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博士学位论文

基于尼泊尔案例的绿色水电设计与评价

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

Green Hydropower Design and Evaluation Case for Nepal

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内 容 摘 要

绿色可持续水电的理念主要关注的是水电开发过程中的环境与管理问题，关于如何提高绿色水利设施设计与建造水平、保证下游水量最大化且发电量最优等相关研究正在蓬勃发展，需要进一步研究相关领域内容。尽管绿色水电这个概念在上世纪早已被提出，但是各国在绿色水电开发的理念上存在差异，许多国家的绿色水电理念中没有提及在天然河道中，不同季节不同水位条件下，如何不影响鱼类洄游的问题。另外，传统的水利设计理念只考虑在高水位阶段如何冲泄泥沙的问题，而没有考虑旱季时期如何保证持续向下游宣泄泥沙。因此，本文选择尼泊尔一座小型引水式发电站作为研究对象，开展绿色水电相关设计并进行经济性评价。所选的尼泊尔小水电站目前存在着较多的问题，例如枯水期，电站引水发电造成分流堰至电站尾水之间的下游区断流，从而引发许多生态环境和其他社会经济问题。为解决这些问题，有必要研究更有利于可持续发展的小水电设计理论和方法，使小水电站以更有效的方式服务社会。

本文研究的目标是基于绿色水电设计理念，在保证最优发电量的条件下，能够持续地宣泄泥沙，并确保下游生态需水量。此外，本文研究并设计了一种鱼道结构，使鱼的洄游不受季节水位涨落的影响。课题以尼泊尔的一座小水电站为例，通过分析河流每个月的水文特征来进行设计，为未来绿色水电设计理念的发展提供技术支持。本课题的主要研究结果如下：

1、研究了急性变温对鱼类行为的影响，它是鱼道设计的重要因素。结果表明，在 5°C(急性降温), 15°C (适应温度) 和 25°C (急性升温)条件下，急性温度变化影响鱼类临界游泳速度(Ucrit)、耗氧率(MO_2)、摆尾频率(TBF)和摆尾幅度(TBA)。急性降温至 5°C 或急性升温至 25°C，临界游速都将显著下降，在适应温度时最大。15°C 条件下耗氧率随游泳速度增加而增大，而 5°C 和 25°C 时，耗氧率随游泳速度增加反而下降。与 15°C 条件下相比，摆尾频率和幅度在 5°C 和 25°C 时均下降，且拟合直线(TBF-U)的斜率也均低于 15°C 时。

2、将雨季和旱季天然河流水位变化的影响纳入鱼道设计。根据天然河流水流方向进行鱼道选址，以吸引更多的鱼类进入鱼道。采用流体计算软件 ANSYS Fluent 14.5 模拟鱼道中的流场及水流速度。根据设计标准和经验公式计算了鱼道设计的关键因素：流量、流速、入口流速，水深及体积耗散功率等。鱼道设计的结果表明，上游的鱼道出口通常的水流深度是 2.5m，当洪水季节溢流高度升至 0.5m 以上，鱼道仍可有效工作。当旱季的河流深度由 2.5m 下降至 0.5m 时，设计的鱼道也可以正常工作，从而保证不同季节因产卵或其他原因需洄游的鱼类都能通过鱼道。旱季里河流流量很小时，可利用闸式鱼道和堰式鱼道之间的开放河道产生诱鱼水流，吸引鱼类进入鱼道。两鱼道间的开放河道还可用于降河洄游鱼类的过鱼通道以及定期将泥沙冲泄至下游。

3、通过对未来可持续绿色水电开发的研究，遴选了绿色水电的评价指标。评价标准被分为三个方面，即技术、环境和社会-经济。环境和社会-经济因子与技术相关的条件下，使技术标准最大化。

