# FISH PASSES

## DESIGN, DIMENSIONS AND MONITORING

DVWK

# Fish passes – Design, dimensions and monitoring

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# Preparation of this publication

This co-publication by FAO and DVWK (German Association For Water Resources and Land Improvement) is a translation of a book that was first published by DVWK in German in 1996. The FAO Fisheries Department has decided to produce the English edition to make available the valuable information contained in this technical document on a world-wide scale as no comparable work was so far available, especially as regards the close-to-nature types of fish passes.

This document was translated into English by Mr. D. d'Enno, Translator, United Kingdom, and Mr. G. Marmulla, Fishery Resources Officer, FAO, Rome. It was edited by G. Marmulla and Dr. R. Welcomme, FAO Consultant and former staff member of FAO's Fisheries Department.

The German edition "*Fischaufstiegsanlagen – Bemessung, Gestaltung, Funktionskontrolle*" was prepared by the Technical Committee on "Fishways" of the DVWK and published in the DVWK "Guidelines for Water Management" that are the professional result of voluntary technical-scientific co-operative work, available for anyone to use. The German edition was financially supported by the German Federal Inter-State Working Group on Water (LAWA).

The recommendations published in these Guidelines represent a standard for correct technical conduct and are therefore an important source of information for specialist work in normal conditions. However, these Guidelines cannot cover all special cases in which further, or restricting, measures are required. Use of these Guidelines does not absolve anyone from responsibility for their own actions. Everyone acts at his or her own risk.

# Acknowledgments

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# Abstract

**Key words:** fish pass; fishway; fish ladder; technical fish passes; close-to-nature types; hydraulic calculation; upstream migration; free passage; river rehabilitation; restoration; longitudinal connectivity; monitoring

Many fish species undertake more or less extended migrations as part of their basic behaviour. Amongst the best known examples in Europe are salmon (*Salmo salar*) and sturgeon (*Acipenser sturio*), which often swim several thousands of kilometres when returning from the sea to their spawning grounds in rivers. In addition to these long-distance migratory species other fish and invertebrates undertake more or less short-term or small-scale migrations from one part of the river to another at certain phases of their life cycles.

Fish passes are of increasing importance for the restoration of free passage for fish and other aquatic species in rivers as such devices are often the only way to make it possible for aquatic fauna to pass obstacles that block their up-river journey. The fish passes thus become key elements for the ecological improvement of running waters. Their efficient functioning is a prerequisite for the restoration of free passage in rivers. However, studies of existing devices have shown that many of them do not function correctly. Therefore, various stakeholders, e.g. engineers, biologists and administrators, have declared great interest in generally valid design criteria and instructions that correspond to the present state-of-the-art of experience and knowledge.

The present Guidelines first refer to the underlying ecological basics and discuss the general requirements that must be understood for sensible application of the complex interdisciplinary matters. These general considerations are followed by technical recommendations and advice for the design and evaluation of fish passes as well as by proposals for choosing their hydraulic dimensions correctly and testing the functioning. Fishways can be constructed in a technically utilitarian way or in a manner meant to emulate nature. Bypass channels and fish ramps are among the more natural solutions, while the more technical solutions include conventional pool-type passes, slot passes, fish lifts, hydraulic fish locks and eel ladders. All these types are dealt with in this book. Furthermore, particular emphasis is laid on the importance of comprehensive monitoring.

These Guidelines deal with mitigation of the upstream migration only as data on improvement of downstream passage was scarce at the time of the preparation of the first edition, published in German in 1996. Therefore, the complex theme of downstream migration is only touched on but not developed in depth.

# Foreword by FAO

In many countries of the world inland capture fisheries, in their various facets, play an important role in securing food availability and income and in improving livelihoods either through food or recreational fisheries. Since years, the Food and Agriculture Organization of the United Nations (FAO) does not relent to promote the concept of sustainability in the use of resources and sustainable development continues to be a highly desirable goal in all fisheries and aquaculture activities. However, to achieve this objective in capture fisheries, especially, not only improved fisheries management but also sound ecosystem management is needed.

Freshwater is becoming a more and more precious resource and there is increased competition for its use by the various sectors, e.g. agriculture, fishery, hydropower production, navigation etc., of which fishery is generally not the most important one economically. The responsibility for the protection of the aquatic ecosystem usually lies outside the fishery and in many cases, the fishery has to be managed within the constraints imposed by the external sectors. Activities such as dam construction for water supply and power generation, channelization for navigation and flood control, land drainage and wetland reclamation for agricultural and urban use all have a profound impact on the aquatic ecosystem and thus on the natural fish populations. One of the worst effects of dams and weirs is the interruption of the longitudinal connectivity of the river which means that fish cannot migrate freely anymore. This does not only concern the long-distance migratory species but all fish that depend on longitudinal movements during a certain phase of their life cycle.

