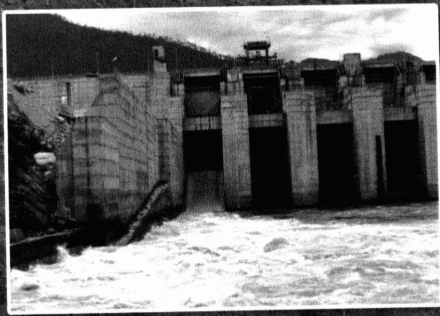
Status of Fish Migration and passes with special reference to India



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Foreword

Fish migration is a well known phenomenon occurring in many fish species for different purpose in their life cycle. Migration may occur for short distances in a river or can involve thousands of kilometers between freshwater and marine environment. One of the best known example is *Tenualosa ilisha* in India. Dams constructed on rivers obstruct free flow of water upstream and downstream of impoundments thus impacting the natural recruitment of migrating fish stocks, thereby depleting their stocks, which has serious socio-economic fallout on riverine fisheries.

In order to mitigate their negative impact the "Fish passes" are constructed to facilitate movement of migratory fishes upstream and downstream to complete natural life cycle on one hand and maintain the ecological integrity of the river as well.

In India a few fish passes have been constructed but has served limited purpose to maintain fish stock. This area needs intensive research effort to study migration including behaviour of the fishes and hydraulics of river to design effective fish passes.

This communication is an attempt by authors to document the present state of knowledge on fish passes their designs put in operations abroad and in India. General guidelines have also been given for the benefit of researchers, fishery managers and other stakeholders in India. The CIFRI has developed a pilot design that is being trial tested at Bichum Dam in NE region.

K. K. Vass
Director
CIFRI

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Contents

1. Introduction

Fish passes are engineering structures that facilitate the free upstream or downstream movement of aquatic organisms especially fish stocks across these structures placed besides dams and weirs. The objective of this movement is by no means limited to benefiting fish but rather aims at suiting all aquatic organisms. Presently, the term"fish pass" is used in a broader sense to refer not only to the fish movement but to all aquatic organisms that perform migrations.

2. Why Fish migrates

Migration : Fish populations are highly dependent upon the characteristics of its aquatic habitat, which supports all their biological functions. It is most marked in migratory fish, which require varied hydrological situations, environments for the different phases of their life cycle viz., reproduction, production of juveniles, growth and sexual maturation. Thus species needs to move from one environment to another in order to survive and complete its life cycle.

Types of migration : Based on migration behaviour, fish can be divided into potamodromous and diadromous groups. Potamodromous species live in fresh water and migrate over local to regional distances. Migration can be lateral, from river to floodplain, or longitudinal from river mouth to small running waters upstream. Diadromous species migrate during their life cycle between saltwater and freshwater habitats. They can be divided into anadromous, catadromous and amphidromous species. Anadromous species like Atlantic salmon, sea lamprey, Atlantic sturgeon and the shads reproduce in fresh water and migrate to the sea where they grow to the adult stage. As an adult they migrate for spawning back to fresh water, often homing very specifically to their birthplace. The catadromous eel enter freshwater as juveniles where they grow to maturity prior to their return migration to salt water for spawning. Amphidromous species like flounder, herring and mullet are marine species that can also stay in fresh water, their migration occurring for refuge or feeding. In a broader view, fish's movement can be grouped into the following types depending upon the purpose of their movement. Examples of the various types and reasons for fish movement are as depicted below.

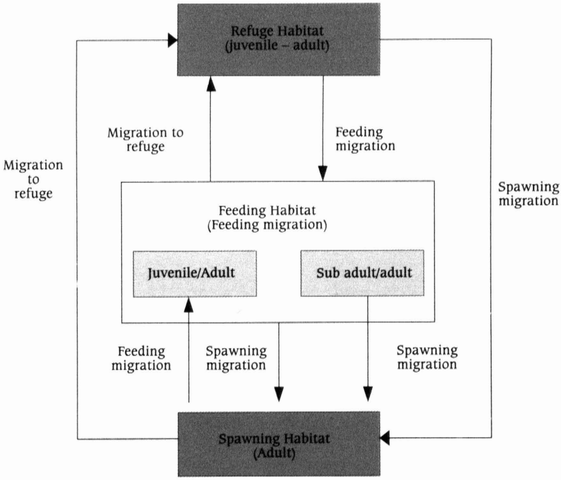
Movement	Purpose
Local movement	access food, avoid predators, shelter
Daily movement	access habitat, food and shelter, defend territory, avoid predators
Seasonal movement	breeding cycle in response to rising water levels or temperatures
Upstream movement	access to new habitats or established spawning areas
Downstream movement	post-spawning movement
Lateral movement	access food, breeding cycle and juvenile recruitment to habitat areas

Hill stream fishes in the rivers of India generally migrate for three major events; wintering, feeding, and spawning. Migratory behaviour of riverine fish is outcome of optimal conditions required by fish for growth, survival and reproduction during different life history stages. Therefore, in general migration up or down the rivers involves a cyclic movement between at least two, more often three habitats. The young fish that emerge from the spawning habitats used previously by their parents, either passively or actively move to their first feeding grounds. This trophic migration ranges from few metres to several thousand of kilometers away. Later on, the juveniles move from their first feeding habitat to a growing habitat when unfavourable conditions approach (winter and turbidity). When this cycle of feeding and refuge habitat is over, the fish start reproductive migration to an appropriate spawning habitat. The spawning habitat may also vary from few metres to several thousand of kilometers. Broadly, there are three principal categories of migrations.

a) Reproductive (spawning) migration

b) Feeding (trophic) migration

c) Refuge migration



3. Migratory fish species

3.1 World

Table 1 : Migratory fish species

Country	Anadromous	Catadromous	Potamodromous	Amphidromous
United States	Salmon (*Oncorhynchus* spp.) Atlantic salmon (*Salmo salar*), shad (*Alosa sapidissima*), alewife (*Alosa pseudoharengus*), striped bass (*Morone saxatilis*), smelt (*Osmerus mordax*) and sea-run brook trout (*Salvelinus fontinalis*)		carp, northern squawfish, suckers, shiner, whitefish, chub, dace, crappie, catfish, trout, ictalarids etc.	
Europe	Atlantic salmon, sea-run brown trout, sea lamprey, Allis shad and eel		brown trout, northern pike and European grayling. (brown trout, cyprinids, percids, *Vimba vimba*, Several whitefish species (*coregonus* sp.), grayling (*Thymallus thymallus*), northern pike (*Esox lucius*)	lamprey (*Lampetra fluviatilis*)
England	Atlantic salmon (*Salmo salar*) ; Sea trout(*Salmo trutta f. trutta*); Allis shad (*Alosa alosa*,) Twait shad (*Alosa fallax*)			
France	Atlantic salmon (*Salmo salar*);Sea trout(*Salmo trutta f. trutta*);sea lamprey (*Petromyzon marinus*) Allis shad (*Alosa alosa*,)	Eel (Anguilla anguilla)	Brown trout(*Salmo trutta f. fario*) northern pike (*Esox lucius*) grayling (*Thymallus thymallus*)	
Germany and Austria			Brown trout(*Salmo trutta f. fario*, cyprinids, percids)	
USSR	Acipenceridae, Clupeidae		Cyprinidae viz., *Vimba vimba*, Percidae and siluridae	

Country	Anadromous	Catadromous	Potamodromous	Amphidromous
Portugal	Atlantic salmon (*Salmo salar*);Sea trout (*Salmo trutta f. trutta)*		Brown trout (*Salmo trutta f. fario*)	
Spain	Atlantic salmon (*Salmo salar*);Sea trout (*Salmo trutta f. trutta*);		Brown trout (*Salmo trutta f. fario*)	
Norway, Sweden	Atlantic salmon (*Salmo salar*);		Brown trout(Salmo trutta f. fario, northern pike (*Esox lucius*) grayling (*Thymallus thymallus*	River lamprey (*Lampetra fluviatilis*)
Africa		striped mullet, freshwater mullet and four species of eels	*Labeo, Barbus, Alestes, Distichodus* and *Citharinus*	
Australia		striped mullet (*Mugil cephalus*) and barramundi (*Lates calcarifer*)		
NewZealand	lamprey (*Geotria australis*), five galaxiids (*Galaxias* spp.), two smelts (*Retropinna* spp.), four bullies (*Gobiomorphus* spp.)	three eel species (*Anguilla* spp.), black flounder (*Rhombosolea retiaria*), grey mullet (*Mugil cephalus*)	the torrentfish (*Cheimarrichthys fosteri*)	
Latin America			*Semaprochilodus* sp. and *Prochilodus* sp. *Pimelodus sp.*, *Brachyplatystoma* sp., *Pseudoplatystomas* sp. and *Plecostomus* sp.	
Japan	salmonids (*Oncorhynchus* spp.), and the	Japanese eel, gobies (*Rhinogobius* spp.	ayu (*Plecoglossus altivelis*),	
China	Japanese eel,	Carps		
Nepal		*Tor* sp. and *Bagarius*		

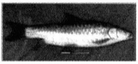
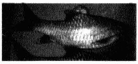
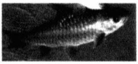
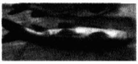
There are about 8 000 species of fish which live in freshwater and a further 12 000 which live in the sea; and there are about 120 species which move regularly between the two (Cohen, 1970).

