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CHAPTER 9

THE DESIGN OF FISHWAYS FOR SHAD

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1. INTRODUCTION

Until recent years most fish passage facilities in France had proved to be either totally inefficient or else had only a very low efficiency for Allis shad (*Alosa alosa*). The installation of dams on rivers with shad populations had almost always resulted in the species becoming rare in, or even disappearing from, the reaches above the dams. This phenomenon is not restricted to France. In 1923 a commissioner of the Bureau of Fisheries stated in a letter to the Federal Power Commission on the subject of American shad (*Alosa sapidissima*) “that it was very doubtful whether any shad would ascend a fishway of any description or any height”. Until 1955, the only facilities that were considered to be effective for this species on the North American continent were the two enormous fishways (around 10 m in width) at the Bonneville dam on the Columbia River. These fishways accounted for around 10% of the total cost of the hydroelectric power station (DALLEY, 1980).

It seems appropriate to integrate the experience in fish pass design acquired for both species of shad (*Alosa alosa* and *Alosa sapidissima*) in so far as all the observations made, both in France and North America, indicate that their migratory behaviour is very similar.

2. SWIMMING ABILITY AND MIGRATORY BEHAVIOUR OF THE SHAD

2.1. Swimming ability

While the shad is a good swimmer, it has a lesser ability than salmon or sea trout. Field observations show (CTGREF, 1981) that water velocities of around 2 m/s constitute a major difficulty for many of them when the distance to be passed is more than several tens of metres.

Burst speeds were estimated during observations at the St. Laurent-des-Eaux weir on the Loire (LITAUDON, 1985). At a temperature of 16-17°C speeds varying between 3.1 m/s and 4.7 m/s, depending on the individual, could be sustained for only a short period of time (around 6-7 seconds). The maximum swimming speeds, which the shad could only sustain for a few seconds, were estimated to be between 4.1 m/s and 6.1 m/s.

These figures are similar to those recorded for the American shad. Observations (WEAVER, 1965) were made on the distances swum by more than 8000 individuals in a channel around 30 m long, in which the velocity of the flow varied between 3.5 m/s and 4.15 m/s. Passage was voluntary and the fish were not handled at any time. Not one shad was able to pass through the complete length of the channel and the average distances attained by shad in their attempts to ascend the channel varied inversely with the velocity of the flow. Mean distances attained when the velocities in the channel were 3.5 m/s, 3.85 m/s and 4 m/s were 9 m, 7.1 m, and 5.7 m respectively, and this was under the most favourable temperature conditions (21°C). By comparison all the steelhead trout, whose swimming performance is comparable to that of Atlantic salmon, passed the full length of the channel without any problem. According to this data, the maximum swimming speed for the majority of shad varies between 4.3 m/s and 4.6 m/s, with 10% of the individual fish having burst speeds lower than 3.9 m/s or greater than 4.9 m/s.

Transposing the model proposed by BEACH (1984) from salmonids to shad (taking into account the size and morphology of shad), a range of curves was obtained for different temperature, which accorded well with observations made in the field. The maximum swimming speeds at 20°C would vary between 4.0 m/s and 5.4 m/s depending on the size of the individual, and the corresponding endurance would be between 5 and 16 seconds. At lower temperatures the maximum speed is considerably reduced, *e.g.* to between 3.5-4.3 m/s at 15°C. The upper limit of cruising speed would vary between 0.80 m/s and 1.4 m/s, depending on the length of the fish.

Velocities of around 3.5 m/s to 4 m/s over distances of a few metres represent obstacles that are difficult for shad to pass. A difference of around one metre between the upstream and downstream water levels at an obstruction is sufficient for these velocities to be reached. This means that even obstructions of a moderate height may constitute serious obstacles to shad migration, particularly if the flow is “plunging”, as will be further explained below.

As a rule of thumb, it is suggested that the maximum distance which can be covered by a shad is: less than 3 metres in a flow of 3.25 m/s; 5 metres in a flow of 3 m/s; and around 10-12 metres in a flow of 2.5 m/s. In optimal thermal conditions the same distances may be achieved when the quoted water velocities are increased by 1 m/s.

2.2 Migratory behaviour

Shad tend to move in the upper layer of the water column and hesitate to pass through submerged openings: surface passage must therefore be provided in the fishway.

Shad also **move in shoals,** which behaviour dictates that the fish passage facilities must also be as wide as possible to avoid breaking up these groups.

