# Manual to evaluate the functionality of step-pool fish passes

# AEPS Methodology (1.0)

GOBIERNO DE ESPAÑA
VICEPRESIDENCIA TERCERA DEL GOBIERNO
MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO
CONFEDERACIÓN HIDROGRÁFICA DEL DUERO, O.A.
CHD CONFEDERACIÓN HIDROGRÁFICA DEL DUERO
itagra.ct centro tecnológico agrario y agroalimentario
GEA Grupo de Ecohidráulica Aplicada
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This manual has been prepared within the collaboration framework established between the Group of Applied Ecohydraulics (GEA) of the University of Valladolid, Itagra ct and the Duero River Basin Authority (CHD), in order to assess the hydraulic performance of the existing step-pool fish passes in the Duero basin.

**Management and coordination:**
Francisco Javier Sanz Ronda (GEA)
Andrés Martínez de Azagra Paredes (GEA)
Arturo Prieto Blanco (CHD)
Ignacio Rodríguez Muñoz (CHD)
Juan Carlos Bernabé de la Iglesia (CHD)
José María Rubio Polo (CHD)
Urbano Sanz Cantalejo (CHD)

**Authors:**
Jorge Valbuena Castro (GEA)
Francisco Javier Sanz Ronda (GEA)
Ana García Vega (GEA)
Juan Francisco Fuentes Pérez (GEA)
Francisco Javier Bravo Córdoba (GEA)
Alberto Navas Pariente (GEA)
Jorge Ruiz Legazpi (GEA)
Néstor Joel González Alemán (GEA)
Ray Elvis Smarth Apinas (GEA)
Andrés Martínez de Azagra Paredes (GEA)
Arturo Prieto Blanco (CHD)
Ignacio Rodríguez Muñoz (CHD)
Juan Carlos Bernabé de la Iglesia (CHD)
José María Rubio Polo (CHD)
Urbano Sanz Cantalejo (CHD)

**Cover photo:** Fish passes in Vegas del Condado (Porma River, province of León), in Salto de San Fernando (Tormes River, province of Salamanca) and in Quintana del Puente (Arlanza River, province of Palencia).

**English Traslation:** Cristina Novo

**Citation:** CHD, 2016. Manual to evaluate the functionality of step-pool fish passes. AEPS Methodology (1.0). Coordination: Sanz-Ronda *et al*.; Authors: Valbuena-Castro *et al*. Published by Duero River Basin Authority. Valladolid. 139 pages.

**Group of Applied Ecohydraulics (GEA).**
Department of Hydraulics and Hydrology
Technical School of Agricultural Engineering (province of Palencia) – University of Valladolid
Tel: +34 979 108358 e-mail: escalasparapeces@gmail.com web: www.gea-ecohidraulica.org
Address: Campus La Yutera, Avenida Madrid 44 (edificio Aulario), 34004 Palencia, Spain.

# Table of contents

# List of figures

# List of tables

# Summary

Fish passes, also known as fishways or fish ladders, are structures to allow fish to move upstream and downstream over river obstacles. In the past few decades, they have been increasingly used worldwide. However, and in spite of their ecological importance, there is no standarised methodology to assess their efficiency, neither from a hydraulic point of view nor from a biological point of view, and the number of studies carried out to see if they were fit the purpose they were built for is still very low.

This work develops a methodology to assess the performance of the most common type of fish pass, the step-pool fish pass. It focuses on the needs of the species that are more widely distributed in the Iberian Peninsula, and of special importance in the Duero river basin: the native trout or brown trout (*Salmo trutta*), the Iberian barbel (*Luciobarbus bocagei*) and the Northern straight-mouth nase (*Pseudochondrostoma duriense*). The methodology intends to be simple, quick and convenient enough to allow its use without having sophisticated equipment and without requiring much personnel. The methodology provides quantifiable results that are useful to identify the problems a fish pass may have, as well as the way of solving them and how urgent it is to do so, thereby optimising the effort and resources dedicated to improving the longitudinal continuity of our water courses.

# 0. Rationale

The responsibilities of the Duero River Basin Authority (CHD) include the protection of the 'Hydraulic Public Domain' (DPH, a figure in Spanish legislation which refers to public waters), water concessions, as well as preparing the River Basin Plan for the Spanish portion of the Duero River Basin District.

The protection of the DPH includes issuing concessions for the right to use the water, with some requirements. One of them is installing systems that allow fish to get through any structure across the water course, to allow fish populations to migrate, thus ensuring the longitudinal continuity of the river and the water body (Article 126 bis of the Regulation on the Hydraulic Public Domain, on the conditions to ensure river continuity).

Furthermore, such protection is achieved through the DPH supervision and control role of the Enforcement Offices (Comisarías de Aguas), in charge of a comprehensive programme to monitor hydropower facilities, that has led to the construction and adaptation of many fishways, in order to comply with national and regional regulations and the terms of concession agreements.

The preparation and review of River Basin Plans requires, among other things, setting up a Programme of Measures to achieve the environmental objectives established under the Water Framework Directive. In this regard, Article 22 of the regulations relative to the River Basin Plan for the Spanish portion of the Duero River Basin District establishes a series of measures to prevent disruptions to the continuity of the water course. Point 5 of the said article says that "The assessment of permeability will be done according to hydromorphological indicators of continuity, to evaluate the state of water bodies in the river category..."

Complying with these provisions in the River Basin Plan entails knowing the permeability of each weir or dam associated with hydropower stations and other uses, according to the permeability index prepared for the Duero basin. Based on that permeability index, a fragmentation index is calculated and used to assess the status of water bodies in the river category. These indices are explained in detail in the document "Criteria to assess the status of surface water bodies in the river category", which is Appendix IV of Annex 8.2 to the Plan, which can be downloaded at:

*www.chduero.es/manuales-guias-e-inventarios*

In the Duero basin information system, MÍRAME-IDEDuero, information on the assessment of the status of each water body can be found at:

*www.mirame.chduero.es*

This manual intends to be a useful tool for the above, defining in an objective manner the permeability of barriers associated with step-pool fish passes in all their phases: design, implementation and operation.

Finally, it is important to note that the manual has been drafted as part of the work in the specific collaboration agreement between the River Basin District and the Agriculture and Food Technological Institute (Itagra.ct) of the University of Valladolid to carry out a programme to monitor the measures to improve the longitudinal continuity at hydropower stations in the Duero basin.

# 1. Background

Throughout history, and particularly in the 20th century, human beings have engaged in countless changes to water courses all over the world, being the construction of barriers such as dams and weirs one of the most important river modifications (Malmqvist & Rundle 2002; Nilsson *et al*. 2005; Katopodis & Williams 2012; Sanz-Ronda *et al*. 2013). These structures have negative impacts on fish fauna because, among other things, they break the longitudinal continuity of rivers, causing what is known as "the barrier effect" (Roscoe & Hinch 2010; Santos *et al*. 2012; Williams *et al*. 2012; Sanz-Ronda *et al*. 2013; Febrina *et al*. 2015). This effect prevents or limits the natural movements of fish fauna, to the point where it alters their reproductive behaviour (delayed spawning, spawning in inappropriate grounds, etc.) and community structure (isolation of populations, diversity reduction, genetic degeneration, etc.) which can lead to drastic reductions in fish populations, or even make them disappear (Jungwirth *et al*. 1998; Santos *et al*. 2002; Nilsson *et al*. 2005; Sanz-Ronda *et al*. 2013; Febrina *et al*. 2015). Faced with these adverse effects, several solutions have been proposed, one of them being the construction of passage structures known as fish passes or fishways (Katopodis 1992; Clay 1995; Bunt *et al*. 2012; Foulds & Lucas 2013; Sanz-Ronda *et al*. 2013).

To complete or complement their life cycles, fish move both upstream and downstream, and both types of movement are equally important (Lucas *et al*. 2001). Historically, more attention has been paid to upstream movements because they are related to the spawning and thus, of higher visibility and importance in terms of conservation (Lucas *et al.* 2001; Malmqvist & Rundle 2002). This tendency is changing, however. Thus, the current concept of barrier permeability associated with fishways includes movements in both directions (Jungwirth *et al*. 1998; Agostinho *et* *al*. 2002; Larinier & Travade 2002; Armstrong *et al*. 2004; Katopodis & Williams 2012; Sanz-Ronda *et al*. 2013).

There are many fishways in the world but only a small portion of them have been assessed, so the knowledge about how well they work is limited and often not very reliable (Agostinho *et al*. 2002; Santos *et al*. 2002; Roscoe & Hinch 2010; Noonan *et al*. 2012; Cooke & Hinch 2013). In the few studied cases, the obtained results have been widely different. Whereas sometimes they have a positive effect on fish (adequate transit, without delays), other times they do not work or they may even be detrimental (delays, agglomerations, predation, dispersal of invasive species, etc.) (Roscoe & Hinch 2010; Bunt *et al*. 2012). Therefore, just because there is a fishway, it does not always mean that fish can get through a barrier, or at least that they can do it properly (Roscoe & Hinch 2010). It is thus very advisable that all these structures be assessed before, during and after they are built to ensure their correct design, implementation and operation, according to the original project, as well as their suitability for the fauna involved, and always taking into account the changing hydraulic conditions in the area (Jungwirth *et al*. 1998; Roscoe & Hinch 2010; Sanz-Ronda *et al*. 2013; Towler *et al*. 2013; Febrina *et al*. 2015).

The assessment may include two approaches: from the point of view of the hydraulics, and from the point of view of the biology. Whereas the first one studies the relationship between aspects of the biological behaviour of fish (swimming ability and behaviour) previously known, and the hydraulics of the fishway as a whole (flow within the structure, design, dimensions and location in relation to the water surface) (Sanz-Ronda *et al.* 2014), the second one focuses on the actual behaviour of individuals in the fishway itself, analysing the number and diversity of fish fauna that uses the structures. Both criteria should be integrated to ensure a thorough assessment of the structure.

The logical way of assessing a fish pass, in the design phase or after it has been constructed, is to start with the hydraulic and design aspects. This will enable detecting and solving any problems affecting how it works. Once any existing issues have been identified and corrected, they can be assessed from a biological standpoint. However, in practice, and due to technical and economic requirements, often only hydraulic variables used to establish the dimensions are contemplated as a coarse assessment method to determine the efficiency of a fish pass (Sanz-Ronda *et al*. 2013).

Furthermore, even though currently there is plenty of literature that deals extensively with the topic of fish passes using different approaches (design manuals (Larinier *et al*. 1992; Clay 1995; Martínez de Azagra 1999; DVWK 2002;), scientific articles (Wang *et al.* 2010; Sanz-Ronda *et al*. 2013), international conferences (Fish Passage, Ecohydraulics), courses and training material (Sanz- Ronda *et al*. 2009 and later), to name a few), only a few focus specifically on the hydraulic assessment (Kemp & O´Hanley. 2010; Solà *et al*. 2011; Ordeix *et al*. 2011; Schmutz & Mielach 2013; Baudoin *et al*. 2015) or the biological assessment (Castro-Santos *et al*. 2009, Bunt *et al*. 2012; Sanz-Ronda *et al*. 2016). The latter require sampling and/or marking and the detection of fish going through the fish pass, something that needs a lot of resources (economic resources and time) to obtain significant results. However, the obtained conclusions are extremely reliable.

The hydraulic evaluation procedures mentioned are based on measuring a series of key parameters in a step-pool fish pass (*e.g.*, the width of the openings, the length of the pools, the step height and the water depths), to do a preliminary qualitative and quick analysis of how well it is working. That is, they require fewer resources, but the results only provide an indication, since they do not analyse other variables of interest in the fish pass (water discharge, power dissipation, the water depth in the openings), or outside the fishway (attraction of fish towards it).

Therefore, it is necessary to develop an evaluation method that is objective, quick, reliable and easy to apply in step-pool fish passes. This is the purpose of this document.

# 2. Objectives

Developing a technical methodology to evaluate the movement of fish upstream through a step-pool fish pass. The methodology proposed must:

- Be convenient and simple to use.
- Have a biological and hydraulic rationale.
- Consider all stages of the upstream movement of fish: attraction to the pass, entry into it, passage, and exit.
- Be able to determine quantitatively how well the fishway works and identify its problems.
- Be useful in all phases of a project (drafting, administrative assessment and post-implementation).
- Provide conclusive and easy to interpret results to make management decisions in the context of a river basin authority.

# 3. Introduction to the methodology

An ideal fish pass allows fish to get through without delays, injuries, safety issues or selectivity in terms of the individual fish that are able to use it, whether because of age, sex or species (Martínez de Azagra 1999; DVWK 2002; Armstrong *et al.* 2004; Roscoe and Hinch 2010; Bunt *et al.* 2012b).

Among the different types of existing fish passes, the most common ones worldwide are those known as step-pool fish passes (Martínez de Azagra 1999; Larinier 2002b; Armstrong *et al.* 2004; Sanz-Ronda *et al.* 2013; Fuentes-Pérez *et al.* 2014). These fishways connect the water bodies upstream and downstream from an obstacle using a series of water pools in a stepped arrangement, where the water flows over cross-walls or through openings in them such as notches, slots or orifices (Clay 1995; Martínez de Azagra 1999; DVWK 2002; Larinier 2002b; Sanz-Ronda *et al.* 2013).

**Figure 1. Step-**pool fish passes connected by submerged notches and bottom orifices (top) and by vertical slots (bottom).

The methodology focuses on three fish species widely distributed in the Iberian Peninsula and of special importance in the Duero river basin: the native trout or brown trout (*Salmo trutta* Linnaeus 1758), the Iberian barbel (*Luciobarbus bocagei* Steindachner 1864) and the Northern straight-mouth nase (*Pseudochondrostoma duriense* Coelho 1985), all of them with known and similar swimming ability (Castro-Santos *et al.* 2013; Sanz-Ronda *et al.* 2015); in addition, there are previous studies on their upstream movement using step-pool fish passes (Sanz-Ronda *et al*. 2016; Bravo-Córdoba *et al*. 2016). Furthermore, the methodology contemplates only the upstream usage of the fish pass, since for downstream movements fish can use different options: the fishway itself, spillways, specific structures for downstream migration, falling over the top of the obstacle, through the turbines, etc. (Baudoin *et al.* 2014).

**Figure 2.** The fish species considered in this document: brown trout (left), Iberian barbel (centre) and the Northern straight-mouth nase (right). Source: Néstor Joel González Alemán.

Although fish passes must work year-round (Martínez de Azagra 1999; DVWK 2002), it is essential they do optimally during the most important season (breeding) due to the expected number of movements and to ensure the sustainability of fish populations (Larinier 2002b; Armstrong *et al.* 2004). Therefore, the proposed methodology is recommended for meanconditions (discharge and working regime of the fishway and diversion complex) during the migration of the breeding season.

Within the geographical context of the Duero river basin, the upstream spawning migration of brown trout usually takes place from November to December, and may continue until January or February (Doadrio 2002). The Iberian barbel and the Northern straight-mouth nase usually swim upstream for breeding purposes from March until June and even July (Doadrio 2002), but in the Duero basin it usually occurs in May and June (Sanz-Ronda *et al.* 2013). However, trout also make displacements at the beginning of the summer, looking for cooler waters upstream, and cyprinid species often do in the fall (particularly the nase) due to trophic reasons (Lucas *et al.* 2001).

The assessment of a fish pass should consider the four most important stages or categories (Odeh 1999; Castro-Santos *et al.* 2009): attraction (A), entry (E), passage (Ps), and exit (S) (Figure 3)[1]. The attraction (A) studies the easiness to approach the fishway by the fish. The entry (E) refers to how the fish enter the pass from the river (downstream). The passage (Ps) analyses the path they follow inside the fish pass from the bottom to the top of the pass. The exit (S) studies the process of leaving behind the pass to continue travelling upstream, once the fish have reached the uppermost pool.

[1] The abbreviations and notation used henceforth can be found in Annex A.1. Notation and abbreviations, in addition to being found on the page where they are first mentioned.

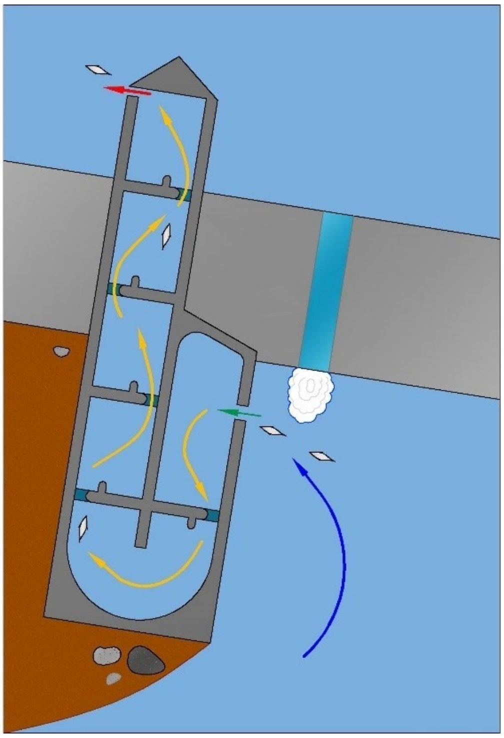


**Figure 3**. Categories to consider in an assessment: attraction (A) (blue), entry (E) (green), passage (Ps) (yellow) and exit (S) (red).

The above four categories comprise 44 aspects which are relevant to carrying out an assessment. Of those, 20 are referred to as "essential variables", which their analysis is critical, because they determine to a great extent the passage of fish (Table 1). They are quantitative variables and the necessary equipment to study them is a measuring tape, a level and a pole. The remaining 24 aspects are known as "relevant observations" (O) and refer to complementary aspects that facilitate the function and management of the fishway, or facilitate the fishes' upward movement (Table 2). They are usually qualitative variables, which are assessed by the person doing the evaluation (often presence/absence).

**Table 1**. Essential variables in each category.

| Category | Essential variable | Notation |
|---|---|---|
| Attraction | Relative attraction discharge | $Rel\ Q_{attraction}$ |
| | Location of fish entrance | $U_E$ |
| Entry | Difference in water level between the river and the lower pool | $\Delta H_E$ |
| | Depth at the entrance | $h_E$ |
| | Width at the entrance | $b_E$ |
| | Depth prior to the entrance | $h_{prior\ E}$ |
| | Orientation of the entrance in relation to the river | $Ort_E$ |
| | Type of entrance | $T_E$ |
| Passage | Difference in water level between consecutive pools or head drop | $\Delta H_{Ps}$ |
| | Volumetric power dissipation | $N$ |
| | Mean water level in pools | $t_{med}$ |
| | Water depth in openings between pools | $h_{Ps}$ |
| | Width of openings between pools | $b_{Ps}$ |
| | Type of opening between pools | $T_{Ps}$ |
| Exit | Difference in water level between the river and the upper pool | $\Delta H_S$ |
| | Depth at the exit | $h_S$ |
| | Width at the exit | $b_S$ |
| | Depth after the exit opening | $h_{after\ S}$ |
| | Orientation of the exit in relation to the river | $Ort_S$ |
| | Type of exit | $T_S$ |

**Table 2**. Relevant observations included in each category.

| Category | Relevant observations |
|---|---|
| Attraction | Maintenace and cleaning |
| | Accessibility |
| Entry | Maintenance and cleaning |
| | Elements to regulate water level drops |
| | Flow discharges at the entrance |
| | Absence of other flow discharges that drive fish away from the fish pass |
| | Rounded edges |
| | Accessibility |
| Passage | Maintenance and cleaning |
| | Pool shape |
| | Baffles in pools |
| | Conservation of structure |
| | Bed naturalised with stones |
| | Rounded edges |
| | Darkness due to elements covering the fishway |
| | Leeway in the fishway walls |
| | Accessibility |
| Exit | Maintenance and cleaning |
| | Gate to regulate the discharge |
| | Device to prevent the entry of debris |
| | Safe exit |
| | Rounded edges |
| | Accessibility |

# 4. Principles to apply the methodology

Based on the existing literature and the field and lab experience of the Group of Applied Ecohydraulics (GEA) of the University of Valladolid, for each of the considered variables a score ranging from 0 (minimum) to 10 (maximum) was established, based on how well they allow fish to move up the fish pass.

Assigning a score of 0 implies that an aspect is not recommended for most of the individuals in the target fish population, whereas 10 points indicate that, in theory, it is suitable for all individuals (Annex A.2.).

To apply the methodology, first the different essential variables and the relevant observations in the fish pass have to be measured and analysed (Table 1 and 2). Those aspects are included in a form to be filled out in the field (Annex A.5.). Next, the data is quantified following the scoring criteria for each essential variable (section 4.1.) and each relevant observation (section 4.2.).

Once each essential variable has been assessed, the score for each of the 4 categories is determined according to equations 1 to 4. The proposed equations (1 to 4) calculate a geometric mean[2] of the different essential variables considered in each category:

$$A = (Rel\ Q_{attraction} \cdot U_E)^{1/2} \qquad \text{(Eq. 1)}$$

$$E = (\Delta H_E \cdot h_E \cdot b_E \cdot h_{prior\ E} \cdot Ort_E \cdot T_E)^{1/6} \qquad \text{(Eq. 2)}$$

[2] The geometric means gives a null value (0) if one of its variables has a value equal to 0. This way, if all are suitable except for one that is completely inappropriate, a null result is obtained, that is to say, fish cannot ascend the fishway.

$$Ps = (\Delta H_{Ps} \cdot N_{Ps} \cdot t_{med} \cdot h_{Ps} \cdot b_{Ps} \cdot T_{Ps})^{1/6} \quad \text{(Eq. 3)}$$

$$S = (\Delta H_{S} \cdot h_{S} \cdot b_{S} \cdot h_{after\ S} \cdot Ort_{S} \cdot T_{S})^{1/6} \quad \text{(Eq. 4)}$$

Similarly, after calculating the score for each relevant observation separately, the score for each of the four categories is then calculated, but in this case, using an arithmetic mean[3]:

$$PO_i = \frac{O_{i1} + \ldots + O_{in}}{n_O} \quad \text{(Eq.5)}$$

where $PO_i$ is the sum of the relevant observations in category *i*, $O_{i1}$ is the score of the first one and $O_{in}$ the score of the last one, and $n_o$ is the total number of observations.

In the *Ps* category, the scores for each variable for the standard design pool are calculated, which would include most of the pools in the fishway. However, any pools with unique characteristics are also taken into account (named as odd pools), that is, pools which are different from most for some reason (often, because of poor construction)[4]. After,

[3] The arithmetic mean penalises null values (0) in the total score, but the final score is not zero if one of the observations obtains a poor score (value = 0) and the rest do not. This is because the relevant observations, if present, improve the overall performance of the fishway. However, if not present, the fish pass may continue to work properly.

[4] A resting pool similar to the standard pool, except for its length, would not be considered an odd pool.

the total score for each variable for all pools is calculated according to the equation (Eq. 6), that is, as an arithmetic mean of the obtained scores[5]:

$$Score = \frac{n_{standard} \cdot Score_{standard} + \sum Score_i}{n_{total}} \qquad \text{(Eq. 6)}$$

where *Score* is the final score of the essential variable or relevant observation considered in the assessment, $n_{standard}$ is the number of standard pools, $Score_{standard}$ is the score of the variable or observation for the standard pool, $Score_i$ is the score of that variable or observation for a odd pool *i*, whereas $n_{total}$ is the total number of pools.

Finally, the extent to which changes or improvements are needed is determined for each of the essential variables or for the set of variables comprised within a certain category (Table 3)[6].

**Table 3**. Result of the assessment and the need for improvements or additional assessments based on the scores obtained for each of the essential variables. This criterion is also applicable for the set of variables within a certain category.

| Reference range | Result of the assessment | Changes or improvements |
|---|---|---|
| 0 ≤ *Parameter* ≤ 4 | Very detrimental | Critical or biological assessment |
| 4 ≤ *Parameter* ≤ 6 | Detrimental | Strongly needed or biological assessment |
| 6 ≤ *Parameter* ≤ 8 | Beneficial | Advisable |
| 8 ≤ *Parameter* ≤ 10 | Very beneficial | Optional |

[5] Using a standard pool as proposed facilitates field work. However, if doing a comprehensive assessment (the entire fishway) and/or there are many odd pools, each pool can be considered independently, calculating after the arithmetic mean of the whole set.
[6] If a score of 0 is obtained in one of the categories, or for the entire fish pass, the reasons for it should be explained.

In addition, and separately, it can be ascertained whether it is convenient to undertake improvements and changes in the relevant observations, either considering them individually or as a set within a certain category (Table 4).

**Table 4**. Result of the assessment and appropriateness of improvements for each of the relevant observations or a set within a category, based on the scores obtained.

| Reference range | Result of the assessment | Changes or improvements |
|---|---|---|
| $0 \leq Parameter \leq 2$ | Very detrimental | Strongly needed |
| $2 \leq Parameter \leq 5$ | Detrimental | Needed |
| $5 \leq Parameter \leq 8$ | Beneficial | Advisable |
| $8 \leq Parameter \leq 10$ | Very beneficial | Optional |

## 4.1. Essential variables [7, 8, 9 and 10]

### 4.1.1. Attraction (*A*)

#### 4.1.1.a. Relative attraction discharge ($Rel\ Q_{attraction}$)

It refers to the discharge or flow rate that attracts fish in the surroundings of the fish pass (water turbulence, noise, oxygenation, etc.) and draws them to the entrance. If the attraction flow is too low in comparison to the flow discharged over the weir, it does not make it easy for fish to locate the pass quickly and simply, nor they come close to the pass. This variable is determined as the ratio between the flows that generate attraction, which are the discharge through the fishway and an auxiliary flow (if any), divided by the total river discharge (Eq. 7 and 8).

[7] It is advisable, and sometimes it is essential, to stop the water flowing through the fish pass to be able to measure the geometrical variables correctly.
[8] The water level in a pool will be measured at the centre of the pool. The water level in the river will be measured as close as possible to the fish pass, as long as it is a horizontal area without waterfalls or turbulence.
[9] The water level in the river will be measured as close as possible to the fish pass, as long as it is a horizontal area without waterfalls or turbulence.
[10] All measurements will be taken with the mean river flow during the migration period.

$$Q_{attraction} = Q_{fishway} + Q_{aux} \quad \text{(Eq. 7)}$$

$$Rel\ Q_{attraction} = \frac{Q_{attraction}}{Q_{river}} \cdot 100 \quad \text{(Eq. 8)}$$

Where $Rel\ Q_{attraction}$ is the % of flow that serves as attraction compared with the total flow or ecological flow ($Q_{river}$, in $m^3/s$); $Q_{fishway}$ is the water flow through the fishway ($m^3/s$); and $Q_{aux}$ is the auxiliary flow to attract fish[11] ($m^3/s$).

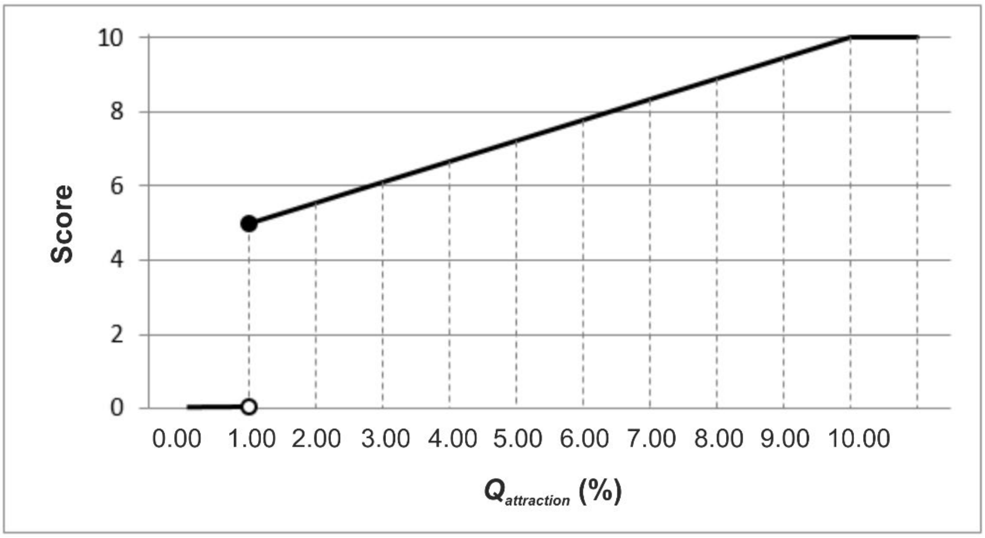



**Figure 4**. Score for variable *Rel* $Q_{attraction}$. Values lower than 1.00 % are given a score of 0 and values equal to 1.00 % are given a score of 5.

$Q_{river}$ refers to the mean discharge during the migration period (Duero river basin: May-June for cyprinids and November-December for trout). In the case of hydropower stations with turbines at the foot of the dam (without a channel that returns turbined water to the river), the turbined discharge should be used. If the return channel is far from the weir, it is not used, since it does not have an effect on how the fishway works.

[11] To be considered as an auxiliary flow, it must be located at ≤ 3 m from the fishway entrance, because that is the maximum distance from which the fishway flow itself is thought to attract fish (Bunt et al. 1999, 2012a; Aarestrup et al. 2003). Otherwise, it is not taken into account, and it can even be negative for attraction purposes.

However, it must be noted that the confluence between the returning turbined water and the river can be a critical point for the upstream orientation of fish (Bravo-Córdoba *et al.* 2016). Anyway, the ratio between the ecological flow and the maximum turbined discharge is usually greater than 5% in the hydropower stations in the Duero basin.

