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Water quality – Assessment of damage to fish passing through pumping stations and hydropower plants – Methods based on live fish passage survival test and blade strike model

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Water quality - Assessment of damage to fish passing through pumping stations and hydropower plants - Methods based on live fish passage survival test and blade strike model

Wasserbeschaffenheit - Verfahren zur Ermittlung der Fischdurchgängigkeit von Wasserförderschnecken, Pumpen und Spiralturbinen, die in Pumpwerken und Wasserkraftwerken verwendet werden

This European Standard was approved by CEN on 13 July 2025.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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European foreword

This document (EN 18110:2025) has been prepared by Technical Committee CEN/TC 230 “Water analysis”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2026, and conflicting national standards shall be withdrawn at the latest by March 2026.

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Introduction

Purpose of the standard

In recent years, there has been a growing focus on enhancing ecological water quality, with a specific emphasis on fish populations. International legal frameworks, such as the Water Framework Directive (WFD) [1], the European Eel Regulation [2], and the Benelux Free Fish Migration Decision [3], have played a pivotal role in shaping the measures adopted in this regard. Human activities related to water management, drinking water supply, irrigation, and electricity production require the installation of pumps and turbines that can have significant environmental impacts on fish populations. For the environmental sustainability of these sectors, their impact must be studied and, if needed, the best available mitigation measures must be applied. It is the reason why significant efforts are being made by various stakeholders, including water management authorities, resource agencies, pump and turbine manufacturers, ecological consultancy firms, and research institutions, to enhance the chances of survival for fish passing through pumping stations and hydropower plants.

To address these environmental challenges and ensure the effective protection of fish populations, it is crucial to establish standardized procedures for assessing the impact of new and existing turbomachines on fish survival. This standard aims at providing a basis for planning, conducting, and reporting fish survival studies in pumps and turbines. It will lead to more consistency in results among study sites and machines.

Mechanisms of fish mortality

Damage to fish in pumping stations or hydropower plants can have different causes [13]. Mechanical injury by blade strike is generally regarded as the primary cause of injury and mortality in pumps and turbines with low to moderate heads. Grinding of fish along rough walls or entrapment in small gaps and clearances can also lead to damage. Other causes are rapid pressure changes that can result in barotrauma, and excessive shear forces in a fluid flow with high velocity gradients. The actual pump or turbine system is often where the risk is highest, but also other parts of a plant can be the source of damage, for instance at trash racks, in nearly closed guide vanes, long pipelines, or siphons, near butterfly valves, or oscillating no-return valves.

Methods to assess fish survival

Water management authorities are increasingly transitioning to the use of pump and turbine systems that pose fewer risks to fish. Decisions to that effect are usually based on survival tests done in the field at existing plants, or on laboratory experiments done in test facilities for new designs of pumps and turbines that are safer for fish. These survival tests can use either live fish or artificial, dummy fish with integrated sensors. Another alternative route to estimating fish survival is to use computational models that are well-validated with information from prior tests. Each of these methods has its advantages and disadvantages. The final choice depends on the stage of development and the desired level of accuracy.

1. *Fish survival tests in the field*

Fish survival tests conducted in the field at the actual plant site, using live fish and real environmental and operational conditions, yield results that most closely reflect what will be experienced in practice. The fish should be representative of the population for which the survival is being estimated, and operating conditions should reflect the most common modes of operation, or worst-case conditions if such conditions occur on a regular basis. Survival tests like these come closest to reality, where resident fish are entrained naturally into the intake structure of a plant, are subjected to all stressors during passage, and can display their natural behaviour. The use of artificial dummy fish with integrated sensors [17], can give additional information but they cannot replace tests with live fish. While the recorded values of acceleration, rotation, and pressure changes may give valuable information about stressors along a trajectory, these readings alone are (as of yet) difficult to correlate with actual damage to fish. Current studies are expected to improve their predictive powers.

Some previous studies of fish survival in existing plants use naturally-entrained fish that are collected in nets after passage through the pump or turbine. The obvious advantage is that these are fish types and sizes resident at the site. Further, these fish display natural behaviour as they approach and enter the intake. Still, it is recommended for most survival tests to use introduced fish because it offers greater experimental control in terms of sample sizes, species, size classes, and the duration of the tests. The condition of introduced fish is also known prior to release which allows for an accurate assessment of passage-related damage, especially if the tests are paired with the release of a control group of fish that are biologically identical and undergo the exact same handling, release, collection, and holding procedures as the test fish, with the exception of passage through the pump or turbine.

