# **BAW**Letter 02/2016

## Requirements for the Planning of Fish Lifts and Fish Locks

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### 1 Starting situation

To date, there is a lack of general, comprehensive design recommendations for the construction of fish lifts or fish locks. DWA Guideline no. 509 (DWA, 2014) provides information on fish lifts and fish locks in Chapter 8.4, "Sonderkonstruktionen" (Special facilities). In this case the term "Special facilities" refers to upstream technical fishways like fish lifts and fish locks which, based on the present state-of-the-art, are not generally recommended for construction although, under specific boundary conditions, they may be superior in terms of effectiveness and costs. DWA Guideline no. 509 (2014) assesses the future potential of fish lifts and fish locks as follows: "Fish lifts and fish locks on German waterways will surely continue to be exceptions in the future, only being preferred to standard upstream fishways under very specific boundary conditions."

Currently more than 100 fish lifts and fish locks are operated worldwide (Arcadis, 2015). In a number of national and international projects to restore ecological connectivity fish lifts and fish locks are preferred over standard designs (e.g. Kühlmann et al., 2015; Schletterer et al., 2015; Fischer et al., 2015). A closer look at the ecological, hydraulic and technical design-related conditions of fishway facilities, both completed and in planning, shows that while all technical solutions have some features in common, fish lifts and fish locks are essentially special-purpose solutions optimised for the respective site (and partly protected by patent law).

Water level fluctuations in the headwater and cost advantages are often given as arguments for installing fish lifts/locks instead of standard fishway structures (e.g. vertical-slot-passes). This is especially the case if the available space on the banks is limited, the head is high and existing structures favour the installation of a fish lift or a fish lock. To date it is not possible to derive general criteria needed to assess the potential of different designs for a particular location in advance. Even if the available space is considerably limited and heads are high, a vertical slot pass near the bank can be more cost efficient than a fish lift or a fish lock. On the other hand, fish lifts or locks may prove to be more economical solutions than standard designs, including sites with small heads. Also, the potential costs arising from an existing patent as well as the maintenance costs must be considered.

Apart from the cost factor, the ecological function is the key issue when assessing a facility . A fish lift or a fish lock generally enables the fish to overcome the water level difference between the tailwater and the headwater without effort – and, especially in locations with high heads, this might prove a significant advantage over standard fishways.

However, some difficulties are associated with the operation of installed systems, such as the species and/or size selectivity of certain facility types (e.g. DWA, 2014; Arcadis, 2015; Haro & Castro-Santos, 2012) or a general lack of effectiveness based on design-related deficits and lack of scientific data, for example.

The aim of this publication is to define the requirements to be observed in the pre-planning phase for a fish lift or a fish lock. Not all of the requirements outlined are of immediate relevance for pre-planning. However, some of them will be included in the following so as to provide planners with a better basis for decision making. Generally, reference is made to the information contained in the DWA Guideline no. 509 (2014).

The purpose of this **BAW**Letter is not to provide a description of the range of technical systems available. Planners are advised to refer to the existing literature for an overview of available technological solutions and associated constraints. A summary of the current literature is provided in chapter 4 and more specifically in Arcadis (2015).

## 2 Fish lift or fish lock?

Fish lifts and fish locks are distinguished according to the underlying design principle (refer to DWA, 2014). However, currently there is no reason to generally favour one of the systems; rather, the benefits and drawbacks depend on local boundary conditions and to some extent on the preferences entertained by the planner based on his/her experience with the different types. For a description of different designs refer to DWA (2014) and Arcadis (2015).

## 3 Requirements for planning fish lifts and fish locks

### 3.1 Fish ecological requirements

Planning a fish lift or lock and planning other fishway types require the same considerations regarding the applicable fish species. The requirements as set forth in the “Guideline Upstream Fishways on German Federal Waterways” (BAW/BfG, 2015) and the DWA Guideline no. 509 (2014) are applicable.

As elaborated in Chapter 3.3 a fish lift/lock must be designed to allow the mass upstream migration of fish. Conntecitvity must also be ensured “around the clock” on at least 300 days a year. Planners must take into account that fish lifts or locks provide no or only limited connectivity for benthic invertebrates and some fish species which prefer to migrate close to the ground or which are weak swimmers (DWA, 2014). This aspect must be discussed with the appropriate technical and fishing authorities prior to the planning phase.