### 4.1.1.b. Location of the fish entrance ($U_E$)

This variable represents the position of the fishway entrance in relation to a theoretical ideal location. It affects the easeness with which fish find the entrance. The most suitable locations are those where the entrance is as further upstream as the obstacle allows, next to the base of the obstacle, close to the banks (Figure 5), next to the base and/or the places where a large volume of flow concentrates (*i.e.* the turbine outlet at the foot of a dam, attraction flows from spillways, etc.)[12] (Clay 1995; DVWK 2002; Larinier 2002b; Katopodis *et al.* 2013). This helps guide the fish to the pass entrance, as long as there is enough depth in the area (ideally ≥ 0.60 m) so they can reach the inside of the fish pass without being too exposed to predators, becoming injured with scrapes or suffering stress. If in the theoretical location (*i.e.*, as further upstream as possible) there isn't a minimum depth (< 0.60 m), then it is not considered suitable and instead the best option would be one immediately downstream from it, but deep enough.

When there is a straight weir across the water course (perpendicular to the water flow), locations close to the bank and/or wherever a large volume of flow concentrates are preferable (Figure 6) (Larinier 2002b). Figure 7 shows several configurations for different weir structures which are not recommended, because the weir structure deters fish from finding the fish pass entrance.

[12] There can be many different cases and the flow over the weir is also an important factor. A common case are very wide weirs, with an ecological flow which is uniformly distributed (or not) over the crest, in a braided stretch of river, divided into several channels. In this case it is recommended to choose the smaller channel (in terms of size and water flow) to know which would be the best place to locate the fishway. The case study (Section 5) analyses a similar situation.

Thus, for this parameter the aptness of the following aspects must be assessed (Table 5), and afterwards a score to the variable must be assigned according to an average value:

- Location next to the bank (or without a flow over the crest between the bank and the fish pass).
- Location as further upstream as possible (or without a flow over the crest between the fish pass and the weir abutment located upstream).
- Location next to the base of the obstacle (or far from it, if all the water flow concentrates through the fishway).
- Location where a larger volume of flow concentrates (if there is an area with natural discharge, an attraction flow from a spillway or next to returning turbine water from a hydropower station at the foot of the dam).

**Table 5.** Assessment of the different aspects to be considered for parameter $U_E$[13].

| Degree of aptness | Score |
|---|---|
| Very suitable | 10 |
| Suitable | 6.7 |
| Not suitable | 3.3 |
| Very unsuitable | 0 |

[13] If all the water flow in that stretch of the river concentrates through the fishway, the location will always be optimal.

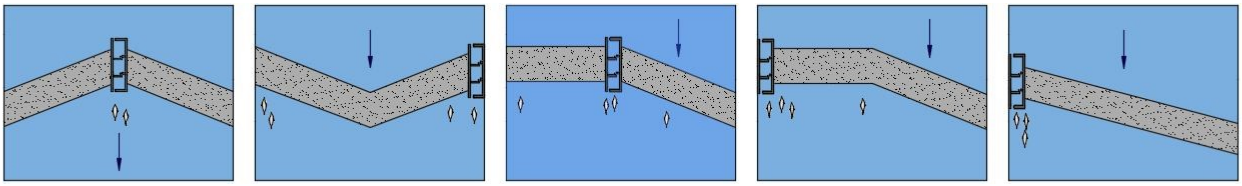


**Figure 5.** Suitable locations based on the topography. Any location where a major portion of the flow concentrates can also be considered ideal.

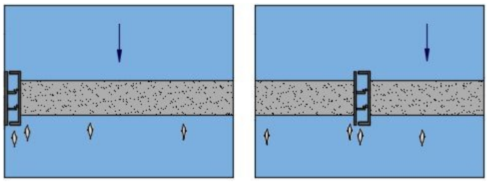


**Figure 6.** Indifferent locations (or not?). Being close to the banks is always more interesting.

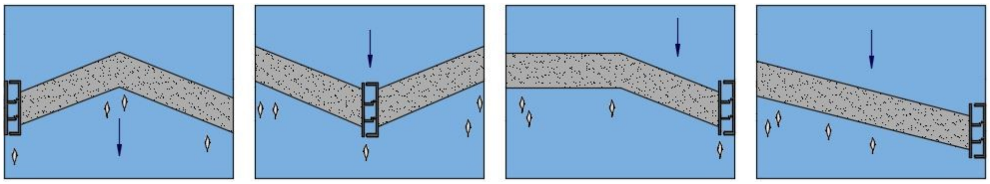


**Figure 7.** Locations which are not recommended, unless there is an attraction flow to help fish to find the fish pass. For example, the location may not be appropriate, but if all the water flow concentrates there, then it is optimal.

## 4.1.2. Entrance (*E*)[14]

### 4.1.2.a. Difference in water level between river and the lower pool ($\Delta H_E$)

This variable represents the difference in water level or head drop ($\Delta H_E$) (m) measured between the water level in the river and the water level in the most downstream pool (Figure 8). If the head drop is too small, the attraction to the fishway by the water flowing through it is very limited, thus reducing the chances the fish will enter the fishway. On the other hand, if this variable is too large, the proportion of individuals from

[14] If there are two entrances, each one of them will be assessed independently.

the fish population that are able to overcome the current and enter the fish pass is small or null[15].

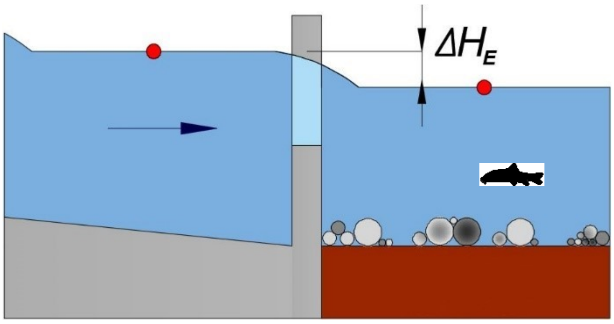



**Figure 8**. Explanation of $\Delta H_E$ in a fish pass and measuring points (in red).

**Figure 9.** Difference in water level at the entrance: small (left); suitable (centre) and too large (right).

[15] This value varies depending on the discharge, and is only considered a problem if it is very high or very small for ordinary flows. Sometimes, if the discharge during the field visit is within the top range of ordinary flows during the migration period, it can happen that the entrance is submerged and the head drop is small. In this case, the water velocity can also attract fish and it must be checked whether it is > 1.0 m/s at the entrance (using the continuity equation: $v = Q/AreaM$). If that is the case, the variable is assigned a score of 5. If the entrance opening has a gate or slot operating system to regulate the head drop $\Delta H_E$, the impact is minimal. If the opposite occurs (excessive head drop with low flows), there is a bigger problem. It is important to consider all of these issues during the visit to the fish pass.

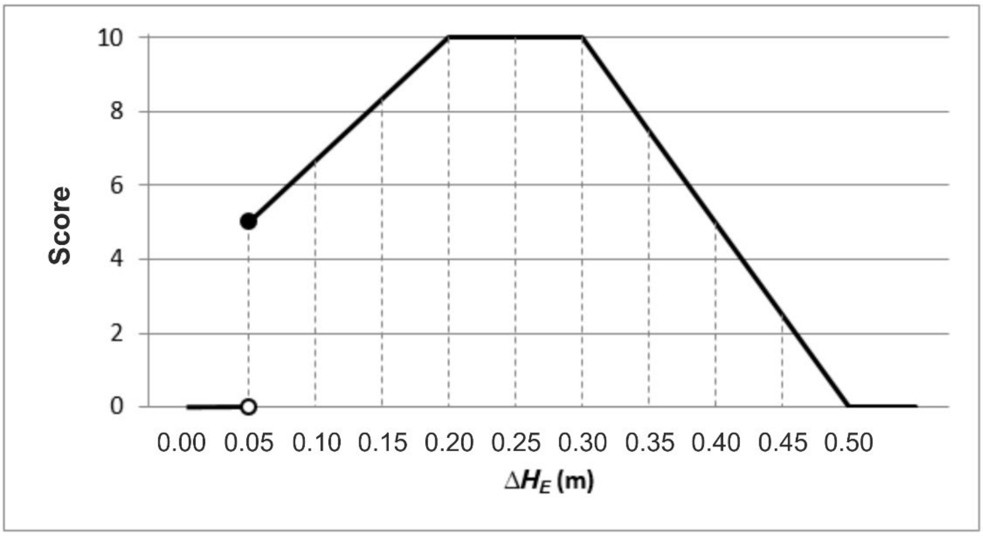



**Figure 10**. Score for variable $\Delta H_E$. A value lower than 0.05 m would result in a zero score, if the water velocity is less than 1.0 m/s. If the water flow is 1.0 m/s or more, then the score assigned would be 5.

### 4.1.2.b. Depth at entrance ($h_E$)

This variable represents the water height ($h_E$) (m) at the fish pass entrance (Figure 11). It is measured as the difference (m) between the water level in the river and the sill height (the edge of the entrance opening) (m). If this height is too small, the fish may be injured with scrapes or are forced to jump to enter the pass, although, above a certain threshold (20 cm), no access issues are expected.

When $h_E$ is less than 10 cm, the type of discharge is considered to be "free" or “plunging” in terms of the fish moving upstream, something that is also contemplated in sections

4.1.2.c, d and f. In this case, and also in a conventional free discharge, the variable is calculated as (h) the height difference between the water level in the pool and the sill height (the edge of the fish entrance opening).

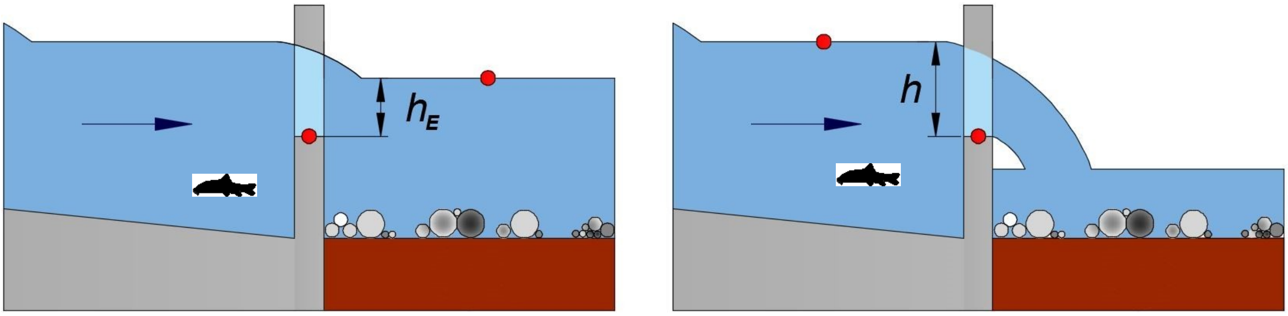



**Figure 11**. Measuring $h_E$: side view of entrance and where measurements should be taken (shown in red) for a submerged discharge (left) and a free discharge (right).


**Figure 12.** Diagram of depth at the entrance, where the edge of the entrance opening is shown in yellow and the variable is shown in red.

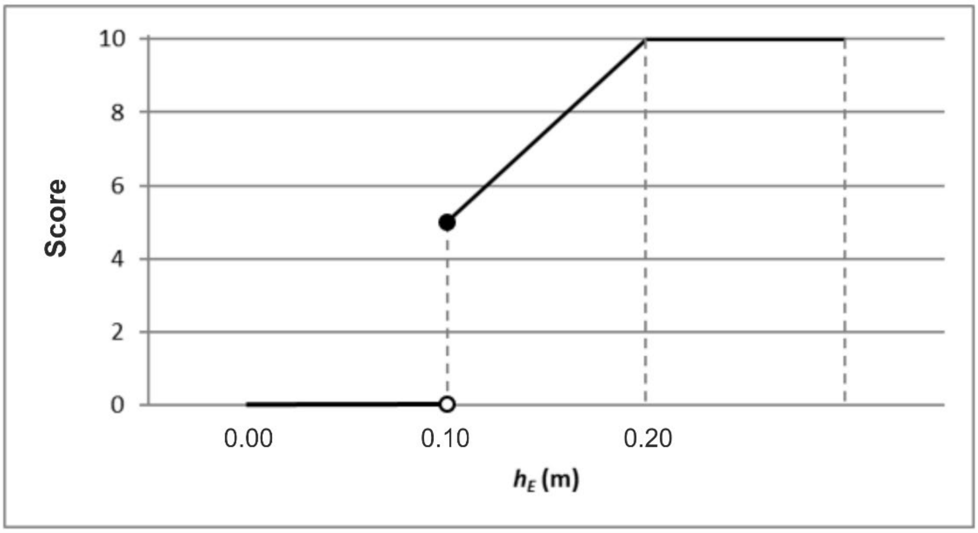



**Figure 13**. Score for variable $h_E$. If there is a free discharge, the variable is calculated as the water level in the pool measured from the sill (h). Likewise, when $h_E$ is less than 0.10 m in a submerged discharge, the discharge is considered to be a "free" discharge and $h_E = h$.

### 4.1.2.c. Width at entrance ($b_E$)

This variable represents the width ($b_E$) (m) at the entrance through which fish enter the fishway (Figure 14). If it is an orifice, the height (*d*) should be considered as well as the width (*b*) to calculate the area ($m^2$) ($Area = b_E \cdot d_E$). If the entrance element is too small, there is a high risk of it becoming obstructed by debris driften by the current, of fish may be injured with scrapes, or the larger individuals may find difficult to get through. When there is a combination of an orifice and a notch, the final value will be the average of both of them. If the entrance opening is trapezoidal in shape instead of rectangular, $b_E$ is considered as the mean value of the largest base at water level and the smallst base.

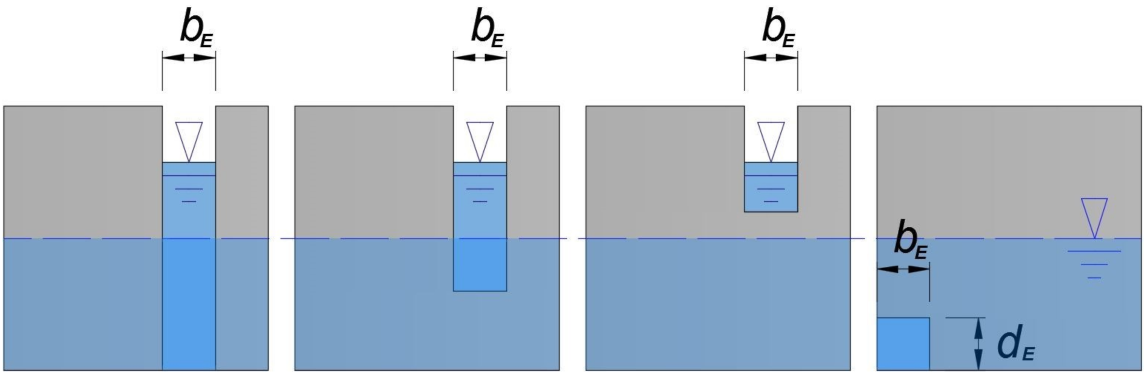



**Figure 14.** Measurement of $b_E$ in a vertical slot (left), a submerged notch (left centre), a surface notch (right centre) and a submerged orifice, together with height ($d_E$) (right) (the dashed line represents the water level in the river). If the entrance opening is trapezoidal, the variable corresponds with the mean value of the largest base at water level and the smallest base.

**Figure 15.** Entrances with different widths: 20 cm (left), 80 cm (centre) and more than 100 cm (right)

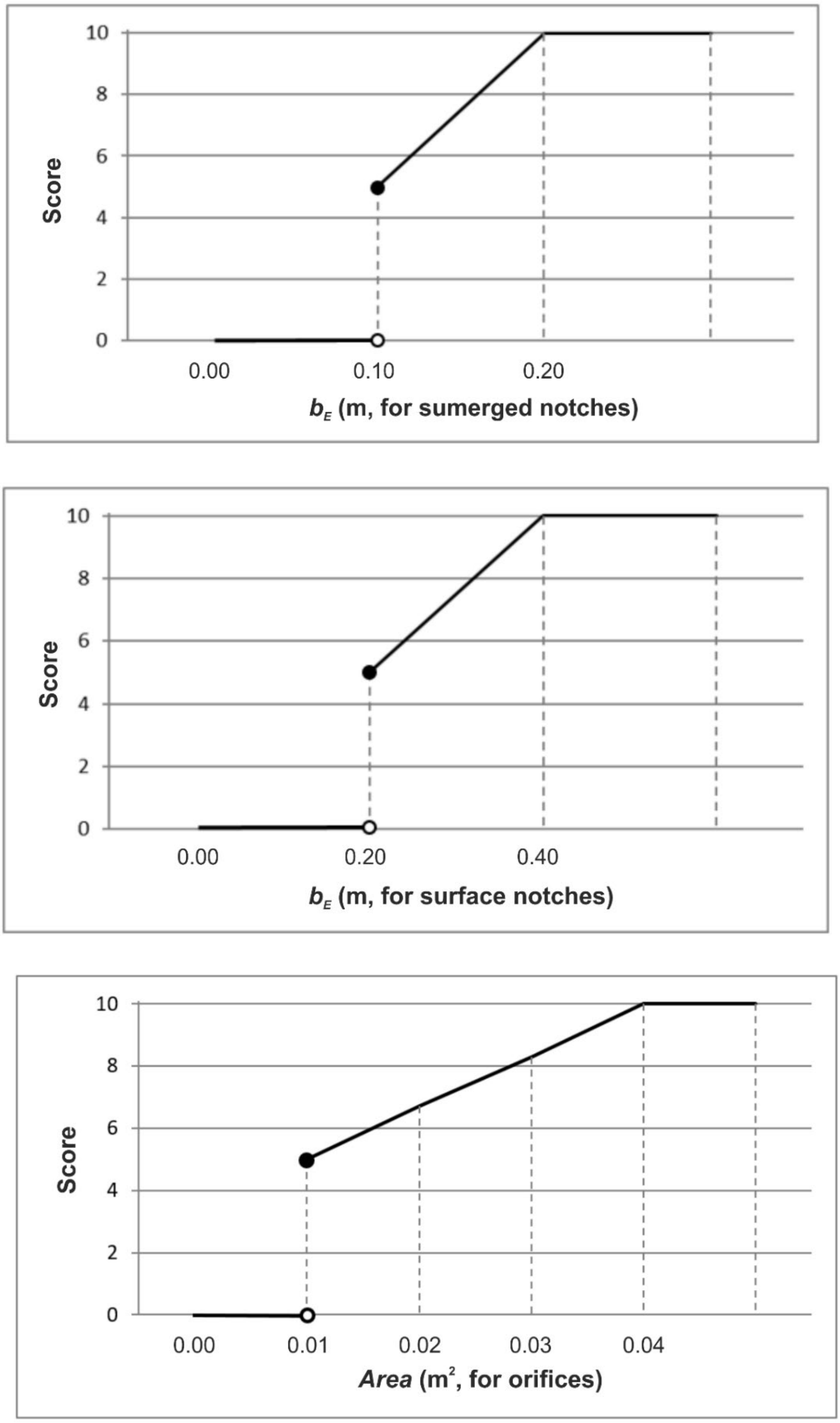



**Figure 16**. Assessment of the entrance width for submerged discharges (top), free discharges (centre), as well as the area of an orifice[16] (bottom).

### 4.1.2.d. Depth prior to entrance ($h_{prior\ E}$)

It refers to the water depth prior to the entrance that allows fish to gather, rest and gain momentum to enter the fishway from the river (Figure 17). If the depth ($h_{prior\ E}$) is too low, fish passage is more difficult. It is measured as the water depth (m) in the river in the surroundings of the fishway entrance.

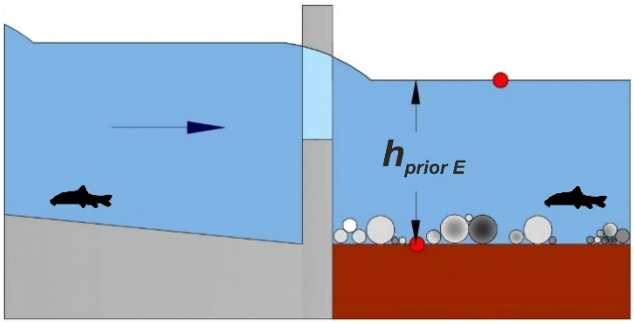



**Figure 17**. Graphical explanation of the variable $h_{prior\ E}$ and where should measurements be done (in red).

[16] Both $b_E$ and $d_E$ have to be ≥ 0.10, otherwise they will receive a score of 0. Usually the entrance opening removes sand and it has a smaller size than the remaining openings in the fishway.

**Figure 18.** View of the pool in the river at the entrance (in red) of a fish pass.

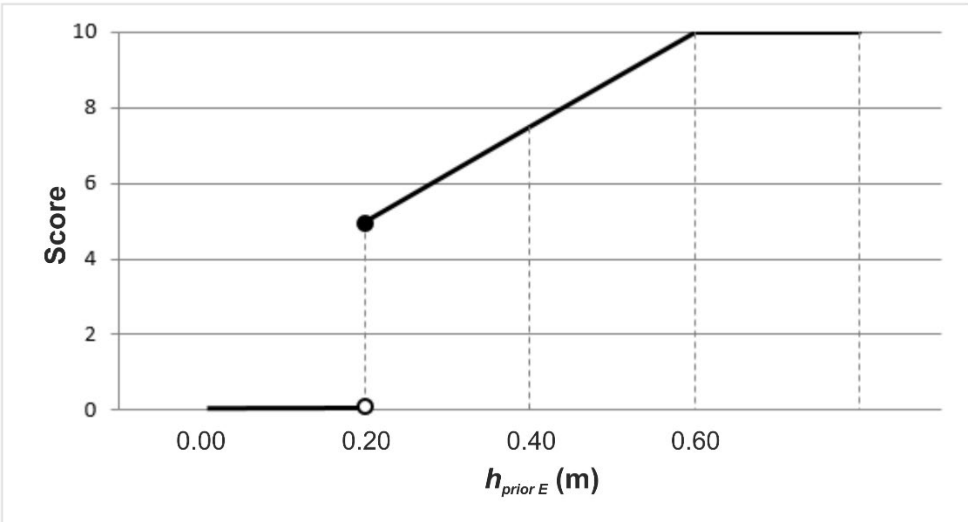



**Figure 19**. Score for variable $h_{prior\ E}$. When the depth is less than 0.20 m, the resulting score is zero. If there is a free discharge, a minimum depth at the base > $2 \cdot \Delta H$ is needed to obtain a score of 5.

### 4.1.2.e. Orientation of entrance in relation to the river ($Ort_E$)

It indicates the alignment of the fish entrance in relation to the longitudinal axis of the river (sexagesimal degrees) (Figure 20).

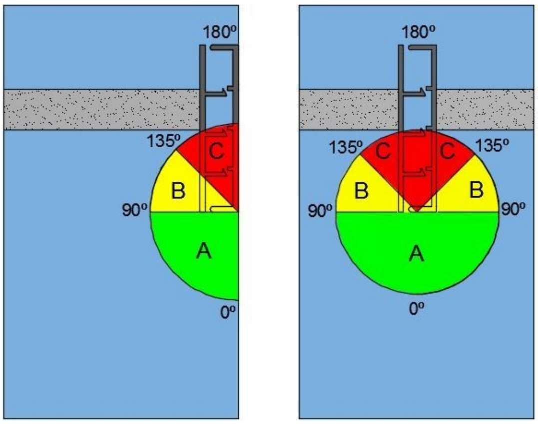



**Figure 20**. Diagram to rate the orientation of the entrance.

**Table 6**. Assessment of $Ort_E$ based on the orientation of the entrance to the fish pass.

| Category | Description | Score |
|---|---|---|
| A | The entrance is parallel to the current and in the same direction of approaching fish (0º ≤ α ≤ 90º) | 10 |
| B | The entrance is perpendicular to the current (90º < α ≤ 135º) | 1-5[17] |
| C | The entrance is parallel to the current and in the opposite direction of approaching fish (135º ≤ α ≤ 180º) | 0 |
| NOTE: α is the angle between the entrance and the longitudinal axis of the river | | |

### 4.1.2.f. Type of entrance ($T_E$)

It refers to the entrance into the fish pass (Figure 21). Different types of discharges attract fish in a different way and are more or less recommended, and this variable tries to quantify it.

[17] Based on proximity to zone A and the local characteristics of the entrance.

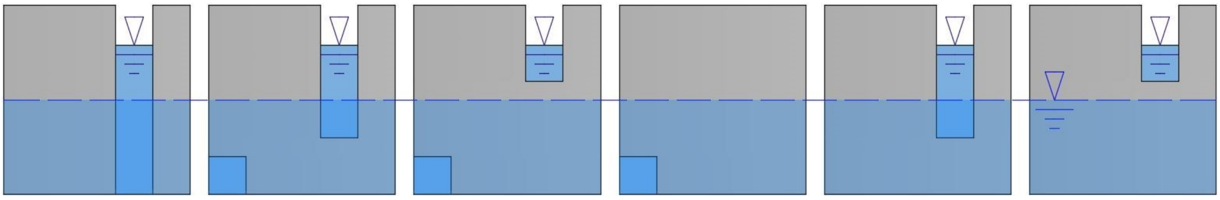


**Figure 21**. Types of fish pass entrances (the dashed line represents the water level in the lower pool), from left to right: vertical slot (up to *p*<0.25 m), submerged notch + orifice, surface notch + submerged orifice, submerged orifice, submerged notch and surface notch.


**Figure 22.** Different types of fishway entrances: vertical slot (A), surface notch + submerged orifice (B), submerged notch + submerged orifice (C), submerged notch (D), and surface notch (E).

**Table 7**. Scores for the different types of entrances.

| Type of entrance element | Score |
|---|---|
| Vertical slot ($p$ < 0.25 m; with or without an orifice) | 10 |
| Submerged notch + submerged orifice | 10 |
| Surface notch + submerged orifice | 8 |
| Submerged discharge notch | 7 |
| Submerged orifice at the bottom | 5 |
| Surface notch | 5 |
| Orifice with a free discharge | 0 |

### 4.1.3. Passage (*Ps*)[18 and 19]

#### 4.1.3.a. Difference in water level between consecutive pools ($\Delta H_{Ps}$)

This variable, also named ashead drop, represents the difference in water level ($\Delta H_{Ps}$) (m) between two consecutive pools (Figure 23). If the head drop is too small, fish are less motivated to swim upstream. On the other hand, if it is too large, moving from one pool to the next one up will be more difficult, and fewer fish will be able to get through the pass[20].

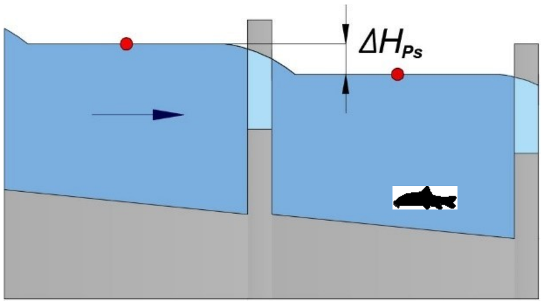



**Figure 23**. Explanation of variable $\Delta H_{Ps}$ and the measuring points (in red).

[18] Sometimes because of construction flaws or obvious anomalies, the pools are not uniform. In this case, it is not possible to consider only a standard pool, and instead odd pools must also be taken into account, applying equation 5. It can happen that the upper pool is a odd pool. In that case, all variables are calculated for it, including *ΔH*, which would be considered again at the exit.

[19] If the openings between pools are totally or partly blocked, the water level in one or several pools may change. If this happens, it is recommended the use of the topographic height of the openings/bottom of pools rather than considering it an odd pool.

[20] This value varies depending on the river discharge, which affects the head drop in the pools closer to the entrance. Sometimes, if the discharge during the field visit is within the top range of ordinary flows during the migration period, it can happen that the entrance is submerged and the head drop is small in the pools closer to the entrance. In that case, the water velocity also attracts fish and usually it is not a problem for passing fish. If the opposite occurs (excessive head drop with low flows), there is a bigger problem. It is important to consider all of these issues during the visits to the fish pass.

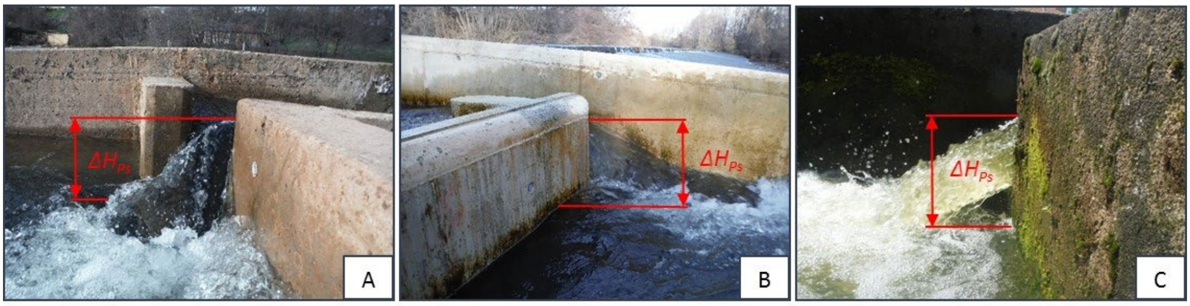



**Figure 24.** Diagram of the difference in water level between consecutive pools in fishways with vertical slots (A), submerged notches (B) and free discharges (C).

