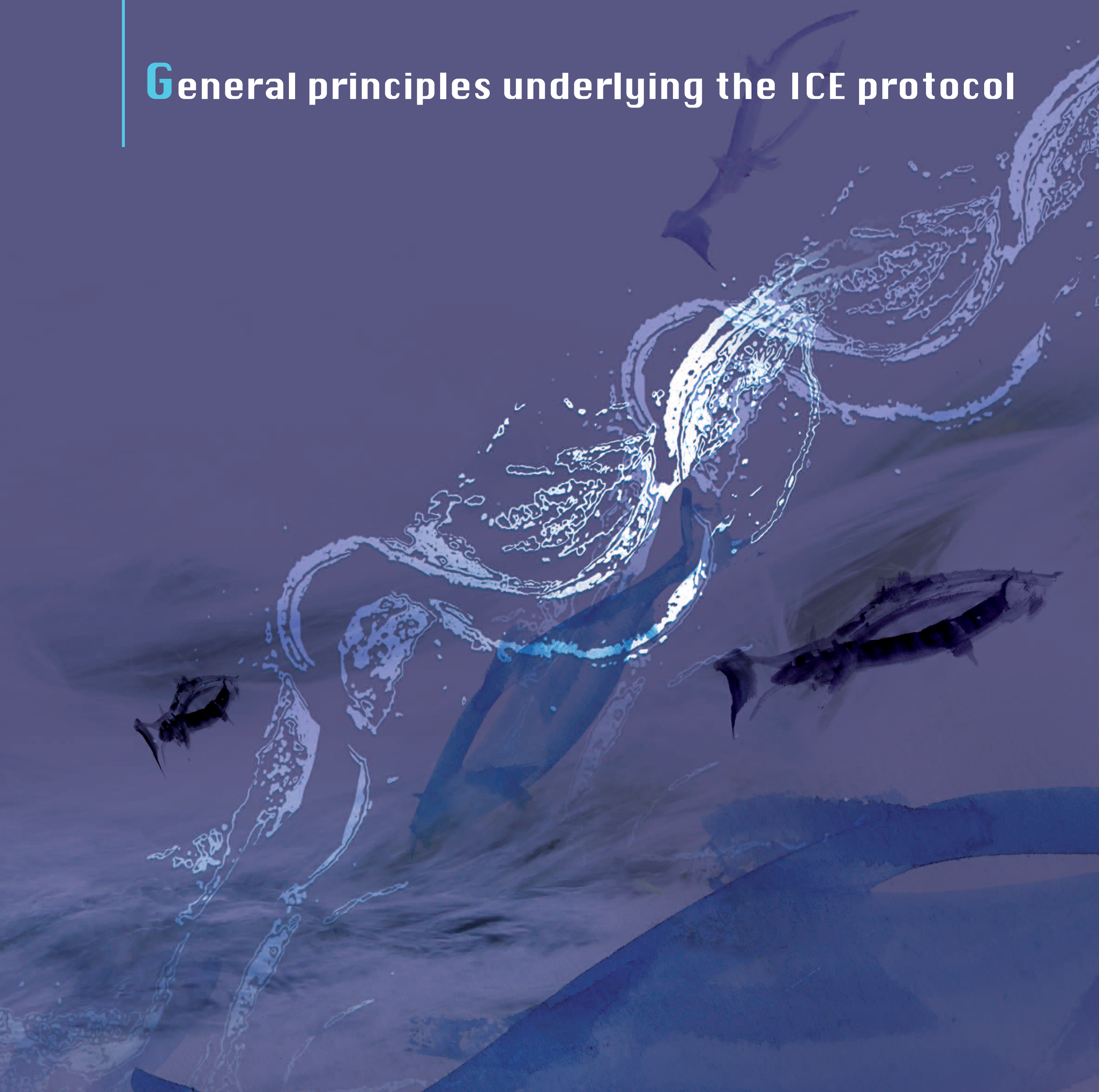
B

General principles underlying the ICE protocol



Protocol modus operandi

Protocol objectives and limits

The purpose of the ICE protocol is to objectively assess the passability of obstacles by fish, while avoiding as much as possible the need to bring in experts.

This method may be implemented by a limited team (two to three persons) and in a fairly short time, generally less than two hours.

Caution. There is, however, a limitation concerning downstream migration. Given the complexity of the biological mechanisms involved and the in-depth knowledge required on the local hydrology, on draw-off conditions and on the hydromechanical characteristics of each structure, no simple and integrated criteria have been established to assess the passability of structures in the downstream direction. **An assessment of the potential impact of a water intake on downstream migration will always require a specific study of the structure by specialised technicians.**

The ICE protocol deals essentially with determining the passability of a structure by fish migrating upstream. In the process of implementing the protocol, the collection of field data required to assess downstream-migration conditions is nonetheless carried out.

The assessment of discontinuities in upstream migration using the ICE protocol should make it fairly easy to determine the passability of a structure according to **passability classes** adapted to the given species or **group of species**.

The ICE protocol is essentially based on a comparison of the typological and geometric characteristics of obstacles and the hydraulic conditions around the obstacles with the physical capabilities of the fish species analysed.

For example, generally speaking, the protocol consists of **identifying for each obstacle the potential passageway(s)**, characterising their geometric features and the hydraulic conditions, and comparing the results with the physical capabilities of the given species, as suggested by Ovidio *et al.* (2007).

The description of the geometric characteristics of each section of a potential passageway for fish (see Figure 24) consists essentially of determining the corresponding long profile.

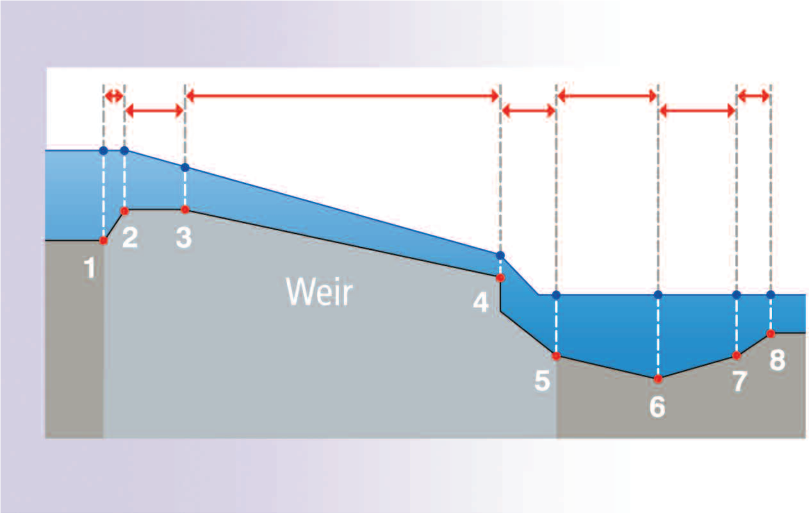
The procedure is therefore to collect the altimetric data for each specific point in a structure corresponding to a significant change in the profile, e.g. a break in a slope. These data should be collected, following the flow of water, from the bottom of the river immediately upstream of the structure to the end of the plunge pool downstream of the structure (see Figure 25). The measurements taken of the altimetric data and of the distances between the measurement points are then used to draw one or more long profiles of the potential passageways for fish.

Figure 24

a, b © Burgun - Onema

Examples of the long profiles that must be calculated in order to characterise a structure. (a) For this type of structure with three identical gates, a single long profile should be sufficient. (b) For this weir, a second long profile should be drafted for the dry section that may be under water if different hydrological conditions arise.

Figure 25



Example of a long profile for a simple structure.

The passability of an obstacle depends above all on the hydraulic conditions pertaining at each point in the structure and that the fish must attempt to overcome, depending on their swimming and jumping capabilities. Mapping of the hydraulic gradient along the entire profile is therefore particularly important and must be carried out simultaneously with the measurement of the physical characteristics of the structure. The hydraulic conditions depend not only on the type of structure (glacis with a continuous slope, stepped weirs, fixed or movable vertical obstacles, structures comprising culverts, flows under gates, etc.) and its geometry (height, profile, slope, length, roughness), but also the discharge flowing over or through it. The discharge depends on the hydrological conditions during the migration period, which can vary widely.

Passability can therefore vary with the river discharge, for example, the structure may be a total barrier during a low-flow period and not represent an obstacle at all during a high-flow period.

Consequently, an ICE assessment should be carried out under the hydrological conditions most common during the migratory period of the given species.

This may create very difficult and/or dangerous conditions when measuring certain important structural features of the structure and make it impossible to determine its passability.

Low-flow conditions make it easy to access structures and measure the various structural features, however they may significantly complicate the passability assessment (maximum head-drop, minimum depths, less depth in the plunge pool, etc.) and they are not particularly representative of the hydrological conditions most common during migratory periods.

For these reasons, a number of visits under different hydrological conditions (low and medium flow conditions) may be necessary to determine or improve the analysis of the ICE passability classes. When an assessment is carried out under hydrological conditions differing significantly from those encountered by a species during the migratory period, it is advised, in addition to the standard assessment procedure, to ignore the disqualifying parameters resulting from the discharge (generally the water depth and overflow height) when determining the passability class. This assessment not taking into account the parameters resulting from the discharge is a means to evaluate the impact of hydrological conditions on the passability of the structure and also whether it would be worthwhile to return to the site when other hydrological conditions prevail.

