

Importance of Design Factor in Improvement of Fishway Efficiency

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Abstract: Properly designed fishway plays an important role to mitigate the migrating problem of fish and help them meet their life cycle's basic requirements, especially the spawning activities with enhancing the local ecosystem as well. However, the fishways are still constricted at the small section of the dam or weir giving less priority and the designs of fishways are further limited by engineering, hydraulic and economic constraints. Thus, this paper presents an overview of the fishway design history and their consequences following different available literatures till date. Furthermore this paper also suggests on considering some important parameters during design such as turbulence, roughness coefficient, minimum head difference, slope which have a key role in improving the working efficiency of fishway. In addition, this review provides following recommendations: i) Need to improve downstream design of fishway and associated experimental methodology, ii) Consideration of river temperature with dissolved oxygen and their effect on fish behavior during design work, iii) Importance of further research work on coarse species along with other economically important fish, and iv) Updating the fishway design by considering fluctuating water level condition in the river. Hence this paper can contribute in the enhancement and restoration of fisheries resources from the perspective of fish passage design problems and their solution. Furthermore it may help the new researchers and designers to upgrade the existing design concept for the better result in fishway efficiency in coming future.

Keywords: Attraction Efficiency, Dam, Discharge, Fishway, Passage Efficiency, Velocity

1. Introduction

Barriers across river such as dam and weir usually have adverse impact on natural fish population and may contribute to the extinction of many aquatic species. Dams are threatening many aquatic species in Europe and North America, as well as in other continents due to less awareness and concerns on biology, behavior, fishery and population dynamics of the fish species. In recent time, the major concern is that the fisheries and the associated livelihoods are in risk due to an effect of construction of dams, which generally have effect on the normal pattern of water temperature, flow regime, water chemistry, nutrient transport, fish movement, and community structure in a river system. This in turn will have an impact on spawning. Obstacles generally change the hydraulic and morphological properties of the river and it can

create many threats to aquatic life such as (i) Dams and weirs significantly reduce flow velocity and the variability of the current, (ii) Water temperature rises in the reservoir due to reduced flow velocity and the longer retention time of the water in the impoundment, (iii) Energy flow is interrupted by increased sedimentation of organic matter causing the metabolic processes in rivers, (iv) Spawning migrations are blocked by impassable obstruction, e.g., dam, and the fish may spawn in parts of the river where conditions are less suitable, and (v) Channel reaches below dams that fall dry due to the diversion of maximum water by bypass power stations constitute a further problem in downstream for aquatic organisms [1].

A fishway is any type of riverine channel segment created to passively facilitate fish migration across an elevated barrier without any direct human or mechanical intervention [2]. Fish

passage facilities are an effective means of mitigating the impact of barriers, e.g., dams, weirs, and road crossings, on migrating fish. Fish migration takes place mostly in three directions: upstream, downstream and laterally. The general principle of upstream fish passage facilities, which is also called fish passes or fishways or sometimes even fish ladders, is to attract fish and help them move up from the obstruction by opening a waterway.

Fishways have a long history, with the earliest one recorded more than 300 years ago in France [3-5] when the southern province of France, Bearn, made it mandatory that weirs and dams construction must take into consideration of a passage for fish for their smooth movement. In 1883, Scotland has built the world's first pool fishway on a tributary of the River Teith explained by Nanjing Hydraulic Research Institute in 1982, however, their attempt to pass fish was not successful because the fishway was different from the fish's habits [6].

China has a vast system of reservoirs about 86000 and the fisheries of these reservoirs are intensively exploited and maintained by stocking from hatcheries so that little need has been realized to construct fish passes [5, 7]. The first fish passes are only 40 years old [7] and around 60 to 80 fish passes have been built [8]. The main target species are

potamodromous species, mainly four species of carp and in catadromous species, mostly Japanese eel. Most of the used fish passes were pool-type.