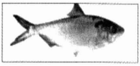
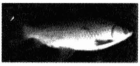
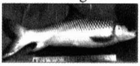
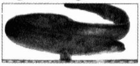
3.2 India

Characteristics of some Indian migratory fishes

Almost all the native fish fauna perform local and daily movements for their basic biological needs. Barring a few, most of the Indian migratory fishes are potamodromous. In India, among fresh water fishes, the big catfish *Pangasius pangasius* - a notable potamodromous, travels longest distance upstream for the purpose of reproduction. Fishes living in hill streams *Tor sp.* and *Schizothorax* sp. exhibit both up and downstream movement periodically in response to rising water levels or temperatures to access food or to new habitats or to spawning areas or for the purpose of post-spawning movement. *Tenualosa ilisha* is the most popular anadromous species of India and used to ascend longest distance in the rivers of both Eastern and Western India, more particularly in Ganges river system from the sea for breeding before commissioning of Farakka barrage. However, their movement became highly restricted after commissioning of Farakka barrage leading to collapse of the largest single species fishery in the upstream Ganges. India does not have many catadromous species. The one noteworthy catadromous species is Indian mottled eel, *Anguilla bengalensis* living in freshwaters and going to the sea to spawn. Some of the migratory fishes of importance is tabulated below (Table 2).

Table 2 : Migratory fish species of India

Species	Migration period												Spawning time
	J	F	M	A	M	J	J	A	S	O	N	D	
Tor putitora 					U	U	U	U	U	D	D	D	Aug-Sept
Tor tor 						U	U	U	U	D	D	D	May-August
Acrossocheilus hexagonolepis 					U	U	U	U	U	D	D	D	May-June; Aug. - Sept.
Schizothorax richardsonii 			U	U	U								March-May
Schizothorax progastrus 			U	U	U								March-May

Species	J	F	M	A	M	J	J	A	S	O	N	D	Spawning time
Tenualosa ilisha 							U	U	U				Jul-Sept
Pangasius pangasius 						U	U	U					June-August
Catla catla 					U	U	U	U					May-August
Labeo rohita 					U	U	U	U					May-August
Cirrhinus mrigala 					U	U	U	U					May-August
Labeo calbasu 					U	U	U	U					May-August
Anguilla bengalensis 						D	D						June-July

3.3 Behaviour of Migratory fishes

Seasonal migration of fish is sometimes extensive but can be manifested in an irregular way. The exact migration period can vary each year, as it is stimulated by internal and/or external physiological change and by external factors such as changes in light level, hydrology, water quality or temperature. Dispersion and displacement, predator avoidance and prey availability also trigger migration. The interaction between internal and external factors determines whether a fish will migrate or not. For most fish species peak migration occurs in the period shortly before spawning. Subsequent dispersion of fish larvae occurs mainly in late spring and early summer. Other dispersal movement depends on external factors and can occur at any time during the year.

Downstream migration as part of juvenile dispersion mainly takes place during the night, partly as a predator-avoidance response but also due to the fact that juvenile fish have not yet fully developed their mechanism for orientation.

Swimming behaviour of fishes : To understand fish passage requirements through weirs or dams, it is important to first examine how fish swim. Fish use the following swimming modes to negotiate waterways:

1. Burst speed - Fish can swim at high speeds for only short periods of time (seconds). This speed is normally used to negotiate high flow conditions. Fish must rest between such bursts of speed. This speed may be used by fish to try and negotiate barriers to move upstream. The majority of native fish do not reach speeds that enable them to "jump" barriers.

2. Sustained speed - Fish can swim at moderately high speeds for longer periods (minutes). This speed can be used to negotiate medium flow conditions associated with flowing streams. However, fish will also need to rest between periods of sustained speed.

3. Cruising speed - Fish can swim at their cruising speed continuously with little effort (days). This speed is used in low flow or no flow conditions, such as in pools in a waterway. Cruising speed is generally the speed used when fish rest.

The swimming ability of the fish species of the potential natural fish fauna and all its stages and average length of the fishes available in a specific river has to be considered in setting the length of a fishway. Resting zone or resting pools should be provided in fishways. Here fish can interrupt their ascent and recover from the effort.

Morphological features of some fishes (Table 3):

Table 3 : Average length and other morphological features of commonly found Hillstream fishes in India

Species	Average length (cm)	Comments
Schizothorax richardsoni	36-62	Body elongated,cylindrical with strong pectoral fin
S. progastus	37-56	Medium size, spindle shaped body
Acrossocheilus hexagonolepis	24-38	Body elongated, spindle shaped with round belly
Garra lissorhynchus	8-15	Compressed body, modified pectoral fin, ventral attaching pad
G. gotyla	8-15	-do-
Glyptothorax coheni	6-17	Provided with ventral sucker
G. brevipinnus	7-14	-do-
Pseudoecheneis sulcatus	8-17	Compressed head, strong pectoral spine with ventral sucker
Labeo dyocheilus	23-24	Spindle shaped body
Tor tor	80-90	Sub- cylindrical
Tor putitora	60- 75	Sub- cylindrical

4 . Impact of migratory obstruction to fishery

River water flow regulation by construction of dams, weirs and barrages have the following direct and indirect effects on fish and fisheries

i) Obstruction to the ascend of fish to their spawning habitat

Several fish species like *S. richardsonii, S. progastus, Tor tor. T. putitora, Garra gotyla* etc., which require upstream migration to reach the spawning ground in order to reproduce will be obstructed by dams/weirs in their specific pathways from successfully reaching their spawning grounds and breed. As a result depletion of their population will occur.

Weir construction in hill streams of Himachal Pradesh

ii) Spawning habitat will be obliterated

Generally, the areas having sandy and gravel bed, shallow depth, feeble or no currents are preferred sites for fish breeding and spawning. Creation of the dams obviously would result in inundations of these sites resulting in the loss of breeding grounds.

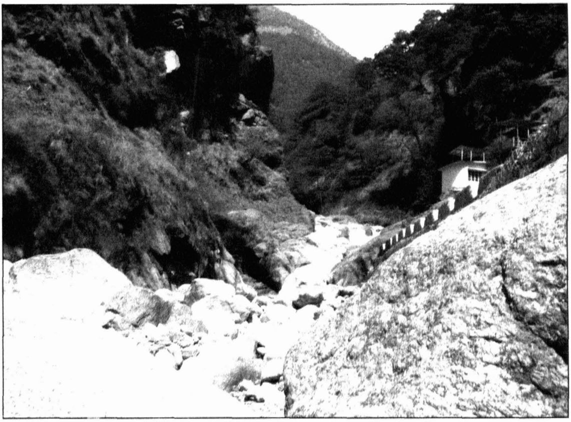
iii) Changes in river water quality

Barricading the flowing water through the concrete construction result in stagnation and thermal stratification of water changing its chemical composition. These changes in the properties of water consequently lead to complete/partial disruption and or disturbance of the trophic structure inhabiting the ecosystem.

iv) Natural flow to downstream will be altered

The operation of the dams as per the need of the power generation will have direct impact on the downstream normal flow pattern in terms of volume and velocity of water. This may result in a delay or absence of flood exposing the marginal habitat due to reduction in flow volume. These abrupt changes are deleterious to the fisheries in many ways.