When a number of passageways have been detected for a structure, each passageway may have a different passability level. In a single structure, some passageways may be considered insurmountable according to the ICE protocol, whereas others may be easily passable. To be truly effective, the passageways deemed passable must also be detectable by the fish. This may be a major problem if they are very narrow compared to the overall obstacle and/or if they receive only a minute and unattractive fraction of the total discharge flowing over or through the structure.

When multiple passageways exist, the ICE protocol cannot determine the degree of attractiveness of each. In such cases, the decision concerning the overall ICE passability class of the structure will call on a fairly high level of technical expertise. That will generally require prior measurements to determine the distribution of discharges at the site as a function of the hydrological conditions.

For the ICE protocol, the characterisation of hydraulic conditions in and over structures has been voluntarily and significantly simplified.

In those cases where more in-depth assessments must be carried out, a hydraulic model of the specific site should be prepared. The model will serve to improve the characterisation of the hydraulic conditions at the site for different discharges and to compare the results with the passage capabilities of the species.

This detailed, hydraulic model will require the development and calibration of a digital application based on a number of physical (precise geometry of the structure, roughness of surfaces) and hydraulic (discharges, conditions at the furthest upstream and downstream points as a function of the discharges, etc.) data points.

Figure 26

a, b © Steinbach - Onema
c, d © Chanseau - Onema
e, f © Burgun - Onema

Examples of structures and different discharge conditions. On the left, (a) (c) (e) show low-flow conditions. On the right, (b) (d) (f) show high-flow conditions.

For example, there are a number of freeware programmes for this type of analysis, notably the two presented below.

■ The FishXing programme was developed by the USDA-Forest Service Pacific Northwest Research Station. The programme, which may be downloaded from **http://stream.fs.fed.us/fishxing/**, was initially designed to analyse the passage of fish through road structures, however it may be used on a more general basis, notably to model simple weirs.

■ The HEC-RAS programme was developed by the U.S. Army Corps of Engineers and may be downloaded from **http://www.hec.usace.army.mil/software/hec-ras/hecras-download.html**. This programme is better suited to modelling the hydraulic conditions in or over any type of structure. On the other hand, it does not correlate the data with the swimming capabilities of fish, as is the case with FishXing. The comparison between the hydrological conditions and the biological factors therefore requires a further step. This software is extensively used by engineering firms specialised in ecohydraulics and in river hydraulics. For example, it was used to determine a number of assessment criteria for the ICE protocol.

The different types of obstacles covered in upstream-migration assessments

The different types of obstacles covered in upstream-migration assessments are the following:

- structures (weirs and dams) made up entirely of fixed parts;
- structures having gates that may be partially or totally opened;
- road, highway and rail structures;
- mixed, more complex structures featuring different types of components;
- tidal structures.

Different criteria have been established to assess the passability of each type of obstacle for the main fish species in continental France. The following chapters are structured around this notion of different types of obstacles and present for each the relevant criteria and the assessment procedure. A separate chapter is devoted to eels in order to fully address their very special passage techniques.

Caution. Some structures are equipped with a fish pass. In the framework of the ICE protocol, a "pre-assessment" of the pass should also be carried out under normal operating conditions (normal discharge and maintenance conditions). The purpose of the pre-assessment is to rapidly identify those fish passes that are clearly not well suited to the species in question and for which a more in-depth assessment may be necessary. However, the pre-assessment is not an in-depth assessment of the hydraulic functioning of the fish pass nor is it a means to check the conformity of the pass with applicable regulations.

Necessary expertise for assessments of obstacles blocking downstream migration

General situation

Downstream migration, i.e. movement heading downstream, may occur during different biological stages depending on the species, notably:

- the juveniles of anadromous species (Atlantic salmon, sea trout, brown trout, shad, etc.);
- the adults of anadromous species following reproduction (salmonids, Twaite shad, etc.);
- the adults of catadromous species prior to reproduction (eels).

During their downstream migration, fish may be confronted with various problems at structures, e.g. modifications in water quality, exposure to predators in reservoirs, delays to migration, falls over spillways and flood gates, passage through turbines in hydroelectric plants, flows drawing them into industrial and agricultural water intakes with possible passage through pumping systems, etc.

Systems designed to limit the impacts

Different technical solutions have been tested more or less recently, mainly in Europe and North America, to avoid or limit the harm done to fish in structures.

The technical progress made and the practical feedback for Atlantic salmon smolts are far greater than for other species, however the studies on eels over the past decade have also produced substantial technical results.

Among the main technical solutions developed to date are:

- the installation of fine screens directing the fish to one or more bypasses (see Figure 27cd);
- shutdown of systems during migration;
- installation of fish-friendly turbines and pumps causing few or no injuries to fish (see Figure 27ab).

Generally speaking, behavioural barriers (lights, noises, electrical fields, bubbles, etc.) have turned out to be relatively ineffective and do not currently provide sufficient results.

Similar to fish passes for upstream migration, structures intended to ensure the safe downstream migration of species must be designed on a case by case basis, be adapted to the specific features of each site and take into account the morphological characteristics and migratory behaviour of the given species or group of species.

Figure 27

a, b, c, d © Ecogea

(a, b) Example of a fish-friendly turbo-generator, (c, d) fish-friendly water intake with a rising incline made of narrowly spaced bars and surface bypasses enabling fish to escape downstream.

For more information on designing and sizing facilities intended to reduce injuries during downstream migration, a number of technical guides may be consulted, notably those listed below.

- *Larinier M., Porcher J.P., Travade F., Gosset C. (1994). Passes à poissons. Expertise, Conception des ouvrages de franchissement. Conseil Supérieur de la Pêche, Collection Mise au point.*
- *Larinier M., Travade F., (1999). La dévalaison des migrateurs : problèmes et dispositifs. Bulletin Français de la Pêche et de la Pisciculture, 353-354, 181-210.*
- *Larinier M., Travade F. (2002). Downstream Migration : Problems and Facilities. Bulletin Français de la Pêche et de la Pisciculture., 364 suppl : 181-207.*
- *Travade F., Larinier M. (2006). French experience in downstream migration devices. In: Free passage for Aquatic Fauna in rivers and other water bodies. International DWA-Symposium on water resources management. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall, pp. 91-99. ISBN 978-3-939057-19-2.*
- *Courret D., Larinier M. (2008). Guide pour la conception de prises d'eau " ichtyocompatibles " pour les petites centrales hydroélectriques. Rapport ADEME – GHAAPPE.*

In addition, Chanseau *et al.* (2012) recently drafted a summary document based current technical and biological information presenting the position of the Onema South-West regional office on the solutions recommended for downstream migration, notably concerning water intakes at small hydroelectric plants, once the decision to reduce their impacts has been taken.

■ Expertise required to assess a hydroelectric plant

Assessment of the potential injuries caused by an installation

Taking the example of a headrace for a hydroelectric plant (see Figure 28), depending on the discharges flowing through the diversion system (dam, weir) and in the headrace respectively, and on the configuration of the dam and the water intake at the plant, some of the fish migrating downstream will transit via the diversion system (spillway, gates, flaps, etc.) and the rest are drawn into the headrace leading to the hydroelectric plant.

Figure 28

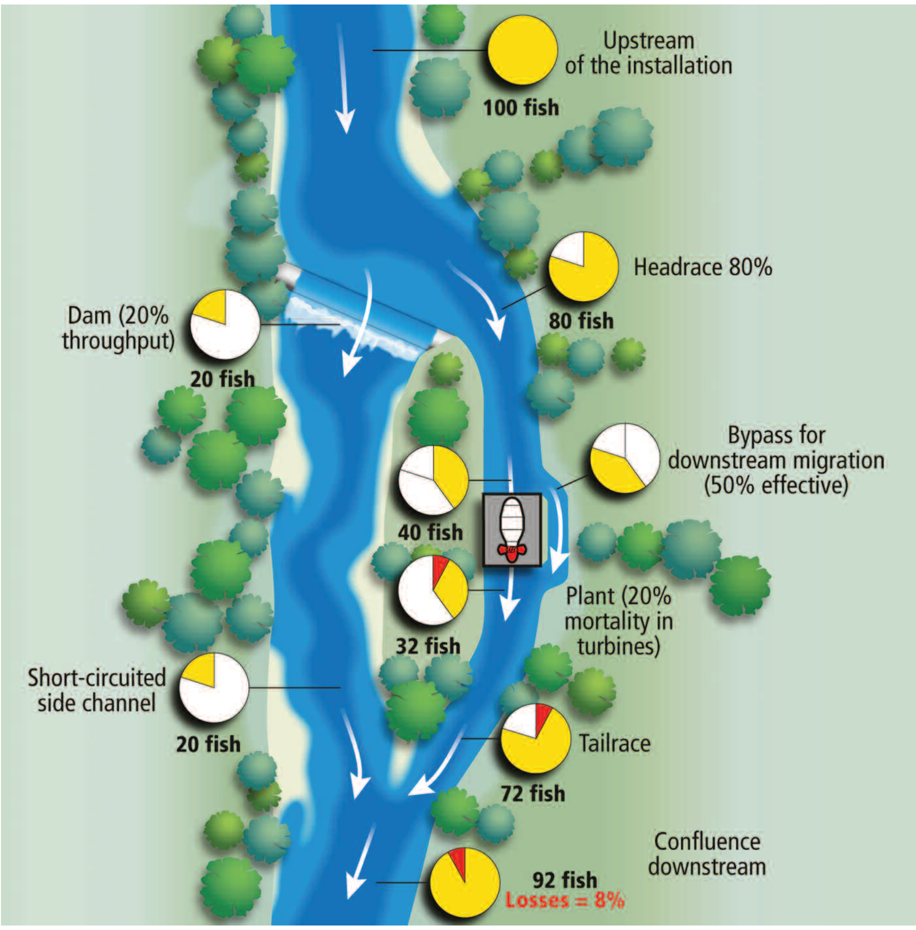


Diagram of a typical installation and basis for modelling the downstream migration. According to Voetgle and Larinier, 2004.