### 3.2 Attraction of and entrance to a fishway

The requirements regarding attraction are identical both for fish lifts/locks and other types of design. For more detailed information refer to the “Guideline Upstream Fishways on German Federal Waterways” (BAW/BfG, 2015) and the DWA Guideline no. 509 (2014).

According to the DWA Guideline 509 (2014) medium flow velocities of about 1.0 m/s must be specified for the attraction flow at the point where it enters the tailwater unless higher flow rates occur in the course of the fishway.

From the point of view of fish ecology low velocities are generally advisable. However, this requires more water and space in the area of the entrance chamber to achieve sufficient attraction flows. To enable a comparison of different fishway types at the same position at a specific site, identical requirements and boundary conditions regarding attraction should be applied. For this reason the flow velocity in the entrance of the fishway should be equal for all alternatives and, according to current advice provided by BfG/BAW, it should not exceed the maximum velocity in the slots/narrow places of the respective alternatives.

## 3.3 Passability of an entrance chamber or pool-type fishway preceding the fish lift/lock

It is not advisable to have a direct connection between the fish lift or fish lock and the tailwater, i.e. the entrance to the lock/lift should not correspond with the entrance to the tailwater of the facility as a whole.

Usually, an entrance chamber is located between the entrance to the tailwater and the entrance to the fish lift/fish lock (Fischer et al., 2015; Lehmann and Kühlmann, 2015; Arcadis, 2015), or the downstream area of the fishway is designed as a pool-type structure (e.g. vertical slot pass) leading up to the lift/lock (Schletterer et al., 2015; Mueller et al., 2013; Arcadis, 2015)

### 3.3.1 Entrance chamber

The need for an entrance chamber (also referred to as trap chamber in DWA, 2014) or a pool-type fishway downstream of the lock/lift is essentially due to the fact that fish lifts and fish locks are discontinuous systems where fish may have to wait before continuing their way and cannot ascend to the headwater by immediately following the continuous flow path. Ascending fish that are already in the fishway while waiting to continue their migration upstream are probably less likely to turn away from the entrance to the lift than fish that have to wait in the larger tailwater area. Also, according to the current state of knowledge, in many locations the entrance chamber is needed, to increase the operating flow in the fishway by adding auxiliary water in order to produce an adequate attraction flow in the tailwater. Based on current evaluations this auxiliary water should preferably be injected into the fishway upstream of the fishway entrance. Generally, the hydraulic requirements for the entrance chamber are the same as the requirements for a standard design entrance pool. Since the fish may have to cope with the flow conditions prevailing in the entrance chamber for some time, the chamber should have sufficiently large areas where weak swimmers are not required to swim faster than at their prolonged speed. The maximum flow velocity in the migratory corridor should be 0.6 m/s as recommended by Travade and Larinier (1992). The velocity should not fall below 0.3 m/s.

A conceivable alternative would be not to add the auxiliary water in the entrance chamber but to install an auxiliary water basin preceding the entrance chamber in the swimming direction of the ascending fish.

There are currently no universal design rules applicable to the dimensions of the entrance chamber. However, in most cases, if auxiliary water is injected into the entrance chamber, the hydraulic requirements will almost certainly determine the dimensions of this chamber (see above). Here, the DWA Guideline refers to examples based on the experience gained by Travade and Larinier (1992).

The minimum dimensions of an entrance chamber specified in DWA (2014) are as follows:

| Target species | Length (m) | Width (m) | Height (m) | Volume ($m^3$) |
|---|---|---|---|---|
| Trout | > 1.5 | > 1.0 | > 0.8 | > 1.2 |
| Salmon | > 2.5 | > 1.5 | > 1.0 | > 4.0 |
| Shad | > 5.0 | > 2.5 | > 1.5 | > 19.0 |

Significantly larger dimensions may be necessary for fish belonging to the sturgeon family. This issue must be discussed with the client in the pre-project phase.

DWA (2014) also refers to Travade and Larinier regarding the recommended water volume of approximately 15 litres per kilogram fish weight, e.g. 5 to 15 litres per single trout, 30 litres per shad and 80 to 150 litres per salmon. When applying these values it is important to bear in mind that migratory activities may increase at certain times and that it is therefore insufficient to use an average number of fish per time unit. Thus, Larinier et al. (1992) assume the value per hour to be in the range of 1.5% – 2% of the total annual number of fish during periods of strong migratory activity – a value corroborated by some first surveys at the fishway in Koblenz. Generally, planners should try to include the ascending biomass and number based on the experience gained for the site in question. Besides design requirements, these findings should be used also to adapt operational control of the facility.