4、通过水电项目的水力计算得到最大排放流量下的最佳发电量。当前的尼泊尔水电政策是要求维持月平均 10%的排放流量，此流量在季风期的旱季是不够的。本课题设计的流量为 1.151m^3/sec，而当前政策规定的流速在旱季只有 0.23m^3/sec。本设计将下游受到的不利影响最小化，全年平均每月的最小排放流量为 30%，旱季的最大值可达 63.9%，且对常规发电的影响非常小。此外，连续的排放到下游河流中有助于提高河流深度，即使是在旱季，可从现有的 30cm 提高到 60cm，从而有利于维持正常的水温和溶氧。更重要的是，此设计有助于管理洪水季的过量河水：洪水季节采用两种泄洪道，一个在堰的上游，另一个在入口后方，它们有助于维持鱼道内正常的流速和流量。

5、从社会-经济、生态和环境三方面对本研究的绿色水电设计进行了经济分析及评价，并与已有的设计相比较，得到了较好的结果。经济分析结果表明，本设计的效率成本比例 (B/C) 为 2.11，内部收益率 (IRR) 为 20.67%，净价值 (NPV) 为 $16,109,000。而现有设计的效率成本比例为 2.08，内部收益率为 20.21%，净价值为 $16,081,000，低于本课题的设计结果。

关键词：绿色水电　鱼道　小水电设计　经济分析

Abstract

Existing green sustainable hydropower concepts have mainly focused on environmental and management issues while the technical design improvement for the power optimization at maximum downstream release is booming and require further study. Despite the concepts of green hydropower have been proposed by the last century, but there are differences between countries and there is no specific method on how to improve the fish migration throughout the year in different fluctuating water level in Natural River. Consequently, the traditional design is only about releasing the sediments during high flow period. However, they do not have proper method to release the sediment continuously during dry period. So, a run-of-river small hydropower (diversion type hydropower station) project of Nepal was considered as a case study, and green hydropower design and evaluation was presented. Apparently, there seems to be enormous problem existed in small hydropower run of river (ROR) especially during dry season, in downstream-depleted reach between the diversion weir to power station, causing eco-environment and other socio-economical issues. Hence, there is a need to develop a proper sustainable design and method to solve these issues and improve the future small hydropower development in an effective way.

Therefore, the objective of this research is to assure continuous release of downstream water and sediment with optimal power generation based on the green hydropower design concept. Furthermore, this research has also developed a fishway design for fish migration without being influenced by the year fluctuating river flow. Taking ROR small hydropower project of Nepal as a case, conceptual green hydropower design has been proposed by analyzing average monthly river hydrology, providing technical support for future green hydropower design concepts. This research was divided into following five sections to meet the research objectives.

1. In this research work, an experiment on effects of acute temperature difference in fish behavior was carried out, as it is very important parameter for the fishway designing. Consequently, it was obtained the new result on acute temperature change effect on fish critical swimming speed (U_{crit}), oxygen consumption rate (MO_2), tail beat frequency (TBF) and tail beat amplitude (TBA) at 5^oC(acute low temperature), 15^oC (normal temeperature) and 25^oC (acute high temperature). The U_{crit} value decreased significantly when acute temperature changes at 5°C and 25°C; U_{crit} was highest near the optimal temperature. Oxygen consumption rate (MO_2) increased with the swimming speed at 15°C; however, at 25°C and 5°C, the MO_2 decreased with the swimming speed. Both TBA and TBF decreased

at 5°C and 25°C compared with values at 15°C. The slopes of the regression lines (ΔTBF/ΔU) at 5°C and 25°C seemed lower compared with 15°C.

2. The fishway design was developed by considering fluctuating water level in Natural River during wet and dry periods. According to the Natural River flow direction, the positions of the fishways are selected to attract more fish naturally. Design was based on computer model and ANSYS Fluent 14.5 software was used to simulate the flow pattern and the velocity inside the fishways. Discharge, flow velocity, attraction velocity, water depth, volumetric power dissipations which are the key parameters in fishway designing were calculated following standards and formulas given in different literatures. The results of the fishway designing indicate that, fishways can work efficiently even during flood period when the overflow height rose to 0.5m above from the normal flow depth of 2.5m in upstream river at fish exit (weir crest) position. Consequently, when the river flow depth dropped from 2.5m to 0.5m at the bottom surface of upstream weir during dry period, the new design can work smoothly to migrate the fish continuously for the spawning at different periods and other related lifecycle activities. Environmental flow release through open channel situated between the sluice fishway and weir fishway was utilized to create additional attraction velocity during dry period when the river has a minimum flow. Open channel designed between two fishways can be used as a fish passage for the downstream migration throughout the year including the regular sediment release to the downstream river.