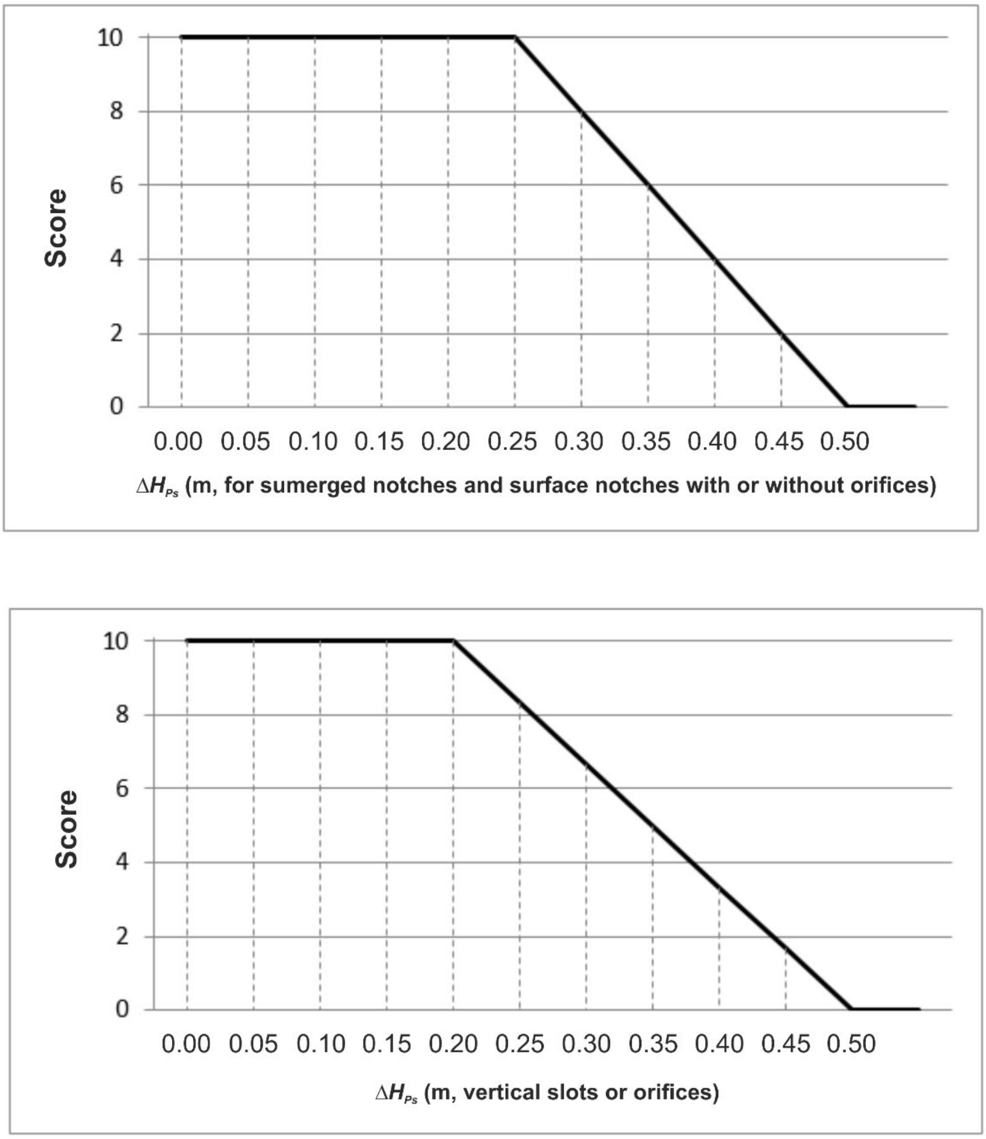



**Figure 25**. Score for variable $\Delta H_{Ps}$ for submerged notches and surface notches[21] (with or without orifices) (top), and for vertical slots or orifices (bottom).

[21] The free discharge will be effective if the water depth at the base is > 2 · Δ*H* (otherwise the score will be 0).

### 4.1.3.b. Volumetric power dissipation (*N*)

This variable represents the energy of the water flow which dissipates in a certain volume of water inside the fishway pools (*N*) (W/m$^3$) (Eq. 9). If the value of this variable is too small, there is no negative effect on fish, whereas if it is too large, water recirculates and there is turbulence inside the pools which disorients fish and interferes with their movement up the pass. It is calculated with the following equation:

$$N = \frac{g \cdot \rho \cdot Q_{fishway} \cdot \Delta H'}{B \cdot L \cdot t_{med}} \qquad \text{(Eq. 9)}$$

Where *N* is the power dissipation per unit volume (W/m$^3$); *g* is the acceleration due to gravity (9.81 m/s$^2$); $\rho$ is the density of water (kg/m$^3$); $\Delta H'$ is the difference in water level between the pool under study and the previous one (m); *B* is the width of the studied pool (m); *L* is its length of the pool (m); and $t_{med}$ is the mean water level in the studied pool (m).

**Figure 26.** Pools where the volumetric power dissipation has a low value (< 50 W/m$^3$) (left), a typical value (150 - 175 W/m$^3$) (centre) and a too high value (> 350 W/m$^3$) (right).

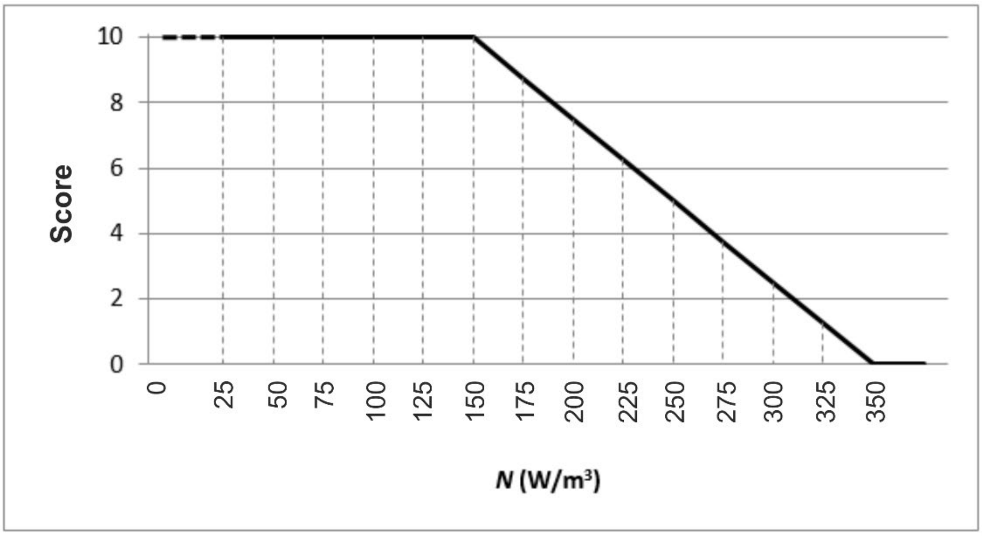



**Figure 27**. Scoring graph for variable *N.*

### 4.1.3.c. Mean water level in pools ($t_{med}$)

This variable represents the average depth ($t_{med}$) (m) inside the fishway pools (Eq. 10 and figure 28). If the value of this variable is too small, it can make it difficult for individuals to move inside the pools, not allowing them to rest; fish can be exposed to predators, become injured with scrapes and suffer great stress. All of this can discourage fish from climbing up the fishway. It is calculated with the following equation:

$$t_{med} = \frac{p + h_{Ps} + p' + h'_{Ps} - \Delta H'_{Ps}}{2} \qquad \text{(Eq. 10)}$$

where $p$ is the sill height of the opening downstream from the pool under study (m) (Figure 28); $h_{Ps}$ is the height difference between the water level in the downstream pool and the downstream sill height (m) (Figure 28); $p'$ is the sill height of the opening upstream from the pool under study (Figure 28); $h'_{Ps}$ is the height difference between the water level in the pool under study and the upstream sill height (Figure 28); and $\Delta H'_{Ps}$ is the difference in water level between the pool under study and the upper one[22 and 23] (Figure 28).

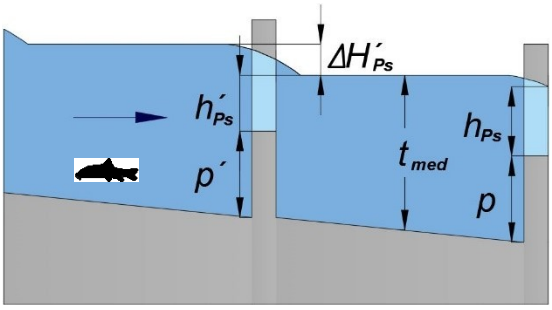



**Figure 28**. Graphical explanation of the variables used to calculate $t_{med}$.

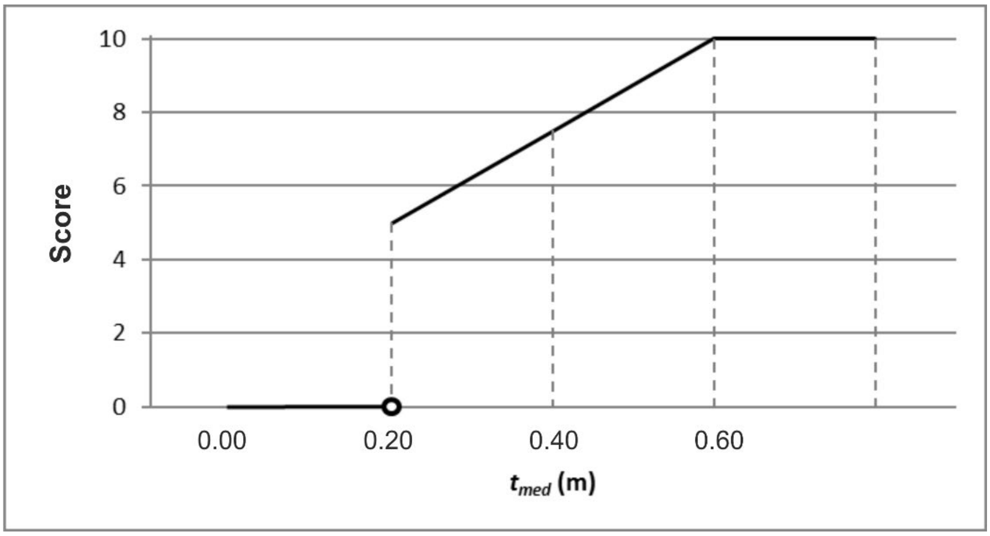



**Figure 29**. Score for variable $t_{med}$[24] When the mean depth is less than 0.20 m, the resulting score is zero.

[22] In vertical slot fishways the value of p and $p'$ is usually 0.00 m (although up to p<0.25 m a fishway can be considered as a vertical slot because the hydraulic behaviour similarity).
[23] If it is not possible to measure the different variables required to calculate the mean water level, the measurement of depth in the middle of the pool can be used instead.
[24] If there is a free discharge, a minimum depth at the base > $2 \cdot \Delta H$ is needed to obtain a score of 5.

### 4.1.3.d. Water depth in openings between pools ($h_{Ps}$)

This variable represents the water depth in the openings ($h_{Ps}$) (m) through which fish move between pools (Figura 30). For submerged flows, it is measured as the height difference between the sill height (the edge of the notch or slot)[25] and the water level in the lower pool.

If the value of this variable is too small, fish can become injured or are forced to jump from one pool to the next, whereas if it is too large, there is no negative effect on fish.

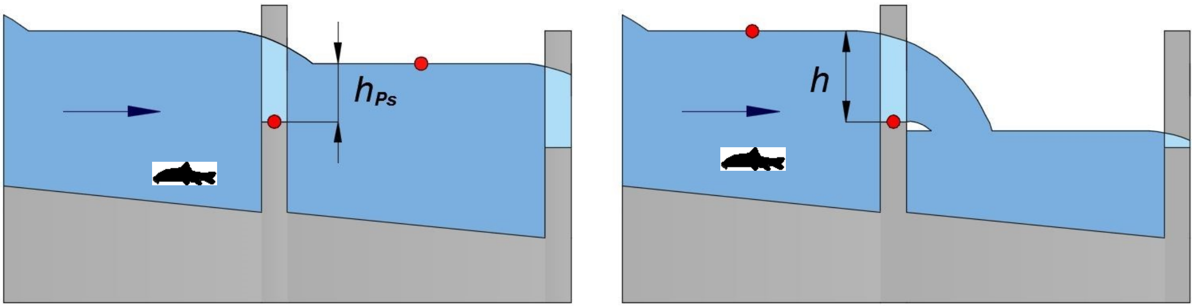



**Figure 30**. Side view of variable $h_{Ps}$ in an opening, showing the measuring points (in red) for a submerged discharge (left) and a free discharge (right).

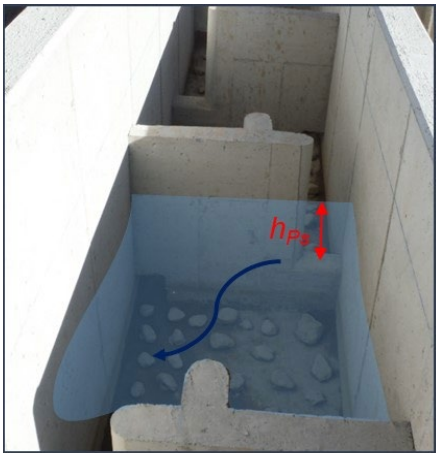



**Figure 31.** Example of the water depth (in red) as fish pass through a notch (the blue arrow shows the direction of the water flow).

[25] Usually $p$ = 0 in vertical slots. If the pools were only connected through a submerged orifice, this variable would be superfluous, since it is contemplated in the previous section.

When $h_{Ps}$ is less than 10 cm, the type of discharge is considered to be "free" in terms of the fish moving upstream, something that is also contemplated in sections 4.1.3.c, e and f. In this case, and also in a conventional free discharge, the variable (h) is calculated as the height difference between the water level in the pool and the sill height (the edge of the opening from the lower pool).

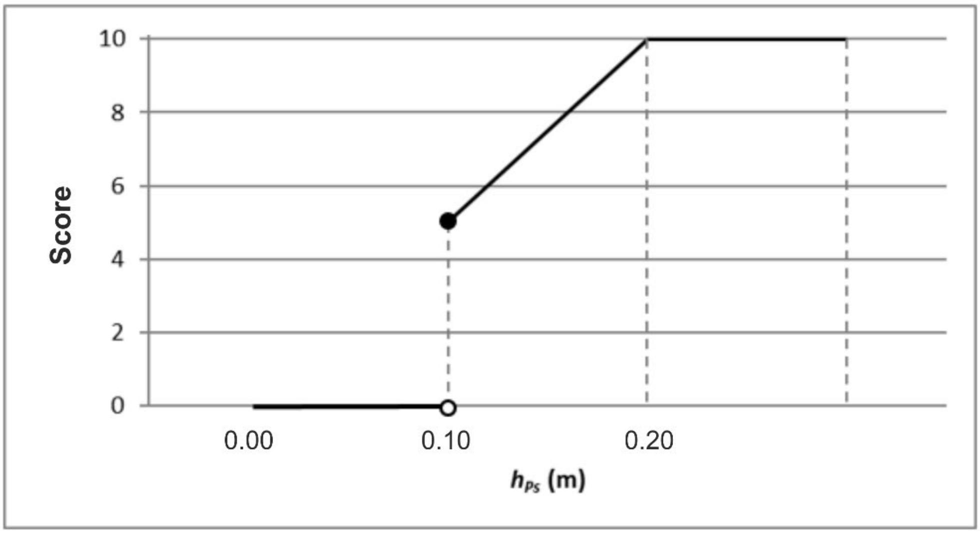



**Figure 32.** Assessment of variable $h_{Ps}$. If there is a free discharge, the variable is calculated as the height difference between the water level in the pool and the sill height (h). Likewise, when $h_{Ps}$ is less than 0.10 m in a submerged discharge, the discharge is considered to be a "free" discharge and $h_{Ps}$ = h.

### 4.1.3.e. Width of openings between pools ($b_{Ps}$)

This variable represents the width ($b_{Ps}$) (m) of the openings through which fish move between pools (Figure 33). If the opening is a submerged orifice, the height ($d_{Ps}$) should be considered as well as the width ($b_{Ps}$) to calculate the area ($m^2$) ($Area = b_{Ps} \cdot d_{Ps}$). If the width of the openings is too small, they can become obstructed by debris driften by the current, and fish may be injured with scrapes, or the larger individuals may find difficult to get through. When there is a combination of an orifice and a notch, the final value will be the average of both of them. If the opening is trapezoidal in shape instead of rectangular, $b_{Ps}$ is considered as the mean value of the largest base at water level and the smallest base.

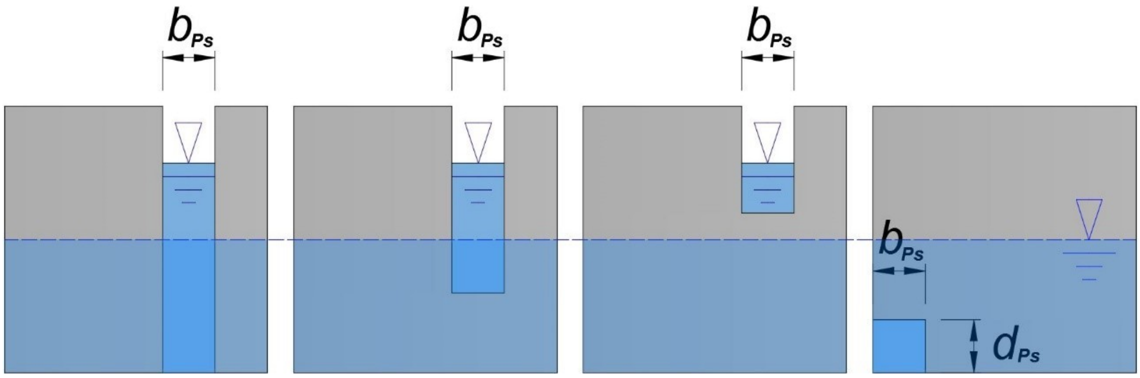



**Figure 33**. $b_{Ps}$ in a vertical slot (left), a submerged notch (left centre), a surface notch (right centre) and a submerged orifice, together with height ($d_{Ps}$) (right) (the dashed line represents the water level in the river).

**Figure 34.** Openings connecting pools with different widths: 20 cm slots (left), submerged notches, also 20 cm wide (centre), and surface notches, 133 cm wide (right).

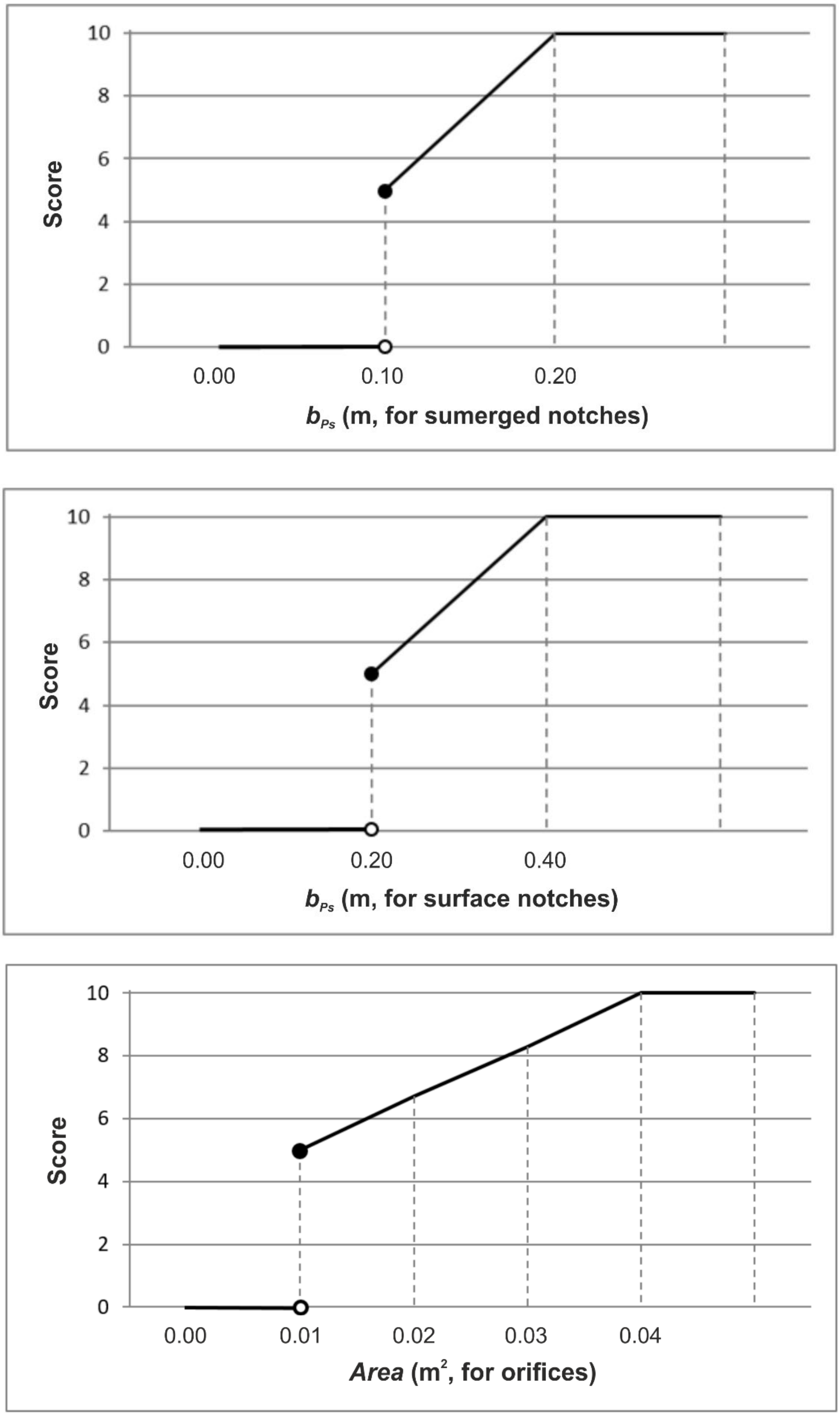



**Figure 35**. Score assigned to the width of the openings for submerged notches (top), for surface notches (centre), and for the area of a submerged orifice[26] (bottom).

[26] Both $b_{Ps}$ and $d_{Ps}$ have to be ≥ 0.10, otherwise they will receive a score of 0.

### 4.1.3.f. Type of opening between pools ($T_{Ps}$)

It takes into account the different types of openings between pools (Figure 36). This variable quantifies the different hydraulic connections and how they affect fish attraction.

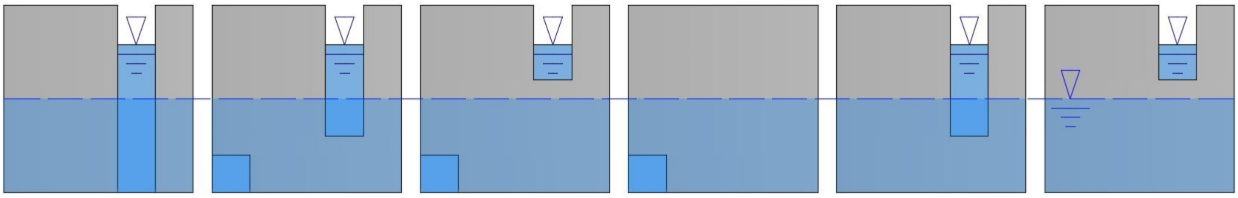


**Figure 36**. Different types of commonly used openings (from left to right) (the dashed line represents the water level in the lower pool): vertical slot (up to $p$<0.25 m), submerged notch + orifice, surface notch + submerged orifice, submerged orifice, submerged notch and surface notch.

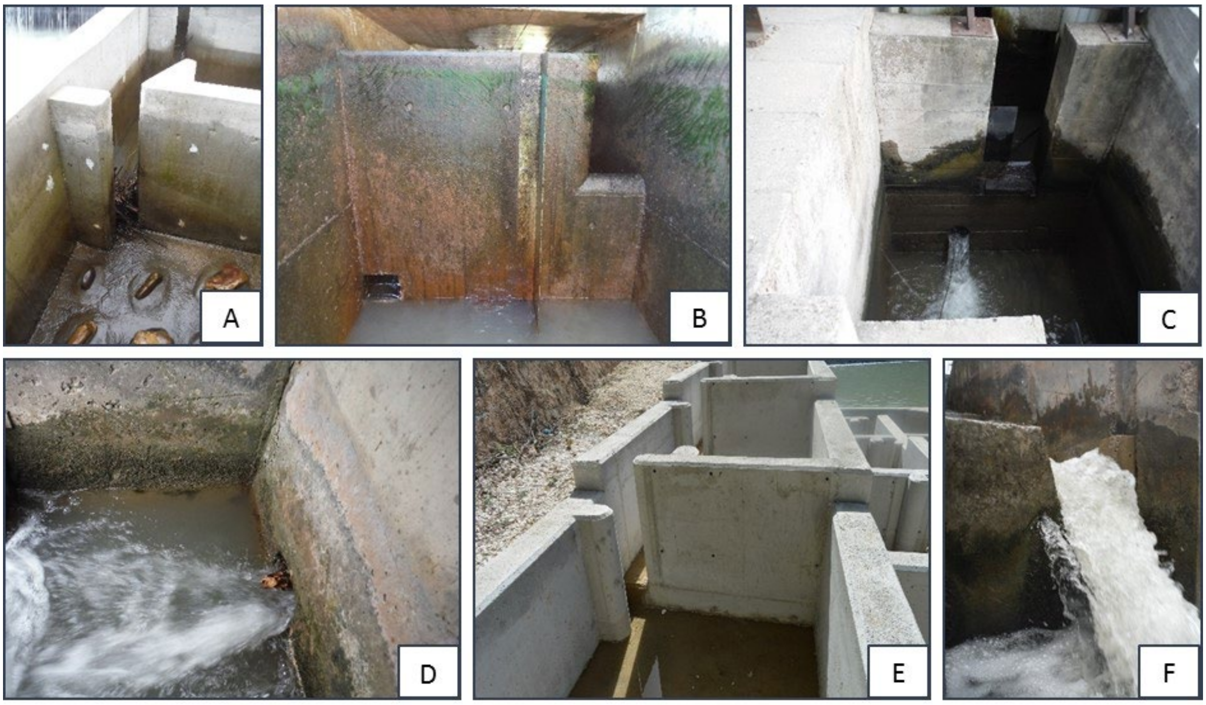



**Figure 37.** Different types of openings in pool fish passes: vertical slot (A), submerged notch + orifice (B), surface notch + submerged orifice (C), submerged orifice (D), modified vertical slot (E) and surface notch with an orifice in the cross wall (F).

**Table 8**. Assessment of the type of opening between pools

| Type of opening between pools | Score |
|---|---|
| Vertical slot ($p < 0.25$ m; with or without an orifice) | 10 |
| Submerged notch + submerged orifice | 10 |
| Surface notch + submerged orifice | 8 |
| Submerged notch | 7 |
| Submerged orifice | 5 |
| Surface notch | 5 |
| Orifice with a free discharge | 0 |

## 4.1.4. Exit (*S*)[27]

### 4.1.4.a. Difference in water level between the river and the upper pool ($\Delta H_S$)

This variable represents the difference in water level or head drop ($\Delta H_S$) (m) measured between the water level in the river and the water level in the upstream pool (Figure 38). If the difference in water level is too small, the fish may be not be so interested in leaving the fishway, whereas if it's too big, the proportion of fish able to overcome the current and exit the fish pass is small or null.

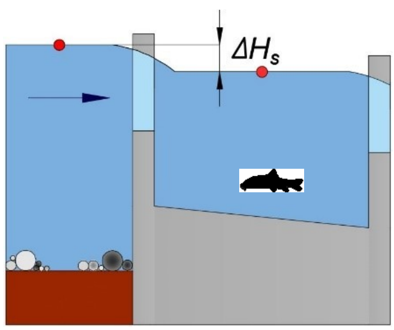



**Figure 38**. Explanation of variable $\Delta H_s$ at the exit opening with the locations where measurements should be taken (in red).

[27] If there are two exits, each one of them will be assessed independently.

