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The use of radio telemetry for optimizing fish pass design

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Abstract

A radio telemetry study of adult Atlantic salmon (*Salmo salar L.*) was conducted in 2000 and 2001, for the purpose of optimizing the design of a new fish passage facility at the Baigts hydroelectric plant, located on the Gave de Pau river in the southwest of France. The efficiency of the old Denil fish pass, located on the bank opposite the tailrace, had previously been evaluated at 30-40% of its potential. The decision was taken to build a new fish lift at the only possible location on the site, i.e. at the existing fish pass entrance. Initially, only the lower part of the fish lift was built and its efficiency evaluated. The behaviour of 70 wild salmon was studied from early July 2000 to mid-December 2001. They were trapped, radio-tagged and released at the Puyoo dam, 8 km downstream from the plant. During the 2000 study, the spill discharge at the dam varied significantly, notably during a prolonged stoppage of the plant. The efficiency of the fish pass was increased to 80%, but part of this increase, which was difficult to assess, was for the period when the turbines were closed and all of the river flow spilled over the dam. Following the first year's results, attraction flows varying from 7.5 m^3s^{-1} to 11.5 m^3s^{-1} were tested in 2001. The auxiliary attraction discharge was nevertheless relatively dispersed, being divided between the fish lift entrance, an existing radial gate, a flap gate and the existing downstream bypass channel. The rates of average upstream passage increased to 87%, which may be partly attributed to (i) increased fish pass attractivity due to higher dam spillage via the nearest flood gate and (ii) longer times spent by fish inside the first pool of the fish facility due to an anti-return device installed at the fish pass entrance. In addition, migration delays were greatly reduced with the median blockage duration decreasing from 53 days in 2000 to 9 days in 2001. Nevertheless, considering the migration delays and the position of the obstacle on the river, a long way downstream from major spawning grounds, the efficiency of the fish pass still has to be improved. This will be done by concentrating all attraction discharge release very close to the fish lift entrance. A small turbine (with a maximum discharge of 10 m^3s^{-1}) will be installed in the near future.

Introduction

Since the beginning of the last century, thirty-eight obstacles (dams or low weirs) have been built on the *Gave de Pau* river with the result that Atlantic salmon (*Salmo salar* L.) have almost entirely disappeared from the river. A restoration plan was undertaken about twelve years ago and led to the building of facilities at obstacles that had previously not been equipped with fish passes. A first radio telemetry study was performed from 1995 to 1997 (Chanseau *et al.*, 1999) to assess the impact of the different obstacles. It concluded that the Baigts hydroelectric power plant, with its sixty-year old fish pass, remained one of the most severe obstacles to salmon migration. This lack of efficiency, evaluated at 30 to 40% of its potential, was due to the poor design of the fish pass, its limited discharge and the location of the entrance, on the left bank, on the opposite side of the river from the tailrace. However, most of fish visited the fish pass entrance (Chanseau and Larinier, 1999).

In the light of these results, it was decided that a new fish passage should be built. The best location for this new fish pass was unquestionably on the right-hand bank near the tailrace. However, given the limited available space on the bank and the particular layout of the intake screens, it would have been difficult and also very expensive to build a fish pass there.

The decision was thus taken to install a new fish lift at the only reasonably feasible location on the site, i.e. at the existing fish pass entrance. At first, only the lower part of the fish lift was built and its efficiency evaluated through a provisional fish trap. The second stage of work was only to be launched if the relevant authorities found that the fish lift, after radio telemetry assessment, was efficient enough.

This paper describes the main results of the two-year radio telemetry study conducted in 2000 (Chanseau and Larinier, 2001) and 2001 (Bau *et al*., 2002a), prior to the final design of the fish lift, describing only those results that directly influenced the design of the fish pass for Atlantic salmon (*Salmo salar* L.).

Materials and methods

Study site

The Baigts hydroelectric power plant is located in the southwest of France, on the *Gave de Pau* River, 20 km above its confluence with the *Gave d'Oloron* river and approximately 50 km from the estuary. The annual mean flow is around 80 m^3s^{-1}. The plant consists of a powerhouse located on the right bank and a dam 57 m long located on the left bank. The maximum turbine discharge (there are three Kaplan turbines) is 90 m^3s^{-1} and the rated head is around 13 m. The spillway has two radial gates and a smaller flap gate surmounting a bottom slide gate adjacent to the power intake. A downstream bypass is located at the downstream end of the intake screens while a steep open channel, 1 m wide, conveys downstream bypass flow to the tail water. The old Denil fish pass is located on the left bank, on the opposite side from the tailrace and is 80 m long (Fig. 1).

