CHAPTER 4

LOCATION OF FISHWAYS

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1. ATTRACTIVITY OF FISH PASSAGE FACILITIES

In order for a fishway to be effective it is necessary for the migratory fish to find the entrance (fish entrance, *i.e.* the downstream end of the fishpass) with as little delay as possible. The width of the entrance is small in proportion to the overall width of the obstacle, and its flow represents only a limited fraction of the total flow on the river. The only active stimulus used to guide the fish towards the entrance is the flow pattern at the obstruction.

The attractivity of a fishway is linked to its location in relation to the obstruction, and particularly to the location of its entrance(s) and the hydrodynamic conditions (flow discharges, velocities and flow patterns) in the vicinity of the entrance(s). The entrance must neither be masked by the turbulence coming from turbines or from the spillway, nor by recirculating zones, nor static water.

The problem of fishway attractivity differs depending on which species are being considered. With diadromous species the aim is to attract ***all the fish***, or at least the greatest possible number of those which reach the obstruction, ***without delaying*** their migration in any way. For riverine species, for example cyprinids, it is usually sufficient to re-establish, to a certain extent, ***the longitudinal connectivity*** of the river, *i.e.* the communication between downstream and upstream stocks in order to avoid isolation of populations. In this case more attention is paid to the “comfort” of fish in the fishway (low velocities and turbulence level) rather than their attraction to it (high flow discharge in the facility).

2. FACTORS INFLUENCING THE CHOICE OF LOCATION OF A FISHWAY

The configuration of an obstruction to migration (arrangement of the spillway, power station, water intake, operation of plant, etc.) can vary infinitely. The following examples of typical situations illustrate some of the principles that should guide the designer in the choice of the location of a fishway and of its entrance.

At an existing dam, or a natural obstruction such as rapids or a waterfall, on a river in which there is still a population of migrating fish, it is possible to observe and record the behaviour of the fish at the obstruction. Their migratory route, the areas where they congregate and the points on the dam where they attempt to pass can be identified. This information will then help the designer in the choice of the location for the fishway entrance.

Where any new obstruction is being designed, or on a watercourse where migrating species have disappeared but restoration has been planned, it is only possible to make

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suppositions about the behaviour of the fish and the experience of the designer becomes of paramount importance.

A fishway sited ***on or near the riverbank*** is usually preferable to a location in the middle of the obstruction, as fish (especially salmonids and shad) tend to migrate along the banks rather than in the centre of the river. This behaviour is more pronounced during high flow when greater advantage can be taken of lower velocities near the banks.

Generally, fish tend to travel **as far upstream as possible**, until they are prevented from passing further by either a fall or water velocities which are so high that they are impossible to pass, or else by extreme turbulence.

It is therefore advisable to install the entrance to the fishway as close as possible to the most upstream point or line reached by the migrating fish.

A fishway on an obstruction which is at an marked angle to the direction of flow of the watercourse should be positioned at the most upstream point of the barrier (Figure 1a) wherever possible.

The location of the fishways in Figures 1b and 1c are incorrect; the first because the entrance of the fishway is too far downstream of the weir, and the second because it is located in the downstream angle of the weir.

In the case of a chevron shaped weir, installing the fishway at the most upstream point, *i.e.* the part in the centre of the river, seems to be the most favourable from a strictly biological point of view. However, in some cases this may mean that it is difficult, or even impossible, to arrange for access and therefore monitoring or maintenance (Figure 1d).

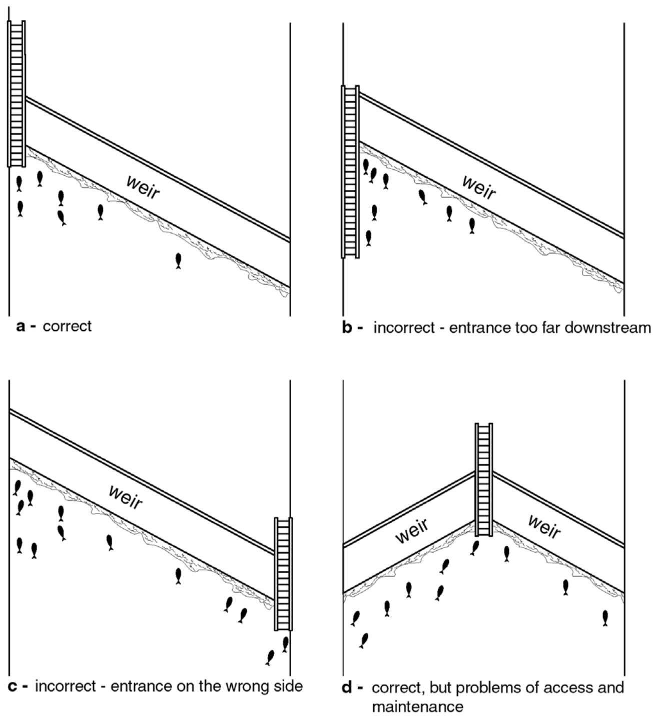


Figure 1: Schematic plans illustrating the installation of a fishway on an oblique weir.

Where the obstruction is at right angles to the banks the fishway should be located on one side or the other. The particular constraints of the site should be taken into account including the flow patterns, and the topography of the bed immediately downstream from the obstruction, *e.g.* the presence of pools, of a predominant flow channel, etc. (Figure 2a). However, on a wide obstruction it is usually advisable to install a fish passage facility on both sides (Figure 2b).