A severely reduced flow regime minimize the variability of the current, so that only the bottom of the river channel is wetted and pools of stagnating water are formed (so called trap effect). Riverine species can no longer find an adequate habitat. The water would warm up in summer and there is danger of drying up completely.

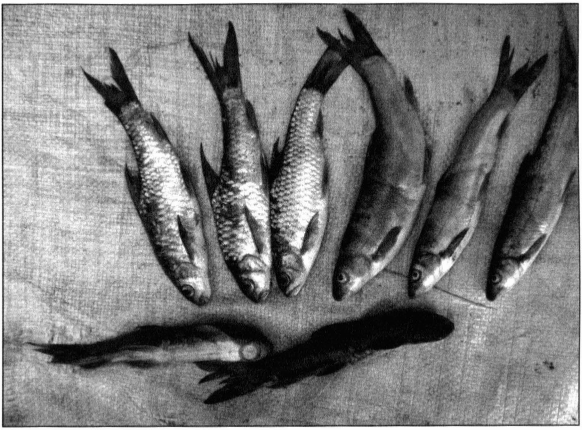


Boulder type weir in hill stream of Himachal Pradesh reducing flow downstream

Establishing minimum flow requirements for the impaired channel stretch downstream of a dam attempts to counter these problems (DVWK, 1995)

v) Prevention of young migratory fish and refuge migrants from descending to the lower reaches

During adverse ecological conditions the unfavourable temperature, turbidity, flood etc., the fish seek refuge in comfortable regions downstream. Likewise, the juveniles move to their feeding grounds. These movements are hampered by the obstruction created in their pathways thereby threatening their survival.



Juveniles of some migratory hill stream fishes

In addition, adverse repercussions can result from indirect effects such as disruption of food webs downstream, stranding of fish during rapid flow fluctuations and siltation in reservoir above the dam.

vi) Biodiversity Change : Complete absence of fish in a portion of the river above the barrier may consequently result (Sugunan, 1995) as experienced in Cauvery river on which Mettur Dam has been constructed. One of the oldest irrigation barrage constructed across river Ganges at Hardwar (1860- 70) did not have any device for fish movement. This resulted in large-scale destruction of fish near the downstream pool, which led to incorporating a fish ladder at a later stage.

The same has been the experience at other dams such as Hirakud (constructed in 1957) on Mahanadi river which is without a fish pass structure. A survey prior to the impoundment (1950) recorded more than 103 species (Job *et al*, 1955). But while the dam has affected migratory fishes like *Tor masal* and prawns, other varieties such as Indian major carps and bagrid catfishes have adapted well to the lentic conditions. The commercial species have however decreased to 40 (Sugunan 1995). Interestingly for Rihand reservoir in Uttar Pradesh 42 species of fish fauna that existed prior to impoundment were reported to be 44 during the post impoundment phase between 1971-81 (Natarajan et al 1982). For Ukai reservoir on Tapti River operational in 1975 with a lake area of 520Km^2 indigenous species before impoundment were *Tenualosa ilisha, Tor tor, Aorichthys sp*. After impounding the fish stock has got thinner although the hilsa has a smooth passage from the Arabian sea to the dam through Kakrapar weir a major structure built across the river downstream of the dam. After construction of Ukai dam indigenous ichthyofauna of the river were *T. ilisha, T. tor* and *A. seenghala* etc which has now been replaced by major carps with a good annual yield. Young ones of the Indian major carps which escape from the dam through the outlets has created a good productive zone in the 112 Km stretch downstream of the dam (Tripathy 1990).

But considerable loss of fish production and retarding of growth occur during spilling over a high spillway without any screen and due to the absence of a fish pass. This has also been the experience at Hirakud dam (Das 2001) where the reservoir spills too often in early monsoon releasing nutritious water and fish.

The effect of dams is not always deleterious provided well-managed exploitation of wide varieties of fish suitable to the environment is made. If the reservoir is located upstream of the migration route of the anadromous fish, fisheries is not affected to any significant extent (Lower Indra, Lower Suktel dams in Orissa, 1998). However the over whelming evidence of reduction of fish species upstream of Indian dams (Sehgal, 1990, Sugunan, 1995) do call for serious intervention by suitable structures at a dam or a barrage to sustain aquatic biodiversity. Beas dam in the Himalayan region has resulted in a sizeable reduction of Mahseers and schizothoracines in the winter catches from 10.1-13.5% in 1964 to 1.0-0.5% in 1985-87. *T. putitora* which used to migrate in the Beas river upto Sultanpur, Kulu almost 150 Km upstream of Beas dam cannot travel now beyond Pando (Petr, 1999). Thus longitudinal connectivity in rivers is critical ecologically to satisfy the diverse migratory needs of aquatic species. Free longitudinal passage through rivers is mainly impeded by sudden drops, weirs or dams that cannot be passed by aquatic organisms.

5. Fish migration facilities developed in different countries

Table 4 : Details of fish migration facilities

Country	Target species	Type of fish pass	Number constructed	Reference
United states and Canada	Pacific salmon and steelhead trout ,American shad, alewife and blueback herring, *Alosa* spp. striped bass	Pool-type fish passes with lateral notches and orifices ,or vertical slot pool fish passes. Denil fish passes and Fish lifts	Upstream facilities and downstream passage technologies are respectively in use at 9.5 and 13 percent of the FERC-licensed hydropower plants	Clay 1995 (OTA 1995).
England	Atlantic salmon and sea-run brown trout	Pool-type fish pass in England and Wales, Denil fish passes.	380 fish passes in England and Wales	(Beach 1984) (Amstrong 1996 Cowx 1998

Country	Target species	Type of fish pass	Number constructed	Reference
France	Atlantic salmon, sea-run brown trout, sea lamprey, Allis shad and eel, brown trout, northern pike and European grayling	Denil fish passes,. Fish lifts or large pool-type passes with large and deep passages (vertical slot)	500 fish passes	(Larinier 1998).
Germany and Austria	Brown trout, cyprinids, percids	natural-like bypass channel, conventional pool and weir fish passes		(Parasiewicz et al. 1998). (DVWK 1996; FAO/DVWK 2002).
USSR	Salmonids Acipenseridae, Clupeidae, Cyprinidae, Percidae and Siluridae	Conventional pool and weir fish passes Large fish locks, fish sluice, fish lifts and mobile devices for fish collection and transport		Pavlov (1989)
Spain	Atlantic salmon and brown trout	Pool and weir fish pass, including vertical fish slot. Denil type and other non-standard designs have been used	115 fish passes	Elvira, Nicola and Almodovar 1998
Norway Sweden	Salmon, brown trout, grayling and coregonids	Pool and weir type fishways, and combinations of pool and Denil fishways	420 fishways	Grande 1990
Japan	Salmonids Japanese eel, gobies and the ayu	Over 95 percent of fish passes are conventional pool and weir fish passes, the others are vertical slot and Denil type.	10000 fish passes	Nakamura and Yotsukura 1987 Nakamura *et al.* 1991 Nakamura 1993).
China	potamodromus species of carp and catadromous species, mainly Japanese eel.	Most fish passes are pool-type.	60 to 80 fish passes	Wang (1990) and Clay (1995), (Nakamura 1993).
Nepal	*Tor* sp. and *Bagarius* sp.	Pool type and vertical slot passes	a couple of fish passes	
Bhutan	Snow trout, chocolate mahseer	Pool type	One	CIFRI, 2002

Country	Target species	Type of fish pass	Number constructed	Reference
South Africa,	catadromous species: striped mullet, freshwater mullet and four species of eels	European and North American designs for salmonids	Few existing fish passes (only 7 in 1990,)	Mallen-Cooper 1996) Bok 1990),
Australia	salmon and trout ,striped mullet and barramundi	Pool-type fish passes, vertical-slot fishways	50 fish passes have been recorded	Mallen-Cooper and Harris 1990).
New Zealand	eel lamprey, salmon galaxiids ,smelts ,bullies ,torrent fish grey mullet and black flounder , brown and rainbow trout		eight passes had been constructed upto 1980	Jowett 1987
Latin America	salmonids.	Pool-and-weir types, recently, fish locks and mechanical fish lifts have been built for obstacles over 20 m in height.	46 fish passes with another 7 planned or under construction.	Quiros (1989 Godinho *et al.* (1991)

6. Design and function of different upstream fish passes

6.1 General requirements of fish pass

The general criteria that fish passes should meet include the biological requirements and the behaviour of migrating aquatic fish.Thus while designing fish passes the following criteria are of paramount importance (FAO/DVWK, 2002).

