# 04 - FISH AND FLOW – MAINTAINING THE BALANCE BETWEEN HYDROMETRIC UNCERTAINTY AND AIDS TO FISH PASSAGE AT FLOW GAUGING STRUCTURES.

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## Abstract

Continuous flow determination on many river systems in the UK and Ireland can often be best achieved by the use of control structures in order to provide stable stage vs. discharge relationships. These can either be purpose built flow measurement structures or structures that have been built for another purpose utilised for flow monitoring. Structures have a detrimental impact on the passage of fish and can result in significant ecological impacts. Data from many flow gauging structures are of prime strategic importance, often with long and homogeneous records. As such it is essential their integrity is protected. The Water Framework Directive (WFD) and other similar initiatives, have resulted in considerable pressure to either remove flow measurement, and other, structures or to install aids to fish passage. The Environment Agency in England and Wales has instigated a number of excellent research initiatives to investigate the impacts of fish passes on hydrometric (hydrological monitoring) performance and the use of fish passes as flow measurement structures. This research has aided the development of an International Hydrometric Standard on the use of fish passes at flow measurement structures. The laboratory research that has been undertaken by HR Wallingford, the University of Cranfield and others, on behalf of the Environment Agency, has been widely published. This paper describes some of the practical experiences of the authors in the field evaluation of the impact of fish passes, hydrometric design considerations, maintenance issues and uncertainty in flow determinations. Particular emphasis is placed on the most cost effective methods of improving fish passage including retrofit baffle solutions. The paper demonstrates some of the key issues, the uncertainties in flow determinations associated with various options and in certain circumstances the potential for fish passes to improve hydrometric performance. Brief consideration is also given to alternative flow measurement techniques that can be used if structural controls are removed or significantly modified.

## 1. INTRODUCTION

Many habitats have historically been damaged by the use of barriers that obstruct the migration of fish and other species. A great number of these are remnants of an industrial past. However flow measurement structures also present a barrier to fish and many are impassable to even the most athletic of species. Fish are categorised into two types: migratory (diadromous) and resident (potadromous). However even resident fish populations such as brown trout will move around a reach of river and use different areas for spawning and feeding. With increasing importance particularly in legislation other species such as elver must also be considered. Therefore, it is often necessary to incorporate both a fish pass and an eel/elver pass into a single gauging station.

The incorporation of fish passes at structures was first introduced into legislation by the Salmon and Freshwater Fisheries Act 1975. This required new obstructions, or those rebuilt for more than half their width, to include a fish pass. This legislation has since been enhanced and the achievement of Good Ecological Status / Potential for Water Framework Directive will require connectivity and free passage for a wider range of fish species.

Hydrometric structures are normally engineered to the relevant International Standards to ensure that they are capable of being utilised to determine flow accurately. Structures that are both well installed and maintained are widely recognised as one of the best means of determining flow to a low level of uncertainty. Non standard structures calibrated through ratings can also be suitably stable and sensitive but provide an equally problematic barrier to fish passage.

A number of solutions to aid the passage of fish are available from highly engineered separate channels to removal of structures and replacement with alternative technology. The costs of installing fish passes are often high and there are still conflicting views on the best type of arrangement both from hydrometric and fish passage perspectives. A long and homogeneous flow record can be valuable for a range of flood and water resource issues. Further to this the ecological conditions caused by a structures afflux provide a valuable habitat for a wide range of species.

## 2. SUMMARY OF RECENT RESEARCH

In recent years the Environment Agency has commissioned a number of laboratory research and field based trials to determine the most suitable and cost effective means of introducing aids to fish passage while maintaining the hydrometric integrity of the flow measurement structure. In particular HR Wallingford have undertaken studies on Larinier Fish Passes with different baffle heights. The initial research was based on a 100 mm baffle but subsequently work has been undertaken with 75 and 150 mm baffles. A methodology is now available for estimating the discharge coefficient for any baffle height. In addition the maximum stage for flow monitoring purposes at Larinier gauging stations has now been extended to 0.65 m. The 100 mm baffle research formed the basis of the International Standard on Fish Passes at flow measurement structures (ISO 26906: 2009).