When a bypass for the downstream migration of fish exists at the water intake of the plant, a certain percentage transit the bypass and return without injury to the tailrace, while the remainder transit the turbines. Depending on the characteristics of the turbines, mortality rates are more or less high.

The survivors then join the fish that travelled (generally without injuries) via the diversion system (dam) and/or the bypass, and continue their migration downstream.

Assessment of the potential impact of a water intake on downstream migration requires a certain level of expertise based not only on the various on-site studies carried out, but also on in-depth knowledge of the functioning of installations, the hydrology of the river and the distribution of discharges at the site.

An assessment of the potential impact of a structure on downstream migration must generally determine the site parameters presented below.

■ **The percentage of fish effectively entering the water intake,** which is a function of discharges during the migratory period, the discharge entering the water intake and the configuration of the installation (dam, water intake). Experiments have been carried out on numerous sites, often using radio-monitoring techniques, and produced valuable information on the behaviour of fish, particularly smolts and silver eels migrating downstream, and notably on encountering dams and water-intake screens (Croze & Larinier, 1999; Croze *et al.*, 1999 and 2001; Chanseau *et al.*, 1999 and 2002; Travade *et al.*, 1999 and 2010; Bau *et al.*, 2008 and 2013).

■ **The potential injuries suffered depending on the type and the characteristics of the hydromechanical devices equipping the installation** (turbines, pumps, etc.). Experiments have been carried out in various countries (United States, Canada, Sweden, Scotland, Germany, France) on different species (primarily the salmonid juveniles and eels) to assess the injuries (percentage of deaths and types of injuries) sustained when transiting different types of turbines. The experiments produced fairly similar results and a number of general conclusions may be drawn on the potential injuries suffered by fish. Equations indicating approximate mortality levels of fish as a function of the type of turbine and its hydromechanical characteristics (number of blades, rotational speed, runner diameter), the head-drop and the size of the fish have been proposed, particularly for salmonid juveniles and silver eels (Larinier and Dartiguelongue, 1989; Gomes and Larinier, 2008).

■ **The permeability of water-intake screens** which depends essentially on the spacing between the bars and the effectiveness of the bypasses for downstream migration (when they exist and are open).

Assessment of the potential injuries in a river or river basin

In addition to estimating potential mortalities caused by a single structure, it is important, particularly for diadromous fish, to calculate potential mortalities along the entire migratory path taking into account the position of each structure and the habitats located upstream.

Studies to determine the cumulative losses along an entire migratory path have been carried out for smolts and eels, notably in the Adour-Garonne basin (SW France) (Bosc and Larinier, 2000; Pallo and Larinier, 2002; Voegtlé and Larinier, 2004, 2008; Voegtlé, 2010).

It should be noted that a basic premise in all these studies is that the distribution of fish in an area depends directly on the quantities of available habitat. In most cases, the existing obstacles also influence upstream migrations, thus modifying the "theoretical" distribution of fish.

The RefMADI reference dataset developed by Onema in conjunction with the Ecology ministry proposes a set of data sheets presenting the assessment method for upstream and downstream migration at a hydroelectric plant. Data sheets specifically addressing the downstream migration of eels along entire migratory paths and for individual structures may be consulted and downloaded at **http://www.onema.fr/refmadi**.

Caution. For the ICE protocol, given the complexity of the mechanisms involved in downstream migration and the in-depth knowledge required on the local hydrology, on draw-off conditions and on the hydromechanical characteristics of each structure, it was decided not to propose an assessment procedure based on simple criteria. To determine the downstream passability of structures, a specific study carried out by highly specialised technicians remains indispensable.

Definition of species groups

Presentation of the species groups

To meet the objectives of the ICE protocol, the various species were grouped according to their swimming capabilities, i.e. essentially their maximum speeds and the minimum water depths required for swimming, and their jumping capabilities. These characteristics are the two main biological traits influencing their capacity to overcome physical barriers (see the section on the passage capabilities of fish). This is, however, a rather simplified approach that occasionally groups species having considerably different eco-ethologies and/or morphologies.

Only upstream migration for reproductive purposes (with the exception of eels) was taken into account given that this type of movement is particularly impacted by fragmented environments. In terms of passage capabilities, the **study focused on adult fish or those approaching their sexual maturity** (except for eels which are present in French waters during their juvenile stages).

The distribution of fish into different ICE species groups is discussed below and presented in table form at the end of this section (see Tables 3 and 4). **A total of eleven species groups were established**, where some are divided into subgroups.

NB Eels constitute a separate group given that their passage capabilities differ significantly from those of other species.

For each ICE species group or subgroup, the swimming speeds set for U_{max} were determined using notably the Videler (1993) equations as well as experimental studies focusing on the passage of obstacles and visual observations of fish clearing obstacles.

The minimum depths required for a group of species to swim were determined based on the form factors and by adopting as a general guideline a minimum depth (h_{min}) of approximately 1.5 times the body depth of the fish (see the section on the passage capabilities of fish in the first chapter titled Ecological continuity and fish).

NB An effort was made not to exaggerate the number of groups for the ICE protocol. However, in special cases requiring more precise study of a particular species, a more in-depth analysis is possible using more sophisticated tools.

Many of the species mentioned are likely to move about and clear obstacles at younger ages (ontogenetic movements). Assessments on juvenile fish of the various species are also possible. In this case, it is necessary to reduce the maximum swimming speeds U_{max} and the minimum water depths h_{min} mentioned below. Practically speaking, it may be easier to use the values supplied for a smaller species having a comparable morphology, for example, an Atlantic salmon smolt will generally have swimming capabilities relatively similar to those of a brown trout of equivalent size.

■ **Group one**

This group comprises anadromous salmonids, namely the Atlantic salmon (*Salmo salar*) (see Figure 29a) and sea trout (*Salmo trutta*) (see Figure 29b).

Figure 29

a © Onema
b © Fagard - Onema

Examples of species in the first group. (a) Atlantic salmon, (b) sea trout.

These two species, in the adult stage, have the greatest passage capabilities in terms of swimming and/or jumping.

Migrating fish are generally very large, ranging from 50 to 100 cm, depending on the number of years spent in the ocean. For smaller sea trout, see Group 4a (brown trout measuring between 25 and 55 cm).

On the other hand, for lake trout reaching large sizes in the adult stage, it is advised to consult the data for this first group rather than Group four.

For Group 1, **a maximum speed U_{max} of approximately 4.5 to 6.5 m/s** was selected (average speed approximately 5.5 m/s). This is in line with numerous reference data on these species (Kreitmann, 1932; Stuart, 1962; Bell, 1986; Booth *et al.*, 1997; Colavecchia *et al.*, 1998; Beach, 1984; Lauritzen *et al.* 2010).

Atlantic salmon and sea trout are excellent jumpers. The maximum head-drop that they can overcome by jumping is approximately 1 to 2.5 metres depending on the size of the fish and if the conditions just below the obstacle are conducive to jumping (see Figure 30).

The minimum water depth h_{min} selected to ensure passage is approximately 20 cm.

Figure 30

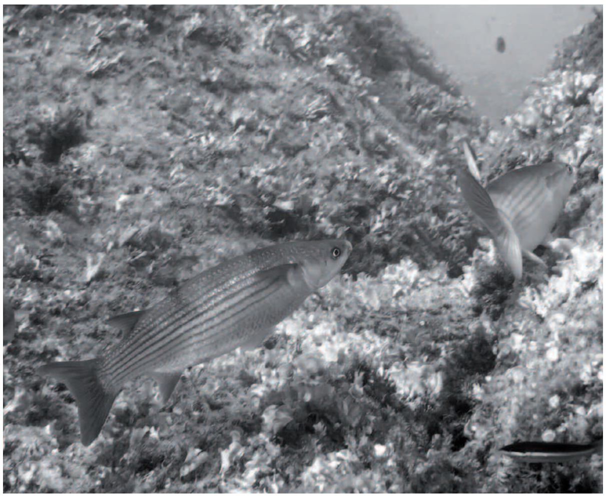
a, b © Chanseau - Onema

Examples of obstacles cleared by Atlantic salmon in the Gave de Pau River.

■ **Group two**

This group is made up of the thicklip grey mullet (*Chelon labrosus*) and the thinlip mullet (*Liza ramada*), two catadromous fish (see Figure 31). Following the migration of the juveniles from the sea (the reproduction site) to brackish or fresh waters, the fish spend most of their trophic period in estuaries and rivers, before migrating downstream as adults to reproduce in the sea (Liao, 1981, in Gautier and Hussenot, 2005).

Figure 31



© Daufresne - Irstea

Examples of species in Group two. Thinlip mullet.