Trapping shad in too small a volume of water, even for a short period, may result in a high mortality rate.

Shad appear to need a definite current to orientate. In static or very turbulent water the species become disorientated. They seem to prefer laminar, streaming flow, even if it has a significant velocity. They appear to avoid very turbulent and/or aerated water zones wherever possible (eddies downstream of a plunge, hydraulic jump, boils and upwellings at the outlet of the draftubes of turbines). When in these areas they move and orientate with far more difficulty than salmonids.

Unlike most salmonids shad **do not leap**, but generally only pass obstructions by swimming. For this reason they have great difficulty in passing “plunging flows” in which they tend to become disorientated, positioning themselves with their heads facing downstream in the counter-current at the surface.

A number of observations have shown that shad are easily **trapped in corners,** and also in the induced recirculation zones caused by sudden expansions in the channel section of fish facilities. These observations were made both on the American shad in the United States, and on Allis shad in France (C.T.G.R.E.F., 1981). Consequently it is important to ensure that passage is provided along the walls and to minimise the volume of the recirculation zones wherever possible, while at the same time preventing the phenomenon of short-circuiting between pools which would adversely affect the hydraulic efficiency of the fishway.

The behaviour of the shad in fish passage facilities is characterised by frequent **fall-back activity**, which can result in the whole shoal moving back downstream when the fish find themselves trapped by particular currents. This can occur in an recirculation region with a vertical axis caused by a sudden transition of the flow section or a change in direction of the fishway, or in a recirculation region with a horizontal axis caused by a submerged orifice.

Visual observations at several sites, and also different radio-tracking studies, have shown that shad explore much less actively at the foot of obstructions than do salmonids. They are inclined to dwell in “comfortable” areas for a considerable time, thus slowing the overall rate of migration.

The shad also appears to be very sensitive to sudden changes in light. It is necessary to light underground sections of fishway and, more generally, to light any particularly dark zones or areas with dark shadows in the facility.

3. POOL FISHWAYS

Provided particular design criteria are followed, pool passes can be efficient for shad.

The flow in the pass must be “streaming” and not “plunging”, because the fish orientates itself in relation to the surface currents and does not jump.

There must be no deep submerged orifices, as shad tend to remain trapped in the counter-currents at the surface of the water column above the orifices. Some control sections with submerged orifices have had to be abandoned on the West Coast of the USA after they caused blockages and fish mortalities (MONK *et al*., 1989). Similar blockages of shad passage have also been observed in the pool control section upstream of the baffle fishway at Bazacle dam on the Garonne river (DARTIGUELONGUE, 1990).

The fish must be guaranteed passage **along the walls**, and central notches or slots must be avoided. At least one vertical slot or lateral notch must be provided, but it is best to provide one on each side of the facility.

As far as possible, the presence of large recirculation zones must be avoided because the fish tend to become trapped in them (Rainbow fishway on the Farmington River, Turners Falls on the Connecticut River, and Tuilières on the Dordogne). In particular this applies to pools where a change in the direction of the pass is effected since these generally have a larger volume and very particular flow patterns. Where these zones are difficult to eliminate it is possible to deny the fish access to them by using “lead” screens (DARTIGUELONGUE *et al.*, 1992).

Shad move in large shoals and it is necessary to ensure that the fishway does not break them up. Thus large pools and the maximum width of traverses possible should be used.

The notches or slots must have a minimum width of 0.45-0.50 m.

The pools must be sufficiently deep (minimum 1.20 m) with limited aeration and turbulence. The maximum volumetric power dissipation should be 150 watts/m^3.

Head drops between the pools should not exceed 0.30 m. It is preferable to use lower head differences of 0.20-0.25 m, since these are the head differences for which “streaming flows” are most easily generated, and which most facilitate the use of wide traverse (either slots or notches).

When all the above design criteria are fulfilled this generally results in large facilities, carrying significant flows (generally more than 1 m^3/s), and having pool volumes which in most cases are greater than 12 m^3.

Several examples of fish passage facilities that have been considered to be efficient for shad (Figure 1) can be cited:

- Ice Harbour type passes on the Columbia (Bonneville, John Day, etc.) and Connecticut (Turner Falls) rivers in the USA, provided that the head on the overflow weir crest was around 40 cm and created a streaming flow (RIDEOUT *et al.*, 1985). In the case of relatively short pools, increasing the head from 0.30 to 0.40 m meant that every second notch on alternate sides had to be closed in order to prevent the phenomenon of short-circuiting, and to help reduce turbulence in the pools.

