HYDRAULIC DESIGN OF BORLAND FISH LOCK FOR ORDU TURNASUYU HYDRO ELECTRIC POWER PLANT

by

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B.S., Civil Engineering, Boğaziçi University, 2007

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Civil Engineering
Boğaziçi University
2019

ACKNOWLEDGEMENTS

First, I would like to express my sincere gratitude to my thesis supervisor, Prof. Atilla Akkoyunlu for his guidance, support and encouragement throughout the preparation of this thesis. Without his sympathy, patience and guidance, accomplishment would be impossible.

I extend my sincere thanks to Prof. Orhan Yenigün and Prof. F. İlter Türkdoğan, for their kind and supportive attitude and for showing high interest and giving valuable advices for my thesis.

I want to convey special thanks to Özgün Güler and Azim Turhan from IOG Engineering Company for sharing their experience on Flow 3D.

I also want to convey special thanks to Rıza Gümüsboga from DSI General Directorate for his support for the information about the Fish Passes in Turkey.

Lastly, I would like to thank my wife, my mother and my mother in law for their endless support in this process.

ABSTRACT

HYDRAULIC DESIGN OF BORLAND FISH LOCK FOR ORDU TURNASUYU HYDRO ELECTRIC POWER PLANT

The adverse impacts of artificial(man-made) obstacles such as dams and weirs on aquatic organisms have long been known. These artificial obstacles are critical threats especially to migratory species. Today these obstacles and threats can be made passable by the construction of fish passes. While the construction of fish passages does not remove the main ecological damage caused by dams, such as the loss of river continuum or river habitat, the negative ecological impact of barriers is reduced to a certain point and ecological compatibility is increased[1].

Fish passes are facilitates that enable the migration of aquatic organisms over obstructions to upstream or downstream or both direction[1]. Construction of a fish pass is the most common and reliable way for restoring the longitudinal connectivity of rivers. There are many types of fish passes that are being applied at present such as technical fish passes, close to nature type fish passes, fish locks and fish lifts. In this study general information about all types of fish passes mainly titled as close-to-nature types of fish passes, technical fish passes and fish lifts will be given and Borland Fish Locks will be investigated and mentioned in detail.

The main purpose of this study is to emphasize the challenges of designing a fish pass for a high height dam or weir and to design a Borland fish lock, which has never been done before in Turkey, for Turnasuyu Hydropower Plant Project which will be installed on Turnasuyu River in Ordu. Also research studies that were done before were investigated in detail to understand the behavior of salmonids in order to make assumptions for the design parameters. These design parameters are given in detail in Chapter 4.

ÖZET

ORDU TUNASUYU HİDROELEKTRİK SANTRALİ BORLAND BALIK GEÇİDİ HİDROLİK TASARIMI

Barajlar ve regülatörler gibi insan yapımı engellerin göç eden balıklara olan olumsuz etkileri uzun süredir bilinmektedir. Bu insan yapımı engeller, özellikle göçmen türler ve yüksek oksijen ihtiyacı olan türler için kritik tehditlerdir. Bugün bu engeller ve tehditler, balık geçitlerinin inşasıyla aşılabilir. Balık geçitleri inşa edilmesi, barajların neden olduğu nehir habitatının kaybı veya nehirlerin boyuna bağlanabilirliğinin kaybı gibi temel zararı ortadan kaldırmaz ancak bu önlemler, bu engellerin olumsuz ekolojik etkilerini bir dereceye kadar azaltarak ekolojik uyumluluklarını arttırır[1].

Balık geçitleri, su organizmalarının barajlar ve regülatörler gibi göç etmesine engel olan memba ve mansap göçlerini kolaylaştıran yapılardır[1]. Balık geçiti, nehirlerin boyuna bağlanabilirliğini sağlamak için en yaygın ve güvenilir yoldur. Teknik balık geçitleri, doğala benzer balık geçitleri, balık eklüzleri ve balık asansörleri gibi günümüzde uygulanmakta olan birçok balık geçiti türü bulunmaktadır. Bu çalışmada, esas olarak doğala benzer balık geçitleri, teknik balık geçitleri ve balık asansörleri olarak adlandırılan tüm balık geçiti türleri hakkında genel bilgiler verilecek ve Borland Balık Eklüzleri detaylı olarak incelenecek ve anlatılacaktır.

Bu çalışmanın temel amacı, yüksek bir baraj veya regülatör için balık geçiti tasarlamanın zorluklarını vurgulamak ve Ordu İli’ nde yapılması planlanan Turnasuyu Nehri üzerinde kurulacak olan Turnasuyu Hidroelektrik Santrali Projesi için tüm detayları ile daha önce Türkiye’ de hiç yapılmamış olan Borland Balık geçidi tasarlamaktır. Ayrıca tasarım parametrelerinde varsayımlar yapabilmek ve alabalıkgillerin davranışını anlamak için daha önce yapılan detaylı araştırma çalışmaları ayrıntılı olarak incelenmiş ve tasarım için kullanılacak kriterler Bölüm 4’ de detaylı olarak verilmiştir.

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1. INTRODUCTION

Many fish species migrate long or short distances in certain periods of their lives due to their instinctual behavior. Examples of these species are the salmon (*Salmo salar*) and sturgeon (*Acipenser sturio*) which travel thousands of kilometers to the spawning areas from the sea. In addition to these long-distance migratory species, other fish and invertebrates migrate from one part of the river to the another in short or small periods at certain stages of their life cycle[1].

In the Middle Ages, many dams and weirs in Europe have been built to benefit water power. These historical structures still constitute an important part of our cultural existence. In parallel with industrialization and the increase in the world population, rivers continue to be used extensively by people for a variety of purposes[1].

In addition to the usage purposes such as flood control, transportation and drinking water supply, hydroelectric energy production has encouraged the development of new dams especially as a result of the recent renewable energy resources. In this context, hydroelectric energy is intensively supported in order to reduce the carbon dioxide released from fossil energy sources to nature. As a result of the construction of barriers like weirs and dams, the character and nature of river ecosystems has been significantly affected. These water structures cause all parts of the river to be submerged and transformed into reservoirs by losing their river character. These obstacles also interfere with the longtitunal connectivity of the river, making it impossible for aquatic organisms to pass through. Along with other factors such as water pollution, this leads to a decrease in the populations of some fish species (e.g. salmon, sturgeon, allis shad), and sometimes to extinction[1].

The negative effects of artificial(man-made) obstacles such as dams and weirs have long been known. For example, in the thirteenth century, the Countess of Julius had an edict on the Rur River (the branch of the Maas River in North Rhine-Westphalia), which ordered the holding of all dams during the period when the salmon migrated. While such extreme solutions are not applicable today, existing obstacles can only be overcome by building a fish passage. While the construction of fish passages does not remove the main ecological damage caused by dams, such as the loss of river continuum or river habitat, the negative ecological impact of barriers is reduced to a certain point and ecological compatibility is increased. The reconstruction of the connection between aquatic ecosystems has contributed significantly to the reproduction of endangered fish species in rivers, and more generally to the conservation of species and habitats. Today, the re-establishment of the longitudinal connectivity of rivers is a sociopolitical target shared with the public. This objective can be achieved by eliminating the inevitable obstacles by replacing them with bottom ramps or bottom slopes or fish passages[1].

"Fish passes are structures that facilitate the upstream or downstream migration of aquatic organisms over obstructions to migration such as dams and weirs. While the objective of re-linking waterbodies is by no means limited to benefiting fish but rather aims at suiting all aquatic organisms, such terms as "fish ladders", "fishways", "fish passes" and "fish stairs" will be used throughout these guidelines in the absence of a more appropriate general term that would encompass other aquatic organisms as well as fish." These terms are coming from history because in the past it was seen that only fish were given importance to help them to reach the upper parts of the river. Today, the term "fishway" is used in a broader sense covering all migratory aquatic organisms[1].

Fish ladders can be constructed in a way that is technically useful or mimic nature. Natural solutions include bypass channels and fish ramps, as well as more technical solutions such as classic pool type passages and slotted passages. Apart from the common types, special structures such as eel ladders, fish lifts and fish locks are used[1].

One of the oldest fish lock type is Borland Fish Lock. With this study a Borland Fish Lock is designed for the first time in Turkey for Ordu Turnasuyu HEPP project.

2. INTRODUCTION TO THE FISH PASSES

2.1. Definition and Aim of Fish Passes

Longitudinal connectivity of rivers is mainly prevented by sudden artificial drops, weirs or dams that cannot be passed by aquatic organisms. The construction of a fish pass is the most common and reliable solution for restoring unhindered passage through a river[1]. “Fish way” and “fish ladder” words are used in North America and “fish pass” is used in Europe. No matter how they are named in different areas of the world and which type of fish species they are designed for, all of the fish passages have basically the same definition. They are water passages that allow the fish to pass from or around an obstacle without excess stress[2].

The aim of a fish passage is to direct migratory species to a specified entrance at the downstream and to guide them to pass the obstacle or sometimes in the opposite direction. This is possible with a water course linking downstream to upstream(conventional fish passes) or by transporting them with a mechanized system (Fish locks and Fish Lifts)[3].

In order to decide if a fish pass is effective, fish should find the entrance easily and should pass the facility with in a reasonable time without any injury.

Many behavioral aspects of the targeted species should be taken into account while designing a fish pass. The most important issue for effectiveness is water velocity and the flow pattern that fish will encounter during the passage of the fish way. The velocity and the profile should be in a range that allow the ones that are not superior and have low swimming capabilities to pass the passage[3].

Some species are affected from the flow regime very easily such as high water level variations, too much aeration, flow with turbulence and eddy currents, too large or too small water velocities. All of these can decrease the effectiveness. Other than these hydraulic conditions fish are very sensitive to dissolved oxygen level, water temperature, noise, odor etc.[3].

Fish have preferences or in some cases needs about the ambient light intensity. The gradation of light and optimum light intensity differs for fish types such as some need light to ascend the facility however some are lucifuguos. Also if the light conditions differ too much inside the fish pass, at the entrance or at the exit it can be repulsive for fish species and decrease the effectiveness of the facility[3].

The behavioral analysis of the fish according to these parameters and observations have been documented poorly till now so it is very hard for the engineers to design an effective fish pass[3].

2.2 Types and Principles of Fish Passes

Fish passages are either for upstream migration of species or downstream migration of species, active or passive or sometimes in any combination of these. Active passage means fish is passive to pass the facility and there are some active mechanized structures that help the fish to ascend the fish pass such as fish elevators and locks. Passive passage means fish is active to pass the facility and the facility is passive such as technical fish passes which have very small of moving parts and Close to Nature Types of fish passes. There are many types of active and passive fish passes that are in use [4]. (Table 2.1.)

Table 2.1. Types of Fish Passes

Types of Fish Passes		
Close to Nature Type Fish Passes	**Technical Fish Passes**	
	Active Fish Passes	**Passive Fish Passes**
- Bottom Ramps and Slopes	- Fish Locks	- Pool Passes
- Bypass Channels		- Vertical Slot Passes
- Fish Ramps	- Fish Lifts	- Denil Passes
		- Eel Ladders

The main characteristic of the passive types of passage is providing a hydraulic flow for attraction and hydraulic connection between upstream and downstream of the dam or weir and let the fish decide when to pass the passage. Technical fish passes and close to nature types of fish passes are examples of passive passages[4].

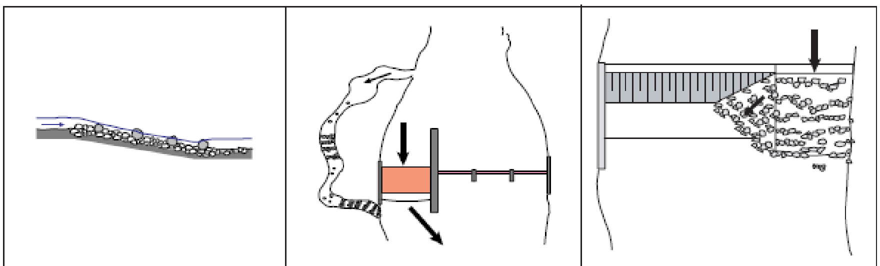
The main characteristic of the active types of passage is providing mechanized assistance for fish to pass through the passage. Fish lifts(fish elevators) and fish locks are examples of active passages. Active passages do not provide a constant hydraulic connection between upstream and downstream of the dam or weir and operate with cycles in a period of time during the day[4].

2.2.1. Close-To-Nature Types Of Fish Passes

Close to nature type fish passes are essentially ramps, slopes and channels that are constructed in the most similar way possible as a replication of nature. Also In addition, the materials that naturally exist in rivers have been used in the construction[1].

The construction types are, for the most case, specifically designed for each project so it is not possible to generalize the constructions. Close to nature type fish passes are more successful than the technical fish passes in terms of addressing the biological needs in relation with connectivity of rivers. Moreover, thanks to the designs are imitating the nature, new running water biotopes are formed in a watercourse[1].

Bottom ramps and slopes, bypass channels, fish ramps are the common "close-to-nature types" of fish passes (Figure 2.1.):



a) **Bottom ramp and slope:**	b) **Bypass channel:**	c) **Fish ramp:**
A sill having a rough surface and extending over the entire river width with as shallow a slope as possible, to overcome a level difference of the river bottom. This category also includes stabilizing structures (e.g. stabilizing weirs), if the body of the weir has a shallow slope similar to the slope of a ramp or slide and is of loose construction.	A fish pass with features similar to those of a natural stream, bypassing a dam. As the dam is preserved unchanged, its functions are not negatively affected. The whole impounded section of the river can thus be bypassed.	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 fish can ascend. Independently of their slope, they are all called ramps; in general the incorporation of perturbation boulders or boulder sills is required to reduce flow velocity.

Figure 2.1. The three types of natural-looking fish passes [1]

2.2.1.1. Bottom Ramps And Slopes.

Principle. A bottom ramp or slope aims to dissipate the energy arousing from hydraulic head difference (Difference between the upstream and downstream) within a certain distance by keeping the slope of the hydraulic gradient as mild as possible. Decreasing the slopes, making the velocities lower and placing rocks are the most favorable method for restoration of river continuum as this is the best way to replicate the nature[1].

It's necessary to make modifications on the sills in a way that letting the fish pass easily and ensure longitudinal connectivity in rivers. Using concrete as a bottom ramp and constructing steep hydraulic drops are unfavorable for the upstream migration of species. Bottom ramps and slopes are especially preferred rehabilitating steep slopes or vertical drops[1].

DIN 4047, Part 5, explains the difference between a bottom ramp and a bottom slope depends on the gradient of the slope. The slopes with gradients of between 1:3 and 1:10 are called ramps whereas the slopes between 1:20 to 1:30 are bottom slopes[1].

Overall Assessment. Construction of bottom ramps with a mild slope is ecologically the most favorable way to built a fish passage in a river where the obstacle can not be removed completely[1].

- The use of concrete material should be minimized and natural materials should be used as much as possible provided that the stability requirements[1],
- Maintenance and operation requirement is as low as only regular waste and debris removal is needed however after flood incidents there may be rehabilitation needs[1],
- The migratory species can pass the passage in both directions; from upstream to downstream and from downstream to upstream[1].

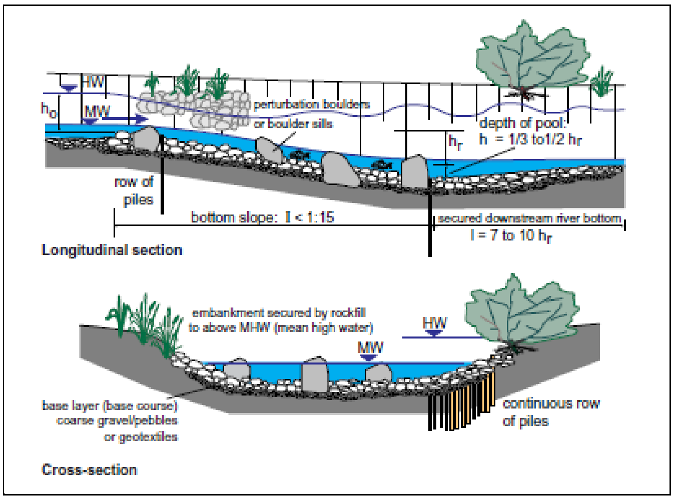


Figure 2.2. Bottom slope as rockfill construction [1]

2.2.1.2. Bypass Channels.

Principle. A bypass channel is a natural looking channel that allows fish to bypass an obstacle and pass through the natural river. This channel can be quite long. Bypass channels are particularly suitable for the existing dams since there is no need to make any change in the existing structure[1].

Generally, only a certain percentage of the discharge of the river is diverted to the bypass channel. But for the case of retired dams, weirs etc. which fulfilled the economical life time, the total discharge except the floods can be diverted through the bypass channel[1].

The major drawback for bypass channels is relatively large spaces are needed for the construction. However bypass channels manage recreate close to identical flow conditions as in undisturbed rivers and preserve or reestablish river continuum[1].

Overall Assessment. The superior features of bypass channels are as follows:

- They visually fir perfectly to nature[1],
- They can be passable by small fish and benthic invertebrates[1],
- They form new habitats in secondary biotope, especially for rheophilic species[1],
- They are less likely to be blocked, maintenance need is low and easy to operate[1],

- They are suitable for inserting to existing dams that have no fish passages without the need for structural changes[1],

The inferior features of bypass channels are as follows:

- They need large space and deep excavations may be needed [1],
- The length of the channel is long[1],
- Since they are free flow structures they are very sensitive to water level variations[1],
- Downstream connection at tail water is usually only possible with technical fish passages[1],

2.2.1.3. Fish Ramps.

Principle. A fish ramp is an integrated structure to a dam or a weir. It does not spread over the whole width of the river as in bottom ramps. Cascades systems are formed by using large boulders in order to make sure that desired water depths and flow velocities are obtained and fish are able to migrate upstream[1].

The width of the ramp mostly depends on the discharge needed for upstream migration of fish. Ramps perform less than desired at times such as floods, which lead to high discharge rates[1].

Figure 2.3. Krewelin weir, Dölln Stream [1]

Overall Assessment. Overall assessment of fish ramps is as follows:

- They are suitable for inserting to existing dams or weirs that have no fish passage[1],
- They can be passable by small fish, fry and benthic invertebrates[1],
- The migratory species can pass the passage in both directions; from upstream to downstream and from downstream to upstream[1],
- They feature a natural looking and visually appealing design[1],
- They are less likely to be blocked, maintenance need is low[1],
- Their guide currents are sufficient and can be easily detected by the fish[1],
- They provide a living space for the rheophilic species[1].

Their disadvantages are:

- They need large space[1],
- They need relatively big amount of flow rates[1],
- Since they are free flow structures they are very sensitive to water level variations[1].

2.2.2. Technical Fish Passes

"Technical fish passes include the following types:

> Pool passes, Vertical slot passes, Denil passes (counter flow passes), Eel ladders, Fish locks and Fish lifts.

In this study only the common types of technical fish passes will be given"[1].

2.2.2.1. Pool Passes.

Principle. The basic principle of the pool passes is to divide the entire channel from the upstream to the downstream with sections of curtain walls to form successive stepped pools. Water usually passes through the openings in the curtain walls (orifices) and the potential energy in the water gradually dispersed in the pools[1]. (Figure 2.4)

Fish Pass from one pool to the other by using the openings at the top(free flow) and at the bottom (orifice flow). The fish face high flow velocities only moving through the openings of the curtain walls, while inside of the pools speed of the flow is low which provides relaxation and recovery for the fish. The bottom of the pass should be rough so that the benthic fauna can be able to pass the fish pass[1].

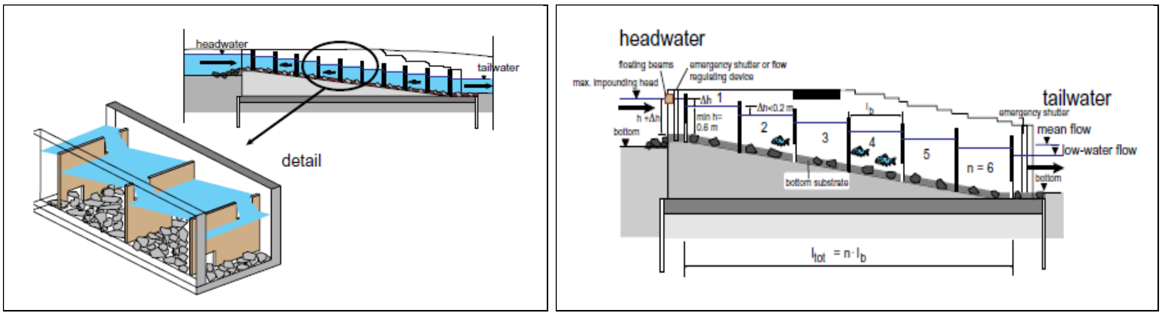


Figure 2.4. (a) Conventional pool pass (b) Longitudinal section through a pool pass[1]

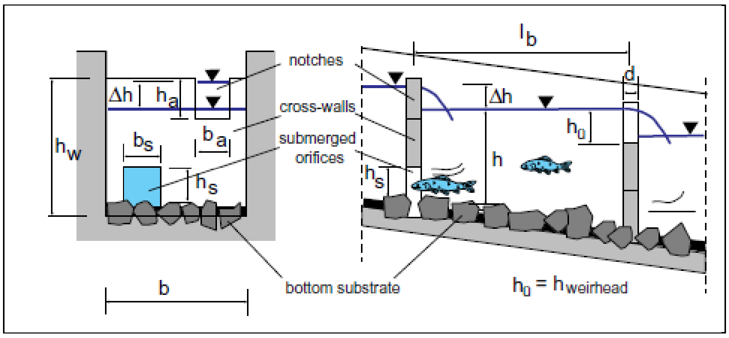


Figure 2.5. Pool-pass terminology [1]

Table 2.2. Recommended dimensions for pool passes [1]

Fish species to be considered	Pool dimensions[1)] in m			Dimensions of submerged orifices in m		Dimensions of the notches[3)] in m		Discharge[4)] through the fish pass m^3/s	Max. difference in water level[6)] Δh in m
	length l_b	width b	water depth h	width b_s	height h_s[2)]	width b_a	height h_a		
Sturgeon[5)]	5 – 6	2.5 – 3	1.5 – 2	1.5	1	-	-	2.5	0.20
Salmon, Sea trout, Huchen	2.5 – 3	1.6 – 2	0.8 – 1.0	0.4 – 0.5	0.3 – 0.4	0.3	0.3	0.2 – 0.5	0.20
Grayling, Chub, Bream, others	1.4 – 2	1.0 – 1.5	0.6 – 0.8	0.25 – 0.35	0.25 – 0.35	0.25	0.25	0.08 – 0.2	0.20
upper trout zone	> 1.0	> 0.8	> 0.6	0.2	0.2	0.2	0.2	0.05 – 0.1	0.20

"Remarks

1) h_s – clear orifice height above bottom substrate.

2) If a pass with both top notches and submerged orifices is planned, the larger pool dimensions should be applied.

3) The discharge rates were determined for $\Delta h = 0.2$ m. The lower value relates to the smaller dimensions of submerged orifices in pools without top notches; the higher discharge is obtained for the larger submerged orifices plus top notches ($\Psi = 0.65$).

4) The difference in water level refers to the difference in level between pools."[1]

Overall Assessment. Being a long-established type of fish passes, pool passes are clearly proven to be functional under the right circumstances concerning the design, layout and maintenance. Pool passes serve as migration facility to a large spectrum of aquatic species such as fish that have high swimming capacity, low swimming capacity and benthic fauna[1].

Pool passes can be functional even with flow rates as low as 0,05 m^3/s to 0,5 m^3/s which is a very big advantage[1].

However since the orifice openings are relatively small and located at the bottom they can be obstructed with the river debris and alluvial materials and stop working properly. In order not to have these type of problems regular maintenance should be made at least on a weekly basis which is a disadvantage of pool passes[1].

2.2.2.2. Vertical Slot Passes.

Principle. A slot pass, also known as vertical slot pass, was originated in North America, where it has been commonly used since the middle of the twentieth century. In the Federal Republic of Germany it has been a part of constructions over the last few years[1].

The slot pass is a modification of a pool pass where vertical slots indent the entire height of curtain walls (Figure 2.6). These curtain walls may have one or two slots, depending on the size of the stream and the flowrate. In the single slot design the slots are always designed on the same side[1].

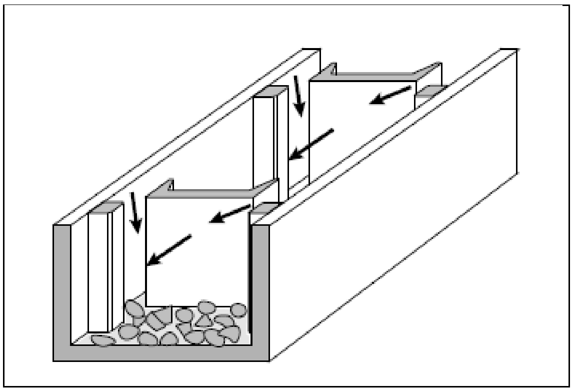


Figure 2.6. (a) Example of a slot pass with two slots (b)Slot pass at the Bergerac weir on the Dordogne (France) [1]

Overall Assessment. Slot passes are ideal ways to ensure the ascent of strong and weak swimming fish as well as small fish

Further advantages are:

- The vertical openings extending along the entire height of the curtain walls are suitable for the bottom-living and open-water fish[1],
- Flow velocities are lower near the bottom of the slots which allows fish with low swimming capacity and benthic invertebrates to pass the passage. For this purpose, a few large stones with the purpose of breaking energy is laid on the floor material [1],
- Not sensitive to both upstream and downstream water levels[1],
- Since the openings extend along the entire height they are less likely to be blocked[1],
- They can be used both in rivers with high flow rates and with low flow rates as low as 100 l/s[1].

Taking everything into consideration, it's a better idea to choose slot passes over conventional pool passes. The up-to-date data also supports this idea[1].

2.2.2.3. Denil Passes.

Principle. A Belgian engineer, G. Denil, invented a fish pass slightly over a century ago. It was initially called a “counter flow pass”, which also depicts the way the system Works, while it is named after its inventor later, “Denil pass”. [1]

A key feature of this type of fish passes is their linear channels where baffles are situated turned against the flow direction, standing relatively close to each other (Figure 2.7. (a)). An important amount of energy is dispersed thanks to the backflows between the baffles and the way the work leads to a relatively low flow velocity in the lower part of the baffle cutouts. With this feature, the Denil pass can have a sharp slope compared to other kinds of fish passes while it can also cope with height difference at a small to medium scale in short distance[1].

The Denil pass may be considered as particularly desirable due to its compact construction and the fact that it can be assembled precast to be installed in an existing dam, It also serves as an answer for the dams that lack space for a fish pass[1].

In Denil’s original design, there were concave-shaped baffles in the fish passes whereas later various different models were created, including LARINIER 1992b. Among all, the most useful version of such passes is the one known as “standard Denil pass” which features U-shaped sections in the baffles (see Figure 2.7. (b))[1].

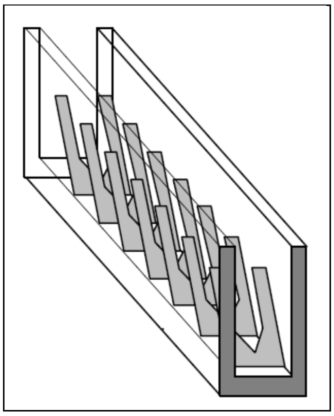
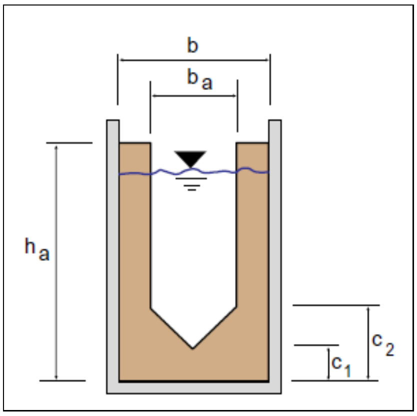


Figure 2.7. (a) Denil pass (schematic)



(b) Baffles in a Denil pass (standard Denil, terminology) [1]

Table 2.3. Guide values for channel widths and slopes in Denil passes [1]

Fish fauna to be considered	Channel width b in m	Recommended slopes I as %	1 : n	Water discharge[1] Q in m³/s for $h^*/b_a = 1.5$
Brown trout, Cyprinds and others	0.6	20.0	1 : 5	0.26
	0.7	17.0	1 : 5.88	0.35
	0.8	15.0	1 : 6.67	0.46
	0.9	13.5	1 : 7.4	0.58
Salmon Sea trout and Huchen	0.8	20.0	1 : 5	0.53
	0.9	17.5	1 : 5.7	0.66
	1.0	16.0	1 : 6.25	0.82
	1.2	13.0	1 : 7.7	1.17

"Note: 1) Calculated according to Equation (1) with the recommended dimensions of the cross-walls according to Table 2.4. $Q = 1.35 \times b_a^{2.5} \sqrt{(g \times I)} \times (h^*/b_a)^{1.584}$*"* *(1)*

Table 2.4. Guide values for the design of baffles in a Denil pass depending on the selected channel width[1]

		Tolerance range	Recommended guide values
Baffle width	b_a/b	0.5 – 0.6	0.58
Baffle spacing	a/b	0.5 – 0.9	0.66
Distance between the lowest point of the cutout and the bottom	c_1/b	0.23 – 0.32	0.25
Depth of the triangular section	c_2/c_1	2	2

Overall Assessment. The advantages of the Denil Pass are as follows:

- Their inclination angle can be steep; thus requires less space[1],
- They are suitable for inserting to existing dams or weirs that have no fish passage and precast members can be used[1],
- They are not sensitive to tail water level changes and they generally produce a good attraction current at the downstream[1].