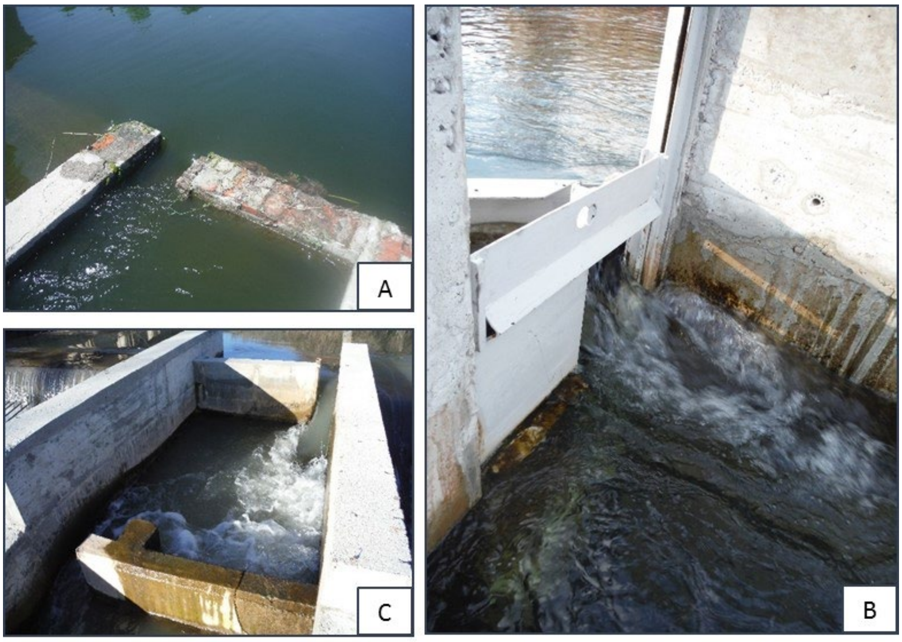



**Figure 39.** Difference in water level at the exit of a fishway: small (A), suitable (B), and excessive (C).

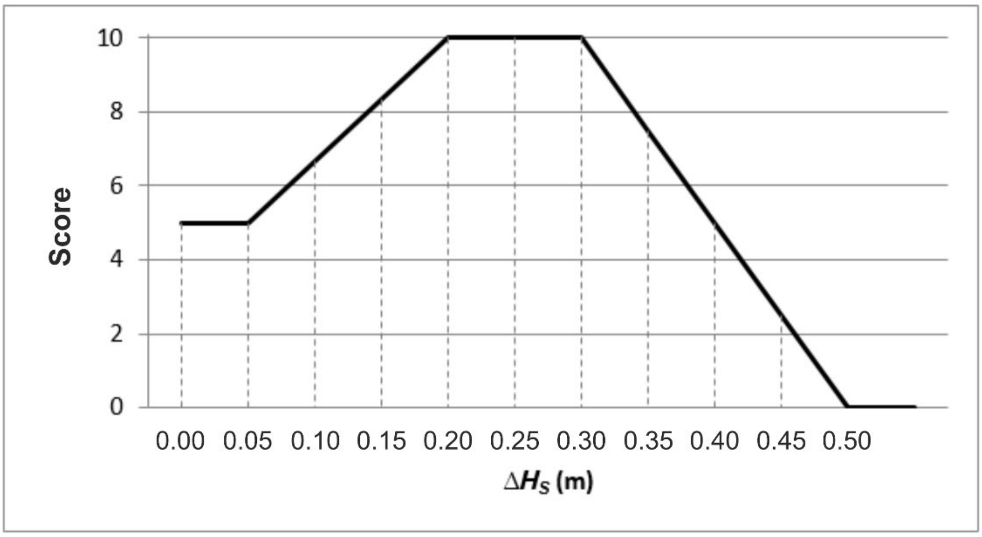



**Figure 40**. Score for variable $\Delta H_s$. If there is a free discharge, a minimum depth at the base > $2 \cdot \Delta H$ is needed to be able to assess this variable.

### 4.1.4.b. Depth at exit ($h_S$)

This variable represents the depth ($h_s$) (m) at the exit of the fishway (Figure 41). It is calculated as the height difference between the water level in the upper pool and the sill height (the edge of the opening). If it is too small, the fish may be injured with scrapes or have to jump to exit the pass.

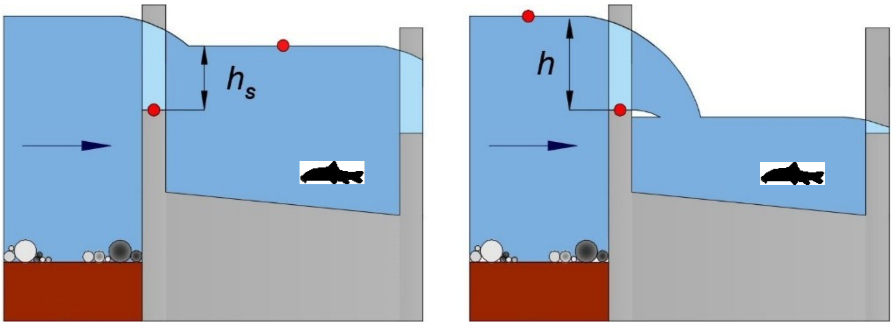



**Figure 41**. Variable $h_s$ at the exit opening with a submerged discharge (left) and a free discharge (right).


**Figure 42.** Depth at exit seen from the inside of the fish pass (closed gate).

When $h_s$ is less than 10 cm, the type of discharge is considered to be "free" in terms of the fish moving upstream, something that is also contemplated in sections 4.1.4.c and f. In this case, and also in a conventional free discharge, the variable (h) is calculated as the height difference between the water level in the river and the sill height (the edge of the exit opening).

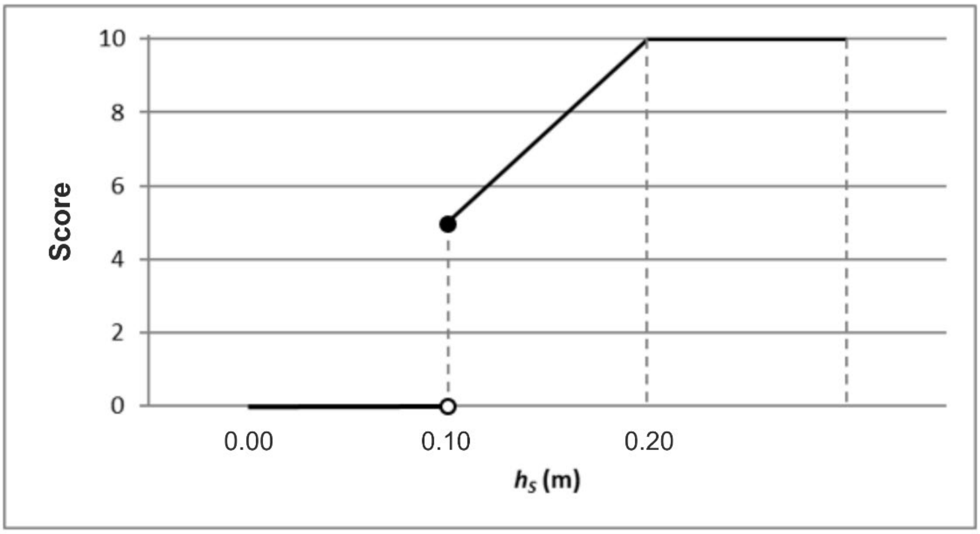



**Figure 43**. Assessment of variable $h_S$. If there is a free discharge, the variable is calculated as the height difference between the water level in the river and the sill height (h). Likewise, when $h_s$ is less than 0.10 m in a submerged discharge, the discharge is considered to be a "free" discharge and $h_s = h$.

### 4.1.4.c. Width at exit ($b_S$)

This variable represents the width ($b_s$) (m) at the exit through which fish leave the pass and return to the river (Figure 44). If the opening is a submerged orifice, the height ($d_S$) should be measured as well in order to calculate the area ($m^2$) ($Area = b_S \cdot d_S$). When there is a combination of an orifice and a notch, the final value will be the average of both of them. If the exit opening is trapezoidal in shape instead of rectangular, $b_S$ is considered as the mean value of the largest base at water level and the smallest base.

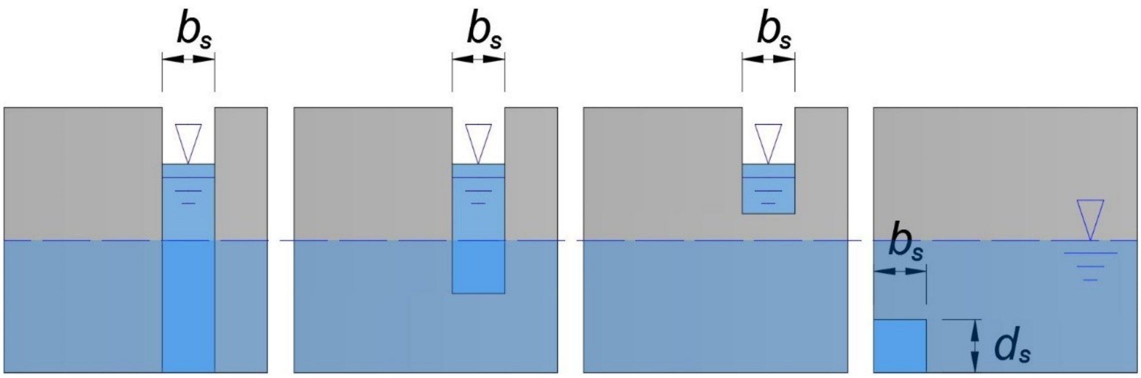
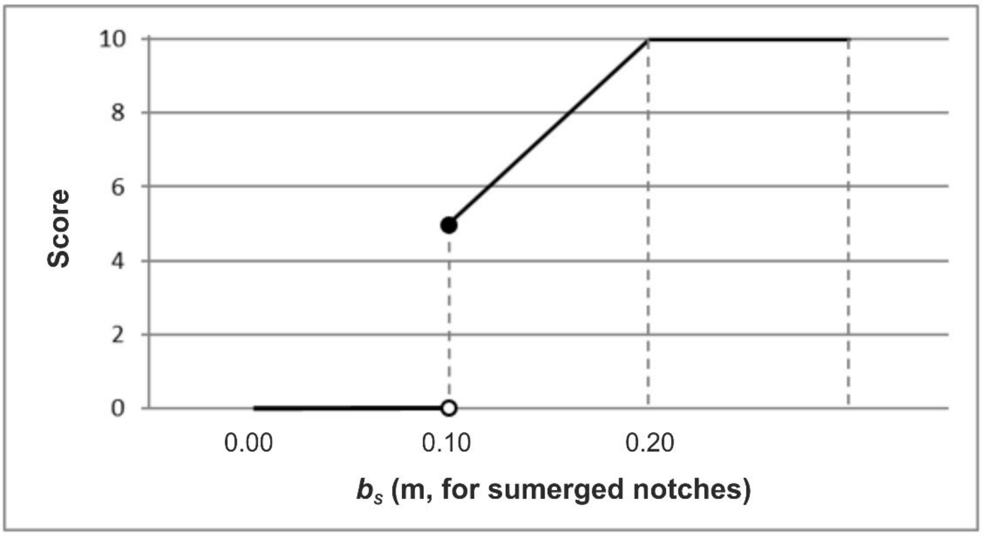
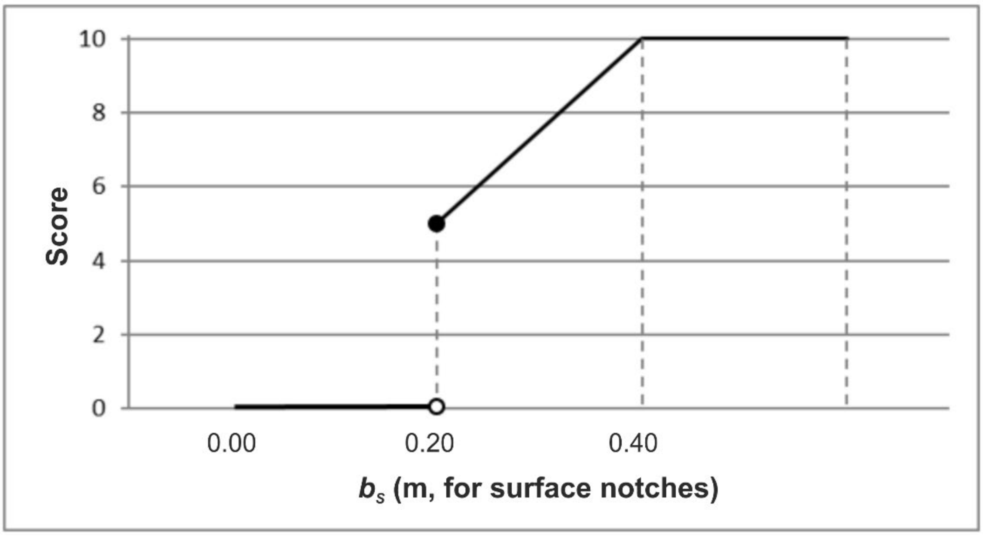



**Figure 44**. Width of different types of exit openings ($b_S$) (from left to right) (the dashed line represents the water level in the lower pool): vertical slot, submerged notch, surface notcj, and submerged orifice (with the height $d_s$).

**Figure 45.** Fish pass exits with different widths: 20 cm (left) and 50 cm (right).





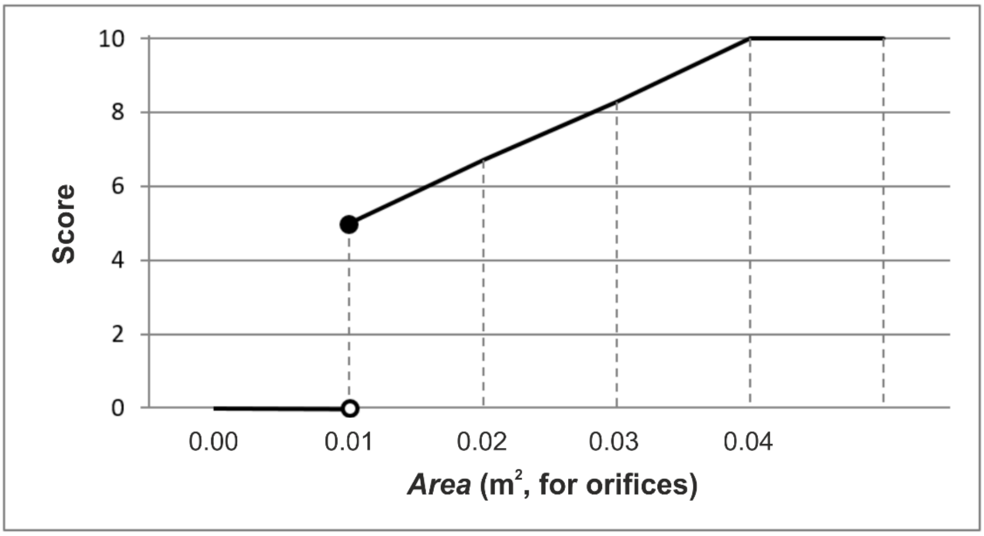




**Figure 46**. Assessment of the width of the exit openings for submerged notches (top), for surface notches (centre), and for the area of a submerged orifice[28] (bottom).

### 4.1.4.d. Depth after the exit opening ($h_{after\ S}$)

This variable represents the depth ($h_{after\ s}$) (m) in the river upstream from the fish pass (Figure 47). It is calculated as the difference in height between the water level in the river and the sediment accumulated on the channel. If the value of this variable is too small, fish may find it difficult to swim upstream when they exit the fishway without becoming injured with scrapes, suffer stress or be easily preyed upon. If the value of the variable is large

[28] Both $b_S$ and $d_s$ have to be ≥ 0.10, otherwise they will receive a score of 0.

enough fish can leave the fishway and continue swimming up the river without running any risks.

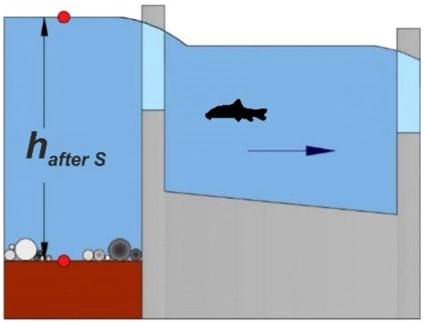



**Figure 47**. Measurement of variable $h_{after\ S}$.

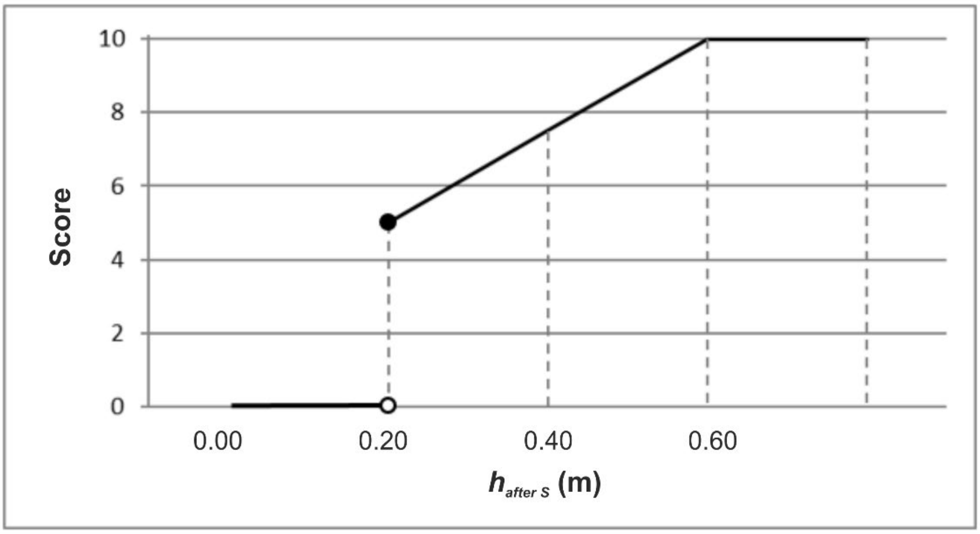



**Figure 48**. Graph to assign a score to the variable $h_{after\ S}$.

### 4.1.4.e. Orientation of exit in relation to the river (*Ort$_s$*)

This variable represents the alignment of the fishway exit in relation to the longitudinal axis of the river (figure 49).

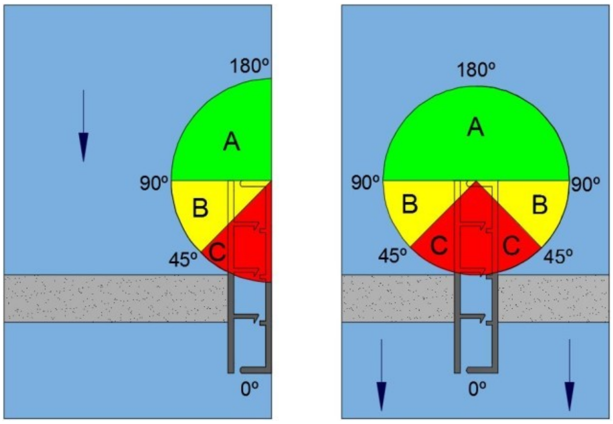



**Figure 49**. Classification of exit in terms of its orientation.

**Table 9**. Assessment of variable *Ort$_S$* based on the orientation of the exit.

| Category | Description | Score |
|---|---|---|
| A | The exit is parallel to the current, but in the opposite direction (90º ≤ α ≤ 180º) | 10 |
| B | The exit is perpendicular to the current (45º ≤ α < 90º) | 1-5[29] |
| C | The exit is parallel to the current, and in the same direction (0º ≤ α < 45º) | 0 |
| NOTE: α is the angle between the exit and the longitudinal axis of the river | | |

### 4.1.4.f. Type of exit (*T$_S$*)

It refers to the exit from the fishway that fish use to return to the river (Figure 50). This variable quantifies the attraction that the different types of discharges generate.

[29] Based on proximity to zone A and the local characteristics of the exit.

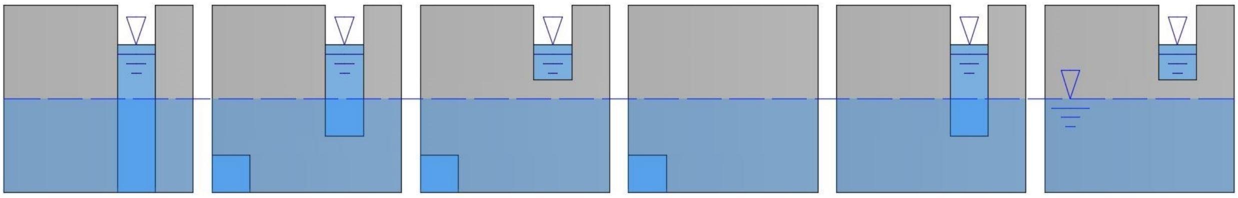


**Figure 50**. Types of fish pass exits (from left to right) (the dashed line represents the water level in the lower pool): vertical slot up to *p*<0.25 m), submerged notch + orifice, surface notch + submerged orifice, submerged orifice, submerged notch and surface notch.

**Figure 51.** Most common types of exits: vertical slot (A), submerged orifice (B), surface notch (C) and submerged discharge (D).

**Table 10**. Score assigned to each of the types of exit.

| Type of exit element | Score |
|---|---|
| Vertical slot (p < 0.25 m; with or without an orifice) | 10 |
| Notch with submerged discharge + submerged orifice | 10 |
| Surface notch + submerged orifice | 10 |
| Notch with submerged discharge | 10 |
| Submerged orifice | 5 |
| Surface notch | 5 |
| Orifice with a free discharge | 0 |

## 4.2. Relevant observations

The four categories considered include a series of relevant observations that are taken into account during the assessment of a fish pass (Table 2).

Namely, each of the aspects is analysed against what is considered optimal for ascending fish, either because it facilitates upstream fish migration or because it allows proper management and maintenance of the fish pass (Annex A.2.). Thus, based on how close an observation is to the ideal situation, it receives a score according to Table 11. Equation 5 is used to calculate the final score for the relevant observations in each category, and Table 4 indicates their average suitability.

**Table 11**. Categories to assign each of the relevant observations for scoring.

| Categories to assign the relevant observations | Resulting score |
|---|---|
| Very suitable/ very beneficial | 10 |
| Suitable/ beneficial | 5 |
| Unsuitable/ detrimental/ does not exist | 0 |

Next some guidance is presented of what is considered more or less suitable in term of scoring the main relevant observations to take into account:

**Table 12**. Guiding criteria to score the main relevant observations.

| Associated categories | Relevant observations | Score | | |
|---|---|---|---|---|
| | | **Unsuitable/ detrimental/ does not exist (0 points)** | **Suitable/ beneficial (5 points)** | **Very suitable/ very beneficial (10 points)** |
| *A, E, Ps, S* | **Maintenance and cleaning** | Obstructions completely prevent upstream movement. | Obstructions interfere with, although allow, upstream movement. | Obstructions do not affect upstream movement. There is no debris. |
| | **Accessibility** | Fishway access/entry are complicated. | Fishway access/entry are easy. | Fishway access/entry are very easy. |
| *A, E, Ps, S* | **Rounded edges** | There are no rounded edges. | Only some edges are rounded. | All the edges are rounded. |
| *E* | **Elements to regulate water level drop** | The elements create an unsuitable drop. There are no elements. | The elements create a beneficial drop, though not optimal. | The elements create an optimal drop (that any individual can overcome). |
| | **Flow discharges at entrance** | No flow helping with attraction. | A flow helps slightly with attraction | A flow helps with attraction. |
| | **Absence of other flow discharges that drive fish away from the entrance** | Large discharges and/or medium-low discharges close to the fish pass. | Medium-low discharges far from the fish pass. | There are no other discharges. |
| *Ps* | **Pool shape** | Neither *L* nor *B* comply with the design recommendations: *L:* 7-12 times β and *B*: 4-8 times β. | *L* or *B* meet the design recommendations. | Both *L* and *B* comply with the design recommendations. |
| | **Baffles in pools** | There are no baffles. | Baffles are too small and/or their size and location is unsuitable | The size and location of baffles is suitable. |
| | **Condition of the structure** | There are serious water leaks and/or major damage in walls. | There are some important water leaks or minor damage in walls. | There aren't any serious leaks or damage in walls. |
| | **Bed naturalised with stones** | There are no stones. | There are few stones or they are incorrectly located. | There are many stones. |
| | **Darkness due to elements covering the fishway** | Complete darkness in some stretches. | Partial darkness in some stretches. | There are no dark stretches. |
| | **Leeway in the fishway walls** | Insufficient leeway in the entire | Minimal leeway in the entire pass (> 20 cm - < 40 cm). | Well suited leeway in the entire pass - (≤ 20 cm). (≥ 40 cm). |
| | **Gate to regulate discharge** | There are no gates. | The discharge cannot be properly regulated and/or interferes with exiting fish. | The discharge can be properly regulated and it does not interfere with exiting fish. |
| | **Device to prevent entry of debris** | There isn't any device. | A device partly prevents entry of debris | A device prevents the entry of most debris |
| | **Safe exit** | Insufficient distance to crest (< 2 m) and to turbines or water intakes (< 5 m). | Sufficient distance to crest (≥ 2 m) or to turbines and water intakes (≥ 5 m). | Suitable distance to crest (≥ 2 m) and to turbines or water intakes (≥ 5 m). |

**NOTE: The relevant observations are explained in further detail in Annex A.2.**

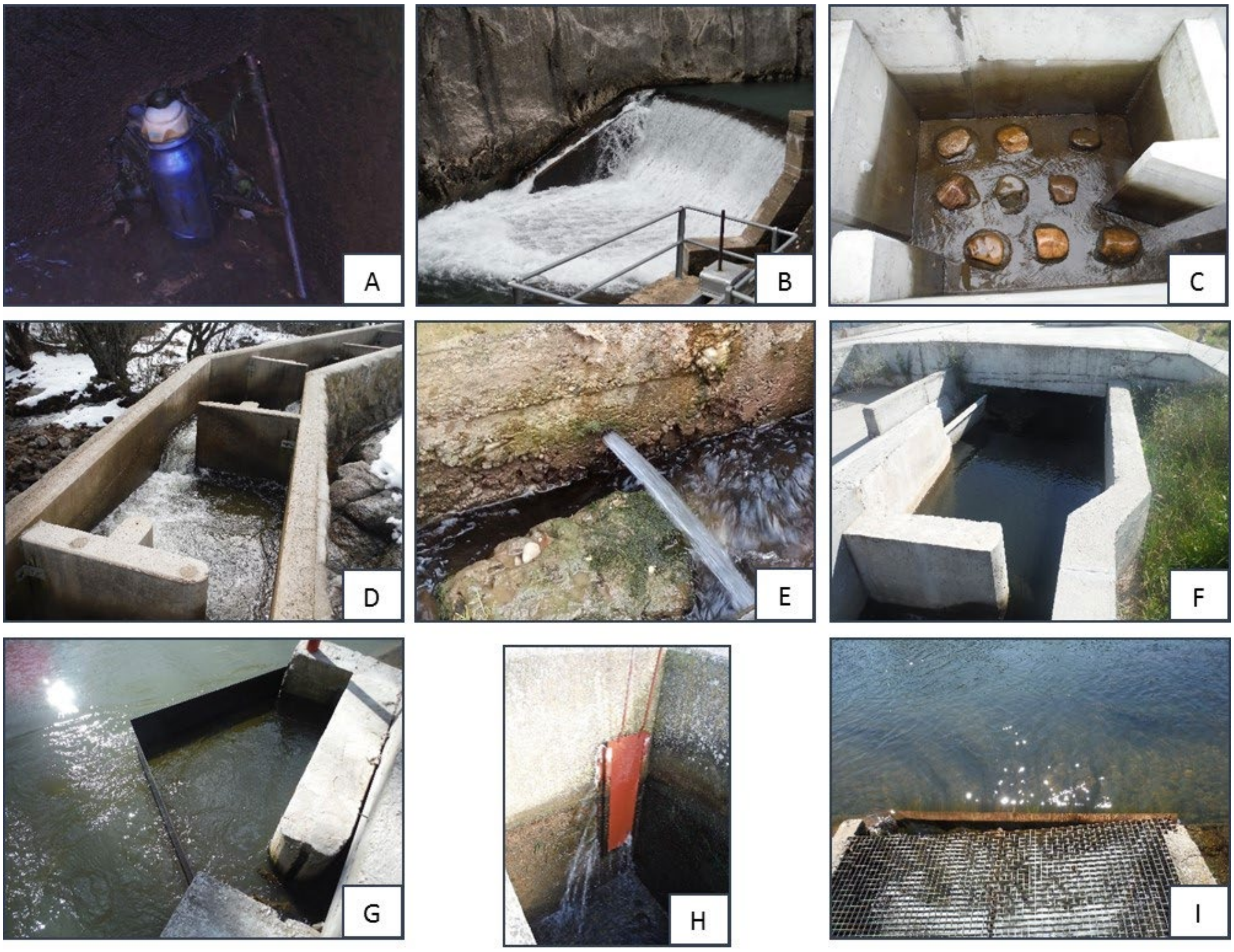



**Figure 52.** Images of some of the aspects contemplated in the relevant observations: maintenance and cleaning (A), accessibility (B), naturalised bed (C), baffles in pools and rounded edges (D), water leaks (E), darkness (F), device to prevent entry of debris (barrier to hold floating debris) (G), gate to regulate discharge (H) river depth due to silting (I).

# 5. Case study

The case study is located in the fish pass at the weir of the Almenara hydropower station, in the Tormes River, in the vicinity of the municipality of Almenara de Tormes (Salamanca, Spain (41º03´29,86´´N, 5º49´27,75´´O)).

In this river stretch there are several native fish fauna species of the *Cyprinidae* family such as the Iberian barbel and the Northern straight-mouth nase (MÍRAME-IDEDuero 2016), namely two of the three fish species the proposed methodology focuses on. In addition, there are several exotic speacies of the *Cyprinidae*, *Salmonidae*, *Poeciliidae*, and *Centrarchidae* families (MÍRAME-IDEDuero 2016).

The collection of information for the assessment process was carried out in June 2015. The studied weir has an “L” shape (Figure 53) and the crest length is about 230 m (C.H.D. 2015). The fish pass is closer to the right bank, looking downstream, and on the branch of the river that has a larger water flow, stable throughout the year, that is, where there is more attraction for fish. That branch of the river has an approximate width of 14.5 m.

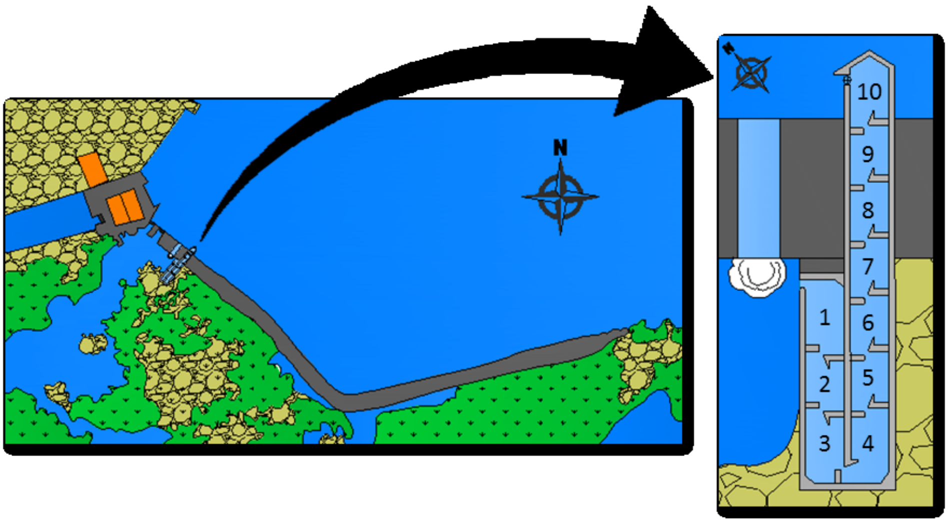



**Figure 53**. Surroundings of the fish pass (left) and detailed sketch of it with the pools numbered as considered in the assessment (right).

