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A study to reduce the impacts of Assiut barrage on Nile river fish production

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ABSTRACT

The river environment with its structural and hydraulic features creates habitats for aquatic life of which fishes are the most notable. The up stream and down stream fish migrations are ecological imperatives for fish life cycle. The Egyptian government has established a series of dams and hydropower stations which are urgently needed due to rapidly growing population. However , these control structures with its hydropower generation stations not only create a barrier for fish life cycle, but also they can induce mortality to fish by passage through turbines. Fish passage facilities are hydraulic structures designed to assist upstream migrating fish to restore their life cycle and for safely transition downstream of turbines.

This study investigated the negative impacts of Assiut barrage as water control structures on productivity of Nile tilapia at the governorates which located downstream the barrage. In order to restore Nile River fish production in Assiut barrage, it is recommended to design an efficient fish passage system in the form of pool and weir fish way but with using an orifice at the bottom of the weir to accommodate the weak leaping ability of Tilapia fish.

Key words: Water control structure, hydropower station, fish migration, fish life cycle, fish passage system.

INTRODUCTION

The development of fishery resources of the Nile River has been a target of the decision-makers because of its broad social impact on a wide range of citizens. The production of fish from Nile River has subjected to many changes after the establishment of water conservancy projects and hydropower generation stations. The hydropower projects not only create a barrier for upstream movement, but they can also induce mortality to fish by passage through turbines. In order to increase the Nile river fish productivity after the hydropower station regulators and all dams, it is recommended to restore the fish life cycle through fish passages system. The conceptual design considerations and main features of fish passage system have to be studied.

A fish ladder, also known as a fish way, fish pass or fish steps, is a structure on or around artificial barriers (such as dams and locks) to facilitate fish migration. Most fish ways enable fish to pass around the barriers by swimming and leaping up a series of relatively low steps (hence the term ladder) into the waters on the other side. Experiences with fish passage facility in Africa have been few and unsatisfactory. At Sennar dam a fish ladder was built but was soon destroyed and not replaced. At Gebel Aulia, the fish ladder was found to provide apparently poor access and many migrating Nile perch were unable to surmount it (Worthington, 1973). In the state of Queensland, a tropical and sub-tropical region of Australia, about 22 fish passes were built prior to 1970, most of them on tidal dams (Barry, 1990). Early designs were based on fish passes used for salmon and trout in the northern hemisphere. The majority of these fish passes were judged to be ineffective in providing native fish passage, mainly striped mullet (*Mugil cephalus*) and barramundi (*Lates calcarifer*) (Beitz, 1997) which support important commercial fisheries. Under the guidance of a Fish Pass Coordinating Committee, Queensland has begun a programme of fish pass design, construction and monitoring which better reflects the requirements of native fish. A major programme of retrofitting existing fish passes has been launched (Jackson, 1997).

As noted by Northcote (1998), with possibly some 5000 species of freshwater fishes in South America and probably more than 1300 in the Amazon Basin (Petrere, 1989), the potential for fish passage problems at dams is enormous. Most dams have no facilities for fish passage (Quiros, 1989). Northcote (1998) listed only 46 fish passes with another 7 planned or under construction in Latin America. As noted by Clay (1995), Latin American experience seems to be following that of other parts of the world, with limited success, because of lack of knowledge of the species involved and lack of application of the criteria needed for good fish pass design.

This paper reviews the negative impact of water control structures on Assiut barrage as on productivity of Nile fish specially tilapia at the governorates which located downstream the barrage. Also, their impacts on fish community and life cycle of fish.

MATERIALS AND METHODS

The study area:

The study reach is about 382 km length and its average width is about 500 m. It extends from downstream Assiut Barrage to upstream Delta Barrage (Fig. 1).

There are 12 water level gauging stations on the study reach (Table 1), which are read daily and the obtained data have been assembled to determine present water level profiles (Rasslan and Abd El bary, 2001).