The cost of installing Larinier fish passes is relatively high. Therefore other solutions such as retrofit baffles have been researched at several sites. The first retrofit baffle arrangement was installed on the Moors River at Hurn Court in Dorset, this raised concerns over entrained air and turbulence. A further configuration was researched at the University of Cranfield (Servais, 2007). In addition, HR Wallingford (2003) have also undertaken some preliminary research for the Environment Agency on retrofit baffles and have proposed a methodology for estimating the position of the highest top baffle on Crump weirs to ensure there is no adverse impact on the modular limit.

A field evaluation project to test the laboratory findings on Larinier and retrofit baffle fish passes in the field was also commissioned by the Environment Agency. Preliminary field evaluations were also undertaken to review the impact of eel passes on the performance of flow measurement structures.

Many of these solutions are now being used in upgrades to gauging stations finding a balance between ecological concerns, hydrometric data quality and cost.

## 3. FIELD EVALUATION OF FISH PASSES

### *3.1 Field evaluation of Larinier fishpass on the River Stour at Loudsmill*

The Larinier Super Active Baffle Fish pass was a further development of the baffle fish pass or Denil (Denil 1909). The Larinier provides a separate channel and reduces the velocity by providing a series of baffles which are installed on the bed of the pass.

***Figure 1:*** *Larinier Super Active Baffle Fish pass*

When operating as a flow measurement structure the crest of the Larinier is treated as the invert of the lateral section of the top baffle. The Larinier is then considered to behave like a flow measurement structure with the head measuring device zeroed to the crest of the top baffle. The first Larinier to be installed at a gauging station for flow measurement was at Loudsmill on the River Stour (Dorset). The fish pass rating has been developed using the methodology described in White et al (2006) and more recently adopted in ISO 26906 (2009).

The existing gauging structure consisted of two Crump weirs. The Larinier was installed through a broad crested flanking wingwall on the main Crump.

The performance of the Larinier fish pass as a flow measurement structure was judged by the fit of the gauged data to the theoretical stage discharge relationship. Gaugings were undertaken over the critical flow range to assess the performance of the derived theoretical rating.

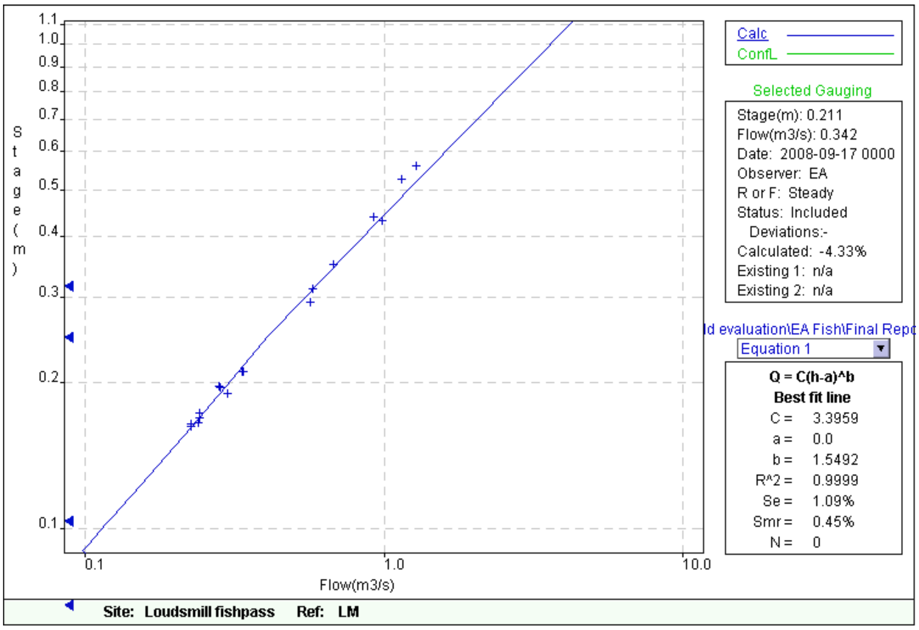


***Figure 2:*** *Comparison of Larinier fish pass stage-discharge relationship with spot flow gaugings*

The presence of a floating trash boom resulted in problematic flow disturbances at higher discharges. The use of a separate stilling well is critical in ensuring stage is measured with a suitable degree of accuracy. If transposing the primary head measurement device care must be taken to ensure that the trash boom does not cause an issue in head measurement.

### *3.2 Evaluation of retrofit baffles on the River Enborne at Brimpton*

The arrangement of timber or similar baffles on the downstream face of a weir structure is undertaken to reduce the critical velocities on the downstream face. This can be a relatively low cost, retrofit method.