The future fish facility, once completed, will be located on the left bank, at the base of the dam, very close to the existing fish pass entrance. Its lower part comprises a large holding pool and a 1.2 m wide, gated entrance. A provisional trap has been installed in the upstream part of this pool. The facility is partly fed through the old fish pass (1 m^3s^{-1}) and partly directly from the headpond (maximum 2.5 m^3s^{-1}) after the energy has been dissipated by passing through several pools. One part of the flow is injected upstream from the trap and the other part laterally, downstream from the trap, through a vertical screen. An electrical winch is used to raise the trap and to free fish upstream (Fig. 2) from the pass.

In 2001, it was decided to increase the proportion of the fish pass flow passing through the trap and to install a V-trap at the downstream pool entrance.

Tagging and Fish movement

Over the two years 2000 (170 days from 19 June to 4 December) and 2001 (182 days from 18 June to 16 December), 70 (29 in 2000 and 41 in 2001) wild Atlantic Salmon (mainly grisle 60-89 cm total leugth) were captured in the fish pass located at the Puyoo dam, 8 km downstream from the study site and were anesthetised (with 2-phenoxyethanol, 0.25 mll^{-1}, then clove oil, 26 $mmoll^{-1}$) before being tagged with radio transmitters (Advanced Telemetry System; with a frequency range of 48 to 49.9 MHz ; 60x20 mm; 20-22 g in air; lifetime: 220 days; pulse rate: 56 to 58 per minute) that were introduced into the fishes' stomachs via the oesophagus. Each radio tag had a unique output frequency. The tagged fish were released just upstream of the Puyoo fish pass. The tagging and tracking procedures are similar to those used by Solomon & Storeton-West (1983) and have been described by Chanseau *et al*. (1999).

The fish movements were determined using five automatic listening stations (Advanced Telemetry System; receiver model R2100; DCC II model D5040) to define 6 principal detection zones: zone 1 (Z1) corresponding to the tailrace, zone 3 (Z3) to the dam, zone 2 (Z2) to a zone located between the two preceding zones at the downstream end of the dividing wall, zone 4 (Z4) at the fish pass entrance, zone 5 (Z5) at the downstream entrance pool to the fish lift and finally zone 6 (Z6) at the holding trap of the fish lift (Figs. 1 and 2). Daily manual tracking (either on foot or by car) was used to complete the automatic radio monitoring.