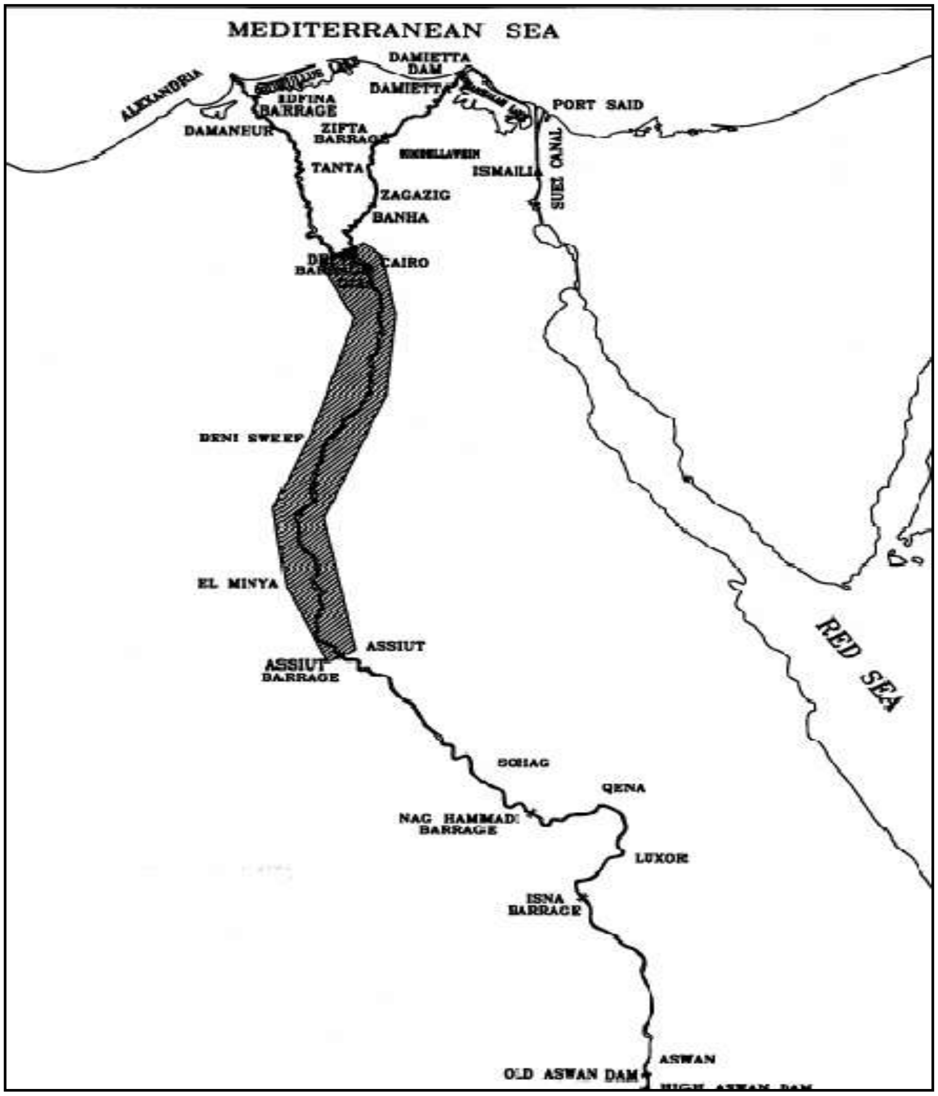

Fig. (1): Reach from downstream of Assiut Barrage to upstream Delta Barrage

Table (1): Water level gauging stations along reach study

Serial No.	Station Name	Kilometer from Aswan Dam
1	Assiut	544.75
2	Maabda	576.2
3	El Mandra	612.1
4	Qalandool	649.4
5	El Minia	687.55
6	El Sheikh Fadl	735.55
7	Beba	778.9
8	Beni Sweif	808.6
9	El Korimat	839.15
10	El leethy	873.7
11	El Roda	927
12	Delta Barrage	954

Hydraulic simulation of Assiut barrage reach (downstream the barrage)

One of the main considerations when a fish ladder design was suggested in this study is to depict the relationship between water surface elevation and flow rate (rating curve). In case of large variations in water levels, the vertical slot fish way can be used, while in case of limited variations in water levels, pool and weir fish way is suggested.

Due to the irregular shape of the Nile cross-sections the most suitable model to compute changes in water surface elevation is HEC-2 model. This computer simulation program uses numerical method named standard step method, is the most suitable model to compute changes in water surface elevation between adjacent irregular cross sections on the basis of solving the one dimensional energy equation between the flow cross sections. The standard step iterative method is used to solve the energy equations for the unknown upstream water level starting from a known level at the downstream of the computation reach. For HEC-2 model requirements, the cross-sections have to be arranged from downstream to upstream and sorted in a descending order based on the cross-section number. Each cross-section is defined as three parts, channel, right and left over-banks, each having a different roughness coefficient. One must not interpret, however, flood plains as low or non-contributing areas. Flow over flood plains exists and is taken into account in the model by specifying Meaning's values for these areas.

The methodology incorporated in HEC-2 model is mainly based on several assumptions:

1-Steady flow

2-Gradually varied flow

3-One dimensional flow with correction for horizontal velocity distribution

4-Small channel slope

5-Friction slope (averaged) constant between two adjacent cross sections

6-Rigid boundary condition.

Data Used for Model

The information required running any water surface model could be grouped under two main parts, geometric and hydrologic data. All river models interpret an alluvial stream as a series of cross-sections, more or less equally spaced, which describe the actual shape of the riverbed at these locations (Nahla *et al.*, 2001). The available cross-sections in the reach under study (reach 4) from Assiut Barrage to Delta Barrage) consists of 40 cross-sections with different spacing between series of cross section which have been surveyed in 1997. The cross-sections were first arranged from the upstream to the downstream. The geometric data records used in these runs consists of:

1) Cross-sections profiles description,

2) Roughness coefficient Manning's (n) for each cross-section.

The hydrologic data for this reach consists of discharge data at Salam which is located downstream Assiut Barrage at kilometer 544.77 from Aswan. The discharge measurements at this site are generally performed about 40-50 times per year. Rating curves are then developed for each calendar year. The second part of the hydrologic data for the reach consists of the water levels at gauging stations. Twelve gauging stations along the reach are available on daily basis. The maximum water levels (Fig. 2) are considered at year 1997, 1998. In this study the obtained data of the years 1995 was used for the calibration and the data of 1997 was used for the verification.