- Fishways with paired vertical slots 0.55 m wide (Bergerac fishway on the Dordogne, Puyoo on the Gave de Pau).

- Single, vertical slot fishways, or fishways with a deep lateral notch, provided that the traverses were sufficiently wide, *i.e.* around 0.45 to 0.50 m (fishways at Ramier and Bazacle dams on the Garonne, Sainte-Livrade dam on the Tarn, Ardus weir on the Aveyron). In this type of vertical slot fishway, the extent of the recirculation zones must be minimised by reducing the width-length ratio of the pools as much as possible, and by directing the flow properly into the pools towards the lower third of the side wall. The height of the sills in the slot must also be reduced as much as possible.

- “Chicane” fishways of the type used in control sections of some large facilities (Vernon dam, Connecticut River, Bonneville and John Day dam, Columbia River, MONK *et al.*, 1989). The great advantage of this type of fishway is the almost complete absence of large recirculation zones. However, the low head difference required between pools (around 15 cm maximum) means that a huge fishway has to be constructed to dissipate sufficient energy.

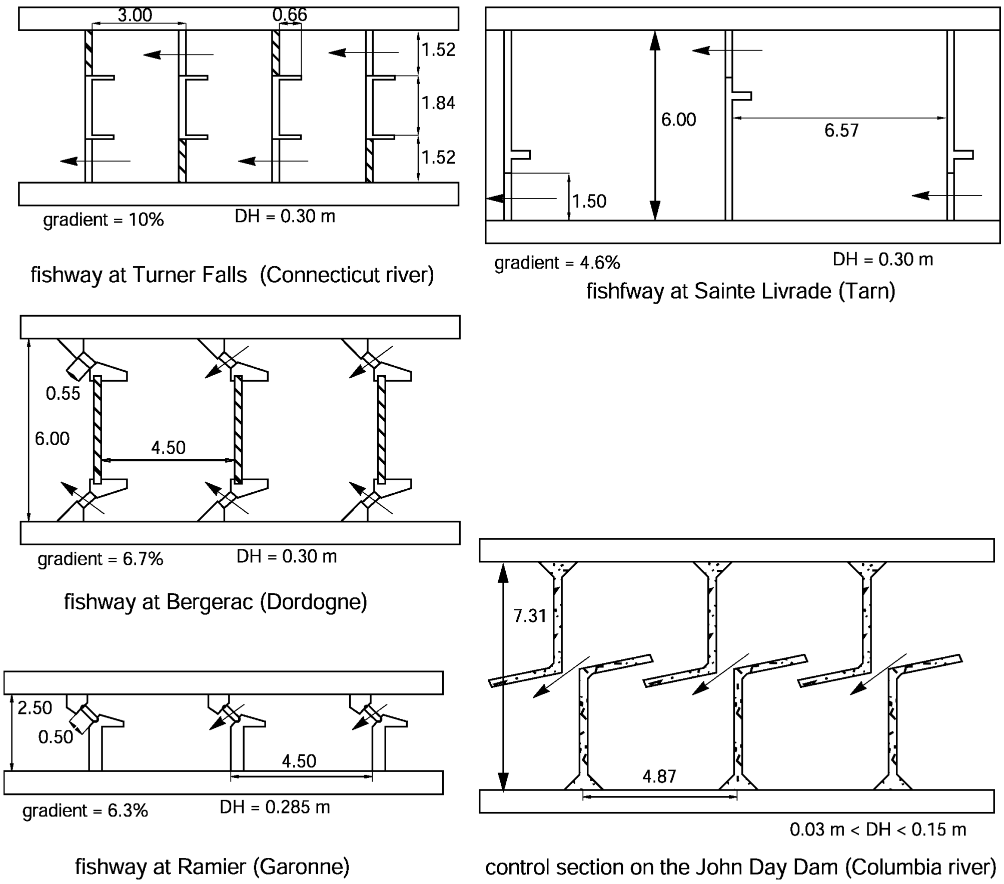

Figure 1: Pool fishways utilised by shad.

4. BAFFLE FISHWAYS

Although France, the USA and Canada each have several baffle fishways that are used by shad, it is still difficult to give a clear indication of the efficiency of these passes for this species.