3. This research has further developed the additional evaluation standard as per the new research findings for the future sustainable green hydropower development. Accordingly, the standards were divided into three parts such as technical, environmental and socio-economical. The maximum value was given to the technical standard as environmental and socio-economical factors are depended on the technical values.

4. Hydraulic calculation for the hydropower project was carried out to find the optimize power generation at maximum downstream release. Current Nepalese hydropower policy requires only 10% release of the average monthly flow to maintain downstream environmental flow, which is not sufficient during the dry period of the monsoon cycle. Accordingly, the environmental flow specified in the proposed design is 1.151m^3/sec, but current policy would allow a release rate of only 0.23m^3/sec during the driest month of the year. The proposed design can minimize the negative downstream impacts with minimum release of 30% of the average monthly flow throughout the year with 63.9% during the driest

month creating very minimum effect on regular power generation. Furthermore, the continuous environmental release to the downstream river will help to increase the river depth from existing 30cm to about 60cm even during the driest month, which in turn will help to maintain the normal temperature and Dissolved Oxygen (DO) to required level. Moreover, this new design has a new option to manage the extra water during flood season using two designed spillway, one at upstream of weir and the other after the intake section, which will help to maintain the normal velocity and discharge inside the fishway.

5. An economic analysis was conducted to evaluate the new developed green hydropower design concept comparing with the existing design from aspects of socio-economy, ecology and environment issues. The proposed new design has shown the good results compared with the existing design. Economic analysis result shows that new developed design has Benefit Cost ratio (B/C ratio) of 2.11, Internal Rate of Return (IRR) of 20.67% and a Net Present Value (NPV) of US $16,109,000 compared with the existing design having (B/C ratio)=2.08, (IRR)=20.21%, NPV=US $16,081,000.

Key words: Green Hydropower   Fishway   Small Hydropower Design   Economic Analysis

Contents

Introduction

Green hydropower development has come across for the eco-environmentally friendly sustainable hydropower development. The standard of green hydropower is to keep the structure and function of the river eco-system in a good condition. Green hydropower certification thus comes into being as a management system. It aims to minimize the adverse impacts of the hydropower project on eco-environment and provide reliable and acceptable eco-labeling for electricity consumers. To minimize the socio-economic and environmental impacts of hydropower, the Sweden green hydropower certification and the US Low Impact Hydropower Institute have developed the green hydropower certification criteria. The main objectives of the above two certification procedures are a) Subjects of the certification are hydropower stations under the operation phases b) Accredited hydropower stations should meet the specific standard procedure.

Both of the above two certification procedures cover major factors in river eco-system, but there are still some differences. The green hydropower certification basically adopts a qualitative approach, while the low impact hydropower certification mainly relies on approving documents from relevant government authorities.

It seems that both of them fail to come up with concrete technical indicators and standards of the threshold. Regarding green hydropower, some similar research activities have been carried out in China as well. Green hydropower researches in China are qualitative [1, 2]. Some researchers put forward an index system covering major factors in river eco-system but did not establish the assessment standard [3, 4]. Some researchers take a quantitative analytic approach to the assessment of each index but fail to make the study of the representation and classification of the indicators themselves [5, 6]. On the basis of exploring the implication of green hydropower and in view of features of hydropower project's impacts on river eco-system, Yu et al tried to establish an index system for green hydropower with an assessment standard on a quantitative approach supplemented by qualitative approach but this is also a tentative approach only [7].