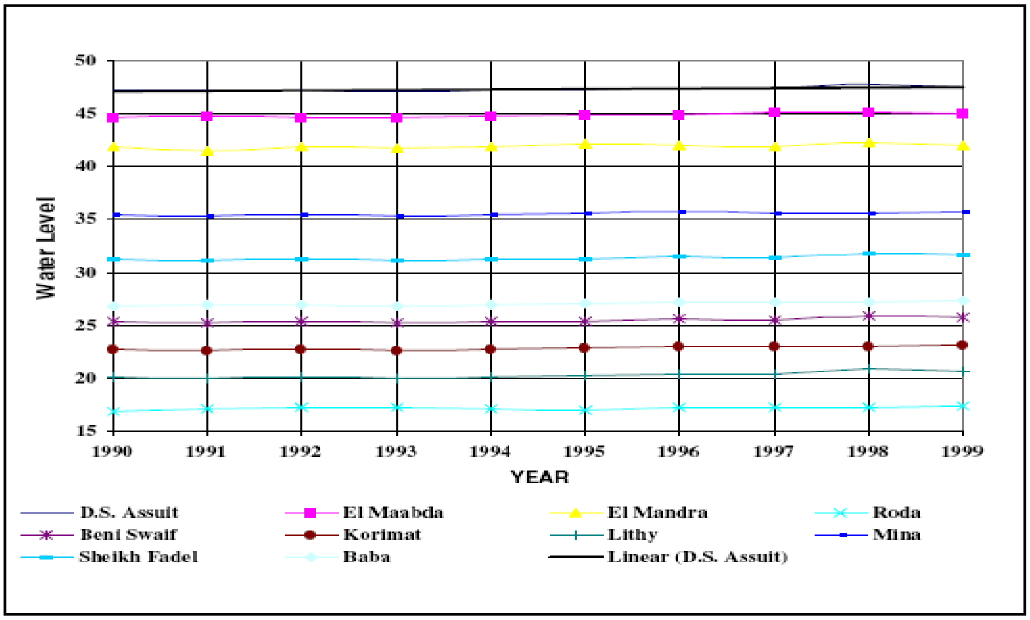

Fig. (2). Maximum water levels for different gauging stations

RESSULTS

Calibration

The model calibration was performed to simulate, by trial and error, the actual conditions and water levels for different discharges with the measured water levels. The calibration runs were made for maximum discharges 173 mm^3 /day at year 1995. The computed water levels were compared with the measured water levels at the gauging stations (Table 1).

Figure (3) shows the computed water levels (C.W.L), measured water levels (M.W.L), mean bed levels (M. B.L) and thalwag path. From the graph, it can be noticed that there is close relationship between computed and measured water levels.

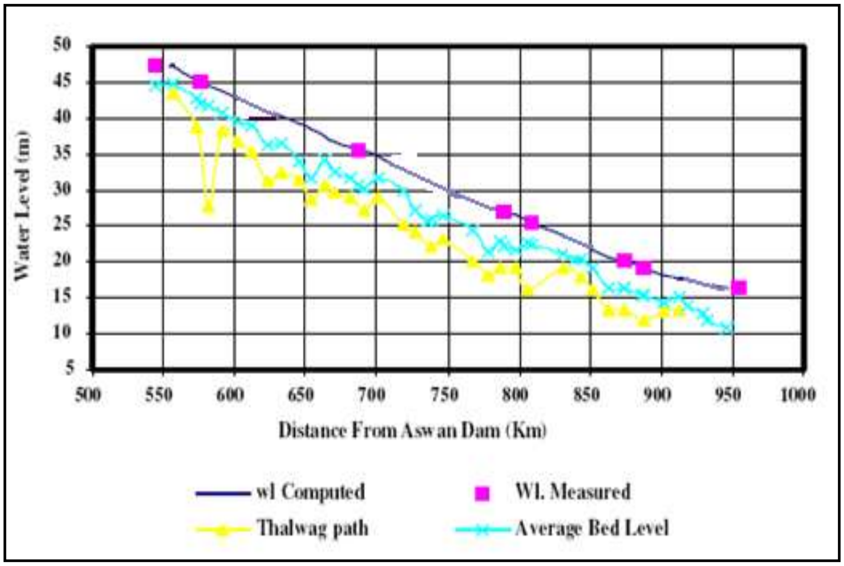

Fig. (3). Calibration model

Verification

Good model performance can be observed as the computed water levels closely match the measured water levels at gauging stations. Consequently, the model can be used safely in the prediction runs for different flow and water level conditions as shown in Figure (4).