The disadvantages of this type are as follows:

- They are sensitive to reservoir/upstream water level changes, maximum allowed water level difference is 20 cm[1],
- They need relatively big amount of flow rates[1],
- They are sensitive to be clogged and to be out of order easily. They need regular maintenance[1].

The observations on the Denil passes, looking into ascending fish, show that they function sufficiently well for various species, such as cyprinids (the barbel etc) and salmonids which are weak swimmers, however; current data indicates that the chances for small fish and fish with low swimming performance to pass through are not quite high. Longer structures affects these kinds of fish adversely, too. For this very reason, the species which are large and have a higher swimming performance are at an advantage[1].

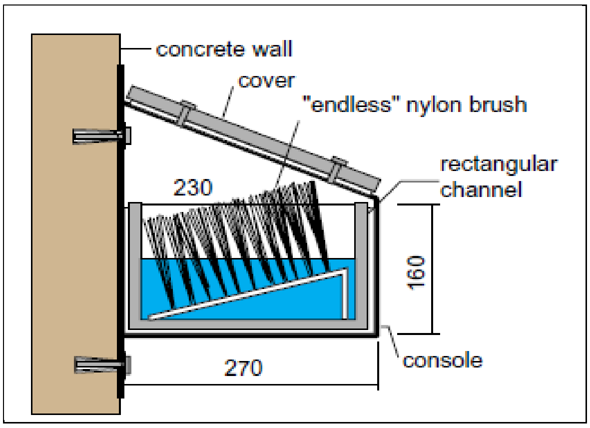
Furthermore, the monitoring showed that it's impossible for microorganisms and invertebrate benthic fauna to ascent[1].

2.2.2.4. Eel Ladders.

Peculiarities of eel migration. A type of a migrating fish, eels inhabit in nearly all kinds of stagnant and flowing water that connects to the sea. It's only after their sexual maturity when they leave fresh water and head to the sea through the river bottoms, most likely to spawn there[1].

"Mitigation facilities specially attuned to the performance of glass eels can be useful in addition to existing fish passes, particularly in the estuary area of rivers where the ascending eels are still very small." Common kinds of fish passes are still functional for longer eels, that's why, there is no need for separate eel ladders in such places[1].

Figure 2.8.(a) Eel (*Anguilla anguilla*)



(b) The eel ladder at the Zeltingen dam on the Moselle [1]

Overall Assessment. It's important to note that an eel ladder is only functional in order to help eel ascent while it lacks means to let other types of fish overcome obstacles on the way. If other kinds of fish need aid, it's necessary to have other types of passes, such as pool passes and Denil passes. Eel ladders should be constructed in the estuary areas of rivers particularly for young eel[1].

2.2.2.5. Fish Locks.

Fish locks are in use as means of mitigation for a while and they are commonly used in the Netherlands, Scotland, Ireland and Russia[1].

A fish lock resembles a ship lock in terms of their structures (see Figure 2.9) as they are made of a lock chamber, a lower inlet and an upper outlet equipped with devices to open and close the locks. The two differ in the way they function as ship locks are impossible to serve as fish passes and are also inadequate with regards to maintain fish migration. While a ship lock may be useful for fish passage in only rare occasions, there are some factors that make them unfit, such as not having permanent guide current, sluice gates staying open only shortly, filling procedures creating turbulence in the chamber and the location of the lock at the dam[1].

On the other hand, temporary arrangements can be made in order to utilize a ship lock to help fish migrate upstream in exceptional situations, such as throughout the main season for eel or salmonids migration[1].

Principle . The way a fish lock functions is described in Figure 2.9. It comes down to four functional stages:

(i) The lock remaining inactive, the water level in the chamber is as high as tailwater with the lower gate being open. A guide current is being released in order to attract the fish into the lock chamber. A slight opening of the upper sluice gate or producing a guide current transferring water via a bypass ends this stage. In this way, the fish are collected in the chamber[1].

(ii) The lock chamber is getting full. The upper sluice gate is gradually wide open while the lower one is shut down. Thanks to the flow originated in the headpond, the fish are guided towards the upper exit of the chamber[1].

(iii) The levels of headpond or reservoir and the water in the chamber are identical. The fish head out of the chamber following a current at the exit to the reservoir after the tailwater receives water via a pipe or slot in the lower sluice gate[1].

(iv) After a period of time(enough time for the fish to leave the lock and swim into the reservoir) lower sluice gate is opened and upper one is closed to empty the lock. The lock is inactive again and the cycle starts from the beginning again[1].

The timing for all the operations are carried out automatically. In most cases the timing varies on between an half-hourly and hourly basis while it should be noted that only monitoring controls can regulate the optimum timing and other temporary arrangements such as the seasonal ones[1].

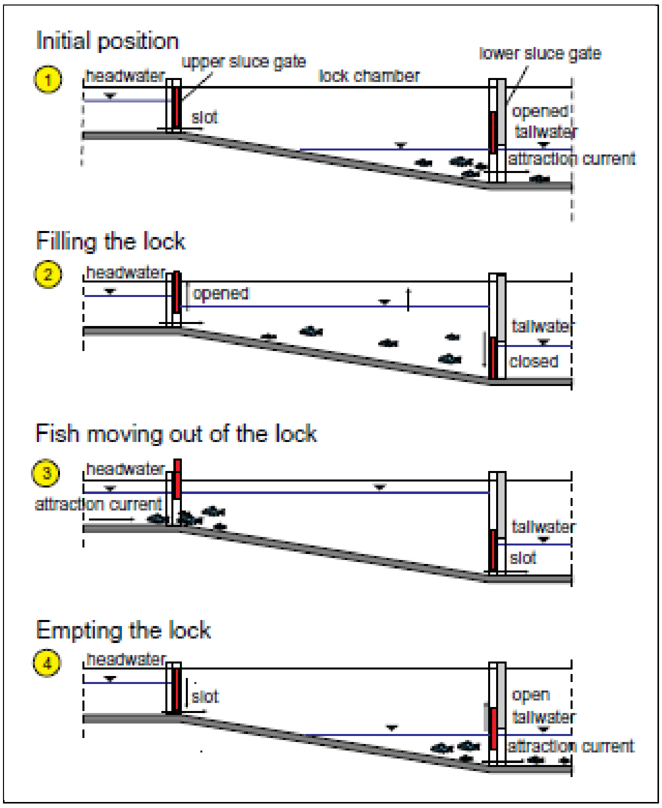


Figure 2.9. How a fish lock works (schematic longitudinal section)

Overall Assessment. The superiority of fish locks over classical technical fish passages is the following conditions if;

- The Space is limited,
- Height difference is high

Equally the fish lock offers structural advantages if very large (e.g. sturgeon) or low performance fish species have to be taken into consideration. With the data present, it is not possible to say that fish locks have superior advantages on the passage of invertebrates, bottom living fish and small fish[1].

Traditional fish passes are less of a work once they are compared with fish locks, whose mechanized parts, operation and control systems need more care and maintenance[1].

2.2.2.6. Fish Lifts.

Principle. Conventional fish passes are barely applicable in some places with remarkable height differences varying from > 6 to 10 m and lower discharges available, because of some reasons that include costs, lack of space and performance of the fish. When a problem arises due to height differences, a lift comes in handy to ensure fish passage from the downstream tailwater to the upstream reservoir[1].

A vessel(trough) is used as the transport means; in order to empty the vessel an outlet gate can be used at the bottom corner of the vessel or the vessel can be tilted to pour the water inside the vessel. When the vessel(trough) is at the bottom position, it is embedded in the base. Fish should be attracted to the fish lift with an attraction flow. The lower sliding gate of the lift is closed at regular intervals. In addition, this gate may be movable horizontally towards the vessel to direct the fish to the vessel. Since the sliding gate is closed the fish collected above the vessel(trough) are trapped and can not go anywhere. The vessel starts to go upward and accordingly fish starts to go upward with the rising vessel. A water-tight connection can be made between the vessel(trough) and the upper water level, or the trough should be emptied directly into the head water in the upstream. With the water in the trough, fish reach the upper channel where there must also be a significant attraction flow[1].

The operation is mostly carried out automatically while migration patterns decide the frequency of this operation[1].

Overall Assessment.

(i) No need for large spaces, and can be used in high height dams. However, construction costs are quite high[1],

(ii) Since the fish are transported passively to the upstream, fish lifts are suitable for the transport of large fish and species with poor swimming capacity[1],

(iii) Fish lifts are not suitable for the downstream migration of fish[1],

(iv) Fish lifts are not suitable for the upstream migration of invertebrates[1],

(v) High water level fluctuations in tail water causes problem to provide the optimum attraction flow[1],

(vi) Construction, operation and maintenance costs are higher related to classical fish passes[1],

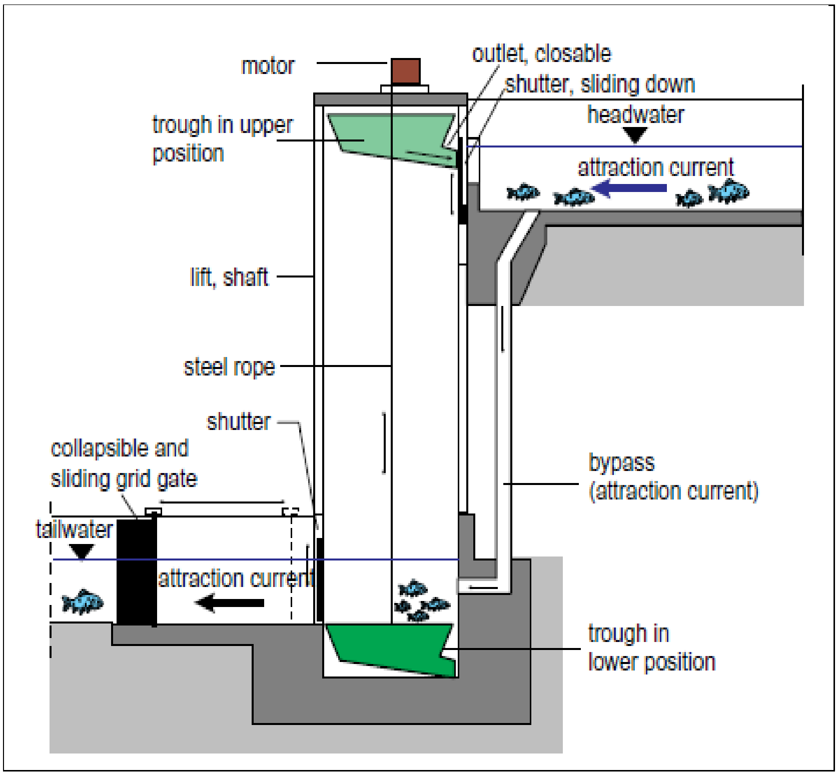


Figure 2.10. Schematic view of the structure of a fish lift and functional principle [1]

2.3. Existing Fish Passes and Regulations about Fish Passes in Turkey

The law about the fish passes in Turkey is as following:

- *Fisheries Law No. 1380 - Prevention of Prohibitions on Rivers:*

(i) *Item 22.* "It is forbidden to establish nets, barriers, fences and similar obstacles in the rivers without the permission of the Ministry of Food, Agriculture and Livestock."

"It is obligatory to make fish passages or elevators for the passing of water products in facilities such as dam and weir which will be established on the rivers and they should be kept in operation continuously." [5]

(ii) *Item 36 article (g).* "Those who violate Item 22 shall be fined with an administrative penalty of five hundred million liras. The activities of such persons are stopped by the court and the barriers are decided to be removed at their own expense." [5]

In Turkey the first fish pass was built in 1953 on Seyhan weir which is located on Seyhan River. The information about the total number of fish passes built on weirs and dams in Turkey are obtained from DSI General Directorate Operation and Maintenance Office and given in Table 2.5:

Table 2.5. The Number and Type of Fish Passes That are Present in Turkey

Facility Type	**Dam**	**Lake**	**Hydro Power - Run of the River Type**	**Weir**	**TOTAL**
Technical Fish Pass	5	2	379	41	427
Fish Lift	3				3
Total Facilities	820	2	627	270	1719
Total Fish Pass	8	2	379	41	430

As Seen in the Table 2.5 almost all of the fish passes in Turkey are Technical Fish Passes and there have been only 3 fish lifts constructed until now in Turkey. Also it is seen from the Table 2.5 that there is no fish lock is present on any facility in Turkey. Further details of fish passes for each facility in the first 6 regional directorates(There are 26 Regional Directorates in DSI at Total) of DSI are given in Appendix A from Table A.1 to Table A.5 below for informatory purposes. For Table A.1 to Table A.5 List of Symbols are given below:

Aim	E	: Energy	I	: Irrigation
	DW	: Drinking Water	F	: Flood
Pass Purpose	FP	: Fish Pass	NE	: Not Existing
Fish Pass Type	P	: Pool Pass	VSP	: Vertical Slot Pool Pass
	FL	: Fish Lift	CT	: Collect and Transport

3. CHALLENGES OF FISH PASS DESIGN ON HIGH HEIGHT DAMS/WEIRS AND INTRODUCTION TO BORLAND FISH LOCKS

Fish passes are crucial facilities that should be present on any obstacles built on a river to provide migration of species and river continuum. However designing a fish pass for higher dams or weirs have many challenges. The higher the obstacle the harder for the fish to pass through it.

Generally, when the upstream water level in the reservoir is constant, the design of the water intake structure of the fish pass does not constitute a problem. However, special designs should be considered for dams where the water level changes are observed. In such a case, the fish passage needs to be designed in such a way that it continues to operate with little impact on the changing water levels, or that appropriate structural arrangements for the water intake have to be included in the project. When the maximum change in the upstream water level is between 0.5 and 1.0 m, vertical slot pass, a type of technical fish pass, can be used. However, in cases where the change of water level exceeds 1 m, it is necessary to construct more than one water intake structure at different elevations to maintain the function of the fish passage or to consider mechanized fish passages. In order to ensure that the fish pass through the passage easily, there should not be severe turbulence at the exit of the passage and the flow rate should not exceed 2 m/s[1].

In order to understand the effect of the height increment on the velocity of exit water, in the general orifice formula; velocity of the water is equal to √(2xgxh). By putting h = 0,2 m and g = 9,81 m/s^2 in the equation the corresponding value of v becomes 1,98 m/s. Since the velocity over 2 m/s must be avoided at the fish pass exit; there should be exits in every 0,2 m and also these exits should be connected to pools and/or channels at downstream side to connect the stream bed and upstream side to connect the reservoir. This means 50 different exits and 50 different pools and/or channels should be constructed even for a weir that has 10 m change in reservoir elevation. The space needed for this type of structure makes it in most cases impossible to construct active fish passes to high height dams or weirs where there is a significant variation in reservoir elevation. Also even if there is enough space to construct this type of fish passes it is not economical and cost efficient. In these type of projects(significant variations in reservoir elevations) Fish Locks and Fish Lifts given in 2.2.2.5 and 2.2.2.6 are used to overcome these challenges. In this thesis study only Borland Fish Locks will be mentioned in detail in Chapter 3 and Chapter 4 and other types are mentioned briefly only in Chapter 2.

3.1. Borland Fish Locks

A fish lock is a facility to ascend fish over an obstacle such as a dam or a weir by attracting the fish into a pool(entrance pool) at tail water elevation and raising the pool to the reservoir elevation(exit pool or upper chamber) and then allowing the fish to swim into the reservoir[2].

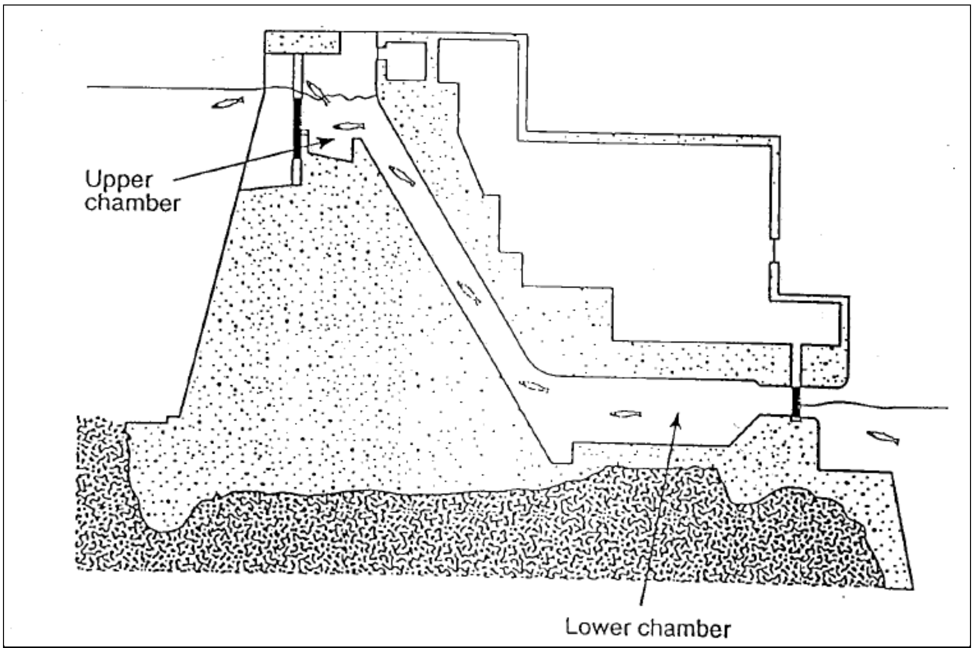


Figure 3.1. Classic Borland fish lock [8], [9], [10]

“Fish Locks have much shorter history than conventional type of fish passes. A. Mr. Malloch of Perth, Scotland, has been credited with evolving a scheme similar to modern fish locks around 1900, but evidently this was too early for the idea to be accepted, as no immediate applications followed. The period of initial applications of fish locks on a practical scale corresponds to a period when dams were being designed that were much higher than any previously conceived. This was in the 1920s. As long as dams were less than 15 m in height, conventional (active) fishways were considered to be unduly expensive. But as dams higher than this became more common, and some were envisaged on salmon streams to height of 100 m, there was more incentive to find alternative methods for providing adult fish passage. Another factor besides economy was instrumental in the development of these devices. This was the fear that fish would not be physically capable of ascending active fishways over high dams." [2]

The first of the modern fish locks in Europe was constructed in 1949 at Leixlip Dam on the River Liffey near Dublin, Ireland. The designer of the lock was J.H.T. Borland and later installations took his name as Borland Fish Locks or fish passes. Since then many have been constructed on dams or weirs up to 61 m height. They are accepted successful for the passage of salmon and trout[2].

Generally Borland Fish Locks are used on dams or weirs more than 10 m in height. Conventional types of fish passes are more convenient and cost effective for lower dams and weirs[2].

Borland Locks are also used for downstream migration of salmon, smolts and kelts. Also when the turbines are off and spillways are not working, the only hydraulic connectivity is provided with the help of Borland Locks. In 1957 according to an unpublished report of The Salmon Research committee of the Scottish Home Department and North of Scotland Hydroelectric Board, as many as 458 kelts descended Torr Achilty fish lock and in one season 13.943 smolts were recorded descending the Meig Dam fish lock[2].

Borland fish locks consist of two pools one is located at the upstream(Exit Pool) at reservoir water elevation and the other one is located at downstream(Entrance Pool) at tail water elevation and an inclined or vertical channel combining these two pools. In each pool one sluice gate is located to provide water entering and water exiting. While the sluice gate is closed at the downstream pool to provide water exit a by-pass vane is installed.

The North of Scotland Hydro-Electric Board standardized the Borland Fish Locks as shown in Figure 3.2[6].

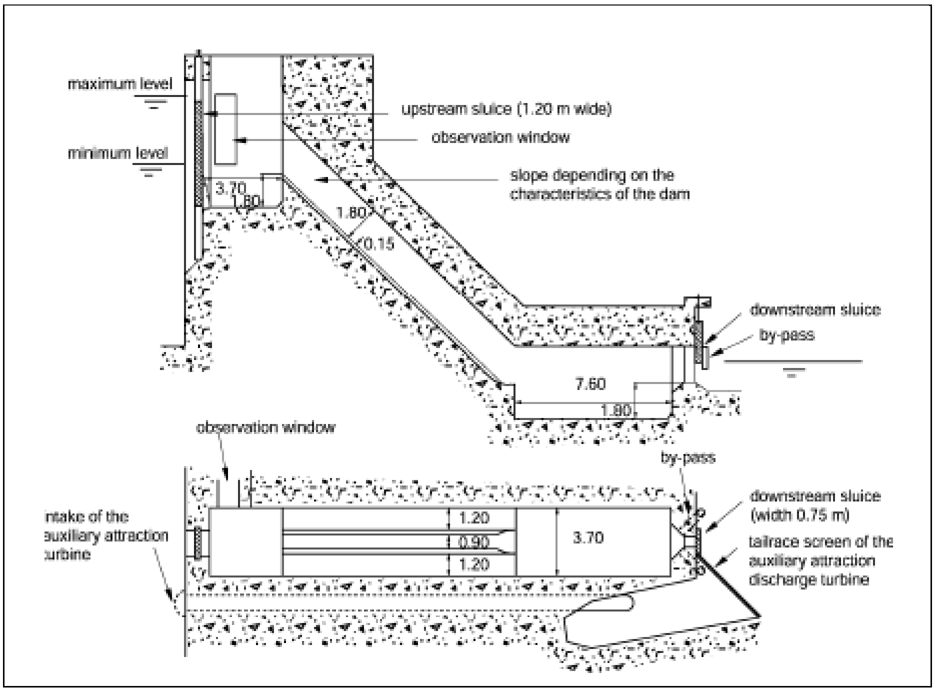


Figure 3.2. Cross-Section of a Borland fish lock [6]

The working principle of a Borland Fish Lock is very simple and similar to navigation locks used for boats. By opening the sluice gate at the upper chamber(exit pool) attraction flow is led to the fish lock and then continues through the downstream chamber(entrance pool) and finally exits to stream bed. Fish are attracted to downstream chamber with this flow and after some period of time downstream chamber sluice gate is closed and fish that are present in the downstream chamber are trapped. Since the upstream sluice is open water starts to rise till the water level in the fish lock is the same as the reservoir level. Then by-pass vane at the downstream chamber is opened and by this way descending current is started to flow to encourage the fish to leave the fish lock[6].

The operating cycle can be summarized as follows (Figure 3.3):

(i) Attraction phase : In the attraction phase, the sluice gate at the downstream pool (entrance pool) is open. The flow is controlled by the sluice gate at the upstream pool (exit pool). Flow entering from the upstream sluice gate flows through the inclined channel and then downstream pool(entrance pool) and then flows out of the lock and reaches to tail water. This flow attracts fish to enter into the downstream pool(entrance pool)[6].

(ii) Filling/Exit phase : After a specific period of time (enough time needed for fish to be attracted to enter into downstream pool (entrance pool)) the sluice gate at the downstream pool is closed. The lock starts to fill up with water. Fish follows the rising water to the upstream pool when the lock is fully filled with water. Sluice gate at the upstream pool is still open. Then by-pass vane at the downstream pool is opened and fish are attracted to leave the upstream pool (exit pool) with this flow. Fish exit the upstream pool and swim into the reservoir[6].

(iii) Emptying phase : After a specific period of time (enough time needed for fish to exit the upstream pool and swim into the reservoir), the upstream sluice gate is closed and since the by-pass vane is still open the lock starts to be emptying. The emptying process is mainly done by by-pass vane slowly in order not to repel the fish in the vicinity of the tail water. When the water in the lock becomes low enough for the sluice gate to be opened; the flow coming out the lock will not disturb the fish in the tail water. Since the appropriate conditions for the fish at the tail water are provided; the sluice gate at the downstream pool is opened. After the lock is emptied then sluice gate at the upstream pool is opened and attraction phase starts again. Each operation cycle(starting from attraction to the end of emptying) lasts one to four hours[6].

Since Borland Fish Lock design is very flexible it can be applied for a spectrum of dam heights from several meters to over 60 meters[6].

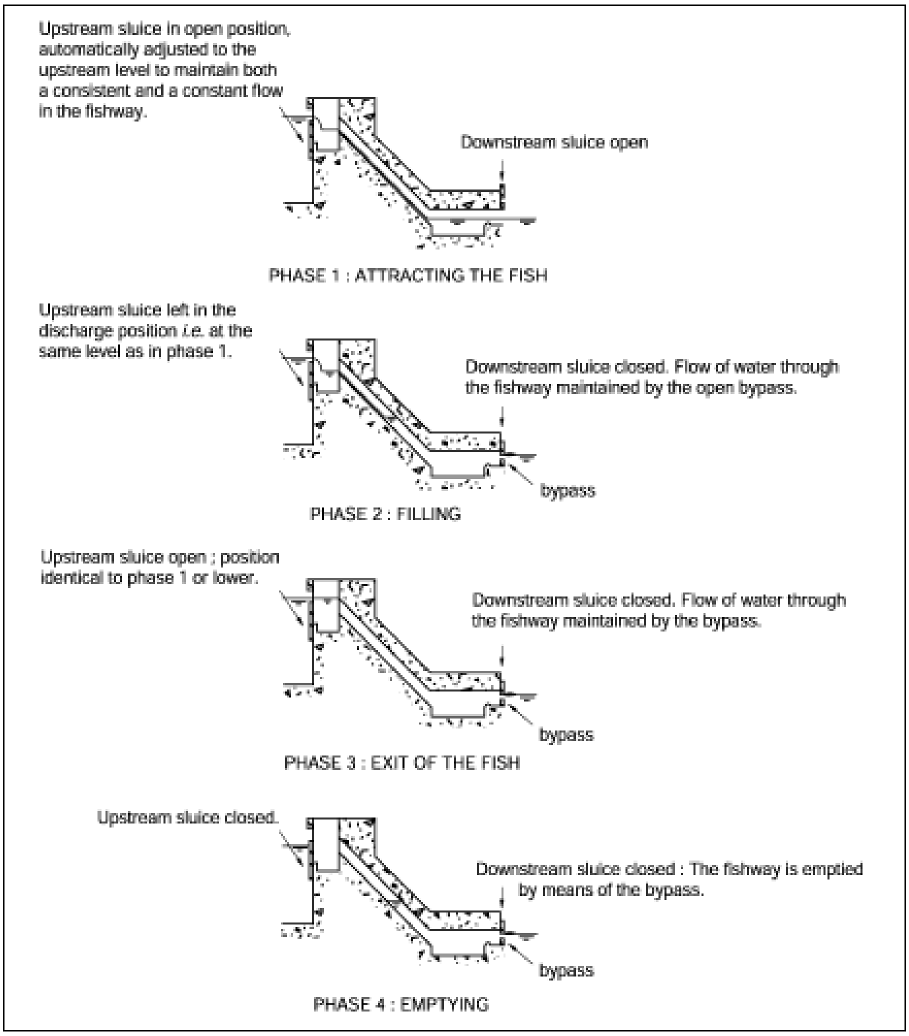


Figure 3.3. Diagram showing the operating principle of a Borland Fish Lock [6]

An alternative open Borland Fish Lock can be applied when the head difference is less than 4 or 5 meters. (Figure 3.4.)[6].

