IMPACTS OF DAMS ON FISH FAUNA /FEASIBILITY OF MITIGATION MEASURES/

Emese Horváth[1], *Miguel Angel Toledo Municio*[2]
[1]*Technical University of Budapest, Department of Water Resources Engineering*
[2]*Technical University of Madrid, Department of Hydraulics and Energetics*

SUMMARY

Dams have variable impacts on the environment, one of them that they hamper fish migration. Fish passes are constructed to improve situation. Fish behaviour, characteristics of migration and fish swimming ability are key information to fish pass design. This paper intends to give an overview on fish pass requirements, type of fish passes, describing their advantages and disadvantages, and points out possible research areas. Spanish experiences are highlighted.

Keywords: environmental impacts, dams, reservoirs, fish passes

1. BRIEF OVERVIEW OF IMPACTS OF DAMS ON FISH

Humans started to build dams and canals a long time ago and this way influenced the natural flow regime. In 2600 BC. the first large dam (14 metres height, 113 metres crest length) was built at Sadd el Kafara in Egypt in the Garawi ravine facing Memphis. (Schnitter, 1994). Dam construction and the dam and reservoir itself has variable impacts: social, economical, geophysical and impacts on water quality, climate, flora and fauna... From all these impacts which related to each other very closely the impacts on fish will be observed in more details. Fish has importance in our society as not only a living being but it has been a basic food for thousands of years and fishing is a sport or recreation activity for a lot of people.

Fish are affected directly by physical barrier of migration routes and movement of fish; inundation of spawning grounds within the reservoirs; irregular releases of dam and periodic inundation or drying out of spawning grounds and refuge area downstream of the dam. Fish are affected indirectly to different level, depending on species, by modification of velocity, temperature and quality of water. The change in habitat caused by construction of a dam modified the fish community, population densities and areas utilised by a particular species. By the protection of scarce fish our aim is to keep up the diversity of our environment and maintain the ecological balance. In the following, let's look at what has been done to make it possible for fish to pass through the dam.

---

[1] PhD Student
[2] Professor of Dams

2. HISTORY OF FISH PASS BUILDING, LEGISLATION

Fish pass (U.K.) fishway and fish ladder (U.S.A.) are synonyms and refer to the designed structure, which give the fish an easier route over or round the obstacle by allowing to overcome the water head differences in a series of stages, reducing the water velocity in a sloping channel or applying elevator. According to Szalay (1967) the first fish pass was designed in Maine in 1806 in North America. From this time onward thousands of fish passes were built and a lot of them did not fulfil the expectations. This way a debate started on the necessities of fish passes. We do agree with Szalay that there is no need to build them in all dams, but where it is essential the fish pass has to be built the way that it works adequately.

In Ireland from 1842 exists legislation on fish pass construction mainly for salmon, trout and eels. The Spanish Law first time mentioned fish passes in 1879. At present the Law 20 of February 1942 about Freshwater fishing obliges the construction of the passes for fish to make them overcome the obstacles, especially in sites with salmon and trout. Furthermore it orders what is the minimal discharge which has to be kept in passes and application and maintenance of screens which prevent fish from entering the all type of water diversion and turbines. The Council Directive 92/43/EU on Habitats aims to maintain the biodiversity, including the variety of fish species. In a lot of countries exists law which covers the free movements of migratory fish and makes it necessary to assure the efficient passage through different obstacles in streams.

3. FISH MOBILITY

Originally fish passes were built only for fish like salmon and trout although a lot of other species which moving along the river are stopped by barriers.
Diadromous fish are those that migrate from freshwater to seawater or the reverse. A*nadromous* species spend a large portion of their life cycle in the ocean and return to freshwater to breed. Fish which called *catadromous* spend their life in freshwater but migrate to sea to reproduce. The term *amphidromous* refers to fish whose migrate from freshwater to the sea or vice versa and it is not for breeding purpose, but occurs regularly. *Potamodromous* fish moving entirely within freshwater looking for food or spawning ground.