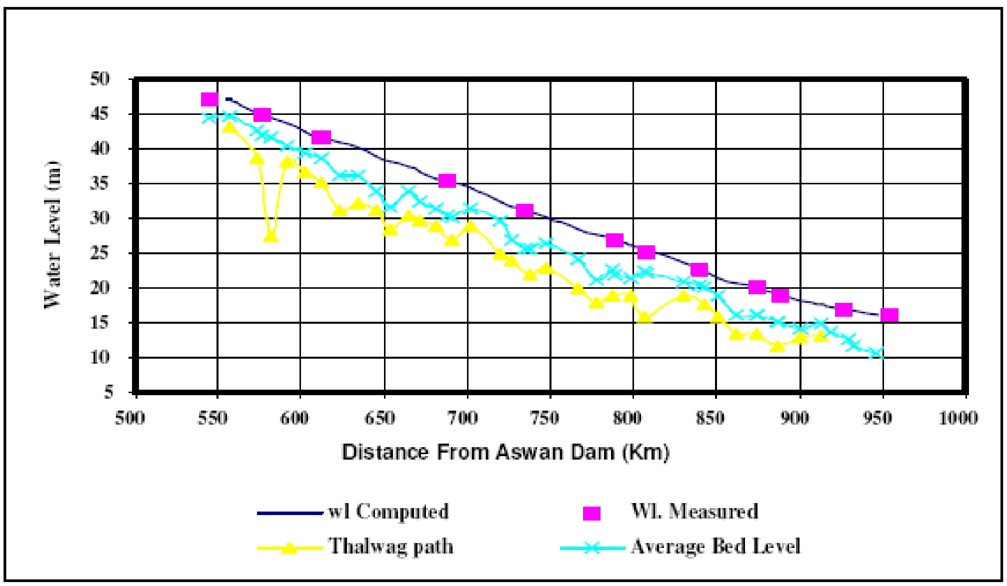

Fig. (4). Verification model

Prediction of Water Surface Profiles (WSP)

Different water discharges are considered for this analysis. These discharges are: 350, 400, and 500 million m^3/day (Figs. 5, 6 & 7). In addition to these discharges, the emergency release from High Aswan Dam, which is 605 million m^3/day (Fig. 8) is also included in the model analysis. Two operating water levels at Delta Barrage were used for 350 m.m^3/day discharge as shown in Figure (5). These levels are: Min. normal operating level (16.33 m), Expected max operating level (17.00 m).