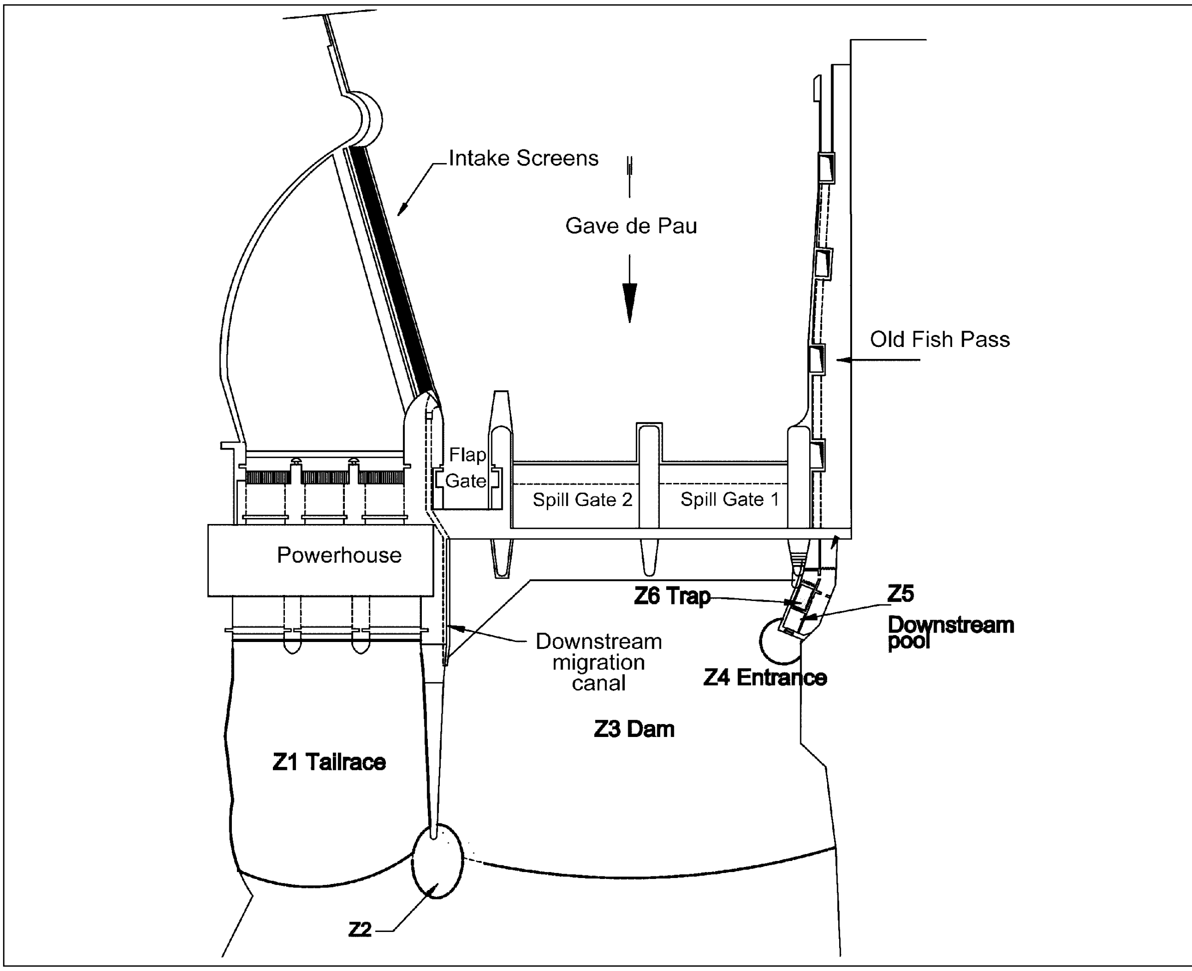

Fig. 1 – Plan of the Baigts power plant.

Water temperature, river flow and turbine operation
Water temperature (°C), and river flows downstream of the plant (m^3s^{-1}) were recorded automatically and saved at 1-hour intervals. Turbine operation was monitored every 3 minutes to estimate flow in the tailrace at any given time.

In 2000, four separate periods could be distinguished according to the rate of flow spilling over the dam:

i) 1st period: before 8 March 2000, when all discharge on the dam side passed through the fish pass (2.5 m^3s^{-1});
ii) 2nd period: from 8 March 2000 to 24 September 2000, when 2.5 m^3s^{-1} passed through the fish pass and 1 m^3s^{-1} more through the downstream migration channel;
iii) 3rd period: from 24 September 2000 to 25 October 2000, when the turbines were stopped and all river discharge passed under the dam gates;
iv) 4th period: from 25 October 2000 to 5 December 2000, when 4 m^3s^{-1} passed through the flap gate, 3.5 m^3s^{-1} through the fish pass, i.e. a minimum spill discharge on the dam side of 7.5 m^3s^{-1}. During this period, increase in river discharges resulted in more important spillage, which generally varied from 25 to 33 m^3s^{-1}.