Shortcomings of the existing green hydropower concepts

The proper technical design and efficient methods usually guide the management and environmental issues caused by the hydropower development. However, after reviewing green hydropower certification guidelines and standards given by the different institutions and literatures, it is found that existing green hydropower concepts are basically focused on management and the environmental issues on the green hydropower development. These guidelines are provided with very nominal information on hydraulic design improvement techniques and which has no specific design criteria to mitigate the negative impacts on eco-environment issues. Furthermore existing green hydropower concepts are qualitatively based applied only in the operation phase of the project and used for certification purpose only. The Green Hydropower criteria have been established as relatively simple objective criteria for distinguishing the hydropower in the marketplace. The criteria should not, however, be considered as a benchmark for exemplary environmental operations at hydropower facilities. While the criteria is intended to be a national base and specific region for evaluating impacts of hydropower, not all environmental impacts associated with hydropower facilities are addressed by the criteria. In addition, the certification of some facilities as a Green Hydropower does not mean and should not imply that other hydropower projects as high impact.

Consequently, green concepts have hardly mentioned the power optimization during downstream water releasing process, which is the key factor for the sustainable hydropower development. From existing green concepts, sediments can be released to downstream only during the high flow period, which in turn creates lots of sediment deposition problems during the dry period. This may tends to impact on downstream substrate stability and fish habitats, including effects on soil and bank erosion by trapping the sediments at upstream of weir. Similarly with the existing design, they are focused on the fishway facilities which are basic parameter for the green hydropower certification. However, it is not clear how it is possible to migrate the fish during the wet period and dry period when the river flow height is respectively very high or low. It shows that green hydropower concepts, have still some limitations for the long-term sustainable hydropower development as it is developed only for operation phase of the project with more focuses on certification issues.

Hence, our research is conceptualized with new design to meet the optimize power generation with maximum downstream release followed by continuous release of sediments to the downstream. Concepts on the fishway design, which can be used throughout the year for fish migration, will create the new idea about hydropower development. The new design is conceptualized with sustainable manners considering long-term socio-economic and environmental benefits. Hence, this research can be considered as a new innovative idea used for clean, green and sustainable hydropower development in future.

Objective

The main objectives of this research are,

1) Improve the technical design of small hydropower run of the river dam/ weir so that it will have continuous release of environmental flow to obtain the optimal power generation. Release the sediments continuously to protect the stability of the downstream river bed and fish habitats.
2) Improve the efficiency the fish passage with the proper fishway design so that fish can migrate throughout the year without effecting their important spawning period.
3) Improve the socio-economic and environmental condition of downstream affected area with the new improved green hydropower engineering design.
4) Carried out the economic analysis to evaluate the new design concept benefits with the existing one.

Chapter 1 Literature Review

This chapter discusses about the green hydropower concepts including the important factors required in environmental friendly hydropower design. It further discusses about the fishway overview design history and its important design parameters.

Green power is generally defined as energy produced by renewable or sustainable energy resources having minimum environmental impacts than nuclear or fossil-fueled energy production. There are different Green source of energy such as wind, solar, hydropower, geothermal, biomass including landfill gas. These clean energy sources have a great demand and utilization due to lots of concerns over global warming issues. People of different countries now have the option of buying their power directly from green source of energy, which have less environmental impacts.

Hydropower is one of the best options for these green and clean sources of energy as it has no such impacts which generally obtained from the burning of fossil fuels. However, in recent days people recognize that hydropower is not always environmental friendly because hydropower dams can have significant negative impacts on the Natural River, aquatic life and human population that depend on them. Hence, recent days’ people start to identify the hydropower projects, which have very minimum socio-economic and environmental impacts. This new research can contribute to identify appropriate hydropower development with new conceptual green hydropower design which will be sustainable in long run.

1.1 The Characteristics of Green Hydropower and Philosophy

The green hydropower development has come across for the eco-environmental friendly sustainable hydropower development. The essence of green hydropower is to keep the structure and function of the river eco-system in a good condition. Being an important source of renewable energy, hydropower project is of great value to the social and economic development of the world. In addition, hydropower project can play multiple roles in flood control, navigation, water supply etc. However, hydropower project exert certain adverse impacts on river eco-system which requires effective counter measures. Green hydropower certification thus comes into being as a management system. It aims to minimize the adverse impact of hydropower project on eco-environment and provide reliable and acceptable eco-labeling for electricity consumers [8, 9, 10].