The Yangtang fishway exists on the Mishui River, which passes 45 species and more than 580000 fish per year. This fish pass effectiveness was monitored quite well i.e., 5000 hours of observation annually. The effect of the Yangtang fish pass was found to be significant as the statistics of fish harvest showed that the annual fish output in the upstream part of the Mishui River increased to 3.5 times compare with that in the years before the fishway building. Similarly this fish pass has been specifically designed to pass very small fish, with very low turbulence in pools and low drops about 0.05 m between pools. The attraction flow of $16 \text{ m}^3\text{s}^{-1}$ and the collection gallery above the turbines are considered to play an essential role in the effectiveness of the fish pass facility. Yangtang fish pass is one of the few examples of a well-designed fish pass, adapted to native species and well monitored in developing countries [9]. Since the fishway construction in different countries including China has a long history but the real status and construction scenario is looking different compare to its total number and the effectiveness (Table 1) [10].

Table 1. (Fishway Research Status) [10].

Country	Year	Location	Fishway	Remarks
France	1662	Bern province	Fishway Construction	The earliest fishway was constructed
The United States, Canada	Early 1960's		Fishway Construction	100 numbers or more
Japan	Early 1960's		Fishway Construction	35 numbers
Japan	Late 20th century		Fishway Construction	More than 1400 numbers
North America	Late 20th century		Fishway Construction	400 numbers
England and Wales.	Late 20th century		Fishway Construction	About 380 numbers
United States	Late 20th century		North Branch dam Fishway	Climbing the height of 60m
United States	Late 20th century		The Pardon Fishway	Total length of 4.8 km
China having following three stages:	(1958-1980)		Fishway Construction	Initial stage
	(1980-2000)		Fishway Construction	Stagnant period
	(2000-present)		Fishway Construction	Secondary development period
China	1958	Zhejiang's Fuchun river	Fishway Construction	First fishway when designing Seven Mile Ridge hydropower
China	1960	Heilongjiang's Xingkai Lake	Xingkailiu and Liyukang fishways	Two numbers
China	1966	Jiangsu Province	Doulongwa Fishway	
China	1980's		Anchui's Yuxi flood gate Fishway, Jiangsu Liuheay fishway and Tuanjie river fishway including Hunan's Yangtang fishway and other.	Fish passage structures were more than 40 numbers
China	(1980-2000)		Fishway Construction	Stagnant period, no construction
China	2003	HuiChun city, Jilin province	Fishway Construction	When the LaoLongKou water conservancy was built
China	2004	Zhejiang province	Fishway Construction	Fishway with the length of 500 m and the width of 2 m in each side of the Cao'e River brake
China	2005	Han xinglong water conservancy hub		Fishway with the length of 461.6m and the width of 3 m and the depth of 2m built on its right bank beach

Since 1930, physical and numerical hydraulic studies and improved biological assessments have provided a more comprehensive scientific knowledge and a more reliable basis

for designing and operating fish passage systems. Current development in biology, particularly with enhanced understanding of fish behavior, advanced hydraulic concepts,

more nature-like solutions, improved interdisciplinary or ecohydraulic approaches, and increasing focus on fish passage efficiency in field assessments, indicate that fish passage systems are becoming more effective and more adaptable to small and large bodied fish, as well as freshwater and multiple species [11-13]. However, the earliest fish bypass structures were generally poorly designed for local hydraulic conditions and fish species. Thus, it is required to focus more on the importance of design parameters that will enhance the effectiveness and efficiency of fishway in coming future. This paper contributes to the enhancement and restoration of fisheries resources from the perspective of fish passage design problems and their solution. It further highlights the importance of upgrading the existing design concept for the better result in enhancing fishway efficiency.

2. Overview of Fishway and Its Design Parameters

In general, most of the papers have discussed the fishway design used in upstream migration compared to the downstream. However, the design of downstream passage also needs to take into consideration about the swimming ability and behavior of the target species and the physical and hydraulic conditions at the water intake as in case of upstream fish passes [14]. Fishways success depends on interaction of fish behavior and swimming ability with hydraulic characteristics (Table 2) [1].

Table 2. (Different Fishway Structures and Effectiveness) [1].