Diadromous			Potamodromous
Anadromous	Catadromous	Amphidromous	
Lampetra fluviatilis, Petromyzon marinus, Acipenser sturio, Alosa alosa, Alosa fallax, Salmo salar, Salmo trutta	Anguilla anguilla	Atherina boyeri, Dicentrarchus labrax, Platichthys flesus	Salmo trutta, Barbus, Chondrostoma...

Tab. 1 Migrating fish species of Spain (Elvira et. al, 1995)

There are several characteristics of migration, which are useful to know to understand this activity: periodicity, direction, distance, speed, duration and orientation mechanism, bioenergetics, physiology.

A major factor in the design of fish pass is the swimming ability of the fish in terms of speed and endurance. Maximum swimming speed (burst speed) of fish differs according to water temperature and length of the fish. Zhou (1982) and Wardle (1975) prepared graphics to show the this relationship for six salmon species. An increase in temperature results in a dramatic reduction in endurance at maximum swimming speed. The velocity of the water over the weirs or through the orifices or slots of the pool type pass must be less than the burst speed. Burst speed is a not sustainable speed, when fish utilise its red aerobic muscle. While the velocity in the pools has to be less than the cruising speeds, it can be maintained for a long period of time and fish utilise its anaerobic white muscle (Beach, 1984). Pavlov (1989) introduced the expression of threshold velocity for the minimum current velocity that leads fish to orientate against it. The critical velocity occurs when the flow starts to carry away the fish.

4. GENERAL REQUIREMENTS FOR A FISH PASS

The entrance has to be found easily from upstream and downstream too: The entrance has to be built as close as possible to the point of the most upstream limit of the migrating, in this case at the same line with the dam. As fish prefer to move close to the bank of the river and because easier maintenance means the construction of fish pass on one or two sides of dams (Richardson,1961). Fish can be led towards the pass with barriers. Upstream exit has to be in a zone with small velocities that the fish will not be washed over the spillway, but not in dead zones with recirculation. The jet of water coming from the fish pass entrance should enter a relatively less turbulent area of water so that it is a distinguishable flow that fish can detect. Internal or external attraction water can be introduced to increase performance of the fish pass.

Velocity of stream: To give a general idea about this issue it can be said that the maximum velocity of the flow used for designing passes for salmon can be 1,4-2,0 m/s, while considering other species 1 m/s is recommended by Szalay (1967).

The turbulence: Within a fish pass it should not exceed 200 W/m^3 for fish pass for salmon, 100-150 W/m^3 for species other than salmon (Mallen-Cooper). In the case of the pool type pass it can be done by constructing larger pools and avoiding rectangular underwater weirs, orifices.

Sufficient discharge, water depth: For fish passes on River Glomma in Norway only the 0,2-1% percentage of the total flow is available. The discharge in the fish passes relative to the dam discharge or discharge through turbine has great importance. Linløkken (1993) suggests constructing fish passes to the minimum discharge. Installation of penstocks can regulate the water levels in the case of pool type passes. (Brown, 1964, 9 Itobashi, Nakamura, Mizuno, 1991). According Mallen-Cooper (1991) in Australia a minimum depth of one metre is needed in the fish pass as many species are reluctant to enter shallow water.

Head loss between pools of the pass: The advised maximal head loss is 0.45 m. The old salmon fish passes built in Australia have 0.3 m a head loss per pool which in some cases completely excluded native fish from using the fish pass. The head loss for the weir and pool type fish pass with orifice of River Manzanares is 0.10 m.

Water quality conditions can be improved in the fish pass to facilitate fish ascending (Dissolved oxygen content, temperature).

Optimal light conditions: Majority of fish prefer to overcome obstacles during the day,

but Anguilla anguilla, Alosa alosa, Alosa fallax are able to ascend fish passes during night (Szalay, 1967; UNION FENOSA).
Economic construction and maintenance: Maintenance should not be forgotten, although trash racks (screens 25x30 cm) at the top of fish passes prevent much debris entering the fish pass. Operations without manual controls are favourable.