To minimize the socio-economic and environmental impact of hydropower plants, the Sweden green hydropower certification and the US low impact hydropower institute have developed the green hydropower certification criteria. Main objective of the above two certification procedures are a) Subjects of the certification are hydropower stations under operation phases b) Accredited hydropower stations should meet specific standard procedure.

According to the Sweden green hydropower and the US low impact hydropower and with reference to the definition of green electricity and environment labeling, green hydropower defines as for hydropower projects under operation phase, if the adverse impact of hydropower projects on eco-system can be reduced to a certain degree through effective planning, design, construction and operation management. Green hydropower has further express, i) Green hydropower should focus on the impact of hydropower projects on the structure and function of the river eco-system. A comprehensive assessment of the hydropower project should take socio-economic property of the project into consideration, ii) Standard of green hydropower is to keep the structure and function of the river eco-system in a good condition. Whether the condition of river eco-system under the influence of hydropower project meets requirements depends on a comprehensive assessment of all ecological factors in line with relevant technique standards. Green Hydropower and Low Impact Hydropower institutions have been used to certify the environmentally friendly hydropower production, if the project meets their basic guidelines and criteria so that no major environmental problem occurs after the standard requirements are fulfilled.

1.2 Green Hydropower Standards

The Green Hydro standard offers operational criteria and guidelines for achieving a good status in rivers affected by hydropower use [8]. Indicators and standard are key components of green hydropower certification system. In Sweden, green hydropower certification assesses the impact of hydropower station on ecology from five aspects such as, hydrological character, connectivity of the river, solid materials regime and morphology, landscape features and biotopes and biological communities.

In the United States, the low impact hydropower certification establishes an assessment procedure which include the natural river flows, quality of water, fish migration issues and protection, watershed protection, protection of threatened and endangered species, cultural resource protection, recreation activities and facilities recommended for dam removal if it does not work following the environmental issues.

Although both of the above two certification procedures cover major factors in river eco-system, there are still some differences i.e., the green hydropower certification basically adopts a qualitative approach, while the low impact hydropower certification mainly relies on approving documents from relevant government authorities.

1.2.1 Green Hydropower Certification (GHC)

In 2001, the Swiss Federal Institute proposed the Green Hydropower Certification for Environmental Science and Technology (EAWAG) and it has been applied successfully in number of hydropower project in Switzerland and many other European countries. According to its manual, the Green Hydropower Certification provides a set of common minimum standards which cover 45 scientifically defined goal combining ecological impacts and management options [11] whereas more details on green hydropower certifications given by Bratrich and Truffer [12] are explained in Table 1.

Table 1 The environmental management matrix with basic goals for a Green Hydropower Certification (GHC)

Management field → / Environmental field ↓	In-stream flow regulations	Hydro-peaking regulations	Reservoir management	Bed-load management	Design of power plant
Hydrological character	…follows the seasonal changes and the variability of natural discharge patterns	…is slowed down sufficiently to allow aquatic organisms to migrate to safer areas; …minimizes critical temperature effects.	…assures the timing of reservoir flushing only during high discharge.	…requires minimum flow regimes in diverted river reaches which enable sediment transport, bank erosion and deposition as in the natural case.	…involves control systems to prevent abrupt release of high water flows; …includes technical measures to meet minimum flow regimes at any time.
Connectivity of river systems	…ensures interconnection with ground water and lateral tributaries and allows fish migration.	…avoids stranding of aquatic organisms outside the main channel.	…allows fish to pass with the headwaters, if they are stocked with a natural fish population.	…ensures that lateral stream inlets retain a functional connectivity.	…ensures unimpeded up- and downstream migration, preferably by creating bypass channels, (technical aids need a record of functionality)
Solid materials regime and morphology	…preserves natural structure of the riverbed and maintains solid transport		…avoids excessive silting or erosion in the tail-waters during flushing.	…allows for a necessary influx of bed-load into tailwaters to prevent the erosion of the river-bed and to develop a typical morphology.	…optimizes the weir design for bed-load transport in order to maintain an equilibrium bed-load level in the tailwaters.
Landscape features and biotopes	…maintains hydraulic characters and preserves inventoried floodplains.	…preserves the specific landscape features of the river and allows safe recreational activities.	…preserves habitats requiring conservation; …pays special attention to requirements of migratory birds.	…permits an adequate influx of bed-load into the tail-water for maintaining a typical riverine landscape	…avoids any new buildings in protected areas; …optimizes bypass channels as substitute habitats for rheophilic organisms.
Biological communities	…preserves natural biodiversity and sustains the reproduction of native fish species. …ensures that temperature regime and dilution capacity remain close to natural level	…minimizes long-term damage to biodiversity; …maintains the age class distribution of native fish populations; …prevents irreversible drift of organisms; …preserves the diversity of habitats.	…schedules flushing outside critical seasons for the reproduction of important fish species; …ensures that rare and endangered species are not disappearing due to reservoir flushing.	…ensures that typical riverine habitats are forming.	…protects wildlife from harmful contact with installations and machines.