6.1.1 Optimal position of fish pass

In rivers fish utilise the whole width for migration. Fish passes in dams provide the migrating fishes a small part of the dam for their migration. Thus positioning of the pass is extremely important. Fish usually migrate upstream in or along the main current. For the entrance of a fishway to be detected by majority of upstream migrating organisms it must be positioned at the bank of the river where the current is highest.

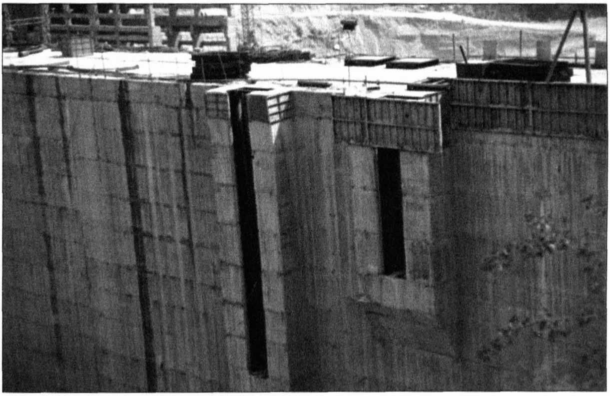
6.1.2 Fish pass entrance

The perception of current by aquatic organisms plays a decisive role in their orientation in rivers. Fish that migrate upstream as adults usually swim against current (positive rheotaxis). If migration is blocked by an obstruction, the fish seek onward passage by trying to escape laterally at one of the dam's side. In so doing they continue to react with positive rheotaxis and in perceiving the current coming out of a fishway, are guided into the fish pass. The optimum range of velocity at which the attracting current exits the fishpass should be within the range of 0.8 to 2.0 ms^{-1} (SNIP, 1987).

Since diurnal fish avoid swimming into dark channels the fish pass should be in daylight and thus not covered over. If a small portion of the fish way is not exposed to sunlight the fishway should be lit artificially in such a way that lighting is as close as possible to natural light.

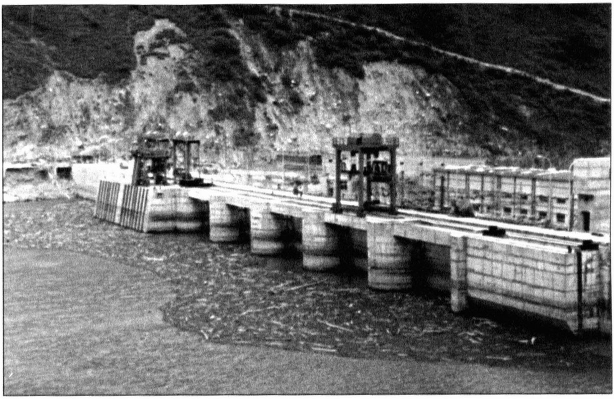
6.1.3 Fish pass exit and exit condition

In general, if the headwater level of the impoundment is constant the design of the water inlet does not present a problem. However, special provisions have to be made at dams here the headwater level varies, where variations in level exceed one meter, several exits must be constructed at different levels for the fishway to remain functional.



Upstream fish exit at different levels

Strong turbulence and current velocities over 2.0 ms^{-1} must be avoided at the exit area of the fish pass so that the fish leaves the pass for headwater more easily. The water intake of the fishway should be protected from debris by a floating beam.



Accumulation of debris upstream near fish exit

6.1.4 Discharge and current conditions

The discharge required to ensure optimum hydraulic conditions for fish within the pass is generally less than needed to form an attracting current. However, the total discharge available should be put through the fish pass to allow unhindered passage of migrants, especially during periods of low flow. The turbulence of the flow through the fishway should be as low as possible so that all aquatic organisms can migrate through the pass independent of their swimming ability. In general the current velocity in fishway should not exceed 2.0 ms^{-1} at any narrowpoint such as orifices or slots.

The flow through the fishway is very important and should be well within the sustained swimming capabilities of the fishes concerned to make the passage efficient and effective. The fish has to undertake both the burst and cruising speeds depending upon the demands of the situation with gradual transition between these two speeds while moving up or downstream.

6.1.5 Lengths, slopes of a fish pass

The body length of the biggest fish species that occurs or could be expected to occur in a particular river is an important consideration in determining the dimensions of fish pass.

The average body length of the longest fish species expected in the river as well as the permissible difference in water level must be considered in defining the dimension of a fish pass. The maximum permissible slope of the fish passes normally is less than 1:15.

6.1.6 Design of bottom

The bottom of a fish pass should be covered along its whole length with a layer at least 0.2 m thick of coarse substrate. Ideally the substrate should be typical for the river. The rough bottom must be continuous upto end including the exit area of the fish pass as well as at the orifices.

6.2 Different kinds of fish passes

6.2.1 Pool pass

Principle :It is generally a concrete channel from the head water to the tail water . This channel is divided into a succession of stepped pools from the headwater to the tailwater by crosswalls of wooden or concrete.This crosswalls are fitted with submerged orifices and top notches on alternate sides. Fish migrate from one pool to the next through openings in the cross-walls. During migration the pools with their low flow velocities provide shelter to the fishes (Fig. 1).

Design : The pool passes may be straight from headwater to tailwater. It may be curved or folded at180^0, resulting in a shorter structure. The entrance to the fish pass downstream must be located in such a way that dead angles or dead-ends are not formed

Pool dimensions : The pool dimensions must be selected in such a way that the ascending fish have adequate space to move and that the energy contained in the water is dissipated with low turbulence. On the other hand, the flow velocity must not be reduced to the extent that the pools silt up. A volumetric dissipated power of 150 W/m^3 should not be exceeded to ensure that pool flows are not turbulent. The pool size must be chosen as to suit the behavioural characteristics of the potential natural fish fauna and should match the size and expected number of migrating fish. Table 5 gives the recommended minimum dimensions for pool sizes and the design of the cross-walls taken from various literature sources and adapted to the hydraulic design criteria and empirical values for functioning fish passes The smaller pool dimensions apply to smaller watercourses and the larger values to larger watercourses.

The bottom of the pools must always have a rough surface in order to reduce the flow velocity in the vicinity of the bottom and make it easier for the benthic fauna and small fish to ascend. A rough surface can be produced by embedding stones.

Table 5 : General Pool Pass Dimension

Fish species	Pool (m) length	Pool (m) width	Pool (m) depth	Orifices (m) width	Orifices (m) height	Notches (m) width	Notches (m) height	Discharge m3/sec	Difference in water level	slope
Tor sp.	>1.0 upto 10m	> 0.8	>0.6 upto 2m	0.2	0.2	0.2	0.2	2.0	0.2 Upto 4m	1:7 to 1:15

Source : FAO/DVWK, 2002, Larinier

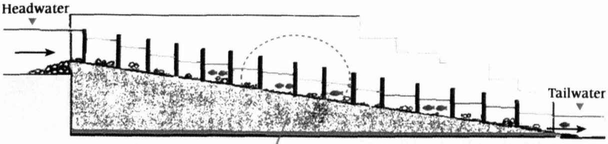
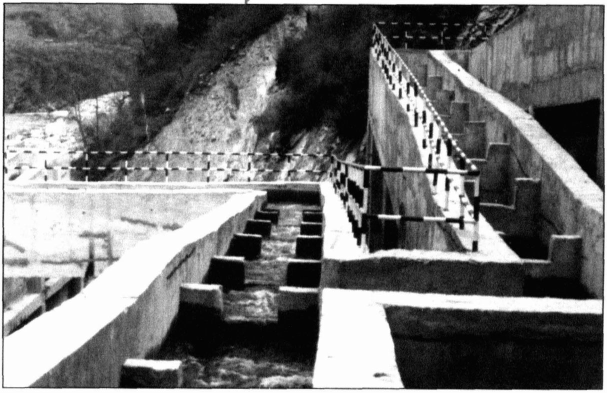


Fig. 1 : Diagrammatic representation of a conventional pool pass (After Jens 1982, DVWK 2002)



Pool pass in Kuruchu Dam, Bhutan

Application : Pool passes are suitable for maintaining the possibility of migration at dams for both strongly swimming fish, and for bottom oriented and small fish. In pool passes a continuous rough bottom can be constructed whose spaces offer opportunities for ascent to the benthic fauna.