In some cases it is possible to modify the morphology of the riverbed downstream of the obstruction in order to direct fish towards the fishway. For example, relatively high rip-rap protection might be installed across the central section of the watercourse and for a certain distance immediately downstream of the installation, while at the same time creating two deeper side channels. In this way the fish are channelled towards the fish passage facilities (Figure 2c).

The inherent constraints of the site may result in placing the entrance of the fishway relatively far downstream of the obstruction (in the case of a very long natural bypass channel for example, Figure 2d). In such a case, in order to compensate for the unfavourable location of the fish entrance, it is strongly recommended that the flow through the facility be increased so that it represents a very significant fraction of the discharge of the river during the migration period.

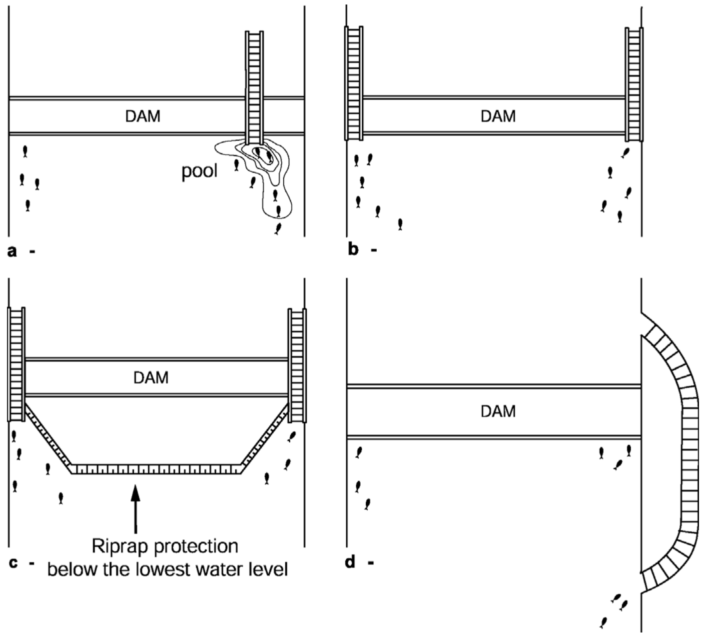


Figure 2: Plan illustrating the installation of a fishway on a weir that is at right angles to the direction of river flow.

In the case of a hydroelectric scheme, where all the flow discharge passes through the turbines, migrating fish are generally attracted to the turbine draft tubes. The entrance to the fishway must therefore be adjacent to the powerhouse, preferably in the river bank (Figures 3a and 3b).

The entrance to the fishway must be located at the furthest point upstream in the immediate area where fish are congregating downstream of the obstruction. It should not be positioned either in the centre of the river or else too far downstream (Figure 3d).

In the case of a large power plant equipped with several turbines it may be possible to collect the fish across the full width of the powerhouse using a collection gallery with several entrances located above the turbine draft tubes. This must be done where new facilities are being constructed. The entrances are generally equipped with automatically operated gates that are used as overflow weirs. The gates adjust to maintain a specified difference in water level between the collection gallery and the tailrace, so that the velocity at the entrance stays more or less constant, irrespective of the water level downstream. The main entrances must be positioned at either end of the powerhouse (Figure 4), and secondary entrances can be situated between the different turbines, where the turbulence level is generally lower. It is however preferable not to have too many entrances as experience has shown that where the number is too large there is a risk that fish entering the gallery by one entrance will swim out of it at another.

In the case of a wide river it may be necessary to provide not only several entrances but also more than one fishway because a single pass cannot be expected to attract fish from the opposite bank. Migrating fish may arrive either at the bank where the powerhouse is located or at the opposite bank where the spillway is discharging and it is therefore advisable to plan two separate fishways, each with one or more entrances (Figure 3c).

When the plant is on a diversion canal it is often difficult to decide whether it is preferable to install the fishway at the dam or at the powerhouse. A careful study must be made of water flow regimes at each location and of plant operation during the migrating period. Fish can be attracted to the continuous flow from power generation or else to the dam in the case of frequent spills during the migration period. Experience has shown that it is often essential to provide two separate fishways. At times of low flow, most of the fish will be attracted to the turbines, while during periods of higher flow, a significant percentage of migrators can congregate below the dam. Should the diversion be very long, the fish will be much more likely to become trapped in one of the arms (tailrace or river), and have a very small chance of finding a single fishway