Type	Dimensions and discharge	Range of application	Advantages and disadvantages	Effectiveness
Slot passes	Pool dimensions: $l_b > 1.90$ m; $b > 1.20$ m; $h > 0.5$ m; Slot width: $s > 0.17$ m. Discharge can be from $Q = 140$ l/s up to several cubic metres per second.	Generally used for small and medium heads including variable impounding heads. Can be used for small streams and large rivers. The minimum tailwater depth must be $h > 0.5$ m.	Relatively high discharges can be sent through, thus good attraction currents can form. More reliable than conventional pool passes because of the lower risk of clogging of the slots.	They are currently the best type of technical fish pass, being suitable for all species of fish and are passable for invertebrates if a continuous bottom substrate is built in.
Pool passes	Pool dimensions depend on the river zone; $l_b > 1.4$ m; $b > 1.0$ m; $h > 0.6$ m. Submerged orifices: $b_s/h_s > 25$. 25 cm. Discharge $Q = 80$ to 500 l/s.	Generally used for small and medium heads, at melioration dams and at hydroelectric power stations.	Only relatively low discharges allowed; there is great risk of clogging with debris.	Suitable for all species of fish if the dimensions of the pools and orifices are chosen as a function of the fish size that can be expected to occur. There might not be sufficient attraction current at low discharges.
Denil passes	Channels: $b = 0.6$ to 0.9 m; $h > 0.5$ m; < 1.5 ; $Q > 250$ l/s. Channel lengths can be 6 to 8 metres; resting pools are required for heights > 1.5 to 2 m.	Generally suitable for small heads, particularly for retrofitting of old milldams when there is not much space.	Relatively high discharges; should not be used for variable headwater levels; not sensitive to varying tailwater levels; need little space; cheap; good formation of attraction current.	According to present knowledge, less suitable for weak swimmers or small fish. Selective. Benthic fauna cannot pass.

Q: Discharge or flow.

h: Water level difference.

b: Pool width.

l_b : Pool length.

b_s : Submerge orifice width.

h_s : Submerge orifice height.

The performance of fishway varies greatly with their type, design and operating regime, and with the species concerned, and is often the product of experience in dealing with these variables [15]. Construction of instream barriers and the subsequent impacts on migration is one of the major threats to freshwater fish diversity worldwide [16, 17]. Barriers restrict access to spawning grounds and preferred habitats, thus preventing dispersal and recolonisation [18-20]. Providing passage for both small and large fish requires specific engineering solutions. The appropriateness of any solution is largely dependent on what direction fish are attempting to move. Biologically oriented fishway research has focused mostly on anadromous fish species (e.g. salmonids) [21, 22]. Therefore, considerably limited information on coarse species has been available. Recent studies have proven that these species can travel considerable distances for reproduction, refuge and feeding purposes [22-24]. Study of swimming

energetics and kinematics of juvenile *S. chongi* at a single temperature provide data useful for the design of fishways [25]. Likewise, Chinese sturgeons conserve energy by swimming efficiently and have high fatigue recovery capability which will be important during fishway designing [26]. Therefore, there is an increasing need to conduct many studies to accommodate movements and behavior of different fish within fishway and to assess the effect of potential key-variables that should be considered for the successful development of future designs.

A number of studies have addressed the flow circulation patterns, the jet characteristics and the turbulence generated by the energy dissipation in pools for different configurations, and their relevance for the development of suitable hydraulic criteria for passage of salmonid species [27-29]. However, passage studies focused on coarse species are limited. Therefore, extensive studies still need to be

carried out on coarse species [22, 30] for the real effectiveness of fishway. The modification of internal flow characteristics in the pools by placement of submerged structures to examine the extent to which turbulence, particularly the horizontal Reynolds shear stress component can be reduced, and thus facilitate and shortening the passage time of small individuals, should be considered. To improve the effectiveness of fish passage for larger species, it can be modified by incorporating orifices into the traditional pool and weir design, reported in the studies of swimming behavior for sturgeon [31-33]. Likewise other important design considerations are appropriate flow speed, passage time [34], maximum speed for sustained swimming [35], hydraulic conditions [36], and swimming performance [37]. Similarly protocols for testing swimming performance shall be well-established and the results are of interest to fish physiologists as they provide design criteria for construction of fishways [38-40]. The relevance of swimming behavior and performance to fishway issues is a motivated work in this field [32].

3. Correlation Between Effective Fishway and the Design Parameters

Some important parameters need to be consider during effective fishway designing are discussed below.