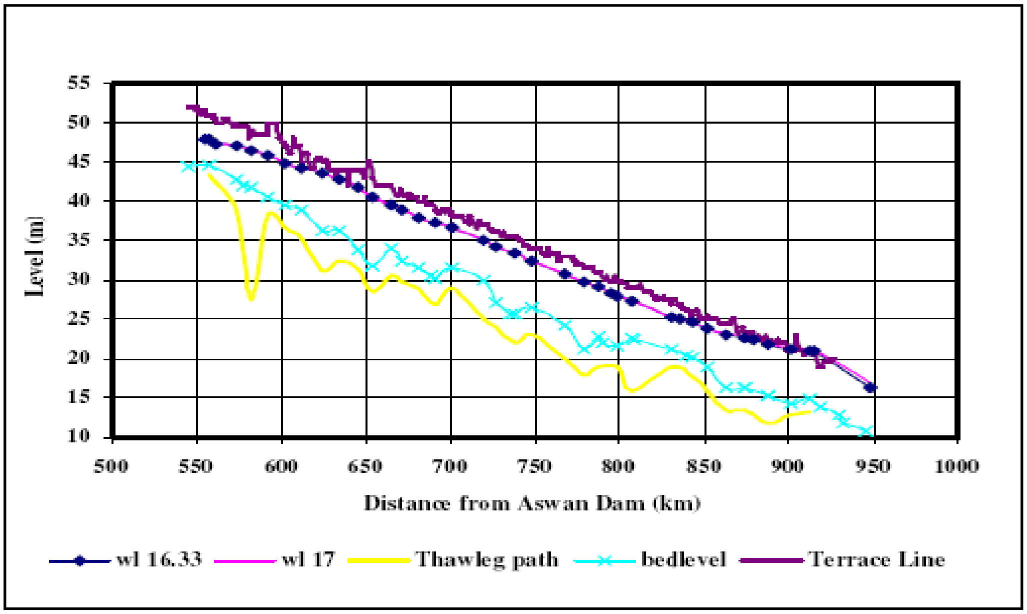

Fig. (5). Model results for 350m.m3/day

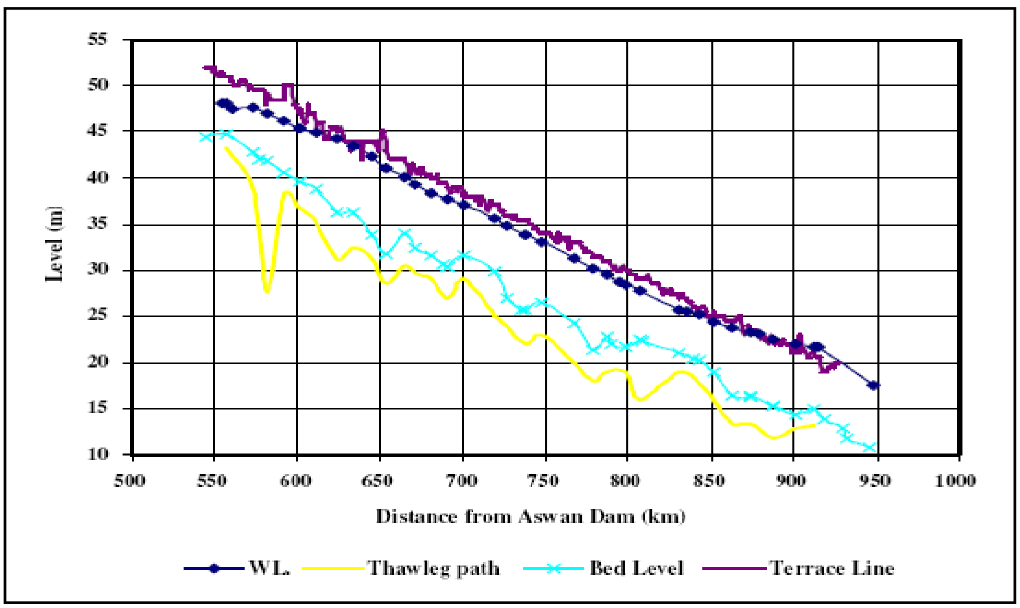

Fig. (6). Model results for 400m.m3/d

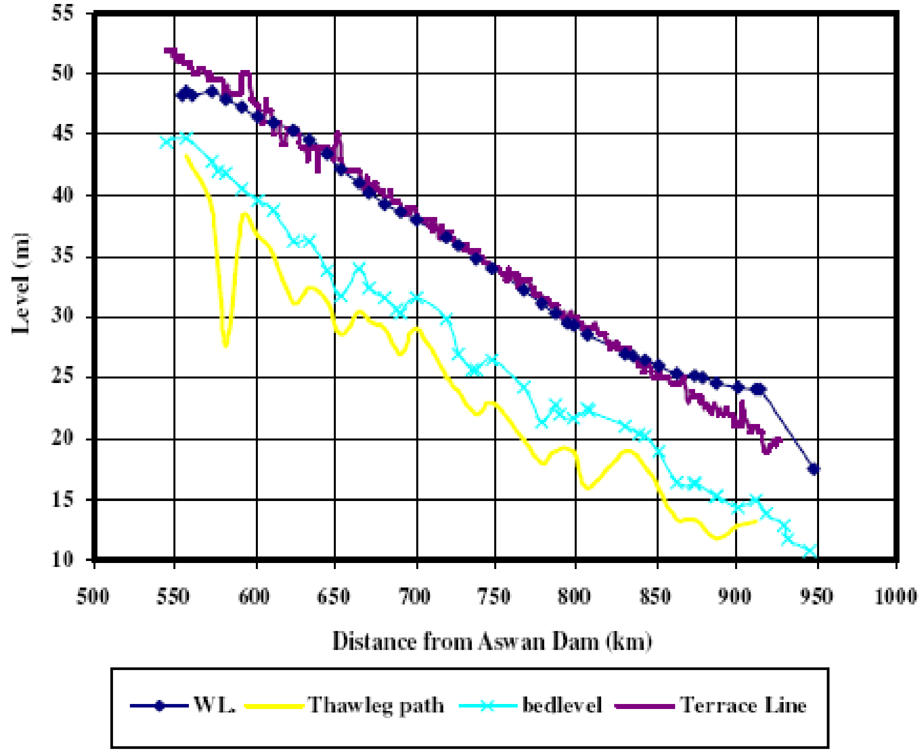

Fig. (7). Model results for 500m.m^3/day

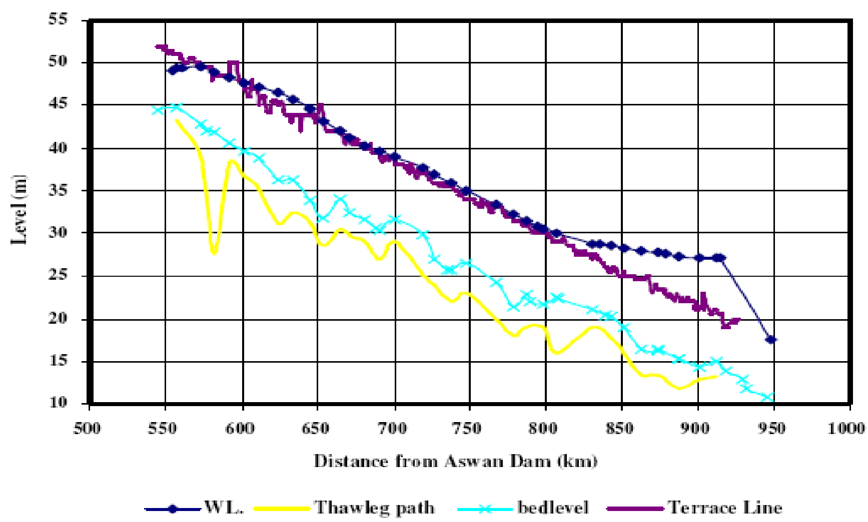

Fig. (8). Model results for 605m.m3/day

Suggested Fish Ladder Design For Assiut Barrage

The HEC-RAS model results showing a limited variation in the tail water fluctuation hence we recommend using pool and weir type but with using an orifice at the bottom of the weir to accommodate the weak leaping ability of Tilapia. The orifice assists with hydraulic control and allows fish to swim upstream rather than be forced to jump to move upstream as shown in Figure (9). In this study tilapia fish was considered as the target species, which has a weak leaping ability.

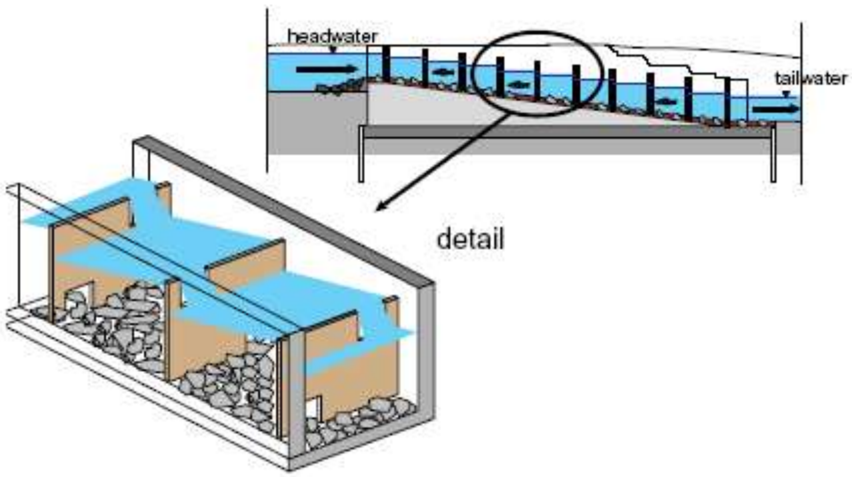

Fig. (9): Conventional pool and weir pass (longitudinal section and pool structure).