1.2.2 Low Impact Hydropower Certification (LIHC)

Accordingly, in 1999, the Low impact Hydropower Certificate has been established by Low Impact Hydropower Institute (LIHI) of the United States. The main objective of the certification program is to minimize the environmental impacts from hydropower generation through market incentives. According to LIHI handbook [9], a set of following goals explaining in Table 2 have defined in eight criteria need to be fulfill to meet the certification requirement.

Table 2 Standards used in the Low Impact Hydropower Certification (LIHC)

Criteria	Goals
River flows	The river flow facilities need to consider according to the basic requirement for fish, wildlife, including water quality, seasonal flow fluctuations.
Water quality	Water quality need to be protected in the river.
Fish passage and protection	The facility need to provide effective fish passage considering different types of fish migration.
Watershed protection	Proper action need to be followed to protect, mitigate and enhance environmental conditions in the watershed.
Threatened and endangered species protection	There should be no negatively impact on threatened or endangered species
Cultural resource protection	There should not have impact on cultural resources.
Recreation	The facility should provide free access to recreational activities on the public's river.
Facilities recommended for removal	To avoid encouraging the retention of facilities that has been considered for removal due to their environmental impacts.

1.2.3 Sustainability Guidelines of International Hydropower Association

Similarly, another approach in sustainable hydropower is from the International Hydropower Association (IHA). IHA that tries to address all the social, economic and environmental aspects related to the hydropower development through its guideline. IHA has introduced Sustainability Guidelines to develop new hydro projects considering environmental, social and economic aspects including the management and operation method of the existing power schemes. In adopting their own guidelines, the members of the International Hydropower Association are committed to developing and operating their projects, in collaboration with all stakeholders, in a way that is environmentally friendly, socially responsible and economically efficient so that hydropower projects can make a major contribution to achieving sustainable energy and resource development. IHA Sustainability Guidelines has mentioned a number of broad principles for the sustainable hydropower development. The guidelines follows the important values identified in the World Commission on Dams (WCD) report [13] such as equity, participatory decision-making, efficiency, accountability and sustainability. The following charts given in Figure 1 sustainability profile, will be considered for the sustainability analysis based on the International Hydropower Association (IHA) guidelines and the supporting evidence scores.