Observations have shown very clearly that shad have far more difficulty than salmonids in negotiating the helical currents that characterise baffle fishways.

Several hundred shad have been monitored using a plane baffle Denil fishway (gradient 13%, width 1.22 m, length 12 m) on the Narraguagus River (DALLEY, 1980).

The plane baffle fishway at Beaucaire (two flights with 8% and 10% gradients, width 1.30 m, overall length 40 m) on the Rhône has not proved to be efficient for shad (C.T.G.R.E.F., 1981). The fact that this facility does not work may not, however, be attributable solely to the hydraulic conditions in the fishway. The failure could also be explained to a large extent by other factors including:

- the difficulty of monitoring the pass without interfering with its efficiency;

- the need for the fish to pass through an unlit tunnel and a dark upstream section of the pass;

- a very turbulent auxiliary flow that does not help to guide the fish towards the entrance of the fishway.

However, the most important factor is the low attractivity of the fishway (poor location of the entrance which is situated 1500 m from the obstruction.

Each year several thousand shad arrive at the Bazacle dam in Toulouse. The dam is fitted with both a pool pass with vertical slots and a chevron type baffle fishway comprising three flights, each around 12 m in length (gradient 17%, width 1.50 m) (DARTIGUELONGUE, 1991, 1992). However, the shad using the baffle fishway only represent a very small percentage (around 1%) of the total numbers of shad passing the dam, the vast majority using the pool pass. The better siting of the entrance to the pool pass is doubtless a major factor in the difference in efficiency of the two fishways.

On a small lateral channel discharging into the river Rhône, an experimental fishway with chevron baffles (gradient 16%, width 1.80 m, length 10 m, cross section of the baffles 0.10 x 0.10 m) was tested at a 1.80 m high gauging weir (BARIL, 1988). More than 350 shad were counted passing through the fishway when the unit flow discharge was between 300 and 750 l/s/m. However, the actual efficiency was very closely related to the hydraulic conditions at the entrance of the fishway. Shad used it only when they were guided towards it by a lead-net. In the absence of a lead-net the shad preferred to keep away from turbulent zones at the entrance to the fishway, and therefore remained at the foot of the obstruction.

In the river Douve (Normandy), recently built chevron type baffle fishways have successfully allowed a small population of shad to pass low obstructions (RICHARD, comm. pers.).

Several tests have been carried out to compare the respective efficiency of a baffle fishway and a pool pass on the same site.

In Canada (CONRAD, comm. pers.), experiments have shown that shad prefer to use a plane baffle Denil fishway, rather than a pool pass situated nearby. This result may be due on the one hand to the greater attractivity of the baffle fishway (a much larger discharge), and on the other hand to very small dimensions of the pools, which render the pool pass much less suitable for the shad than the baffled fishway.

In the USA, tests have been carried out in the Bonneville laboratory to study the possibility of using baffle fishways in order to guide the migrators from a pool pass towards a magnetic detection device (SLATICK, 1975). The fishway tested was an Alaskan-type fishway (gradient 24%, overall width 0.56 m, free width 0.35 m, length 8 m), with a maximum discharge of 160 l/s when full. These experiments showed that shad were generally much more reluctant to enter the facility than salmonids. However, a large proportion of shad used the fishway, provided they were given enough time and that the hydraulic conditions were suitable at the entrance and exit of the facility. In particular, the most significant results were obtained when the fish were guided towards the entrance of the fishway by a lead screen. When offered a simultaneous choice between a pool pass (with a central notch and “plunging flow”) and the baffled fishway, all the shad and most of the salmonids chose the latter.

These results on the comparative efficiency of the baffle fishways and the pool fish passes, which always favoured the former, must be considered very cautiously, because the pool passes were small and mainly of the “plunging flow” type that are not favoured by shad. The results would have undoubtedly been quite different if the pool passes had been larger, with a flow comparable to that in the baffled fishway, and above all if they had possessed “streaming flow”.

5. FISH LIFTS AND LOCKS

Trapping shad in a small volume of water, even for a short period, may lead to a considerable mortality rate. Thus, in fish lifts designed for shad, the fish have to be trapped in a large holding pool (minimum dimensions around 5 m x 2.5 m x 1.5 m) with a predetermined minimum volume of water (around 30 l/shad) for each fish present (TRAVADE *et al.*, 1992).

This generally results in the need for the provision of a mechanical crowder, which travels laterally and confines fish in the space above the lifting tank just before the lifting operation. The minimum volume of the tank must be calculated on the basis of around ten litres per shad.