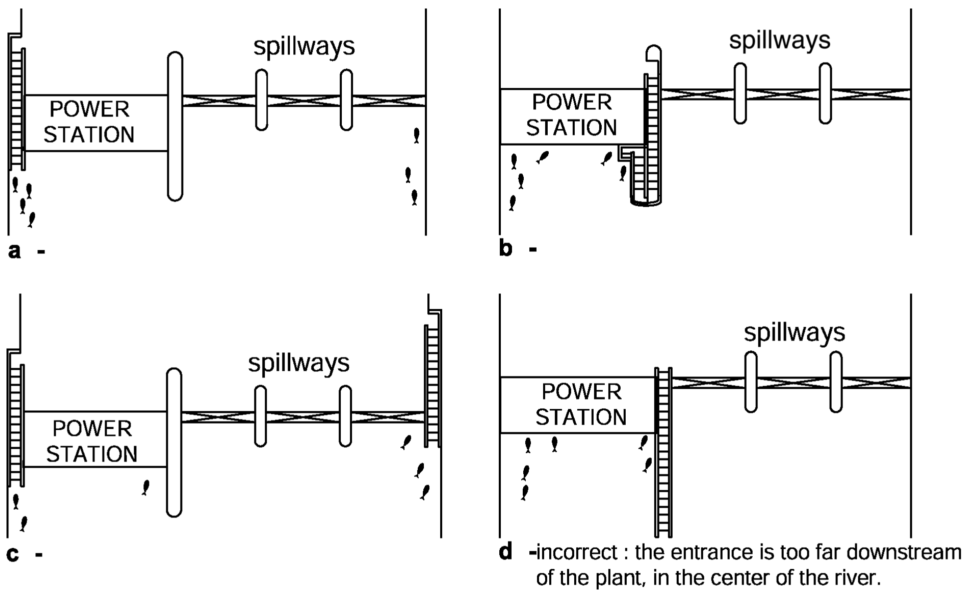


Figure 3: Installation of a fishway at a hydroelectric power plant.

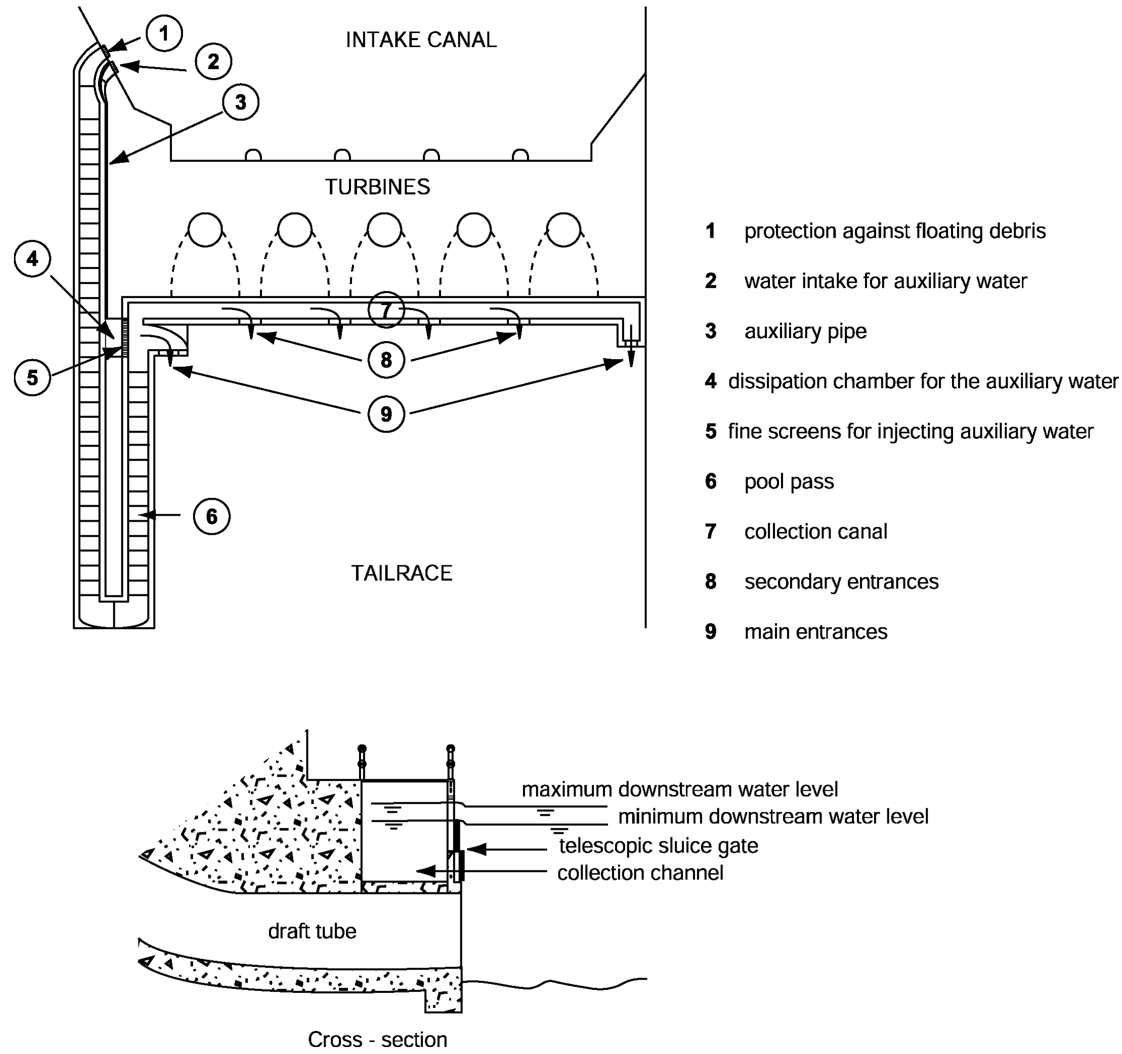


Figure 4: Schematic plan of a collection gallery with multiple entrances situated above the draft tubes of the turbines.

The use of electric screens has be envisaged. A few of them have been installed in France as an alternative to the construction of fishways at hydroelectric powerhouses for preventing fish from entering the tailrace, thus ensuring that they remain in the original river channel. Their efficiency was not evident, and their installation has even been considered to be more detrimental than useful on short tailraces. These barriers are still in an experimental stage and, in any case, their use does not preclude the need for a significant ecological flow to attract fish in the bypassed river.