The Fisheries Department's Regular Programme and field-based activities are tailored to provide management advise on best practices and help implementing the Code of Conduct for Responsible Fisheries and the relevant Technical Guidelines. In the framework of the Department's Major Programme, the Inland Water Resources and Aquaculture Service (FIRI) implements, *inter alia*, an activity on prevention of habitat degradation and rehabilitation of inland fisheries, including considerations regarding fish migration and mitigation measures. As normative work under this activity, FIRI gathers, reviews, analyzes and disseminates information in relation to dams and weirs and their interactions with fish and fisheries and promotes the rehabilitation of the aquatic environment as an appropriate tool for the management of inland waters.

In the attempt of making aquatic resources more sustainable, FIRI pays special attention to improved fish passage and restoration of the free longitudinal connectivity as these are important issues on a worldwide scale that attract growing interest. This book "Fish passes – design, dimensions and monitoring" which has originally been published in German by Deutscher Verband für Wasserwirtschaft und Kulturbau e.V., DVWK (German Association For Water Resources and Land Improvement) is an extremely valuable contribution to the mitigation of obstructed fish passage. It first refers to the underlying ecological basics and discusses the general requirements, that must be understood for the sensible application of the complex interdisciplinary matters, before it gives technical recommendations and advice for the design of fish passes, the correct choice of their hydraulic dimensions and the evaluation of their effectiveness. Based on knowledge and experience from mainly Europe and North America, the book describes the various types of fish passes, with special emphasis on "close-to-nature" solutions. Monitoring is dealt with as a key element for success.

The FAO Fisheries Department decided to co-publish the English edition to make widely available the valuable information contained in this technical document. This is the more important as no comparable book existed so far in the Anglophone literature, especially as regards the close-to-nature types of fish passes. It is hoped that this book contributes largely to increase the awareness of the need for unobstructed fish passage and to multiply the number of well-designed and well-dimensioned fish passes around the globe to restore lost migration routes.

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# Foreword to the English edition by DVWK

Great efforts have been undertaken in Germany in the past decades to bring the water quality of surface waters back to an acceptable state, defined as “slightly to moderately loaded” according to the German biological water quality classification. Improvements were mainly achieved through the construction of sewage treatment plants for purifying domestic and industrial sewage. Today efforts in water protection management are more and more directed towards the restoration of the natural ecosystem functions of the river channel, its banks and the former floodplains. Changes in channel morphology should therefore be reversed as far as possible, and obstructions that cannot be overcome by migratory fish be eliminated.

In 1986, the responsible Ministers of the five riparian countries of the river Rhine, the third largest river in Europe, and the relevant Directorate of the European Commission set a political agenda for the restoration of the Rhine and agreed to undertake actions to enable the return of salmon and other migratory fish to the Rhine and its tributaries by the year 2000. To achieve this objective, fish passes were, and still are, required in many places, but generally valid design criteria were lacking for the construction of fully functional fishways, particularly for solutions that look natural and blend well with the landscape. To satisfy this demand the German Association for Water Resources and Land Improvement, DVWK (Deutscher Verband für Wasserwirtschaft und Kulturbau e.V.), the professional, non-governmental and non-profit body representing German experts engaged in water and landscape management, prepared and published these Guidelines in 1996. In the meantime the salmon has already been detected again in the river Rhine and some of its tributaries. What a progress!

An interdisciplinary working group of biologists and engineers compiled research results and experiences from Germany and other countries that reflect the current state-of-the-art of technology in this field. With the publication of these Guidelines in English, the DVWK hopes to contribute to making the experience and guidance on restoring the longitudinal connectivity of flowing surface waters available to hydro-engineers and fishery specialists in other countries. With this book we hope to make a contribution to the transfer of knowledge across national boundaries, and will be pleased if it gives useful suggestions for the forward-looking management of waters in Europe and world-wide.

Bonn, October 2002
Dr. Eiko Lübbe,
Chairman of the DVWK’s Standing Committee
on International Cooperation.

# Foreword[1]

Fish passes are of increasing importance for the restoration of free passage for fish and other aquatic species in rivers. Such devices are often the only way to make it possible for aquatic fauna to pass obstacles that block their up-river journey. They thus become key elements for the ecological improvement of running waters.

The efficient functioning of fish passes is a prerequisite for the restoration of free passage in rivers. Studies of existing devices have shown that many of them do not function correctly. Many specialists have therefore declared great interest in generally valid design criteria and instructions that correspond to the present state-of-the-art of experience and knowledge.

A specialized Technical Committee set up by the German Association for Water Resources and Land Improvement has determined the current state-of-the-art technology for construction and operation of fish passes, through interdisciplinary co-operation between biologists and engineers. Research results and reports from other countries have been taken into account.

The present Guidelines first refer to the underlying ecological basics and discuss the general requirements that must be understood for sensible application of the complex interdisciplinary matters. These general considerations are followed by technical recommendations and advice for the design and evaluation of fish passes as well as by proposals for choosing their hydraulic dimensions correctly and testing the functioning.