Netting, balloon tagging, and telemetry are widely used methods to collect or monitor fish after passage. Of these methods, collection nets are used most because they are versatile and although not cheap, once in place, allow for a cost-effective assessment of multiple species, size classes, and operating conditions. If constructed as a so-called full-flow net, covering the entire flow through one or more units, and sealed properly, it can result in total recovery of released fish. Uncertainty related to fish that are not recovered is then eliminated. Partial-flow nets lack all these advantages and must be avoided if possible. They exhibit low recapture rates of released fish and potential intrusion of downstream resident fish. Consequently, uncertainty levels of mortality rates are high.

Balloon tag and telemetry (radio or acoustic) are alternative methods to assess passage-related fish mortality. Both have a low initial cost but high unit cost if large numbers of fish are required. For this reason, such studies often have limited numbers of operating conditions, species and size classes, and small sample sizes. Tagging fragile species or small fish may come with high handling-induced losses. Further, tagged fish can be impacted in their swimming ability causing a bias in the results.

In balloon tag studies fish are tagged with a self-inflating tag and released. Contact with water inflates the tag after a while, buoys the fish to the surface and allows recovery by a boat crew. Telemetry is different in that fish are not recovered after release. Instead, their movement after passage is monitored. Often tagged dead fish are released as well to distinguish between the movements of live and dead fish. Injury and mortality can be detected by monitoring changes in behaviour and lack of active swimming. The assessment of delayed mortality rates can be hindered by a restricted survey zone and the uncertainty in classifying live and dead fish may lead to errors.

2. Fish survival tests in the laboratory

Survival tests in a laboratory or a factory share some of the characteristics of tests in an existing plant. The pump or turbine that is being assessed will have the exact same geometry except it is usually a model at a smaller scale, operating at a different flow rate and shaft speed. Tests may be done with fish of a different size class which requires scaling of the results with obvious uncertainties. The risk of barotrauma in a scale model is different from a full-scale installation. In addition, scale-model test rigs often do not entail all the components a real plant has, like a forebay with intake structure, a penstock, or auxiliaries like a trash rack or a gate valve. As a result, survival tests at model-scale are not easily translated to conditions at the actual plant. Laboratory tests at model scale are typically done during the development of a new type of pump or turbine design and results need eventual validation at full-scale.

3. *Model-based prediction of fish survival*

A model-based prediction of fish survival can provide a fair estimate of what is to be expected in reality. Such predictions are useful in the early stages of a new pump or turbine design before the laboratory survival tests take place. Water authorities can make use of these models to estimate survival rates of machines not yet commissioned or compare expected fish survival in existing installations before and after commissioning. A first quantification of the impact can thus be obtained without the use of live fish. It complies with the European Directive 2010/63/EU [4] and the aim to replace all animal research with non-animal methods. The decision to conduct subsequent tests with live fish can be made contingent on the results of a computational model.

Several models exist that estimate mortality due to blade strike, being the primary cause of damage to fish passing through many pumps and turbines. These models are usually based on a blade encounter model to predict the likelihood of a collision between a fish and a blade, followed by an empirical model to predict the probability of that collision being fatal. The blade encounter model can be replaced by a Computational Fluid Dynamics (CFD) calculation of the flow through a pump or turbine. The trajectories of fish, modelled as passive objects moving through the machine, can be calculated and the likelihood of a blade collision be estimated. These CFD calculations offer the additional possibility to calculate pressure changes and values of velocity shear along fish trajectories. Yet, no matter how advanced the CFD method is, the resulting survival rates will still be estimations: trajectories rely on the points of entry, on assumed mass density of the fish, on fish flexibility and swimming behaviour, and the eventual damage and mortality relies on correlations with stressors like strike velocity, pressure, and shear rate.

Small installations

In general, when determining the need for fish survival tests, one should inquire whether a pump or turbine installation constitutes a bottleneck for local or migrating fish species. How many fish are likely to pass through the installation and are these species considered endangered? In addition, for small installations, the question arises as to whether it is meaningful to conduct fish survival tests for relatively large fish in small pump or turbine installations if these fish are effectively excluded from entrance by screens and trash racks with small mesh sizes. A survival test in which fish are introduced before the intake but downstream of a screen is likely to provide an unrealistic image of actual mortality.