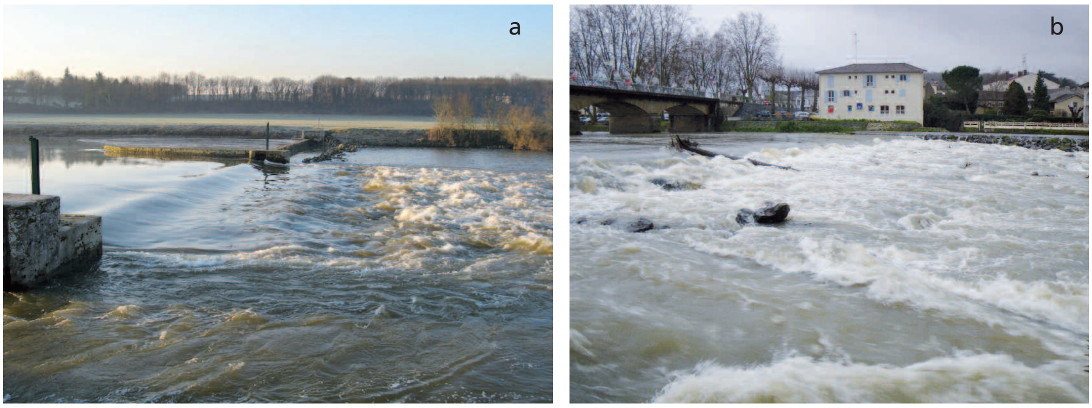
During their upstream migration, mullets are often caught in migratory fish passes located in the lower and middle sections of rivers (Briand and Boussion, 1998). Current knowledge on these species in terms of obstacle passage is, however, rather limited. A few observations have been made on French rivers (Garonne, Dordogne, Loire, Seine, Vilaine, etc.) that confirm the high migratory potential of this group of species.

At the time of the upstream migration, mullets are generally between 30 and 70 cm long. On the whole, they are good swimmers and jumpers, capable, in certain configurations, of overcoming head-drops exceeding 1.5 metres (see Figure 32).

A **maximum speed U_{max} of approximately 4.0 to 5.5 m/s (average speed approximately 4.75 m/s)** was selected for this group, which corresponds to the maximum speeds of the flathead mullet (Mugil cephalus), i.e. approximately 4 m/s for fish around 20 cm long, according to FishBase.

The minimum water depth h_{min} selected to ensure passage is approximately 10 cm.

Figure 32



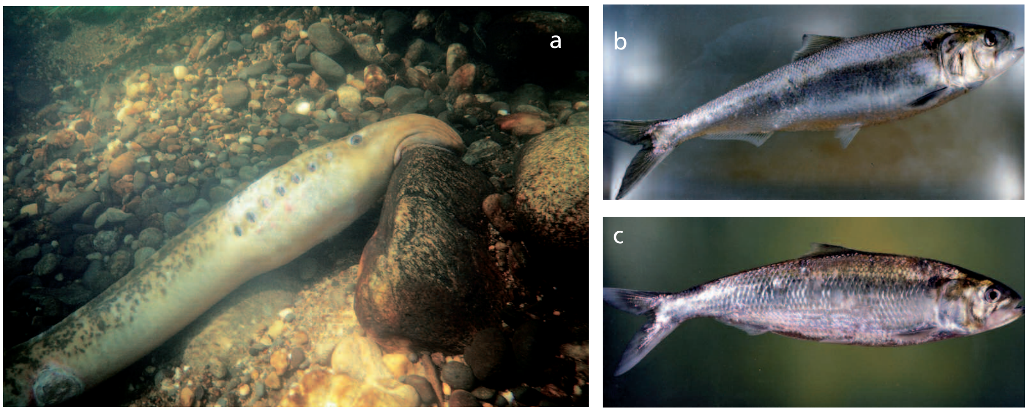
a © Steinbach - Onema
b © Voegtlé - Ecogea

Examples of obstacles cleared by mullets. Mullets are capable of overcoming (a) this weir on the Cher River and (b) the weir in the town of Aire-sur-Adour (Adour River).

■ Group three

This group is made up of Allis shad (*Alosa alosa*, see Figure 33b), Twaite shad (*Alosa fallax fallax*, see Figure 33c) and sea lamprey (*Petromyzon marinus*, see Figure 33a), which are anadromous fish from the Clupeidae and Petromyzontidae families respectively.

Figure 33



a © Ecogea
b, c © Vigneux - Onema

Examples of species in Group three. (a) Sea lamprey, (b) Allis shad, (c) Twaite shad.

Shad and lampreys were divided into three subgroups (3a for Allis shad, 3b for Twaite shad and 3c for sea lampreys) due to their very different morphologies in terms of their lengths and particularly the **minimum water depths h_{min}** required to overcome an obstacle while swimming (**15 cm for Allis shad, 10 cm for Twaite shad and sea lampreys**).

The shad frequently caught in migratory fish passes and radio-monitoring studies, notably in the Rhône River (Roche and Broche, 2005), provided evidence of their capabilities in swimming over obstacles (see Figure 34).

At the time of migration, Twaite shad are approximately 30 to 50 cm long and Allis shad from 45 to 70 cm long.

The **maximum speeds U_{max}** selected for the two species are fairly similar, though slightly lower for Twaite shad given its smaller size. The speeds are 3.5 to 5.0 m/s (average speed approximately 4.25 m/s) for Allis shad and 3.0 to 4.5 m/s (average speed approximately 3.75 m/s) for Twaite shad, which corresponds to the reference data for the species (Larinier and Travade, 2002).

Shad cannot jump and rapidly encounter difficulties in overcoming obstacles where there are plunging jets.

Figure 34

a, b © Roche - Onema

Examples of passable and impassable obstacles for shad. (a) Weir on the Ardèche River that shad can clear. The photo shows hydrological conditions enabling passage. (b) Weir on the Cèze River that shad cannot pass, except when discharges are very high, which is rare during the migratory period.

The swimming technique of sea lamprey differs significantly from that of shad. According to the scientific literature, its swimming capabilities are not as good (Almeida *et al.*, 2007; Mesa *et al.*, 2003), but lampreys have a particular means of overcoming obstacles called "burst and attach" (Quintella *et al.*, 2004) which consists of a rapid succession of sprints at maximum speed (bursts), followed by the fish holding on to the substrate with its sucker mouth (attach). Using this technique, sea lampreys have better passage capabilities than if their maximum swimming speeds alone are taken into account. This explains why they were placed in Group three.

For sea lampreys, **a maximum speed U_{max} similar to that of Twaite shad, i.e. approximately 3.0 to 4.5 m/s** was selected (average speed approximately 3.75 m/s).

Migrating lampreys are generally 60 to 90 cm long.

Similar to shad, sea lampreys cannot jump, which means they cannot easily overcome vertical obstacles where the jet is not in contact with the structure and there are no contact points for its sucker (Kemp *et al.*, 2008) (see Figure 35).

Figure 35

© Ovidio - Université of Liège-LDPH

Example of a vertical obstacle that blocks lampreys during their upstream migration.

■ Group four

The fourth group comprises the holobiotic subgroup of brown trout (*Salmo trutta*) in the Salmonidae family (see Figure 36). In terms of their systematic biology, it is the same species as sea trout, however the fish are often smaller and have lesser swimming capabilities.

Figure 36

© Ecogea

A species in Group four. Brown trout.

Group four is divided into two subgroups according to size (15 to 30 cm and 25 to 55 cm). This distinction is due to the great variations in the size of migrating adults depending on the type of river and the thermal regime (streams at the head of river basins, small and larger rivers, rivers flowing to the sea).

NB As noted above, smaller sea trout (< 50 cm) fall into Group four (Subgroup 4a for brown trout measuring between 25 and 55 cm). On the other hand, for lake trout reaching large sizes in the adult stage (> 50 to 60 cm), it is advised to consult the data for Group one.

The swimming capabilities of trout are well documented in the scientific literature (Kreitman, 1933; Hertel, 1966; Beach, 1984; Bell, 1986) and the maximum speed of the largest specimens can reach 5 m/s. Visual observations (Stuart, 1962) and radio monitoring (Ovidio and Philippart, 2002; Ovidio *et al.*, 2007) have revealed that trout are capable of overcoming different types of small obstacles (falls, slopes, combinations of the two) by jumping and/or by swimming (see Figure 37).

Subgroup 4a

For this group made up of the largest fish (25 to 55 cm), a **maximum speed U_{max} of between 3.0 and 5.0 m/s** (average 4 m/s) was selected. For this size class, the **minimum water depth h_{min} selected to ensure passage is approximately 10 cm.**

Subgroup 4b

For this group made up of the smaller adults (15 to 30 cm), a **maximum speed U_{max} of between 2.5 and 3.5 m/s** (average 3 m/s) was selected. For this size class, the **minimum water depth h_{min} selected to ensure passage is approximately 5 cm.**

Figure 37

a, b, c © Ovidio - University of Liège-LDPH

Examples of obstacles cleared by radio-monitored brown trout in Southern Belgium. (a) Aisne River, (b) Lhomme River, (c) Ourthe River, (d) Vesdre River. Photos a and b show low-flow levels. Photos c and d show hydrological conditions conducive to passage.

■ **Group five**

This group is made up of pike (*Esox lucius*) from the Esocidae family and asp (*Aspius aspius*) from the cyprinids, two carnivorous, holobiotic species (see Figure 38).

Figure 38

© Ecogea

Examples of a species in Group five. Pike.

Studies on the migration and passage of obstacles by pike in rivers have been carried out in France (Dubost and Vauclin, 2004) and in Belgium (Ovidio and Philippart, 2002 and 2005). Movements upstream are frequently observed, with maximum distances of approximately 16 km (Belgium, Ourthe-Amblève Rivers) and 20 km (France, Ill River), occasionally including passage of dams, both equipped and not equipped with migratory fish passes (see Figure 39).