In preparing these Guidelines it became clear that some questions, particularly those related to the design and integration of fish passes at dams used for hydroelectric power production, could not be answered to complete satisfaction. The reasons are, firstly that there is little reliable data on the functioning of fishways and that the behaviour of fish in the vicinity of fish passes needs further study. Secondly, defining the dimensions of close-to-nature constructions by applying the present hydraulic calculation models can only provide rough approximations. There is thus still a considerable need for research that would fill such gaps in our knowledge. For the same reason, it is, unfortunately, not possible to respond immediately to the wish for recommending standards for fish guiding devices and downstream passage devices that many professionals concerned with the subject have expressed.

The Technical Committee was composed of the following representatives of consulting firms, engineering consultants, energy supply companies, universities and specialized administrations:

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Herewith the Technical Committee wishes to thank the representatives of fishery associations, angling clubs, the Society of German Fishery Administrators and Fishery Scientists, the dam operating companies and experts from public authorities and administrative bodies who have supported the work of the Technical Committee through special contributions and advice. All those who sent in constructive suggestions at the reviewing stage are also thanked.

Bonn, November 1995 Werner Schaa

# Contents

# List of Figures and Tables

# 1 Introduction

Many fish species undertake more or less extended migrations as part of their basic behaviour. Amongst the best known examples are salmon *(Salmo salar)* and sturgeon *(Acipenser sturio)*, which often swim several thousands of kilometres when returning from the sea to their spawning grounds in rivers. In addition to these long-distance migratory species other fish and invertebrates undertake more or less short-term or small-scale migrations from one part of the river to another at certain phases of their life cycles.

Weirs had already been installed during the Middle Ages in many streams and rivers in Europe to exploit their water power potential. These historical features still constitute an essential component of our cultural landscape. Rivers continue to be subject to further wide ranging and intensive anthropogenic uses as a result of industrialisation and increasing human populations.

Besides such purposes as flood control, navigation and production of drinking water, hydropower production plays an important role in the construction of new dams today, especially under the aspect of the increased promotion of the use of renewable energy. Hydro-electric energy is therefore vigorously promoted as a means of reducing $CO_2$ emission from fossil energy sources. The character and quality of river ecosystems are deeply affected when obstacles such as dams and weirs are placed across a river. The construction of dams and weirs results in the flooding of entire sections of rivers that are thus transformed into water storage impoundments and lose their riverine character. Moreover, these obstacles interrupt the longitudinal connectivity of a river so that unhindered passage for aquatic organisms is no longer ensured. This, together with other factors such as water pollution, leads to a decrease in the population size of some fish species (e.g. salmon, sturgeon, allis shad), sometimes to levels close to extinction.

The negative effects of man-made barriers such as dams and weirs on migratory fishes were known early on. For instance, in the thirteenth century the Count of Jülich delivered a writ for the Rur (tributary of the Maas in North Rhine-Westphalia) ordering that all weirs should be opened for salmon migrations (TICHELBÄCKER, 1986). Certainly such radical solutions are no longer practical today, but present-day obstacles can be made passable by the construction of fish passes. Although constructing fish passes does not eliminate the basic ecological damage caused by the dams, such as loss of river habitat or loss of longitudinal connectivity, this measure attenuates the negative ecological impact of these obstructions to a certain extent and thereby increases their ecological compatibility. For instance, the success of the programme begun in the mid 1980s to reintroduce salmon and sea trout in rivers of North Rhine-Westphalia should not be attributed exclusively to the improved water quality due to the construction of sewage treatment plants but also to the re-linking of potential spawning waters (the Sieg river system) to the main river (Rhine) by building fish passes at critical obstacles (STEINBERG & LUBIENIECKI, 1991). Moreover, this re-linking of aquatic ecosystems is an important contribution to efforts to facilitate the recolonization of rivers by endangered fish species and, more generally, to species and habitat conservation. Today, the restoration of the longitudinal connectivity of rivers is a declared sociopolitical goal. This can be achieved by either decommissioning (i.e. the demolition) barriers that are no longer required, by replacing them with bottom slopes or through construction of fish passes.

Fish passes are structures that facilitate the upstream or downstream migration of aquatic organisms over obstructions to migration such as dams and weirs. While the objective of re-linking waterbodies is by no means limited to benefiting fish but rather aims at suiting all aquatic organisms, such terms as “fish ladders”, “fishways”, “fish passes” and “fish stairs” will be used throughout these Guidelines in the absence of a more appropriate general term that would encompass other aquatic organisms as well as fish. This terminology is also to be seen against the historical background since in the past emphasis was laid on helping fish to ascend rivers. Today, the term “fishway” is used in a broader sense to refer not only to the fish fauna but to all aquatic organisms that perform migrations. It further broadens its meaning to also include downstream migration - an aspect which is becoming increasingly important.

Fish ladders can be constructed in a technically utilitarian way or in a manner meant to emulate nature. Bypass channels and fish ramps are among the more natural solutions, while the more technical solutions include conventional pool-type passes and slot passes. Apart from the conventional types, special forms such as eel ladders, fish lifts and hydraulic fish locks are also used. These Guidelines present the current state of knowledge on fish passes for *upstream* migration only and give advice on, and instructions for, their construction,