5. TYPES OF FISH PASSES

5.1 Migration from downstream to upstream

Pool & weir design (pool pass, pool & traverse, steeped pool)
The most well known type of fish pass consists of a series of pools in steps leading from a river under a dam to the reservoir. The fish ascend by jumping or swimming from pool to pool. In Japan more than 1400 of this type of fish pass exist (Sasanabe, 1990). In Holland there are pool and weir systems with height of less than 5 meteres for trout, salmon and cyprinids. In Spain it is the most common type of fish pass.
The following pool type passes can be distinguished according to the place where fish can move from one pool to the next one, through or over cross walls (are known as baffles): weir, orifice, weir and orifice or vertical slot (pool and jet) is shown in *fig 1*. The latter is a combination of Denil and pool type fish passes when there is a slot over the fool height of baffle. Vertical slot of fish pass are suitable for low head weirs lower than 6.5 m according to Mallen-Cooper. With pool and weir type fish pass, the energy given up by the water in passing from pool to pool is dissipating in turbulence in the pool itself. Ideally the flow is not large compared to the pool volume so that it is possible for the pool to absorb this turbulence and dissipate its energy before the water flows over or through the baffle to the next pool. To reduce the turbulence large rest pools can be built at certain intervals. Advantage of the pool system over steep channel is that more variety of species can ascend. The cost of maintenance is low.

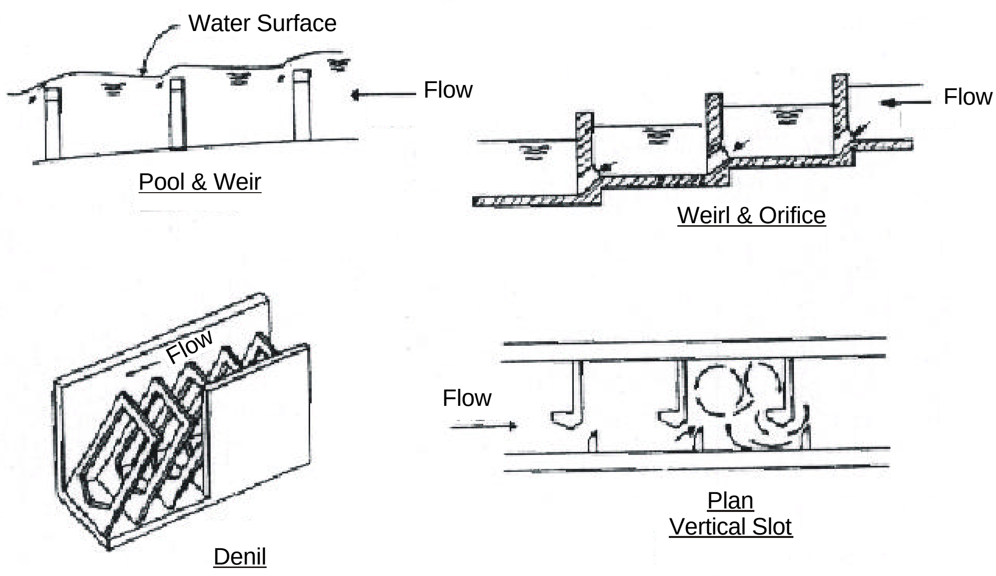

Fig. 1 Fish passes after Clay (1995)