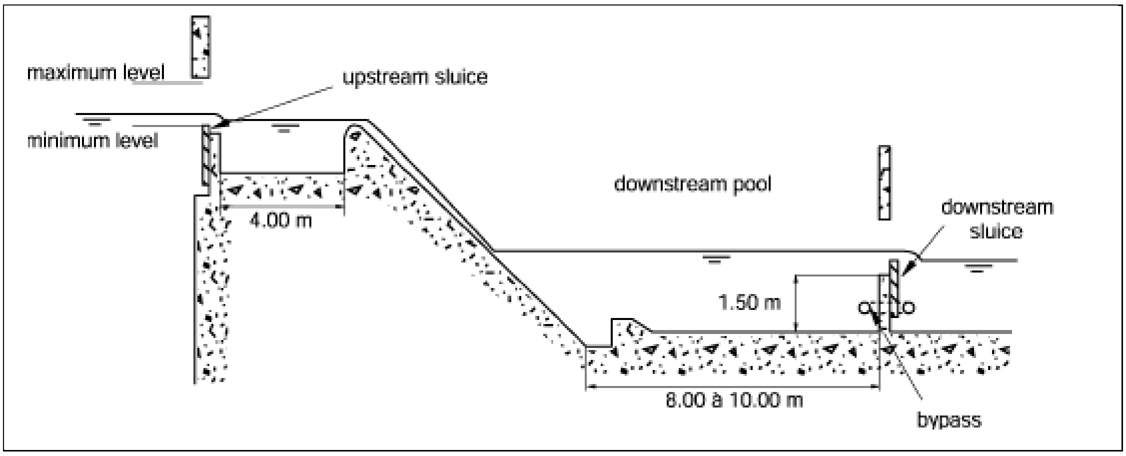


Figure 3.4. Schematic Plan of an open fish lock for a low head installation [5]

4. BORLAND FISH LOCK DESIGN FOR ORDU TURNASUYU HYDRO POWER PLANT

Turnasuyu Hydro Power Plant Project is located in Ordu in Black Sea Region of Turkey. The project has not been started construction yet. The project consists of 2 high weir bodies and 2 power plants which are located as cascade projects. The first weir body is called Inoren and the second one called Buben. They are very similar to one another. In this thesis study, I will concentrate on only Inoren weir. Google earth view of Inoren weir and reservoir area is given in Figure 4.1.

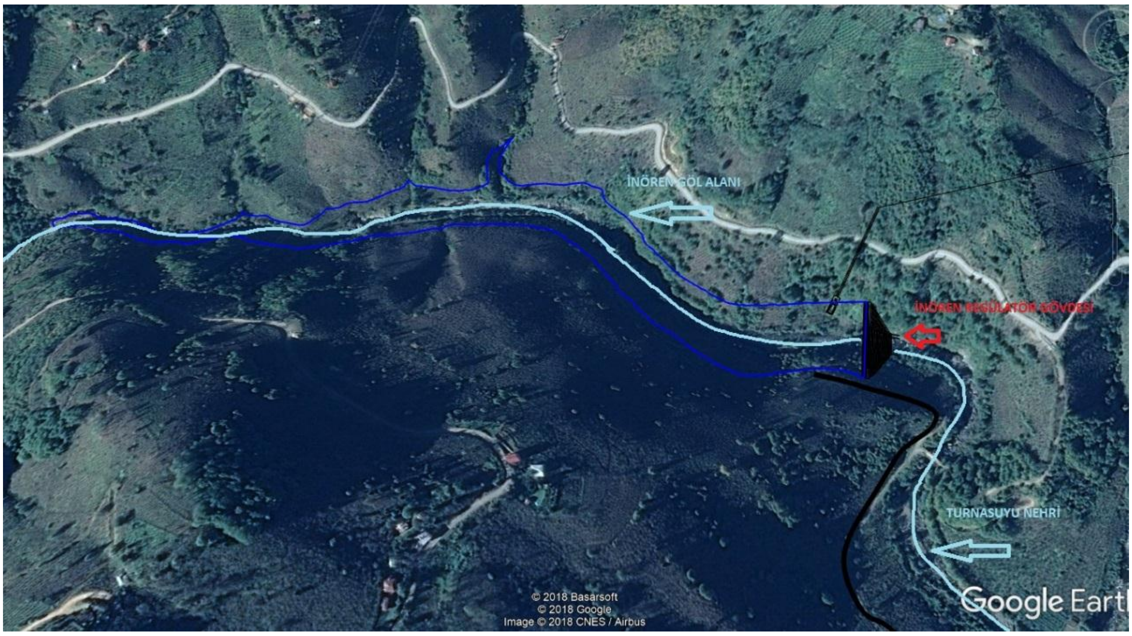


Figure 4.1. İnören Weir General Layout Plan on Google Earth

General Characteristics of the Inoren Project are given below:

Catchment Area	: 211.5 km^2
Annual Average Flow	: 4.22 m^3/s
Dam Type	: Roller Compacted Concrete Gravity
Dam Height From the Thalweg	: 34.50 m
Dam Height From the Foundation	: 37.00 m
Total Reservoir Volume	: 1.200.000 m^3

Active Reservoir Volume	: 370.000 m^3
Ecological Flow	: 0.516 m^3/s
Thalweg Elevation	: 337.50 m
Maximum Operation Water Level	: 367.00 m
Minimum Operation Water Level	: 362.50 m
Design Flowrate	: 13.40 m^3/s
Tunnel Diameter	: 3.00 m (Modified Horseshoe Shape)
Tunnel Length	: 4767.00 m
Surge Tank Diameter	: 8.00 m
Maximum Water Level In Surge Tank	: 381.02 m
Design Head	: 180.02 m
Installed Power	: 22.00 MW
Tailwater Elevation	: 181.00 m
Annual Electricity Generation	: 51.495 GWh/Year

Inören Weir is located on Turnasuyu river in Ordu. In order to discover the ecological environment and to minimize the effects of the project on the existing ecology an Environmental Impact Assessment Report is prepared by three scientists and this report is approved by General Directorate of Environmental Impact Assessment. According to this report the most important fish specie that should be taken into account for the ecological flow and fish pass design is *salmo trutta fario* (A type of fish in the salmonids group). Spawning migration to the upstream of the river is an important characteristics of *salmo trutta fario*. For this fish specie the reproduction period is assumed to start in April and end in June in the Environmental Impact Assessment Report which means more attention should be paid to the fish passes between these months[11][12].

Since Inoren weir has 4,50 m water level variations (maximum operating level – minimum operating level) at the reservoir and the total height of the weir is 34,50 m from the thalweg; technical fish passes or close to nature fish passes can not be a solution for the ecological needs of this project. A comparison was made between fish lifts and fish locks to choose the most efficient fish pass type for Inoren weir and finally fish locks are chosen to be designed because of the superior features of the fish locks that are given below:

- Fish lifts are not suitable for the downstream migration of fish[1],
- Fish lifts are not suitable for the upstream migration of invertebrates[1],
- Maintenance and operation costs of the fish lifts are higher than the classical fish passages, and fish locks,
- The construction cost of the fish lock will be cheaper than a fish lift on Inoren Weir. (Because of the inclined downstream face geometry of the weir, a fish lock will be constructed on the weir with no additional foundation or support costs)

A Borland Fish Lock type fish pass is a very effective fish pass for spawning migration of salmonids and a serious amount of research studies has been done for salmonids' behavior against Borland Fish locks. Also Borland Fish Lock is very effective for the upstream migration of fish which is the most important case for reproduction of salmonids. So a Borland Fish Lock type fish pass has been decided to be designed for this project.

A schematic view of Borland Fish Lock is given in Chapter 3 but since every project has different ecological flow conditions, different heights, different fish crowd, different fish species etc. every fish lock should be designed specifically for each project.

In order to design the Borland fish lock of Inoren weir a serious literature research has been done and some design criteria have been formed. The design is based on these criteria:

(i) The upstream sluice of the fish lock should be adjustable to provide constant free flow for the fish pass,

(ii) Generally, when the upstream water level in the reservoir is constant, the design of the water intake structure of the fish pass does not constitute a problem. However, special designs should be taken into account for dams where the change in the water level is observed. In such a case, the fish passage needs to be designed in such a way that it continues to operate with little impact from the changing water levels, or that appropriate structural arrangements for the water intake have to be included in the project[1],

(iii) The maximum cruising speed(the maximum speed at which fish can swim continuously without showing any signs of fatigue) is:

$V_{cr} = 0.15 + 2,4 \times L$ [7]

L = Body Length of the Fish

For L = 0,8(For *Salmo Trutta f.* in Table 4.1.) the corresponding value of V_{cr} is 2,07 m/s.

The speed of flow in the entrance pool, inlet channel, resting pool and attraction channel of the fish lock (bottom pools and channels) should not be greater than maximum cruising speed.

Table 4.1. Average body lengths of adults of some larger fish species [1]

	Fish species	**Body length [m]**
Sturgeon	*Acipenser sturio*	3.0
European catfish	*Silurus glanis*	2.0
Pike	*Esox lucius*	1.2
Salmon	*Salmo salar*	1.2
Huchen	*Hucho hucho*	1.2
Sea lamprey	*Petromyzon marinus*	0.8
Sea trout	*Salmo trutta f. trutta*	0.8
Allis shad	*Alosa alosa*	0.8
Barbel	*Barbus barbus*	0.8
Lake trout	*Salmo trutta f. lacustris*	0.8
Bream	*Abramis brama*	0.7
Orfe	*Leuciscus idus*	0.7
Carp	*Cyprinus carpio*	0.7
Chub	*Leuciscus cephalus*	0.6
Grayling	*Thymallus thymallus*	0.5
Twaite shad	*Alosa fallax*	0.4
River lamprey	*Lampetra fluviatilis*	0.4
Brown trout	*Salmo trutta fario*	0.4

(iv) Placing the fish passage exit structure (the entrance of the fish) to as near as possible to the dam or weir body will minimize the formation of the dead zone between the dam and the entrance to the fish passage. This issue is important because the fish ascending upstream can easily be obstructed and trapped in the dead zone[1],

(v) The attraction effect depends on the resulting flow rate, angle and the ratio of the river flow to the flow rate of the water exiting from the fish passage. The attracting current should be detectable in areas preferred by the target species, especially at the downstream; in this area the fish are forced to swim due to the tail water characteristics. Attracting flow water velocity from the fish passage should be between 0.8 and 2.0 m/s except for special cases[1],

(vi) The connection between the fish passage and the natural stream bed can be facilitated by making the entrance of the fish easier. This can be achieved by a ramp with a maximum slope of 1/2 (30^0)[1],

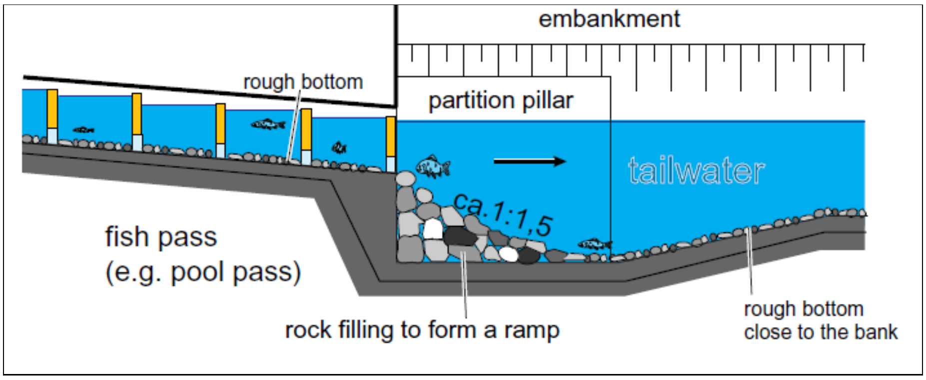


Figure 4.2. Underwater rockfill ramp connecting the fish pass entrance with the river bottom

(vii) Fish that are mainly active during the day are called diurnal fish. Diurnal fish are reluctant to enter the dark channels. To overcome this problem, the daylight should enter into the fish passage and not be covered. If this is not possible, the passage should be artificially illuminated by lighting as close to natural light as possible[1],

(viii) It is suggested that the exit of the fish pass (water intake) should be located at enough distance from the turbine intake structure to prevent the fish exiting from the fish pass from drifting into the turbine. The distance between the fish passage and the turbine intake structure should be at least 5 m[1]. Because of this reason the fish lock intake is designed at the opposite bank of the weir with the headrace tunnel intake.

(ix) Placing resting pools and/or resting areas should be useful. While migrating to upstream through a passage, fish especially weak ones, can take a break and recover themselves in these areas[1],

(x) The fish that are migrating to downstream should not be injured due to impact of crashing to the side walls of the exit pool. The length of the exit pool should be long enough that free fall of dropping(free jet) water passing through the sluice gate should not hit the side walls, it should drop directly into the water to avoid injury of downstream migrating fish. The path of the flow jet dropping into the exit pool can be expressed by the parabolic equation:

$$-y = x^2 / 4H \qquad \text{(Reference [15] page 376)}$$

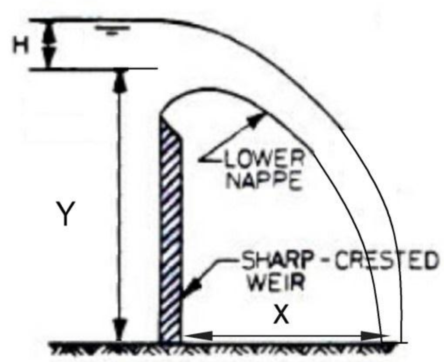


Figure 4.3. Trajectory of free jet flow

Where H is the head on the center of the opening.

(xi) "Experiments showed that fish could not stand an impact velocity greater than 16 m/s when dropped into a pool. When striking velocities exceed 16 m/s damage begins to occur"[13], [14]. Regenthal dropped fish from a helicopter 50 ft(15,23 m), 185 ft(56,38 m) and 325 ft (99 m) into a hatchery pond[14].The results are given in Table 4.2:

Table 4.2. Survival Rates of Fish dropped from a helicopter

Size of Fish	**Percentage Survival**		
(cm)	**50 ft(15,2 m) drop**	**185 ft (56,2 m) drop**	**325 ft (99 m) drop**
15 – 18	100%	98%	98%
30 – 38	100%	25%	7%
66 – 71	100%	50%	0%

Experiments show that the free fall drop height of water at the exit pool should not be bigger than 15,2 m and the flow velocity at the end of the inclined pipe should not be bigger than 16 m/s to avoid injury of downstream migrating fish.

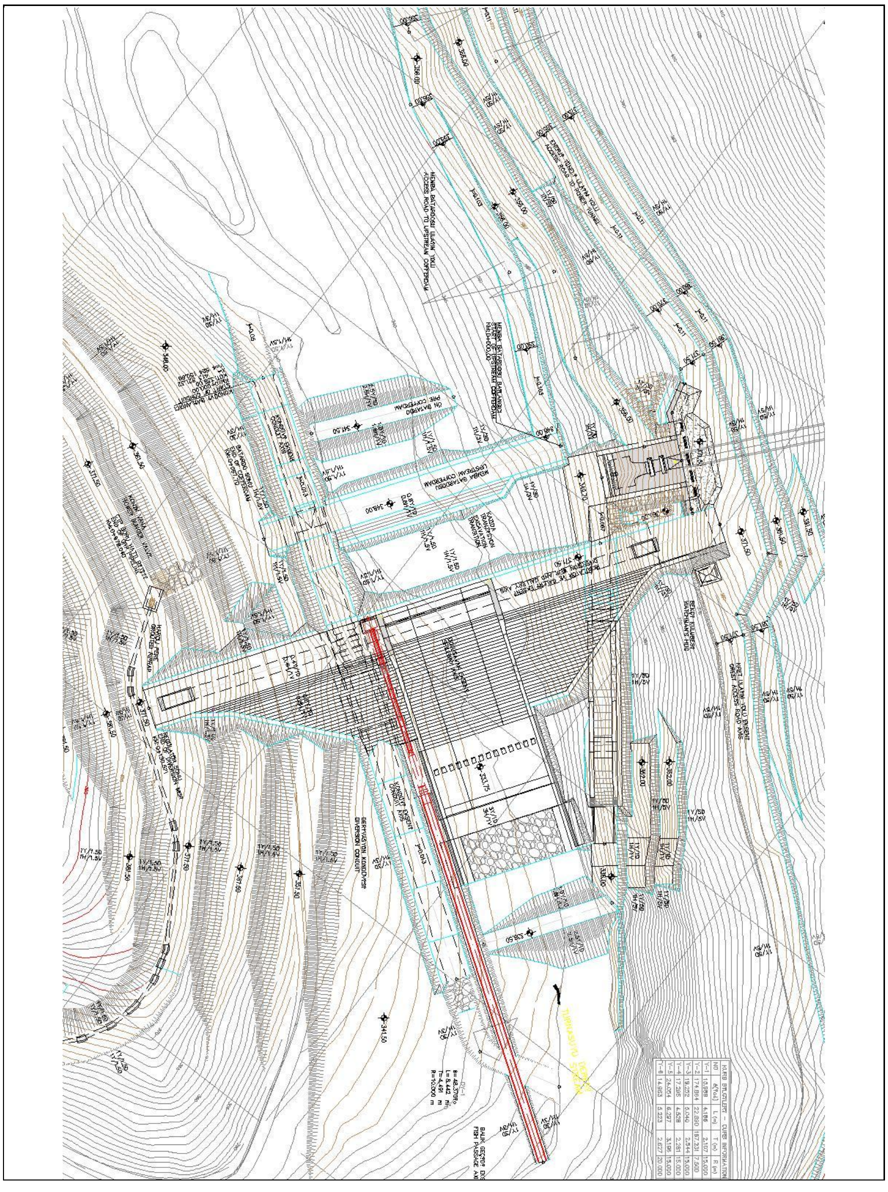


Figure 4.4. Inören Weir General Layout – Final Design Projects (Fish Pass is in red color)

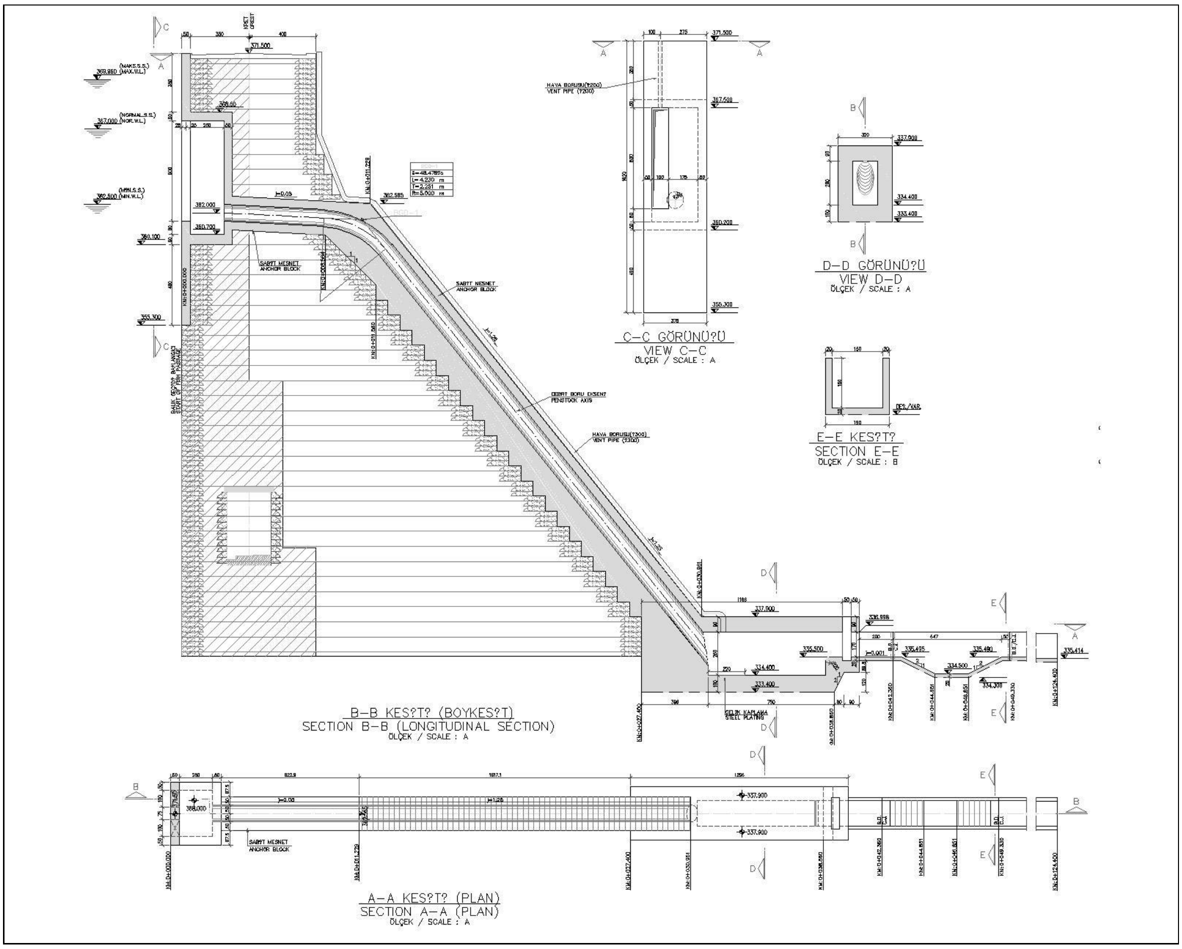


Figure 4.5. Inören Weir Fish Pass Sectional View – Final Design Projects

4.1. Hydraulic Design of Borland Fish Lock for Inoren Weir

In order to be able to adjust the flowrate with a free surface flow according to varying reservoir elevations, the entrance of the exit pool is designed with a sluice gate opening from upwards to downwards. Also, to minimize the interference effects of the water spilling from the sluice gate into the exit pool on the water flowing into the pipe, the sluice gate is not located at the central axis of the exit pool; instead it is located at the left side of the exit pool. The entrance flow of the exit pool should be equal to the ecological flow that was decided in the Environmental Impact Assessment Report and Ecosystem Evaluation Report of Turnasuyu Project, which is 0,516 m^3/s[11]. Hydraulic calculations are made for only attraction phase where free flow conditions occur. The filling and emptying phases will be managed mechanically by sluice gate and bypass vanes. The calculations will start from the flow entering into the exit pool and end at the exit of the attraction channel where fish pass channel connects to the stream bed.

The flowrate over sharp crested weirs are calculated by two different methods:

(i) Prof.Dr. Tülay Özbek, Açık kanal akımlarının Hidroliği ve Hidrolik Yapılar, page 250 [16]

$$Q = \frac{2}{3} \times \sqrt{2g} \times 0{,}615 \times (B - 0{,}1 \times h) \times h^{1{,}5}$$

Q = Discharge (m^3/s)
g = Acceleration of gravity (m/s^2)
B = Net Crest Length (m)
H = Head being considered on the crest (m)

By putting Q = 0,516 m^3/s and B = 1,00 m in the equation; the corresponding value of h is equal to 0,445 m.

h = 0,445 m

(ii) Design of Small Dams, United States Department of the Interior, Bureau of Reclamation, Third Edition, 1987, page 365-368 [15]

$$Q = C \times L \times H_e^{3/2}$$

Q = Discharge (m^3/s)
C = Discharge Coefficient (C is taken from Ref. [17] Table No:2, Page 42)
L = Effective Length of Crest (m)
H_e = Actual Head being considered on the crest (m)

$$L = L' - 2 \text{ x } (NK_p + K_a) \text{ x } H_e$$

L = Effective Length of Crest (m)
L’ = Net Length of Crest (m)
N = Number of piers
K_p = Pier contraction coefficient
K_a = Abutment contraction coefficient
H_e = Actual head on crest (m)

By putting K_a = 0,2, N = 0, C = 2,177, Q = 0.516 m^3/s, and L' = 1,00 m in the equation; the corresponding value of h is equal to 0,44 m.

h = 0,44 m

As can be seen from the calculations above, h values that was calculated with two different methods are approximately the same.

The water will flow into the exit pool with a 0,445 m height and will fill the exit pool. The length of the exit pool should be long enough so that free fall dropping (free jet) water passing through the sluice gate should not hit the side walls, it should drop directly into the water to avoid injury of downstream migrating fish. The path of the flow jet dropping into the exit pool can be expressed by the parabolic equation: (Figure 4.3)

$$-y = x^2 / 4H \qquad \text{(Ref. [15] page 376)}$$

where H is the head on the center of the opening. For H = 0,445 m / 2 = 0,2225 m and y = (367 m – 0,2225 m -360,7 m) = 6,0775 m the corresponding value of x is equal to 2,326 m meaning that the length of the exit pool should not be less than 2,326 m. The length of the exit pool is chosen to be 2,50 m. (Figure 4.7)

After the exit pool is filled, since the pipe has % 0,5 slope which is a steep slope($S > S_c$) the water will go into the pipe with a height which is equal to critical depth(d_c) of the flow.

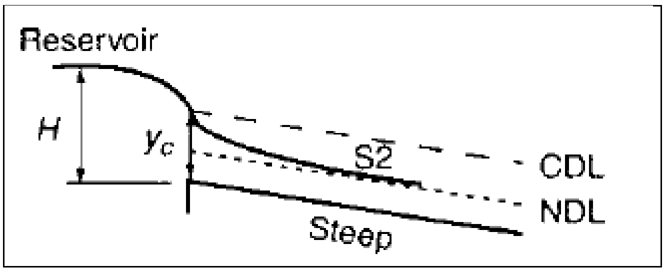


Figure 4.6. Flow profile water coming from a reservoir and flowing into a steep sloped channel (Ref. [18] page 164 Figure 5.3(d))

S = 0,05 m/m (Slope of the Pipe)

n = 0,012 (Manning Coefficient for Steel Pipe)

Q = 0,516 m^3/s

For Fr = 1 => $V^2 = g \times d_c$ => $Q^2/A^2 = g \times d_c$ solving this equation for a circular pipe; d_c is equal to 0,405 m. The flow will continue with S2 flow profile(S2 flow profile is a Gradually Varied Open Channel Flow Profile; see Ref [18] page 163,164) through the pipe. The water surface levels at the pipe are calculated with standard step method and given in Figure 4.9. (a).