DISCUSSION

Effect of Dams on fish communities

The construction of a dam on a river can block or delay upstream fish migration and thus contribute to the decline and even the extinction of species that depend on longitudinal movements along the stream continuum during certain phases of their life cycle. The dam obstructs migration between feeding and breeding zones. The effect can become severe, leading to the extinction of species, where no spawning grounds are present in the river or its tributary downstream of the dam. The concept of obstruction to migration is often associated with the height of the dam. However, even low weirs can constitute a major obstruction to upstream migration. Whether an obstacle can be passed or not depends on the hydraulic conditions over and at the foot of the obstacle (velocity, depth of the water, aeration, turbulence, etc.) in relation to the swimming and leaping capacities of the species concerned.

For any given target species, an obstruction may be total, i.e. permanently insurmountable for all individuals. It may be partial, i.e. passable for certain individuals. It may be temporary, i.e. passable at certain times of the year (under certain hydrological or temperature conditions). During low flow conditions weirs may be insurmountable because the depth of water on the face is too shallow to permit fish to swim. They may however become passable at a higher discharge rate, as water depth increases and the fall at the structure generally decreases. The negative impact on fish caused by temporary obstacles, which delay them during migration and which may cause them to stay in unsuitable zones in the lower part of the river, or cause injury as a result of repeated, fruitless attempts to pass, must not be underestimated (Gerd Marmulla, 2001)).

Dead fish are commonly found in the stilling pool and adjacent downstream channel of dams and mainly these are fish which failed to survive passage through the dam.

Increased upstream and downstream predation on migratory fish is also linked to dams, fish being delayed and concentrated due to the presence of the dam and the habitat becoming more favorable to certain predatory species.

The effect of hydraulic turbines on fish life

The downstream migration of fish at hydroelectric generating stations can induce fish mortality or injury at the Upstream, Downstream from the powerhouse, or during the passage through turbines. Fish mortality above the power station and dam is caused by: increased predation resulting from delays in downstream migration, or by a weakening of fishes fighting an inadequate water flow. The causes of fish mortality induced by contacts with turbine parts can be grouped in four categories (Ruggles and Collins, 1980; Travade *et al.,* 1987; Larinier and Dartiguelongue, 1989; Cada, 1990; Eicher, 1993; Ferguson, 1993; Cada *et al.,* 1997; Cook *et al.,* 1997; Franke *et al.*, 1997; Turnpenny,1998) :

1) Contact of fish with one of the turbine parts.
2) Sudden acceleration or deceleration.
3) Variation in pressure which may become negative or increase to three times the reference pressure, potentially causing the rupture of the swim bladder.
4) Cavitation, which is caused by the creation of gas bubbles in a liquid, may cause various injuries to the fish.

Below the power station and the dam, fish mortality results from:

1) Contact with a structure (migration device, spillway and dam).
2) Too high a free fall from the dam.
3) Increased predation induced by fish weakening or disorientation

The most famous types of turbines are Francis, and Kaplan. The used turbine In the Egyptian hydro power station is Kaplan type. Overview studies on mortality caused by turbine passage indicated mortality rates ranging from 0 to 100 % for Francis turbines (Bell *et al.,* 1967; Ruggles and Collins, 1980; Bell,1990; Winchell *et al.,* 1992; Larinier, 1992). In general, it appears that the mortality rate is rarely below 10 % (Eicher *et al.,* 1987).

The mortality rate varies from 0 to 90 % in Kaplan turbines but it generally ranges from 5 % to 20 %, with a mean value of 15 % (Eicher *et al*., 1987; Larinier and Dartiguelongue, 1989; Larinier, 1992). Table (2) (Winchell *et al.*, 1992) summarizes the mean mortality rates observed for different species in Francis and Kaplan turbines, based on recent studies in which the most frequent sampling biases have been avoided.

Table (2): Average mortality rate (%) of species in Kaplan and Francis Turbine.

Species or group of species	**Average mortality Rate**	
	Kaplan Turbine	**Francis Turbine**
Resident[1]	6.3	5.8
Wild Interoduced[2]	30.2	37
Migratory Species[3]		
Salmonids (salmon, trout)	7.6	18.2
Clupeids (shad, alewife)		
adult	3.6	16
juvenile	19.1	28.6
Centrachids (Cravvie bass)	8.5	11.7

(From Winchell *et al.*, 1992)
1 Unspecified species
2 Hatchery fish injected in the turbine for the test
3 Includes true migratory fish and species doing only migration within a watershed

Fish Passage Design

The design of upstream fish passage requires a dynamic integration of fish behavior, physiology, bio-mechanics, hydraulic analysis, hydrologic study, and engineering approaches. The proper assessment of this integration will achieve safe, timely and efficient upstream fish passage. Safe passage means that migrant fish are passed upstream of an impediment with minimal induced injury and mortality rates. Timely passage occurs when delay time for upstream migrants is minimized. Efficient passage means that most of the migrating fish are passed upstream of the dam.