Steep channel /Denil fish passes

G. Denil Belgian engineer (1908) invented the channel fish pass using baffles for energy dissipation. The baffles are closely spaced and set at an angle to the axis of the channel. see *fig. 1*. Its max. Slope is 25º, resting pools required in every two metres. In Denmark it was installed at the hydroelctric power station at Tange on Gudenå river to overcome 10 metres height with 7 resting pools. In U.S.A. in Main the length of the Denil fish pass is 227 m, and its height 15,2 m (Zeimer,1962). It was unsatisfactory in Russia according to Pavlov. Denil fish passes were built in Ireland, England, Canada.... Alaska is a Denil type fish pass which can operate using smaller discharge. Hydraulic studies were prepared by Rajaratnan and Katopodis (1984) for simple Denil and Alaska type fish passes. Aluminium Denil fish passes was used in Alaska where it was placed at natural obstructions that are accessible only by helicopter. Its advantage is that occupies minimal space. Its disadvantage is that not easily adapted to variations in the reservoir and downstream water levels, can be used only in the case of less than 10 metres height differences, preferable less than 2.5 m.

Fish lock/elevator/lift

Borland Fish Lock was named after a Scottish hydraulic expert. Fish raised hydraulically from the downstream level to the reservoir level. The lock consists of a lower chamber at downstream water level and an upper chamber at reservoir level, with an inclined connected shaft between the two chambers (See *fig. 2*). Lately locks are built with vertical shafts. In Scotland for Orrin Dam four separate fish locks were built to operate over a specific range of reservoir levels. The heights vary from 20 m to 40 m. It operates at regular intervals, usually about 4 hours (Dickerson, Morton, 1961.) It is cost efficient according Brown (1964), utilises less water than the pool type system, less effort required from the fish. The passage downstream of smolts and kelts is easily made through Borland Fish Locks. It can operate to overcome up to 60 meters height difference. Difficulties: complicated operation, duration of cycle can be one to four hours. It is operating only periodically which reduces its efficiency, and requires operator. Darkness at the entrance can distract fish.
Elevator has trapping and trucking function, it is applied more economically than locks at dams over 60 metre height, there is less delay at entry but its operating cost is high.

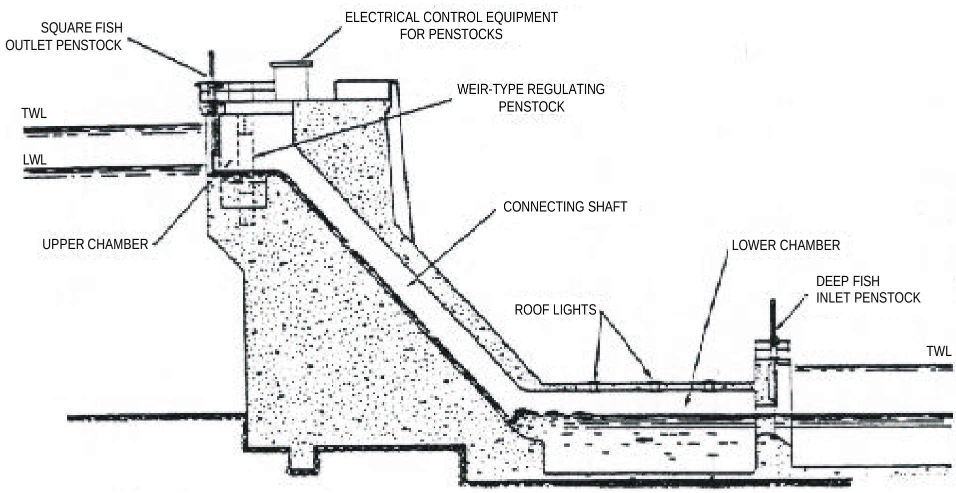

Fig. 2 Borland fish lock after Brown (1964)

Riffles and bypass stream
They are solutions only for overcoming small height differences – their gradients 1-3% - utilised in Denmark (Nielsen, 1994).

5.2 Migration from upstream to downstream

For the downstream migrating young and some adult anadromous- and grown catadromous- fish it is difficult to find the way through large reservoir because the minimal velocity. If a downstream pass is not constructed, fish can descend through spillway or through turbines. There are studies about the possible mortality rate due to passage through turbines, Cassidy (1991) found that it is 15% at each dam of river Columbia. Mortality is caused by physical impacts of turbine blades, sudden reduction of pressure, intense local pressure in the cavitation zones. Spilling can cause fish fatality through gas bubbles in the blood but fish of 15-18 cm in length have a 98% probability to survive drops of less than 90 m (Clay, 1995).