The specifications of the lift (the volume of the holding pool and tank, and the maximum frequency of lifting of the tank) must take into account the hourly peak period of shad migration, which could vary from 1% to 2.5% of the annual total passage (CHANSEAU *et al.*, 2000).

The free gap between the bars of the lift screen must be no greater than 2.5-3 cm.

The largest part of the auxiliary flow (all of it, if the velocity permits) must be injected upstream of the tank. The velocity of the flow at the entrance to the inscale (the non-return device) at the holding pool must be around 1 m/s.

The minimum width of the upstream transfer channel must be 1.5 m, and the minimum velocity of the flow 0.30 m/s.

Traditional “Borland” locks are of limited use because their efficiency is too dependent upon the behaviour of the species. However, it is possible to use a lock where the head drop at the dam is moderate and when other solutions appear to be problematical, provided that it operates with a free water surface (like a navigation lock) and also that the holding pool is both long enough and has sufficient volume and that care is taken to create a surface flow with sufficient velocity during the exit phase in order to induce the fish to swim out.

Navigation locks can be used for passage of shad, provided that their operation is adapted to shad behaviour. Sufficient attraction flow must be created in the downstream approach channel to the lock, and it is necessary to create significant velocity when the lock is full to induce shad to proceed upstream out of the lock. While navigation locks are regularly used on the river Rhône to achieve shad passage, their operating regime as a fish facility is incompatible with that required for navigation. As a result only a few daily lock operations can be performed during the migration period.

Sonic tracking has been recently used to assess the passage efficiency of adult American shad through navigation locks on the Cape Fear river, North Carolina, USA. Passage efficiency was varied from 18% in 1997 to 61% in 1998. During low flows, passage efficiency was improved by increasing attraction flow emanating from the lock entrance, by conducting as many lockages as possible in a day and by closing one of the lower gates to better retain fish in the lock chamber after they have entered (MOSER *et al.*, 2000).

6. ATTRACTION AND SITING OF A SHAD FISHWAY

Compared to salmonid passes, it is necessary to be much more demanding with respect to the siting of the pass, the position of the entrance(s), and the quality of the attraction at the obstruction (in terms of velocity, flow discharge and flow pattern at the entrance).

Generally, shad will explore the area at the foot of the obstruction much less than salmonids. If a single entrance can be considered as sufficient to obtain good passage for salmon in some cases, the same does not apply to shad. Where the power station is more than 20 m wide, a collection gallery becomes essential to ensure an acceptable efficiency. Experience has shown, where only one entrance is possible, that turbine operation usually has to be managed very carefully to enable the shad to find and enter the fishway, which is the case at power stations both at Bazacle on the Garonne and at Mauzac on the Dordogne.

The main entrances must be situated along the banks, and the velocity at the entrances must be relatively high (around 2 m/s).

Screens must be fitted to any auxiliary attraction flow to prevent fish from diverting into them, and to ensure that the fish are guided towards the fishway entrance.

7. EFFICIENCY OF SHAD FISHWAYS

Shad fishways are always less efficient than salmonid fishways. In the case of salmonids it is not unusual to have passes which are 95% to 100% efficient. An efficiency of 75% is exceptional for shad fishways, 50% is excellent, and unfortunately 10% to 20% is common.

However, even in the most favourable circumstances where there are several nearby obstructions on the same river equipped with well-monitored fishways, it is difficult to evaluate the true efficiency of a facility, since it is indeed rare not to find areas that are favourable for reproduction between the different obstructions.

At the first two obstructions (Essex and Pawtucket) on the Merrimack River (East Coast USA), which are around 15 km apart, the percentage of shad passing through one plant then the other is, on average, around 10%. It varies between a minimum of 3% and a maximum of 23% (STOLTE, 1991).

Between 1989 and 1996, the percentage of shad which passed through the Golfech lift on the Garonne and then used the Bazacle fishway (situated around 100 km upstream) varied between 6% and 34% (average 18.5%). The percentage of shad which passed through the Bazacle fishway and then used the Ramier fishway situated immediately upstream was estimated to be more than 70% in 1990 (DARTIGUELONGUE, 1990). This exceptionally high percentage was correlated with particularly favourable hydrological conditions (very low flow in the Garonne), which made the fish passage entrance highly attractive.