**Figure 3:** *Low cost baffle solution at Brimpton*

A retrofit baffle configuration was installed at Brimpton Gauging Station on the River Enborne in Berkshire. Brimpton Gauging Station is an asymmetrical compound Crump weir. If the baffles are too high relative to the existing weir crest, or placed too close to the crest of the weir, this will impact on the measured head of water upstream, potentially creating non-modular flow conditions.

Research undertaken by Servais (2007), highlighted the potential for entrained air as a concern once the method was installed on a full sized structure. This and other concerns such as accumulation of debris, can make the pass unattractive to fish.

The arrangement was assessed through the completion of a range of gaugings within the critical flow range gaugings indicate that there was limited impact on upstream head, with the deviation of gaugings from the rating similar to those observed for the pre-baffle gaugings.

### *3.3 Field evaluation of eel/elver passes on hydrometric performance*

Two main types of eel / elver pass exist, the up and over pass using a bristled tube with a constant pump of water and an invasive method. The authors experience has been undertaken on the invasive type of pass.

The invasive method of elver pass consists of a board with short bristles that the elver/eel uses to negotiate a barrier (Figure 4). This plate can be mounted horizontally on the downstream face of the weir but is more usually mounted vertically along the side of the crest placing the bristles against the wall of the channel. The retro fitting of these passes in this manner essentially narrows the weir structure. Bristled tiles have been developed to improve the invasive method.

***Figure 4:*** *In weir Elver / Eel pass*

Field evaluation was undertaken at four Crump weir gauging stations in Hampshire in the south of England to provide an initial impact assessment of this type of pass on the hydrometric performance of the gauging station. The impact was assessed through spot flow gauging, stage measurements and analysis of the ratings. Comparisons were made between stage and flow measurements taken with the eel passes in place and with them removed.

The evaluation showed as would be expected that the impact of the eel pass was inversely proportional to the overall width of the weir. In the evaluation flow through the bristles was deemed insignificant in terms of the overall total flow. Though flow through the bristles can be estimated the main problem is that the bristles can become clogged quite easily so the adjustment will vary with time.

### *3.4 Pool and traverse fish passes*

This method is one of the earliest forms of fish pass and provides passage over a weir by constructing barriers with slots to create one or a number of navigable pools like a series of steps. Fish are able to rest in each of the pools and a sufficient depth is provided to allow them to reach appropriate burst speeds to navigate the weirs.

***Figure 5:*** *Pool and Traverse Fish Pass*

The pool and traverse is covered in ISO 26906 (2009) based on research undertaken in the Netherlands. Also the use of pool and traverse type arrangements have been recommended at several gauging stations which the authors have been involved with in recent years to provide solutions with limited engineering requirements. The key consideration is to ensure that the installation of downstream traverses do not result in a reduction in the modular limit.

## 4. PRACTICAL EXAMPLES

### *4.1 Design Considerations*

The authors have been involved in a number of gauging station reviews to recommend suitable aids to fish passage while ensuring that the hydrometric integrity of a measurement site is maintained. Consideration is given to preserving the record of flow at a site while at the same time proving fish passage. The use of hydro-acoustics has been a valuable tool for providing alternatives to flow measuring structures. However, acoustic technologies will not be appropriate at all sites and in many situations will require calibration.

### *4.2 Teston*

Teston Lock on the River Medway in SE England which currently consists of a sluice gate which when closed performs a rectangular thin plate and a Crump Weir requires fish and canoe passage and a raising of the height of the sluice gate. As the Medway is navigable at this location navigation levels have to be maintained while at the same time not exacerbating the risk of flooding. A Larinier fish pass is proposed to be installed in an old by-pass channel which will be engineered for fish and canoe passage. In view of the need to use the Larinier fish pass for canoe passage rubber baffles are proposed. These have not been previously researched from a hydraulic and hydrometric perspective so concerns have been expressed on their impacts on data quality. Ideally these should be laboratory researched but at the very least it is proposed to undertake a detailed field evaluation. Another consideration at this site was to ensure that velocities in the approach channel to the upstream side of the Larinier were not too high for fish when they exit the pass.

***Figure 6:*** *Teston Lock – existing gauging station*

### *4.3 Truro*

Truro gauging station is a compound Crump weir that had a pre-barrage maintaining head for an ornamental leat. A range of solutions were considered at the site for improved fish passage including modification of an existing transit time ultrasonic system, a relocation of the off-take and various configurations of fish pass. The replacement of the existing pre-barrage with a compound solution incorporating a Larinier fish pass and thin plate weir was also considered.