Figure 39

a, b © Ovidio - University of Liège-LDPH

Examples of obstacles cleared by radio-monitored pike in the Amblève River (Southern Belgium). The photos show hydrological conditions lower than the optimum passage discharge. (a) General view of the obstacle, (b) zoom on the passage zone.

The swimming capabilities of pike are relatively well known (Harper and Blake, 1991; Frith and Blake, 1991; Meixer *et al.*, 2010).

Concerning asp, the spring migrations of thousands of fish may be observed each year at the fish passes in Iffezheim and Gambsheim on the Rhine. Their rapid expansion since 2001 to the main rivers in the Rhine-Meuse basin is a clear sign of their migratory capabilities (Burgun, 2005).

The scientific literature contains little information on this species. Friedrich (2003) measured in the Elbe River swimming speeds greater than 2 m/s during the migration before and after reproduction. However, given the large size and the morphology of the fish similar to pike, the maximum speed is probably fairly high.

For the two species, the size of adult fish commonly exceeds 50 cm and can reach 75 cm for asp, and even exceed 100 cm for pike, which means that, in light of their morphology, a **minimum water depth h_{min} of approximately 15 cm should be selected to ensure passage** of both species.

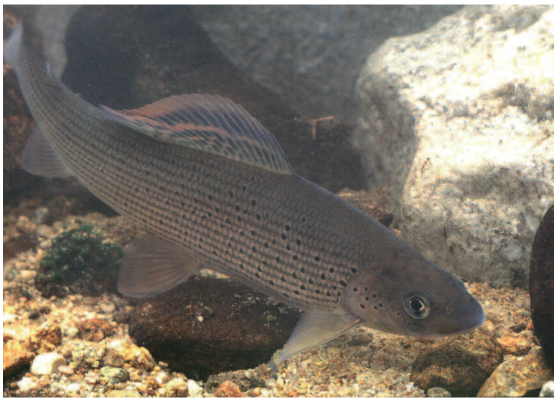
Pike and asp are not thought to have a true jumping capability and generally use their swimming capabilities to overcome physical obstacles.

A **maximum speed U_{max} of approximately 3.5 to 5.0 m/s** (average speed approximately 4.25 m/s) was selected, which corresponds to the maximum speeds mentioned in the scientific literature.

■ Group six

The only fish in this group is the grayling (*Thymallus thymallus*), a holobiotic species from the Salmonidae family (see Figure 40).

Figure 40



a © Onema

The species in Group six.
Grayling.

Grayling can cover several kilometres during their reproduction migration that takes place at precise times (Parkinson *et al.*, 1999; Meyer, 2001; Ovidio *et al.*, 2004; Lucas and Bubb, 2005) and is often followed by a rapid return to their home base.

The scientific literature contains little information on the capabilities of grayling to overcome obstacles. However, research done using radio-monitoring techniques in the Belgian Ardennes by Ovidio *et al.* (2007) revealed that grayling do have a certain capability to clear obstacles of up to one metre by swimming or jumping (see Figure 41).

Figure 41

a, b © Ovidio - University of Liège-LDPH

Examples of obstacles cleared by radio-monitored grayling in Southern Belgium. Obstacles in the Aisne River. The photos show hydrological conditions lower than the optimum passage discharge.

Its jumping capabilities would appear to be slightly inferior to those of brown trout. For example, Lucas and Bubb (2005), using pit tags, showed that grayling had more difficulty than trout in clearing a V-shaped obstacle with a head-drop of 0.4 metre (a success rate of 36% for grayling and 84% for brown trout).

Maximum swimming speeds are fairly similar, but slightly inferior to those of brown trout. A **maximum speed U_{max} of approximately 3.0 to 4.5 m/s** (average speed 3.75 m/s) was selected.

At the time of the reproduction migration, grayling are generally between 25 and 50 cm long.

Similar to Group 4a, which corresponds to the larger brown trout, given the morphology of grayling, a **minimum water depth h_{min} of approximately 10 cm should be selected to ensure passage.**

■ Group seven

Group seven is made up of rheophilic cyprinids that are generally large in size (barbel *Barbus barbus*, nase *Chondrostoma* nasus and chub *Squalius cephalus*, see Figure 42a) and river lamprey (*Lampetra fluviatilis*, see Figure 42b) from the Petromyzontidae family.

Figure 42

Examples of species in Group seven. (a) Chub, (b) river lamprey.

Similar to Group three, this group was divided into two subgroups (7a for the rheophilic cyprinids and 7b for river lampreys) due to their very different morphologies in terms of the **minimum water depths h_{min} required to overcome an obstacle while swimming (10 cm for the rheophilic cyprinids, 5 cm for river lampreys).**

Subgroup 7a

Large rheophilic cyprinids have vital needs and the physical means for migrations over several kilometres and even dozens of kilometres in unfragmented rivers (Baras, 1992; Fredrich, 2003; Fredrich *et al.*, 2003; Lucas and Batley, 1996; De Leeuw and Winter, 2008; Ovidio *et al.*, 2007; Ovidio and Philippart, 2008).

They are also found in abundant numbers in different types of fish passes (Lucas, 2000; Slavik *et al.*, 2009; Larinier, 2002; Ovidio *et al.*, 2007).

Given the size of the migrating fish, generally between 25 and 80 cm, a **maximum speed U_{max} of 2.5 to 4.0 m/s** (average speed 3.25 m/s) was selected for Group 7a, which is in line with the swimming speeds mentioned in the scientific literature (Kreitmann, 1933; Lucas and Fear, 1997; Environmental Agency, 2007). Rheophilic cyprinids have no true jumping capabilities.

A number of biotelemetric studies have revealed that rheophilic cyprinids have little motivation and/or aptitude to overcome physical barriers (see Figure 43ab). It is not rare to see fish accumulating at the foot of obstacles in fragmented rivers (Lucas and Fear, 1997; Hubert and Kirchofer, 1998; Ovidio and Philippart, 2002; Horky *et al.*, 2007; Ovidio and Philippart, 2008).

Figure 43

Examples of obstacles not overcome and of an obstacle overcome by species in Group seven. (a and b) Obstacles not overcome by radio-monitored barbel and nase during their upstream migration in the Ourthe (a) and the Vesdre (b) Rivers, (c) obstacle overcome by nase and chub monitored using acoustic telemetric techniques in the Rhône River. The photo shows hydrological conditions close to the optimum passage discharge.

However, a recent study carried out in the Rhône River (Capra *et al.*, not published) revealed that nase, chub and barbel are capable of overcoming a rock chute (see Figure 43c, above).

Subgroup 7b

Similar to the sea lamprey, the river lamprey is capable of clearing obstacles using the "burst and attach" technique (Quintella *et al.*, 2004), however its capabilities are more limited given its smaller size (Kemp *et al.*, 2008).

Using this technique, river lampreys have better passage capabilities than if their maximum swimming speeds alone are taken into account, which explains their presence in Group seven. They are also capable of using the deepest layers in water flows.

To account for this particular feature, an **equivalent maximum speed U_{max} close to that of rheophilic cyprinids, i.e. approximately 2.0 to 3.5 m/s** (average speed 2.75 m/s) was selected for river lampreys.

Migrating lampreys are generally 30 to 45 cm long.

Similar to rheophilic cyprinids, river lampreys cannot jump, which means they cannot easily overcome vertical obstacles where the jet is not in contact with the structure and there are no contact points for its sucker (Kemp *et al.*, 2008).

■ Group eight

This group comprises nine holobiotic species, namely four ubiquitous Cyprinidae (common bream *Abramis brama*, white bream *Blicca bjoerkna*, ide *Leuciscus idus*, daces *Leuciscus* spp. except *idus*) , two limnophilic Cyprinidae (common carp *Cyprinus carpio* and tench *Tinca tinca*), one Lotinae (burbot *Lota lota*) and two Percidae (pikeperch *Sander luciperca* and perch *Perca fluviatilis*).

The group was divided into four subgroups based essentially on the differences in size between the species.

Subgroup 8a comprises only common carp because its size and morphology require a considerable minimum water depth h_{min} of approximately 25 cm.

Subgroup 8b comprises pikeperch and common bream because, in spite of the difference in size, their morphologies require a fairly significant minimum water depth h_{min} of approximately 15 cm.

Subgroup 8c includes smaller species (white bream, ide, river burbot, perch, tench), generally between 20 and 50 cm in size (see Figure 44). Given their physical characteristics, these five species require a minimum water depth h_{min} of approximately 10 cm.

Subgroup 8d groups the dace species (except the ide), whose morphologies (length, body depth) require a slightly smaller water depth of approximately 5 cm.

Figure 44

a, b © Daufresne - Irstea

Examples of species in Group eight. (a) Tench, (b) perch.

Subgroups 8a and 8b

The scientific literature is not abundant, however it is known that common bream and common carp have the potential to cover several kilometres (even several dozen kilometres) during their biological cycle (Molls, 1997; Hladık and Kubecka, 2003; Jellyman, 2009; Jones and Stuart, 2009; Paragamian *et al.*, 2005). These species may be found abundantly in fish passes (Horky *et al.*, 2007; Ovidio *et al.*, 2007; Stuart *et al.*, 2008) and bream are occasionally mentioned as one of the most abundant species in migratory passes on large European rivers (Ovidio *et al.*, 2013; Chanseau *et al.*, 2000).