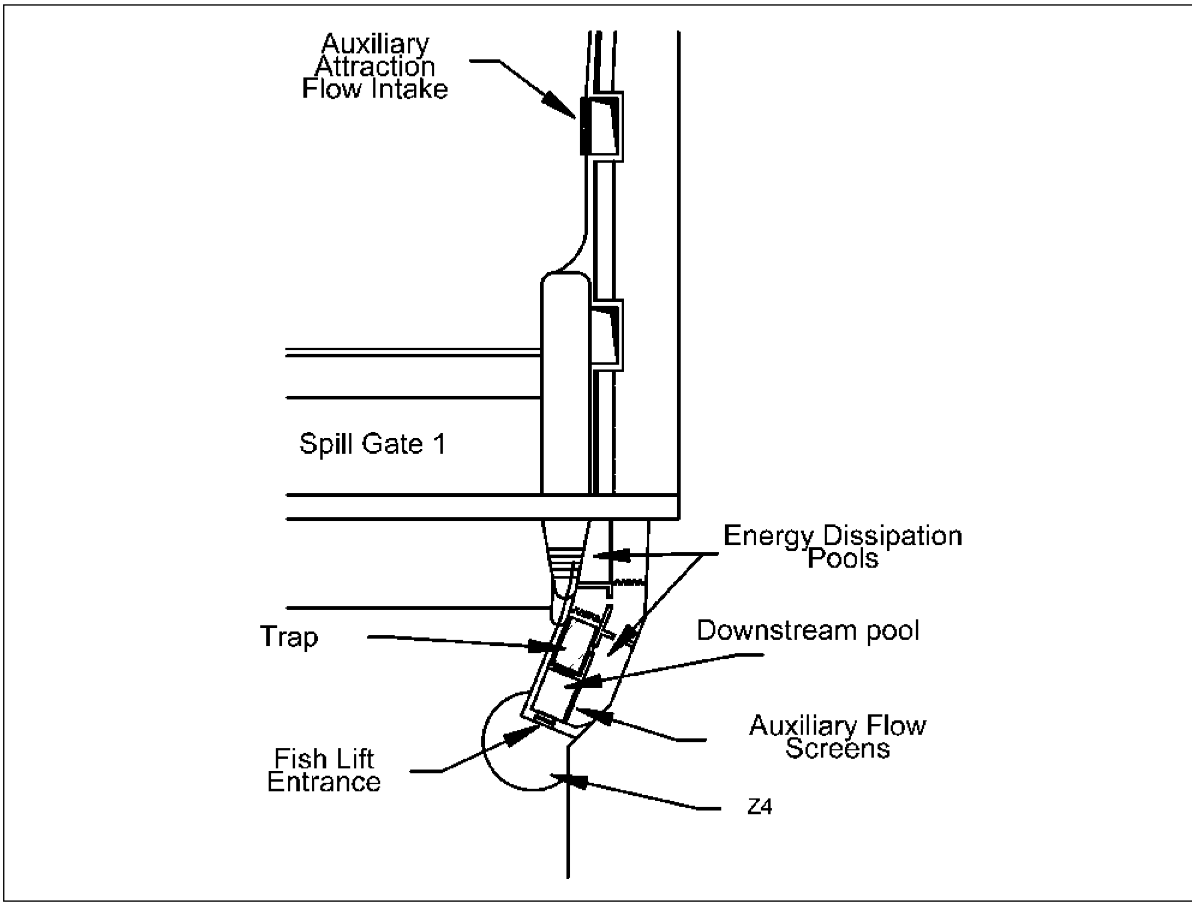

Fig. 2 – Plan of the left bank showing the old fish pass and the new fish lift entrance.

In 2001, in the light of the results for 2000, it was decided to let the attraction discharge at the dam vary from 7.5 m^3s^{-1} to 11.5 m^3s^{-1}, depending on the turbine discharge (Table 1). The attraction discharge release was nevertheless relatively dispersed, between the fish lift entrance (3.5 m^3s^{-1}), through the existing downstream bypass channel (2 m^3s^{-1}), the flap gate (2 m^3s^{-1}) and one of the two radial gates (2 to 4 m^3s^{-1} under the gate then through a siphon pipe above the gate).

Table 1 – Variation of attraction discharge at dam according to the turbine discharge (in 2001)

Turbine discharge (m^3s^{-1})	Fish pass discharge (m^3s^{-1})	Downstream migration canal discharge (m^3s^{-1})	Flap gate discharge (m^3s^{-1})	Radial gate or siphon pipe discharge (m^3s^{-1})	Total discharge (dam side) (m^3s^{-1})
0-40	3.5	2	0	2	7.5
40-60	3.5	2	0	4	9.5
60-90	3.5	2	2	4	11.5

Results

Fish passage

In 2000, of the 29 salmon tagged, 25 were recorded near the plant. Two never showed up at the plant and two others probably either regurgitated the transmitter or died. Three other fish which had been tagged during another study undertaken at the same time in the estuarine part of the Adour basin, reached the plant and were monitored. Three individuals died during the study. Twenty fish were trapped in the facility and passed over the Baigts plant, i.e. 80%. However, part of this increase, which was difficult to assess, can be attributed to the period when all of the river flow spilled over the dam. Only 12 fish (48%) were trapped while the plant was in operation. Eight individuals were trapped during a prolonged stoppage of the plant due to work on the intake screens (from 29 September 2000 to 25 October 2000). As it was difficult to judge whether these fish could have passed while the plant was operating, we can only assume that the efficiency of the facility is between 48% and 80% (as compared with 34% for 1995-1997). The first quartile and the median of the delay for the trapped fish were respectively 23 and 53 days.
In 2001, of the 41 salmon tagged, 31 were recorded near the plant. Two other fish, which had been tagged for another study undertaken at the same time in the estuarine part of the Adour basin, reached the plant and were also monitored. Only 30 individuals were taken into account since three of the 33 individuals had disappeared prematurely. Twenty six fish were trapped in the facility and passed over the Baigts plant. The overall efficiency can be estimated at 87%. The first quartile and the median of the delay for the trapped fish were respectively 0.7 and 9 days.