***Figure 7:*** *Truro Gauging station existing layout.*

The combination of uncertainties between multiple flow measurement solutions including a pipe meter for the leat led to potentially high errors in the estimate of discharge.

Various options were identified including rock ramps with bristled passes and full pool and traverse sections. The final option requires stakeholder and fisheries input.

### *4.4 Anglian Region*

A number of sites were assessed for the Environment Agency Anglian region. A series of solutions were suggested based on the most suitable for the species involved and the most cost effective solutions. Maintaining suitable uncertainties at the key flows was also considered. Pool and traverse, retrofit baffles, and a by-pass with acoustic device were all recommended at different stations.

A site at Marham gauging station was assessed and a Larinier was considered most efficient from both fish passage and hydrometric measurement. A Larinier fitted to the existing structure was also considered cost effective. However the aesthetic qualities of the Larinier were not deemed suitable for the area and a bypass channel with hydroacoustic device was considered the most suitable solution.

## 5. UNCERTAINTIES IN DISCHARGE DETERMINATIONS

### *5.1 Flow measurement uncertainties*

The uncertainty of a hydrometric measurement is an important factor and is often overlooked. The end users of hydrometric data for water resources and flooding related issues require accurate data on which to make judgements e.g. regarding the development of a flood plain or ensuring sufficient reservoir storage. An estimate of how uncertain any given value may be is an important element of these decision making processes. All flow measurements whether they are current meter gaugings, flow measurement structure derived or from some other technique have a degree of uncertainty which is a combination of individual measurement and assumption uncertainties that form part of the flow derivation process.. When a fish pass is added to an existing structure the uncertainties in the determined flow are altered. Therefore, it is important to be able to estimate uncertainties in the flow determinations for both the pre- and post-fish pass situations so that the impact of the proposed fish pass can be ascertained during the design stage. If the uncertainties are likely to be increased then the design should be modified accordingly if possible so that the impact at the very least is negligible.

The overall uncertainty ($U^*_c$) for a flow measurement structure is a combination of the combined uncertainties in the discharge coefficient ($C_e$), the structure geometry and the stage. For example the uncertainty for a Crump weir is given by the following uncertainty equation:

$$U_c^*(Q) = \sqrt{u^*(C_D)^2 + u^*(b)^2 + (1.5u^*(h_1))^2} \quad \text{Equation 1}$$

$U_c^*(Q)$ = overall uncertainty in the discharge estimate
$u^*(C_D)$ = uncertainty in the discharge coefficient
$u^*(b)$ = uncertainty in the breadth/width of the structure
$u^*(h_1)$ = overall uncertainty in the stage measurement

The most significant source of overall uncertainty is normally the uncertainty in the stage measurement.

Generally a well constructed and maintained flow measurement structure operating within its design range should be capable of delivering flow data to within 5 – 10% at the 95% confidence level (two standard deviations). The challenge presented as pressures increase to provide fish passage is protecting the measurement accuracy.

### *5.2 Uncertainty analysis for Loudsmill gauging station*

It is important to preserve the overall integrity of a measurement structure where fish passage is to be provided and consider its primary purpose in providing valuable hydrometric data. The Larinier has a good laboratory calibration and appears to be capable of performing to similar levels of uncertainty as other ISO flow measurement structures. Therefore, it is recommended in the Environment Agency's fish pass manual as the most appropriate fish pass for use at hydrometric sites.

At certain sites it may be possible to improve the low flow sensitivity of the gauging station by the incorporation of a fish pass. The Larinier is usually incorporated with a lower crest height than the main structure and due to its narrow width (minimum of 600 mm and then increasing in 300 mm increments), it may be significantly more sensitive.

Uncertainty analysis has been undertaken for the Loudsmill Gauging Station with and without the fish pass (Figure 6). As a result of the lower and narrower structure formed by the fish pass, combined uncertainties at very low flows are reduced.