3.1. Suitable Position for a Fish Pass

In general, in the natural river when there is no any obstructions such as weir, dam then fish can easily move upstream without giving much attention to the flow direction and other factors. However, when there exists any barrier across the river, fish find the difficulties to confirm the proper waterway to move upstream. Similarly the possible dimensions of any fishways are usually severely limited by engineering, hydraulic and economic constraints, particularly in larger rivers. Thus, the position of fishway at the dam plays a significant role. Fish usually migrate upstream following the path in or along the main current possibly the bank of the river where the water current is maximum. With a position near the bank, the fish can be more easily linked to the bottom or bank substrate. Usually at hydroelectric power stations, fish pass is placed on the same side of river as the powerhouse [1].

A fish pass, which extends far into the tail water below the dam, considerably limits the possibility that fish find the entrance. Thus, a design fault that has been responsible for the failure of many fish passes. Where dams or weirs are placed diagonally across the river and overflow along their entire crest, upstream migrating fish usually concentrate at the upstream, narrow angle between weir and bank. Therefore, the fish pass should clearly be sited in this area. Facilitating movement of fish back to mainstream habitats can be achieved through the construction of specialist floodplain fishway or potentially by manipulating the river hydrograph [41]. Improving lateral connectivity not only benefits native

species, but also facilitates the movement of non-native species utilizing floodplain habitats [42, 43].

In case of a wide river it may be necessary to provide not only several entrances but also more than one fish pass because a single fish pass cannot be expected to attract certain species from the opposite bank. Migrating fish may arrive either at the bank where the powerhouse is located or at the opposite bank where the spillway is discharging and it is therefore advisable to design two separate fish passes, each with one or more entrances [44]. Hence, the good design that comprises of experience and knowledge in fish behavior in Natural River also plays an important role.

3.2. Fish Pass Entrance and Attraction Flow

For a fish pass to be considered efficient, the entrance must be designed so that fish find it with a minimum of delay as "No fish in = No fish out" [45]. It is explained that the perception of the current by aquatic organisms plays a decisive role in their orientation in rivers. Fish that migrate upstream as adults are usually swim against the main current. However, they do not necessarily migrate within the maximum flow but, depending on their swimming abilities, they may swim along its edge. If migration is blocked by an obstruction, the fish seek onward passage by trying to escape laterally at one of the dam's sides. In such case they continue to react with positive rheotaxis and, in perceiving the current coming out of a fishway, are guided into the fish pass. The properties of the tailrace below a dam where water velocity and degree of turbulence influence the attracting current that forms at the entrance to the fish pass. The velocity at which the attracting current exits the fish pass should be within the range of 0.8 to 2.0 m s⁻¹. Particularly where the tailwater level fluctuates, a special bypass can be used to channel additional flow directly from the headwater to the entrance of the pass in order to boost the intensity of the attracting current. The bypass can be in the form of a pressure pipe, but it is usually better to have an open channel. Except for special cases flow velocity should not exceed 2m s⁻¹. In many cases this is directly below the weir or dam, at the foot of the barrage or at the turbine outlets. A critical problem is how to construct the fish pass entrance so that fish can swim into the fishway even at low water levels. Entry into the fish pass can be made, even for bottom-living fish species, by linking the fish pass to the natural river bottom. This can be done with a ramp with a maximum slope of 1:2. Some existing fish passes have their entrances oriented towards the weir and thus at an angle of 180° relative to the river current. In such cases the entrance is unsuitable and it cannot establish an attracting current to enable the fish to find the entrance to the fishway [1].

Overall passage effectiveness are determined by properly utilized the method of attracting fish to locate systems for upstream movements. No fish passage system, will work successfully if fish do not find, or are not attracted to the entrance regardless of type, configuration or internal passage efficiency. Proper flow management at a hydroelectric project is an important methodology that can be used to attract fish

and flow releases near a fishway entrance which help the migrants to locate it effectively. Approaches to attracting fish to passage systems need to consider species, hydraulics and site-specific conditions. Usually site-specific biological and hydraulic studies are needed to develop concepts into effective fish passage [46]. New Technology like tracking fish through telemetry [22, 47] has helped in quantification of fish guidance, attraction and fish passage efficiencies mainly for upstream fish passage systems [46]. Fishway with attraction current is explained in Figure 1 [1].