Fish Passage nature and Biomechanical Ability

Fish utilize a number of different swimming speeds for the variety of situations that they encounter during their life cycle. These include Burst, Cruising and sustained speed which can be maintained by a fish for a duration of only a second, several hours and few minutes, respectively.

Features of an Upstream Fish Passage Facility

The elements of the fish passage system can be summarized as following:

1) Fish way Entrance and attraction flow. The most important aspects of a fish way entrance design are:

   a) Location of the entrance, When choosing an entrance location, high velocity and turbulent zones in a powerhouse or spillway tailrace should be avoided.
   b) Flexibility in operating the entrance flow to accommodate variations in tailrace elevation**.** Fish way entrances may be adjustable submerged weirs, vertical slots, orifices, or other shapes. Some species will avoid using orifices, and at these sites, orifices should not be used.
2) Auxiliary Water System**,** which is a hydraulic system that augments fish ladder flow to provide additional attraction flow. It contains flow control systems, such as control gate, or turbine intake flow control**.**
3) Transport Channels, which conveys flows between different sectors of the upstream passage facility, providing a route for fish to pass. Its design must avoid hydraulic transitions or lighting transitions. It must not expose fish to any moving parts.
4) Counting Stations which provide a location to observe and enumerate fish utilizing the fish passage facility. It including a camera or fish count technician and counting window.
5) Fish way Exit Section, which includes the following features:
   - Add-in auxiliary water valves and/or diffusers
   - Exit pools with varied flow.
   - Exit channels.
   - Coarse trash rack (for fish passage).
   - Auxiliary water fine trash racks and control gates.

6) Fish ladder (Vertical Slot- Denil-pool and Weir).

Vertical Slot Fish Way

In the vertical slot fish way (Fig. 10), baffles are installed at regular intervals along the length to create a series of pools Fish easily maintain their position within each pool.

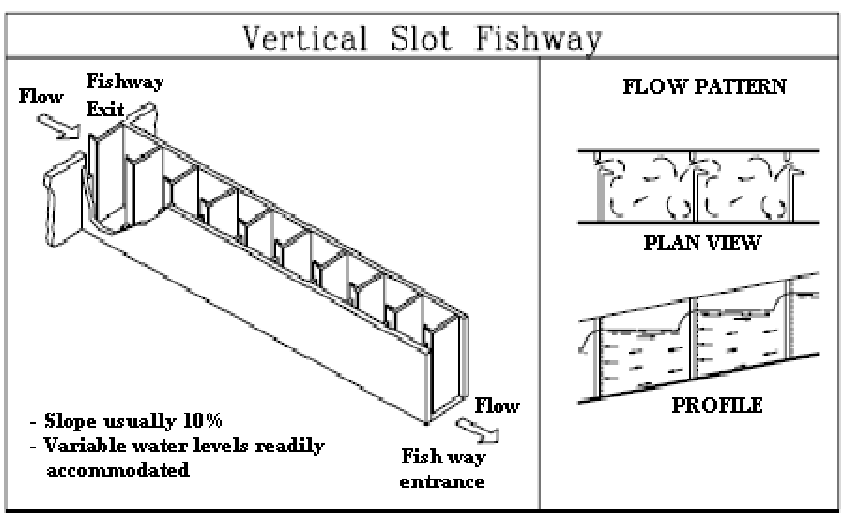

Fig. (10): Vertical slot fish way

The main advantage of the vertical slot fish way is in its ability to handle large variations in water levels also in this type the entire water column is available to fish, which accommodates a wider species variety - since some fish move near the surface and other fish move closer to the streambed. The disadvantage of this type of ladder is that it can require more water to operate. The water velocity through this slot requires fish moving upstream to either burst through the water by swimming quickly, or jump between the water elevation differences.

Denil Fish Way

Denil fish way consists of a rectangular chute with closely spaced baffles or vanes located along the sides and bottom. Over the years various versions of the Denil fish way have been developed and used for fish passage. Two of the more common Denil fish way types used today is shown in Figures (11 & 12). The plain Denil (Fig. 11) contains a series of planar baffles pointing upstream, at an angle of 45 degrees with the fish way floor.