It is not always possible to install a fishway at the powerhouse, particularly when the water is conducted to the turbines in a very long (*e.g.* several km) pressurised conduit or tunnel. The effective performance of a fish passage facility situated at the dam depends entirely, in such cases, on a continuously significant ecological flow in the part of the river which has been bypassed.

The siting of the pass entrance at an obstruction is not the only factor to be taken into account when positioning a fishway. The exit of the pass (exit for the fish, *i.e.* upstream end of the fishway) should not be situated in a fast flowing zone near a spillway, weir or sluice, where there is a risk of the fish being swept back downstream. Furthermore it should not be situated in a static area, or in a recirculation zone where the fish could become trapped. For preference, the exit should be located at the bank in an area of moderate downstream velocity.

Positioning fishways at or near the bank line is usually preferable to positioning them in the middle of an obstruction. Not just because migrating fish generally tend to move along the banks, but also to facilitate access for inspection, monitoring, and maintenance.

Fishways should not be installed in areas where natural silting or sedimentation is occurring, particularly on the inside of bends.

3. HYDRAULIC CONDITIONS AT THE ENTRANCE TO THE fishway

3.1 Flow patterns

The flow leaving the fishway should be detectable by the fish at the greatest possible distance from the entrance. The attractivity will depend on the direction and the momentum (discharge x velocity) of the entrance jet. The greater the momentum of the jet, the further the entrance jet penetrates the tailwater and the more attractive is the entrance of the fishpass.

It is essential that the jet of water leaving the pass is neither masked by other currents or cross-currents, nor by flow patterns in the tailwater with which it cannot compete, such as hydraulic jumps or eddies. The jet leaving the pass must remain distinct in the channel downstream.

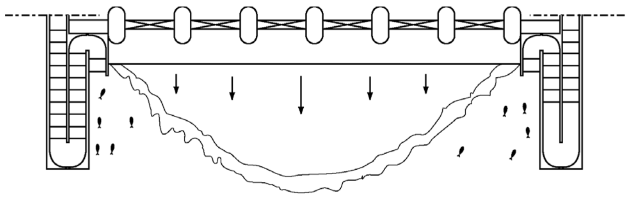
At the foot of the ***turbines*** *or* ***spillway*,** the jet leaving the fish pass must not be directed perpendicularly to the general axis of the channel: such a jet will be broken up immediately and not persist very far downstream. On the contrary, the flow must be directed parallel to or only at a slight angle to the direction of the flow. Directing the exit flow at right angles to the direction of the flow axis should only be considered if the entrance to the fishway is located away from the main flow for some reason, or else in a low velocity zone.

At the ***spillway***, it is sometimes possible to adjust the flow through the control structures to improve the attraction of the fishways.

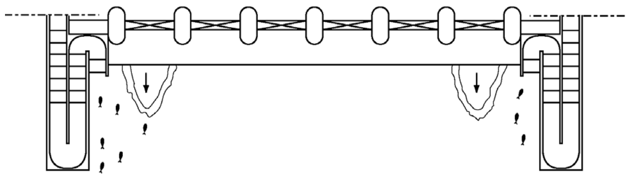
In periods of high discharge, when the full spillway capacity is not required, the opening of the control structures can be reduced gradually from the centre towards the banks. This will have the effect of creating a “barrier” of turbulence and high velocities thus guiding the fish towards the entrance to the fishway (Figure 5a).

When the spilled discharge is low, spilling should be concentrated on the sides nearest to the fishways (Figure 5d). The use of central gates, which would attract the fish away from the fishways, should be avoided.

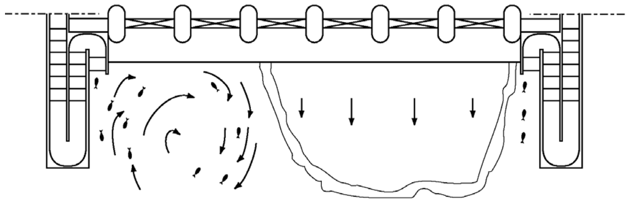
In periods of high flow, no sluice gates should be left closed between open gates, as this would create a static water zone which could trap the fish (Figure 5d). Similarly it would be advisable not to reduce the discharge too much at the bank in order not to create a recirculation eddy which would cause an upstream current near the entrance of the fishway and which could totally mask the entrance of the pass (Figure 5c).



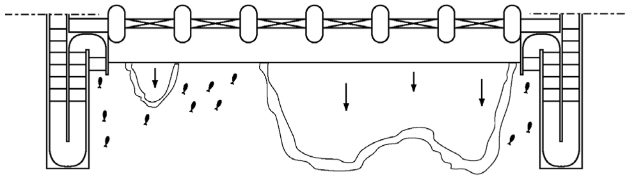
a - Optimum discharge arrangement during high flow periods



b - Optimum discharge arrangement during low flow periods



c - Discharge arrangement to be avoided (recirculation eddy)



d - Discharge arrangement to be avoided : static water zone next to a fast flowing zone

Figure 5: General guidelines for adjusting spill distribution to improve fish passage.

Deciding upon the best position for fishway entrances where turbines are involved is rarely obvious. The hydraulic barrier to the fish may be at the exit of the draft tubes, upstream of a zone of "boiling" water engendered by the large turbulent eddies resulting from turbine discharges. On the other hand when the residual energy from the water leaving the turbine is significant, the hydraulic barrier to the fish may occur further downstream. Finally, the location of the hydraulic barrier can vary within the same site, depending upon which specific turbines are in use at any one time. The jet leaving the fishway must not discharge into the large and unstable, turbulence patterns issuing from the turbines. These flow patterns will mask the fish pass jet.