This fishway comprises 10 pools connected by vertical slots, two of them considered odd pools (pools 1 and 10) (Figures 53 and 54). Also on this bank, the weir crest has been lowered in a 2 m wide stretch to increase fish attraction to the fish pass (Figures 53 and 55). In addition, on the opposite bank there are two gates to empty the weir, and the turbine house of the power station (both the gates and the power station are more than 5 m further from the fish pass) (Figure 56).

**Figure 54.** The inside of the fishway, and a detailed view of one of the vertical slots that connect two of the pools (right).

**Figure 55.** Water slide to attract fish (left) and its outflow next to the fishway entrance (in red) (right).

**Figure 56.** Gates to empty the weir, located on the bank opposite from the fish pass, next to the hydropower station.

The size of a standard pool is 2.40 m long x 1.80 m wide x 1.03 m mean water depth (taking into account pools from 2 to 9, from upstream, although excluding from the calculation the pools 2 and 4), with an estimated fishway discharge of 0.31 $m^3/s$) (Figure 57). The pools are connected by vertical slots with an average width of 21 cm (Figures 54 and 57).

**Figure 57.** Standard pool.

The fish pass has a gate to regulate the water inflow through the structure, which facilitates cleaning and maintenance (Figure 58). It also has a baffle that reduces the amount of debris carried by the water into the fishway (Figure 58). The exist is located approximately 1.50 m from the weir's crest. Both the exit and the entrance are perpendicular to the water flow.

**Figure 58.** Gate and baffle at the point where fish exit, that, is, where water goes into the fishway.

The annual average discharge in the Tormes river in the stretch under study is 26.12 $m^3/s$ (gauging station 2087 in Salamanca, data from 1915 to 2012 (CEDEX 2015)). The mean monthly discharge of May is 32.30 $m^3/s$ and the one of June is 23.63 $m^3/s$ (data from 1915 to 2012 (CEDEX 2015)). During the assessment, in June

2015, during the cyprinid breeding migration period, the discharge measured by the gauging station was 17.99 $m^3/s$ (Automation Hydrological Information System of the Duero 2015).

Furthermore, the established environmental flow for the stretch of the river where the fish pass is found is 2.11 $m^3/s$. During the assessment, the difference in the water level upstream and downstream of the barrier was 1.93 m and the water flow through the water slide to attract fish was about 0.15 $m^3/s$ (calculated based on a discharge width of 2 m and a water height or head of 12 cm). The water flow through the fish pass was estimated as 0.32 $m^3/s$ and was calculated as an average of the flow through the vertical slots that connect the standard pools, and, specifically, the slots that did not have any anomalies in terms of their hydraulic behaviour (all the slots connected the pools were considered, expect for those between pools 2 and 4 and those connecting the pass with the river) (Annex A.3., Eq. 15 and 16).

To collect the data, a measuring tape and a Leica TC307 total station with prism and pole were used to measure aspects related to the essential variables.

Figure 59 and Table 13 show the data and aspects analysed in the field:

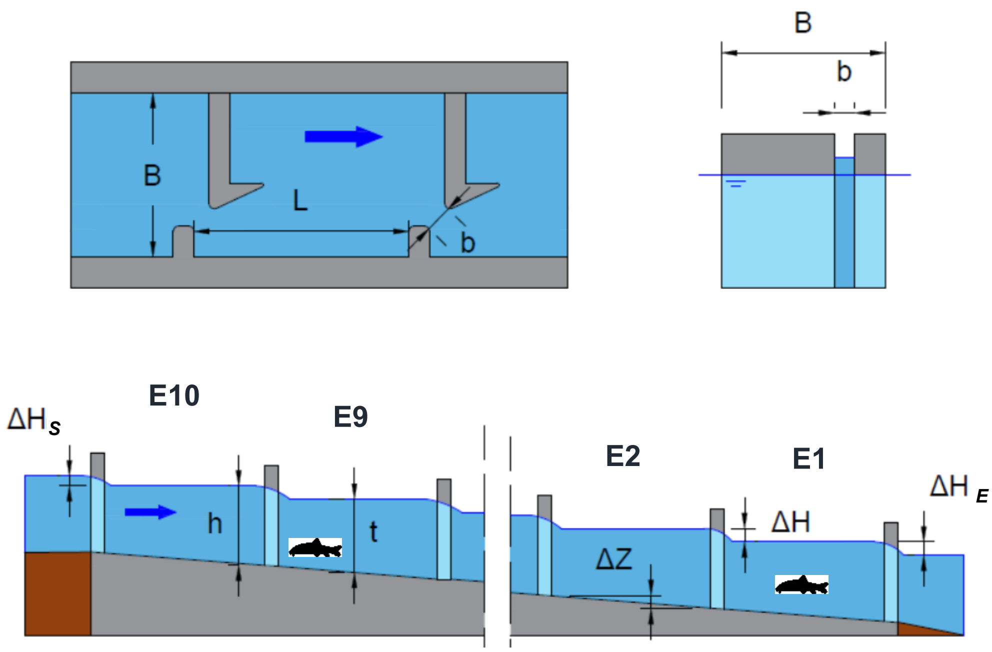



**Figure 59.** Diagram of the plan of a pool "E" (top left), cross section with a cross wall (top right) and side view of the fish pass (bottom) with the measured variables.

**Table 13**. Information collected in the field.P=pool.

| VARIABLE | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Width of downstream opening, *b* (cm)** | 40 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| **Width of pools, *B* (m)** | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 |
| **Length of pools, *B* (m)** | 3.46 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 3.0 |
| **Water level measured from bottom of opening, *h* (m)** | 0.77 | 1.04 | 0.97 | 1.29 | 1.25 | 1.23 | 1.15 | 1.14 | 1.11 | 1.03 |
| **Difference in water level between consecutive pools, *ΔH* (cm)** | 13.1 ([30]) | 33.9 ([31]) | 16.3 | 35.8 ([31]) | 11.6 | 14.6 | 10.9 | 22.9 | 16.9 | 14.0 ([32]) |
| **Difference in height (drop) between the bottom surface of consecutive pools, *ΔZ* (cm) ([33])** | 16.3 | 18.1 | 24.5 | 19.7 | 18.2 | 19.5 | 20.4 | 21.7 | 19.3 | 15.7 |

[30] Value equal to that of $\Delta H_E$.
[31] Variable affected by a partial obstruction in the slot downstream form the pool under study and which will not be taken into account to calculate the score for the standard pools.
[32] $\Delta H_S$ = 3.4 cm.
[33] The difference in height between the bottom surface of consecutive pools, Δ*Z*, is used to estimate the difference in water level, Δ*H*, when there are obstacles that affect the normal hydraulic function of the fish pass.

**Table 14**. The information collected in the field is used to fill out the field form proposed in this document.

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| Number of standard pools | 8 | Total number of pools | 10 |
|---|---|---|---|

| ATTRACTION | | |
|---|---|---|
| | Parameter | Measured value |
| Essential variables | Auxiliary flow to attract fish ($m^3/s$) | 0.15 |
| | Water flow in the fishway ($m^3/s$) | 0.32 |
| | Mean river discharge during the migration period ($m^3/s$) | 2.11 |
| | Location next to the bank | Very suitable |
| | Location as upstream as possible | Very suitable |
| | Location next to the base of the obstacle | Very suitable |
| | Location where a large volume of flow concentrates | Very unsuitable |
| Relevant observations | Maintenance and cleaning | Very suitable |
| | Accessibility | Suitable |

| ENTRANCE | | |
|---|---|---|
| | Parameter | Measured value |
| Essential variables | Difference in water level between the river and the lower pool (m) | 0.13 |
| | Water level measured from sill at entrance (m) | 0.77 |
| | Depth at the entrance (m) | 0.64 |
| | Width at the entrance (m) | 0.40 |
| | Area of entrance opening ($m^2$) | - |
| | Smallest dimension of opening (m) | - |
| | Depth prior to the entrance (m) | 1.21 |
| | Orientation of the entrance in relation to the river (º) | Zone A |
| | Type of entrance | Vertical slot |
| Relevant observations | Maintenance and cleaning | Very suitable |
| | Accessibility | Very suitable |
| | Rounded edges | Suitable |
| | Elements to regulate water level drop | Unsuitable/does not exist |
| | Flow discharges at entrance | Very suitable |
| | Absence of other flow discharges that drive fish away from the entrance | Unsuitable |

| PASSAGE | | $E_{standar}$ | $E_1$ | $E_{10}$ |
|---|---|---|---|---|
| | **Parameter** | **Measured** | | |
| Essential variables | Difference in water level between consecutive pools or head drop (m) | 0.16 | 0.13 | 0.14 |
| | Width of pool (m) | 1.80 | 1.80 | 1.80 |
| | Length of pool (m) | 2.40 | 3.46 | 3.00 |
| | Sill height of the opening between pools (m) | 0.00 | 0.00 | 0.00 |
| | Water level measured from edge of opening (m) | 1.14 | 0.77 | 1.03 |
| | Water depth in openings between pools (m) | 0.95 | 0.64 | 0.89 |
| | Width of openings between pools (m) | 0.21 | 0.40 | 0.21 |
| | Area of opening connecting pools ($m^2$) | - | - | - |
| | Smallest dimension of opening (m) | - | - | - |
| | Type of opening between pools | Vertical slot | Vertical slot | Vertical slot |
| Relevant observations | Maintenance and cleaning | Suitable | Very suitable | Very suitable |
| | Accessibility | Very suitable | Very suitable | Very suitable |
| | Rounded edges | Very suitable | Very suitable | Very suitable |
| | Pool shape | Very suitable | Very suitable | Suitable |
| | Baffles in pools | Very suitable | Very suitable | Very suitable |
| | Condition of structure | Very suitable | Very suitable | Very suitable |
| | Bed naturalised with stones | Very suitable | Very suitable | Very suitable |
| | Darkness due to elements covering the fishway | Very suitable | Very suitable | Suitable |
| | Leeway in the fishway walls | Very suitable | Very suitable | Very suitable |

| EXIT | | |
|---|---|---|
| | **Parameter** | **Measured value** |
| Essential variables | Difference in water level between river and the upper pool (m) | 0.03 |
| | Water level measured from sill at exit (m) | 0.92 |
| | Depth at the exit (m) | 0.89 |
| | Width at the exit (m) | 0.50 |
| | Area of exit opening ($m^2$) | - |
| | Smallest dimension of opening (m) | - |
| | Depth after the exit opening (m) | > 0.60 |
| | Orientation of exit in relation to the river (º) | Zone A |
| | Type of exit | Vertical slot |
| Relevant observations | Maintenance and cleaning | Very suitable |
| | Accessibility | Very suitable |
| | Rounded edges | Unsuitable |
| | Gate to regulate the discharge | Very suitable |
| | Device to prevent the entry of debris | Suitable |
| | Safe exit | Suitable |

The scores for each of the essential variables and the relevant observations within each category are shown in Table 15.

**Table 15**. Scores for the different essential variables and relevant observations.

| Category | Variable / Observation | Code | Value ($E_{standard}$/ $E_1$/ $E_{10}$) | Score ($E_{standard}$/ $E_1$/ $E_{10}$) |
|---|---|---|---|---|
| Attraction | Relative attraction discharge (%) | $Rel\ Q_{attraction}$ | 22.3 | 10.0 |
| | Location of fish entrance | $U_E$ | 3 of 4 | 7.5 |
| | Maintenance and cleaning | $O$ | 10.0 | 7.5 |
| | Accessibility | | 5.0 | |
| Entrance | Difference in water level between the river and the lower pool (m) | $\Delta H_E$ | 0.13 | 7.7 |
| | Depth at the entrance (m) | $h_E$ | 0.64 | 10.0 |
| | Width at the entrance (m) | $b_E$ | 0.40 | 10.0 |
| | Depth prior to the entrance (m) | $h_{prior\ E}$ | 1.21 | 10.0 |
| | Orientation of the entrance in relation to the river | $Ort_E$ | Zone A | 10.0 |
| | Type of entrance | $T_E$ | Vertical slot | 10.0 |
| | Maintenance and cleaning | $O$ | 10.0 | 5.8 |
| | Accessibility | | 10.0 | |
| | Rounded edges | | 5.0 | |
| | Elements to regulate water level drop | | 0.0 | |
| | Flow discharges at the entrance | | 10.0 | |
| | Absence of other flow discharges that drive fish away from the fishway | | 0.0 | |
| Passage | Difference in water level between consecutive pools or head drop (m) | $\Delta H_{Ps}$ | 0.16/0.13/0.14 | 10.0/10.0/10.0 |
| | Volumetric power dissipation (W/m$^3$) | $N$ | 109.7/92.9/84.8 | 10.0/10.0/10.0 |
| | Mean water level in pools (m) | $t_{med}$ | 1.06/0.71/0.96 | 10.0/10.0/10.0 |
| | Water depth in openings Between pools (m) | $h_{Ps}$ | 0.95/0.64/0.89 | 10.0/10.0/10.0 |
| | Width of opening between pools (m) | $b_{Ps}$ | 0.21/0.40/0.21 | 10.0/10.0/10.0 |
| | Type of opening between pools | $T_{Ps}$ | Vertical slot | 10.0/10.0/10.0 |
| | Maintenance and cleaning | $O$ | 5.0/10.0/10.0 | 8.9 |
| | Accessibility | | 10.0/10.0/10.0 | |
| | Rounded edges | | 10.0/10.0/10.0 | |
| | Pool shape | | 10.0/10.0/5.0 | |
| | Baffles in pools | | 10.0/10.0/10.0 | |
| | Conservation of structure | | 10.0/10.0/10.0 | |
| | Bed naturalised with stones | | 10.0/10.0/10.0 | |
| | Darkness due to elements covering the fishway | | 10.0/10.0/5.0 | |
| | Leeway in the fishway walls | | 10.0/10.0/10.0 | |
| Exit | Difference in water level between river and the upper pool (m) | $\Delta H_E$ | 0.03 | 5.0 |
| | Depth at the exit (m) | $h_E$ | 0.89 | 10.0 |

| | | | | |
|---|---|---|---|---|
| | Width at the exit (m) | $b_E$ | 0.50 | 10.0 |
| | Depth after the exit opening (m) | $h_{after\ S}$ | > 0.60 | 10.0 |
| | Orientation of the exit in relation to the river | $Ort_E$ | Zone A | 10.0 |
| | Type of exit | $T_S$ | Vertical slot | 10.0 |
| | Maintenance and cleaning | $O$ | 10.0 | 6.7 |
| | Accessibility | | 10.0 | |
| | Rounded edges | | 0.0 | |
| | Gate to regulate the discharge | | 10,0 | |
| | Device to prevent the entry of debris | | 5.0 | |
| | Safe exit | | 5.0 | |

Based on the scores assigned to the essential variables and the relevant observations, the score for each category is calculated:

**Table 16**. Total score, reference range, classification and improvement needs for each category.

| Category | Variable / observation | Score | Reference range | Classification of the category | Changes or improvements |
|---|---|---|---|---|---|
| Attraction | Essential variables | 8.7 | 8 < *Category* ≤ 10 | Very beneficial | Optional |
| | Relevant observations | 7.5 | 5 ≤ *Category* < 8 | Beneficial | Recommended |
| Entry | Essential variables | 9.6 | 8 < *Category* ≤ 10 | Very beneficial | Optional |
| | Relevant observations | 5.8 | 5 ≤ *Category* < 8 | Beneficial | Recommended |
| Passage | Essential variables | 10.0 | 8 < *Category* ≤ 10 | Very beneficial | Optional |
| | Relevant observations | 9.4 | 8 < *Category* ≤ 10 | Very beneficial | Optional |
| Exit | Essential variables | 8.9 | 8 < *Category* ≤ 10 | Very beneficial | Optional |
| | Relevant observations | 6.7 | 5 ≤ *Category* < 8 | Beneficial | Recommended |

It should be noted that, at the time of the assessment, the vertical slots connecting pools 1 and 2, and 3 and 4, were partially obstructed by debris carried by the water that could affect the normal function of those pools (Figure 60) (Fuentes-Pérez *et al.* 2014). As noted by Martínez de Azagra (1999), DVWK (2002) and Towler *et al.* (2013), this type of issues is the main cause of alterations in the correct performance of these structures.

**Figure 60.** Partial obstruction observed in the slot connecting pools 3 and 4.

Looking at the essential variables in each category, it can be seen that all of them have a high score, this in theory would enable fish to move up the fish pass (8.7 points for *A*; 9.6 for *E*; 10.0 for *Ps*; and 8.9 for *S*) (Table 16). On the other hand, the analysis of relevant observations detects more problems than with essential variables, although in all categories upstream fish movement is facilitated (7.5 for *A*; 5.8 for *E*; 9.4 for *Ps*; and 6.7 for *S*) (Table 16).

Based on all this, it is recommended taking action with regard to the relevant observations for attraction, entry and exit. At the entrance, it is recommended installing some element that enables regulating the water level drop between the lower pool and the river, avoiding discharges that may drive away fish from the fishway during the migration period (specifically, opening the gates on the opposite bank of the river). Concerning the exit, it is recommended the use of a more efficient device to prevent the entry of debris into the fishway, and increase the height of part of the weir crest to ensure fish exit the fishway safely, with no risk of being washed off downstream of the barrier.

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# A.1. Notation and abbreviations

The following abbreviations and symbols have been used in this document:

$\rho$: absolute density of water in the water body under study (≈ 1000 kg/m$^3$).

$\Delta H$: difference in water level between consecutive water bodies (m).

$\Delta H_E$: difference in water level between river and the lower pool (m).

$\Delta H_{Ps}$: difference in water level between consecutive pools (m).

$\Delta H_S$: difference in water level between the upper pool and the river (m).

$\Delta Z$: difference in height between the bottom surface of consecutive pools (m).

$A$: attraction.

*Area:* area of a submerged orifice (m$^2$).

*AreaM*: wet area (m$^2$).

$b$: width of openings between pools (m).

$B$: width of a pool (m).

$b_E$: width at entrance (m).

$b_{fish}$: intercostal width of target fish (cm).

$b_{Ps}$: width of openings between pools (m).

$b_E$: width at exit (m).

$C$v: discharge coefficient for a slot.

$C_o$: discharge coefficient for an orifice (with a value of 0.876).

$C_n$: discharge coefficient for a notch.

$C_s$: Submergence coefficient for a submerged notch.

$d_E$: height of entrance opening (m).

$d_{Ps}$: height of opening connecting two pools (m).

$d_S$: height of exit opening (m).

*E*: entrance.

*g*: gravity acceleration (9.81 m/s$^2$).

*GEA*: Group of Applied Ecohydraulics of the University of Valladolid.

*h:* water level measured from the edge of the opening that connects two consecutive pools (m).

$h'_{Ps}$: water depth in the opening upstream from a pool (m).

$h_E$: depth at entrance (m).

$h_{fish}$: dorsoventral height of target fish (cm).

$h_{prior\ E}$: depth prior to entrance (m).

$h_{after\ S}$: depth after the exit opening (m).

$h_{Ps}$: water depth in openings between pools (m).

$h_S$: depth at exit (m).

*HV*: vertical slot.

*L*: length of a pool (m).

$L_{fish}$: length of target fish (cm).

*N*: Volumetric power dissipation (W/m$^3$).

$n_{standard}$: number of standard pools in the fishway under study.

$n_{total}$: total number of pools in the fishway under study.

*O*: relevant observations

$O_{i1}$: score for the first relevant observation for category *i*.

$O_{in}$: score for the last relevant observation for category *i*.

$Ort_E$: orientation of entrance in relation to the river (°).

$Ort_S$: orientation of exit in relation to the river.

*p*: sill height of the opening downstream from the pool under study (m).

*p´*: sill height of the opening upstream from the pool under study (m).

$PO_i$: score for the relevant observations for category *i*.

*Ps*: passage.

*Score*: weighted score for an essential variable or relevant observation in the passage category.

$Score_i$: score for an essential variable or relevant observation for a unique pool "*i*" in a fishway.

$Score_{standard}$: score for an essential variable or relevant observation for the standard pool in a fishway.

*Q:* discharge (m$^3$/s).

*Rel* $Q_{attraction}$: attraction flow relative to the total flow in the river branch where the fish pass is located (%).

$Q_{aux}$: auxiliary flow which does not go through the fishway and helps to attract fish ($m^3/s$).

$Q_{river}$: river discharge at the time of the assessment ($m^3/s$).

$Q_{fishway}$: discharge through the fishway ($m^3/s$).

$Q_v$: water flow through a vertical slot ($m^3/s$).

$Q_f$: water flow through a free discharge notch ($m^3/s$).

$Q_o$: water flow through a submerged orifice ($m^3/s$).

$Q_s$: water flow through a submerged notch ($m^3/s$).

*S*: exit.

$T_E$: type of entrance element.

$t_{med}$: mean water level in a pool (m).

$T_{Ps}$: type of opening between pools.

$T_S$: type of exit element.

$U_E$: location of fish entrance.

*v*: water velocity (m/s).

# A.2. Rationale behind the essential variables and relevant observations

The used numerical assessment criteria are based on widely agreed recommendations from design guidelines for fish passes, scientific and technical publications and field experiments.

The maximum score for each variable (10) corresponds to the minimum or maximum value for the parameter under consideration, depending on each case, as advised in the design guidelines. Likewise, the lowest rating (0) is given to unacceptable values for the parameter under consideration. If there are any discrepancies, the most conservative value for the variable should be chosen.

## 1. Essential variables

### 1.1. Attraction

#### 1.1.1. Relative attraction discharge ($Rel\ Q_{attraction}$)

Fish tend to follow the river's main current as they swim upstream (DVWK 2002). Thus, the attraction flow ($Q_{attraction}$; the discharge in the vicinity of the fishway) has to be large enough to capture the attention of fish. If there is no attraction, a well-designed fish pass will not be useful. Thus, the larger the attraction flow is, the more probable it is that fish will find the fish pass (Larinier 2000, 2002a; Calles and Greenberg 2009; NMFS 2011).

Different authors recommend an attraction flow between 5 and 10% of the total discharge in the river during the migration period (Larinier 1992,1998; NMFS 2011; Williams *et al.* 2012). Other researchers think that lower attraction flows may be enough, especially for large rivers: between 1% and 5% of the discharge through the dam (Larinier 1998, 2002a). Some fish species, such as the nase, are more sensitive than barbel or trout, when it comes to locate structures where the attraction flow is close to 1% of the average annual discharge (Zitek *et al.* 2012) or < 2% of the river discharge at that time (Bravo-Córdoba *et al*. 2016).

Based on the above, a conservative value of 1% has been considered as the lowest threshold that facilitates finding the fish pass, and 10% as the optimal value.

The attraction flow can go through the fishway itself or the flow through the fishway may be complemented with specific structures for that purpose (spillways over the crest, pipelines encased in the wall). When the fish pass is located next to returning turbined water, the flow through the turbine helps with attraction.

The attraction flow, $Q_{attraction}$, is calculated with the following equation:

$$Q_{attraction} = Q_{fishway} + Q_{aux} \quad \text{(Eq. 11)}$$

[34]

Finally, the relative attraction flow, *Rel* $Q_{attraction}$, is calculated and given a score according to the following equation and the figure below:

[34] To be considered as an auxiliary flow, it must be located at ≤ 3.00 m from the fishway entrance, because that is the maximum distance from which the fishway flow itself is thought to attract fish (Bunt *et al.* 1999, 2012b; Aarestrup *et al.* 2003). Otherwise, it is not taken into account, and it can even be negative for attraction purposes.

$$Re.\ Q_{attraction} = \frac{Q_{attraction}}{Q_{river}} \cdot 100 \qquad \text{(Eq. 12)}$$

where $Q_{river}$ is the usual discharge in the river stretch where the fishway is located during the migration period.

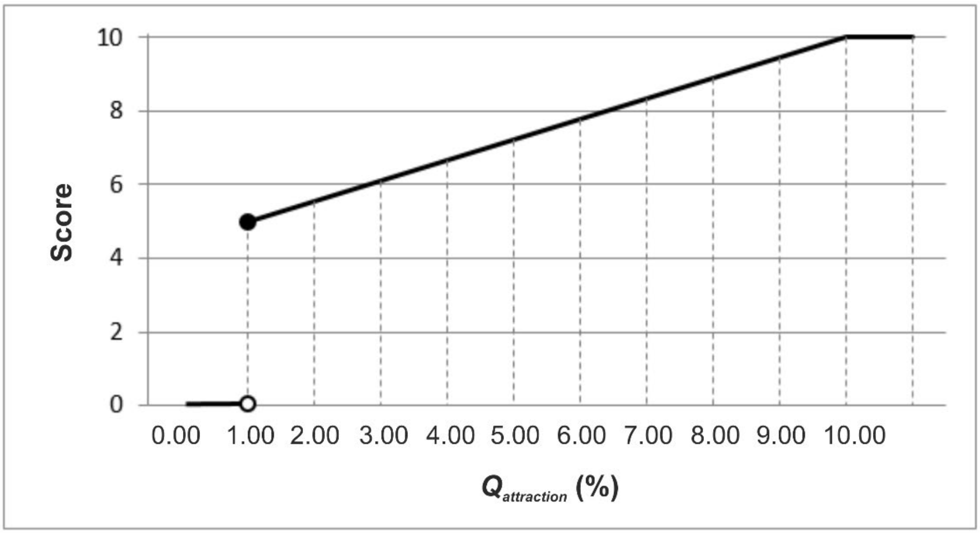



**Figure 61.** Score for *Rel* $Q_{attraction}$.

**Table 17.** Explanation of how *Rel* $Q_{attraction}$ is scored.

| *Rel* $Q_{attraction}$ | Rationale | Score |
|---|---|---|
| < 1% | An attraction flow which will only attract a small number of fish. | 0 |
| = 1% | A flow that starts to be attractive to fish fauna. | 5 |
| ≥ 10% | The attraction flow is large enough to attract most individuals | 10 |

## 1.1.2. Location of the fish entrance ($U_E$)

The best location for the entrance to a fish pass is a) close to one of the banks (to help fish find it, because they tend to move between the *thalweg* and the banks) (Clay 1995; DVWK 2002; Larinier 2002b; Katopodis *et al.* 2013), b) as further upstream as possible, c) close to the base of the obstacle (if the water flow over the crest is the same, the funnel formed by the weir's abutment that is further upstream and the bank is where most fish concentrate) (Clay 1995; Bunt 2001; DVWK 2002; Armstrong *et al.* 2004) and/or d) next to areas with an attraction flow, such as the point of returning turbined water in the case of hydropower stations with turbines at the foot of the dam (because fish fauna tend to follow the largest flow) (DVWK 2002; Larinier 2002b, 2008; Aigoui *et al.* 2008).

Therefore, this variable will focus on quantitative criteria based on the above. That is, the degree of compliance with each of the requirements for the location of the fishway entrance will be considered and $U_E$ will be assessed as the arithmetic mean of all of them[35]:

- proximity to the bank.
- as further upstream as possible in relation to the obstacle.
- next to the base of the obstacle.
- where a large volume of flow concentrates.

**Table 18.** Assessment of the different aspects to be considered for parameter $U_E$ [36]

| Degree of aptness | Score |
|---|---|
| Very suitable | 10 |
| Suitable | 6.7 |
| Unsuitable | 3.3 |
| Very unsuitable | 0 |

[35] Section 4.1.1.b includes some additional details.
[36] If all the water flow in that stretch of the river concentrates through the fishway, the location will always be optimal.

## 1.2. Entrance

### 1.2.1. Difference in water level between the river and the lower pool ($\Delta H_E$)

Fish should be able to discern easily the water flow at the entrance of the fish pass from other flows in the surroundings, and do so from as far as possible (Armstrong *et al.* 2004). The attraction to the entrance depends on the discharge and the water velocity in the entrance. The higher both variables are, the further the effect in the water column and the higher the attraction (Larinier 2000). The water velocity in the entrance of the fish pass must be above 1.0 m/s for all fish species, and preferably around 2.0 to 2.4 m/s, ideally for large size salmonids (equivalent to a water level drop of 0.20 to 0.30 m). When the entrance to a fish pass is located close to returning turbined water and competes with the flow from the turbines, the water flow velocity must be at least twice as high as the velocity of water leaving the turbine (Armstrong *et al.* 2004).

In this case, it will be proposed as optimal values for the difference in water level those between 0.20 and 0.30 m. Values above 0.50 m are not recommended, as per the observations explained in detail further in this document (Annex A.2.), because the velocities or water level drops are hardly compatible with the swimming and/or jumping ability of fish. Neither are low values of the variable ($\Delta H$ < 0.05 m) of interest, as they could cause velocities of less than 1.0 m/s. Sometimes, the difference in water level can be difficult to measure (small drops), so the velocity of the outflow should be checked by simply using the continuity equation ($v = Q/AreaM$).