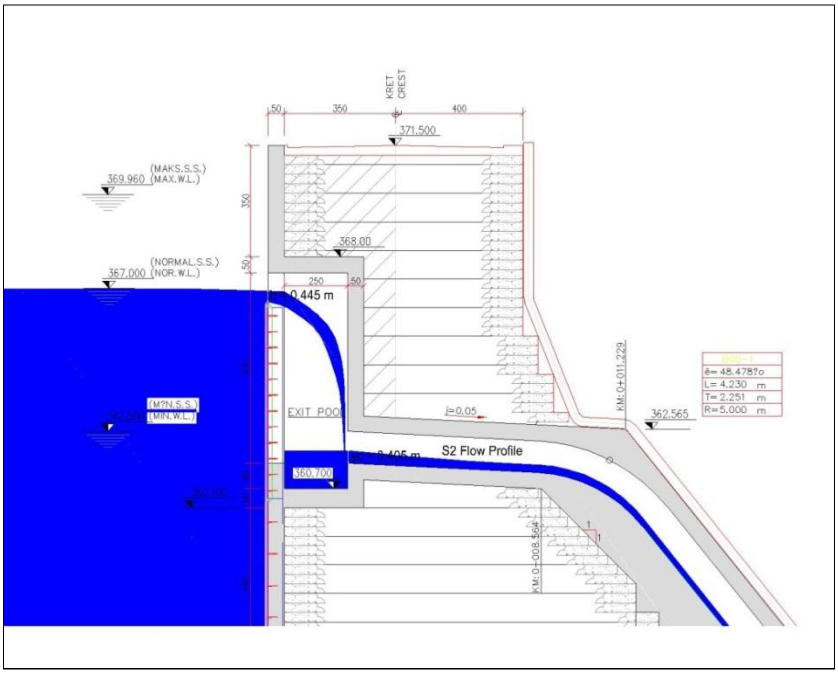


Figure 4.7. Flow profile at Entrance and Exit of Exit Pool

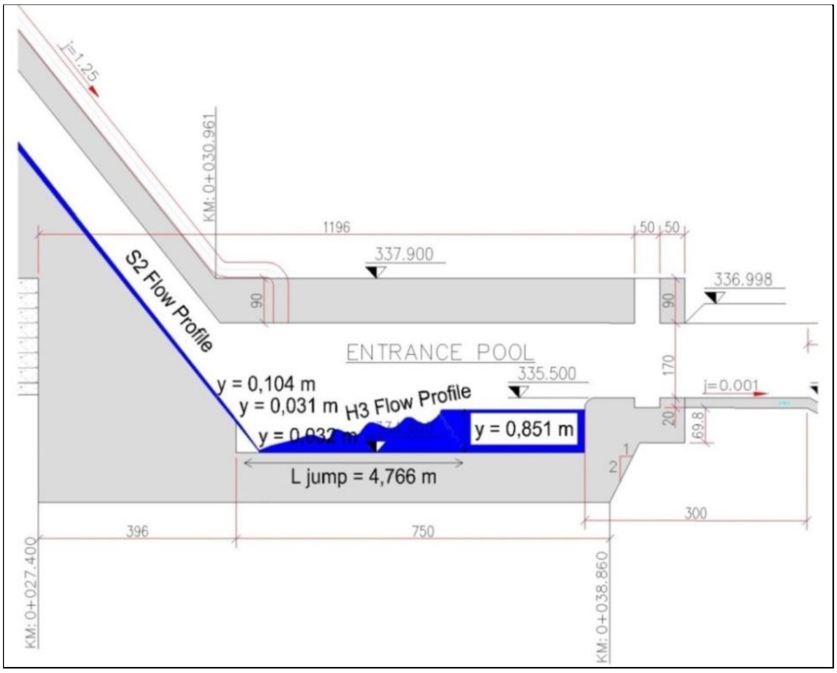
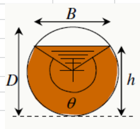


Figure 4.8. Flow profile at Entrance Pool

(a) Standart Step Method Calculation Table For Inclined Pipe Section and Upstream of the Entrance Pool

Channel Bottom Level	Y	X	Tan φ	Q	d	B	A	P	R_H	$R_H^{4/3}$	V	$hv = V^2/2g$	Fr	E = dcosφ + hv	J_e	J_{eort}	ΔL	Δh	$ΔH_e$	ΣΔh	Water Surface Elevation	H	$H_{assumed}$	$H_{assumed}$- H	
m	m		m	m^3/s	m	m^2	m				m/s	m													
361,20	0,00	0,00	0,00	0,516	0,405		0,299	1,380	0,216	0,130	1,728	0,152	1,00	0,558	0,003		0,00	0		0	361,61	361,76	361,76	0,00	From Reservoir to Steep Slope Canal Transition d = yc
360,90	0,30	5,96	0,05	0,516	0,257		0,160	1,063	0,150	0,080	3,232	0,533	2,41	0,789	0,019	0,011	5,96	0,07		0,07	361,16	361,69	361,69	0,00	S2 Profile
360,00	1,20	9,61	0,25	0,516	0,186		0,100	0,891	0,113	0,054	5,140	1,347	4,57	1,527	0,070	0,044	3,76	0,17		0,23	360,19	361,52	361,53	0,00	S2 Profile
359,03	2,17	10,38	1,25	0,516	0,155		0,077	0,809	0,096	0,044	6,667	2,265	6,51	2,362	0,146	0,108	1,24	0,13		0,37	359,28	361,39	361,39	0,00	S2 Profile
359,00	2,20	10,41	1,25	0,516	0,154		0,077	0,807	0,095	0,044	6,704	2,291	6,56	2,387	0,149	0,147	0,04	0,01		0,37	359,25	361,38	361,39	0,00	
357,00	4,20	12,01	1,25	0,516	0,131		0,060	0,739	0,082	0,035	8,552	3,728	9,12	3,809	0,297	0,223	2,56	0,57		0,94	357,21	360,81	360,81	0,00	
355,00	6,20	13,61	1,25	0,516	0,120		0,053	0,706	0,075	0,032	9,710	4,806	10,84	4,881	0,428	0,362	2,56	0,93		1,87	355,19	359,88	359,88	0,00	
350,00	11,20	17,61	1,25	0,516	0,109		0,046	0,671	0,069	0,028	11,197	6,390	13,14	6,458	0,642	0,535	6,40	3,43		5,30	350,17	356,46	356,46	0,00	
345,00	16,20	21,61	1,25	0,516	0,105		0,044	0,661	0,067	0,027	11,717	6,998	13,97	7,064	0,732	0,687	6,40	4,40		9,70	345,17	352,06	352,06	0,00	
340,00	21,20	25,61	1,25	0,516	0,104		0,043	0,657	0,066	0,027	11,893	7,209	14,25	7,274	0,763	0,747	6,40	4,79		14,48	340,17	347,27	347,27	0,00	
335,00	26,20	29,61	1,25	0,516	0,104		0,043	0,656	0,066	0,027	11,957	7,286	14,35	7,351	0,775	0,769	6,40	4,93		19,41	335,17	342,35	342,35	0,00	
334,91	26,29	29,68	1,25	0,516	0,104		0,043	0,656	0,066	0,027	11,952	7,280	14,34	7,345	0,774	0,775	0,12	0,09		19,50	335,08	342,26	342,26	0,00	
334,90	26,30	30,10		0,516	0,031	1,5	0,047	1,562	0,030	0,009	11,086	6,264	20,09	6,295	1,916	1,916	0,42	0,81	0,25	20,56	334,93	341,20	341,20	0,00	Channel Expansion (Circular Section to Rectangular Section
334,40	26,80	30,10		0,516	0,032	1,5	0,048	1,564	0,031	0,010	10,717	5,853	19,10	5,885	1,714	1,815	0,50	0,91		21,47	334,43	340,29	340,29	0,00	Pool Bottom (Rectangular Section)

D	1,00 m	Circular Cross Section
B	1,50 m	Rectangular Cross Section
S_{01}	0,05 m/m	
S_{02}	1,25 m/m	
n	0,012	
Q	0,516 m^3/s	
g	9,81 m/s^2	



Flow Area = $\frac{1}{8}(\theta - \sin\theta)D^2$

Wetted Perimeter = $\frac{1}{2}\theta D$

Hydraulic Radius R_H $\frac{1}{4}\left[1 - \frac{\sin\theta}{\theta}\right]D$

Hydraulic Depth D_H $\left[\frac{\theta - \sin\theta}{\sin\theta/2}\right]\frac{D}{8}$

(b) Standart Step Method Calculation Table For Upstream Inclined Channel Section of Resting Pool

Channel Bottom Level	Y	X	Tan φ	Q	d	B	A	P	R_H	$R_H^{4/3}$	V	$hv = V^2/2g$	Fr	E = dcosφ + hv	J_e	J_{eort}	ΔL	Δh	$ΔH_e$	ΣΔh	Water Surface Elevation	H	$H_{assumed}$	$H_{assumed}$- H	
m	m		m	m^3/s	m	m^2	m				m/s	m													
335,50	0,00	0,00		0,516	0,229	1,5	0,344	1,958	0,175	0,098	1,502	0,115	1,00	0,344	0,003		0,00	0,00		0,00	335,72	335,84	335,84	0,00	From Inlet Channel to Steep Slope Canal Transition d = yc
334,50	1,00	1,99	0,50	0,516	0,073	1,5	0,109	1,646	0,066	0,027	4,725	1,138	5,59	1,203	0,120	0,061	2,23	0,14		0,14	334,58	335,70	335,70	0,00	S2 Profile

B	1,50 m	Rectangular Cross Section
S	0,5 m/m	
n	0,012	
Q	0,516 m^3/s	
g	9,81 m/s^2	

Figure 4.9. (a) Standard step method calculations for inclined pipe, (b) Standard step method calculations for upstream inclined channel section of resting pool

As can be seen from Table 4.9.(a) column 6 (d values) when water exits from the circular pipe and enters into the rectangular channel cross section(expansion) the water depth will decrease from 0,104 m to 0,031 m after the expansion of the cross section. The water depth becomes 0,032 m at the bottom of the entrance pool and at this point, bottom slope of the channel will be horizontal. The water comes from steep bed slope ($S>S_c$) and goes into horizontal bed slope (S=0) which means a hydraulic jump with a H3 profile will occur. Depth of water before and after the hydraulic jump is calculated with the formula given below:

$$\frac{D_2}{D_1} = \frac{1}{2} \times \left(\sqrt{1 + 8F_1^2} - 1\right)$$

D_1 = Depth of water before the jump (m)

D_2 = Depth of water after the jump (m)

F_1 = Freud number before the jump

Putting D_1 = 0,032 and F_1 = 19,10 in the equation; the corresponding value of D_2 is equal to 0,851 m. D_2 = 0,851 m

The length of the hydraulic jump can be found from Figure 4.10.:

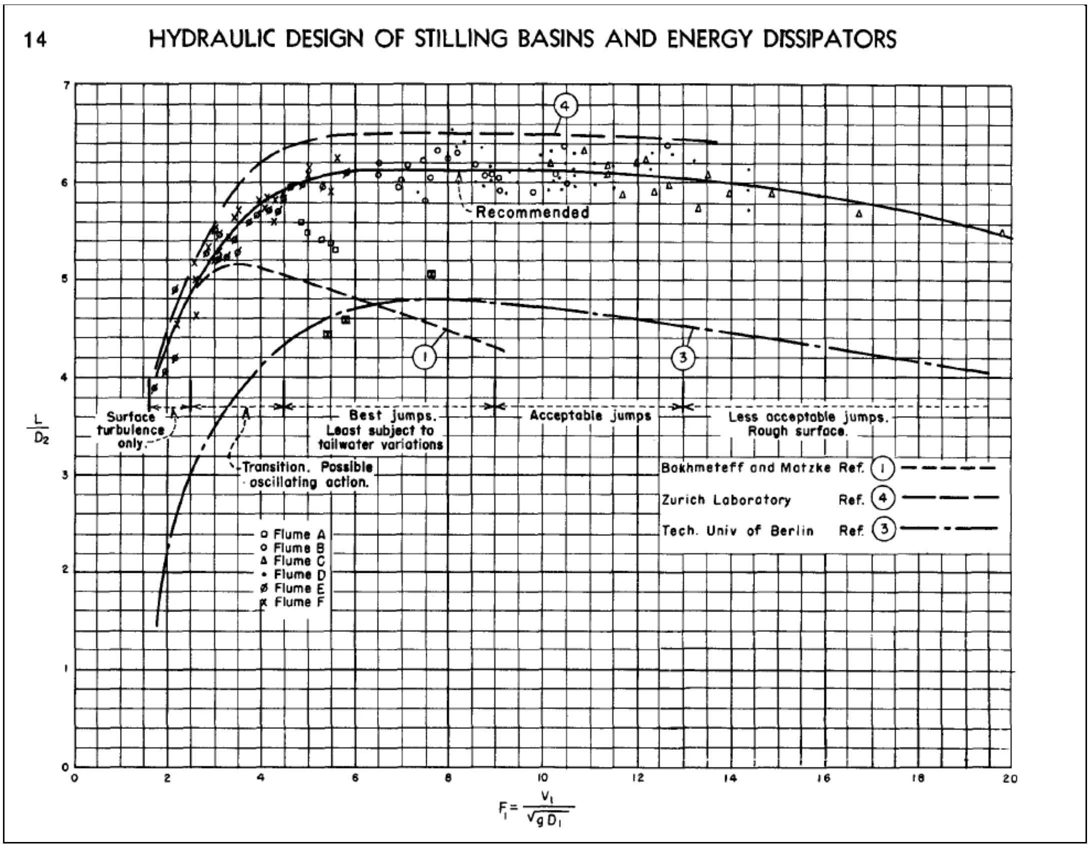


Figure 4.10. Length of Jump in Terms of d_2 (Ref. [19] page 14, Figure 7)

By using Figure 4.10. for F_1 = 19,10 the corresponding value of L/D_2 is equal to 5,6 which gives L_{jump} = 4,766 m.

After the jump, the depth of the flow will be 0,851 m. The downstream end of the entrance pool should have enough height so that the jump does not sweep out the pool and the jump becomes submerged. If so, after the jump, since the flow continues incoming to the pool the water will accumulate in the entrance pool and the water level in the entrance pool will start to rise till the water depth at the inlet channel becomes critical depth(dc), and the flow passes with critical depth through the inlet channel.

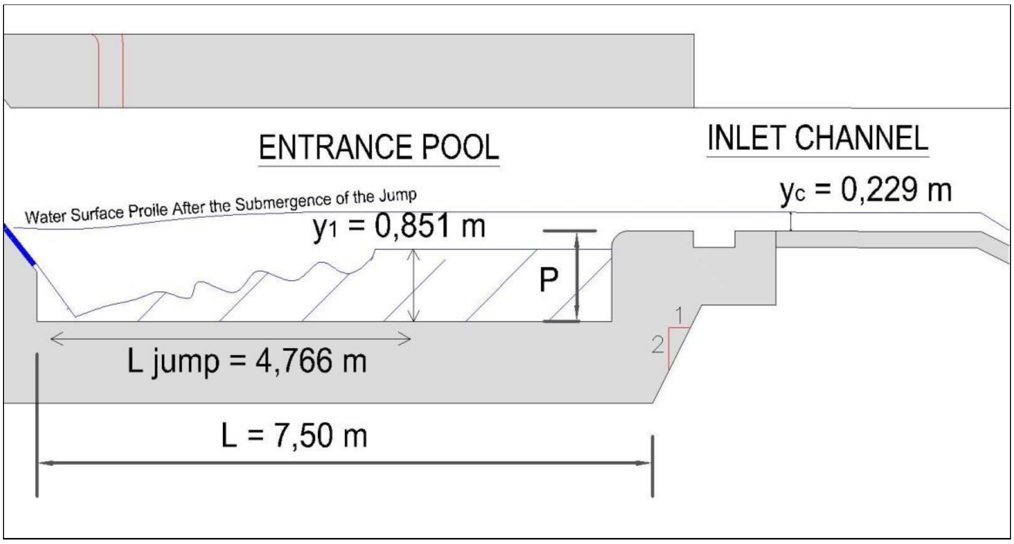


Figure 4.11. Entrance Pool Exit Height

To find the minimum P height(Figure 4.11.) that the flow passes at critical depth at the inlet channel; we write the energy equation between the point after the jump and the point at the inlet channel where water depth will be at critical depth; we get the equation below (hydraulic losses are neglected):

$$y_1 + V_1^2/2g = y_c + V_c^2/2g + P_{min}$$ (Ref [22] Page 397)

Q	$= 0{,}516\ m^3/s$	
B	= 1,50 m (Channel Width)	
y_1	= 0,851 m	
q	= Q/B	$= 0{,}344\ m^3/s/m$

V_1	$= Q/(Bxy_1)$	$= 0,404$ m/s
y_c	$= (q^2/g)^{1/3}$	$= 0,229$ m
V_c	$= q/y_c$	$= 1,50$ m/s

When we put the values of y_1, V_1, y_c and V_c in the equation above we get:

$P_{min} = 0,851 \text{ m} + 0,404^2 / (2 \times 9,81) – 0229 \text{ m} – 1,50^2 / (2 \times 9,81)$

$P_{min} = 0, 516$ m

P is chosen to be 1,1 m where P = 1,1 m > P_{min} .

As can be seen from Figure 4.12, P is equal to 1,1 m and chosen to be bigger than the water depth after the hydraulic jump(0,851 m). After being submerged, the jump will propagate to upstream and the water surface profile will become S1(S1 is a Gradually Varied Open Channel Flow Profile, see Ref [18] page 163,164) profile.

In the previous paragraphs it is stated that the water depth in the inlet channel will be at critical depth. Key design factor for this issue is to design the inlet channel like a broad crested weir. By this way the flow profile can be predicted easily and flow characteristics can be calculated easily. The location of the critical stage at the crest of a broad crested weir varies according to hydrostatic head and weir dimensions. Studies done by H.J. Tracy [20] showed that at sufficiently high head-to-length ratios the nappe tends to spring clear of the weir crest, and the structure no longer performs as a broad-crested weir. At the opposite extreme, for very small head-to-length ratios, the weir crest becomes a reach of open channel in which frictional resistance predominates, and for which the discharge is more properly evaluated by one of the open-channel flow formulas than by a weir formula.

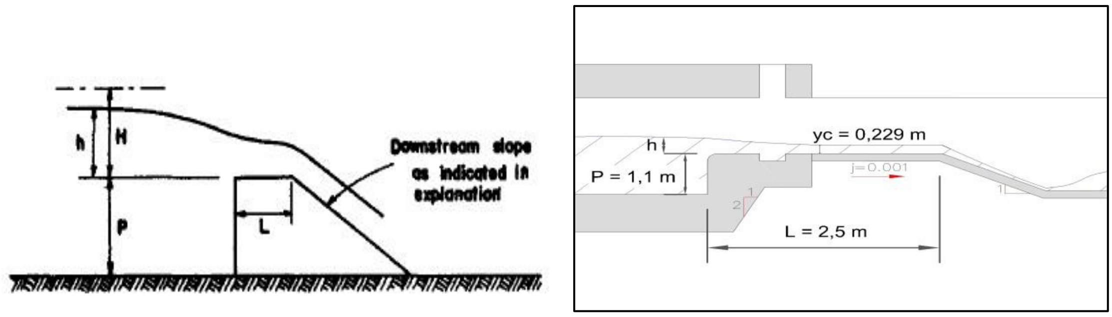


Figure 4.12. Broad Crested Weir with Inclined Downstream [20] and Inlet Channel

Singer reported that [21],[23] the discharge coefficients of broad crested weirs (C_d) depend on weir height (P) as well as crest length (L). It was also expressed that the discharge coefficient is a function of h/L and h/(h+P).

"If the weir crest is sufficiently long; due to energy loss, of necessity, causes an adjustment of depth and leads to the formation of a standing-wave pattern typical of flow at or near critical depth. This standing-wave configuration first appears roughly at an h/L ratio of about 0,08. All profiles for smaller ratios of head to length show similar standing-wave characteristics." Also if the entrance of the weir (upstream face) is rounded as given in Figure 4.13; it is suggested to change the lower limit from 0,08 to 0,144 in order not to have these standing waves[20].

"If, on the contrary, the weir crest is relatively short and the head is large, the flow over the weir will be entirely curvilinear. In the upstream crest zone, this profile is somewhat lower vertically than that for the weir of great enough length to permit a zone of approximately parallel flow to form. This curvilinear profile appears when the h/L ratio becomes greater than about 0,40." [20]

Further studies done by Singer in1964 [21] considered the range for broad crested weirs to have a parallel critical depth zone and to avoid standing waves as;

$0,08 \leq h/L \leq 0,33$

$0,18 \leq h/(h+P) \leq 0,36$

and for the geometry of the weir within this range C_d is constant and equal to 0,85 for square edged broad crested weirs. Azimi et al. in 2009 found that when $0,094 < r/P < 0,25$ where r is the radius of rounded upstream entrance of the weir, C_d values are increased. Considering the broad crested weir with a rounded entrance with r/P greater than 0,09 C_d varied with both h/L and h/(h+P) and the correlation between these parameters are given in Figure 4.14[21].

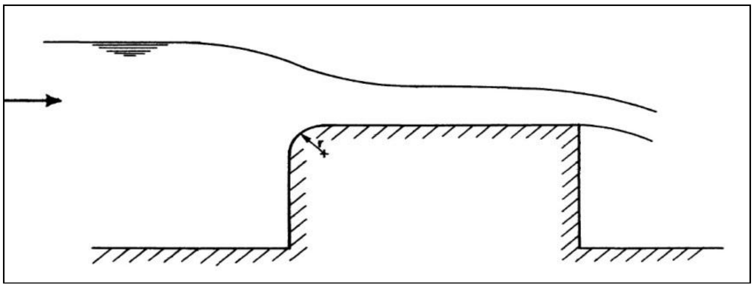


Figure 4.13. Broad crested weir with rounded entrance

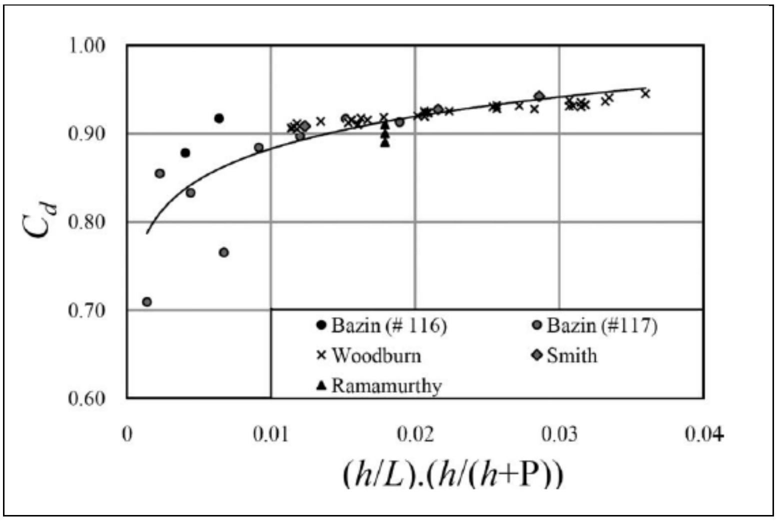


Figure 4.14. Variation of Cd for long-crested weir with rounded entrance (0< h/L <0.1)[21]

The inlet channel (Broad Crested Weir) geometry is as follows:

Q	= 0,516 m^3/s
B	= 1,50 m (Channel Width)
P	= 1,1 m
L	= 2,50 m

The discharge over the broad crested weir is given as:

$$Q = C_d B \sqrt{8/27}\sqrt{g} h^{3/2}$$

(Ref [21])

By using the equation above and Figure 4.14 with iterative method h is found to be 0,365 m.

h = 0,365 m

h/L = 0,146 m *OK (0,144 ≤ h/L ≤ 0,33 for rounded edge)*

h/(h+P) = 0,25 *OK (0,18 ≤ h/(h+P) ≤ 0,36)*

h/L x h/(h+P) = 0,0365

$0{,}516\ m^3/s = 0{,}92 \times 1{,}50\ m \times 1{,}70489 \times 0{,}365^{3/2}$

h = 0,365 m means that the water depth in the entrance pool after the submergence of the jump is 1,1 m + 0,365 m = 1,465 m

Model studies suggest that another check criteria, to be sure not to have undular flows (standing waves) is :

$$(H - P) / L > 0{,}1$$ (Ref [23] Page 446)

where H is the total water height in front of the weir. When we put the values of H, P and L in the equation above [(1,465 m – 1,1 m) / 2,50 m = 0,146] we get 0,146 which is bigger than 0,1 which also shows that there won't be any standing waves on the crest of the broad-crested weir.

Also the water depth in the entrance pool after the submergence of the jump can be estimated by Bernoulli equation:

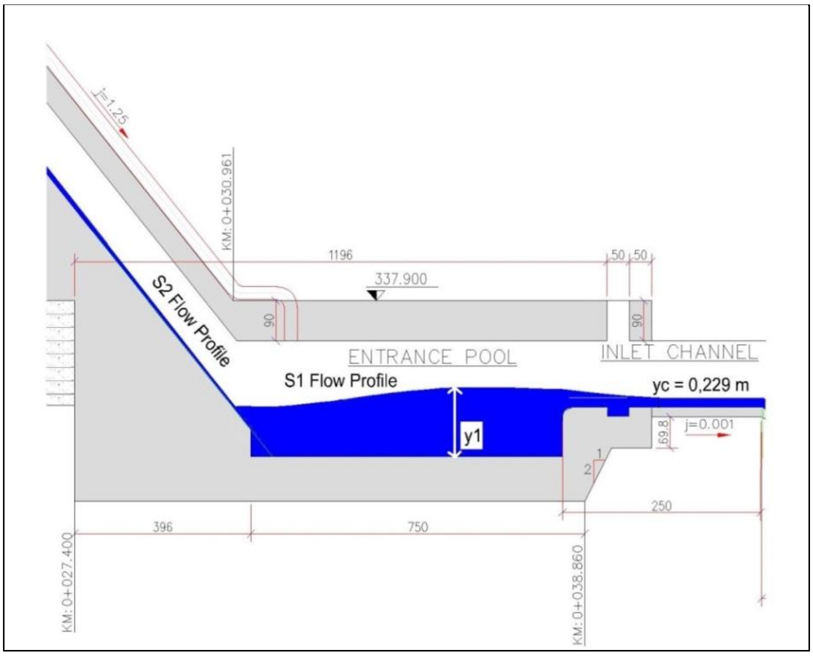


Figure 4.15. Flow Depth at the Entrance Pool

$$y_1 + V_1^2/2g = y_c + V_c^2/2g + 1{,}1 \text{ m} + h_L$$

h_L(head loss) can be written as K x ($V_c^2/2g - V_1^2/2g$) and K can be assumed as 0,2. Also if we think that V_1 will be smaller than 0,26 m/s (Since y_1 will be bigger than y_c + 1,1 m = 1,329 m V_1 < 0,516 m^3/s / (1,5 x 1,329) = 0,26 m/s) $V_1^2/2g$ will be smaller than 0,003 m which can be neglected and assumed as "0" for the simplicity of the calculations. Then the equation will be

$$y_1 + 0 = y_c + V_c^2/2g + 1{,}1 \text{ m} + 0{,}2 \text{ x } (V_c^2/2g - 0)$$

by putting y_c = 0,229 m and V_c = 1,50 m/s into equation above the corresponding value of y_1 is equal to 1,466 m.

y_1 = 1,466 m (As can be seen above using two different methods; for broad crested weir equations and Bernoulli equation, the result values of y_1 are approximately the same)

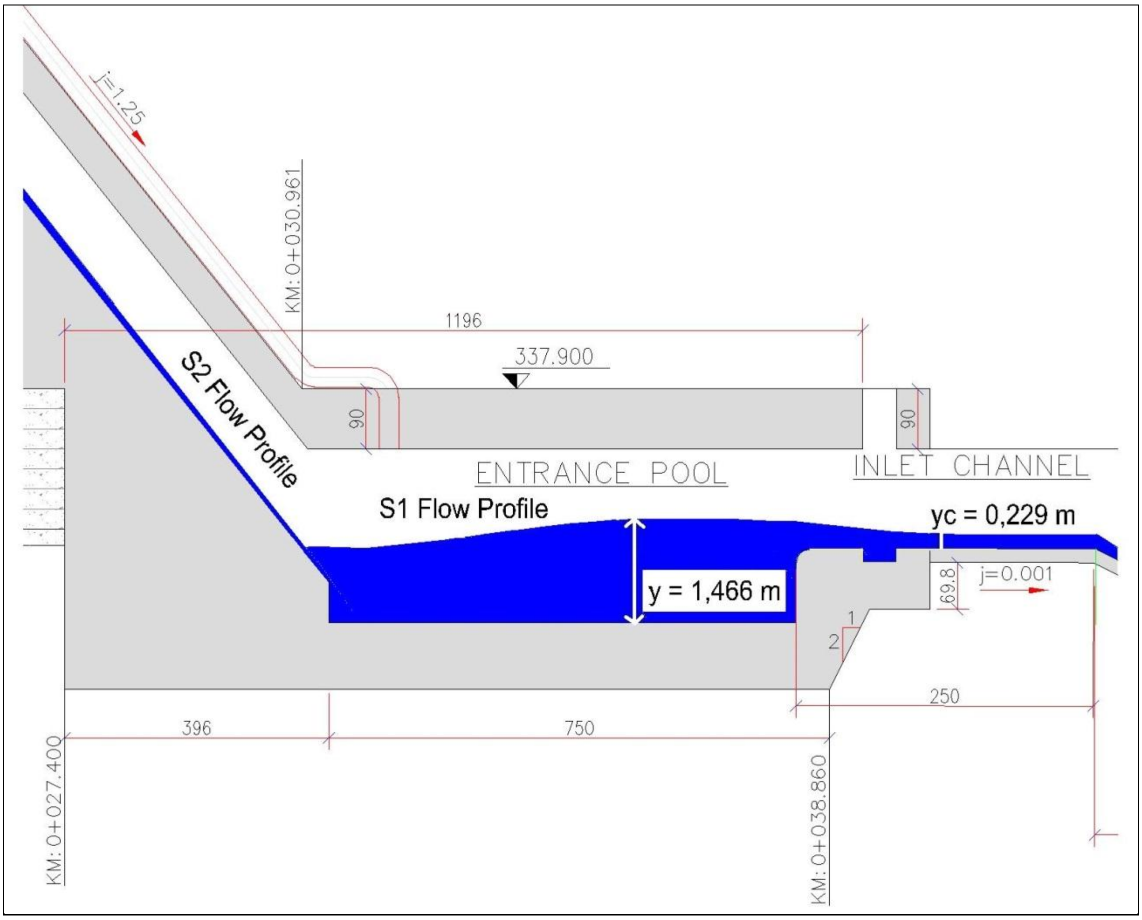


Figure 4.16. Calculated Flow Depth at the Entrance Pool

The length of jump at the sloping channel part of the entrance pool is calculated by using Figure 4.17 and Figure 4.18. In Figure 4.18 the graph is given for Fr = 6 to Fr = 12; however when we look at the higher values of h/d_1 it seems like the lines become similar with a similar slope so it is assumed that the same line with Fr = 12 is applicable for our calculations where Fr = 19,1 and h_d/d_1=1,466 m/0,0321 m = 45. For $h_d/d_1 \approx 40$ in the Figure 4.18; ℓ/d_1 is equal to 25. This means ℓ = 0,8025 m. (Also Figure 4.18 is given for ɷ = 55^0 but the inclined slope of the entrance pool is 51.3^0; it is assumed that the results will not change significantly)