When, at a particular site, the blockage zones cannot be clearly identified or are likely to vary depending on plant operating conditions, the correct location of the fish pass entrances may not be obvious. In such cases the efficiency of a fishway will be considerably improved by installing **several entrances** at points which appear to be the most favourable.

The problem is extremely complicated, and difficult to solve, where the fish passage facility is intended for several species whose swimming capabilities and migratory behaviour are very different, or sometimes even unknown. If the pass is intended primarily for migratory salmonids then the entrance should be as far upstream as possible and relatively close to the turbines. On the other hand, this may not be favourable for small riverine species that do not have the same swimming ability. For these species it is better to have the entrance to the fishway further downstream, in a calmer and less turbulent zone. This requires defining the **target species** clearly at the outset of the project.

The entrance to the fishway should not be masked by a **recirculation zone,** in which the fish may become trapped. If this is the case, the zone should be suppressed by installing riprap protection, or its effect at least reduced by well-placed groynes (Figure 6).

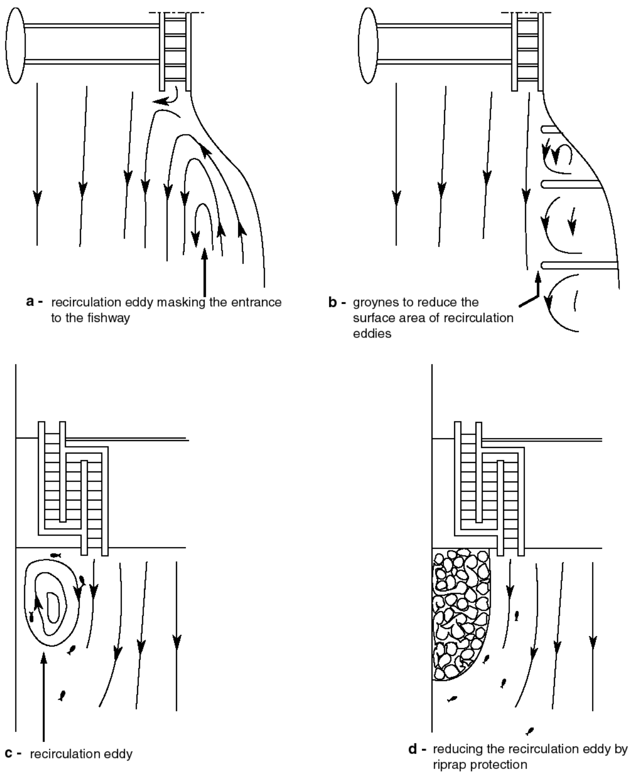


Figure 6: Plan illustrating the principle of reducing recirculation eddies with groynes and riprap protection.

3.2 Water velocity

It is essential to create sufficiently high velocities at the entrance of fishways. They must, however, remain compatible with the passage of all the migrating species involved. For most species, a speed of the order of 1m/s would normally be the minimum at the entrance to the fishway. The optimal speed for salmonids and large migrants is of the order of 2 m/s to 2.4 m/s, which corresponds to a head drop of 0.2-0.3 m at the entrance.

Although water velocity should remain high, the occurrence of a hydraulic jump must be prevented. Restriction of the cross-section of the flow is generally used to create any acceleration required at the entrance. In this respect it must be ensured that the water depth immediately downstream from the entrance is adequate. Irrespective of which type of fishway is provided, there must be a pool of sufficient depth at the foot of the facility to allow the fish to rest without any difficulty.

Particular care must be taken when designing the entrance at the project planning stage, particularly on major rivers. It must be verified that the velocity of the flow at the entrance(s) is sufficiently high for all of the various water levels that may occur downstream of the facility during the migration period, particularly those during high water.

When the downstream water level rises as a result of increased discharge in the river the cross-section at the fishway entrance increases, and, as a consequence, unless discharge in the pass increases considerably, then velocity at the entrance decreases and with it the attractivity of the fishway.

Generally, sufficient entrance velocity can be maintained either by manipulating conditions in the fishway or else at the fishway entrance. The cross-section at the entrance may be adjusted or, alternatively, the discharge in the fishway can be varied, depending upon the water level downstream of the obstruction.

The most common type of device installed to regulate the velocity at the entrance consists of a movable flat gate which is adjusted to maintain a constant and pre-determined difference in water levels between the fishway and the tailwater (Figure 7). This makes it necessary to install two depth gauges, one upstream from the gate in the fishway and the other downstream close to the entrance of the pass. When variations in level are significant it may be advisable to install a telescopic gate with several sections.