6. OVERVIEW OF THE FISH PASSES IN SPAIN

- More than 120 fish passes were built in Spain and the majority approximately 90% are weir and pool system.
- Fish passes were constructed in the case of dams with height smaller than 30 m.
- Less then 20 out of the 1200 large dams have fish passes.
- The passes were built mainly for trout or salmon and only 10% of them were built for other species.
- The majority of the fish passes can be found in the North of the Iberian peninsula in the North catchment area and in the catchment of river Ebro.
- Screen installations are missing at a large number of dams to avoid fish passes through turbines.
- It was found that 33% of examined dams directly affect some of the river sections which were declared to be great importance for their fish fauna by the Directive 78/659/CEE (18th July 1978).
- From the numerous existing fish pass facilities, which protect the fish along their way of migration only a few are applied in Spain. (Elvira et. al, 1995)

7. FISH PASS EFFECTIVENESS AND COSTS

It is very difficult to measure how efficient a fish pass is in reality. It should be known what percentage of the migrating fish has used it in a certain river. An efficient fish pass does not injure the fish and does not cause long delay. There are methods available for fish counting such as trapping, automatic resistivity counters (conventional ones), others like video recording systems are presently under study (Electricité de France EDF). The size, the number of fish and its direction can be obtained by measurements with electrodes**.** The monitoring techniques used today are most of the time expensive and difficult to carry out. Some of them like trapping can damage the fish. In Norway in the Glomma river system 8 fish passes (7 pool type and 1 Denil type) efficiency were examined. It appeared a low number of fish ascending, it was less than the 2% of the estimated stock (Linl∅kken,1993).

If there is a large amount of migrating fish in the river and there is no way to maintain fisheries upstream of the dam a fish pass has to be built. The building, operating, repairing and cleaning cost has to be considered when economic calculations are prepared. In 1992 in France the price of different type of fish passes were: between 3 720 000 Pts and 24 800 000 Pts for pool type; between 2 480 000 Pts and 19 850 000 Pts for sloping channel; between 2 480 000 Pts and 19 840 000 Pts for lifts and automatic lifts 37 200 000 Pts and 62 000 000 Pts (Elvira,1995).

8. FURTHER INVESTIGATION/QUESTIONS/MISSING INFORMATION

1. How does the amount and the type of the migrating fish vary on the specific flow?
2. How does the time of the run relate to the water temperature considering that the temperature of streams can change significantly during a day.
3. Figures on maximum swimming speed on certain water temperature over length of the fish and endurance at maximum swimming speed on certain temperature over length of the fish for endemic fish in Iberian Peninsula have not been researched.
4. In the case of varying reservoir or downstream water level, and if the discharge is small, how can the efficient operation of fish passes be maintained?
5. When is it preferable to construct pool type passes with weirs and when with orifices?
6. How can the fish be attracted to the entrance of fish passes?
7. How can the most suitable type of fish pass be chosen?
8. Monitoring of the operations of the fish passes is important from several points of view: verification of the efficiency of newly built facilities, adjustment of their performances if necessary, knowledge of migratory fish population and of the characteristics of their migrations, and collecting technical and biological information needed for the design and optimisation of future facilities.
9. Improvement of fish counting methods
10. How can the downstream migration of anadromous adult fish be facilitated?

9. CONCLUSIONS

The key elements of fish passes construction are *fish leading to the entrance of the fish pass*, the fish pass entrance should not protrude on the lower side of the weir, it has to be at the same line as the weir axis and favourable hydrodinamical conditions have to be achieved to *promote swift passage for the fish* gathered there. Fish pass construction does not give complete solution for fish migration, only a small step forward. There is still a long way to go.