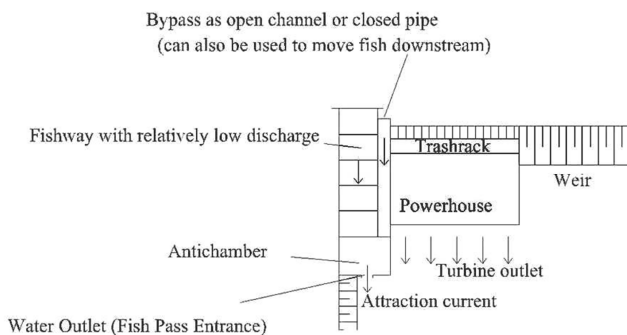


Figure 1. Additional discharge is sent through a bypass into an antechamber downstream of the first pool of the fish pass to increase the attraction current at the fish entrance [1].

3.3. Fish Passage Exit and Exit Conditions

When designing of fish passage, its water inlet (exit into the headwater) must be located far enough from the weir or turbine intake to prevent the fish coming out of the passage from swept into the turbine from the water current. At least 5m distance should be kept between the fish passage and the turbine intake or trash rack. If the water velocity of the headwater is greater than 0.5 m s^{-1} , the exit area of the fish pass has to be prolonged into the headwater by a partition wall. [1].

3.4. Discharge and Velocity Conditions in the Fish Pass

The discharge required to ensure optimum hydraulic conditions for fish within the pass is generally less than that needed to form an attracting current. However, during dry period when the availability of water is less, subsequently the total discharge available should be used in the fish passage to allow unhindered passage of migrants. This method is used for the dams that are not used for hydropower generation. If more water is available to supply the fishway than is needed for the hydraulically sound functioning of the existing or planned fish pass, alternative designs should be carried out. In general, current velocity in fish pass should not exceed 2.0 m s^{-1} at any narrow point such as in orifices or slots and this limit to velocity should be assured by the appropriate design of the pass. The pass should incorporate structures that form sufficient resting zones to allow weak swimming fish to rest during their upstream migration [1].

Water flow velocity is an important factor governing the upstream movements of migrating fish [48, 49], and the provision of suitable flow condition at the downstream of a dam has been identified as an effective method of improving

passage [50]. For fish to be attracted towards a fishway, it is generally held that flows originating from a point near the fishway entrance should be high relative to those released elsewhere along the dam face [50-52].

3.5. Dimensions, Slopes, Resting Pools

Proper dimensions of fishway include information on such features as slope, width, length and water depth as well as the dimensions of orifices and resting pools. These parameters depend mainly on the particular type of fish pass including the available discharge. The body length of the biggest fish species that occurs or could be expected to occur in accordance with the concept of the potential natural fish fauna is an important consideration in determining the dimensions of fish passes. However maximum sizes, such as that of the sturgeon that can grow to 6.0 m in length, are not used. The average body length of the largest fish species expected in the river as well as the permissible difference in water level must be considered in defining the dimensions of a fish pass. For more technical constructions the maximum permissible slope ranges from 1:5 to 1:10, depending on the construction principle chosen, while close-to-nature constructions should show maximum slopes less than 1:15 corresponding to the natural form of rapids. The fishway has a bed slope of 10% is typical [5, 53]. In any case, the requirements of the weakest species, or of the weakest life stages, must be considered when defining the dimensions of a pass. Resting zones or resting pools should be provided in fishways at intervals of such lengths as defined by the difference in level of not more than 2.0 m between pools [1]. The turbulence of the flow through the fish pass should be as low as possible so that all aquatic organisms can migrate through the pass independently of their swimming ability. The volumetric energy dissipation in each pool of a fish pass should not exceed 150 to 200 Watt per cubic meter, of pool volume [1]. Turbulence is frequently identified as the major factor limiting the passage of small-bodied species and can be manipulated in a fishway pool [54], either by: (i) improving dissipation of energy in the pool or (ii) reducing the amount of energy entering the pool [28, 55, 56].

3.6. Effectiveness and Efficiency

The concept of effectiveness and efficiency may be used to clarify the degree of mitigation provided by a fish pass. Effectiveness is a qualitative concept, which checks that the fish pass is capable of letting all target species through within the range of environmental conditions observed during the migration period. Effectiveness may be measured through inspections and checks like visual inspection, trapping, video checks [57].

The efficiency of a fish pass is a more quantitative description of its performance. It may be defined as the proportion of stock present at the dam which then enters and successfully moves through the fish pass in what is considered an acceptable length of time. The methods giving an insight into the efficiency of a pass are more complicated than those for effectiveness. Marking and telemetry are valuable techniques to

assess the overall efficiency of fish passes and the cumulative effect of various dams along a migration path [44].