Very little bibliographic data on swimming speeds is available and generally concerns carp and, to a lesser degree, common bream. The data indicate maximum speeds of approximately 0.6 to 3 m/s (Kreitmann, 1933; Komarow, 1971; Zerrath, 1996; Tudorache *et al.*, 2008).

In spite of its morphology fairly similar to that of pike, pikeperch have significantly inferior swimming capabilities and the maximum speed does not exceed 3 m/s (Peake *et al.*, 2000 in Stizostedion vitreum; Koed and Thorstad, 2001). To our knowledge, no *in situ* observations of weir passages have been mentioned in the scientific literature. On the other hand, fish overcoming dams via fish passes have been regularly observed.

Subgroups 8c and 8d

The species in these subgroups (white bream, ide, burbot, perch, tench, daces) are biologically very different, but have all been observed in migratory fish passes or swimming over weirs (see Figure 45) (Prchalova *et al.*, 2006; Hladık and Kubecka, 2007; Slavik *et al.*, 2009; Ovidio et al., 2013; data from various control stations for fish passes in France), which clearly shows that part of the population migrates upstream during certain periods of the year.

Figure 45

© Voegtlé - Ecogea

Example of an obstacle overcome by young perch during their upstream migration. The Hardy stream with hydrological conditions conducive to passage.

Migrations of several kilometres up to several dozen kilometres have been mentioned in the scientific literature for some of these species. This information is based on telemetric studies (Baade and Fredrich, 1998; Winter and Fredrich 2003; Geeraerts *et al.*, 2007; De Leeuw and Winter, 2008; Kuliskova *et al.*, 2009; Paragamian *et al.*, 2005).

Data on their capabilities in terms of overcoming obstacles are very rare and would seem to indicate a low aptitude for clearing physical barriers. Some of the more ubiquitous of these species have demonstrated a clear preference for reproduction downstream of weirs rather than attempting to overcome the obstacle (Geeraerts *et al.*, 2007; Horky *et al.*, 2007).

For the entire Group eight (8a to 8d), a **maximum speed U_{max} of approximately 2.0 to 3.5 m/s** (average speed 2.75 m/s) was selected. **This group is unable to jump**.

■ Group nine

This group comprises ten **Cyprinidae** (common bleak *Alburnus alburnus*, see Figure 46a, schneider *Alburnoides bipunctatus*, Mediterranean barbel *Barbus meridionalis*, blageon *Telestes souffia*, Crucian carp *Carassius carassius*, Prussian carp *Carassius gibelio*, roach *Rutilus rutilus*, gudgeons *Gobio spp.*, rudd *Scardinius erythrophtalmus* and South-west European nase *Parachondrostoma toxostoma*), two Percidae (Rhône streber *Zingel asper* and ruffe *Gymnocephalus cernuus*), the Cottidae (bullheads *Cottus spp.*, several species are present in France, see Figure 46b), two Cobitidae (spined loach *Cobitis taenia* and stone loach *Barbatula barbatula*, see Figure 46c) and finally one Petromyzontidae (brook lamprey *Lampetra planeri*, see Figure 46d).

Figure 46

a, b © Daufresne - Irstea

Examples of species in Group nine. (a) Bleak, (b) bullhead.

Suite Figure 46


c © Daufresne - Irstea
d © Kardacz - Ecogea

(c) Stone loach, (d) brook lampreys.

The group was divided into two subgroups based essentially on the differences in size between the species and on the benthic behaviour of certain species.

Subgroup 9a comprises the larger species, generally between 10 and 30 cm in length (common bleak, schneider, Mediterranean barbel, blageon, Crucian carp, Prussian carp, roach, rudd and nase).

Subgroup 9b comprises the Rhône streber, bullheads, gudgeons, ruffe, brook lamprey, stone loach and spined loach. These small, fairly benthic species can swim very close to the bottom and take advantage of the low water velocities. They are somewhat smaller than the fish in Group 9a and generally range from 5 to 15 cm in length. To take into account the benthic behaviour of the species in Group 9b and in spite of their smaller size compared to Group 9a, a **minimum water depth h_{min} of approximately 5 cm and similar swimming speeds** were selected for Group 9 as a whole.

None of the species in either subgroup have true jumping capabilities.

Subgroup 9a

Among these species on which very little is known concerning their migratory behaviour, it should be noted that common bleak, schneider, roach and rudd have been caught and observed, often in abundance, in certain migratory passes in France, notably in fish passes originally designed for shad. This indicates that these species, in spite of their small size, are capable of finding passageways by swimming in the deepest layers of water flows (see Figure 47).

For this group, a **maximum speed U_{max} of approximately 1.5 to 3.0 m/s** was selected (average speed approximately 2.25 m/s).

Figure 47

© Ovidio - University of Liège-LDPH

Example of an obstacle not overcome by radio-monitored roach during their upstream migration in the Vesdre River in Belgium. The photo shows low-flow conditions.

Subgroup 9b

Very few data on the mobility and the range of their habitat are available for these small species. They are very rarely caught in migratory fish passes because their small size enables them to slip through the bars of the cages. However, gudgeon, minnows, brook lamprey, stone loach and bullheads have been observed in migratory passes in Southern Belgium (Ovidio *et al.*, 2005, 2007).

Special passes for Rhône streber have also been created in the Rhône basin (Gomes *et al.*, 2005) and are used by the species. Among the 12 species in this group, bullheads have been the most extensively studied in terms of their mobility. They were long thought to be extremely sedentary, however recent use of more suitable techniques on individual fish (dyes, pit tags, microtelemetry) have revealed habitats ranging up to several hundred metres (Knaepkens *et al.*, 2004; Breeder *et al.*, 2009; Ovidio *et al.*, 2009).

Limited data are available in the scientific literature on swimming speeds. Gaudin and Pradelle (2001) have suggested a maximum speed for Rhône streber of approximately 1.3 to 1.4 m/s. De Boeck *et al.* (2006) indicated a maximum speed of approximately 1.1 m/s for stone loach and Zerrath (1996) proposed 2.1 m/s for gudgeon. The maximum speed of the threespine stickleback is thought to be approximately 1.5 m/s (Law and Blake 1995; Whoriskey and Wooton, 1987). Ovidio *et al.* (2007b) showed that bullheads are capable of clearing small weirs (30 to 40 cm high), both natural and man-made having fairly different configurations, but generally having slight slopes (up to 12°) and rough substrates with stones or riprap (see Figure 48). A vertical (straight drop) or subvertical weir 20 to 25 cm high is impassable for the species, which confirms the hypotheses put forward by Utzinger *et al.* (1998).

However, similar to the bullheads, all the other species in Group 9b can take advantage of the deepest layers in the water flow where the velocities are the lowest. To account for this particular feature, a **maximum speed U_{max} was selected for Group 9b that is close to that of Group 9a, i.e. 1.5 to 3.0 m/s** (average speed 2.25 m/s).

Figure 48

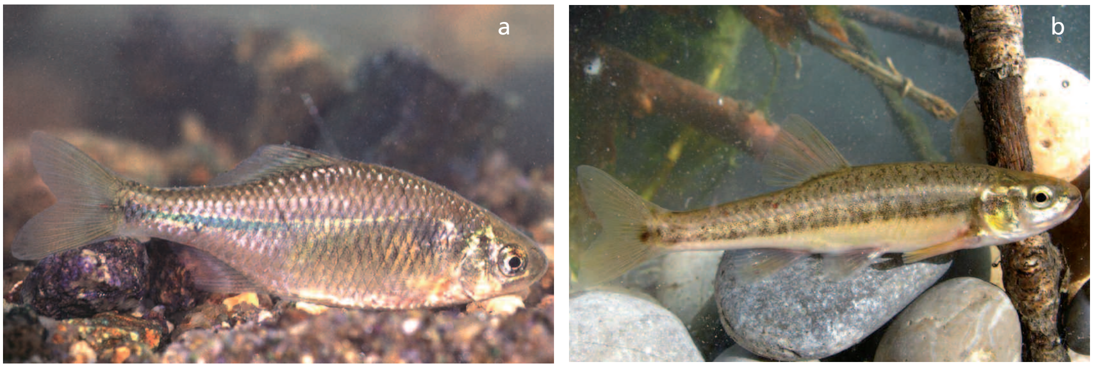
a, b, c, d © Ovidio - University of Liège-LDPH

Examples of obstacles cleared by bullheads monitored using pit tags in the Falogne stream in Belgium. The photos show hydrological conditions conducive to passage.

■ Group ten

This group is made up of five small species from three families, namely three Cyprinidae (sunbleak *Leucaspius delineatus*, bitterling *Rhodeus amarus* (see Figure 49a) and minnows *Phoxinus spp.* (see Figure 49b, several species are present in France, see the Atlas on freshwater fish in France, Keith *et al.*, 2011)) and two Gasterosteidae (threespine stickleback *Gasterosteus gymnurus* and smoothtail ninespine stickleback *Pungitius laevis*).

Figure 49



Examples of species in Group ten. (a) Bitterling, (b) minnow.

Very few data on the mobility and the range of their habitat are available for these small species.

These species are significantly smaller than those in Group nine and range from 5 to 10 cm in length. **Similar to Group 9, a minimum water depth hmin of approximately 5 cm was selected to ensure passage for the entire Group 10.**

Very few data are available on the capabilities of these species to overcome weirs. Holthe *et al.* (2005) demonstrated in laboratory experiments that minnows are not capable of overcoming a head-drop of more than 27 cm.