The relatively low water requirements of between 0.05 and 0.5 m^3/s for normal orifice dimensions and differences in water level are an advantage.

On the other hand, the high maintenance requirements of pool passes are disadvantageous, as there is a high risk of the orifices being obstructed by debris. Experience has shown that many pool passes are not functional during most of the time simply because the orifices are clogged by debris. Pool passes, therefore, require regular, maintenance and cleaning.

Fish pass on Kuruchu river

The fish pass of Kuruchu is pool and weir type with submerged orifices and centrally placed notch. A total of 98 baffels, each of 1.5m high and 1.5 m wide are arranged at a distance of approximately 2.9m. The total depth of the pool is 2m. There are two entrances (fish exit) to the fish pass from upstream placed at 529 and 524 m above sea level respectively. Fish originating at 529m after travelling a little distance downstream meets the pass originating at 524m. The water exit (fish entrance) located at the end of the pass along the right training wall meets the water level of the stilling basin at an elevation of 492 m above sea level.

The vertical head height between the water level of stilling basin and the water entrance at 524 m is 32 m and to achieve this height the fish pass has to traverse a distance of 320 m leading to a slope of 1:10,.This results in a drop of height per pool in the range of 0.3-0.4m.

6.2.2 Slot passes

Principle : It is generally a concrete channel from the head water to the tail water. This channel is divided into a succession of stepped pools from the headwater to the tailwater by crosswalls of wooden or concrete.Vertical slots extending over the entire height of the cross-wall. The cross-walls may have one or two slots depending on the size of the watercourse and the discharge available. In the one-slot design, the slots are always on the same side. The slot pass, was developed in North America and has been widely used there since the middle of the twentieth century (Clay, 1961; Bell, 1973; Rajaratnam et al., 1986).

Design : The same principles as those outlined for conventional pool passes apply to the correct positioning of a slot pass and the location of its entrance at a dam (Table 6).

Table 6 : General One Slot pass dimension

Fish species	Slot width	Pool width (m)	Pool length (m)	Length of projection (m)	Stagger distance (m)	Width of deflecting block (m)	Water level Difference (m)	Minimum depth of water (m)	Required discharge m^3/sec
Tor sp.	0.15-0.17	1.2	1.9	0.16	0.06-0.1	0.16	0.2	0.5	0.14-0.16

(Source Gebler, 1991 & Larinier,1992a)

Application : Slot passes (vertical slot passes) are well suited to guarantee ascent of all types of fish species especially that are weak swimmers and small fishes.

Other advantages are:

- Column and bottom-living fish can easily swim through the vertical apertures that stretch over the whole height of the cross-walls.
- The reduced flow velocities existing near the bottom of the slots allow low performance fish to ascend.
- Not sensitive to varying tailwater levels.
- Slot passes can cope with discharges from over 100 l /s to several m^3/s.

6.2.3 Denil pass

Principle : "Denil pass" is named after its designer (Denil, 1909). The fish pass consists of a linear channel, in which baffles usually of wood are arranged at regular and relatively short intervals, angled at 45° against the direction of flow (Fig. 2). The backflows formed between these baffles dissipate considerable amounts of energy and, because of their interaction, allow a relatively low flow velocity in the lower part of the baffle cutouts. This allows the Denil pass to have a steep slope, relative to other types of fish passes, and to overcome small to medium height differences over relatively short distances.

The "standard Denil pass", with U-shaped sections in the baffles as shown in Fig. 2, proved to be the most functional..

Design

General Denil pass dimension

Fish species	Channel width (m)	Slope (m)	Water discharge m3/sec		Baffles (m)	
				width	spacing	Depth of triangular section
Tor sp. and cyprinids	0.6-0.9	1:5-1:7	0.3-0.6	0.5-0.6	0.5-0.9	2.0

(Source Lonnebjerg (1980) and Larinier 1992b)

Application : The Denil pass is characterized by the following advantages:

- It can have steep slopes with resulting low space requirements;
- It is not susceptible to variations in tailwater level;
- It usually forms a good attraction current in the tailwater.

The disadvantages of this type of construction are:

- High susceptibility to variations in the headwater levels. In practice, only variations of a few centimetres, with a maximum of about 20 cm, are permitted;

- Relatively high discharges needed compared to other construction types;

- Clogging with debris can easily upset its functioning. Denil passes require regular inspection and maintenance.

6.2.4 Fish lock

It is a pit shaped chamber with controllable closures at head water and tailwater openings. The attraction current is formed by controlling the sluice gate openings or by sending water through a bypass.

The use of fish locks as mitigation devices has been known for quite some time now and has been applied especially in the Netherlands, Scotland, Ireland and Russia (Van Drimmelen, 1966; Jens, 1982).

Design : The design of the chambers and closing devices is variable and largely depends on the specific local conditions. When designing the chamber bottom there should be measures to prevent fish being left in areas that become dry.

Application : It is used for high heads, and where space or available water discharge is limited. Planning and construction is often technically demanding. Fish lock require high efforts in maintenance and operating, high construction and service cost, low water consumption. Useful where very large fish e.g. hilsa are to be taken into consideration.

6.2.5 Fish lift

Principle : Where there are considerable height differences (> 6 to 10m) and little water available there are restrictions on the applicability of conventional fish passes, due to the building costs, the space requirement and the physiological abilities and the performance of the fish. Thus the solutions have been developed to carry fish from the tailwater to the headwater using a lift.

A trough is used as a conveyor and is either equipped with a closable outlet gate or can be tilted. When in the lower position, the trough is sunk into the bottom. Fish have to be attracted towards the fish lift by a guide current. In addition, a sliding and collapsible grid gate located in front of the lift, may serve to push the fish into the lift and thus above the transport trough. The lower gate of the lift closes on a regular cycle. The fish gathered above the trough can no longer escape, are "caught" by the rising trough and conveyed to the top. Here a watertight connection may be made to the upper water level or else the trough is simply tipped out above the headwater level into a funnel. Along with the water from the trough the fish reach the upper channel where, once again, there must be a clear attraction current.

The regular cycle is determined according to actual migratory activity. The operation is usually automatic.

The same principles apply to the positioning of a fish lift as for conventional fish passes.

Application

- Little space is required, and large height differences can be overcome with such fish lifts, e.g. even at high dams. However, the structural expenditure is considerable.
- Since the fish are conveyed upstream passively, fish lifts are suitable for species with low swimming performance as well as for the transportation of large fishes.
- Fish lifts are not suited for the upstream migration of invertebrates and the downstream migration of fish.
- Large variations in the tailwater always mean design problems in providing an adequate guide current.
- The expenditure on maintenance for fish lifts is higher than for traditional fish passes.

6.2.6 Fish ramps

It is a construction that is integrated into the weir and covers only a part of the river width, with as gentle a slope as possible to ensure that the fish can ascend. In general the incorporation of perturbation boulders or boulder sills is required to reduce flow velocity, in fish ramps.

A weir can also be converted to a bottom ramp or slide over its whole width if the water levels do not need to be controlled and adequate discharge is available.

The model for designing a fish ramp is again derived from nature. The primary objective of fish ramp design is to mimic the structural variety of natural river rapids or streams with more or less steep slopes (FAO, DVWK 2002).

Principle : A fish ramp is normally integrated directly in the weir construction, and concentrates, as far as possible, the total discharge available at low and mean water level. At by-pass power stations, for example, the necessary residual discharge can be sent through the fish ramp and water only spills over the weir crest during floods.

Big boulders or boulder sills are arranged to form cascades on the fish ramp to ensure the water depths and flow velocities required to allow upstream migration of fish.

The width of the ramp is mainly defined by the discharge at times of upstream fish migration. The efficiency of ramps for facilitating upstream migration might be reduced when discharges are heavy, as in the case of flooding. The need for structural stability is an essential element in calculating the size of a fish ramp that must withstand floods

Design

As a rule, fish ramps are set by riverbanks and the bank that receives the greater portion of the current is the most favourable. The upper, acute angle should be selected for the construction of the fish ramp at submerged weirs standing obliquely in the river. An existing empty evacuation channel or abandoned sluiceway can often be used for the construction of a fish ramp.