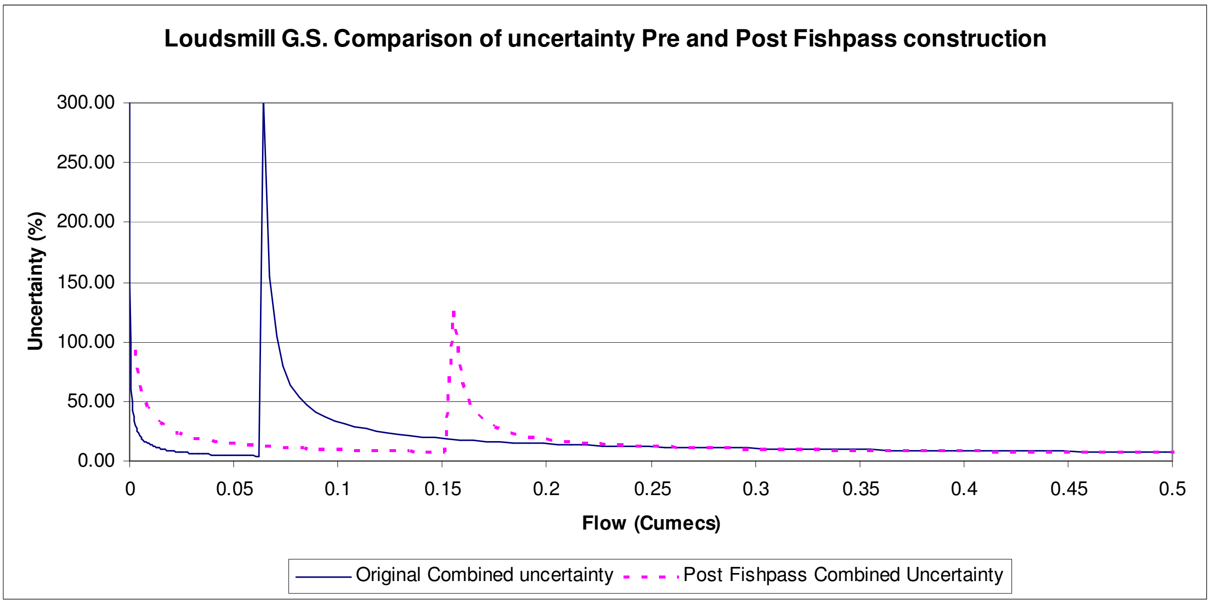


***Figure 6:*** *Combined Uncertainty comparison for Loudsmill Gauging station*

## 6. HYDROACOUSTICS

The use of hydroacoustic devices in flow measurement has been around for many years. However the increasing development of the technology and the subsequent reduction in costs of these solutions has led to their increasing use in flow measurement networks. The prohibitive cost of structures and the potential ecological impacts mean very few major structures are now completed.

Bed mounted devices generally use the Doppler technique where a pulse of sound is sent into the channel and reflected from particles carried in suspension in the water. The same technique is also used in side-lookers or Horizontal - Acoustic Doppler Current profilers. Numerous variations of the Doppler device exist including range gated devices where a velocity profile (horizontal or vertical) can be determined. These solutions generally have a much lower cost in purchase and installation needing much less engineering compared to a conventional structure. The devices do require calibration through the velocity index method, however using this method variable backwater effects can be accounted for allowing measurement in challenging water courses with seasonal weed growth or impacts of gate movement.

Hydro-Logic undertook the design and development of a gauging station on the River Thames near Oxford, UK this stretch of river was heavily controlled and used widely by boat traffic. An H-ADCP device was installed that profiled much of the channel width. Following a calibration effort throughout the full flow range an excellent calibration was achieved with data +/- 8-10%.

Transit time or time of flight systems are also widely used throughout the world and Hydro-Logic have recommended these devices in feasibility studies from the west of Ireland to irrigation channels in Iran. The concept involves the change in travel time of a pulse of sound travelling upstream and downstream. This technology does not require particles to be carried in the water and can be used in very clean mediums.

***Figure 7:*** *Transit time system in Western Ireland*

While these acoustic technologies are considered viable at many sites some channels with high level of suspended solids or entrained air can cause issues with the signal and absorb or refract the signal. Most critical is the need for calibration to ensure a reliable reading is achieved.

## 7. FINAL THOUGHTS

Work and experiences to date have shown it is possible to provide fish passage without having a major impact on the performance of flow measurement structures. At some sites the hydrometric performance may even be improved. However, the provision of fish passage will incur both capital and recurrent costs. To meet the requirements of the WFD, while at the same time optimising costs will require use of a combination of fish passage devices and alternative flow measurement methods supported by further research e.g. use of low cost baffles and the further development of hydroacoustics.

## 8. ACKNOWLEDGEMENTS

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