Influence on fish position of discharge spilling at dam

In 2000, the distribution of the duration of visits of the radio tagged fish to the different reception zones (Z1, Z2, Z3 and Z4) were compared (ANOVA) in relation to flow discharges spilling over the dam (periods 1 to 4). Fish spent proportionally more time in the tailrace during periods 1 and 2 than during periods 3 or 4. Fish stayed for a longer time at the fish pass entrance during the fourth period than during the third period when all the river discharge was spilling through the gates, which partly masked the entrance of the fish pass (Table 2).

Table 2 – Distribution of the percentage of presence in the different zones (Z1, Z2, Z3, Z4) during the four distinct periods and ANOVA results.

Zone	Period				F	p value	Homogeneity of groups
	1	2	3	4			
Z1	25.8	32	30.8	16.5	0.7	0.55	1=2=3=4
Z2	55.9	56.4	22.3	0	9.03	0.0001	(1=2) ≠ (3=4)
Z3	17	11.1	45.5	65.1	14.3	< 0.0001	(1=2) ≠ (3=4)
Z4	1.2	1.2	0.47	18.4	29.4	< 0.0001	(1=2=3) ≠ 4

General fish behaviour

During the two year study, fish spent most of their time in a pool about 500 m to 1,200 m downstream from the plant. The salmon moved many times between this pool and the dam, with 1,557 out of the 2,311 approaches recorded in 2000 and 1,590 out of 1,961 approaches recorded in 2001 lasting less than 3 hours.
In 2000, the number of approaches per day to the plant varied from 1 to 15, while 66% of the number of visits was between 1 and 3. In 2001, the number of visits varied from 1 to 17 with 70% of the number being included between 1 and 4.
In 2000, 15 of the 27 fish, when present below the plant, preferred to stay in the tailrace (Z1), 7 downstream from the dam (Z3) and 5 near the dividing wall (Z2). The duration of visits in these zones was relatively short with 50%, 81% and 68% of the vis-

its to Z1, Z2, Z3 lasting less than 1 hour. In 2001, 17 of the 33 fish preferred to stay in the tailrace (Z1), 7 downstream from the dam (Z3) and 9 near the dividing wall (Z2). The duration of visits in these zones was also relatively short with 60%, 81% and 86% of the visits to Z1, Z2, Z3 lasting less than 1 hour.

Fish behaviour at fish pass entrance

In 2000, while visits to the fish pass entrance (Z4) were relatively frequent (1,250), most were short, with 60% lasting less than 1 minute and 86% less than 5 minutes. All fish visited the fish pass entrance at least once (the mean was 45 times and the median 20 times). Sixty-six percent of the fish were generally monitored near the entrance less than 24 hours after their initial approach (median delay 13 hours).

In 2001, the visits to the fish pass entrance (Z4) were relatively frequent (506), most were short, 76% lasting less than 1 minute and 95% less than 5 minutes. All fish visited the fish pass entrance at least once (with a mean of 15 times and a median of 5 times). Seventy-four percent of the fish were generally monitored near the entrance less than 24 hours after their initial approach (median delay 7.2 hours).

In 2000, the results showed that 1,250 out of 2,198 (57%) visits to the site were followed by a visit to the fish pass entrance (Z4); 264 out of the 1,250 (21%) visits to the fish pass entrance were followed by the fish actually entering the downstream entrance pool (Z5); 20 out of the 264 (7.5%) visits to the downstream pool were followed by the fish entering the trap (Z6), thus enabling them to pass over the dam. Each trapped fish visited the downstream pool an average of 13 times, the fish pass entrance an average of 63 times and the site itself an average of 110 times.

In 2001, 506 out of 1,961 (26%) visits to the site were followed by a visit to the fish pass entrance (Z4); 176 out of the 506 (35%) visits to the fish pass entrance were followed by the fish actually entering the downstream entrance pool (Z5); 26 out of the 176 (15%) visits to the downstream pool were followed by fish entering the trap (Z6). On average, each trapped fish visited the downstream pool 7 times, the fish pass entrance 20 times and the site 75 times.