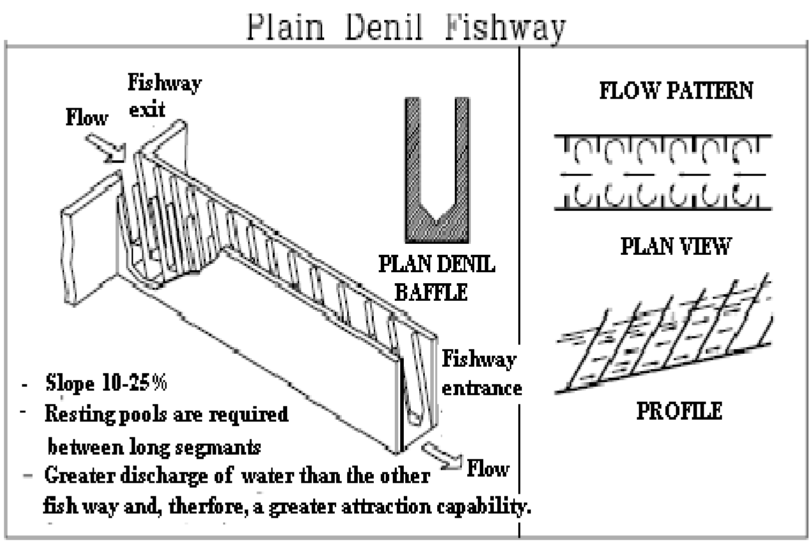

Fig. (11): Plain Denil Fish way

Baffles in the steep pass Denil (Fig. 12) also point in the upstream direction but are angled away from the walls of the chute. The advantage of this type of ladder is that it can be prefabricated and then installed on site, which can be an economical advantage. Additionally this type of installation causes less site disturbance. These fish ways also tend to have much smaller space requirements than other types of ladders. The disadvantage of this ladder is that many species and weaker swimmers cannot ascend the ladder and loose access to upstream habitat.

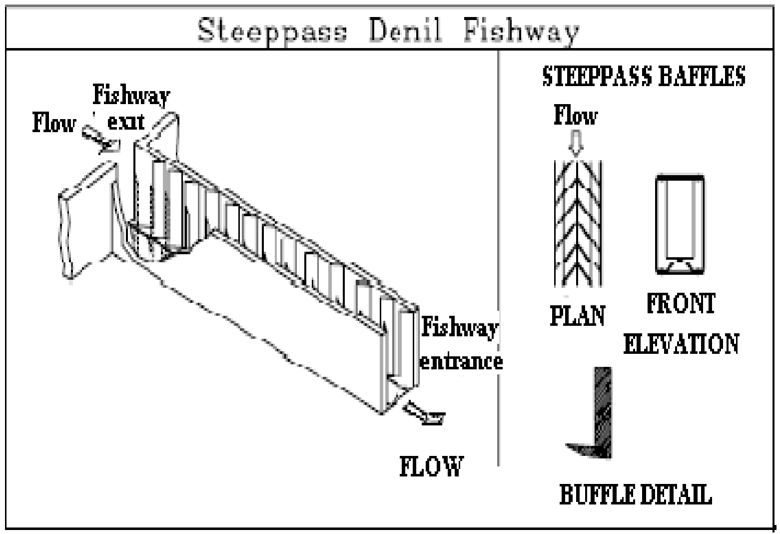

Fig. (12): Steep pass Denil fish way

Pool and Weir Fish Way

The pool and weir fish way consists of a number of pools arranged in a stepped pattern separated by weirs, each of which is slightly higher than the one immediately downstream (Fig. 13). An orifice may also be added to the submerged portion of the weir allowing the fish to pass through the orifice rather than over the weir. While simple to construct, the pool and weir is sensitive to fluctuating water levels and requires adjustments.

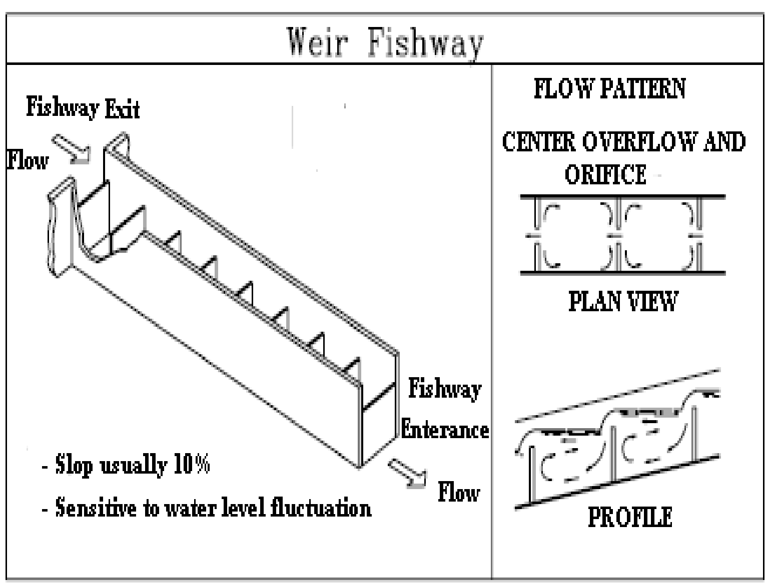

Fig. (13): Pool and weir fish way

In the present study pool and weir fish way was recommended to be used but with using an orifice at the bottom of the weir to accommodate the weak leaping ability of Tilapia fish. The orifice assists with hydraulic control and allows fish to swim upstream rather than be forced to jump to move upstream.

Conclusion and Recommendations

From the results of this study it was obvious that the control structures with their hydropower generation stations not only create a barrier for fish life cycle but also they can induce mortality to fish by passage through turbines. In order to restore Nile River fish production it is recommended to design an efficient fish passage system. This can be done through the following considerations:-

- The accumulated effects of the presence of several barrages along the Nile River.
- Data collection of fish species at present and their run timing.
- Flow distribution into all project components.
- Resolving design uncertainty by model studies.
- The fore bay and tail water rating curve.
- Method of controlling fore bay and tail water changes to maintain fish way design criteria
- Visibility study to determine the target fish and the most suitable style of fish ladder.

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