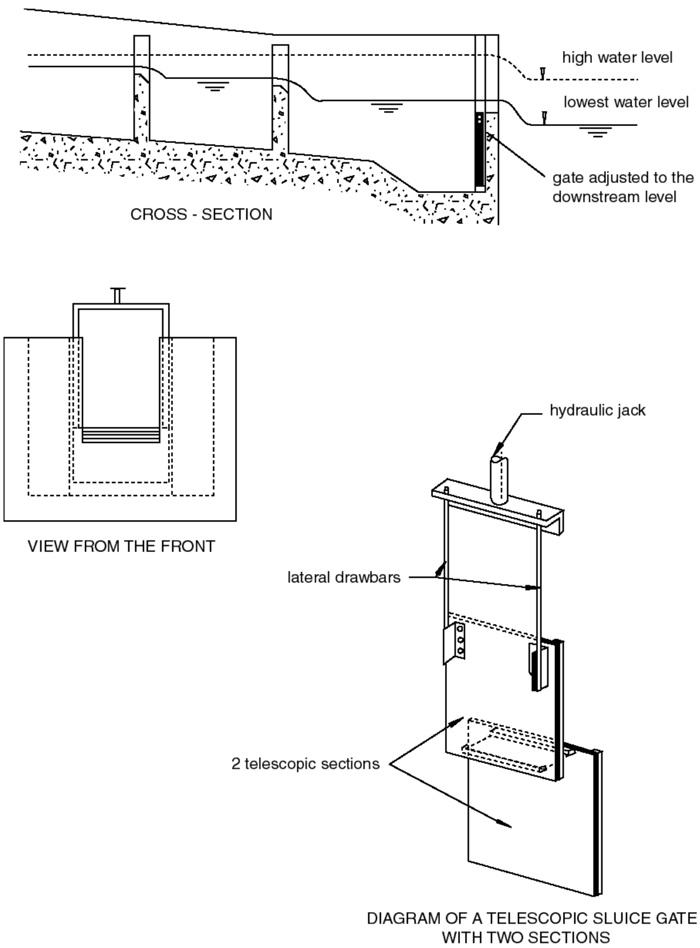


Figure 7: Regulating sluice gate at a fishway entrance.

At more modest plants, or those at which there are less frequent fluctuations in the water levels upstream and downstream, regulation of the velocity may be effected by means of a manually operated sluice gate, or even more simply by stoplogs in a slot at the entrance.

Another solution in order to maintain a fairly high velocity is to vary the discharge through the facility in relation to the downstream level, thus making the installation of a moving part at the fishway entrance unnecessary.

All the above comments on the importance of the hydraulic conditions at the entrance to the fishway demonstrate the **absolute necessity of being fully aware of the range of water levels during the migration periods**, both upstream and downstream of the obstruction.

3.3 Discharge

The discharge through the fish passage facility must be sufficient to compete with the flow in the river during the migration period. It is difficult to give precise criteria, but generally the flow passing through the fishway must be approximately 1 to 5% of the competing flow. It is clear that the higher the percentage flow of the watercourse passing through the fishway, the greater the attraction of the pass will be. ***If the fish passage facility is not correctly positioned then a much greater discharge may be required for its operation***.

It is reasonably possible to direct a large fraction of the flow of the river through the fishway (sometimes more than 50% or perhaps even the entire flow) in the case of small rivers. However, this is not the case in large rivers where the mean flow can exceed several hundred m^3/s. It then becomes difficult, in terms of cost, to maintain a sufficient flow through the facility, particularly during high river discharges. On major French rivers such as the Garonne or the Dordogne (mean annual daily flow around several hundred m^3/s) an attraction flow of around 10% of the minimum flow of the river is used for the lowest design flows. These and between 1% and 1.5% of the highest design flows (generally around twice the mean annual daily flow) seem to be satisfactory for the fishways to work.

Generally, although it may be demonstrated that an increase in the attraction flow generally results in improved efficiency, it is very difficult to quantify the benefit at each site, either in terms of an increased percentage of migrants passing, or a reduction in the delay to migration. In fact two conditions are necessary. It is obvious that improved efficiency depends as well on the higher number of entrances, which itself depends on the increased availability of flow for the fishway.

3.4 Introduction of auxiliary flow into a fishway

When a large flow of water is needed to attract fish into a fishway (several m^3/s) only a fraction may be allowed through the fishway itself in order to limit the size and the cost of the facilities. The auxiliary flow needed for attraction is then introduced at low velocity, and with minimum aeration, either through screens in the downstream section of the pass, or else at the entrance itself. Screens are essential to prevent the fish from becoming trapped in the auxiliary flow rather than entering and using the pass. The clear opening of the screens must be sufficiently small to prevent fish from passing through and depends on the size of the smallest target species.

The auxiliary flow (or supplementary attraction flow) is generally fed by gravity after dissipation of the energy in a pool or a well. In large installations, it may be economical to pump attraction discharge from the tailwater at the required head, or to supply it from the forebay through one or more special small turbines.

There must be a pool upstream of the screens with sufficient volume to ensure sufficient dissipation of energy, and the most homogenous distribution possible of the auxiliary flow through the injection screens (with areas of no flow or negative flow minimised). The approximate volume of this pool may be calculated by taking a power dissipation per unit of pool volume of 1,000-1,500 watts/m^3. This pool is generally equipped with various devices (concrete baffles, staggered vertical beams or steel bars, etc.) to ensure the dissipation of the kinetic or potential energy of the water. It must be ensured that this flow is adequately de-gassed when it reaches the injection screens.

This auxiliary water can be added either through a diffuser in the bed of the pass or by a lateral diffuser (Figure 8). It is generally preferable to inject this water laterally in order to facilitate the maintenance of the screens. Experience has shown that it is not easy to clean horizontal screens on the bottom of the downstream part of the facility.