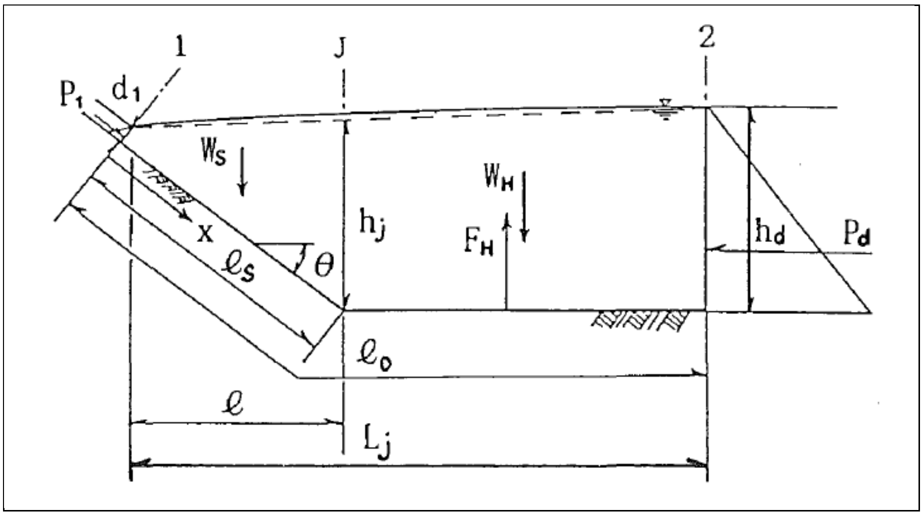


Figure 4.17. Submerged Jump in Sloping Channels (Ref. [24] Figure 14)

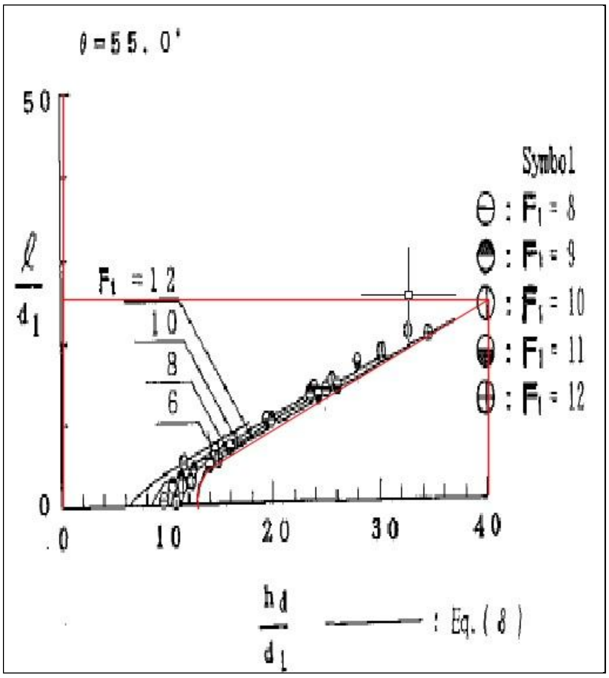


Figure 4.18. Ratio of Sequent Depths for B-Jump ɷ = 55^0 (Ref. [24] Figure 15(c))

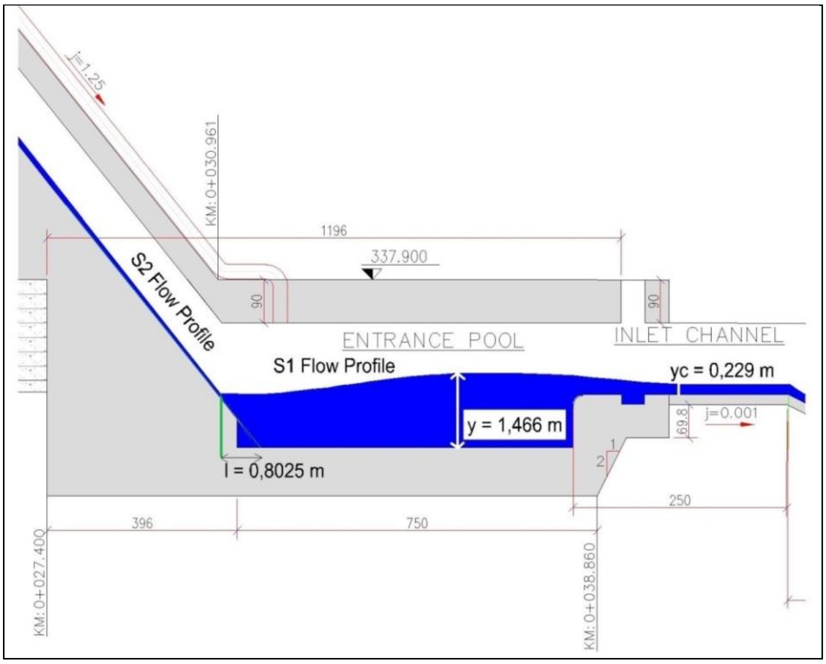


Figure 4.19. Sequent Flow profile at Entrance Pool (After the submergence of the Jump)

The flow profile at the inlet channel will be the same as flow profile over a broad crested weir as given in detail above and will be at critical depth. The bottom slope of inlet channel is mild slope($S<S_c$) and the bottom slope of entrance of the resting pool is steep($S>S_c$) so the water will leave the inlet channel at critical depth. The water profile at the inclined channel of the resting pool will be S2(S2 is a Gradually Varied Open Channel Flow Profile, see Ref [18] page 163,164) profile.

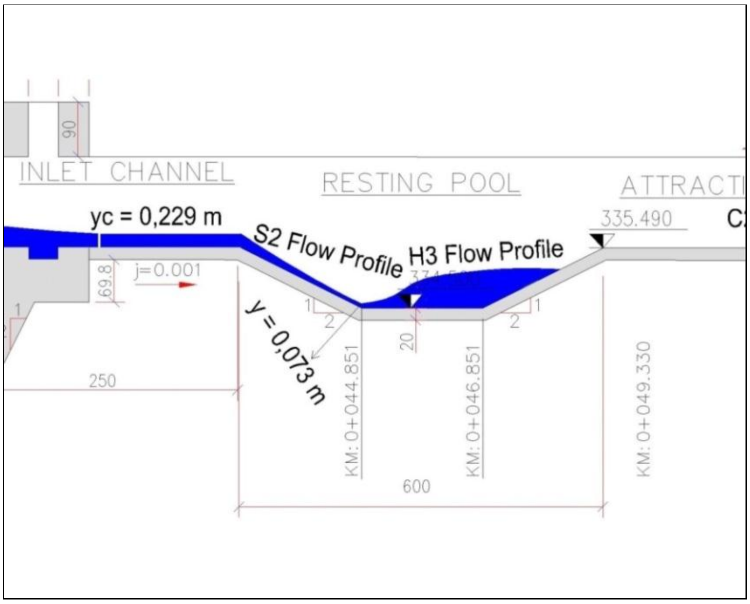


Figure 4.20. Flow profile at Inlet Channel and Resting Pool

The flow will continue with S2 profile through the inclined portion of the resting pool. The water surface levels at the inclined channel till the horizontal channel of the resting pool are calculated with standard step method and given in Figure 4.9. (b).

As can be seen from Figure 4.9. (b) column 6 (d values) the water depth becomes 0,073 m at the bottom of the resting pool and at this point bottom slope of the channel will be horizontal. The water profile comes from steep slope($S>S_c$) and goes into horizontal slope ($S=0$) means a hydraulic jump with a H3(H3 is a Gradually Varied Open Channel Flow Profile, see Ref [18] page 163,164) profile will occur. Hydraulic jump is calculated with the formula given below:

$$\frac{D_2}{D_1} = \frac{1}{2} \times \left(\sqrt{1 + 8F_1^2} - 1 \right)$$

D_1 = Depth of water before the jump (m)

D_2 = Depth of water after the jump (m)

F_1 = Freud number before the jump

Putting D_1 = 0,073 and F_1 = 5,57 into the equation, the corresponding value of D_2 is equal to 0,54 m.

D_2 = 0,54 m

The length of jump can be found by using Figure 4.10.; for F_1 = 5,57 the corresponding value of L/D_2 is 6,1 which gives L_{jump} = 3,294 m.

After the jump the depth of the flow will be 0,54 m however as can be seen from Figure 4.20; the attraction channel bottom elevation is 0,99 m above the resting pool bottom. So after the jump since the flow continues incoming to the pool the water will accumulate in the resting pool and the water level will start to rise till the water depth at the attraction channel of the resting pool become normal depth(d_0). (see Figure 4.21)

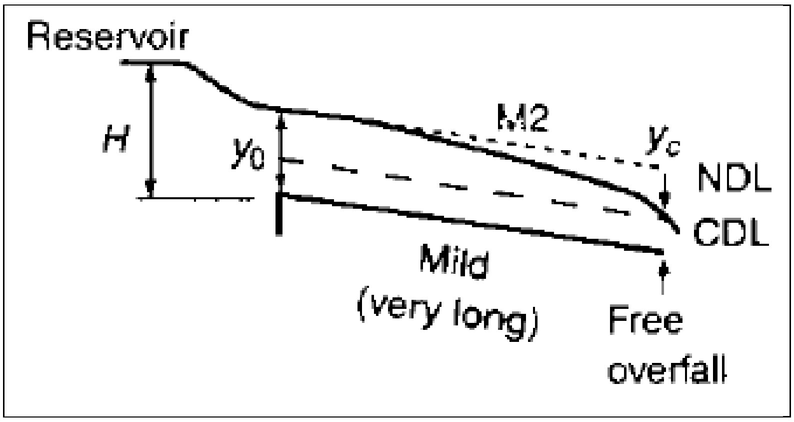


Figure 4.21. Flow profile water coming from a reservoir and flowing into a long mild sloped channel (Ref. [18] Page 164 Figure 5.3(e))

The jump will become a submerged jump. The jump will propagate to upstream and the water surface profile will become S1(S1 is a Gradually Varied Open Channel Flow Profile, see Ref [18] page 163,164) profile.

The water depth in the resting pool after the submergence of the jump can be estimated by Bernoulli equation:

$$y_1 + V_1^2/2g = y_0 + V_0^2/2g + 0{,}99\ \text{m} + h_L$$

h_L(head loss) can be written as K x ($V_0^2/2g - V_1^2/2g$) and K can be assumed as 0,2. Also if we think of that V_1 will be smaller than 0,26 m/s (Since y_1 will be bigger than y_0 + 0,99 m = 1,332 m $V_1 < 0{,}516\ m^3/s\ /\ (1{,}5 \times 1{,}332) = 0{,}26$ m/s) $V_1^2/2g$ will be smaller than 0,003 m which can be neglected and assumed as “0” for the simplicity of the calculations. Then the equation will be:

$$y_1 + 0 = y_0 + V_0^2/2g + 0{,}99\ \text{m} + 0{,}2 \times (V_0^2/2g - 0)$$

by putting y_0 = 0,342 m and V_0 = 1,01 m/s into equation above the corresponding value of y_1 is equal to 1,394 m.

The length of jump at the sloping channel part of the resting pool is calculated by using Figure 4.17 and Figure 4.22. In Figure 4.22 the graphs are given for Fr = 6 to Fr =

12, so it is assumed that the Fr = 6 line can be used for our calculations where Fr = 5,57 and h_d/d_1=1,394 m/0,073 m = 19. For h_d/d_1 = 19 in the Figure 4.22; ℓ/d_1 is equal to 30. This means ℓ = 2,19 m. (Also Figure 4.22 is given for $\alpha = 26^0$ but the inclined slope of the entrance pool is 26.6^0; It is assumed that the results will not change significantly)

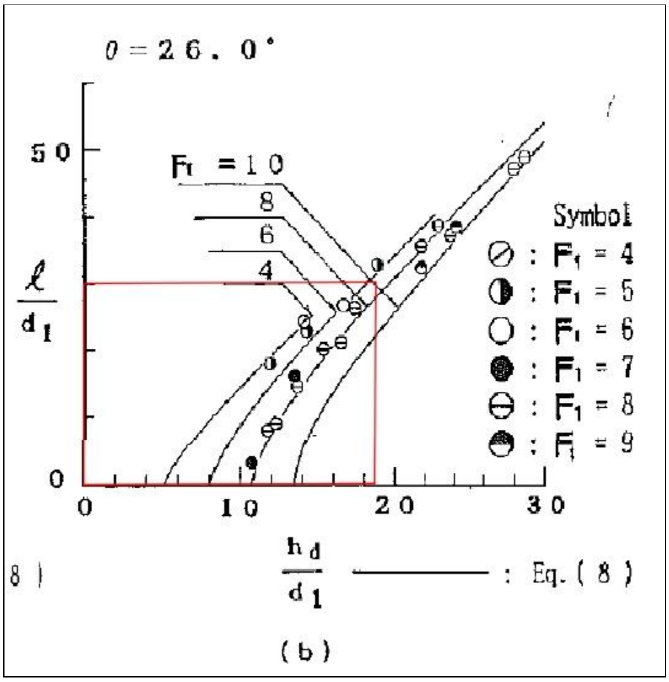


Figure 4.22. Ratio of Sequent Depths for B-Jump for $\alpha = 26^0$ (Ref. [24] Figure 15 (b))

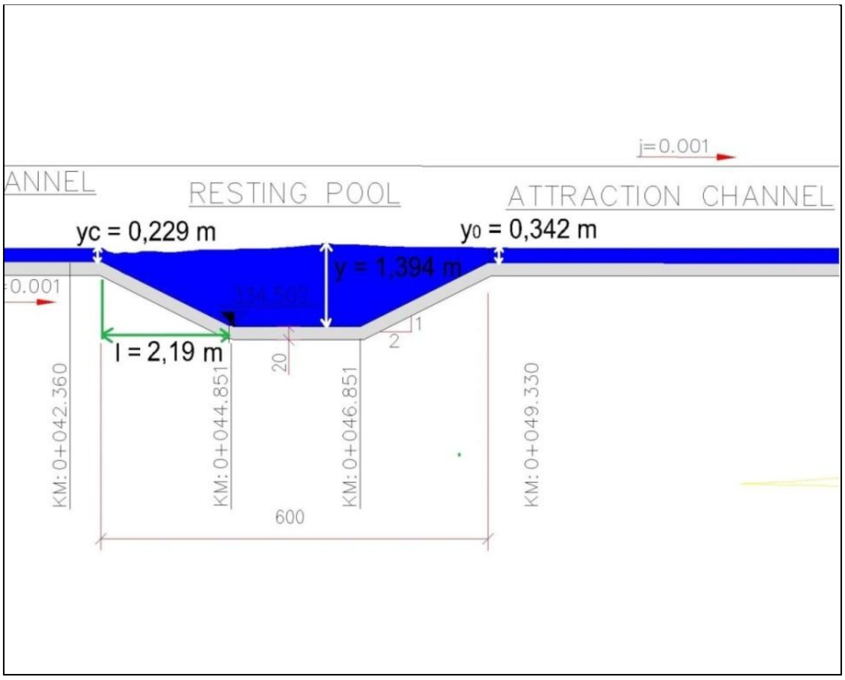


Figure 4.23. Sequent Flow profile at Resting Pool(After the submergence of the Jump)

The flow will leave the resting pool at normal depth(d_0)(see Figure 4.23) and the flow profile in the attraction channel will be M2 profile that the depth of the flow gradually descends to critical depth(d_c) at the end of this channel (see Figure 4.21) where the flow exits to stream bed. The bottom slope of attraction channel is mild slope($S<S_c$) and the exit of the attraction channel to the stream bed is free flow. The water depth at the exit of the attraction channel will be at critical depth(d_c).

The attraction channel is connected with a slope of 1/5 (10^0 degree) inclined bed to the stream bed to attract the fish.

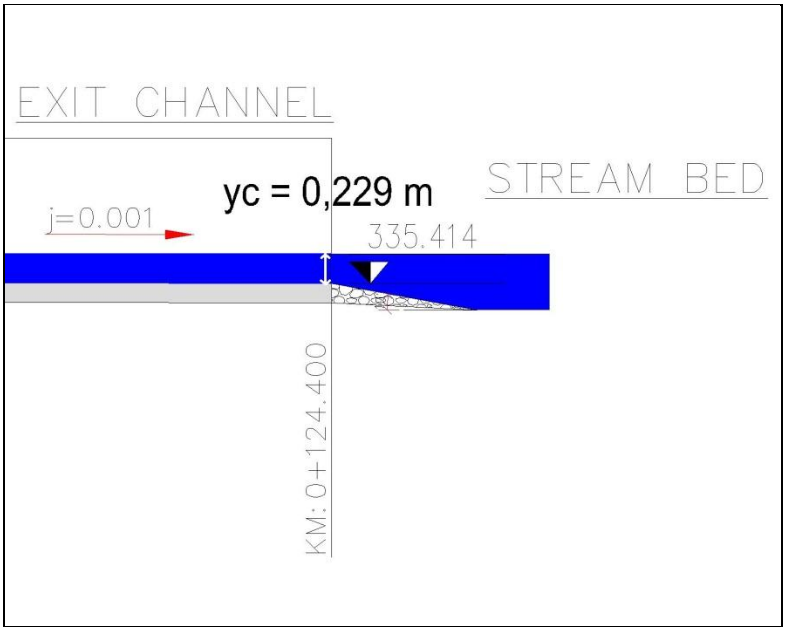


Figure 4.24. Connection of the attraction channel to the stream bed

4.2. Flow 3D Computer Software Results for Inoren Fish Lock Design

FLOW-3D is computer software that provides a complete and versatile CFD simulation platform for investigating the dynamic behavior of liquids and gas in a wide range of industrial applications and physical processes. FLOW-3D focuses on free surface and multi-phase applications, serving a broad range of industries including microfluidics, bio-medical devices, water civil infrastructure, aerospace, consumer products, additive manufacturing, inkjet printing, laser welding, automotive, offshore, energy and automotive. To check the results of the hydraulic calculations and to see the velocity distribution along the pools and depth distribution along the system; flow 3D is used. The results of flow 3D are given below:

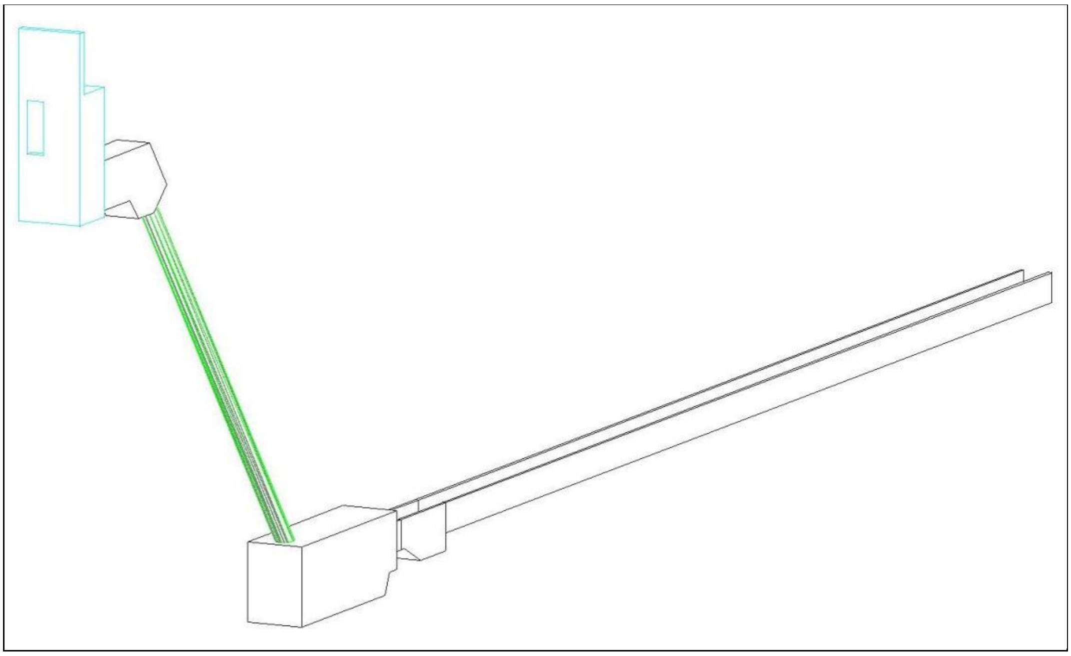


Figure 4.25. 3D Model of Inoren Weir Borland Fish Lock

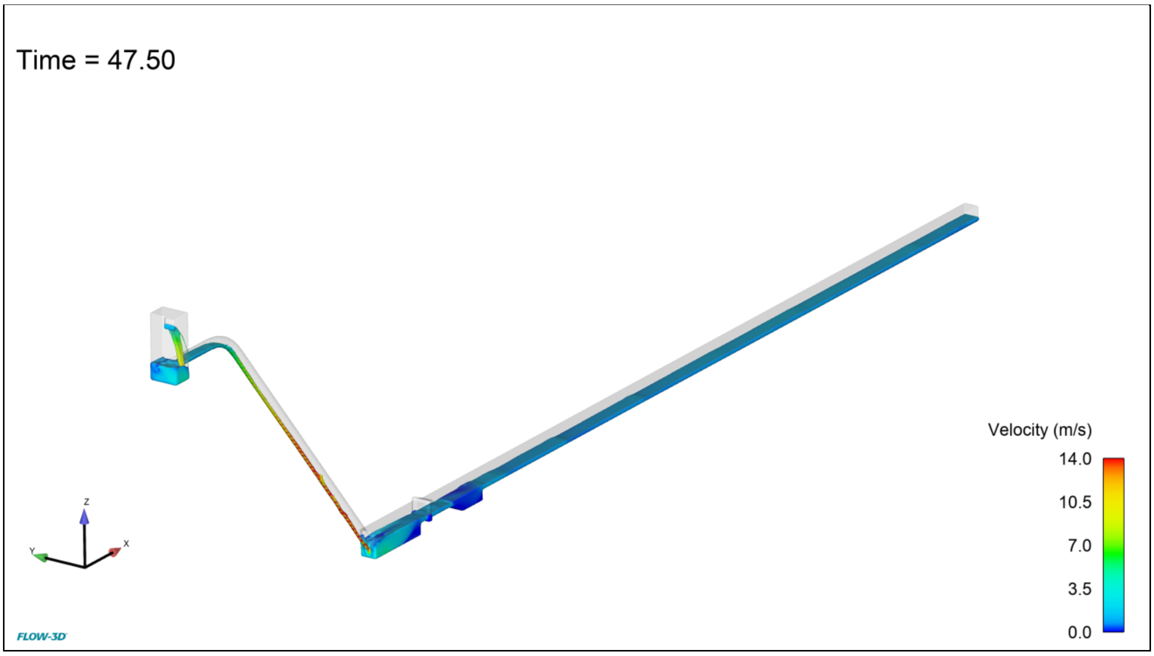


Figure 4.26. Flow 3D Velocity Distribution Profile Along the System (3D view)

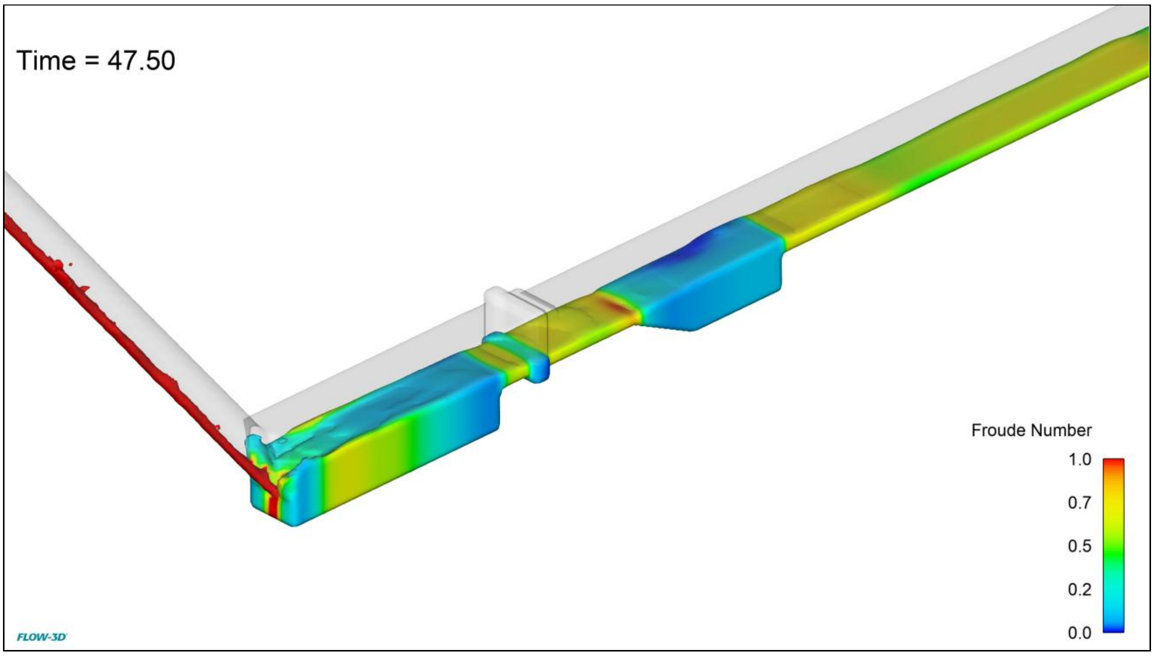


Figure 4.27. Flow 3D Freud Number Distribution Along the System (3D View)

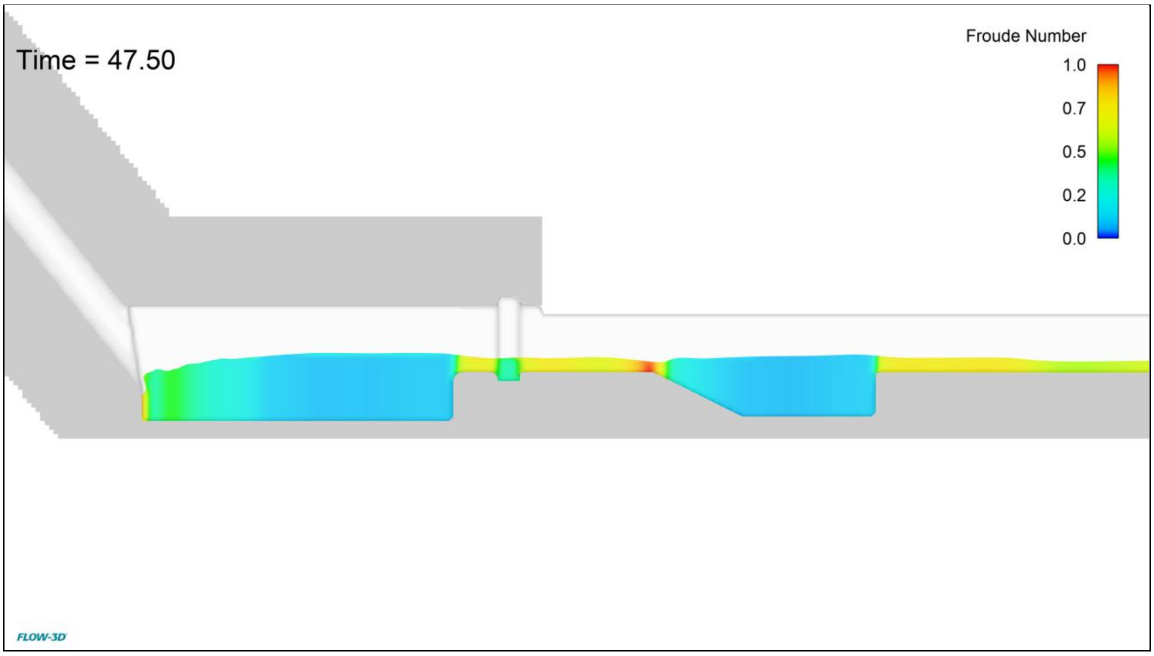


Figure 4.28. Flow 3D Freud Number Distribution Along the System (2D View at the Center of the Channel and Pools)