Useful data for defining the required dimensions of an entrance chamber can be derived from experience gained in model tests or installed facilities (e.g. the fishways in Iffezheim/Rhine, Baldeney/Ruhr (Oberle et al., 2015), Wallstadt (Fiedler, 2016)).

The installation of structures guiding the fish in the entrance chamber and a chamber layout leading the fish to the entrance to the lift/lock is estimated to be advantageous.

A fish crowder generally poses a threat of injury to the fish and is susceptible to faults. A design without fish crowder would therefore be desirable; however, very little experience has hitherto been gained from such alternatives. If fish crowders are planned, a fish friendly design and mode of operation should be envisaged and determined in the planning process.

Moreover, when planning the entrance chamber it is essential to ensure that fish are prevented from swimming into the area below a lifted transport tank because of the risk of injuries caused by the descending tank. Implementation of suitable fish protection measures is mandatory.

### 3.3.2 Downstream pool-type fishway

In some cases it may be necessary to build a fishway (e.g. vertical slot pass) downstream of the fish lift/fish lock in addition to or instead of the entrance chamber. An important reason for adopting this approach is that in this case water level fluctuations in the tailwater would have no or only minimal impact on the entrance to the lift/lock. Account must be taken of the spatial conditions on-site, i.e. local boundary conditions can influence the decision for a particular design.

## 3.4 Entrance to the fish lift or fish lock

The entrance dimensions must comply with the minimum geometrical requirements according to DWA (2014) which are applicable for the relevant fish species. To enable fish to enter the fish lift/fish lock there must be a continuous attraction flow during the entrance phase from the entrance into the tailwater. Current studies (Hoffmann and Böckmann, 2015; Schmalz and Thürmer, 2015; Fischer and Schmalz, 2015) indicate that a mean flow velocity of 0.5 m/s in the entrance cross section seems to yield the best results regarding the entrance behaviour of the fish. It is essential to ensure that the bottom of the lift/lock is flush with the bottom of the downstream structure; there should be no offset.

An important question to be considered in the planning and regarding the effectiveness of the fish lift/fish lock is the extent to which it is acceptable for the structure to impact the connectivity of upstream migration. The negative impact on effectiveness generated by the discontinuous operation of a fish lift/fish lock, which is often considered a disadvantage, can be (partly) resolved if the ascending fish are prevented from escaping from a transport tank or trap chamber, for example by means of entrance funnels or fish crowders (DWA, 2014). However, such obstacles preventing fish from swimming back are prone to clogging and/or sedimentation which means that these parts of the facility have to be regularly cleaned in order to ensure the effectiveness of the fish lift/fish lock (Hoffmann and Roth, 2016). It is possible to mitigate the disadvantage of discontinuous operation by operating several independent fish locks or fish lifts. Thus, there would always be an entrance open for fish which would not have to wait as long (e.g. Hoffmann and Roth, 2016) before continuing their migratory path.

Generally, a second fish lock/fish lift should be considered. If this is not feasible due to the prevailing spatial boundary conditions it may be possible, after consultation with the client, to change the approach and plan a single facility. This deviation from the basic requirement is especially applicable for sites where there are plans to build several independent fishways.

## 3.5 Passage in the fish lift and the fish lock

The transport tank of a fish lift must be designed with sufficiently large dimensions. According to DWA (2014) the size of the transport tank must be such that a volume of around 15 litres per kilogram of bodyweight is provided. The minimum dimensions specified for the base area are 1.5 m × 1.0 m (for the target species trout). Dimensions of the transport tank depend on the largest fish to be expected, the maximum number of fish expected, the mobility requirements of the fish, and the mode of operation of the fish lift and the lift type. The precise dimensions therefore depend on the site in question and have to be specified for each individual case.

The water depth in a trough-like transport tank should not fall below the values specified for the migratory corridor in DWA Guideline (2014), table 16. The lift should also have a bottom substrate with sufficient stability if the fish leave it on their own volition and the tank is not actively tilted. Where fish lifts are designed with a tilting mechanism no bottom substrate should be used because of the risk of injury to the fish during the tilting process. The use of bottom substrate therefore depends on the type of lift.

For fish locks with large heads a movable grid floor should be used to guide fish into the upstream area of the lock (except for pressure chamber fish locks). The velocity and grid spacing must be small enough to ensure that fish are not injured by the movement of the grid floor. The grid floor must also be kept clean and free from floating debris.