Effective passage systems for both upstream and downstream movements have three basic characteristics such as (i) fish passes are easy to locate by the fish community, (ii) fish passes have hydraulic conditions that match biological needs and that species seek rather than avoid, and (iii) fish passes provide suitable and efficient transport [46]. However, attraction and passage efficiencies are associated mainly with upstream fish passage systems. Attraction efficiency refers to the probability that fish approaching the barrier will locate the fishway entrance, while passage efficiency refers to the probability they will move through the fishway and pass upstream [46].

Effectiveness and efficiency may be limited by how easily fish can locate or be guided to upstream or downstream fish passage systems. Fish passage system choice basically depends on species type and fish habitat management objectives including site conditions, fish attraction and guidance, water level difference, hydraulic characteristics, operational constraints, construction materials, maintenance, and economics. Fish attraction and guidance aspects, biological requirements, and hydraulics are the most critical aspects for effectiveness and efficiency.

Efficiency of fish movement at an area of difficult passage involves knowing how many fish of a particular species attempt to pass upstream relative to the number of fish that successfully pass through [36, 58].

Attraction efficiency was defined as the proportion of fish tagged and released during the study that were subsequently located within less than approximately 3m from a fishway entrance [59] or at the base of a barrier to fish movement and near enough to a fishway entrance for fish to detect fishway attraction flow [60].

Passage efficiency was calculated by dividing the number of fish of a particular species that exited a fishway by the number that was detected at the fishway entrance [59, 60]. Passage efficiency may relate to type of fish passage, its slope and hydraulic head, while attraction efficiency may relate to biological factors such as migratory characteristics and temperature tolerance of the fish species present [2]. The topology of the flow also influences the fish passage efficiency. [61- 63]

Three sequential components of fish passage relevant to both up and downstream migrations are attraction, passage itself, and post passage effects [64], which are very important during design. Fishway entrance, i.e. attraction is a two-step process, consisting of guidance to the fishway entrance and actual entry into the fishway [65]. Indeed, this distinction may be important, as some studies have reported fish approaching the entrance but failing to actually enter [66, 67]. Since guidance, attraction, or passage can independently limit fishway efficiency, evaluating these different components of passage is necessary to understand mechanisms of passage failure, and identify potential mitigation measures.

It is highlighted the importance of assessing physiological consequences of passage that may affect survival or

reproduction and not just efficiency at the barrier [68, 69]. The studies of physiology may also be important in determining how passage by unhealthy fish, when they have low energy reserves or high stress levels, may differ from the passage by healthy fish [36].

4. Observation and Suggestions

It is observed that very few papers have discussed about the downstream fishway designing compared to the fishway in upstream migration. Likewise, all management efforts are on promoting upstream migration than downstream movement, however, fish passage requirements within river channels are bidirectional and equally important in all directions [70]. Similarly, large-bodied fish moving downstream can be delayed or even abandon migration if an appropriate migration pathway is not found [71]. It is thus suggested to have further research to be carried out on downstream fishway access at or near the dam/weir to meet the requirement of entire complete life cycle activities of species.

As every type of species has its important role in ecosystem but the fishway design research has found to be carried out mostly with economically significant species like salmonids while the species considered to be of low commercial value have been generally ignored may be due to limited information available of such species. Hence, it is suggested to have depth study and research on different type of fish regardless of its economic value for the effective design of fishway.

Most of the researchers have only emphasized the importance of fish passage efficiency, i.e., number of fish passes through the fishway but limited research tends to be carried out on fish mortality rate after passing through the fishway as this factor can also guide the real design effectiveness of the fishway. Hence passing efficiency and consequences of fish mortality rate shall be considered precisely.

Generally in pool designing, difference in water head in pool of about 0.2 m have followed which impose a maximum current velocity of 2.0 m s^{-1} for instance at orifices and cross walls. It is recommended that the water level difference between pools in a fishway shall be kept below 0.2 m or that may differ according to river flow pattern and velocity required inside the pool, so that it can comfortably pass the fish having weak swimming performance as well [1] In addition, the designer shall also concentrate on different turbulence factor and vortices created mainly at the slot opening as these play an important role in finding the required dissipation of energy in the pool.