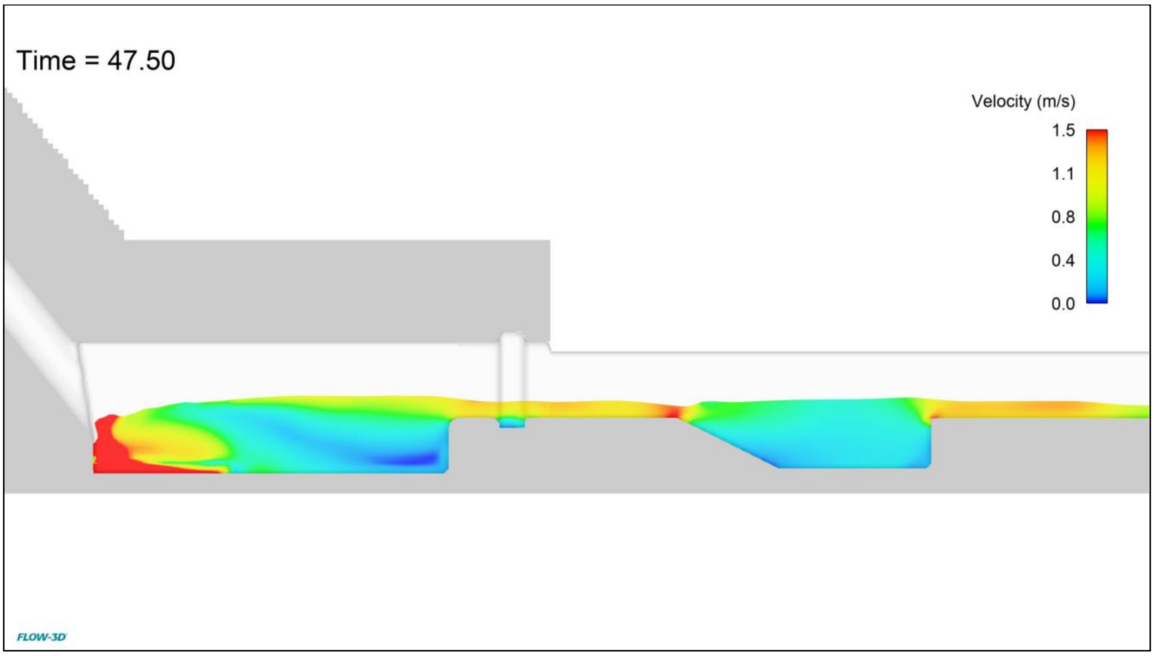


Figure 4.29. Flow 3D Velocity Distribution Along the System (2D View at the Center of the Channel and Pools)

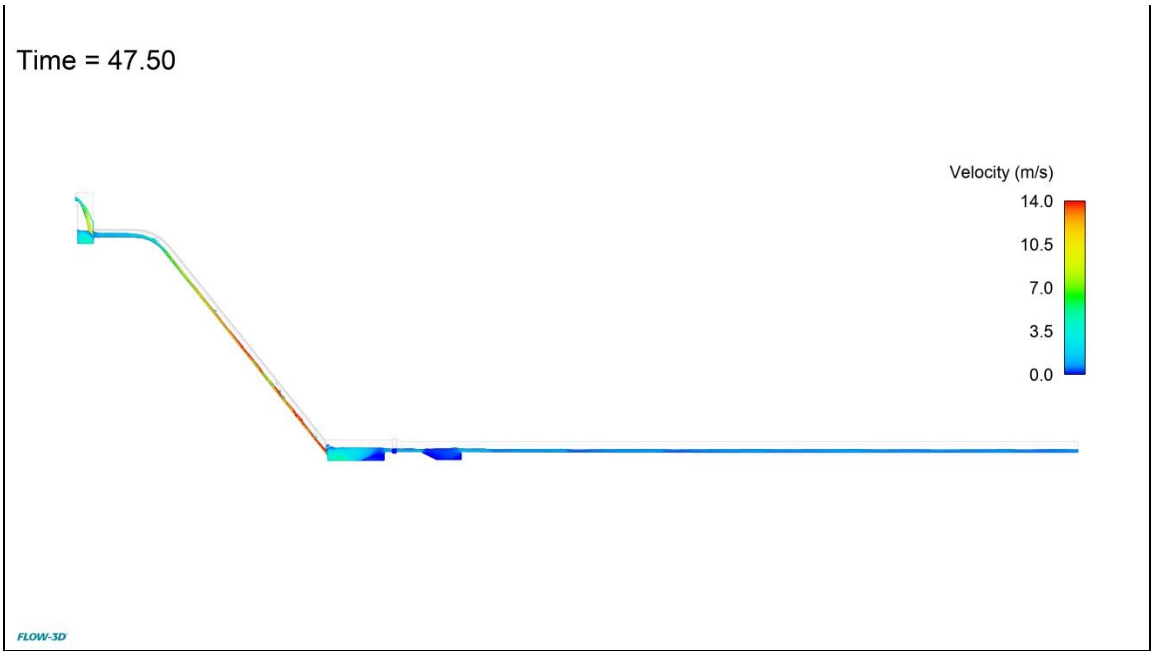


Figure 4.30. Flow 3D Velocity Distribution Along the Whole System (2D View at the Center of the Channel and Pools)

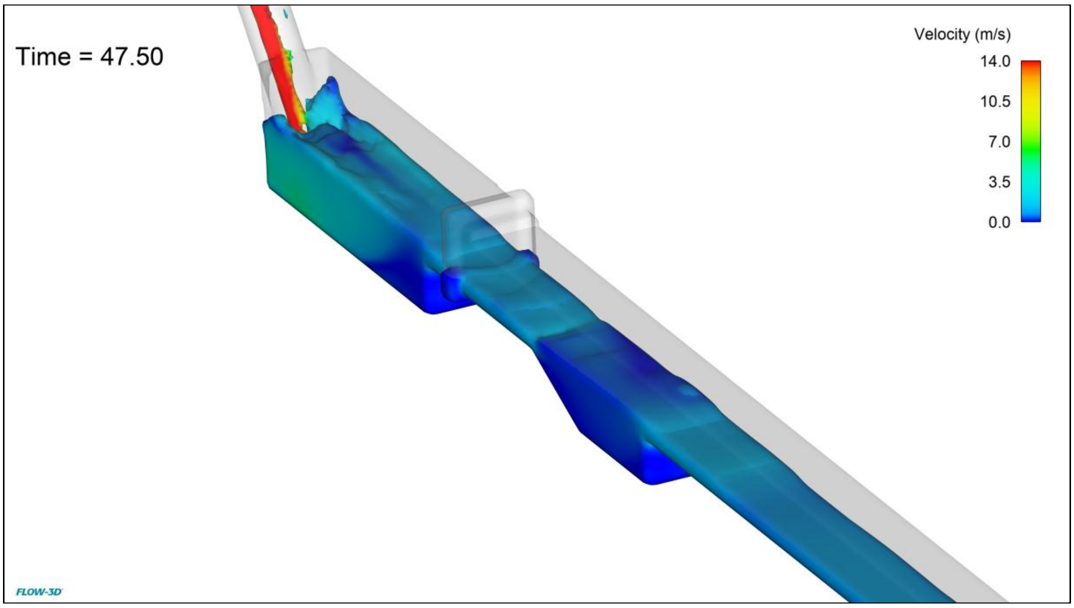


Figure 4.31. Flow 3D Velocity Distribution Along the Whole System (3D View, Different Angle)

4.3. Interpretation of the results of Flow 3D and Comparison With Hydraulic Calculation Results

When we compare the hydraulic calculation results with the flow 3D results it can be seen that the flow profiles, velocity profiles and depth of the flows are nearly the same. To make it more clear; a section-by-section overview can be found below:

(i) Inclined Pipe (At the end of the pipe) :

Maximum velocity	: 11,95 m/s	(Calculated)
	: 13,20 m/s	(Flow 3D)

The reason for this difference is; Flow 3D is using darcy weisbach equation to calculate the friction losses, however; I used manning equation for the calculation of friction losses. Due to the friction loss equation and coefficient differences, the result of the velocity difference is very normal. Also maximum velocities found with both methodologies are lower than 16 m/s which is the upper limit for our fish lock design.

(ii) Entrance Pool :

When we compare the flow profiles, they are nearly the same and maximum flow depth calculated in the entrance pool is 1,466 m. On the other hand, maximum flow depth in flow 3D for this pool is 1,50 m. Due to friction loss equation and coefficient differences, this much velocity difference is very normal.

(iii) Inlet Channel :

When we compare the flow profiles, they are nearly the same at the inlet channel. However in flow 3D the flow is critical only at the end of the channel and near to critical at most part of the channel. It can be caused by the fact that, there is a sluice gate slot present in the channel as can be seen in Figure 4.28 and Figure 4.29. This abrupt expansion and then abrupt contraction of the channel affects the flow profile. Also maximum velocity at the inlet channel is observed at critical section that is equal to $V_{critical}$ = 1,50 m/s. Maximum velocity at the attraction channel is lower than $V_{cruising}$ = 2,07 m/s which is the upper limit for Inoren fish lock design.

(iv) Resting Pool :

When we compare the flow profiles, they are nearly the same and maximum flow depth calculated in the resting pool is 1,394 m. On the other hand, maximum flow depth in flow 3D for this pool is 1,402 m. Due to friction loss equation and coefficient differences this much velocity difference is very normal.

(v) Attraction Channel :

When we compare the flow profiles, they are nearly the same at the attraction channel. In Flow 3D the flow depth is nearly at normal depth at the entrance and goes to nearly critical depth at the end of the channel. The small difference of the flow depths at the entrance (0,36 m vs. 0,342 m) is because of the difference in friction coefficients and friction loss equations between Flow 3D and calculated values. Also maximum velocity at the attraction channel occurs at critical section at the end of the channel that is equal to $V_{critical}$ = 1,50 m/s. Maximum velocity at the attraction channel is lower than $V_{cruising}$ = 2,07 m/s which is the upper limit for our fish lock design.

Table 4.3. Comparison of Flow 3D with Hydraulic Calculation Results

Comparison of Flow 3D with Calculations	**Flow 3D**	**Calculation**	
Velocity at the Entrance of the Entrance Pool	13,20 m/s	11,95 m/s	(Due to Darcy(ε=1,0 mm) vs Manning Friction Loss(0,012) Difference)
Flow Depth at the Entrance Pool	1,50 m	1,466 m	(Due to Darcy(ε=1,0 mm) vs Manning Friction Loss(0,012) Difference)
Flow Profile at the inlet Channel	Nearly Critical Stage	Critical Stage	
Flow Depth at the Resting Pool	1,402 m	1,394 m	Due to Darcy(ε=1,0 mm) vs Manning Friction Loss(0,012) Difference)
Flow Profile at the Attraction Channel	(0,36 m) Nearly Normal Depth at the entrance, Nearly Critical Depth at the exit	(0,342 m)Normal Depth at the entrance, Critical Depth at the exit	Since normal depth changes due to friction coefficient Due to Darcy(ε=1,0 mm) vs Manning Friction Loss(0,012) Difference)

4.4. Estimated Cost and BOQ of Inoren Fish Lock

In order to give an idea about the approximate cost of a Borland fish lock, Inoren weir fish lock Bill of Quantities are derived and given in Table 4.4. Also to make cost estimation of these quantities, DSI Dams and Hydropower Plants Office 2018 Unit Prices have been used.

Table 4.4. Inören Weir Fish Lock Bill of Quantities

Inören Weir Fish Lock Bill of Quantities					
Unit Price No		**Quantity**	**Unit**	**DSI 2018 Unit Price (TL)**	**Total Price (TL)**
	Excavation and Fill Works				
B-15.301	Excavation of loose soil formation	251	m^3	3,20	802
B-15.310	Excavation of Rock formation	585	m^3	18,51	10.819
Sub total for Excavation and Fill Works					11.621
	Concrete, Formwork and Reinforcement Works				
B-16.513	Concrete	455	m^3	224,59	102.188
B-16.501	Portland Cement (TS 19, PÇ 42,5)	159	ton	236,94	37.733
B-23.002	Reinforcement Bars	32	ton	4.088,71	130.225
B-D.304	Drilling of Anchorage bar hole	54	m	33,83	1.826
B-D.305	Placing of Anchorage bars	450,12	kg	6,40	2.881
B-18.501	PVC water stop	165	kg	19,26	3.178
B-21.015/1	F1 type plain formwork	890	m^2	41,28	36.739
B-21.015/2	F3 typeplain formwork	445	m^2	76,65	34.109
Sub total for Concrete, Formwork and Reinforcement Works					348.880
	Gates, Trasracks and Vanes				
B-23.D/4-a	Steel Pipes	10.000	kg	20,89	208.900
B-23.255	Sluice gates (Entrance pool and Exit Pool)	9.750	kg	30,30	295.425
B-23.302	Lift Equipment of Sluice Gates	2.000	kg	48,00	96.000
-----	Entrance pool Bypass Vane (Ø500)	1	adet	-----	45.000
Sub total for Gates, Trasracks and Vanes					645.325
	Transportation Works				
B-07.D/1	Transportaion of Cement(100 km)	159	ton	33,49	5.333
B-07.D/2	Transportation of Reinforcement Bars (170 km)	32	ton	78,95	2.515
B-07.D/4	Transportation of Aggregates (4.15 km)	569	m^3	8,06	4.584
B-07.D/5	Transportation of Excavated Rock (0.75 km)	585	m^3	4,95	2.892
B-07.D/4	Transportation of Excavated Loose Soil (0.75 km)	251	m^3	3,43	859
Sub total for Transportation Works					16.183
TOTAL COST					**1.022.008**

5. CONCLUSIONS AND RECOMMENDATIONS

Fish passes are crucial facilities that should be present on any obstacle built on a river to provide migration of species and River Continuum. However the higher the obstacle the harder it is for the fish to pass through it and the harder it is to estimate the behavior of the fish for designing a fish pass. Borland Fish Lock was designed by J.H.T. Borland to overcome the large difference in river height at either side of many hydroelectric dams, providing a route for both the upstream and downstream migration of the fish. There are many research studies about fish locks on high dams or weirs in the literature. Many have been reviewed for this study but it is concluded that every project has its own ecosystem features. Migration behaviors of fish vary for each specie, even the same specie in different geographic environments behaves differently than the other. Throughout a research study [25] which was made at two hydropower stations located in the same river basin in southern Sweden; migrating atlantic salmon and sea trout were counted through a period of more than fifteen years. The purpose of the investigations was primarily to collect data about the number of fish that pass the fishways, time of fish migration during the year and fish behavior at the fish ways. The study provides knowledge that may be useful in investigations and fishway management in other rivers. The results of the study showed that migration pattern of species vary within a geographic region. For instance rather than a constant water flow, adaptation of fishway entrance to seasonal water flows during the main migration period could be of special value[25].

The way that the fish behaves has an important role on the efficiency of a Borland fish lock. For the fish lock to be efficient, the fish should stay in the entrance pool throughout the attraction stage, they should rise in parallel to the water throughout the filling phase and then lastly leave the lock before emptying phase starts[6].

During the attraction phase the velocity and turbulence status of the downstream entrance pool must be favorable for the fish. Besides this, due to the risk that is brought by intensive turbulence and air entrainment, which may result in the fish staying in the entrance pool and not ascending with the filling water, a proper time should pass for the filling phase; this process should not happen too quickly. Lastly, for avoiding the fish being swept back downstream pool as the emptying phase starts, they should have enough time to leave the lock[6].

Deciding on the most favorable hydraulic conditions for the migrating fish at the beginning is not realistic for sure. Also the behaviors of the related species play a crucial role on determining the most suitable operating cycle. So, it is very important that the lock should be designed as flexible as possible in terms of its operation (regarding the duration of each stage of the cycles, opening range of the sluices, etc.)[6].

A three year study was conducted in Sweden[7-9]. The aim of the study was to provide a quantitative analysis of the movements of returning adult salmon through the Borland fish lock. The experimental aims were to:

(i) Test whether the number of salmon successfully ascending the pass was related to the flow rate during the previous fishing phase,
(ii) Test whether making the exit gate the only source of ambient light in the exit pool changes the time taken by fish to exit the pass during the lifting phase,
(iii) Evaluate the effect of changing the number of lifts on the total daily numbers of fish ascending the pass,

The test results were as follows: velocity and flowrate has an effect on efficiency however making the exit gate the only source of ambient light in the exit pool and the number of lifts does not have an effect on the efficiency of the fish lock.

However some studies suggest that it seems preferable to light the interior of the lock in order to provide a gradual transition between the external light environment and that in the lock itself[6].

As a result, research studies show some general predictions about the behavior of salmonids but the main idea is to design the fish lock as flexible as possible. The main predictions of the studies concentrate on: flow velocity, operation hours, ambient light, number of cycles, depth of flow and water temperature. Since no further study can be done about operation hours, number of cycles and water temperature at the present design stage(because the fish lock is not constructed yet) these issues are not given in Conclusions and Recommendations chapter instead of that these issues are given in the next chapter as Further Studies. So let us concentrate on the issues that are considered in the design stage for Inoren Fish Lock:

Flow Velocity. “Experiments showed that fish could not stand an impact velocity greater than 16 m/s when dropped into a pool. When striking velocities exceed 16 m/s damage begins to occur”[13], [14]. The maximum velocity at the end of the inclined pipe is calculated as 11,95 m/s and observed 13,2 m/s in Flow 3D software ensures that it never exceeds 16 m/s.

Along the entrance pool, inlet channel, resting pool and attraction channel the velocity of the flow never exceeds Vcr = 2,07 m/s except the region of the entrance pool where the flow coming from the pipe intercepts with the existing water in the entrance pool. However this region is even smaller than half of the entrance pool as can be seen from Figure 4.29. So there is enough space for the fish not to be effected from this interference flow at the attraction phase.

The maximum flow velocity at the inlet channel and attraction channel is $V_c = 0,516$ m^3/s /(0,229 m x 1,5m) = 1,5 m/s where the flow will be at critical depth. In operation period for the sake of optimization of the efficiency of the fish lock; higher velocities can be tried by narrowing the channel width by placing some wood or plywood panels/blocks in the attraction channel. Also slower velocities can be tried by submerging the exit of the attraction channel and the efficiency variations can be observed.

Effect of Light in the Fish Lock. Some research studies[6] suggest that the effect of the light inside the fish lock will increase the efficiency of the lock and some[6-9] suggest that it has no significant effect on the efficiency. In order to be sure about the effect of light on efficiency; Inoren fish lock should be designed to have led lights inside the inclined pipe and inside the exit pool whose light color is daylight. It should be tried for a period of time to be sure about the effect of light on the efficiency of the fish lock.

Depth of Flow. In Environmental Impact Assessment Report of Turnasuyu Project [11]; it is recommended to have a minimum flow depth to enable the fish whose maximum body height are 10-14 cm can swim in the fish pass. The minimum flow depth at entrance pool, inlet channel, resting pool and attraction channel is designed to be 22,9 cm which enables the fish even with a maximum body height of 10-14 cm to swim in the fish lock.

Other than the researches and studies that have been done before, two modifications are added to Inoren Fish Lock different than classical Borland Fish Locks. First modification is; in order to enable effective downstream migration and prevent the injuries of fish that will descend from the exit pool to entrance pool, the baffle block which is given in the classical Borland Fish Lock design is extracted from the entrance pool design (Figure 3.1 and Figure 3.4). Also at some cases some of the fish at the exit pool do not exit the lock and remain in the exit pool when the lock starts to the emptying phase. Fish remaining in the exit pool after the emptying phase starts to be washed out down the sloping pipe and injured by the impact of crushing to the baffle block located in the entrance pool. By extracting the baffle block the entrance pool is provided to act like a cushioning pool at the base.

The second and the last modification added to Inoren Borland Fish Lock different than classical Borland Fish Locks is; placing of a resting pool at the downstream of the entrance pool. The design also provides attracting flow by the bypass vane to enable fish to detect the facility during the filling and exit phase because the intake structure of the vane is below the water level in the entrance pool. By this way the ecological flow will always be assured to be given to the resting pool and attraction channel, even if the lock is in the filling or exit phase. By means of this flow any fish arriving at the lock at the same time can wait in the resting pool located at the downstream of the entrance pool. In the classic Borland fish lock since no significant attracting flow and resting pool are available to enable fish to wait for the facility during the filling and exit phase, any fish arriving at the lock at the same time may well leave the area before the cycle returns to the attraction phase.

Lastly, to be able to make all the optimizations that are mentioned in this conclusion part: three night vision cameras(because inside the lock will be dark) should be placed in this Fish Lock. One camera should be placed in the entrance pool, one camera should be placed in the exit pool and one camera should be placed at the entrance of the entrance pool that can record the view of inlet channel and resting pool in order to understand the behaviors of the fish towards variations of the optimizations mentioned in this conclusion part.

Moreover, I hope this study will lead to some further site studies in the future after Inoren project is constructed. It will be very useful to record all the data of these variations and optimizations and publish as a research study to enlighten the behavior of the fish. Because the influence of most of these parameters on the behavior of migratory species is, poorly documented until today. This is why it is not easy to specify design criteria for engineers. By understanding the fish behaviors better; effectiveness of fish locks and the designs may be improved on high height dams and weirs in Turkey.

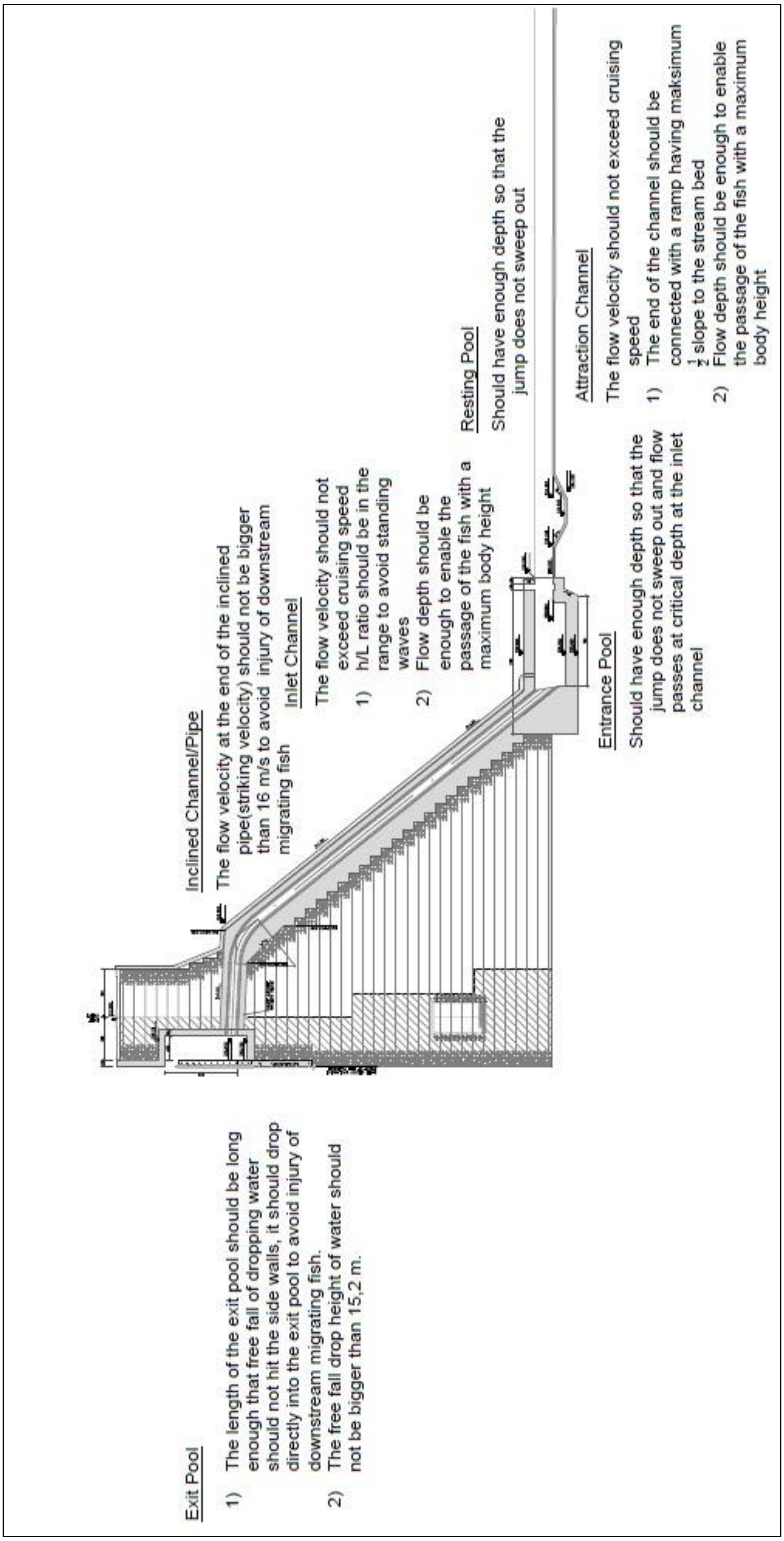


Figure 5.1. Summary of Main Design Criteria of Inoren Fish Lock

6. FURTHER STUDIES

As mentioned in the Conclusions and Recommendations chapter, the results of research studies about general predictions for the behavior of salmonids regarding operation hours, number of cycles and water temperature and also recommendations to these studies are given in here as Further Studies.

Operation Hours. Research studies [10], [25] showed that almost no fish passes the fishways at night hours and almost all of the fish pass the fishways during light hours. So operation hours of Inoren fish lock should be during light hours. Also a night time pass can be tried for a period of time to be sure about the migration behavior of the fish at night time. Also the period of time for each cycle varies in different studies. (in Ref. [2] it is recommended as 5 min filling phase, 25 min exit of the fish phase and 5 min emptying phase however in Reference [7-9] it is recommended as 15 min filling phase, 75 min exit of the fish phase and 15 min emptying phase) Since the sluice gate at the exit pool can be controlled customly and by this way the discharge rate flowing in the system can be adjusted customly; the optimum time for filling phase, exit of the fish phase and emptying phase should be determined by trial and error technique that will result in the maximum number of fish ascending from the entrance pool to the exit pool and the maximum number of fish leaving the exit pool.

Number of Cycles. The optimum number of cycles for each lock is independent according to the migration behavior of the fish species present in the ecosystem. Operation of Inoren fish lock can be started with 3 number of lifts per day (as given in the research study [8], [9] and [10]) and after some time adding one more or decreasing one more lift can be tried for a period of time to find the optimum number of lifts for the fish in Turnasuyu river.

Temperature. Research studies([7], [25], [26], [27], [28]) show that temperature has a significant effect on fish to ascend the fish passes. Fish are poikilotherms. Experiences from several studies indicate that even small obstacles are difficult to ascend at temperatures below about 5-6 ^{0}C and at least 8^{0}C seems to be necessary to ascend larger obstacles[26]. It is for sure that; it is impossible to change the water temperature in the river system but it is possible to operate the fish lock according to the water temperatures. Especially in winter times, operation hours can be determined according to ambient water temperatures. Based on studies conducted in Sweden[25]; salmonid population in different river systems have different migration behaviors according to different temperature intervals. So the optimum water temperature in Inoren Fish Lock should be decided by trial and error technique.