## 3.6 Exit into the headwater

There are different options for an exit from a fish lock/ fish lift. It is essential to ensure that the fish are able to enter the headwater without injury and undue effort at all operational water levels. The ideal solution would enable them to swim freely into the headwater. The requirements applicable to other types of fishways regarding the siting of the exit in the headwater (DWA, 2014) also apply to fish locks/lifts. Thus it must be ensured that the location of the exit enables the fish to immediately continue their upstream migration (e.g. connection to an upstream migration corridor, preventing the risk of drifting back downstream because of high flow velocities).

Where the transport tank of a fish lift is lifted higher than the upstream water level the potential risk of injury to the fish when the tank is emptied has to be taken into account. According to DWA (2014) the trough must either be equipped with a closable outlet or a tilting mechanism. It is emptied when it is in its topmost position, either via a chute or a pipe. To ensure that no fish are left in the tank after emptying, its walls and floor should have a conical shape. When emptying the tank, the free fall of the fish must be prevented if possible, otherwise precautions must be taken by providing a sufficient water cushion and observing a maximum fall height. The requirements pursuant to DWA (2005) must be complied with in this respect, i.e. a water cushion of at least 0.90 m or ¼ of the fall height of max. 10 m must be provided for.

If a chute is used to direct the fish to the flushing channel through which they are transported further upstream, the transitions between the channel sections must be smooth and very clean to prevent any mechanical damage to the fish, the flushing channel must be supplied with a sufficient volume of water and it must be of adequate size. In the flushing channel a minimum flow velocity of 2 m/s (3 m/s if there are strong swimmers) and a maximum velocity of 4.5 m/s must be ensured. The water in the channel must be at least 25 cm deep to permit the larger and greater numbers of fish to pass. It is essential to maintain a flushing flow in the channel for several minutes before and after the flushing process (pre-flushing and post-flushing).

If fish have to exit actively from the fish lift/fish lock into the water column of the headwater the challenge is to incite the fish to swim out of the fish lock/fish lift. For this purpose an attraction flow is recommended: a flow with v = 0.5 m/s acts as a stimulus to fish, inciting them to leave the lift/lock on their own (Roth und Baumann, 2015). Experience has shown that a horizontal flow through the transport tank is particularly efficient (Hoffmann und Roth, 2016). The requirements applicable to the dimensions of the entrance openings also apply to the exit orifices (DWA, 2014). Sufficient time must be allotted for the exit phase as experience has shown that fish need some time for orientation before following the attraction flow to swim out of the facility (DWA, 2014; Hoffmann and Böckmann, 2015). As is the case with standard fishways, an exit near the bottom and/or a connection of the fish lift floor to the bottom of the river is recommended.

Systems designed to support the exit of the fish, such as ultrasonics or the introduction of air are not recommended as the advantages have not been sufficiently investigated so far.

## 3.7 Operation and maintenance

The operational control of the system, i.e. operation schedule of the fish lift/lock is a significant aspect. A fixed annual schedule would not be appropriate as the number of fish willing to ascend depends on many factors and varies widely according to prevailing conditions. Instead, the operation schedule must be as flexible as possible. Real-time surveillance of fish that have entered the facility (e.g. by sonar, video) may prove useful for operational control. The costs of a real-time surveillance system must be taken into account in the cost estimate.

Another aspect to be taken into consideration when comparing different designs refers to the operation and maintenance of the facilities. Again, there are no general criteria, but experience from the operation of different facility types provides a basis for assessing the suitability of fish lifts or fish locks. It is important to protect the facility against clogging and floating debris. The problem of floating debris can occur both from headwater and tailwater directions. Easy and safe access to all parts of the facility must be ensured. There must be monitoring systems for reporting malfunctions to the persons responsible for operation. Regular checks must be performed to ensure the functioning of the fish lift/lock.

When comparing the costs of the alternatives under consideration, the costs of operation and maintenance have to be taken into consideration.

## 3.8 Assessment of effectiveness

The structure must permit an assessment of the facility's effectiveness. An assessment of the effectiveness of fish lifts/fish locks particularly involves determining the number of fish swimming into the entrance chamber in relation to the number of fish actually ascending using the lift and/or lock. Hence, sole counting of fish upstream of a fish lift or fish lock rarely provides sufficient information. However, when counting fish in the entrance chamber, it is not possible to use a fish trap. In this case, only optical/acoustic systems can be used as they do not interfere with upstream migration. Given the variety of possible designs more specific details can only be agreed with the client in the planning phase.

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