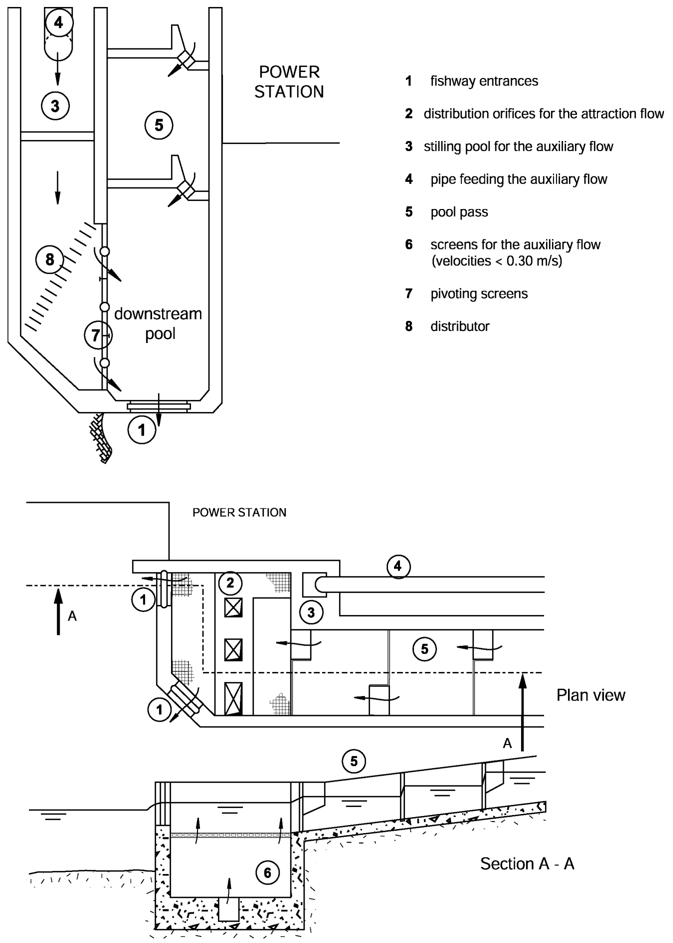


Figure 8: Schematic plans showing the principle of injecting auxiliary flow at a fishway entrance.

The **velocity** of the water through the screens installed at the exit from these diffusers must be sufficiently low (< 0.30-0.40 metre/second) in relation to the velocity in the pass, so that it does not affect the behaviour of the migrator. As far as possible these screens should also act as a guide towards the entrance of the pass. The free gap between the bars depends on the size of the fish likely to use the pass (30 mm clearance for salmon and shad, less for smaller fish).

It must be borne in mind that although the use of an auxiliary flow system can significantly reduce the construction costs of a fishway, this saving must be balanced against the increased maintenance costs associated with the screens, which must be kept clean. Maintenance of the screens can be facilitated by mounting them on small panels with vertical axles, which allow them to turn and thus to be cleaned by counter-current. Whenever maintenance of the screens is likely to be a problem (because of the isolated nature of the site for example or access difficulties), this solution should be avoided in favour of maximising the flow sent through the pass.

The upstream intake of the auxiliary flow is also generally fitted with a screen with spacing equal to, or smaller than that of the downstream injection screens. The screens on the largest installations are equipped with mechanical trash rakes.

There can be constraints at a particular site that make it necessary to locate the entrance of the fishway away from the main outflow from the plant. To increase fishway attractivity in such a case it is possible to use a part of the attraction flow, without the prior dissipation of its energy, to create a high velocity jet issued adjacent to the fishway entrance.

4. PROTECTION OF FISH PASSAGE FACILITIES

Fish passage facilities can be protected against floating debris using several of the methods classically employed on waterworks intakes. These include trash booms, coarse trash racks with sufficiently widely spaced bars (25-30 cm apart, to allow the passage of large migrating fish); masonry or concrete deflectors; even rows of rails, or sheet piles or posts upstream of the fish facility.

The protective screens are installed in an area where the normal velocity through the trash rack does not exceed 0.30-0.40 m/s in order to prevent the feed to the fishway becoming clogged too quickly. This generally necessitates the installation of a buffer pool upstream of the first traverse (in the case of a pool pass) or upstream of the first baffle (in the case of a Denil fishway). This area can also be used to install a fish trap to monitor the facility.

When designing a fish passage facility it is essential to take the hydraulic conditions in the vicinity of the exit into account, since these are likely to play a decisive role in the future maintenance of the pass. There should most definitely not be a recirculation area near to the exit. When the trash rack protecting the fishway is cleaned it is essential to be able to flush the debris (leaves, branches) downstream so that it does not return to block the screen again, which might be the case if it were trapped in a recirculation eddy.

On the other hand, the exit should not be in a excessively high velocity zone since while this situation is favourable for clearing debris it may also pose the risk of fish being swept back downstream when they emerge from the fishway.

It is generally preferable to site the exit of the fishway laterally in the forebay. Figure 9 shows examples of different types of protection for fish passage facilities.

Whatever type of protection is planned, it is necessary to ensure that the pass is easily accessible to facilitate maintenance and repairs. In this respect, as indicated previously, fishways situated on the bank are preferable to those located in the middle of the obstacle.