10. ACKNOWLEDGEMENTS

The support, and advises of Prof. Benigno Elvira, University Complutense of Madrid, Prof. Diego García de Jalón Lastra and Prof. Aurelio Hernandez Muñoz Technical University of Madrid and for the staff of UNION FENOSA Ingenería gretfully acknowledged.

11. REFERENCES

„Monitoring Techniques for fish passes recently used in France" (1992). Collection de notes internes de la Direction des Etudes et Recherches. Biologie, sciencies de la terre et protection de l´ environment. Electricité de France EDF.

Beach, M.H. (1984), „Fish Pass Design", *Fish. Res. Tech. Rep.* No. 78, Min. Agric. Fish. Food, Lowestoft, England. pp. 46.

Cassidy, J.J. (1991) „Intercepting Downstream Migrating Juvenile Anadromous Fish at Hydroelectric Dams" Vienne. ICOLD. Q.64, R.43. pp. 693-709.

Clay, C.H. (1995) „Design of fishways and other facilities" *Lewis Publishers.* Boca Raton, pp. 248.

Davis, C.V. and Sorensen, K.E. (1969) „Handbook of Applied Hydraulics" *McGraw-Hill Book Company*. New York. pp. 23-1 23-13.

Deeher, L. (1991) „Hydroelectric Power Development at the Dalles Dam Fishway" ICOLD. Vienne. Q.64, R.42. pp. 679-691.

Dickerson, L. H. and Morton, R.R. (1961) „Review of Some Recent Dams Built for Scottish Conditions" ICOLD, R.25, N.26.

Elvira, B., Nicola, G.G., Almodóvar, A., Doadrio, I., Perdices, A. And Velasco, J.C. (1995), „Impacto de las Obras Hidraulicas en la Ictiofauna y Analysis de Viabilidad de Algunas Medidas Correctoras", Convenio ICONA - Universidad Complutense, Memorial Final. pp.178.

Itobayashi, Y., Nakamura, M. and Mizuno, M. (1991) „Construction of Nagara River Estuary Weir and Preservation of Fish Resources" Vienne. ICOLD, Q.64., R.24. pp. 409-429.

Linl∅kken, A, (1993), „Efficiency of Fishways and Impacts of dams on the migration of Grayling and Brown trout in the Glomma River System, South-Eastren Norway", *Regulated Rivers*, Vol. 8, pp. 145-153.

Mallen-Cooper, M. () „Fishways in Australia; Past Problems, Present Success and Future Opportunities" *Ancold Bulletin*. No. 93. Pp.

Nielsen, J.(1994) "Fish passage at obstructions in Danish streams"

Pavlov, D.S. (1989) „Structures Assissting the Migrations of Non-Salmonid Fish: U.S.S.R., FAO*" Fisheries Tech. Pap*. No. 308, Food and Agriculture Organization Of the United Nations, Rome pp. 97.

Richardson, G.C. (1961) „Ancillary Works for Dams of the Corps of Engineers in the Pacific Northwest" ICOLD, Rome. R.63.

Sasanabe, S. (1990), „Fishway of headworks in Japan", *Proc. Int. Symp. on Fishways ´90, Gifu*, Japan.

Schnitter, N.J. (1994), „A History of Dams", *A.A.Balkema*, Rotterdam. p.1.

Szalay, M. (1967) „Biology in the Engineering Practice", (in Hungarian) *Mûszaki Könyvkiadó.* Budapest. pp. 144-186.

Wardle, C.S. and Viedeler (1980) „Effects of temperature on the maximum swimming Speed of fishes", In *Environmental Physiology of Fishes* Plenum Press, New York and London, pp. 519-531.

Zeimer, G.L. (1962), „Steppass Fishway Development", Alaska *Dept. Fish and Game Inf. Leafl.* No.12. pp. 27.

Zhou, Y. (1982) „The swimming behaviour of fish in towed gears; a reexamination of The principles", *Fish. Work. Pap.*, Dep. Agri. Fish. Scotl., 4, pp. 1-55.