduction in flow becomes less on wider weirs.
9. On crump weirs between 2m and 4 m wide, boards with 30mm bristles and spaced at 30mm may be installed. This gives the same % reduction in flow as item 8 above.
10. Boards cannot be installed on weirs narrower than 2m.