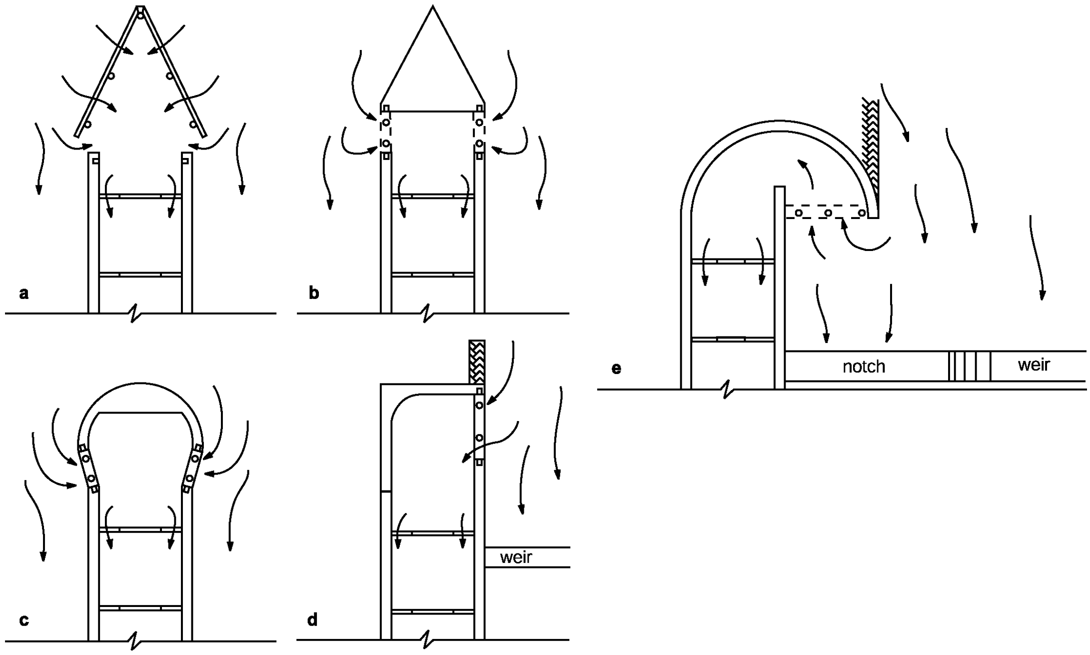


Figure 9: Schematic plans illustrating fishway protection.

Photo 1: Denil fishway at Kapekern on the river Léguer (Britanny). The fishway is installed in the upstream angle of the weir.

Photo 2: Fishway at Uxundoa weir (river Nivelle, Atlantic Pyrénées). The fishpass discharges at the foot of the weir, beyond the turbulence area created by the fall.

Photo 3: Fishway at Vichy dam (river Allier). The main entrance is close to the foot of the dam, immediately downstream of the turbulence zone created by the fall.

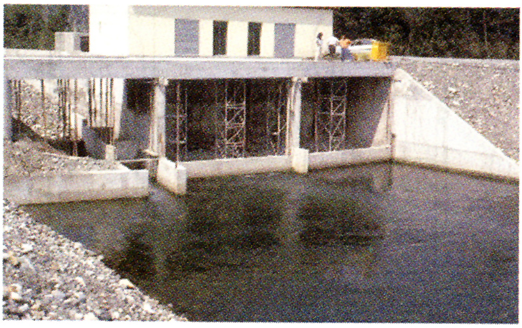


Photo 4: Fishway installed at a small power station at Pointis-Isnard on the river Garonne. The entrance to the fishway is close to the exit from the draft tubes of the turbines.

Photo 5: Natural bypass channel at Chatillon sur Lison (river Loue). The entrance is located in the upstream angle of the weir.

Photo 6: Example of bad location of an old fishway ; the entrance is located too far downstream of the turbines exit and the fishway discharge is too low.

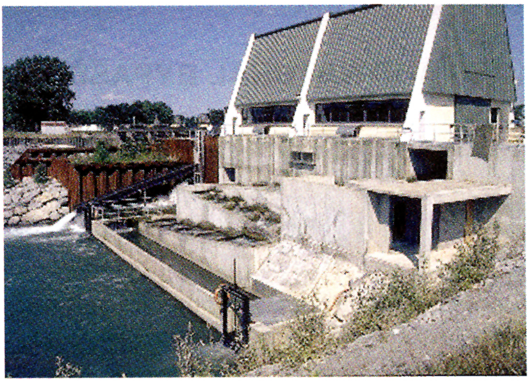


Photo 7: Collection gallery with two entrances at a small-scale power plant (Artix, river Gave de Pau). The vertical slot fish pass has been built above the draft tubes of the turbines.

Photo 8: Collection gallery with several entrances at Mactaquac on the St John River (New Brunswick, Canada).

Photo 9: Introduction of auxiliary water through lateral screens at Iffezheim fish pass (river Rhine). Auxiliary flow is supplied from forebay through a special turbine (fish pass discharge 1.2 m3/s, turbine discharge 11 m3/s).

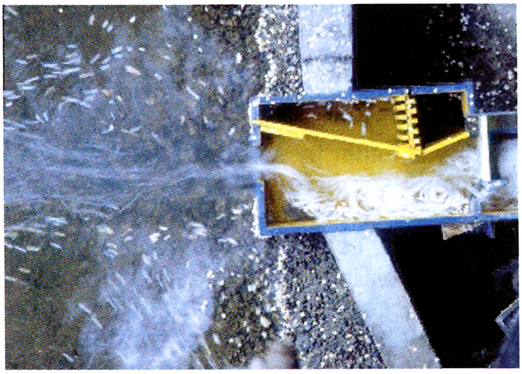


Photo 10: Hydraulic model showing the mean of injection of auxiliary flow at the entrance of a vertical slot fishway (Ramier power plant on the river Garonne).

Photo 11: Upstream protection of a pool fish pass (Beaudreix weir on the Gave de Pau). The fish exit is positioned laterally, the upstream protection wall is rounded.

Photo 12: Floating boom to deflect trash from a pool fish pass intake (Sarrancolin dam, river Neste, Pyrénées).