On the Dordogne, the proportion of shad using the pool pass at Mauzac varied between 6% and 56% of the number observed in the Tuilières fish lift situated around 15 km downstream. This large variation can be explained mainly by two factors. The first is the variability in flow discharge of the Dordogne during the migration period (better passage during low flow). The second is the more or less disturbing effect of the Kaplan turbine discharging near to the entrance to the Mauzac fishway.

The limited efficiency of fishways for shad means that substantial difficulty can be anticipated in restoring major stocks where there is a series of obstructions on the same river, especially where all of the spawning zones are upstream of those obstructions.

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Photo 1: Fish passage facility at Turners Falls (Connecticut river, USA) : every second notch has been closed and the head increased to facilitate shad passage.

Photo 2: Paired vertical slot fishway at the Puyoo weir (Gave de Pau river).

Photo 3: Hydraulic model showing the flow patterns in the paired slot fishway at the Bergerac dam on the Dordogne.

Photo 4: Lateral deep notch fishway at the Sainte-Livrade dam (river Tarn). This large fishway has been installed in a former navigation lock.

Photo 5: Control section with vertical slots in the Vernon fishway on the Connecticut river (USA).

Photo 6: Single vertical slot fishway at Le Bazacle (Garonne river).

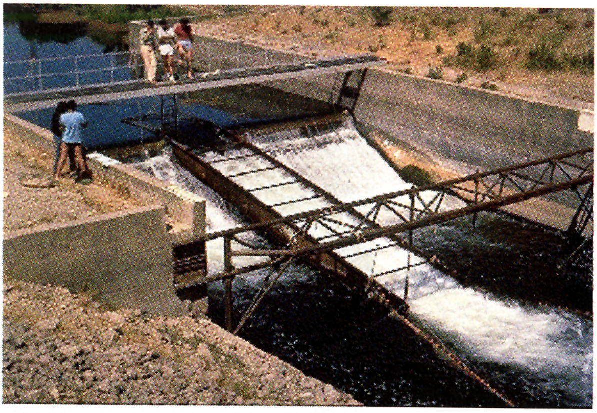

Photo 7: Experimental chevron-type baffle fishway on a lateral canal of the Rhone. Note the net placed downstream to guide the shad to the fishway entrance.

Photo 8: Pool fish pass at the Tuilieres dam on the Dordogne. A screen prevents shad becoming trapped in the recirculation areas.

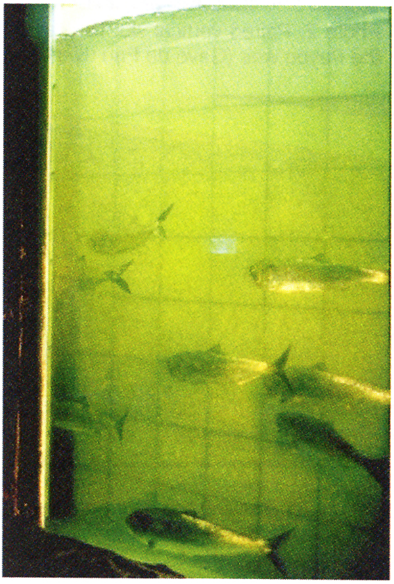

Photo 10: Shad passage at the monitoring station of the Tuilieres fish lift (Dordogne river).

Photo 9: Tuilieres fish lift on the Dordogne river.

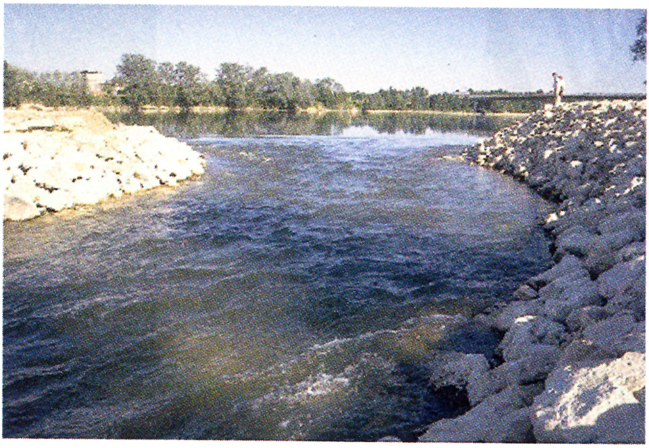

Photo 11: Natural bypass channel entrance at the Beauregard weir on the Garonne river.