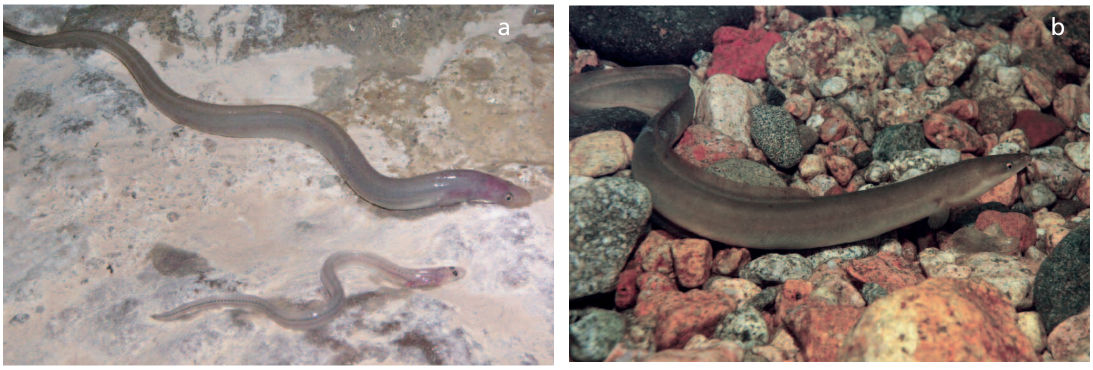
For Group 10, a **maximum speed Umax of approximately 1 to 2 m/s** was selected (average speed approximately 1.5 m/s).

None of the species listed in this group have jumping capabilities.

■ Group eleven

This group is made up of a single species, the European eel (*Anguilla anguilla*), a catadromous species in the Anguillidae family (see Figure 50).

Figure 50



Examples of fish in Group eleven. (a) Glass eel and elver, (b) yellow eel.

As noted in the section on passage capabilities, eels cannot be analysed in the same manner as other fish species due to their technique of overcoming physical barriers by crawling up wet surfaces.

Their swimming capabilities are much lower than their size would suggest. For glass eels, the maximum speed is approximately 30 to 50 cm/s. The distance covered in water flowing at 0.30 m/s is approximately 3 metres and that distance drops to approximately 30 cm in water flowing a 0.5 m/s (Mc Cleave, 1980). For elvers and yellow eels, the maximum swimming speeds are in the 1.0 to 1.5 m/s range (Blaxter and Dixon, 1959).

On the other hand, their ability to crawl enables them to overcome physical barriers with high head-drops and low overflow heights (Steinbach, 2006) (see Figure 51). The smallest eels can climb vertical walls thanks to the surface tension between their bodies and the wet wall (the force is proportional to the length of the fish). However, in growing, the weight to surface tension ratio increases in proportion to their length, which explains why only the smallest eels (less than approximately 12 cm in length) can effectively use this technique.

Finally, eels are not capable of jumping.

Figure 51

a, b © Steinbach - Onema

Examples of obstacles that a certain percentage of yellow eels can overcome by crawling. These structures nonetheless hinder the free movement of the species.

Given the differences in passage capabilities (crawling or swimming) depending on the size of the fish, it was decided to split Group 11 into two subgroups:

- Subgroup 11a comprising elvers and yellow eels, i.e. the larger fish generally between 12 and 40 cm in length;
- Subgroup 11b comprising the younger fish less than 12 cm in length, corresponding to the glass-eel stage.

A maximum speed Umax of approximately 1.5 m/s was selected for Subgroup 11a and 0.5 m/s for Subgroup 11b.

Given that eels generally make use of their ability to crawl over obstacles and, where necessary, to breathe through their skin, **a water depth of approximately 2 cm is thought to be the maximum for their crawling technique to be fully effective. At greater water depths, the forces exerted on the fish hinder effective use of this very particular technique and the sheet of water is sufficient for elvers to swim** (Subgroup 11a).

Species not mentioned in the groups

The Atlas of freshwater fish in France (Keith *et al.*, 2011) lists approximately one hundred fish species for continental France and Corsica.

In view of simplifying the presentation of this protocol, it was decided to discuss only the most common taxa.

The list of selected species is presented in alphabetical order below (see Table 3) and in the ICE species groups according to their swimming and jumping capabilities (see Table 4).

Tableau 3 *Alphabetical list of the main fish species presented in the ICE protocol and the corresponding ICE species group.*

Species	ICE species group
Allis shad *(Alosa alosa)*	3a
Asp *(Aspius aspius)*	5
Atlantic salmon *(Salmo salar)*	1
Barbel *(Barbus barbus)*	7a
Bitterling *(Rhodeus amarus)*	10
Blageon *(Telestes souffia)*	9a
Bleak *(Alburnus alburnus)*	9a
Brook lamprey (Lampetra planeri)	9b
Brown or sea trout [25-55] *(Salmo trutta)*	4a
Brown or sea trout [50-100] *(Salmo trutta)*	1
Brown trout [15-30] *(Salmo trutta)*	4b
Bullheads *(Cottus spp.)*	9b
Burbot *(Lota lota)*	8c
Chub (Squalius cephalus)	7a
Common bream *(Abramis brama)*	8b
Common carp *(Cyprinus carpio)*	8a
Crucian carp *(Carassius carassius)*	9a
Daces *(Leuciscus spp.* except *Idus)*	8d
European eel [glass eel] *(Anguilla anguilla)*	11b
European eel [yellow eel] *(Anguilla anguilla)*	11a
Grayling (*Thymallus thymallus)*	6
Gudgeons *(Gobio spp.)*	9b
Ide (Leuciscus idus)	8c
Mediterranean barbel (*Barbus meridionalis*)	9a
Minnows (*Phoxinus spp.*)	10
Mullets (*Chelon labrosus, Liza ramada*)	2
Nase (*Chondrostoma nasus*)	7a
Perch (*Perca fluviatilis*)	8c
Pike (*Esox lucius*)	5
Pikeperch (*Sander lucioperca*)	8b
Prussian carp (*Carassius gibelio*)	9a
River lamprey (*Lampetra fluviatilis*)	7b
Roach (*Rutilus rutilus*)	9a
Rudd (*Scardinius erythrophthalmus*)	9a
Ruffe (*Gymnocephalus cernuus*)	9b
Schneider (*Alburnoides bipunctatus*)	9a
Sea lamprey (*Petromyzon marinus*)	3c
Smoothtail ninespine stickleback (*Pungitius laevis*)	10
South-west European nase (*Parachondrostoma toxostoma*)	9a
Spined loach (*Cobitis taenia*)	9b
Stone loach (*Barbatula barbatula*)	9b
Streber (*Zingel asper*)	9b
Sunbleak (*Leucaspius delineatus*)	10
Tench (*Tinca tinca*)	8c
Threespine stickleback (*Gasterosteus gymnurus*)	10
Twaite shad (*Alosa fallax fallax*)	3b
White bream (*Blicca bjoerkna*)	8c

Tableau 4 *Table listing the ICE species groups and the corresponding swimming and jumping capabilities.*

ICE species group	Species	Jumping species	Swimming speed (m/s)			Height of jump (m)		
			Min.	*Avg.*	**Max.**	**Min.**	*Avg.*	**Max.**
1	Atlantic salmon (*Salmo salar*) Brown or sea trout [50-100] (*Salmo trutta*)	Yes	**4.5**	*5.5*	**6.5**	**1**	*1.5*	**2.5**
2	Mullets (*Chelon labrosus, Liza ramada*)	Yes	**4**	*4.75*	**5.5**	**0.8**	*1.1*	**1.8**
3a	Allis shad (*Alosa alosa*)	No	**3.5**	*4.25*	**5**	**-**	*-*	**-**
3b	Twaite shad (*Alosa fallax fallax*)		**3**	*3.75*	**4.5**			
3c	Sea lamprey (*Petromyzon marinus*)							
4a	Brown or sea trout [25-55] (*Salmo trutta*)	Yes	**3**	*4*	**5**	**0.5**	*0.9*	**1.4**
4b	Brown trout [15-30] (*Salmo trutta*)		**2.5**	*3*	**3.5**	**0.3**	*0.5*	**0.8**
5	Asp (*Aspius aspius*) Pike (*Esox lucius*)	No	**3.5**	*4.25*	**5**	**-**	*-*	**-**
6	Grayling (*Thymallus thymallus*)	Yes	**3**	*3.75*	**4.5**	**0.4**	*0.75*	**1.2**
7a	Barbel (*Barbus barbus*) Chub (*Squalius cephalus*) Nase (*Chondrostoma nasus*)	No	**2.5**	*3.25*	**4**	**-**	*-*	**-**
7b	River lamprey (*Lampetra fluviatilis*)		**2**	*2.75*	**3.5**			
8a	Common carp (*Cyprinus carpio*)	No	**2**	*2.75*	**3.5**	**-**	*-*	**-**
8b	Common bream (*Abramis brama*) Pikeperch (*Sander lucioperca*)							
8c	White bream (*Blicca bjoerkna*) Ide (*Leuciscus idus*) Burbot (*Lota lota*) Perch (*Perca fluviatilis*) Tench (*Tinca tinca*)							
8d	Daces (*Leuciscus spp.* except *Idus*)							
9a	Bleak (*Alburnus alburnus*) Schneider (*Alburnoides bipunctatus*) Mediterranean barbel (*Barbus meridionalis*) Blageon (*Telestes souffia*) Crucian carp (*Carassius carassius*) Prussian carp (*Carassius gibelio*) Roach (*Rutilus rutilus*) Rudd (*Scardinius erythrophthalmus*) South-west European nase (*Parachondrostoma toxostoma*)	No	**1.5**	*2.25*	**3**	**-**	*-*	**-**
9b	Streber (*Zingel asper*) Bullheads (*Cottus spp.*) Gudgeons (*Gobio spp.*) Ruffe (*Gymnocephalus cernuus*) Brook lamprey (*Lampetra planeri*) Stone loach (*Barbatula barbatula*) Spined loach (*Cobitis taenia*)							
10	Sunbleak (*Leucaspius delineatus*) Bitterling (*Rhodeus amarus*) Threespine stickleback (*Gasterosteus gymnurus*) Smoothtail ninespine stickleback (*Pungitius laevis*) Minnows (*Phoxinus spp.*)	No	**1**	*1.5*	**2**	**-**	*-*	**-**
11a	European eel [yellow eel] (*Anguilla anguilla*)	No	**< 1.5**			**-**	*-*	**-**
11b	European eel [glass eel] (*Anguilla anguilla*)		**< 0.5**					