Discussion

Even though it is difficult to compare the results of the two successive years, considering the difference in river flow conditions, it seems that the passability of the dam increased from between 48 and 80% in 2000 to 87% in 2001. The improvement is obvious concerning the delays, as the first quartile and median delays decreased from 23 and 53 days in 2000 to 0.7 and 9 days in 2002.

The general behaviour of fish is very similar in 2000 and 2001. The main differences concern fish behaviour at the fish pass entrance. The modifications in 2001 (installation of a V-trap at the downstream pool entrance and increase of the flow passing through the trap) have made it possible to reduce the number of visits to the facility entrance before entering the trap and passing upstream.

There is little information on fish behaviour and especially Atlantic salmon, with respect to obstacles to migration and to entrances of fish passes (Gowans *et al*., 1999; Northcote, 1998). In order to be able to evaluate the potential for further improvement, it seemed a good idea to compare fish behaviour at the Baigts plant to that observed at the Castetarbe plant, located 6 km upstream on the same river. The fish pass sited at the Castertarbe plant is recent and well located, on the tailrace side. The Castetarbe fishway was assessed by radio telemetry in 2001, with practically the same fish (Bau *et al*., 2002b). This pass is considered to be efficient and can be used as a reference for the Baigts fish pass (Table 3).

Overall efficiency was estimated at 94% at Castetarbe (versus 87% at Baigts). The first quartile and median of the delay for the trapped fish were 0.4 and 2 days (versus 0.7 and 9 days at Baigts). The percentages of visits to the fish pass entrance followed by fish entering the downstream pool were not very different (26-35%). The percentages of visits to the first downstream pool followed by fish passing upstream were close (18% at Castetarbe versus 15% at Baigts).

Table 3 – Comparison of Castetarbe fish pass and Baigts fish lift in terms of rate of efficiency, delays and frequency of visits.

Site (year)	Baigts (2000)	Baigts (2001)	Castetarbe (2000-2001)
Efficiency (%)	48-80	87	94
Delays (first quartile-median) (days)	23-53	0.7-9	0.4-2
Number of fish pass entrance visits/number of site visits	0.50	0.26	1.96
Number of first downstream pool visits/number of entrance visits	0.21	0.35	0.35
Number of fish passing/number of downstream pool visits	0.075	0.15	0.18
Number of fish passing/number of entrance visits	0.016	0.052	0.063
Number fish visits per fish passing	110	75	8

The main difference between the two sites is the frequency of fish visits to the pass entrance. Each visit to the site was followed by an average of 2 visits to the fish pass entrance at Castetarbe, versus 0.3 visit at Baigts.

On average, each fish which passed upstream of the Castetarbe plant had previously visited the site 8 times versus 75 at Baigts.

Fish behaviour at the fish pass entrance was similar at both Baigts and Castetarbe: the problem of fishes' reluctance to enter the trap entrance, observed at Baigts, seems to have been solved. The main factor explaining the difference in efficiency and delays remains the lower frequency of visits to the fish pass entrance at Baigts as compared to Castetarbe.

In conclusion, the increase of spill discharge on the dam side and the changes made to the trap and the downstream pool of the fish pass significantly increased the efficiency of the Baigts fish pass. While the efficiency rate (87%) seems to be fairly satisfactory, the migration delays remain too long considering the downstream location of the dam on the river. The efficiency still has to be improved. When the fish behaviour is compared to that observed at the Castetarbe plant, it appears that there is still a lot of potential for improving the Baigts fish pass, by increasing the frequency of fish visits to the pass entrance.

In 2001, an attempt was made to improve fish pass efficiency by attracting fish more frequently on the left bank by increasing the spilled discharge on the dam side. However, it will not be possible to release a significant, concentrated flow near the fish pass entrance, unless significant construction is undertaken and this was hardly conceivable for an experimental preliminary stage. All attraction discharge on the left bank should be concentrated close to the fish pass entrance. It was thus decided to install a special small turbine discharging 8 to 10 m^3s^{-1} at the fish pass entrance.

Fish guidance towards the pass entrance should also be improved with the reinforcing of an existing rip-rap groin guiding the flow, stretching from the left bank diagonally towards the end of the dividing wall and the tailrace.

These two modifications should increase the frequency of fish visits to the fish pass entrance and significantly reduce the delay before passage which was the limiting factor when compared to the Castetarbe fish pass reference.

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