While swimming performance is impaired under the highly unnatural conditions where behavior is restricted to rectilinear swimming [72] however many research on fish swimming capability are generally carried out in swim chambers model and designers are using those data for the fishway designing. Hence, it may not always give the good result while comparing with the fish swimming in the natural condition. Thus, it is suggested to use large experimental

channels, which are more compatible with natural environment for better output.

Similarly during fishway model test, roughness coefficient of bottom surface and surrounding areas of fishway shall be selected according to the roughness of the material generally used in the real field scenario to achieve the better performance of fishway. The type and base slope of the fishways are also needed to be selected according to the flow pattern, upstream and downstream water level differences including swimming behavior of the locally available native fish rather than simply imitating the design from other similar type of projects.

During fishway research, it seems the fish are usually acclimated in acclimation tank for certain time and released it to the fishway chamber directly for the experiment purpose. However, in the natural river, fish have its own natural movement and attraction behavior toward the fishway inlet guided by the attraction velocity. The attraction efficiency may not only be compatible during the laboratory test carried out in fishway model. This paper suggests to conduct experiments in large experimental channels taking detailed information of fish behavior found in Natural River. Hence, this is also one of the factors needed to be considered during model test.

Fish passage efficiency is influenced by discharge [24] when the water level in the river is comparatively lower or excessively higher than the swimming capabilities of the fish in general. Consequently the effectiveness of fishway may decrease during such events. Therefore, this paper suggests to modify the design in such a manner that it can always maintain the proper required flow at the inlet of the fishway regardless of flow depth variation in the river.

As reported in [2]: “variation in fish attraction is determined by biological characteristics of the fish”, which is contradictory with the expression “fish attraction efficiency is developed through attraction velocity of water”, as discussed in [1]. Thus, it is suggested to have further research on it to mitigate this contradiction for the improvement of fishway design in future.

Due to global warming effect, normal temperature is also gradually rising every year, which may also have an effect on the natural river environment and different aquatic life living there. At higher temperature, it seems fish swimming tends to become continuous with a constant increase in muscle activity over time [73]. This will result in an increase in maximum swimming speed, but a decrease in endurance, which will affect the ability of fish to ascend fish passes. Thus, the behavior of migratory fish can be influenced by temperature as well [74]. Consequently, it is suggested to consider also the temperature effect as one of the key factors in designing of the fishway.

Hydraulic factors like discharge, velocity and flow patterns of the river are found to be an integral part of the fishway. In addition, it is also suggested to consider some other environmental parameters during design such as dissolved oxygen content, water quality, noise and light effect, which are indirectly affecting the fish movement and

behavior in Natural River.

The importance of fish behavior on encountering conditions associated with fish passes is also significant when facilities fail to sufficiently attract fish to their entrance and in some cases may actually repel those from the inlet [75]. Thus, it is suggested to improve fish pass design with quantifying the behavioral response to factors, such as prevailing discharge and temperature regimes that are likely to impact the degree to which structures impede fish movements.

Furthermore fishway designs depend greatly on the interplay between hydraulics and biomechanics, yet very little data are available on the responses to specific hydraulic settings for these species. Therefore, there are still many factors that may need to be considered for the effective and efficient fishway design in future studies.

5. Conclusion

Fishways are very much important for the restoration of free passage for fish and other aquatic species in rivers from the obstacle like dam, weir. The fishways are seemed to be one of the key elements for the ecological improvement of running water. Their efficient functioning is also very much required for the restoration of free passage in rivers. However, studies of existing devices have shown that many of them do not function in an efficient manner. Thus, group of experts e.g. engineers, biologists and administrators are required to show their common interest to work together for the efficient design criteria. Hence, for the effective fishway design, it needs to consider the fish biology, life stage, behavior, space, swimming ability, and hydraulic conditions, including velocity and turbulence patterns according to the different species and their living environment condition. With the improved design, the fish can easily locate the fish pass or be guided to them and their life cycle basic requirements are easily met with timely migration. Therefore all the design parameters discussed above if taken into consideration can help to make the fishway more functioning with the improvement of its effectiveness and efficiency. Instead of increasing the number of experiments and research works on the fishway, it is recommended to carry out less but more precise work on quality research on fishway designing which is well - suited with fish behavior and natural river characteristics.

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