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APPENDIX A : FISH PASS INFORMATION TABLES

Table A.1. DSI 1. Regional Directorate Fish Pass Information Table

No	Facility	Facility	City	Province	River	Basin	Start of	Aim	Height from	Pass	Fish Pass
	Name	Type			Name	Name	Operation		Thalveg	Purpose	Type
1	M. Kemal Paşa R.	Weir	Bursa	M.Kemal Paşa			1967				
2	B. Karadere R.	Weir	Bursa				1946				
3	Cerrah HEPP	Weir	Bursa	İnegöl	Akdere	Sakarya	1952	E	5,2	FP	P
4	Akdere HEPP	Weir	Bursa	İnegöl	Akdere	Sakarya	2014	E	6	FP	P
5	Oylat I HEPP	Weir	Bursa	İnegöl	Oylat D.	Susurluk	2013	E	20	NE	
6	Suluköy HEPP	Weir	Bursa	İnegöl	Acısu D.	Sakarya	2012	E	5,59	FP	P
7	Suluköy HEPP	Weir	Bursa	İnegöl	Ulupınar D.	Sakarya	2012	E	3,55	FP	P
8	Tüfekçikonak H.	Weir	Bursa	İnegöl	Saçmalı D.	Susurluk	2015	E	6,1	FP	P
9	Tüfekçikonak H.	Weir	Bursa	İnegöl	Aksu D.	Sakarya	2016	E	3	FP	P
10	Tüfekçikonak H.	Weir	Bursa	İnegöl	Aksu D.	Sakarya	2016	E	7,25	FP	P
11	Tüfekçikonak H.	Weir	Bursa	İnegöl	Aksu D.	Sakarya	2016	E	2,6	FP	P
12	Tüfekçikonak H.	Weir	Bursa	İnegöl	Aksu D.	Sakarya	2016	E	3,1	FP	P
13	Dereköy HEPP	Weir	Bursa	İznik	Kaynaksuyu	Marmara	1953	E	1,5	NE	
14	Egemen I HEPP	Weir	Bursa	Keles	Nilüfer Ç.	Susurluk	2010	E	7,1	FP	P
15	Gözede I HEPP	Weir	Bursa	Kestel	Deliçay	Susurluk	2008	E	1,06	NE	
16	Gözede II HEPP	Weir	Bursa	Kestel	Aksu D.	Susurluk	2013	E	2,03	FP	P
17	Suuçtu HEPP	Weir	Bursa	M.Kemal Paşa	Karadere	Susurluk	2014	E	5	FP	P
18	Suuçtu HEPP	Weir	Bursa	M.Kemal Paşa	Ortaburun D.	Susurluk	2014	E	5,6	FP	P
19	Deveci Konağı B. H.	Dam	Bursa	M.Kemal Paşa	Emet River	Susurluk	2013	E	24,1	NE	
20	Uluabat HEPP	No Diversion Structure	Bursa	M.Kemal Paşa	Orhaneli River	Susurluk	2010	E	10,5	NE	
21	Kirazdere HEPP	Weir	Kocaeli	Merkez	Kirazdere	Marmara	2011	E	.-	NE	
22	Egemen I B. HEPP	Weir	Bursa	Osmangazi	Nilüfer Ç.	Susurluk	2011	E	3,55	FP	P
23	Boğazköy B. HEPP	Dam	Bursa	Yenişehir	Göksu D.	Susurluk	2014	E	24	NE	
24	Gölbaşı Dam	Dam	Bursa	Kestel	Aksu D.	Sakarya	1938	I + F	12	NE	
25	Demirtaş Dam	Dam	Bursa	Osmangazi	Ballıkaya D.	Susurluk	1983	I	46	NE	
26	Doğancı 1	Dam	Bursa	Osmangazi	Nilüfer Ç.	Susurluk	1983	DW	65	NE	
27	Hasanağa Dam	Dam	Bursa	Nilüfer	Hasanağa D.	Susurluk	1984	I	30	NE	
28	Büyükorhan Dam	Dam	Bursa	Büyükorhan	Cuma D.		1992	I	32	NE	
29	Kozluören Dam	Dam	Bursa	Kestel	Hacı D.	Sakarya	1999	I	33	NE	
30	Nilüfer Dam	Dam	Bursa	Yıldırım	Nilüfer Ç.		1998	DW	74,5	NE	
31	Uşakpınar Dam	Dam	Bursa	Kestel	Uşakpınar D.	Susurluk	1999	I	31	NE	
32	Çalı Dam	Dam	Bursa	Nilüfer	Kurtkaya D.	Susurluk	2002	I	44	NE	
33	Kurşunlu Dam	Dam	Bursa	İnegöl	Domuz D.	Sakarya	2003	I	40	NE	

Table A.1. DSI 1. Regional Directorate Fish Pass Information Table (cont.)

34	Doğancı 2 (Nilüfer) Dam	Dam	Bursa	Nilüfer	Nilüfer Ç.	Susurluk	2007	DW	74,5	NE	
35	Çınarcık Dam	Dam	Bursa	Orhaneli	Orhaneli Ç.		2008	E + DW + I + F	123	NE	
36	Babasultan Dam	Dam	Bursa	Ketel	Karadere	Sakarya	2009	I	46	NE	
37	Karıncalı Dam	Dam	Bursa	Orhaneli	Bozönü D.	Susurluk	2010	I	29	NE	
38	Dağdibi Dam	Dam	Bursa	Keles	Akdere	Susurluk	2011	I	43,5	NE	
39	Mahmudiye Dam	Dam	Bursa	İznik	Fulacık D.	Marmara	2012	I	39,5	NE	
40	Çiçeközü Dam	Dam	Bursa	Yenişehir	Boğazdere	Sakarya	2013	I	48,5	NE	
41	Ericek Dam	Dam	Bursa	Büyükorhan	Ericek D.	Susurluk	2015	I	23,5	NE	
42	Gözede Dam	Dam	Bursa	Kestel	Bağlar D.	Susurluk	2015	I	25,5	NE	
43	Küçükkumla Dam	Dam	Bursa	Gemlik	Pınarbaşı D.	Marmara	2016	I	29	NE	
44	Aktaş Dam	Dam	Bursa	Büyükorhan	Arabageçit D.	Susurluk	2016	I	32	NE	
45	Ağlaşan Kayacık B.	Dam	Bursa	Kestel	Kızılcıklı D.	Sakarya	2016	I	33,65	NE	
46	Gökçesu Dam	Dam	Bursa	Yenişehir	Sellimandra D.	Sakarya	2016	I	28	NE	
47	Alangünü Dam	Dam	Bursa	İnegöl	Karadere	Sakarya	2017	I	27	NE	
48	Kocayayla Dam	Dam	Bursa	Keles	Küçükalan+Bıçkı +Kendir D.	Susurluk	2018	I	36	NE	
49	Yalıçiftlik Dam	Dam	Bursa	Mudanya	Çakal D.	Marmara	2018	I	34	NE	

Table A.2. DSI 2. Regional Directorate Fish Pass Information Table

No	Facility Name	Facility Type	City	Province	River Name	Basin Name	Start of Operation	Aim	Height from Thalveg	Pass Purpose	Fish Pass Type
1	Emiralem Weir	Weir	İzmir	Menemen	Gediz River	Gediz	1944	I		FP	P
2	Ahmetli	Weir	Manisa	Turgutlu	Gediz River	Gediz	1956	I		FP	P
3	Marmara Gölü	Weir	Manisa	Salihli	Gediz River	Gediz	1953	I		FP	P
4	Adala Weir	Weir	Manisa	Salihli	Gediz River	Gediz	1944	I	114	NE	
5	Alaçatı Weir	Weir	İzmir	Çeşme	Değirmenriver	Küçük Menrivers	1997	DR		NE	
6	Aslanlar Weir	Weir	İzmir	Torbalı	Taşkesik D.	Küçük Menrivers	2013	I	102,7	NE	
7	Avgan Weir	Weir	Uşak	Ulubey	Banaz Ç.	Büyük Menrivers	2013	I		NE	
8	Çilingir Weir	Weir	Manisa	Kırkağaç	Çilingir D.	Kuzey Ege	2015	DR		NE	
9	Çömlekci Weir	Weir	Manisa	Gölmarmara	Gördes Ç.	Gediz	1952	D		NE	
10	Erice Weir	Weir	Uşak	Sivaslı	Banaz Ç.	Büyük Menrivers	2014	I		NE	
11	Gürlek Weir	Weir	Uşak	Banaz	Dede D.	Büyük Menrivers	2014	I	1137	NE	
12	Kıranlı Weir	Weir	İzmir	Bergama	Karabacak K.D.	Kuzey Ege	2013	I	706,5	NE	
13	Öksüz Weir	Weir	Uşak	Banaz	Banaz Ç.	Büyük Menrivers	2015	I	888,5	NE	
14	Yağcılı Weir	Weir	Manisa	Soma	Yağcılı D.	Kuzey Ege	1997	I		NE	
15	Yeşilyurt Weir	Weir	Uşak	Banaz	Banaz Ç.	Büyük Menrivers	2014	I	967	NE	
16	Küçükdarıriver Weir	Weir	Manisa	Kula	Gediz River	Gediz	2008	I		NE	
17	Afşar Dam	Dam	Manisa	Alaşehir	Alaşehir Ç.	Gediz	1977	I + F	43,5	NE	
18	Sevişler Dam	Dam	Manisa	Soma	Yağcılı D.	Kuzey Ege	1981	I	59,5	NE	
19	Balçova Dam	Dam	İzmir	Balçova	Ilıca D.	K. Menrivers	1980	DW	63,4	NE	
20	Güzelhisar Dam	Dam	İzmir	Aliağa	Güzelhisar D.	Kuzey Ege	1981	E	77	NE	
21	Kestel Dam	Dam	İzmir	Bergama	Kestel	Kuzey Ege	1988	I	62,5	NE	
22	Ürkmez Dam	Dam	İzmir	Seferihisar	Ürkmez D.	K. Menrivers	1989	I	32	NE	
23	Seferihisar Dam	Dam	İzmir	Seferihisar	Yassı Ç.	K. Menrivers	1993	I	54	NE	
24	Tahtalı Dam	Dam	İzmir	Menrivers	Tahtalı Ç.	K. Menrivers	1996	DW	54,5	NE	
25	Yortanlı Dam	Dam	İzmir	Bergama	Ilıca D.	Kuzey Ege	2006	I	45,5	NE	
26	Mordoğan Dam	Dam	İzmir	Karaburun	Kuşkudan D.	K. Menrivers	2007	DW	32,2	NE	
27	Kavakriver Dam	Dam	İzmir	Seferihisar	Kavakriver Ç.	K. Menrivers	2008	D	36,5	NE	
28	Ataköy Dam	Dam	İzmir	Menrivers	Karacadağ D.	K. Menrivers	2008	I	27	NE	
29	Beydağ Dam	Dam	İzmir	Beydağ	K.Menrivers	K. Menrivers	2009	I	51	NE	
30	Çaltıkoru Dam	Dam	İzmir	Bergama	İlyas Ç.	Kuzey Ege	2011	I	92	NE	
31	Çıtak Dam	Dam	İzmir	Aliağa	Yörük	Kuzey Ege	2014	I	30	NE	
32	Çatak Dam	Dam	İzmir	Kiraz	Öküz river	K. Menrivers	2014	I	30	NE	
33	Haliller Dam	Dam	İzmir	Kiraz	Kocaharman	K. Menrivers	2014	I	32	NE	

Table A.2. DSI 2. Regional Directorate Fish Pass Information Table (cont.)

34	Süleymanlı Dam	Dam	İzmir	Menemen	Süleymanlı	Gediz	2014	I	28,45	NE	
35	Yenişehir Dam	Dam	İzmir	Tire	Kızılkaya	K. Menrivers	2014	I	33,5	NE	
36	Karakızlar Dam	Dam	İzmir	Torbalı	Değirmenriver	K. Menrivers	2014	I	30,9	NE	
37	Çamavlu Dam	Dam	İzmir	Bergama	Hasanriver	Kuzey Ege	2015	I	37,3	NE	
38	Karaçam Dam	Dam	İzmir	Bornova	İnriver	Gediz	2015	I	28,35	NE	
39	Burgaz Dam	Dam	İzmir	Bayındır	Falaka Ç.	K. Menrivers	2015	I	84,5	NE	
40	Çandarlı Dam	Dam	İzmir	Dikili	Değirmen D.	Kuzey Ege	2015	DW	30,71	NE	
41	Bağyurdu Dam	Dam	İzmir	Kemalpaşa	Bağyurdu river	Gediz	2015	I	37,7	NE	
42	Özriver Dam	Dam	İzmir	Menrivers	Değirmenriver	K. Menrivers	2015	I	29,4	NE	
43	Bademli Dam	Dam	İzmir	Ödemiş	Pirinççi D.	K. Menrivers	2015	I	51	NE	
44	Eskioba Dam	Dam	İzmir	Tire	Tokat river	K. Menrivers	2015	I	27	NE	
45	Karalar Dam	Dam	İzmir	Bergama	Köyyeri river	Kuzey Ege	2016	I	29,5	NE	
46	Bözköy Dam	Dam	İzmir	Karaburun	Uzunriver	K. Menrivers	2016	I	31,5	NE	
47	Gümüldür Dam	Dam	İzmir	Menrivers	Şeytan river	K. Menrivers	2016	I	37,5	NE	
48	Çamtepe Dam	Dam	İzmir	Bergama	Pelitçe (Hayıtlı) river	Kuzey Ege	2017	I	27,5	NE	
49	Salman Dam	Dam	İzmir	Karaburun	Sudeğirmeni river	K. Menrivers	2017	I	42,3	NE	
50	Karareis Dam	Dam	İzmir	Karaburun	Camiboğazı river	Küçük Menrivers	2017	I	34	NE	
51	Aktaş Dam	Dam	İzmir	Ödemiş	Aktaş D.	K. Menrivers	2017	I	100,5	NE	
52	Köseler Dam	Dam	İzmir	Aliağa	Köseler D.	Kuzey Ege	2007	I	25,23	NE	
53	Gördes Dam	Dam	Manisa	Gördes	Gördes Ç.	Gediz	2008	I	82,9	NE	
54	Doğanpınar Dam	Dam	Manisa	Gördes	Geçtin river	Gediz	2013	I	28	NE	
55	Çaltıcak Dam	Dam	Manisa	Kırkağaç	İnriver	Kuzey Ege	2013	I	30	NE	
56	Bebekli Dam	Dam	Manisa	Kula	Bebekli river	Gediz	2013	I	28,97	NE	
57	Kavaklıriver Dam	Dam	Manisa	Alaşehir	Alaşehir Ç.	Gediz	2014	I	29,74	NE	
58	Güneşli Dam	Dam	Manisa	Gördes	İnriver	Gediz	2014	I	42,7	NE	
59	Çelengöz Dam	Dam	Manisa	Kula	Gökriver	Gediz	2014	I	28	NE	
60	Kemaliye Dam	Dam	Manisa	Alaşehir	Değirmenriver	Gediz	2015	I	32	NE	
61	Yurtbaşı Dam	Dam	Manisa	Merkez	Havut river	Gediz	2015	I	36	NE	
62	Gevenlik Dam	Dam	Manisa	Saruhanlı	Paklı river	Gediz	2015	I	27	NE	
63	Ayanlar Dam	Dam	Manisa	Selendi	Alan river	Gediz	2015	I	38,67	NE	
64	Bağyolu Dam	Dam	Manisa	Yunusemre	Ballık river	Gediz	2015	I	29	NE	
65	Eroğlu Dam	Dam	Manisa	Kula	Eroğlu river	Gediz	2016	I	28,14	NE	
66	Mesudiye Altıntaş Dam	Dam	Uşak	Merkez	Kayariver	B. Menrivers	1995	I	28,6	NE	
67	Kozviran Dam	Dam	Uşak	Banaz	Darriver	B. Menrivers	2004	I	38	NE	
68	Küçükler Dam	Dam	Uşak	Banaz	Gavuralriver	Gediz	2004	I	35,3	NE	
69	İsalar Dam	Dam	Uşak	Eşme	Kurbağalıriver	Gediz	2007	I	27	NE	
70	Ahat Dam	Dam	Uşak	Banaz	Kuruçayriver	B. Menrivers	2008	I	39	NE	
71	Yayalar Dam	Dam	Uşak	Sivaslı	Karagürriver	B. Menrivers	2009	I	30,5	NE	

Table A.2. DSI 2. Regional Directorate Fish Pass Information Table (cont.)

72	Karaköse Dam	Dam	Uşak	Banaz	Çayözü	Sakarya	2014	I	26,5	NE	
73	Güllübağ Dam	Dam	Uşak	Eşme	Kocariver	B. Menrivers	2014	I	29,3	NE	
74	Çevre Dam	Dam	Uşak	Merkez	Sazlık river	Büyük Menrivers	2014	I	19,3	NE	
75	Kayaağıl Dam	Dam	Uşak	Merkez	Karabol	Büyük Menrivers	2014	I	30	NE	
76	Gedikler Derbent Dam	Dam	Uşak	Banaz	Yalancı river	Büyük Menrivers	2015	I	30	NE	
77	Alanyurt Dam	Dam	Uşak	Merkez	Çingece river	Büyük Menrivers	2015	I	28,8	NE	
78	Aşağıkaracahisar Dam	Dam	Uşak	Merkez	Kusara	Büyük Menrivers	2015	I	29,5	NE	
79	Derbent Dam	Dam	Uşak	Merkez	Cami river	Büyük Menrivers	2015	I	27	NE	
80	İlyaslı Dam	Dam	Uşak	Merkez	Tümenler	Büyük Menrivers	2015	I	26,7	NE	
81	Bahadır Dam	Dam	Uşak	Banaz	Sıracevizler	Büyük Menrivers	2016	I	40	NE	
82	Uzunriver Dam	Dam	Uşak	Merkez	Uzunriver	Büyük Menrivers	2016	I	23	NE	
83	Kocariver Dam	Dam	Uşak	Merkez	Kocariver	Büyük Menrivers	2017	I	26,76	NE	
84	Salihli Weir	Weir	Manisa	Salihli	Gediz N.			I		NE	

Table A.3. DSI 3. Regional Directorate Fish Pass Information Table

No	Facility Name	Facility Type	City	Province	River Name	Basin Name	Start of Operation	Aim	Height from Thalveg	Pass Purpose	Fish Pass Type
1	Kargı HEPP	Dam	Ankara	Beypazarı	Sakarya N.		2017	E		NE	CT
3	Sarıyar Dam ve HEPP	Dam	Ankara	Nallıhan	Sakarya N.	Sakarya		E		NE	
4	Gökçekaya Dam ve HEPP	Dam	Ankara	Nallıhan	Sakarya N.	Sakarya		E		NE	
5	Yenice Dam ve HEPP	Dam	Eskişehir	Sarıcakaya	Sakarya N.	Sakarya		E		NE	
6	Musaözü Dam	Dam	Eskişehir	Merkez	Mollaoğlu D.	Sakarya	1969	I	19	NE	
7	Porsuk Dam	Dam	Eskişehir	Merkez	Porsuk Ç.	Sakarya	1972	I + DW + F		NE	
8	Kaymaz Dam	Dam	Eskişehir	Kaymaz	Çayırlık D.	Sakarya	1977	I	24,5	NE	
9	Kunduzlar Dam	Dam	Eskişehir	Seyitgazi	Yönek D.	Sakarya	1983	I	28	NE	
10	Çatören Dam	Dam	Eskişehir	Seyitgazi	Harami D.	Sakarya	1987	I	32	NE	
11	Koçaş 1 Dam	Dam	Eskişehir	Sivrihisar		Sakarya	1990	I		NE	
12	Koçaş 2 Dam	Dam	Eskişehir	Sivrihisar	Çağşak D.	Sakarya	1990	I		NE	
13	Erenköy 1 Dam	Dam	Eskişehir	İnönü	Karanlık D.	Sakarya	1994	I		NE	
14	Üççam Dam	Dam	Eskişehir	Han	Üççam D.	Sakarya	2006	I		NE	
15	Aşağı Kuzfındık Dam	Dam	Eskişehir	İnönü	Kocadere	Sakarya	2007	I		NE	
16	Beylikova Depolaması	Depolama	Eskişehir	Alpu	Porsuk Ç.	Sakarya	2010	I		NE	
17	Okçu Dam	Dam	Eskişehir	Sivrihisar		Sakarya	2011	I		NE	
18	Yarıkçı Dam	Dam	Eskişehir	Mihalıççık		Sakarya	2013	I		NE	
19	Diközü Dam	Dam	Eskişehir	Mihalıççık		Sakarya	2015	I		NE	
20	Bahtiyar Dam	Dam	Eskişehir	Mihalıççık		Sakarya	2016	I		NE	
21	Nasrettin Hoca Dam	Dam	Eskişehir	Sivrihisar		Sakarya	2016	I		NE	
22	Beyazaltın Dam	Dam	Eskişehir				2017	I		NE	
23	Enne Dam	Dam	Kütahya	Merkez	Dereboğazı D.	Sakarya	1972	E	24	NE	
24	Söğüt Dam	Dam	Kütahya	Merkez	Ilgın D.	Sakarya	1983	I	20,7	NE	
25	Kayaboğazı Dam	Dam	Kütahya	tavşanlı	Kocadere	Susurluk	1987	I + F	38	NE	
26	Çavdarhisar Dam	Dam	Kütahya	Çavdarhisar	Bedir D.	Susurluk	1990	I	45,5	NE	
27	Gümele Dam	Dam	Kütahya	Gediz	Canbulak D.	Gediz	1999	I		NE	
28	Beşkarış Dam	Dam	Kütahya	Dumlupınar	Kokarçay	Sakarya	2010	I		NE	
29	Gediz Dam	Dam	Kütahya	Gediz		Gediz	2013	I		NE	
30	Hasanlar Dam	Dam	Kütahya	Hisarcık	Kabaklar D.	Susurluk	2013	I		NE	
31	Simav Söğüt Dam	Dam	Kütahya	Simav			2013	I		NE	
32	Uluçam Dam	Dam	Kütahya	Tavşanlı			2013	I		NE	
33	Yemişli Dam	Dam	Kütahya	Tavşanlı			2015	I		NE	
34	Kureyşler Dam	Dam	Kütahya	Aslanapa	Kureşler D.	Sakarya	2016	I		NE	
35	Kiçir Dam	Dam	Kütahya	Simav			2016	I		NE	
36	Şaphane Dam	Dam	Kütahya				2016	I		NE	

Table A.3. DSI 3. Regional Directorate Fish Pass Information Table (cont.)

37	Doğanlar Dam	Dam	Kütahya	Tavşanlı			2016	I		NE	
38	Çukurca Dam	Dam	Kütahya	Domaniç			2017	I		NE	
39	Kemaliye Dam	Dam	Sakarya	Pamukova			2016	I		NE	
40	Pamukova Reg ve HEPP	Weir	Sakarya	Pamukova	Sakarya N.		2001	E		FP	P
41	Çilekli Dam	Dam	Sakarya	Pamukova			2017	I		NE	
42	Ballıkaya Dam	Dam	Sakarya	Akyazı	Mudurnu Ç.	Sakarya	2017	DW		NE	
43	Doğançay 1 HEPP	HEPP	Sakarya	Doğançay	Sakarya N.		2014	E		FP	P
44	Doğançay 2 HEPP	HEPP	Sakarya	Doğançay	Sakarya N.		2014	E		FP	P
45	Adasu HEPP	HEPP	Sakarya	Adapazarı	Sakarya N.		2014	E		FP	VSP
46	Ağaçköy Weir	Weir	Kütahya	Merkez	Koçak Ç.		1961	R		FP	P
47	Yaralı Regulatörü	Weir	Ankara	Polatlı	Sakarya N.		1984	R		FP	P
48	Bugor 2 HEPP	HEPP	Bilecik		Sakarya N.			E		FP	P
49	Bugor 1 HEPP	HEPP	Bilecik		Sakarya N.			E		FP	P
50	Dodurga Dam	Dam	Bilecik	Bozhöyük	Sarısu D.		1977	I + F	26,9	NE	
51	Borcak Dam	Dam	Bilecik	Söğüt	Borcak D.	Sakarya	1998	I		NE	
52	Kızıldamlar Dam	Dam	Bilecik	Söğüt	Söğüt D.	Sakarya	2003	I		NE	
53	Mustafa Eldemir Dam	Dam	Bilecik	Pazaryeri	Bakraş D.	Sakarya	2006	I		NE	
54	Kurtköy Dam	Dam	Bilecik	Merkez	Sabuncu D.	Sakarya	2008	I		NE	
55	Dereboyu Zevye Dam	Dam	Bilecik	Söğüt	Ballık D.	Sakarya	2009	I		NE	
56	Yenipazar Dam	Dam	Bilecik				2010			NE	
57	Selöz Dam	Dam	Bilecik	Merkez			2013			NE	
58	Akçay Dam	Dam	Bilecik	Gölpazarı			2017			NE	

Table A.4. DSI 5. Regional Directorate Fish Pass Information Table

No	Facility Name	Facility Type	City	Province	River Name	Basin Name	Start of Operation	Aim	Height from Thalveg	Pass Purpose	Fish Pass Type
1	Eymir Weir	Weir	Ankara	Gölbaşı		Sakarya				NE	
2	Kışlacık Diversion	D.Kanalı	Ankara			Sakarya				NE	
3	Hacinler Weir	Weir	Bolu		Malen Ç.	B. Karadeniz				NE	
4	Sürmenek HEPP	Weir	Ankara	Merkez	Aladağ Ç.	Sakarya				NE	
5	Kapulukaya Dam ve HEPP	Dam	Kırıkkale	Merkez	Kızılırmak	Kızılırmak	1989	E + I	44	NE	
6	Sulakyurt Dam	Dam	Kırıkkale	Sulakyurt	Taretözü	Kızılırmak	2016	I		NE	
7	Hasandede Dam	Dam	Kırıkkale	Keskin	Kale D.	Kızılırmak	2008	I		NE	
8	Ceritmüminli Dam	Dam	Kırıkkale	Keskin		Kızılırmak	2012	I		NE	
9	Akçakavak Dam	Dam	Kırıkkale	Balışeyh		Kızılırmak	2015	I		NE	
10	Büyükceceli Dam	Dam	Kırıkkale	Keskin		Kızılırmak	2017	I		NE	
11	Kesikköprü Dam ve HEPP	Dam	Ankara	Bala	Kızılırmak	Kızılırmak	1967	I + DW + E	49,1	NE	
12	Çeşmebaşı HEPP	HEPP	Ankara	Kalecik	Kızılırmak	Sakarya	2011			FP	P
13	Kalecik 1 HEPP	HEPP	Ankara	Kalecik	Kızılırmak	Kızılırmak	2013			FP	P
14	Kalecik 2 HEPP	HEPP	Ankara	Kalecik	Kızılırmak	Kızılırmak	2013			FP	P
15	Kalecik 3 HEPP	HEPP	Ankara	Kalecik	Kızılırmak	Kızılırmak	2013			FP	P
16	Hirfanlı Dam ve HEPP	Dam	Kırşehir	Kaman	Kızılırmak	Kızılırmak	1959	E	78	NE	
17	Cevizlidere HEPP	HEPP	Bolu	Bozdağ	Bozdağ Ç.	Sakarya	2013			FP	P
18	Çeltikdere HEPP	HEPP	Bolu	Bozdağ	Uluçay	Sakarya	2013			FP	P
19	Göksu HEPP	HEPP	Bolu	Bozdağ	Göksu Ç.	Sakarya	2015			FP	P
20	Karaköy HEPP	HEPP	Bolu	Karaköy	Aladağ Ç.	Sakarya	2013			FP	P
21	Kayabükü HEPP	HEPP	Bolu	Gökçesu	Devrek Ç.	B. Karadeniz	2010			FP	P
22	Köprübaşı Dam ve HEPP	Dam	Bolu	Mengen	Bolu Ç.	B. Karadeniz	2013			NE	
23	Paşa Weir ve HEPP	HEPP	Bolu	Mengen	Bolu Ç.	B. Karadeniz	2010			FP	P
24	Yazı HEPP	HEPP	Çankırı	Orta	Yazı Ç.	Kızılırmak	2009			NE	
25	Obruk Dam ve HEPP	Dam	Çorum	Merkez	Kızılırmak	Kızılırmak	2009	I + DW + E	67	NE	
26	Kargı Dam	Dam	Çorum	Osmancık	Kızılırmak	Kızılırmak	2015			NE	
27	Pirinçli HEPP	HEPP	Çorum	Osmancık	Kızılırmak	Kızılırmak	2013			NE	
28	Hasanlar Dam ve HEPP	Dam	Düzce	Merkez	Küçük Melen Ç.	B. Karadeniz	1991			NE	
29	Çınar 1 HEPP	HEPP	Düzce	Kaynaşlı		B. Karadeniz	2012	E		FP	P
30	Defne HEPP	HEPP	Düzce	Gölyaka	Aksu Ç.	B. Karadeniz	2010	E		FP	P
31	Aksu HEPP	HEPP	Düzce	Merkez	Aksu Ç.	B. Karadeniz	2104	E		FP	P
32	Hasanlar Kanal HEPP	HEPP	Düzce	Merkez	Küçük Melen Ç.	B. Karadeniz	2011	E		NE	
33	Köknar HEPP	HEPP	Düzce	Kaynaşlı	Uğursuyu D.	B. Karadeniz	2012	E		FP	P

Table A.4. DSI 5. Regional Directorate Fish Pass Information Table (cont.)