It should be not forgotten that this value fluctuates with the river discharge, which increases or decreases the water level and, consequently, also the drop at the entrance of the fish pass (Fuentes-Pérez *et al.* 2014, 2016). It is only considered a problem when it is high or very low with the usual discharges.

Different values of the variable are not proposed according to the type of opening, contrary that for the *Passage*, since the entrance is usually a single opening, the drop is quite variable depending on the river discharge, and its purpose is to encourage the fish to enter.

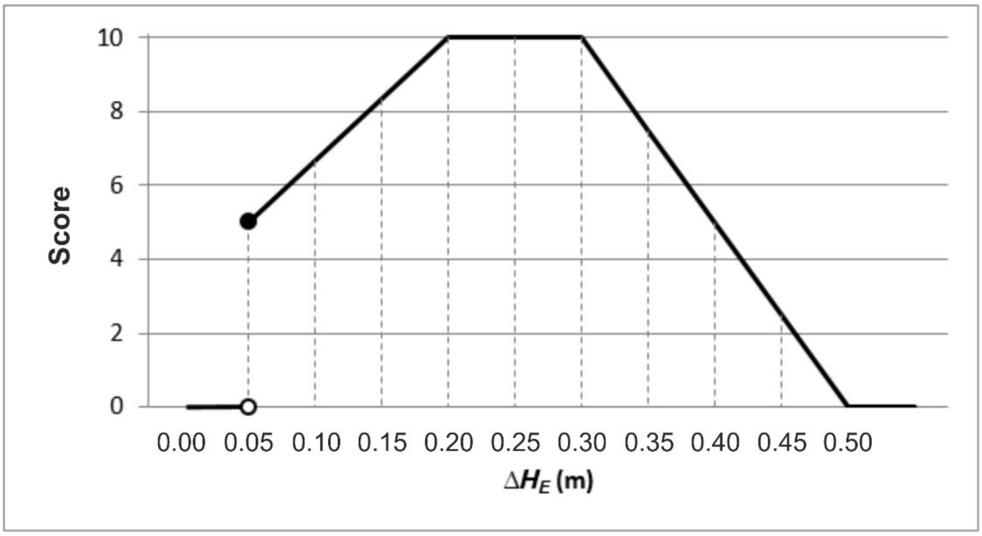



**Figure 62.** Scoring graph for $\Delta H_E$.

**Table 19.** Explanation of how to assess variable $\Delta H_E$.

| $\Delta H_E$ | Rationale | Score |
|---|---|---|
| < 0.05 m[37] | Reduced velocity that decreases the attraction of fish to the entrance. | 0 |
| = 0.05 m | Minimum value that leads to attraction and entry. | 5 |
| ≥ 0.20 and ≤ 0.30 m | Optimal flow velocities. | 10 |
| = 0.40 m | Upper acceptable threshold value. | 5 |
| ≥ 0.50 m | Water flow velocities that most individuals cannot swim against. | 0 |

[37] If the velocity is > 1.0 m/s the variable is considered suitable, though not optimal (score = 5).

### 1.2.2. Depth at entrance ($h_E$)

This variable is explained in section 1.3.4.

### 1.2.3. Width at entrance ($b_E$, $d_E$)

This variable is explained in section 1.3.5.

### 1.2.4. Depth prior to entrance ($h_{prior\ E}$)

It analyses the water depth in the river prior to the entrance, allowing fish to stay at the foot of the fishway while they decide to go inside or while they rest. In addition, it allows them to gain momentum to get into the fishway. If it is too small, fish find it difficult to approach the fishway and enter into it, they may rub against the river bed and the risk of predation increases (DVWK 2002).

Several design manuals recommend the existence of a transition with a trough-shaped pool before the fishway entrance (Clay 1995; Elvira *et al.* 1998; Martínez de Azagra 1999; Larinier 2002b; NMFS 2011) with a depth > 0.50 m (DVWK 2002). From a physical point of view, safe swimming is achieved with values > 0.20 m (Katopodis 1992; DVWK 2002; Armstrong *et al.* 2004) and with values > 0.60 m stress and predation situations are avoided (Martínez de Azagra 1999; DVWK 2002; Larinier 2002b; Baudoin *et al.* 2014). The depth preference of nase, barbel and trout suggest that values > 0.40 m for juveniles and > 0.60 m for adult fish are suitable (Martínez-Capel *et al.* 2004; Ayllón *et al.* 2010).

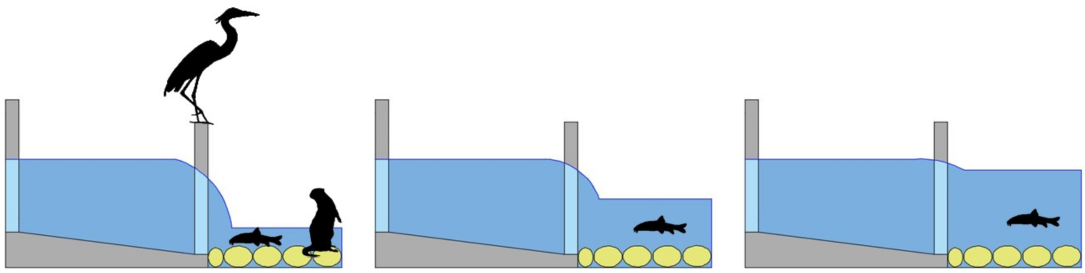


**Figure 63.** Examples of three different depths prior to the entrance: small (left), medium (centre) and large (right).

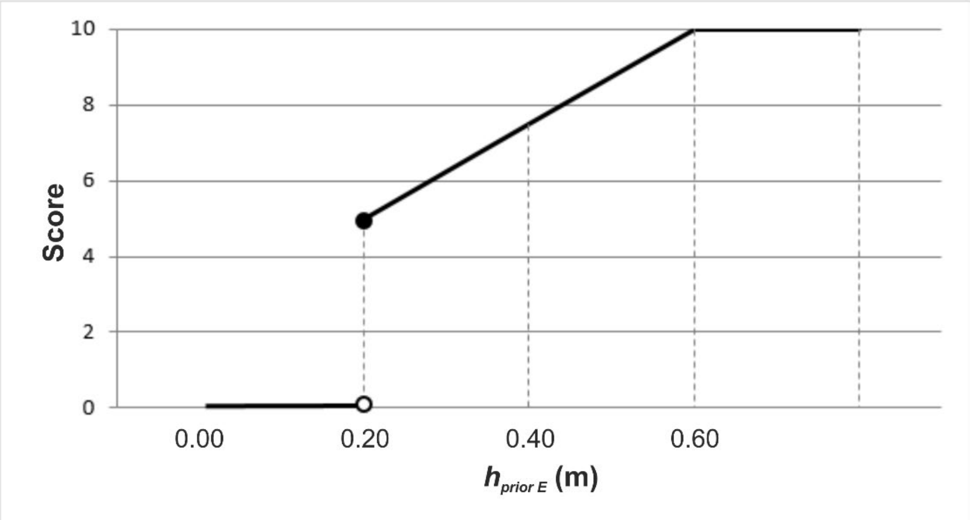



**Figure 64.** Score assigned to $h_{prior\ E}$.

**Table 20.** Detailed explanation of the scoring system for $h_{prior\ E}$.

| $h_{prior\ E}$ | Rationale | Score |
|---|---|---|
| < 0.20 m | Small depth:<br>- High risk of scrapes and bumps.<br>- High risk of predation.<br>- Detrimental for resting.<br>- Detrimental to gain momentum. | 0 |
| = 0.20 m[38] | Minimum threshold for fish access. | 5 |
| ≥ 0.60 m | Large depth:<br>- Low risk of scrapes and bumps.<br>- Low risk of predation.<br>- Very beneficial for resting.<br>- Very beneficial to gain momentum. | 10 |

[38] In a free discharge the minimum depth is > 2 · $\Delta H$.

### 1.2.5. Orientation of entrance in relation to the river ($Ort_E$)

Depending on how the fish pass entrance is oriented in relation to the longitudinal axis of the river and the direction of fish as they move upstream, it is easier for individuals to enter the fish pass. As well, the orientation can have an effect on the extent to which debris enters the fishway (gravel, branches, etc.)

Design manuals recommend that fishway entrances are perpendicular to the river's longitudinal axis or parallel to it, and in the same direction of the current (DVWK 2002; NMFS 2011). Otherwise, the fish have to make unnatural turns to enter the fishway. Thus, the maximum score is given in the first case, and as the orientation of the entrance departs from recommendations, the parameter receives a lower value.

**Table 21.** Rationale to assign a score to $Ort_E$.

| $Ort_E$ | Rationale | SCORE |
|---|---|---|
| Zone A<br>(0º ≤ α ≤ 90º) | - It helps fish swimming upstream to enter the structure (DVWK 2002; Sanz-Ronda *et al.* 2014)<br>- Debris is prevented from entering. | 10 |
| Zone B<br>(90º < α ≤ 135º) | - Fish start to find it more difficult to enter, because they have to do an unnatural turn to access the fish pass.<br>- The ease with which debris enter the fishway is moderate. | from 1 to 5 |
| Zone C<br>(135º < α ≤ 180º) | - It complicates fish access, because they must swim downstream to enter the fish pass and thus be able to move upstream.<br>- In addition, debris easily gets into the fish pass. | 0 |

### 1.2.6. Type of entrance ($T_E$)

This variable is explained in section 1.3.6.

## 1.3. Passage

### 1.3.1. Difference in water level between consecutive pools or head drop ($\Delta H_{Ps}$)

$\Delta H$ is directly related to the flow velocity through submerged notches, slots and orifices, and therefore also to the turbulence in the pools (Fuentes-Pérez *et al.* 2016). $\Delta H$ should be in accordance with the swimming or jumping ability of the target species, since a large difference in water level implies high flow velocity and turbulence, which could affect the ascent of the fish.

The distance fish have to swim with these high velocities in submerged flows is usually no more than 2.00 m (Tarrade *et al.* 2008). Castro-Santos *et al*. (2013) and Sanz-Ronda *et al*. (2015) observed that 95% of juvenile and adult barbel, nase and trout were able to swim up to 2.00 m with a velocity of 3.0 m/s, which would which be equivalent to a $\Delta H$ value of approximately 0.50 m. However, this would be a threshold value which would involve a high energy expenditure and could lead the fish to exhaustion, so the design guidelines recommend the maximum velocity be below 2.0 m/s (DVWK 2002).

Based on the above, design manuals recommend water level drops according to the swimming or jumping ability of fish, usually 0.25 to 0.30 m for the usual combination of submerged notch and orifice, and 0.20 m for vertical slots (Larinier 1992, 1998; DVWK 2002; Baudoin *et al.* 2014). Values higher than that may lead to delays or selection processes. For example, Sanz-Ronda *et al.* (2016) observed that in a vertical slot with a $\Delta H$ value at a particular time of 0.60 m, the 40% approximately of nase in the experiment were able to overcome it (fork length range 12 - 26 cm), although fish were selected according to length (successful fish were those longer than 18 cm).

When there is a free discharge, fish have to jump to be able to climb up the fish pass, thus $\Delta H$ must be lower than the jumping ability of individuals and there must be a minimum depth allowing them to gain momentum before they jump. In general, not very much is known about the jumping ability of Iberian fish. Kondratieff and Myrick (2006), studying Arctic char 13.5 - 26.5 cm long (a salmonid with a swimming ability similar to that of trout and barbel (Castro- Santos *et al.* 2013; Sanz-Ronda *et al.* 2015) and Amaral *et al*. (2016), based on experience with Iberian barbel (average length 18.7 cm) observed that for free discharge notches, the percentage of success in the ascent depends on the combination of depth and slope, obtaining representative success when the depth exceeds 0.20 m, which then decreases with $\Delta H$ = 0.35 – 0.40 m and above. Likewise, Sanz-Ronda *et al*. (2015b) saw that, in natural waterfalls, the majority of specimens of the species covered in this manual, longer than 12 cm, were able to overcome differences in water level > 0.50 m with a depth to allow gaining momentum > 1.00 m. Morán-López and Uceda Tolosa (2016) describe average jumps of southern barbel (*L. comizo* and *L. microcephalus*) of 79.6 cm, with a water depth of 1.00 m and body size below 35 cm. Bravo-Córdoba *et al*. (2016) observed that around 40% of adult barbel were able to overcome a free discharge of 0.60 m in a fishway where the width of the opening was b = 0.20 m and the mean depth $t_m \approx$ 1.00 m. However, these are exceptional situations (one-off jumps) that would entail great effort and energy expenditure if repeated several times, so the design guidelines recommend that $\Delta H$ does not exceed 0.30 m (Larinier 1998) and that, in the case of free discharges, there is a depth of at least twice the difference in water level ($2 \cdot \Delta H$) to gain momentum, and a water level measured from the sill ($h$) in the upper opening of more than 0,20 m to allow safe passage (Baudoin *et al.* 2014).

It has also been observed that voluntary movement through a fishway with submerged notches and orifices with a head drop $\Delta H$ = 0.25 m results in no significant differences in success rate and passage times for barbel and nase, compared to a free discharge and orifice with $\Delta H \approx 0.30$ m (Sanz-Ronda *et al*., 2015b). In contrast, Bravo-Córdoba *et al*. (2016) have noted barbel ascents with lower success rate in a fish pass with free discharge ($\Delta$H ≈ 30 - 35 cm) and submerged orifice in comparison with similar ones with submerged discharge and $\Delta$H ≈ 25 - 30 cm.

Differences in water level that lead to velocities lower than 1.0 m/s ($\Delta$H < 0.05 m), could affect the motivation of fish as they climb upstream (Castro-Santos *et al.* 2013) and their ability to find the right way (Goettel *et al.* 2015). However, such low water level differences can occur on occasion due to obstructions or increased water levels in the river. These are not normal design situations (Fuentes-Pérez *et al.* 2016), so they are not considered in this analysis of the *Passage*, although they are important in the case of the *Entry* and the *Exit*.

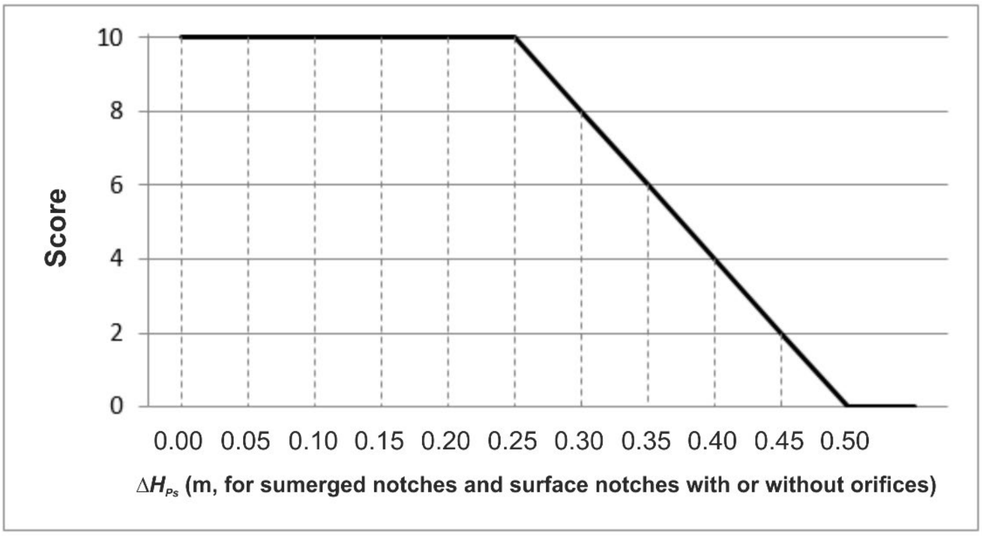



**Figure 65.** Graphic to assess $\Delta H_{Ps}$ for submerged and free discharges in notches, with or without orifices.

**Table 22.** Explanation of how $\Delta H_{Ps}$ is scored for submerged and free discharges in notches, with or without orifices.

| SUBMERGED AND FREE DISCHARGE IN NOTCHES[39] (WITH OR WITHOUT ORIFICE) | | |
|---|---|---|
| $\Delta H_{Ps}$ | Rationale | Score |
| ≤ 0.25 m | Difference in water level that most fish can swim against without difficulty. | 10 |
| = 0.38 m | Fast flow that only the most capable specimens can swim against. | 5 |
| ≥ 0.50 m | Water flow velocities that most individuals cannot swim against. | 0 |

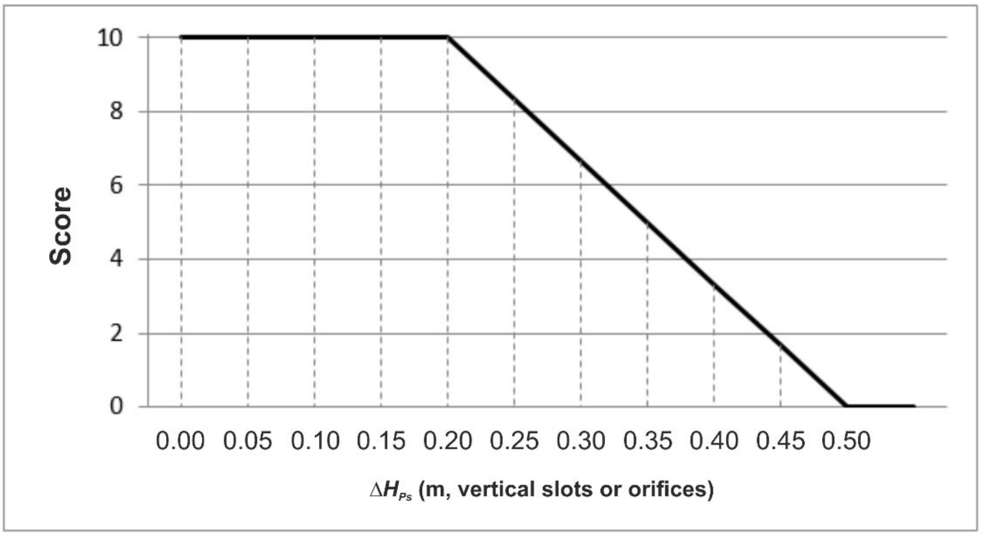



**Figure 66.** Graph to asses $\Delta H_{Ps}$ for vertical slots or orifices.

**Table 23.** Rationale to score $\Delta H_{Ps}$ for vertical slots or orifices.

| VERTICAL SLOT OR ORIFICE[40] | | |
|---|---|---|
| $\Delta H_{Ps}$ | Rationale | Score |
| ≤ 0.20 m | Difference in water level that most fish can swim against without difficulty. | 10 |
| = 0.35 m | Fast flow that only the most capable specimens can swim against. | 5 |
| ≥ 0.50 m | Water flow velocities that most individuals cannot swim against. | 0 |

[39] The free discharge (surface notch) will be effective is the water depth at the base > 2 · $\Delta H$.

[40] They are grouped together given their hydraulic behaviour concerning velocity (Fuentes-Pérez et al., 2015; 2016).

### 1.3.2. Volumetric power dissipation (*N*)

The volumetric power dissipation in a pool is the turbulence indicator most widely used in step-pool fish passes (Towler *et al.* 2015). Excessively large values of this variable are linked to high turbulence (powerful and multiple eddies, and very aerated flows), which may hinder or limit the ascent of the fish as it directly affects the swimming (it entails a high energy expenditure) and the orientation of the fish (Odeh *et al.* 2002; Silva *et al.* 2012). *N* is widely used in fish pass design guidelines and there are recommendations for its magnitude for different species. (Larinier 1992; DVWK 2002). These classic manuals advise maximum values of 150 W/m$^3$ for rheophilic cyprinids and up to 175 - 200 W/m$^3$ for trout, even higher when the fishway has few pools (Larinier 1992; Armstrong *et al.* 2004). However, the above criteria are based on professional judgement and are not the result of controlled experiments on the levels of turbulence that a fish species can withstand (Hotchkiss and Frei 2007).

Silva *et al*. (2012) observed that barbel specimens < 25 cm in length are more affected by turbulence than larger specimens, and that, in general, barbel prefer areas with lower turbulence, observing a negative correlation between ascent time and turbulence levels. On the other hand, Bravo-Córdoba *et al*. (2015) and Sanz-Ronda *et al*. (2016) observed for two different types of fish passes that, for juvenile and adult trout, barbel and nase, there were practically no differences in passage times or in percentage of success during ascent with dissipated energy between 125 - 200 W/m$^3$. Even in pools with one-off values of dissipated energy greater than 300 W/m$^3$, they observed fish moving upstream, although with a decrease in efficiency and selection of specimens by size or swimming ability.

On the other hand, it has not been found that low values of this variable negatively affect fish passage, though it may influence, as previously mentioned, the motivation or the location of the path to follow (Castro-Santos *et al.* 2013; Goettel *et al.* 2015). This can occur in extremely large pools, *i.e.* pre-dams (Martínez de Azagra 1999), hence the assessment curve for variable *N* has been drawn with an initial dashed section up to 25 W/m³.

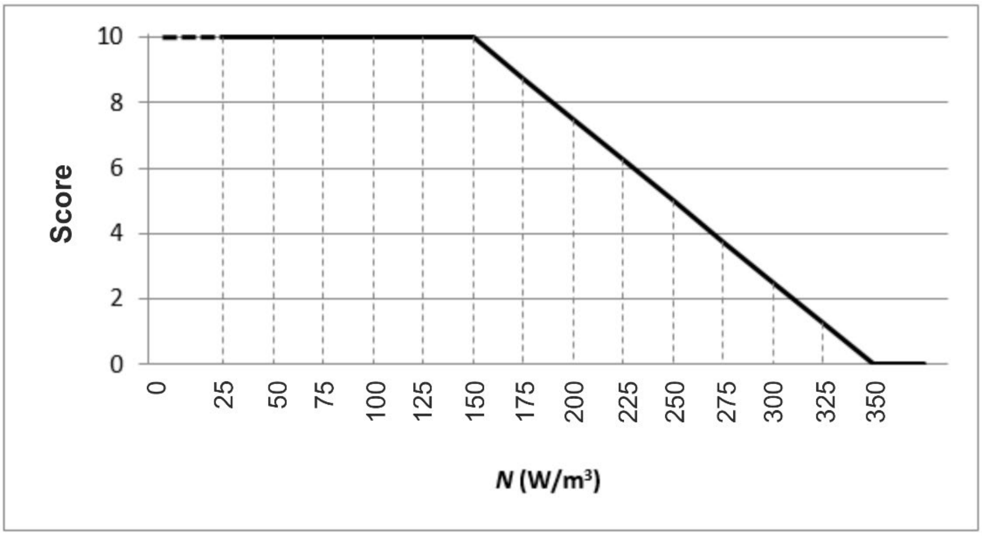



**Figure 67.** Scoring for the volumetric power dissipation.

**Table 24.** Explanation of how variable *N* is scored.

| *N* | Rationale | Score |
|---|---|---|
| ≤ 150 W/m³ | Any target fish can swim upstream without difficulty. | 10 |
| = 250 W/m³ | Too much turbulence for the fish to ascend normally. | 5 |
| ≥ 350 W/m³ | Only the most vigorous and motivated specimens can swim upstream. | 0 |

### 1.3.3. Mean water level in pools ($t_{med}$)

This variable influences the comfort of fish, allowing them to rest, helping to dissipate energy and reducing the risk of predation inside the pools (Armstrong *et al.* 2004), since as depth increases, the probability of being seen decreases (Harvey and Stewart 1991). The design guidelines recommend a value greater than 0.20 m (Katopodis 1992; DVWK 2002; Armstrong *et al.* 2004). With a lower value, fish may become injured with scrapes and suffer stress, because the fish may not get enough rest, and may be too exposed to outside hazards; if on top of that the fish density is high, the negative effects are intensified. However, the higher the value of this variable, the less detrimental the aforementioned problems are. Most authors recommend values greater than 0.60 m in pools for adequate fish ascent (Martínez de Azagra 1999; DVWK 2002; Larinier 2002b; Sanz-Ronda *et al.* 2014). The preference curves of nase, barbel and trout propose as optimal values > 0.40 m for juveniles and > 0.60 m for adult fish (Martínez-Capel *et al.* 2004; Ayllón *et al.* 2010).

In the case of free discharges (surface notches), the depth at the base should be > 2 $\Delta H$ (Baudoin *et al.* 2014) so that fish can gain momentum to jump.

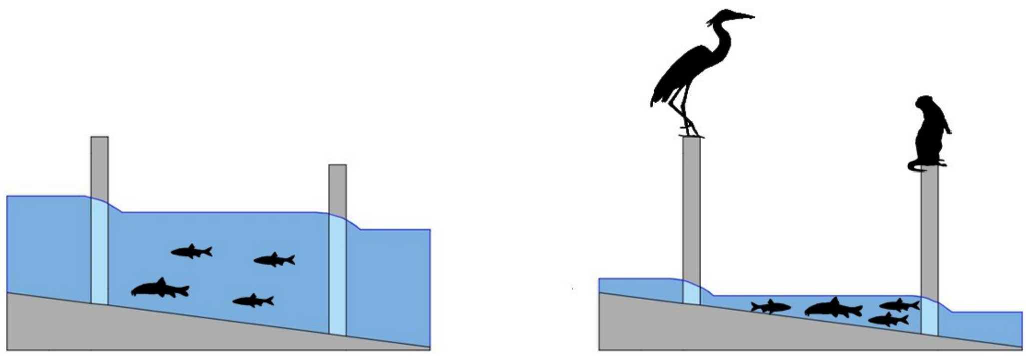


**Figure 68.** Pool in a fishway with a suitable mean water level (left) and too small (right).

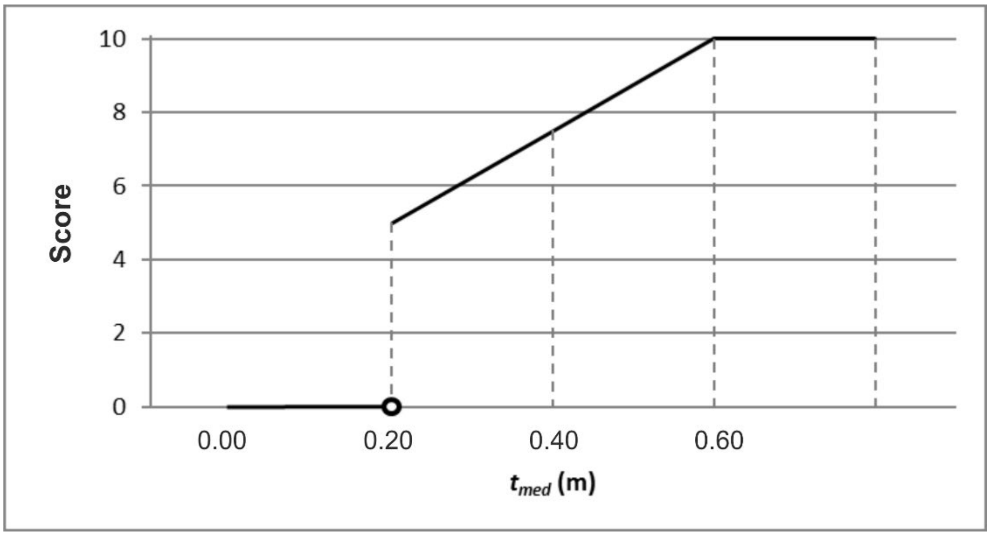



**Figure 69.** Scoring graph for $t_{med}$.

**Table 25.** Explanation of how $t_{med}$ is assessed.

| $t_{med}$ | Rationale | Score |
|---|---|---|
| < 0.20 m | Typical fish get through but are exposed to scrapes, stress, predation, and are not able to rest appropriately. | 0 |
| = 0.20 m[41] | Typical fish get through risking predation and without being able to rest appropriately, but they are not exposed to bumps or scrapes. | 5 |
| ≥ 0.60 m | Typical fish can get through being safe from bumps and scrapes, with a moderate predation risk and find no difficulty to rest and gain momentum | 10 |

### 1.3.4. Water depth in openings between pools ($h_{Ps}$)

The water depth in notches and orifices has to allow the fish to swim and must be consistent with the dorsoventral height ($h_{fish}$) of the larger specimens that are going to swim through the pass, which for the target species is usually < 7-8 cm (González-Alemán *et al.*, 2016), including a safety margin that prevents fish from rubbing against the structure. Minimum values > 1.5 · $h_{fish}$ (≈ 10 cm) and optimal values of 2.5 · $h_{fish}$ (≈ 20 cm) are recommended for fish to get through these critical points (Baudoin *et al.* 2014).

[41] If there is a free discharge (surface notch), a minimum depth at the base > 2 · $\Delta H$ is needed.

Other authors also recommend depths greater than 0.20 m (Katopodis 1992; DVWK 2002; Armstrong *et al.* 2004). Because fish move through openings quickly, protection from predation is not as crucial as in the case of the mean water depth in pools. The higher the value of $h_{Ps}$, the easier it will be for fish to get through.

With a free discharge (*i.e.* surface notches), $h_{Ps}$ matches the water level measured from the sill (*h, where* $h_{Ps} = h$), and a depth > 0.20 m is needed to ensure the fish get into the water current safely (Baudoin *et al.* 2014).

In the case of an orifice, $h_{Ps}$ is equivalent to parameter *d*, which is dealt with in the next section.