Fish ramps installed at fixed weirs with very steep slopes, at obstacles with vertical drops or at weirs equipped with movable shutters often have to be confined on one side by a solid wall. Fish ramps at gently sloping weirs can be given a inclined lateral filling, to prevent the formation of dead corners .If the entire discharge passes through the fish ramp, the guide current is always clearly directed. It is therefore possible to place the entrance to the ramp further downstream. Fish ramps usually join the headwater at the weir crest, which has technical advantages, for diverting water during construction for example. The upstream water inlet (i.e. the fish pass exit") may need to be designed with a narrowed cross-section to limit discharges through the ramp, particularly during flooding.

The width of the ramp should be a function of the available discharge, but should not be less than 2.0 m.

The general requirements of fish ramp design can be defined as follows: mean depth of water 30 to 40 cm, slope< 1 :20 to 1 :30, flow velocity1.6 to 2.0 m/s, bottom substrate rough, continuous connection to the bottom of the river bed shelters, deep zones and resting pools to facilitate upstream migration

Longer sections with gentle slopes and with deeper resting pools are recommended, particularly in the case of ramps longer than 30 m.

Application

Fish ramps are "close-to-nature" constructions and characterised by the following features (FAO/DVWK, 2002):

- They are suitable for retrofitting of low fixed-weir installations.

- They can be passed even by small fish and fry and by the benthic invertebrates.
- They are also suitable for downstream migration of fish.
- They have a natural-looking, visually attractive design.
- They require little maintenance in comparison with other constructions.
- They are not easily clogged; flood debris do not immediately affect the efficiency of the installation.
- Their guide currents are satisfactory and easily located by fish.
- They offer habitat for rheophilic species.

Their disadvantages are:

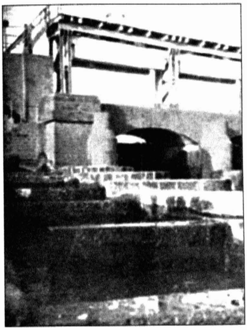
- Sensitivity to fluctuating headwater levels.
- The large discharges necessary for their operation.
- The large amount of space they occupy.

7. Fish pass facilities developed in India

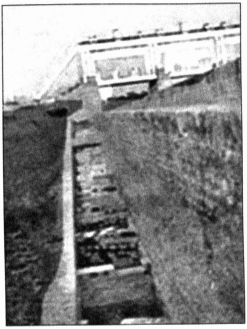
Francis Day as early as 1873, recommended as one of the remedies to prevent injury to fisheries ' that every irrigation weir spanning a river have a practicable fish pass in it'. Dumsford (1911) drew attention of Punjab government to the erection of fish passes and suggested certain principles which should be accepted for guidance. In 1916 the Dept of fisheries, Punjab issued a Bulletin on 'Notes of Fish Ladders ' and recommended the 'Improved Cail Fish Pass for the Punjab. Thus fish ladders were provided in weirs constructed on river Sutlej (at Ropar, Ferozepore, Suleimanki, Islam and Panjnad) on river Ravi (at Balloki and Madhopur) on river Chenab (at Marala and Khanki) and at river Jhelum (at Rasul) . Documentation of performance of these old structures is available from the pioneering monitoring work of Khan , 1940 in Punjab.

Most of the fish ladders constructed during that time was of the pool or fall or step System in which the water is brought down to a lower level by a series of short falls with intervening pools. This type of pass was invented by Cail, an engineer in New castle. Baffle walls were placed right across the width of the pass so as to form partitions. These were pierced by apertures large enough to allow a fish to pass , but not large enough to allow all the water in the pass to get through. Portion of the water flowed over the tops of the partition .A brief description of the fish ladders provided in weirs of the various rivers of Punjab is tabulated below.

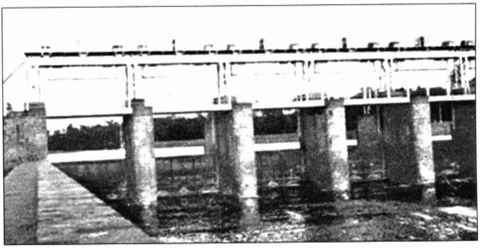
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sutlej	**Weir at Ropar**	**1882**	**Fish ladder of pool step type**	**1926**	***Aspidoparia morar, Labeo rohita, Labeo calbasu, Cirrhinus mrigala, Catla catla,* and Mahseers**
	Weir at Ferozepore	**1929**	**Fish ladder of pool step type**	**1926**	
	Weir at Suleimanki	**1926**	**Fish ladder of pool step type**	**1929**	
	Weir at Islam	**1926**	**Fish ladder of pool step type**	**1930**	
	Weir at Panjnad	**1931**	**Fish ladder of pool step type**	**1931**	
Ravi	**Weir at Madhopur**	**1870**	**Fish ladder of pool step type/ rafting bay**	**1931**	***Aspidoparia morar, Labeo rohita, Labeo calbasu, Cirrhinus mrigala, Catla catla,* and Mahseers**
	Weir at Balloki	**1913**	**Fish ladder of pool step type**	**1921**	
Chenab	**Weir at Marala**	**1910**	**Inclined plane system with straight baffle Wall**	**1910**	***Labeo rohita, Labeo calbasu, Cirrhinus mrigala, Catla catla,* and Mahseers**
	Weir at Khanki	**1889-92**	**Fish ladder of pool step type**	**1934-35**	
Jhelum	**Weir at Rasul**	**1901**	**Fish ladder of pool step type**	**1901**	***Labeo rohita, Labeo calbasu, Cirrhinus mrigala, Catla catla,* and Mahseers**



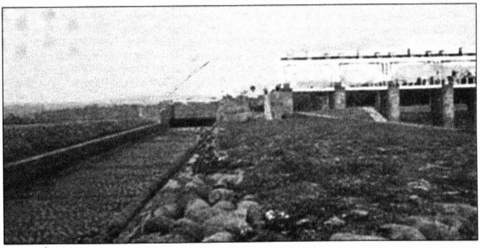
Fish ladder Ropar Weir



Fish ladder Madhopur



Madhopur Weir



Fish ladder and Rafting at Madhopur Weir

(Courtesy : After, Khan, 1940)

After independence limited fish pass facilities were provided in the dams constructed on Indian rivers Ganges , Yamuna , Mahanadi and Jhelum . These facilities provide passage to the Anadromus species *Hilsa ilisha,* potamdromus species *Tor putitora, Tor tor, Schizothorax schizothorax, Schizothorax richardsoni, S. progastus, Acrossocheilus hexagonolepis, L. rohita, C catla, C mrigala, L calbasu*, Amphidromus species *Macrobrachium rosenbergii.*

7.1 Denil type fish passes

7.1.1 Fish pass in the Barrages on Mahanadi at Cuttack and on Kathajuri at Naraj

Mahanadi barrage, completed 1990 is provided with a two-meter wide Denil fish way with five resting pools at El 18.14 m, 17.98m, 17.84 m, 17.69 m, and 16.00 m each having orifice type baffles. The fish way has been designed to develop a velocity of about 1.8 *m/sec* at the upstream entrance pool and about 1.55 to 1.68 m/sec in the Denil Fishway. The pass is designed to function in the upstream water level range of +21.20 and +19.825.

Naraj barrage, functional from 2000 is also provided with a 2 m wide Denil fishway having 7 resting pools of 4.2 m long each and with orifice type baffles (Fig.2).

The Mahanadi delta draining 145000 Km2 basin contained rich fisheries resources with tidal estuaries and extensive flood plains, which were the spawning grounds for fresh water prawns and other species. Due to the barrier of Hirakud dam some 300 km upstream, the migration of hilsa has been halted as the dam does not have a fish pass.

Three types of fisheries of importance are influenced by the Mahanadi barrage and Naraj barrage.They are :

i) Indian major carps dependent for spawning on monsoon floods, especially during early monsoon between mid-June until the end of July. The Mahanadi branch is most important for this species. Due to the existence of Hirakud Dam and the use of water for irrigation, spawning of IMC is limited during years of low rainfall. Artificial floods are necessary in early monsoon by releases from Hirakud dam and with fish passes in both the barrages.

ii) *Macrobrachium* sps. which reproduces in the brackish water zone of the delta; the hatched juveniles migrate upstream into fresh water areas during the post monsoon (three months). Maintenance of the post monsoon discharge in the Mahanadi system and the fish passes in the barrages have helped the sustenance of prawns including the giant fresh water prawn (*Macrobrachium rosenbergii*).

iii) *Tenualosa ilisha* whose population was decreasing, the fish passes have facilitated in upstream migration through both the barrages.