34	Güneş HEPP	HEPP	Düzce	Kaynaşlı	Hamamsuyu D.	B. Karadeniz	2017	E		FP	P
35	Hamzalı HEPP	HEPP	Kırıkkale	Sulakyurt	Kızılırmak	Kızılırmak	2008	E		FP	P
	Kargı HEPP	HEPP	Çorum	Osmancık	Kızılırmak	Kızılırmak	2015	E		FP	P
36	Sema Weir ve HEPP	HEPP	Kırıkkale	Karakeçili	Kızılırmak	Kızılırmak	2015	E		FP	P
37	Kavşakkaya Dam	Dam	Ankara	Kazan	Koca D.	Sakarya		DW	70,5	NE	
38	Çubuk 1 Dam	Dam	Ankara	Altındağ	Çubuk Ç.	Sakarya	1936	R	25	NE	
39	Çubuk 2 Dam	Dam	Ankara	Çubuk	Çubuk Ç.	Sakarya	1965	R	61	NE	
40	Bayındır Dam	Dam	Ankara	Mamak	Bayındır D.	Sakarya	1965	R	30	NE	
41	Kurtboğazı Dam	Dam	Ankara	Kızılcahamam	Ova Ç.	Sakarya	1967	DW	52,6	NE	
42	Asartepe Dam	Dam	Ankara	Beypazarı	İlhan Ç.	Sakarya	1980	I	36,5	NE	
43	Karaahmetli Dam	Dam	Ankara	Polatlı		Sakarya	1980	I		NE	
44	Çamlıdere Dam	Dam	Ankara	Çamlıdere	Bayındır D.	Sakarya	1985	DW		NE	
45	Çanıllı Dam	Dam	Ankara	Ayaş	İlhan Ç.	Sakarya	1991	I		NE	
46	Eğrekkaya Dam	Dam	Ankara	Kızılcahamam	Sey Hamam Ç.	Sakarya	1992	DW	67	NE	
47	Çamalan Dam	Dam	Ankara	Nallıhan	Beydilli	Sakarya	1998	I		NE	
48	Akyar Dam	Dam	Ankara	Kızılcahamam	Bulak Ç.	Sakarya	1999	DW	74	NE	
49	Köprüdere Dam	Dam	Ankara	Evren		Kızılırmak	2000	I	40	NE	
50	Çamlıdere Bayındır Dam	Dam	Ankara	Çamlıdere	Bayındır D.	Sakarya	1985	I	101,7	NE	
51	Ozanköy Dam	Dam	Ankara	Nallıhan	Kocakır D.	Sakarya	2008	I		NE	
52	Doğanözü Dam	Dam	Ankara	Kızılcahamam	Kirmir Ç.	Sakarya	2011	I	34	NE	
53	Peçenek Dam	Dam	Ankara	Ş.Koçhisar		Konya KH	2011	I + DW	34	NE	
54	Belenalan Dam	Dam	Ankara	Nallıhan		Sakarya	2012			NE	
55	Başayaş Dam	Dam	Ankara	Ayaş		Sakarya	2014	I		NE	
56	Mamak Dam	Dam	Ankara	Mamak			2014			NE	
57	Yukarıçavundur Dam	Dam	Ankara	Çubuk			2015	I		NE	
58	Türkşerefli Dam	Dam	Ankara	Haymana		Sakarya	2015	I		NE	
59	Kalecik Dam	Dam	Ankara	Kalecik	Uludere	Kızılırmak	2015	I + E		NE	
60	Orhaniye Dam	Dam	Ankara	Kazan		Sakarya	2015	I		NE	
61	Çalta Dam	Dam	Ankara	Kızılcahamam		Sakarya	2015	I		NE	
62	Kınık Dam	Dam	Ankara	Kızılcahamam		Sakarya	2015	I		NE	
63	Arıklarbağı Dam	Dam	Ankara	Ayaş		Sakarya	2016	I		NE	
64	Bayram Dam	Dam	Ankara	Ayaş		Sakarya	2016	I		NE	
65	Uzunöz Dam	Dam	Ankara	Nallıhan		Sakarya	2016	I		NE	
66	Çukurören Dam	Dam	Ankara	Güdül		Sakarya	2017	I		NE	
67	Kırkkavak Dam	Dam	Ankara	Güdül		Sakarya	2017	I		NE	
68	Tekkeköy Dam	Dam	Ankara	Kazan		Sakarya	2017	I		NE	
69	Koyunbaba Dam	Dam	Ankara	Kalecik	Acı Ç.	Kızılırmak		I		NE	
70	Kargı Dam ve HEPP	HEPP	Ankara	Nallıhan	Sakarya N.	Sakarya	2017	E		NE	

Table A.4. DSI 5. Regional Directorate Fish Pass Information Table (cont.)

71	Gölköy Dam	Dam	Bolu	Merkez	Büyüksu Ç.	B. Karadeniz	1970	I + E	21,5	NE	
72	Çayköy Dam	Dam	Bolu	Göynük	Çayköy D.	Sakarya	1997	I		NE	
73	Gökçesaray Dam	Dam	Bolu	Göynük			2017	I		NE	
74	Alanhimmetler Dam	Dam	Bolu	Kıbrısçık			2017	I		NE	
75	Çorum Dam	Dam	Çorum	Merkez	Çomar D.	Yeşilırmak	1977	DW	47,5	NE	
76	Alaca Dam	Dam	Çorum	Alaca	Suludere	Yeşilırmak	1984	I	44,3	NE	
77	Sincan Dam	Dam	Çorum	Alaca			1992	I		NE	
78	Gökçedoğan Dam	Dam	Çorum	Kargı	Balak D.	Kızılırmak	1992	I		NE	
79	Hıdırlık Dam	Dam	Çorum	Mecitözü	Fakıahmet D.	Yeşilırmak	1996	I		NE	
80	Yenihyat Dam	Dam	Çorum	Merkez	Çekerek D.	Yeşilırmak	1997	DW		NE	
81	Hatap Dam	Dam	Çorum	Merkez	Hatap Ç.	Yeşilırmak	2008	I + DW	42	NE	
82	Koçhisar Dam	Dam	Çorum	Alaca	Büyüköz Ç.	Yeşilırmak	2011	I	37,4	NE	
83	Kunduzlu Dam	Dam	Çorum	Bayat			2017	I		NE	
84	Derekargın Dam	Dam	Çorum	İskilip		Kızılırmak	2017	I		NE	
85	Evci Dam	Dam	Çorum	Boğazkale			2014	I		NE	
86	Sarayköy 1 Dam	Dam	Çankırı	Eldivan		Kızılırmak	1972	I		NE	
87	Güldürcek Dam	Dam	Çankırı	Orta	Yazı Ç.	Kızılırmak	1988	I + DW	51	NE	
88	Karadere Dam	Dam	Çankırı	Eldivan	Karadere	Kızılırmak	1990	I		NE	
89	Mart Dam	Dam	Çankırı	Şabanözü	Hışlar D.	Kızılırmak	1991	I		NE	
90	Seydiköy Dam	Dam	Çankırı	Eldivan	Uludere	Kızılırmak	1995	I		NE	
91	Maruf Dam	Dam	Çankırı	Korgun	Eşek D.	Kızılırmak	1999	I		NE	
92	Alanpınar Dam	Dam	Çankırı	Merkez		Kızılırmak	2009	I		NE	
93	Akhasan Dam	Dam	Çankırı	Çerkeş	Elma D.	B. Karadeniz	2010	I	35,8	NE	
94	Karacaözü Dam	Dam	Çankırı	Yapraklı			2012	I		NE	
95	Sarayköy 2 Dam	Dam	Çankırı	Eldivan	Sakat Ç.	Kızılırmak	2014	I		NE	
96	Ekinne Dam	Dam	Çankırı	Eldivan			2016	I		NE	
97	Yukarıöz Dam	Dam	Çankırı	Yapraklı			2016	I		NE	
98	Demirçevre Dam	Dam	Çankırı	Korgun			2017	I		NE	
99	Hasanlar Dam	Dam	Düzce	Yığılca	Küçük Melen Ç.	B. Karadeniz	1972	I	70,8	NE	
100	Akçakoca Dam	Dam	Düzce	Akçakoca D.		B. Karadeniz	2015	I		NE	
101	Sarıyar Dam ve HEPP	Dam	Ankara	Nallıhan	Sakarya N.	Sakarya	1956	E	90	NE	
102	Gürsöğüt Dam ve HEPP	Dam	Ankara	Beypazarı	Sakarya N.	Sakarya	2018	E	100	NE	
103	Kargı Dam ve HEPP	Dam	Ankara	Beypazarı	Sakarya N.	Sakarya	2017	E	65	NE	
104	Kavşakkaya Dam	Dam	Ankara	Kazan	Koca D.	Sakarya		E		NE	
105	Uruş Dam	Dam	Ankara		Hamamözü Ç.			I	82	NE	
106	Tanrıvermiş Dam	Dam	Çorum		Tanrıvermiş D.				25	NE	

Table A.5. DSI 6. Regional Directorate Fish Pass Information Table

No	Facility Name	Facility Type	City	Province	River Name	Basin Name	Start of Operation	Aim	Height from Thalveg	Pass Purpose	Fish Pass Type
1	Seyhan Dam and HEPP	Dam	Adana	Merkez	Seyhan N.	Seyhan	1956	I + F + E	53,2	NE	
2	Çatalan Dam and HEPP	Dam	Adana	Karaisalı	Üçürge Ç.	Seyhan	1997	I + F + DW + E	70	NE	
3	Yedigöze Dam and HEPP	Dam	Adana	Aladağ	Seyhan N.	Seyhan	2010	I + E	105	NE	
4	Kavşakbendi Dam and HEPP	Dam	Adana	Kozan	Seyhan N.	Seyhan	2013	E	73	NE	
5	Köprü Dam and HEPP	Dam	Adana	Kozan	Göksu N.	Seyhan	2013	E	101	NE	
6	Menge Dam and HEPP	Dam	Adana	Feke	Göksu N.	Seyhan	2013	E	61	NE	
7	Feke 2 Dam and HEPP	Dam	Adana	Feke	Göksu	Seyhan	2010	E	60	NE	
8	Karakuz Dam veHEPP	Dam	Adana	Pozantı	Körkün Ç.	Seyhan	2014	E	32	FP	P
9	Göktaş 1 Dam and HEPP	Dam	Adana	Aladağ	Zamantı I.	Seyhan	2016	E	117,5	FP	FL
10	Göktaş 2 Dam and HEPP	Dam	Adana	Aladağ	Zamantı I.	Seyhan	2015	E	28	FP	P
11	Kozan Dam and HEPP	Dam	Adana	Kozan	Kilgen Ç.	Seyhan	1972	I + E	78,5	NE	
12	Gökkaya Dam and HEPP	Dam	Adana	Saimbeyl i	Göksu N.	Seyhan	2012	E	52,3	FP	VSP
13	Nergizlik Dam	Dam	Adana	Karaisalı	Üçürge Ç.	Seyhan	1996	I	50	NE	
14	Hakkıbeyli Dam	Gölet	Adana	İmamoğl u	Han deresi	Seyhan	1997	I	22,2	NE	
15	Kılıçlı Dam	Dam	Adana	Sarıçam	Sarıça deresi kapılı dere	Seyhan	2006	I + F	27	NE	
16	Yağlıtaş Dam	Dam	Adana	Pozantı	Yağlıtaş Deresi	Seyhan	2014	I	31,19	NE	
17	Baklalı Dam	Dam	Adana	Sarıçam	Baklalı deresi	Seyhan	2014	I	29,95	NE	
18	Bağtepe Dam	Dam	Adana	Kozan	Kılbasız Deresi	Ceyhan	2015	I	24	NE	
19	Postkabasakal Dam	Dam	Adana	Kozan	Eğribucak deresi	Ceyhan	2015	I	28,32	NE	
20	Zerdali Dam	Dam	Adana	Kozan	Bağlık Deresi	Ceyhan	2015	I	24,8	NE	
21	Dölekli Dam	Dam	Adana	Aladağ	Dölekli deresi	Seyhan	2016	I	25,65	NE	
22	Demirçit Dam	Dam	Adana	Karaisalı	demirçözü deresi	Seyhan	2016	I	31,86	NE	
23	Meletmez Dam	Dam	Adana	Kozan	Meletmez D.	Ceyhan	2016	I	42,5	NE	
24	Paşalı Dam	Dam	Adana	Feke	Kuru Ç.	Seyhan		I	25		
25	Yüreğir HEPP	Kanal Santral	Adana	Merkez	Seyhan N.	Seyhan	1972	E		NE	
26	Seyhan 2 HEPP	HEPP	Adana	Sarıçam	Seyhan N.	Seyhan	1992	I + E	5,95	NE	
27	Mentaş Weir and HEPP	Dam	Adana	İmamoğl u	Seyhan N.	Seyhan	2006	E	15,1	NE	
28	Sarıtepe Weir and HEPP		Adana	Feke	Asmaca Ç.	Seyhan	2009	E	8,75	FP	P
29	Çakıt Weir and HEPP	HEPP	Adana	Karaisalı	Çakıt D.	Seyhan	2010	E	6,16	FP	P
30	Himmetli Weir and HEPP	HEPP	Adana	Saimbeyl i	Göksu N.	Seyhan	2011	E	13	FP	
31	Feke 1 Weir and HEPP	HEPP	Adana	Feke	Göksu N.	Seyhan	2012	E	6	FP	P
32	Toros Weir and HEPP	HEPP	Adana	Karaisalı	Çakıt D.	Seyhan	2013	E	5	FP	P
33	Eğlence 1 Weir and HEPP	HEPP	Adana	Karaisalı	Eğlence D.	Seyhan	2013	E	11	FP	P
34	Eğlence 2 Weir and HEPP	HEPP	Adana	Karaisalı	Eğlence D.	Seyhan	2013	E	14	FP	P

Table A.5. DSI 6. Regional Directorate Fish Pass Information Table (cont.)

35	Kıy Weir and HEPP	HEPP	Adana	Kozan	Salam D.	Seyhan	2013	E	1	FP	P
36	Kuşaklı Weir and HEPP	HEPP	Adana	Kozan	Göksu N.	Seyhan	2013	E	15,25	FP	P
37	Çoraklı Weir and HEPP	HEPP	Adana	Saimbeyli	Taşlık D.	Seyhan	2013	E	4	FP	P
38	Yamanlı II -1. Kademe Weir and HEPP	HEPP	Adana	Saimbeyli	Göksu N.	Seyhan	2015	E	14	FP	P
39	Yamanlı II 2. Kademe Weir and HEPP	HEPP	Adana	Saimbeyli	Göksu N.	Seyhan	2015	E	22	FP	P
40	Ahmetli Weir and HEPP	HEPP	Adana	Karaisalı	Körkün Ç.		2016	E	14	FP	P
41	Doğançay 1 Weir and HEPP	HEPP	Adana	Aladağ	Doğançay	Seyhan	2017	E	20,3	FP	P
42	Elbiz 1 ve 2 Weir and HEPP	HEPP	Adana	Feke	Gidres	Seyhan	2018	E	5	FP	P
43	Aşağı Seyhan Ovası Sulaması	Weir	Adana	Merkez	Seyhan N.	Seyhan	1943	I	15	FP	P
44	Aş. Ceyhan-Kozan I. Merh. Sulaması	Weir	Adana	Kozan	Kilgen Ç.	Seyhan	1971	I	4,7	NE	
45	Kesiksuyu (Mehmetli) Dam	Dam	Osmaniye	Sumbas	Kesiksuyu Ç.	Ceyhan	1971	I	70	NE	
46	Aslantaş Dam and HEPP	Dam	Osmaniye	Kadirli	Ceyhan N.	Ceyhan	1984	I + E + F + DW	78	NE	
47	Berke Dam and HEPP	Dam	Osmaniye	Düziçi	Ceyhan N.	Ceyhan	2002	E	154,5	NE	
48	Kaleceik Dam	Dam	Osmaniye	Bahçe	kalecik deresi	Ceyhan	1985	I	77	NE	
49	Düziçi Karacaören Dam	Dam	Osmaniye	Düziçi	Ağaçlıderesi	Ceyhan	2016	I	36	NE	
50	Osmaniye-Karaçay HEPP	HEPP	Osmaniye	Merkez	Karaçay	Ceyhan	1955	E	6,75	NE	
51	Değirmendere HEPP	HEPP	Osmaniye	Kadirli	Keşiş D.	Ceyhan	1987	E	2,65	NE	
52	Ceyhan Berkman HEPP	HEPP	Osmaniye	Merkez	Ceyhan N.	Ceyhan	2006	E	15	FP	P
53	Ceyhan Oşkan HEPP	HEPP	Osmaniye	Merkez	Ceyhan N.	Ceyhan	2006	E	13	FP	P
54	Mehmetli Yamaç HEPP	HEPP	Osmaniye	Sumbas	Kesiksuyu Ç.	Ceyhan	2010	E	57,4	NE	
55	Gökboyun Weir and HEPP	HEPP	Osmaniye	Düziçi	Sabunsuyu Ç.	Ceyhan	2014	E	5	FP	P
56	Akçakoyun Weir and HEPP	HEPP	Osmaniye	Bahçe	Horu Ç.	Ceyhan	2015	E	2	FP	P
57	Kalealtı 1 Weir ve HEPP	HEPP	Osmaniye	Kadirli	Savrun Ç.	Ceyhan	2006	E	19,5	NE	
58	Sabunsuyu 2 (Bozluk) Weir and HEPP	HEPP	Osmaniye	Düziçi	Sabunsuyu Ç.	Ceyhan	2010	I + E	5	FP	P
59	Sayan Weir and HEPP	HEPP	Osmaniye	Kadirli	Savrun Ç.	Ceyhan	2011	E	12	FP	VSP
60	Horu Weir and HEPP	HEPP	Osmaniye	Bahçe	Horu Ç.	Ceyhan	2012	E	3,5	FP	P
61	Erem Weir and HEPP	HEPP	Osmaniye	Düziçi	Sabunsuyu Ç.	Ceyhan	2013	E	4,75	FP	P
62	Kalealtı 2Weir ve HEPP	HEPP	Osmaniye	Kadirli	Savrun Ç.	Ceyhan	2014	E	17	FP	P
63	Köroğlu Weir and HEPP	HEPP	Osmaniye	Kadirli	Savrun Ç.	Ceyhan	2014	E	5	FP	P

Table A.5. DSI 6. Regional Directorate Fish Pass Information Table (cont.)

64	Aş. Ceyhan Aslantaş Cevdetiye I.Mer. Projesi Sul.	Weir	Osmaniye	Merkez	Ceyhan N.	Ceyhan	1975	I + DW	9,95	NE	
65	Kesiksuyu (Mehmetli) Weir	Weir	Osmaniye	Sumbas	Kesiksuyu Ç.	Ceyhan	1971	I	5,72	NE	
66	Çatakboğazı (Erem)Weir	Weir	Osmaniye	Düziçi	Sabunsuyu Ç.	Ceyhan	1969	I	5	NE	
67	Yuvarlaklı Weir	Weir	Osmaniye	Bahçe	Hamiş Ç.	Ceyhan	1987	I	2,8	NE	
68	Sabunsuyu Bozluk Weir	Weir	Osmaniye	Düziçi	Sabunsuyu Ç.	Ceyhan	1993	I	6,65	NE	
69	Kalecik Weir	Weir	Osmaniye	Bahçe	kalecik deresi	Ceyhan	1996	I	3,2	NE	
70	Kesiksuyu Savrun Sulaması	Weir	Osmaniye	Kadirli	Savrun Ç.	Ceyhan	1998	I	2	NE	
71	Alaköprü Dam and HEPP	Dam	Mersin	Anamur	Dragon Ç.	D. Akdeniz	2015	North Cyprus DW	94,00	NE	
72	Berdan Dam and HEPP	Dam	Mersin	Tarsus	Berdan Ç.	D. Akdeniz	1984	I + E + F + DW	41,60	NE	
73	Gezende Dam and HEPP	Dam	Mersin	Mut	Ermenek Ç.	D. Akdeniz	1990	E + F	66,00	NE	
74	Aslanköy Dam	Dam	Mersin	Toroslar	Aslanköy D.	D. Akdeniz	2005	I	28,35	NE	
75	Değirmendere Dam	Dam	Mersin	Merkez	Sıtmapınar D.	D. Akdeniz	2016	I	30,44	NE	
76	Ayaş Dam	Dam	Mersin	Erdemli	Lamas Çayı (Taşıma suyu)	D. Akdeniz	2017	I	32,00	NE	
77	Gözne Dam	Dam	Mersin	Toroslar	Karabucak D.	D. Akdeniz	2017	I	31,20	NE	
78	Kıca Dam	Dam	Mersin	Silifke	Bıcık Deresi	D. Akdeniz	2015	E	28,50	NE	
79	Cemilli Çevlik Dam	Dam	Mersin	Merkez	Çevlik Deresi	D. Akdeniz	2016	I	29,00	NE	
80	Bozyazı Weir and HEPP	HEPP	Mersin	Bozyazı	Bozyazı Ç.	D. Akdeniz	1974	E	2,50	NE	
81	Anamur Reğülatörü ve HEPP	HEPP	Mersin	Anamur	Sulama Kanalı	D. Akdeniz	1967	E		NE	
82	Silifke I HEPP	HEPP	Mersin	Silifke	Sulama Kanalı	D. Akdeniz	1967	E		NE	
83	Derincay Hocantı HEPP	HEPP	Mersin	Mut	Kaynaktan	D. Akdeniz	1968	E		NE	
84	Zeyne HEPP	HEPP	Mersin	Silifke	Kaynaktan	D. Akdeniz	1971	E		NE	
85	Kadıncık 1 Reg. ve HEPP	HEPP	Mersin	Tarsus	Kadıncık Ç.	D. Akdeniz	1971	E	16,00	NE	
86	Kadıncık 2 Reg. ve HEPP	HEPP	Mersin	Tarsus	Kadıncık Ç.	D. Akdeniz	1974	E	16,00	NE	
87	Birkapılı Reg. ve HEPP	HEPP	Mersin	Mut	Kestel Kapızı D.	D. Akdeniz	2004	E	9,50	NE	
88	Pamuk Reg. ve HEPP	HEPP	Mersin	Çamlıyayla	Pamukuk D.	D. Akdeniz	2004	E	8,00	NE	
89	Lamas 3 - 4 Reg. ve HEPP	HEPP	Mersin	Erdemli	Limonlu D.	D. Akdeniz	2009	E	5,50	FP	P
90	Azmak 1 Reg. ve HEPP	HEPP	Mersin	Mut	Ermenek Ç.	D. Akdeniz	2010	E	8,50	FP	P
91	Azmak 2 Reg. ve HEPP	HEPP	Mersin	Mut	Ermenek Ç.	D. Akdeniz	2009	E	3,80	FP	P
92	Kirpilik Reg. ve HEPP	HEPP	Mersin	Mut	Ermenek Ç.	D. Akdeniz	2010	E	3,50	FP	P
93	Otluca 1 Reg. ve HEPP	HEPP	Mersin	Anamur	Dragon Ç.	D. Akdeniz	2011	E	11,50	FP	P
94	Otluca 2 Reg. ve HEPP	HEPP	Mersin	Anamur	Dragon Ç.	D. Akdeniz	2011	E	5,00	FP	P
95	Remsu HEPP	HEPP	Mersin	Tarsus	Berdan Sulama K	D. Akdeniz	2013	E		NE	
96	Dinç 1 Reg. ve HEPP	HEPP	Mersin	Mut	Gökdere Ç.	D. Akdeniz	2012	E	2,25	FP	P

Table A.5. DSI 6. Regional Directorate Fish Pass Information Table (cont.)

97	Dinç 2 Reg. ve HEPP	HEPP	Mersin	Mut	Sason D.	D. Akdeniz	2012	E	2,10	FP	P
98	GÖK Reg. ve HEPP	HEPP	Mersin	Tarsus	Kadıncık Ç.	D. Akdeniz	2010	E	13,00	FP	P
99	Sarıkavak Reg. ve HEPP	HEPP	Mersin	Mut	Kurtsuyu D.	D. Akdeniz	2011	E	1,50	FP	P
100	Dağbaşı Reg. ve HEPP	HEPP	Mersin	Anamur	Sugözü D.	D. Akdeniz	2013	E	10,00	FP	P
101	Yazılı Reg. ve HEPP	HEPP	Mersin	Anamur	Sugözü D.	D. Akdeniz	2014	E	3,50	FP	P
102	Sebil Reg. ve HEPP	HEPP	Mersin	Çamlıya yla	Cehendem D.	D. Akdeniz	2015	E	5,00	FP	VSP
103	Mersim Limonlu Proj. Gilindres Sol Sahil Sulaması	Weir	Mersin	Erdemli	Gilindres Ç.	D. Akdeniz	2003	I	6,60	NE	
104	Mersin-Mut I. Merhale Sulamsı	Weir	Mersin	Mut	Göksu N.	D. Akdeniz		I	8,70	FP	
105	Merisn Mut II. Merhale (Yapıntı) Sulaması	Weir	Mersin	Mut	Pirinçsuyu D.	D. Akdeniz		I	3,30	FP	
106	Mersim Limonlu Proj. Erddemli Kızılalan Alata Sulaması	Weir	Mersin	Erdemli	Alata deresi	D. Akdeniz		I	4,15	NE	
107	Bent Weir	Weir	Mersin	Tarsus	Limonlu D.	D. Akdeniz	1968			NE	
108	Göksu Weir	Weir	Mersin	Silifke	Göksu I.	D. Akdeniz	1950	I	9,70	NE	
109	Çakmak Boğa. Weir	Weir	Mersin	Anamur	Dragon Ç.	D. Akdeniz	1966			NE	
110	Anamur Sulaması	Weir	Mersin	Anamur	Dragon Ç.	D. Akdeniz	1967	I	8,90	NE	
111	Bozuyazı Sulaması	Weir	Mersin	Bozyazı	Bakırçay D.	D. Akdeniz	1965	I	4,00	NE	
112	Berdan Weir	Weir	Mersin	Tarsus	Berdan Çayı	D. Akdeniz		I	4,40	NE	
113	Boğuntu Weir	Weir	Mersin	Anamur	Boğuntu D.	D. Akdeniz	2011	E	7,00	NE	
114	Aşağı Göksu Silifke Ovası I. Merhale Sulaması	Weir	Mersin	Silifke	Göksu nehri	D. Akdeniz		I	7,20	NE	
115	Yarseli Dam	Dam	Hatay	Altınözü	Beyaz Ç.	Asi	1992	I	36,5	NE	
116	Yayladağ Dam	Dam	Hatay	Yaylada ğ	Kureyşi D.	Asi	1998	I + DW	44,4	NE	
117	Reyhanlı Dam	Dam	Hatay	Antakya	Afrin Ç.	Asi	NW	ST	25,2	NE	
118	Tahta Köprü Dam	Dam	Gaziantep	İslahiye	Karasu D.	Asi	1975	STE	44,5	NE	
119	Büyük Karaçay Dam	Dam	Hatay	Samanda ğ	Büyük karaçay D.	Asi	2017	I + DW	102	NE	
120	Samandağ Çökek Dam	Dam	Hatay	Samanda ğ	Kurudere	Asi	2015	I	30	NE	
121	İskenderun Prinçlik Dam	Dam	Hatay	İskender un	Çil Deresi	Asi	2015	I	26,6	NE	
122	Kıtıkhan Kurtlusoğuksu Dam	Dam	Hatay	Kırıkhan	Oluğun Deresi, Kocadere	Asi	2017	I	32	NE	
123	Kuzuculu Weir and HEPP	HEPP	Hatay	Dörtyol	Deliçay D.	Asi	1954	E	2	NE	
124	Yeşilvadi Weir and HEPP	HEPP	Hatay	Dörtyol	Deliçay D.	Asi	2013	E	5	FP	P
125	Kamışlar Weir	Weir	Hatay	Kırıkhan	Karasu Ç.	Asi	1978	I	17,7	NE	
126	Geçitköy Dam	Dam	Girne	Merkez	Geçitköy D.	KKTC	2014	I + DW	58	NE	