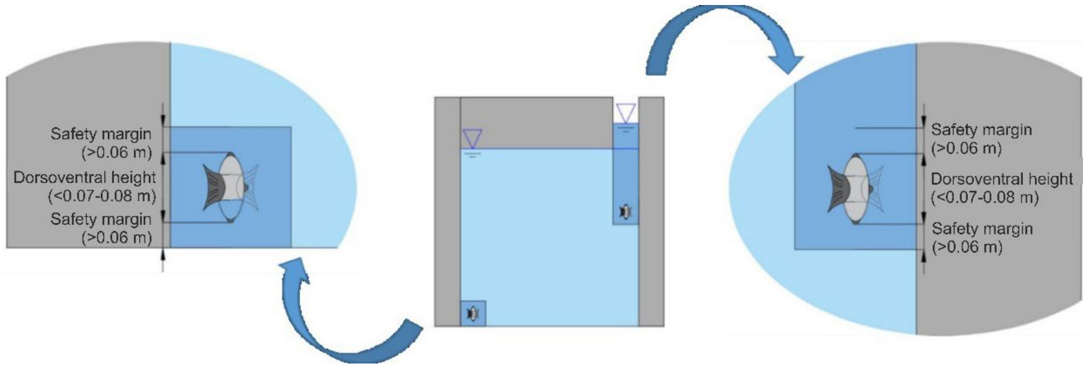



**Figure 70.** Explanation of $h_{ps}$ for a bottom orifice (left) and a submerged notch (right).

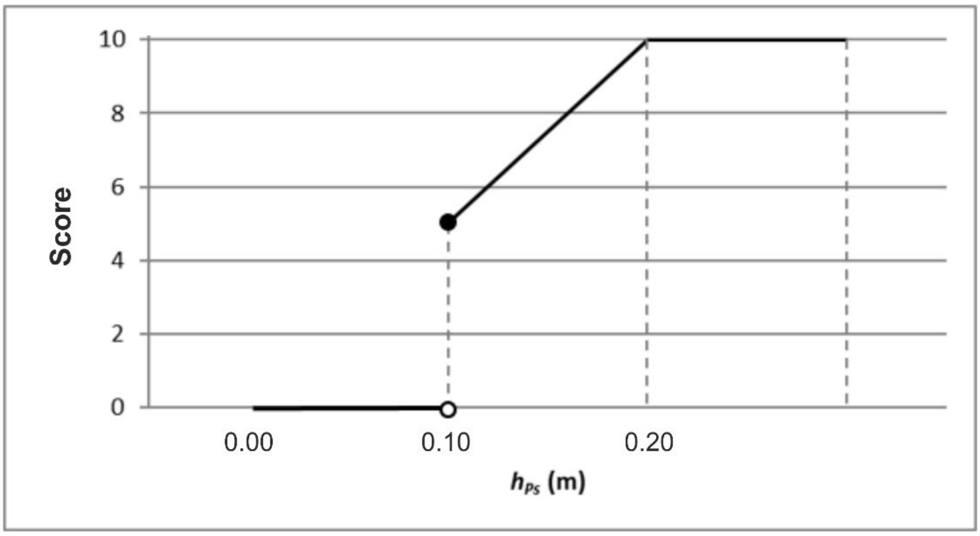



**Figure 71.** Graph to assess $h_{Ps}$. If there is a free discharge, we calculate the variable as the water level measured from the sill (*h*). Likewise, when $h_{Ps}$ is less than 0.10 m in a submerged discharge, the discharge is considered to be a "free" discharge and $h_{PS} = h$.

**Table 26.** Explanation of how variable $h_{Ps}$ is scored.

| $h_{Ps}$[42] | Rationale | Score |
|---|---|---|
| < 0.10 m | Fish would rub against the contour and have part of the body out of the water or, if it is a free discharge, they would not be able to get into the water column after | 0* |
| = 0.10 m | Minimum value for safe passage, provided the fish is in the middle of the water column. It can be problematic if it is a free discharge. | 5 |
| ≥ 0.20 m | There are no risks for the fish. If it is a free discharge, the fish would be able to get into the water column with no problems. | 10 |

* When $h_{Ps}$ is less than 10 cm, the type of discharge is considered to be "free" in terms of fish swimming upstream. In this case, and also in a conventional free discharge (*i.e.* surface notch), the variable (h) is calculated as the height difference between the water level in the pool and the sill height (the edge of the opening from the lower pool).

### 1.3.5. Width of openings between pools ($b_{Ps}$, $d_{Ps}$)

The width of openings between pools must guarantee that the fish can pass through and do so without injury, so it should be greater than the intercostal width of the largest fish that will pass through it, including enough clearance to allow fish to swim without rubbing against the walls. The usual larger specimens of barbel and trout in the Duero basin have an average length ($L_{fish}$) of approximately 50 cm, while nase rarely exceed 35 cm (González-Alemán, *et al.,* 2016). These lengths correspond to intercostal widths ($b_{fish}$) of less than 7 cm (Sanz-Ronda *et al*., 2015; González-Alemán *et al*., 2016). On the other hand, the total amplitude of caudal fin oscillation for subcarangiform fish such as those considered in this work is usually smaller than $0.2 \cdot L_{fish}$ (Videler and Wardle 1991). This equates to a maximum amplitude for the most common large fish of 0.10 m. Logically, the larger this variable is, the easier will be for fish to get through the notch, slot or orifice, and the lower the risk of them being caught and blocking the passage areas.

The design guidelines propose minimum values for submerged notches of b > 0.15 m and recommend values of about 0.20 and 0.25 m (Larinier 1992; DVWK 2002), and larger for free discharges, of about 0.30 to 0.40 m (Armstrong *et al.* 2004). Sanz-Ronda

[42] $h_{Ps} = h$ for a free discharge.

*et al*. (2015b) observed for barbels ranging in length from 14 to 61 cm the same passage efficiency in a fishway with surface notches ($b$ = 0.4 m) as in a fishway with submerged notches ($b$ = 0.2 m), all other hydraulic variables being similar.

In the case of bottom orifices, optimal values $b$ x $d$ > 0.20 x 0.20 are recommended. (*Area* > 0.04 $m^2$; Larinier 1992; DVWK 2002) and the minimum values must be in accordance with what was mentioned at the beginning of this section, greater than 0.10 x 0.10 m. The ascent of fish through orifices of different sizes (0.20 x 0.15 m, 0.20 x 0.20 m or 0.25 x 0.25 m), other parameters being equal ($N$, $\Delta H$) does not affect the percentage of success, nor the transit time (Bravo-Córdoba *et al*. 2014; Ruiz-Legazpi *et al*. 2015; Sanz- Ronda *et al*. 2015).

When there is a notch as well as a bottom orifice, the parameter "width of opening" will be quantified as the average value of both, since the fish can use both connections. Barbels and trout ascend through notches or orifices without a clear preference, while nase prefer submerged notches to orifices, or orifices to surface notches (Sanz-Ronda *et al*., 2015).

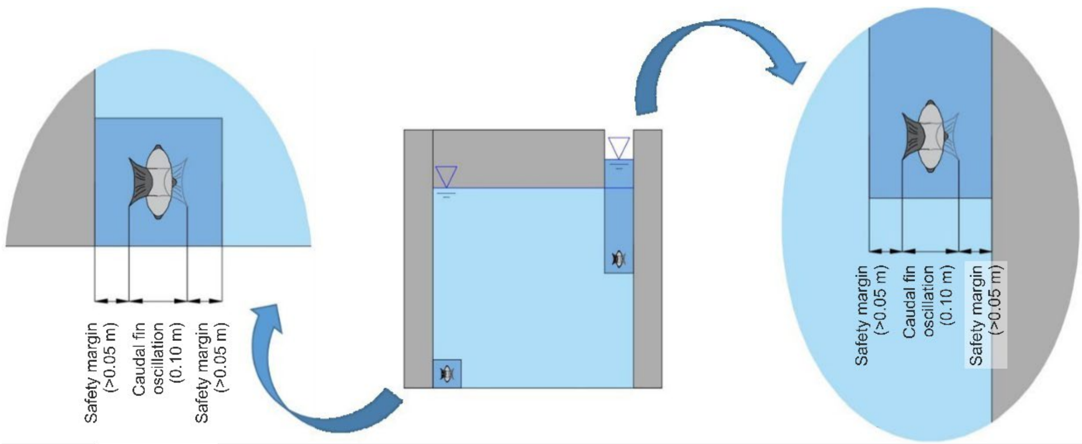



**Figure 72.** Explanation of $b_{Ps}$ for a bottom orifice (left) and a submerged notch (right).

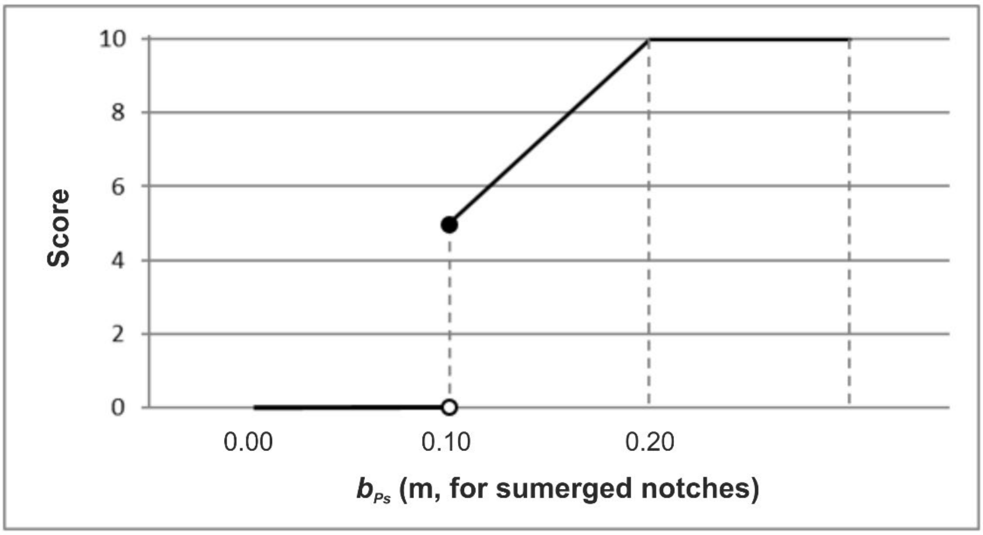



**Figure 73.** Scoring variable $b_{Ps}$ for submerged notches.

**Table 27.** Explanation of how $b_{Ps}$ is assessed for submerged notches.

| SUBMERGED NOTCHES | | |
|---|---|---|
| $b_{Ps}$ | Rationale | Score |
| < 0.10 m | The size is too small, limiting fish transit and favouring blockage. | 0 |
| = 010 m | Minimum passage size, risk of blockage. | 5 |
| ≥ 0.20 m | Optimal values with low probability of blockage. | 10 |

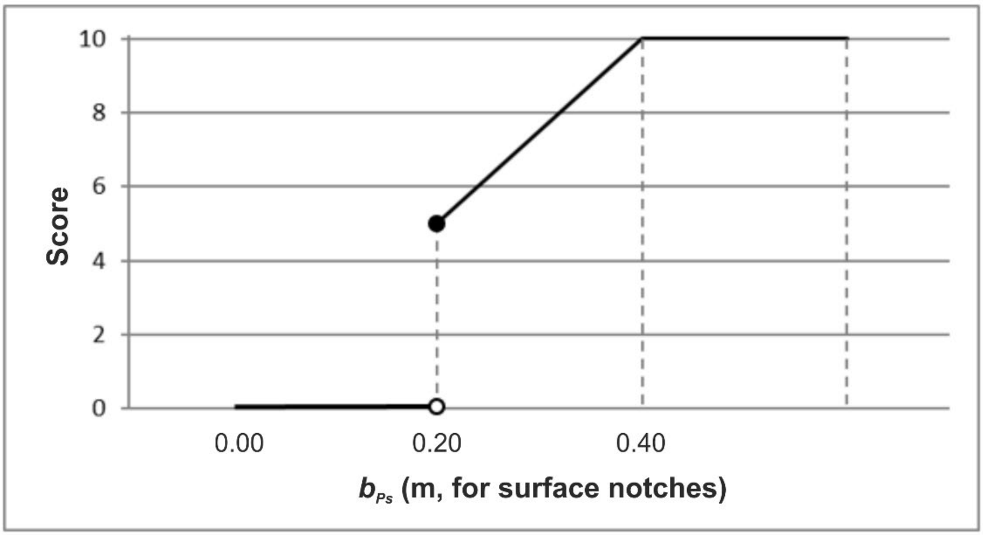



**Figure 74.** Explanation of how $b_{Ps}$ is scored for surface notches.

**Table 28.** Explanation of how $b_{Ps}$ is assessed for surface notches.

| SURFACE NOTCHES | | |
|---|---|---|
| $b_{Ps}$ | Rationale | Score |
| < 0.20 m | The size is too small, thus fish find it difficult to aim as they jump | 0 |
| = 0.20 m | Minimum dimension for a successful jump | 5 |
| ≥ 0.40 m | Optimal values. | 10 |

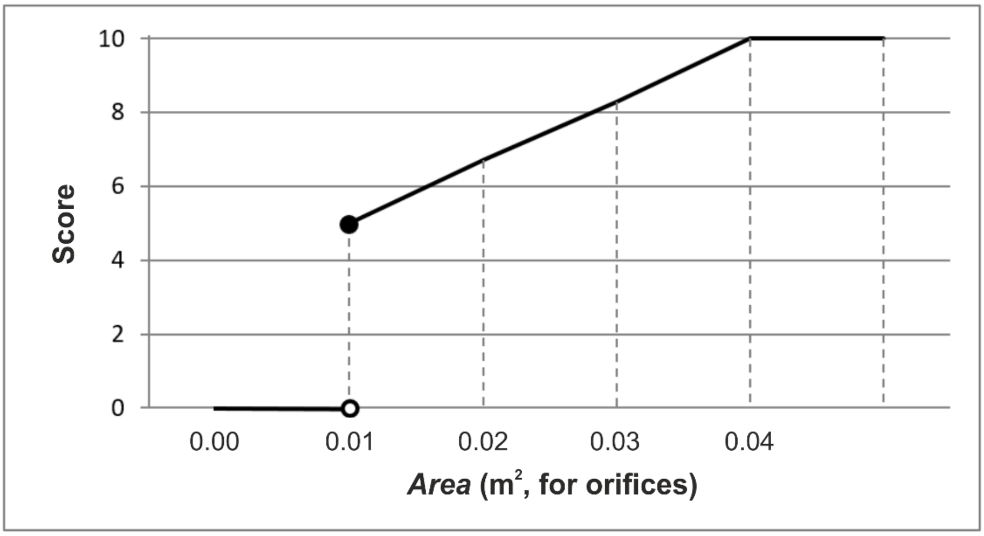



**Figure 75.** Assessing $b_{Ps}$ for submerged orifices.

**Figure 76.** Rationale to score $b_{Ps}$ for submerged orifices.

| *Area*[43] | Rationale | Score |
|---|---|---|
| < 0.01 $m^2$ | The size is too small, thus limiting fish transit and favouring blockage. | 0 |
| = 0.01 $m^2$ | Minimum passage size with some risk of blockage. | 5 |
| ≥ 0.04 $m^2$ | Optimal values with low probability of blockage. | 10 |

[43] *b* or *d* ≥ 0.10 m.

### 1.3.6. Type of opening between pools ($T_{Ps}$)

The passage system between pools is important because it conditions the way fish move, the quality of the energy dissipated, the recirculation areas and the resting zones (Larinier 2002b). For example, a free discharge forces the fish to jump and creates hydraulic conditions inside the pool – plunging flow – characterized by a shallow upward recirculation, that is, a plunging flow. On the other hand, a submerged discharge does not force fish to jump and creates a more horizontal and superficial flow – a streaming flow – so that the upward recirculation occurs at the bottom and is not as strong as in the previous case. (Ead *et al.* 2002; Larinier 2002b). When $h > \Delta H/2$ the flow is clearly submerged (Aigoui *et al.* 2008). In this case there is less selection and fish have more options to get through (they can choose between jumping or swimming and use different depths to move from one pool to the next). (Katopodis 1992; DVWK 2002; Larinier 2002b). In addition, the submerged flow reduces risk (a bad jump can end up with the fish outside the fishway) and facilitates group transit in species that migrate in shoals (*e.g.* nase), where the passage of a first individual encourages the rest to follow. (Sanz-Ronda *et al*., 2015).

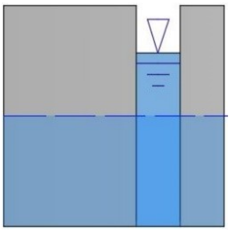
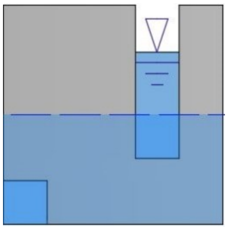
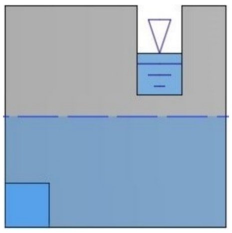
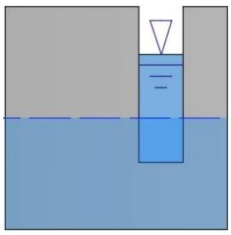
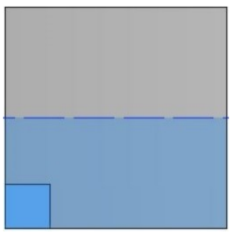
Bottom orifices are also submerged flows and, although there may be fish passes only with orifices, they are usually found in combination with traditional notches. Initially, they were designed for species that prefer to swim close to the bed (Clay 1995; Larinier 2002b). However, some species use submerged notches and orifices interchangeably (barbel and trout), while others (nase) prefer the former (Sanz-Ronda *et al*., 2015b). If given the choice between free discharges and orifices, barbel still show no clear preference, whereas nase prefer orifices and trout prefer notches (Sanz- Ronda *et al*., 2015b).

Few studies have focused objectively on comparing the efficiency of different passage systems. For the three target species, Bravo-Córdoba *et al*. (2018) found no differences in success and transit times in a fishway with submerged notches and orifices comparing it with a fishway with vertical slots, given the same dissipated energy and discharge.

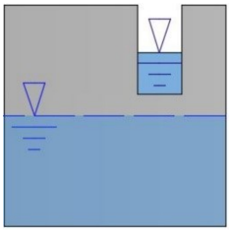
Likewise, Sanz-Ronda *et al*. (2015b) and Bravo-Córdoba *et al*. (2015) observed that there were no differences in the percentage of success nor in the transit time for fish swimming through a fishway with submerged notches and orifices, where $\Delta H$ = 0.25 m, for barbel, nase, and trout, when compared with a fishway with free discharges and orifices, where $\Delta H \approx$ 0.30 m. However, when fish jumped, it was dangerous, and they were not always successful (collisions with the wall or falls outside the fishway). In this case, the bottom orifice greatly facilitated the ascent of nase.

It is also important to consider how different types of openings between pools work when water levels change and how prone they are to clogging so as not to interfere with migration (Fuentes-Pérez *et al.* 2014, 2016). For example, surface notches do not cope well with variations in the water level at the feed stream (if it drops, the flow rate and *h* are greatly reduced), nor at the fish entrance (ΔH increases, it clogs easily and such clogging, if there are no bottom orifices, leaves no alternative for migration (Clay 1995; Aigoui *et al.* 2008)). Submerged orifices adapt better to level variations, but they are also sensitive to clogging and, if not accompanied by another type of opening, the fish will not swim upstream (Clay 1995; Larinier 2002b; Santo 2005). Vertical slots and submerged notches (the latter better if accompanied by orifices) do better when there are changes in water level and are less susceptible to clogging (Clay 1995; Larinier 2002b).

**Table 29.** Aspects considered in the development of the scoring system for the $T_{Ps}$ variable.

| | | | |
|---|---|---|---|
| **Vertical slot**[44] |  | Adapts very well to changes in water flow and partial obstructions (Clay 1995; Elvira *et al.*1998; Martínez de Azagra 1999; DVWK 2002; Larinier 2002b; Armstrong *et al.* 2004; Aigoui *et al.* 2008; Baudoin *et al.* 2014).<br>Fish can get through swimming at whichever depth they prefer (Katopodis 1992; Rajaratnam *et al.* 1992; Larinier 1998,2002b; DVWK 2002; Armstrong *et al.* 2004).<br>Suitable for all target species (fish can get through swimming, with no need to jump) (Elvira *et al.* 1998; Larinier 1998; Armstrong *et al.* 2004; Aigoui *et al.* 2008). | SCORE 10 |
| **Submerged notch + submerged orifice** |  | Adapts very well to changes in water flow and partial obstructions (Clay 1995; Elvira *et al.* 1998; Martínez de Azagra 1999; Larinier 2002b; Aigoui *et al.* 2008).<br>Fish can get through the orifice (close to the bottom) and through the notch.<br>Suitable for all target species (fish can get through swimming, with no need to jump) (Elvira *et al.* 1998; Aigoui *et al.* 2008). | SCORE 10 |
| **Surface notch + submerged orifice** |  | Adapts well to changes in water flow and obstructions (Clay 1995; Elvira *et al.* 1998; Martínez de Azagra 1999; Larinier 2002b; Aigoui *et al.* 2008).<br>Fish can get through swimming, though only close to the bottom, or jumping.<br>Suitable for all species but especially benthic species (that swim near the bottom) and/or have a good jumping ability (Elvira *et al.* 1998; Aigoui *et al.* 2008). | SCORE 8 |
| **Submerged notch** |  | Adapts well to changes in water flow and obstructions (Clay 1995; Elvira *et al.* 1998; Martínez de Azagra 1999; Larinier 2002b; Aigoui *et al.* 2008).<br>Fish can get through swimming, but within a range of depths that is smaller than with previous options.<br>Suitable for any target species, although benthic species (swim near the bottom) are at a disadvantage in comparison with other options (Elvira *et al.* 1998; Aigoui *et al.* 2008). | SCORE 7 |
| **Submerged orifice** |  | Adapts moderately well to changes in water flow and poorly to obstructions (Clay 1995; Elvira *et al.* 1998; Martínez de Azagra 1999; Larinier 2002b; Santo 2005).<br>Fish can get through swimming, though only within a limited range of depths, near the bottom.<br>Suitable for any target species, although those that swim close to the surface are at a disadvantage in comparison with other options. | SCORE 5 |

44 A submerged notch with a sill height $p < 0.25$ m is considered a vertical slot, because it has a similar hydraulic behaviour (Rajaratnam *et al.*, 1992).

| | | | |
|---|---|---|---|
| **Surface notch**[45] |  | Adapts poorly to changes in water flow and partial obstructions (Clay 1995; Elvira *et al.* 1998; Aigoui *et al.* 2008).<br>Fish can only get through jumping.<br>Only suitable for species with good jumping ability (which includes the target species) (Larinier 2002b; Armstrong *et al.* 2004; Aigoui *et al.* 2008). | SCORE<br>5 |

## 1.4. Exit

### 1.4.1. Difference in water level between the river and the upper pool ($\Delta H_s$)

This variable is discussed in length in section 1.2.1, although, contrary to what happens at the entrance, low values ($\Delta H$ < 0.05 m) do not pose a significant problem. Fish have been able to get through the previous openings and continuing to the river is the last step.

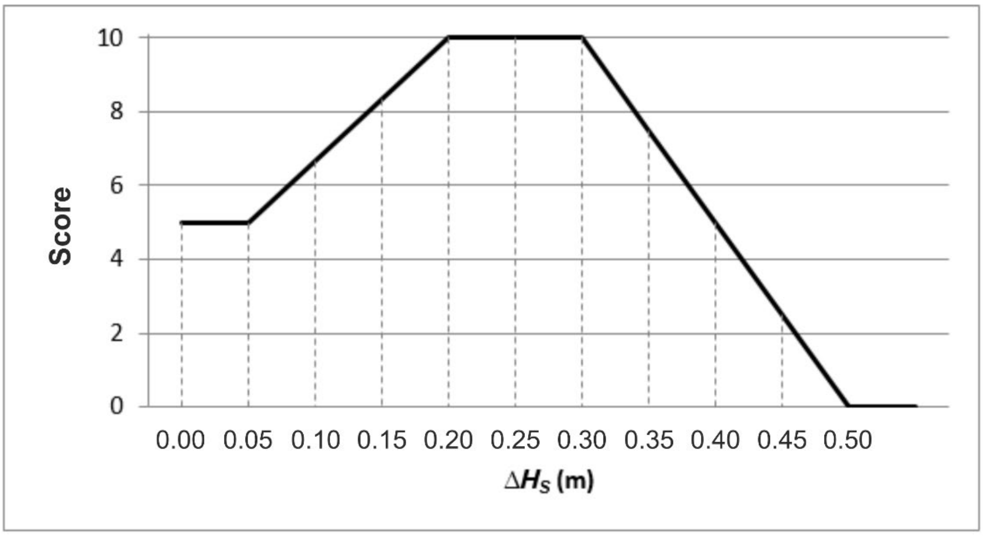



**Figure 77.** Scoring graph for $\Delta H_s$.

[45] If it is a free discharge through an opening, the score would be 0, because fish have to aim well to get into it, which is very complicated.

**Table 30.** Rationale to assess variable $\Delta H_S$.

| $\Delta H_s$ | Rationale | Score |
|---|---|---|
| ≤ 0.05 m | Flow velocities that decrease motivation. | 5 |
| ≥ 0.20 and ≤ 0.30 m | Optimal flow velocities. | 10 |
| = 0.40 m | Upper acceptable threshold value. | 5 |
| ≥ 0.50 m | Water flow velocities that most individuals cannot swim against. | 0 |

### 1.4.2. Depth at exit ($h_s$)

This variable is explained in section 1.3.4.

### 1.4.3. Width at exit ($b_s$, $d_s$)

This variable is explained in section 1.3.5.

### 1.4.4. Depth after the exit opening ($h_{after\ S}$)

This parameter analyses whether the water is deep enough so that fish, once they exit the fish pass, can continue swimming upstream without any risks of becoming injured with scrapes, being preyed upon, suffering excessive stress or resting properly.

The minimum depth, based on what was mentioned earlier in this document (sections 1.2.2 and 1.3.4.) is set as 20 cm (Katopodis 1992; DVWK 2002; Armstrong *et al.* 2004) and optimal conditions are achieved above 60 cm (Martínez de Azagra 1999; DVWK 2002; Larinier 2002b; Sanz-Ronda *et al.* 2014).

### 1.4.5. Orientation of exit in relation to the river ($Ort_s$)

The orientation of the exit affects the ease with which fish leaving the fishway quickly find their way upstream and also affects the entry of debris washed off by the current. An exit pointing downstream and close to the crest of the weir is counterproductive because the recirculating water generated may disorient the fish and even cause them to go down over the lip of the weir (Larinier 2002b). Therefore, exits oriented perpendicular to the river current, or parallel and pointing upstream, are of interest, although the risk of obstructions increases (Aigoui *et al.* 2008; Sanz-Ronda *et al.* 2014).

**Table 31.** Rationale to score $Ort_s$.

| $Ort_s$ | Rationale | Score |
|---|---|---|
| Zone A (90º ≤ α ≤ 180º) | - The closer to 180º, the more natural will be the exit of the fish, swimming upstream, but the probability of entry of debris washed off by the current increases (a barrier to hold floating debris is recommended). | 10 |
| Zone B (45º ≤ α < 90º) | - The risk of fish becoming disoriented as they exit increases.<br>- Low probability of entry of debris washed off by the current. | 1-5* |
| Zone C (0º ≤ α < 45º) | - Fish do not exit naturally.<br>- Low probability of entry of debris washed off by the current. | 0 |

### 1.4.6. Type of exit ($T_S$)

This variable is discussed in detail in section 1.3.6, although it is assessed differently, as per the guidelines in the table in 4.1.4.f.

# 2. Relevant observations

## 2.1. General observations

### 2.1.1. Maintenance and cleaning (attraction, entry, passage and exit)

Regardless of whether the design and execution of a fish pass have been correct, proper maintenance and cleaning are necessary to ensure optimal performance. Otherwise, if not done appropriately, the structure will not work properly, causing problems for fish swimming upstream (DVWK 2002; Santo 2005; Aigoui *et al.* 2008; Towler *et al.* 2013).

**Figure 78.** Obstructions in a notch (left) and in a bottom orifice (right) by debris driven by the current into the fishway.

### 2.1.2. Accessibility to the fishway and its elements (attraction, entry, passage and exit)

It facilitates all those activities related to the management of a fish pass that ensure its correct operation over time (maintenance and cleaning, repair of leaks, regulation of the flow rate through the fishway, assessment work, etc.).

**Figure 79.** Footbridge (left) and concrete ramp (right) providing access to two fish passes.

## 2.1.3. Rounded edges (entry, passage and exit)

Rounded edges minimize damage to specimens when they are inside the pools and collide with passage structures (Clay 1995). In addition, they make the flow adhere to the structure, thus helping fish fauna to swim up the structure (Armstrong *et al.* 2004).

**Figure 80.** Pools with sharp edges (left) and rounded edges (right).

## 2.2. Entrance

### 2.2.1. Elements to regulate water level drop

The difference between the water level in the lower pool and the river may vary depending on the river discharge. It is therefore advisable for the fishway to have some element to enable regulating and adjusting the difference in water level, such as a gate or a notch with a movable sill (Elvira *et al.* 1998; Larinier 2002b).

**Figure 81.** The sill height of a notch with a movable sill is modified to regulate the water level drop at the entrance.

### 2.2.2. Flow discharges at entrance

Sometimes, the entry into the fishway is favoured by nearby complementary flows, either natural or induced (weir lowering, forced pipelines), which help attract the fish to the surroundings of the entrance.