A survey conducted in the year 2000 by the Directorate of Fisheries, Orissa on the functioning of the fish passes in both the barrages reveals that the major portion of the catch is constituted by the species *L. bata, C. reba, L. rohita, C. mrigala, G. giuris, W. attu* and the migratory fish *Tenualosa ilisha* caught during the flooded rainy season at Mundali (7Km upstream of Mahanadi barrage), Ramdashpur and even further upstream which shows possible upstream migration through the fish passes (P. B. Das pers, comm. 2003).

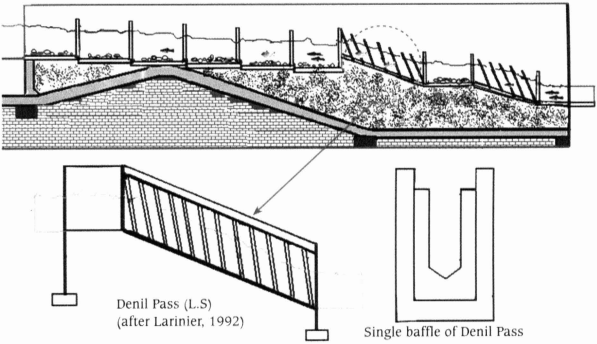


Fig. 2 : Diagrammatic representation of Denil type fish pass in Naraj Barrage (Modified, source, Das 2002)

7.1.2 Hathnikund barrage on Yamuna

This barrage is replacing the Tajewala head works built a century ago by the British from which two major canals, (western and eastern) carrying 20000 ft^3/*sec* each off take for irrigation. The barrage has 18 bays of 18 m each and is provided with one 2m wide Denil type pass, adjacent to the right Divide wall having five resting pools each 14.7 m long at El 331.82, 331.49,331.16, 330.83, 330.50. The Denil fishway is 10m long (Fig. 3). This pass provide safe upstream passage to the mahseers and other carps, which is currently migrating upstream through 8 falls provided in the western Yamuna canal. Migration through the canal has been observed almost over the last 50 years.

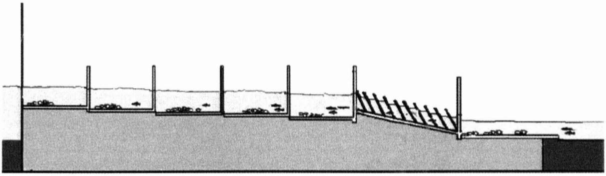


Fig. 3 : Diagrammatic representation of Denil type fish pass in Hathnikund Barrage (Modified, source, Das 2002)

7.2 Pool type fish pass

7.2.1 Sarada Barrage in Ganga Basin: A fish ladder was provided in a covered passage or (tunnel) behind the right pool. The lower end of the tunnel open out into the river below the down stream floor of the under sluice and the upper end opens into the pond at full supply level between the first barrage gate and the down stream end of the regulator. A special small sluice gate at the upper end controls the crest level and amount of water passing down (Das, 2003). The pass was constructed to provide passage for movement to mahseers and trout (P. B. Das pers. comm., 2003).

7.2.2 Run of the River Low Dams in Jammu and Kashmir : For upstream migration of the cold-water fish trout and mahseers fish ladders have been/are being provided in 5 schemes of the Sutlej river system.viz.,1. Upper Sind Hydel stage I 2. Upper Sind Hydel stage II 3. Lower Jhelum at Gantmulla 4. Uri stage I on Jhelum 5. Uri stage II (proposed) 6. Parnai on river Suran (P. B. Das pers. comm., 2003).

One typical scheme at Parnai on Suran river has steps with stagerred baffles. The Uri stage I scheme has been found to be highly successful .(Das, 2003).

7.3 Fish lock in Farakka Barrage

The Farakka Barrage constructed across river Ganga in Murshidabad district of West Bengal is provided with two fish locks between Bay Nos. 24 and 26. (from the right).

Farakka Barrage comprises of 109 bays and is located around 700 Km upstream of the outfall of Ganga Padma - Brahmaputra into Bay of Bengal. Each fish lock is 8.33m wide separated by 6 ft thick pier and 41.07m long between up stream and down stream lock gates. The sill level at upstream side is kept at 15.8m and downstream sill is provided at 9.75m. The fish lock chambers have separate regulatory steel gates on both upstream and downstream ends (Fig. 4).

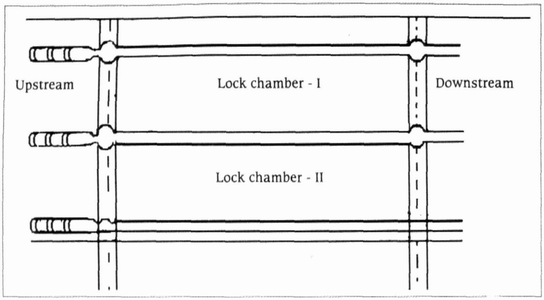
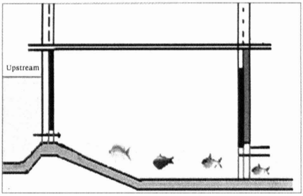
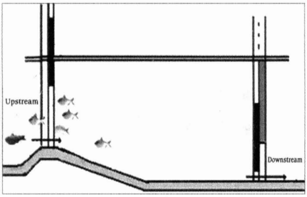


Fig. 4 : Diagrammatic representation of two lock chambers of fish lock in Farrakka Barrage

CIFRI concluded that among the more important fish that are likely to be affected by the construction of the barrage across river Ganga is *Tenualosa ilisha* anadromous in habit, which spends its adult life in the sea and migrates upstream for spawning purposes. Obstruction by the barrage resulting in decline of fish resources by making the spawning area upstream inaccessible to the fish. Migration of the fish towards the downstream of the river is between November and March when average discharge is 800 to 6000 *m3tsec* when the spill way is practically closed. Migration of fish towards upstream occurs during September and October with average discharge in the range 6000 to 67000 *m3tsec* when most of the central bays are open. The period of migration towards upstream quite often extend from July to November. The institute therefore recommended that the suggested fish pass should be so constructed as to operate mainly from July to November for the intended objective of upstream migration.

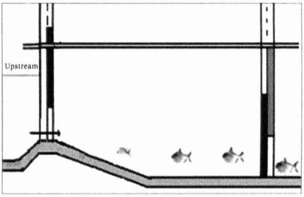
Fish lock gate operation: (Fig. 5) To start the operation initially the downstream gate of each lock chamber is kept fully open. Then the upstream gate of one of the lock chambers (Lock No 1) is partially opened so as to introduce a requisite discharge, which would induce a velocity varying between 1.22 m/sec to 1.83 m/sec per sec. at the downstream entrance of the lock chamber. This velocity induce the fish to swim up into the lock chamber and after specified interval when a sufficient quantity of fish gets accumulated in the chamber, the downstream gate is shut down and the upstream gate is completely opened. The downstream gate however should not be completely shut down but kept slightly open so that a velocity of the order of 0.61 m per second is generated at the upstream end of the chamber. This velocity would induce the fish to move out of the chamber into the upstream pond. During the time when the downstream gate of lock No.1 is partially closed, the upstream gate of the other lock (lock no 2) is opened to induce a velocity of 1.22 m/sec to 1.83 m/sec at the downstream entrance of this lock (lock no. 2). The operation earlier performed on lock no. 1 is repeated on lock no. 2. In this way lock no. 1 and 2 is alternatively subjected to same set of operations so that one lock is used for ingress of fish from the river downstream into the lock chamber while the other lock is used for egress of the fish from the lock chamber to the upstream pond.In its operational condition the operation of the Fish locks was done 3 to 4 times a day and each cycle of operation took about two hours. It is also observed that during the flood period hilsa migration possibly takes place through the bays when all the gates of the barrage are kept above water level and there is minimum head difference (De, 2001).