The species not listed in the tables above can, however, be assigned to one of the groups based on the available biological knowledge and their morphological characteristics (minimum and maximum sizes, form factors, etc.).

Below are brief presentations of current knowledge on sturgeon, flounder and Wels catfish.

Sturgeon (*Acipenser sturio*, see Figure 52b) are anadromous amphibiotic migrators in the Acipenseridae family. Few studies have been made on their swimming capabilities. Lake sturgeon (*Acipenser fulvescens*) are present in North America and adults (approximately 130 cm long) are thought to be capable of maintaining a cruising speed of approximately 1 m/s and reaching speeds of approximately 1.8 m/s for very short periods (Peake *et al.*, 1996).

The scientific literature does not mention any capability to jump over obstacles. Given their morphology, no true jumping capability would seem likely (Lepage, personal paper).

Flounder (*Platichthys flesus*, see Figure 52c) are catadromous amphibiotic migrators in the Pleuronectidae family. Adults spend most of their lives in estuaries and the fresh waters of rivers and may be found up to several hundred kilometres from the sea. When it is time to reproduce, they migrate downstream to the sea to spawn between January and April. After hatching, some of the young fish head for the estuaries of rivers to continue their development. In years past, they travelled fairly far up rivers, for example to Mainz on the Rhine, Metz on the Moselle, Orléans on the Loire, Paris on the Seine, etc.

Adults vary in size between 20 and 50 cm. Their morphology and special swimming technique mean they have very limited swimming capabilities compared to fish of similar size, but with more "standard" morphologies. Duthie (1982) mentioned maximum swimming speeds of less than 1.5 m/s, which is comparable to the species in Group ten. In addition, they have absolutely no jumping capabilities. Another particular feature of flounder is the use of an anaerobic metabolism, even when swimming at limited speeds (Duthie, 1982).

Wels catfish (*Silurus glanis*, see Figure 52a) is a potamodromous species in the Siluridae family that is found increasingly frequently in large European rivers (Copp *et al.*, 2009). Very few data are available in the scientific literature, however it is known that the Wels catfish can undertake movements often mirroring those of its prey (Carol *et al.*, 2007; Pohlmann *et al.*, 2001).

It is found in migratory fish passes increasingly frequently. Studies of Wels catfish carried out at certain fish passes, notably those equipped with control stations and located on large rivers (Garonne, Dordogne Rivers, etc.), have revealed the passage of fish of widely varying sizes (from a few dozen centimetres to over two metres).

Little is known about the swimming capabilities of the Wels catfish. However, a recent study on juvenile *S. meridionalis* (Zeng *et al.*, 2009), a species similar to *S. glanis*, indicated a maximum critical speed of 3.4 body lengths per second at 28°C. In addition, adults are very powerful and capable of brief accelerations to capture prey.

To date, there is no available information on the ability of Wels catfish to jump over physical obstacles. However, the morphology of the fish is certainly a major disadvantage.

Figure 52

Examples of species.
(a) Wels catfish,
(b) sturgeon,
(c) flounder.

a, b, c © E. Vigneux - Onema

Definition of passability classes

The objective of the ICE protocol is to put users in a position to determine the potential impact of an obstacle on the movement of fish, based on simple criteria and easily implemented human and material resources.

The protocol is structured around a comparison of the geometric and hydraulic characteristics of obstacles with the physical swimming and jumping capabilities of the fish species analysed.

Caution. The approach proposed here is designed to be as logical and rigorous as possible, however, it is still a simplification given current knowledge on the passage capabilities of certain species, the highly variable swimming capabilities within a species or group of species, the geometric complexity of certain obstacles causing significant differences in hydrological conditions for a given discharge and the variability of hydrological and thermal conditions during migratory periods.

Given the above, it was deemed preferable to use passability classes, similar to projects comparable to the ICE protocol carried out in other countries (see Table 5).

Tableau 5 *Summary of the main methods developed worldwide to assess the passability of a structure.*

Country	Organisation and/or references	Species	Type of structure	Number of classes	Main criteria
United States	Washington Department of Fish and Wildlife (WDFD, 2000)	Salmonids	Various, essentially road and tidal structures	4 classes: 0%, 33%, 66%, 100%	Level A: slope, head-drop, depth Level B: length, velocity, depth, head-drop, type of structure
	U.S. Department of Agriculture (USDA) (Clarkin *et al.*, 2005)	All species, but particularly salmonids	Road structures	3 classes: green, grey and red	Slope, downstream fall, length, velocity
	Coffman (2005)	3 species groups: salmonids, cyprinids, percids and cottids	Road structures	3 classes: green, red and indeterminate	Slope, downstream fall, length, velocity
New Zealand	James and Joy (2008)	All species	All structures	4 classes	Expert knowledge
Germany	DWA (2005)	All species	All structures	4 classes	The criteria used for fish passes (essentially head-drop)
Belgium (Wallonia)	Wallonia Public Service and University of Liège (2013)	All species	All structures	4 classes	Expert knowledge
United Kingdom	Kemp *et al.* (2008) Kemp and O'Hanley (2010)	Species groups: salmon, trout, lamprey, cyprinids, juvenile salmonids, juvenile eels, smolts, juvenile lampreys, silver eels	All structures	4 classes: 0%, 33%, 66%, 100%	Head-drop, velocity, depth, hydraulic jump
Spain (Catalonia)	Solà *et al.* (2011)	4 species groups: marine/estuarine species, eels, cyprinids, salmonids	All structures	5 classes: ranging from bad to high	Head-drop, plunge pool, water depth, slope, velocity

Five passability classes were selected for the ICE protocol. The definitions for each class are, on the whole, in line with those proposed by Kemp *et al.* (2008) and Kemp and O'Hanley (2010).

A colour code is assigned to each class (0, 0.33, 0.66 and 1) to facilitate implementation and enhance understanding.

Caution. The four passability classes (0, 0.33, 0.66 and 1) should not be understood as passage rates for a species or group of species. They are rather indicators of the need to undertake restoration work on the structure. In this sense, each number is not a percentage, but an indicator of environmental degradation and of the need for an intervention (the closer the indicator is to zero, the greater the need for an intervention).

An indeterminate class (NC) was created for more complex situations where in-depth analysis is required to determine the passability class (complex structures, etc.). This class may be assigned while waiting for a later assessment.

The definitions of the passability classes are presented below. The criteria and the procedure used to determine the passability class(es) of an obstacle as a function of its characteristics and a given group of species will be presented later.

Total barrier (ICE class = 0)

The barrier cannot be overcome by the species/stages of a given species group and constitutes a complete obstacle to their migration.

However, under exceptional conditions, the obstacle may become momentarily passable for a fraction of the population.

High-impact partial barrier (ICE class = 0.33)

The barrier is a major obstacle to the migration of the species/stages of the given species group.

The obstacle cannot be overcome most of the time and/or by a high percentage of the population. Upstream migration is possible only during a limited part of the migratory period or for a limited part of the population in the given group. The obstacle incurs delays in migration that are detrimental to the biological cycles of the species.

Medium-impact partial barrier (ICE class = 0.66)

The barrier is a significant obstacle to the migration of the species/stages of the given species group.

Passage of the obstacle during upstream migration is possible most of the time and for a high percentage of the population. But the obstacle can nonetheless cause non-negligible delays in migration.

Consequently, the obstacle cannot be overcome during part of the migratory period by a significant part of the population in the given group.

Low-impact passable barrier (ICE class = 1)

The barrier is not a significant obstacle to the migration of the species/stages of the given species group.

Most of the population can overcome the obstacle within a short time span and without injury. However, that does not mean that the obstacle does not cause any delays in migration or that all fish in the given group can overcome it without injury.

Barrier having indeterminate impact (ICE class = NC)

Obstacle passability cannot be determined solely on the basis of ICE data. An assessment of the impact requires additional investigations and/or more in-depth analysis.

NB This approach may also be applied to assessments of downstream migration. However, as noted in the section on the protocol objectives and limits, given the complexity of downstream-migration parameters and situations, it was decided not to establish assessment criteria for the passability of structures during downstream migration. A specific study carried out by highly specialised technicians remains indispensable.