### 2.2.3. Absence of other flow discharges that drive fish away from the pass

As they move upstream, fish fauna is attracted by the larger flows (Lundqvist *et al.* 2008; Calles and Greenberg 2009). Thus, if in the section of the channel where the fishway is located there are significant flow discharges close to its entrance, they may reduce attraction to the entrance and disorient the fish (Baudoin *et al.* 2014). This would result in delays or even fish not being able to find the entrance to the fishway.

## 2.3. Passage

### 2.3.1. Pool shape

The design should avoid the flow of water from one pool to the next without enough dissipation of kinetic energy. Neither should the current jets hit the pool walls with high velocity, as they can interfere with the movement of the fish, even inducing them to jump in the wrong place and in the wrong direction (Larinier 2002b). Therefore, when sizing the pools, it is preferable to follow the design recommendations from proven efficiency models. Thus, for pools with submerged or free discharges, the design guidelines indicate that the pool length (L) should be between 7-12 times $\beta$, $\beta$ being the width of the opening (*b*) in vertical slots; the water level measured from the sill (*h*) for surface notches; in the case of submerged notches whichever has the lower value, *h* or *b,* and in submerged orifices the smallest dimension (*b* or *d*) (Clay 1995; Larinier 2002b).

The width of the pool (*B*) is discussed to a lesser extent in the design manuals, its dimensions being limited to meet the criteria for dissipated energy. However, it affects the shape and size of circulation currents (Tarrade *et al.* 2008). Typical values are around 4-8 times $\beta$ (Clay 1995; Larinier 2002b).

In any case, the lower values ($L < 7 \cdot \beta$ and $B < 4 \cdot \beta$) are the ones that can lead to most problems with undesirable recirculation.

### 2.3.2. Baffles in pools

If they are properly sized and located, they stabilise the flow and prevent excessive turbulence inside the pools which may disorient the fish (Baudoin *et al.* 2014). They also lead to recirculation that provides low velocity zones where fish can rest more comfortably (Katopodis 1992; Sanz-Ronda *et al.* 2014).

**Figure 82.** Pools without baffles (left) and with them (right).

### 2.3.3. Conservation of structure

Consideration is given to water leaks from the fishway, as well as structural damage to walls. If leaks are significant enough, they can reduce the flow rate through the pass significantly and, consequently, affect its normal hydraulic operation and the ascent of fish. Similarly, if the walls are damaged or have shifted, they can also compromise the correct functionality of the device and have a negative effect on fish fauna.

### 2.3.4. Bed naturalised with stones

In addition to providing a more natural and predictably more welcoming appearance than a man-made concrete structure, attaching stones to the bottom increases the roughness and generates variations in flow (different velocities) that are favourable for fish with different swimming abilities, while providing places that allow them to rest comfortably (DVWK 2002; Larinier 2002b; Baudoin *et al.* 2014; Sanz-Ronda *et al.* 2014).

**Figure 83.** Unnaturalised bed (left) and bed naturalised by embedding stones (right).

### 2.3.5. Darkness due to elements covering the fishway

It affects the reluctance of fish fauna to enter and ascend through the structure. Many fish species are reluctant to pass through dark areas or shy away from sudden changes in lighting (DVWK 2002; Armstrong *et al.* 2004; Baudoin *et al.* 2014).

**Figure 84.** Examples of fish passes that are partially obscured by elements over them or excessive height of surrounding walls.

### 2.3.6. Leeway in the fishway walls

When moving from one pool to the next, fish swim or jump (they also often do it in submerged notches). The efficiency of the jump depends on the width of the notch and the direction of the fish jumping. Many jumps are unsuccessful and the fish hits the wall or falls outside the fishway (Sanz-Ronda *et al*., 2015). For this reason, it is advisable to have a minimum leeway in the walls of the fishway channel of at least 40 cm from the water level in the pool to prevent fish from falling outside, or else special protections can be used.

**Figure 85.** Fishways with different types of side protections: leeway too small (left), initially insufficient, although this was solved installing side protection fencing (centre) and leeway large enough (right).

## 2.4. Exit

### 2.4.1. Gate to regulate discharge

Gates allow controlling the flow rate inside the fish pass, ensuring that it is within the design range considered, regardless of the discharge in the river where it is located. This makes it possible for the fish pass to function properly and allows the transit of the target species under the different flow regimes of a river throughout the year (Clay 1995; Larinier 1998; DVWK 2002; Baudoin *et al.* 2014).

**Figure 86.** Different gates to regulate the water going into the fish pass.

### 2.4.2. Device to prevent entry of debris

It prevents debris washed off by the current such as leaves, garbage, logs, etc., from getting into the fishway, or makes it less likely. This is recommended to keep the inside of the fishway clean, thus favouring its correct hydraulic operation (Larinier 2002a; Armstrong *et al.* 2004; Towler *et al.* 2013; Sanz-Ronda *et al.* 2014).

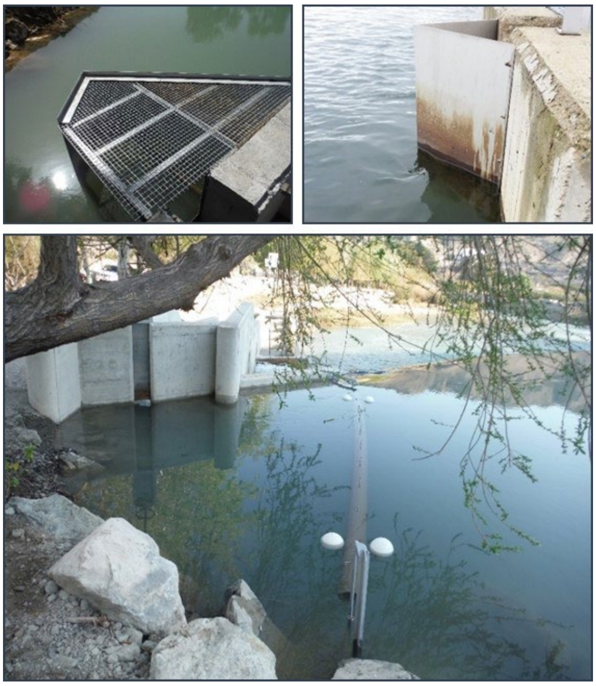


**Figure 87.** Examples of different elements to prevent the entry of debris driven by the current into a fishway.

### 2.4.3. Safe exit

It helps to ensure that once the fish leave the pass they can adapt to the flow conditions of the river before being swept by the current through the spillway, intakes, etc. For this reason, various authors recommend there is a safety distance that prevents fish from being swept away (Clay 1995; Elvira *et al.* 1998). Specifically, Sanz- Ronda *et al.* (2014) mention a minimum distance between the exit and the crest of the obstacle of 2.00 m.; meanwhile DVWK (2002) recommend more than 5.00 m between the exit and the turbine intake or screens. If the fishway does not comply with these minimum distances, a fish barrier may be used instead.

# A.3. Hydraulic discharge equations for a fish pass

The equations to calculate the discharge through the different openings in a fish pass (Poleni 1717 in Fuentes-Pérez *et al.* 2016; Villemonte 1974 in Fuentes-Pérez *et al.* 2014; Clay 1995; Martínez de Azagra 1999; Larinier 2002b; Wang *et al.* 2010) are as follows:

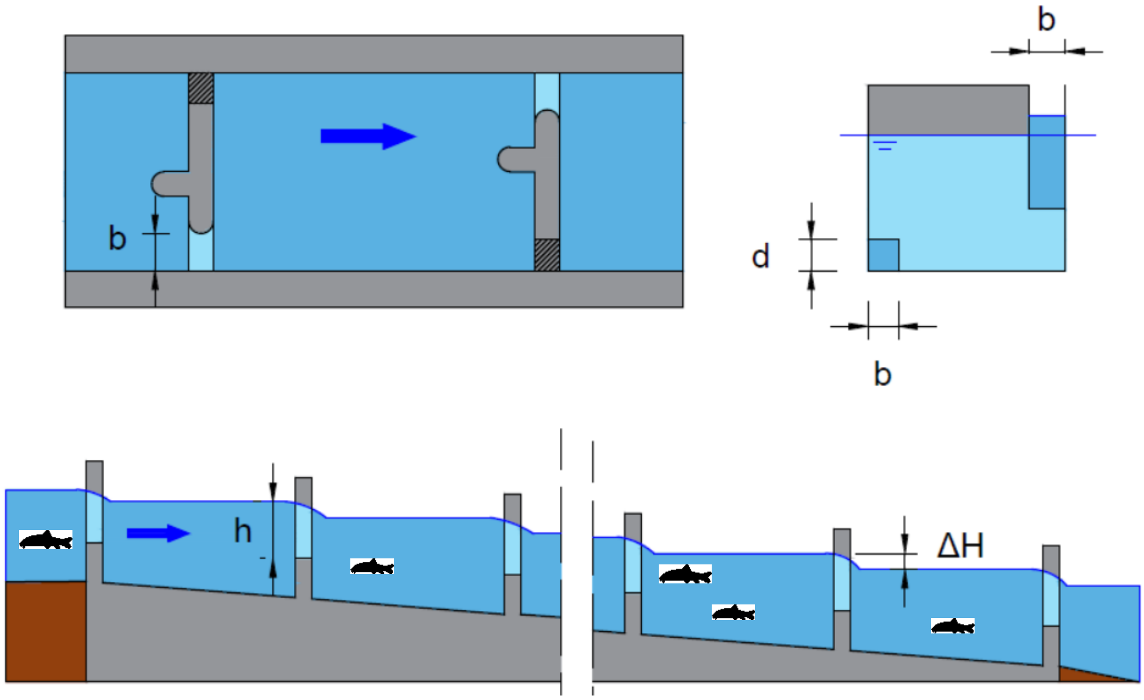



**Figure 88.** Hydraulic variables related to discharge equations: *b* is the width of the opening connecting two pools, *d* is the height of the bottom orifice, *h* is the water level measured from the edge of an opening (notch/slot) and $\Delta H$ is the difference in water level between pools or head drop.

- Discharge through an orifice:

$$Q_o = C_o \cdot Area \cdot \sqrt{2 \cdot g \cdot \Delta H} \qquad \text{(Eq. 13)}$$

where $Q_o$ is the discharge through an orifice ($m^3/s$), $C_o$ is the discharge coefficient for the orifice and *Area* is its area ($m^2$):

$$C_o = 0.876 \qquad \text{(Eq. 14)}$$

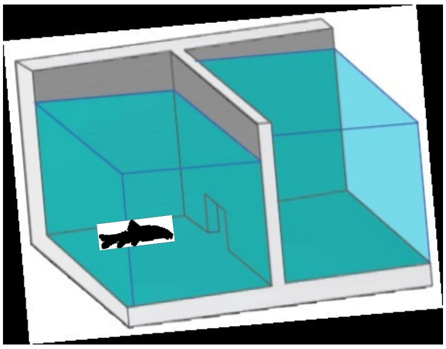


**Figure 89.** Submerged orifice.

- Discharge through a vertical slot:

$$Q_v = \frac{2}{3} \cdot C_v \cdot b \cdot h^{1.5} \cdot \sqrt{2 \cdot g} \qquad \text{(Eq. 15)}$$

where $Q_v$ is the discharge through a vertical slot (m$^3$/s), $\frac{2}{3} \cdot C_v$ is the discharge coefficient for a slot, calculated as (Fuentes-Pérez *et al.* 2016):

$$C_v = 0.72 \cdot \left[1 - \left(\frac{(h-\Delta H)}{h}\right)^{1.5}\right]^{0.33} \quad \text{(Eq.16)}$$

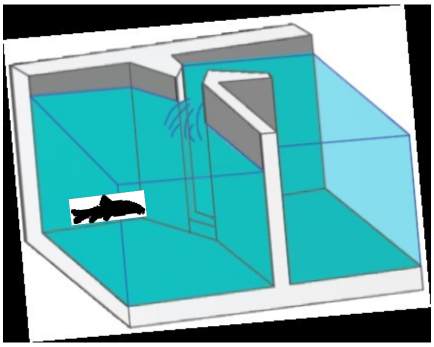


**Figure 90.** Vertical slot.

- Discharge through a surface notch (free/plunging discharge):

$$Q_f = \frac{2}{3} \cdot C_n \cdot b \cdot h^{1.5} \cdot \sqrt{2 \cdot g} \quad \text{(Eq. 17)}$$

where $Q_f$ is the discharge through a surface notch (m$^3$/s), $\frac{2}{3} \cdot C_n$ is the discharge coefficient for a rectangular notch and is calculated with the expression (Fuentes-Pérez *et al.* 2016):

$$C_n = 0.689 \cdot [1 - e^{-8.889 \cdot h}] \qquad \text{(Eq. 18)}$$

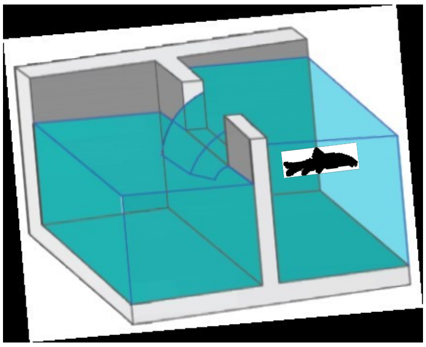


**Figure 91.** Surface notch.

- Discharge through a submerged notch (submerged/streaming discharge):

$$Q_s = \frac{2}{3} \cdot C_n \cdot C_s \cdot b \cdot h^{1.5} \cdot \sqrt{2 \cdot g} \qquad \text{(Eq. 19)}$$

where $Q_s$ is the discharge through a submerged notch ($m^3/s$), $\frac{2}{3} \cdot C_n$ is the discharge coefficient for a free discharge through a rectangular notch and $C_s$ is the submergence coefficient for submerged notches (Fuentes-Pérez *et al.* 2016):

$$C_n = 0.689 \cdot [1 - e^{-8.889 \cdot h}] \qquad \text{(Eq. 20)}$$

$$C_s = \left[1 - \left(\frac{(h - \Delta H)}{h}\right)^{1.5}\right]^{0.331} \qquad \text{(Eq. 21)}$$

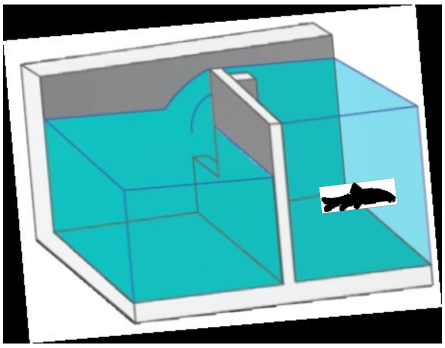


**Figure 92.** Submerged notch.

# A.4. Risk assessment of the work

# 1. Scope of work

Measurement of heights, dimensions and hydraulic parameters in a fish pass with a measuring tape and/or total station and a flow rate meter.

# 2. Work phases

## 2.1. Preliminary phase

Visualisation of the environment and preparation of the equipment.

## 2.2. Topographic survey of a fish pass

Measurement with measuring tape or total station in the fish pass, with and without water flow. One technician stands by the station and another one is with the pole inside the empty fishway (or with the measuring tape and takes data directly). When water is flowing, the technician goes around the outside of the fish pass, taking data on the outside water level.

## 2.3. Measuring discharge

### 1.1.1. Using topographic measurements

The discharge is measured indirectly, using the data from the topographic survey and hydraulic discharge equations.

### 1.1.2. Using a flow rate meter

The water velocity is measured in the notch from the outside, with an impeller flow rate meter.

# 3. Risk assessment

The risk assessment and adoption of preventive measures for the work is carried out according to the table of the Spanish Institute for Occupational Safety and Health (INSHT) (Table 32).

**Table 32.** Levels of risk according to their estimated probability and expected consequences.

| Table of risks by the INSHT | | Consequences (*) | | |
|---|---|---|---|---|
| | | Slightly harmful | Harmful | Extremely harmful |
| Likelihood | Low | Minor risk | Tolerable risk | Moderate risk |
| | Medium | Tolerable risk | Moderate risk | Significant risk |
| | High | Moderate risk | Significant risk | Unacceptable risk |

Each of these risks should be assessed according to their probability and consequences, in a similar way as it is done in the following table:

**Table 33.** Estimation of the likelihood, severity and degree of potential risks of the assessment works.

| Risk | Probability | Severity | Degree of risk |
|---|---|---|---|
| Fall from a height | Medium | Harmful | Moderate |
| Falls at level | Medium | Slightly harmful | Tolerable |
| Falls due to detached objects | Low | Harmful | Moderate |
| Blows or cuts with objects or tools | Low | Harmful | Moderate |
| Fall into a water body < 1.3 m in depth | Medium | Harmful | Moderate |
| Exposure to/inhalation of harmful agents (chemical, biological, etc.) | Low | Harmful | Moderate |

The risks in each of the phases indicated and the preventive measures to eliminate or minimise them are as follows:

## 3.1. Preliminary phase

Risks:

- Undetermined due to the place where the work takes place

Preventive measures:

- Before starting the work, the location of equipment and personnel shall be analysed to avoid possible risks, proximity to watercourses, holes or places with falls from a height, etc.
- Use the personal protective equipment necessary for the risks existing in the facility and/or location, including, as a general rule, a life jacket, safety helmet with chinstrap and appropriate footwear.

**Figure 93.** Preventive measures in the preliminary phase of the works.

## 3.2. Topographic survey of a fish pass

Risks:

- Falls at level.
- Falls from a height.
- Falls due to detached objects.
- Blows and/or cuts with objects.

Preventive measures:

- Prior to going inside of the fish pass, request the owner of the facility to completely close the water inflow, and wait to allow all the water to empty from the fish pass.
- Wear slip-resistant safety footwear.
- Avoid stockpiling materials or equipment in the vicinity of the work area.
- Access to the inside of the fish pass will be through the lowest pools (estimated height 1.75 m).
- Access the fish pass using a manual ladder, following all the preventive measures with this type of equipment.
    - Before using the ladder, you must ensure it is stable. The base of the ladder must be solidly seated. It shall be fixed to prevent it from slipping,

since there might be a layer of green algae on the surface where the ladder rests. It should have anti-slip rubber feet.

- Place the ladder at a 75 º angle with the horizontal.
- When used to access high places, it must extend at least 1.00 m above them.
- Climbing up, down and working from ladders shall be done while facing the ladders.
- The transport and handling of loads while on/from ladders is forbidden when their weight or dimensions may compromise the safety of the worker.
- Ladders shall not be used by two or more people at the same time.

- Try to keep any gaps due to the temporary removal of the tramex grid as little time as possible, limiting the access of personnel to this area. The holes will be protected or suitably marked.
- Personal protective equipment, life jackets, safety helmets with chin straps and appropriate footwear must be worn at all times.

**Figure 94.** Some of the preventive measures to be taken during the topographic survey.

## 3.3. Measuring discharge

Risks:

- Falls at level.
- Falls from a height.
- Blows and/or cuts with objects.

Preventive measures:

- Wear slip-resistant safety footwear.
- Avoid stockpiling materials or equipment in the vicinity of the work area.
- Try to keep any gaps due to the temporary removal of the tramex grid as little time as possible, limiting the access of personnel to this area. The holes will be protected or suitably marked.
- The measurement of the flow rate with a flow rate meter will be done from a safe place, using a pole.
- Personal protective equipment, life jackets, safety helmets with chin straps and slip-resistant footwear must be worn at all times.

**Figure 95.** Some of the preventive measures to be taken when measuring the discharge.

## A.5. Form to collect data in the field

In this section we present a template to be used in the field to collect the data necessary for the assessment of a pool fish pass, to be used with the computer software associated with this document, which facilitates the assessment:

# FIELD FORM TO COLLECT THE INFORMATION NECESSARY TO ASSESS POOL FISH PASSES

| OBSERVATIONS | | | |
|---|---|---|---|
| | | | |
| **Number of standard pools** | | **Total number of pools** | |

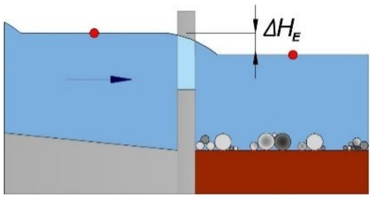
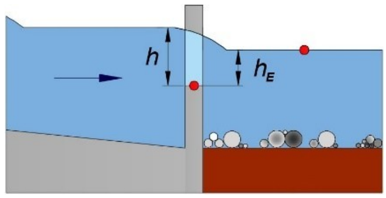
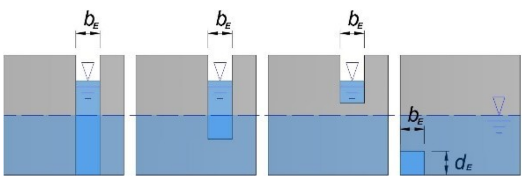
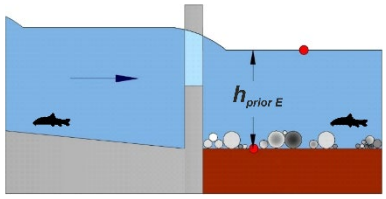
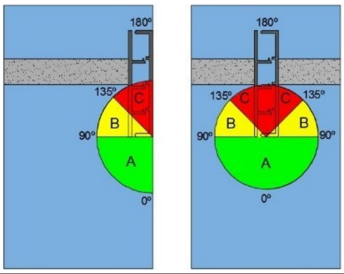
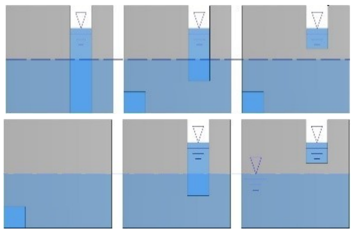
| ATTRACTION | | | |
|---|---|---|---|
| **Name** | | **Parameter** | **Measured** |
| Essential variables | *Rel $Q_{attraction}$* | Auxiliary flow to attract fish ($m^3$/s) | |
| | | Water flow in the fishway ($m^3$/s) | |
| | | Mean river discharge during the migration period ($m^3$/s) | |
| | $U_E$ | Location next to the bank | |
| | | Location as upstream as possible | |
| | | Location next to the base of the obstacle | |
| | | Location where a large volume of flow concentrates | |
| Relevant observations | | Maintenance and cleaning | |
| | | Accessibility | |

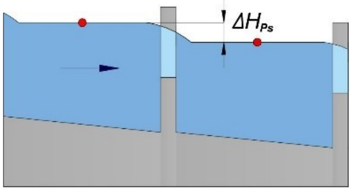
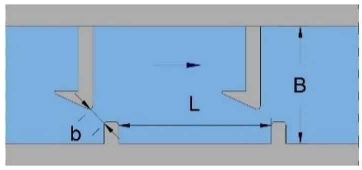
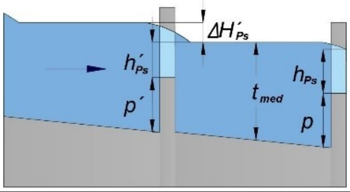
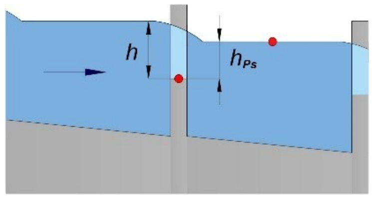
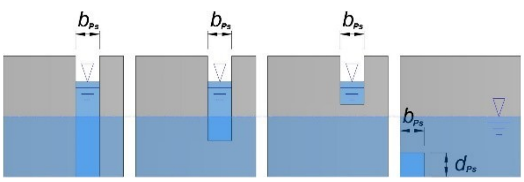
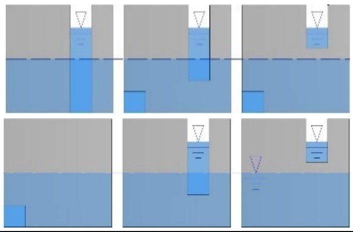
| ENTRANCE | | | |
|---|---|---|---|
| **Name** | | **Parameter** | **Measured** |
| Essential variables | $\Delta H_E$ | Difference in water level between the river and the lower pool (m) | |
| | $h$ | Water level measured from sill at entrance (m) | |
| | $h_E$ | Depth at the entrance (m) | |
| | $b_E$ | Width at the entrance (m) | |
| | $Area_E$ | Area of entrance opening ($m^2$) | |
| | $h_{prior\ E}$ | Depth prior to the entrance (m) | |
| | $Ort_E$ | Orientation of the entrance in relation to the river (º) | |
| | $T_E$ | Type of entrance | |
| Relevant observations | | Maintenance and cleaning | |
| | | Accessibility | |
| | | Rounded edges | |
| | | Elements to regulate water level drop | |
| | | Flow discharges at the entrance | |
| | | Absence of other flow discharges that drive fish away from the pass | |

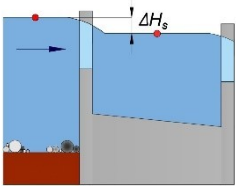
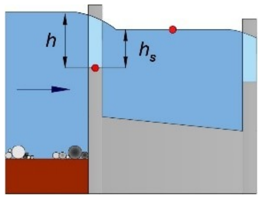
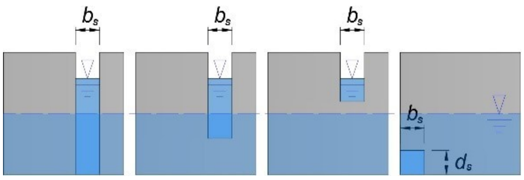
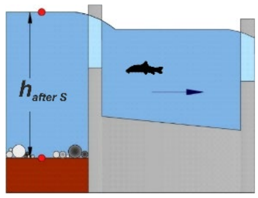
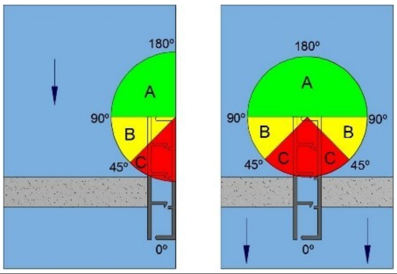
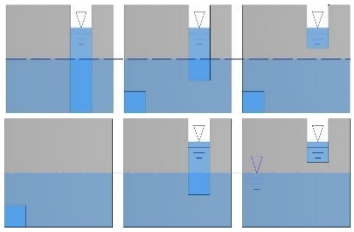
| PASSAGE | | | $E_{standar}$ | $E_{i1}$ | $E_{i2}$ | $E_{i3}$ |
|---|---|---|---|---|---|---|
| **Name** | | **Parameter** | **Measured value** | | | |
| **Essential variables** | $\Delta H_{Ps}$ | Difference in water level between consecutive pools or head | | | | |
| | $B$ | Width of pool (m) | | | | |
| | $L$ | Length of pool (m) | | | | |
| | $p$ | Sill height of the opening between pools (m) | | | | |
| | $h$ | Water level measured from edge of opening (m) | | | | |
| | $h_{Ps}$ | Water depth in openings between pools (m) | | | | |
| | $b_{Ps}$ | Width of openings between pools (m) | | | | |
| | $Area_{Ps}$ | Area of opening connecting pools ($m^2$) | | | | |
| | $T_{Ps}$ | Type of opening between pools | | | | |
| **Relevant observations** | | Maintenance and cleaning | | | | |
| | | Accessibility | | | | |
| | | Rounded edges | | | | |
| | | Pool shape | | | | |
| | | Baffles in pools | | | | |
| | | Conservation of structure | | | | |
| | | Bed naturalised with stones | | | | |
| | | Darkness due to elements covering the fishway | | | | |
| | | Leeway in the fishway walls | | | | |

**NOTE**: "$E_{standard}$" is the standard pool in the fishway; "$E_{i1}$", "$E_{i2}$" and "$E_{i3}$" are the first, second and third unique pools, respectively.

| EXIT | | | |
|---|---|---|---|
| **Name** | | **Parameter** | **Measured value** |
| **Essential variables** | $\Delta H_S$ | Difference in water level between river and the upper pool (m) | |
| | $h$ | Water level measured from sill at exit (m) | |
| | $h_S$ | Depth at the exit (m) | |
| | $b_S$ | Width at the exit (m) | |
| | $Area_s$ | Area of exit opening ($m^2$) | |
| | $h_{after\ S}$ | Depth after the exit opening (m) | |
| | $Ort_S$ | Orientation of exit in relation to the river (º) | |
| | $T_S$ | Type of exit | |
| **Relevant observations** | | Maintenance and cleaning | |
| | | Accessibility | |
| | | Rounded edges | |
| | | Gate to regulate the discharge | |
| | | Device to prevent the entry of debris | |
| | | Safe exit | |

| ENTRANCE | | | |
|---|---|---|---|
| **Variable** | **Explanatory diagram** | **Variable** | **Explanatory diagram** |
| $\Delta H_E$ |   | $h_E$ |   |
| $b_E$ <br> $Area_E$ ($b_E$ x $d_E$) |   | $h_{prior\ E}$ |   |
| $Ort_E$ |   | $T_E$ |  |

| PASSAGE | | | |
|---|---|---|---|
| **Variable** | **Explanatory diagram** | **Variable** | **Explanatory diagram** |
| $\Delta H_{Ps}$ |   | *B*, *L* and *b* |   |
| $t_{med}$, $p$, $h_{Ps}$, $p'$, $h_{Ps}'$ and $\Delta H_{Ps}'$ |   | $h_{Ps}$ |   |
| $b_{Ps}$ <br> $Area_{Ps}$ ($b_{Ps}$ x $d_{Ps}$) |   | $T_{Ps}$ |  |

| EXIT | | | |
|---|---|---|---|
| **Variable** | **Explanatory diagram** | **Variable** | **Explanatory diagram** |
| $\Delta H_S$ |   | $h_S$ |   |
| $b_S$ <br> $Area_S$ $(b_S \times d_S)$ |   | $h_{after\ S}$ |   |
| $Ort_S$ |   | $T_S$ |  |

## GENERAL DIAGRAM