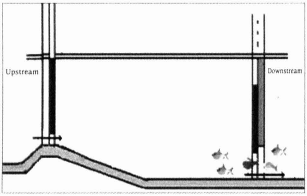




1. Initial Position

3. Fish moving out of lock





2. Filling the lock

4. Empting the lock

Fig. 5 : Operation of fish lock at Farrakka Barrage (Diagrammatic representation)

7.4 Fish ramp

Stepped spillway on Jambhira earth dam in Orissa: An unusual spillway provided by placing concrete blocks on a compacted earth dam stepping down from the crest has been providing migratory path to fish (*L. calbasu*) to move upstream. This step structure with a crest width of 75 m negotiates a drop of 15 m from pond level of EI 68 m to minimum river water level of EI 53 m below. The concrete blocks are placed one over the other with a step height of 0.2 m. As the depth of overfall rarely exceeds 0.3 m, fish (of 10-20 cm) has been found to move up during July-Aug when the reservoir spills. More information on the performance of stepped spillways and their adaptability for fish migration need to be collected / studied in detail. In India at least 70 % of the minor / medium dams are ungated and can incorporate a stepped spillway to help migration (P. B. Das, pers. comm. 2003).

Performance of the fish passes in India : Data on the performance of the fish passes in India is meagre because regular monitoring of the performance of such structures has not been done. Moreover in majority of the cases they have been rendered ineffective due to i) improper maintenance ii) small width of 2-3m which is inadequate in comparison to the width of the river and the volume of migrating fish population existing. In fact many of the fish passes at the tail water end has acted as fish traps for poachers (Sehgal,1999).

8. Fish pass design of CIFRI

8.1 Fish lock at Farrakka barrage

The fish lock constructed at Farrakka barrage was planned very carefully in consultation with the Central Inland Fisheries Research Institute (CIFRI), Barrackpore and designed on the basis of the recommendations of the model studies conducted at the River Research Institute (RRI), Haringhata, West Bengal. Detailed information on the migratory fish species were collected by the Central Inland Fisheries Research Institute (CIFRI) before a fish pass was designed at the Farakka barrage, which was built in 1975 on the Ganges River. This information included data on species' biology and behaviour, their spawning habits, characteristics of migration and swimming performance, number and size of fish passing per hour and, last but not least, the economical value of the fisheries they are supporting. As a result, two fish locks were constructed for the commercially important Hilsa (*Tenualosa ilisha*). The fish locks are not in operation at present and today, the upstream catches are meagre. (De, 2001)

8.2 Pool type fish pass at Bichum dam

CIFRI conducted extensive investigation in the upstream and downstream of the upcoming dams on river Bichum and Tenga in Arunanchal Pradesh to design appropriate fish passes for incorporation in the dam profile.The fish pass designed by CIFRI for incorporation in Bichum dam on river Bichum which is pool type is described below

Bichum Dam Fish Ladder

Kameng Hydro Electric Project

Salient features of Bichum Dam	**Salient Design features of Fish Ladder**	
Location: West Kameng District across Bichum River **Latitude (approx):** 27° 18' 30" E **Longitude (approx):** 92° 37'00"	**Location: West bank at the end of last Dam Block.**	
River: Bichum River	**Type of fish pass: Pool type Fish Ladder**	
Bichum Dam Catchment area : 2277 sq. km. Dam height : 75 m (above deepest from data) Deepest Foundation level : 698 m. Live storage : 4.32 MCM Length of Dam : 230 m Type: Concrete gravity Average river bed level : 770 m. Top of Dam : 773 m. Full reservoir level : 770 m. Maximum drawdown level: 766 m.	**Inlet arrangement:** Three number rectangular type orifice height 0.2 m and wide 1.85m in one vertical line with centre at EL 769, EL768 EL 766 and located at 7.5 m from the right bank end of the dam. **Gate control:** Separate gate control for each orifice from dam top hoisting arrangement. **Minimum reservoir water level for operation of fish ladder:** First inlet orifice: 767.3 m Second inlet orifice: 768.3. m Third inlet orifice: 766.3.m **Fish Ladder invert level at chainage 0.00 m.:** EL 766.2 m. **Design Slope:** 1:10	**Length of Fish Ladder:** 645.2 m **Entry velocity:** 2.65 m/sec. **Energy loss per unit volumetric dimension of pool:** 180 watts. **Spacing of Baffle Wall:** 3.3 m **Thickness of Baffle wall:** 1.3 m. **Height of Baffle wall:** 2.2 m with 0.2m thick sub-strata **Pool dimension:** 2.25 m wide and 4.1 m height up to top of side wall. **Baffle Notch section:** 0.2m x 0.2m **Baffle Bottom orifice Section:** Circular, 0.2 m diameter **Free board in side walls:** 0.3 **Substrata:** Natural river bed with sand, bajris, gravels etc

9. Future research needs

Knowledge on the migratory fish species

1. The meagre knowledge of the swimming ability and migration behaviour of the native migratory species in India, coupled with the lack of available data on their behaviour, has been a major limitation in developing broad guidelines for the most suitable fish pass designs. Therefore, the priority must be given to acquire a better knowledge of fish communities, their biology and their migratory behaviour.

2. Intensive research is essential on the migratory needs of many Indian potamondrous fishes like the mahseers, schizothoracids and Indian major carps.

Designing of fish pass

3. In the absence of good knowledge of the characteristics of the species concerned, the fish passes must be designed to be as versatile as possible. Some passes, such as vertical slot passes with successive pools, are more suitable than others when targeting a vast variety of species because the drop between pools and thus the energy dissipated in each pool can be adapted to the fish size. Selective or highly specific passes, such as Denil passes should be avoided. Also, provisions must be made to allow for modifications of the construction, if necessary, e.g. if indicated by monitoring results. Thus, a comprehensive monitoring programme must be part of any fish passage rehabilitation project and devices to monitor fish passage must be installed. This monitoring process will enable the fish pass to be assessed and the feedback thus obtained may be useful for improving the pass, if necessary, or for designing other fish pass projects in the same regional context (Larinier and Marmulla, 2004).

4. For high dams, when there are numerous species of poorly-known variable swimming abilities, migratory behaviour and population size, it is best to initially concentrate mitigation efforts on the lower part of the fish pass, i.e. to construct and optimize the fish collection system including the entrance, the complementary attraction flow and a holding pool which can be used to capture fish to subsequently transport them upstream, at least in an initial stage. This was the policy adopted by France in the 1980s for the first large passes for shad, until the fish pass technology had been fully mastered for shad (Travade *et al. 1998*).

5. Fish pass design involves a multidisciplinary approach. Engineers, biologists and managers must work closely together. Fish passage facilities must be systematically evaluated. It should be remembered that the fish pass technique is empirical in the original meaning of the term, i.e. based on feedback from experience. If one looks at the history of fish pass techniques, it is clear that the most significant progress has been made in countries that systematically assessed the effectiveness of the passes and in which it was required to provide monitoring results. It is the increase in monitoring and the awareness of the need for checks which is at the origin of progress in fish pass technology in countries such as the United States, France and Germany and, more recently, Australia and Japan (Larinier and Marmulla, 2004).

10. Do we really need fish pass

It has been the observation of many workers throughout the world and in India that fish pass constructed in especially big dams with large head differerence is not always effective. This is because of the following reasons :

i) the uncertainty of the target fish species viz., Mahseers , trout and *Tenualosa ilisha* to negotiate large head difference

ii) the limited width of the passes (1-2m) in comparison to the large width of the river

iii) inadequate information on the population size of the target fish species

iv) the cost of construction involved and

v) lack of regular monitoring and high maintenance cost of the fish pass.

Considering these aspects the other options for the stake holders is to go in for measures to stock required fish species upstream and if required downstream.This can be done by constructing hatcheries for breeding of the desired fish species near the dam site. This measure would serve as an alternative means of maintaining the depleted stock of fishes for exploitation by fishers. This is corroborated by the fact that in China (Wang ,1990 and Clay ,1995), which has a vast system of reservoirs (about 86 000) the fisheries of these reservoirs are intensively exploited and maintained by stocking from hatcheries, so that little need has been felt to construct fish passes. The first fish passes are only 40 years old (Wang 1990) and around 60 to 80 fish passes have been built. The main target species are potamodromous species, mainly four species of carp and catadromous species, mainly Japanese eel (Nakamura 1993).

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