Guiding principles for survival tests

Animal research in the European Union (EU) is governed by Directive 2010/63/EU [4], which establishes guidelines for the protection of animals used for scientific purposes. This Directive emphasizes adherence to the 3Rs principles: replacement, reduction, and refinement, to ensure that animal welfare is prioritized in all scientific experiments. To align with these principles, researchers must carefully address the following ethical and practical considerations:

— The necessity and utility of the planned experiment in relation to existing knowledge derived from prior studies;

— The appropriateness of the selected methods, along with the likelihood of obtaining meaningful and reliable results;

— The absence of viable alternative methods capable of achieving the same objectives;

— The alignment between the chosen animal models and the scientific objectives of the experiment;

— An assessment of potential harm to the animals compared with the anticipated benefits of the results;

— The biological and cognitive characteristics of the species involved, including their sensitivity and fragility;

— Ensuring that the selection of species, particularly non-native species, does not pose a threat to biodiversity;

— Limiting the number of animals used to the minimum necessary to achieve the study’s objectives;

— Maintaining the welfare of trial fish, including decisions around storage and husbandry, to ensure that their physiological and behavioural characteristics remain unaltered as far as possible before, during, and after the trial.

Model-based prediction of fish survival and other alternative methods using sensors to measure fish survival in pumps and turbines may be developed in the near future and could finally replace (or significantly reduce) direct tests on animals. Meanwhile, experiments requiring animal use are needed but must be carefully planned and carried out. The rules and guidelines in this standard are aimed at minimizing the use of test animals as much as possible and maximizing their well-being.

1 Scope

This document is concerned with the assessment of fish survival in pumping stations and hydropower plants, defined as the fraction of fish that passes an installation without significant injury. It does not concern indirect consequences of such installations, usually included in the notions 'fish safety' or 'fish-friendliness', like avoidance of fish affecting migration, behavioural changes, injury during attempted upstream passage, temporary stunning of fish resulting in potential predation, hypoxia due to depleted oxygen levels in turbine intakes positioned deep below the water surface, or the opposite, gas bubble disease in highly turbulent water near the discharge of a turbine.

This document applies to pumps and turbines as well as pumping stations and hydropower plants that operate in or between bodies of surface water, in rivers, in streams or estuaries containing resident and/or migratory fish stocks. Installations include centrifugal pumps (radial type, mixed-flow type, axial type), Archimedes screws, and water turbines (Francis type, Kaplan type, Bulb type, Straflo type, etc.).

The following methods to assess fish survival are described:

— Survival tests involving the paired release of live fish, introduced in batches of test and control fish upstream and downstream of an installation, and the subsequent recapture in full-flow collection nets. The method is applicable to survival tests in the field and in a laboratory environment. (Clause 6);

— A validated model-based computational method consisting of a blade encounter model and correlations that quantify the biological response to blade strike (Clause 7). The model is applicable to pumping stations and hydropower plants with a low to medium head (<8 m) in which blade strike forms the primary cause of fish damage in most cases.

The computational method can be used to scale results from laboratory fish survival tests to full-scale installations operating under different conditions (Clause 8).

The survival tests and computational method can also be applied to open-water turbines, with the caveats mentioned in Annex C.

The results of a survival test or a computed estimation can be compared with a presumed maximum sustainable mortality rate for a given fish population at the site of a pumping station or hydropower plant. However, this document does not define these maximum rates allowing to label a machine as "fish-friendly", nor does it describe a method for determining such a maximum.

This document offers an integrated method to assess fish survival in pumping stations and hydropower plants by fish survival tests and model-based calculations. It allows (non-)government environmental agencies to evaluate the impact on resident and migratory fish stocks in a uniform manner. Thus the document may help to support the preservation of fish populations and reverse the trend of declining migratory fish stocks. Pump and turbine manufacturers will benefit from the document as it sets uniform and clear criteria for fish survival assessment. Further, the physical model that underlies the computational method in the document, may serve as a tool for new product development. To academia and research institutions, this document represents the baseline of shared understanding. It will serve as an incentive for further research in an effort to fill the omissions and to improve on existing assessment methods.

2 Normative references

There are no normative references in this document.