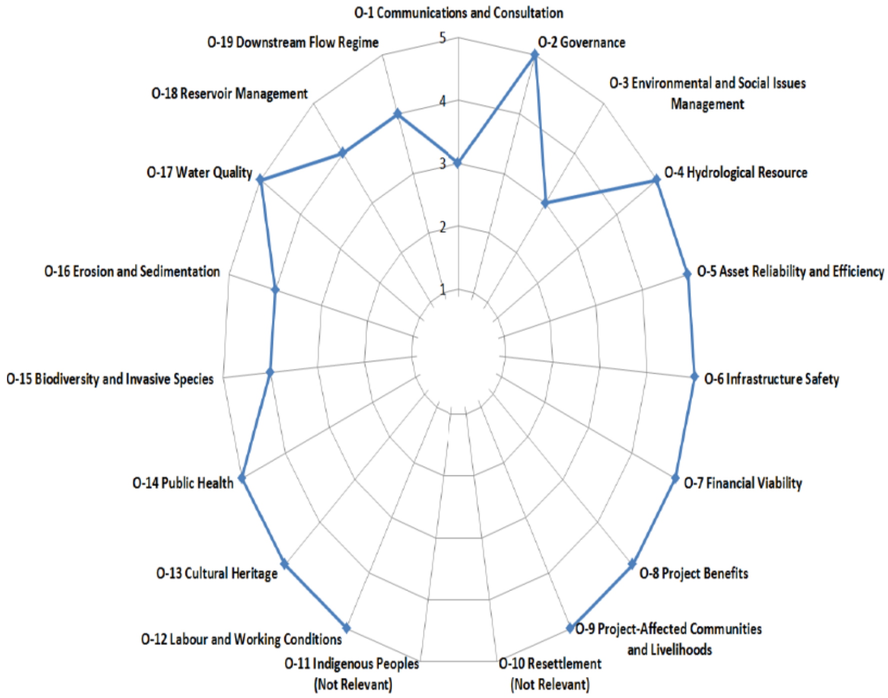

Figure 1 Sustainability profile

Rating assessments have been developed as an aid to IHA members in implementing and complying with the IHA Sustainability Guidelines. They rely on obtaining objective evidence to support high sustainability scores. It is intended to be a simple and easy-to-use approach. This sustainability rating assessment explains the different basic aspects of socio-economic and environmental sustainability pertaining to new energy options. These aspects have been drawn from the IHA's Sustainability Guidelines. The rating scores provide an aid in comparing sustainability in new energy options. The following Table 3 explains the general intent of ratings from score 5 through to 0.

Each of the elements described in Table 3 is prescribed by the IHA to analyze and give them a score of sustainability deviation.

Table 3 Sustainability Ratings

Score	Performance	Description
5	Outstanding	• At or very near international best practice. • Suitable planning and management systems. • Meets the objectives and measurable targets.
4	Good to Very Good	• Standard performance. • Generally suitable, adequate, and effective planning and management systems. • Meets most of the objectives and measurable targets
3	Satisfactory	• Essentially meets the requirements of the *Guidelines* • Generally meet with regulations and commitments. • If some non-critical gaps in planning and management systems. • If some non-critical gaps in meeting objectives and measurable targets.
2	Less that Satisfactory	• Gaps in meeting the requirements of the *Sustainability Guidelines* • Some gaps in compliance with regulations and commitments. • There are gaps in planning and management systems. • There are gaps to meet the objectives and measurable targets.
1	Poor / Very Limited	• Occurrence of Poor performance. • Occurrence of major gaps in regulations and commitments. • Find major gaps in planning and management systems. • Occurrence major gaps in meeting objectives and measurable targets.
0	Very Poor	• No evidence of meeting the requirements • Very poor performance to address basic issues. • Very little or no compliance with regulations and commitments. • Ineffective planning or management systems. • Fails to meet objectives and targets.

Ref: IHA Sustainability Assessment (Sustainability Guidelines) [14]

1.3 Design of Dam considering fish protection

Hydropower, a sustainable clean and renewable energy source (RES), creates very few greenhouse (GHG) gas emissions. RES plays an important role in poverty alleviation and raises the economic standard of the society. It also has multiple benefits such as flood control, fresh drinking water, irrigation, recreation, and other beneficial uses [15]. All these benefits are concerned with well-designed dam with the mechanism to release sufficient quantity of environmental flow to the downstream without affecting the power generation including the fish migration.

Small hydropower projects offer almost emissions-free power solutions as compared with other types of projects. In general, small hydropower projects are developed in remote areas to have sufficient power supply to meet the local demand. Small hydropower projects are quite common in developing countries such as Nepal, India, China, Peru and also highly industrialized country such as USA [16]. Despite having several benefits of hydropower projects, hydropower production also has severe impacts on freshwater ecosystems causing several ecological and environmental problems that will lead to social and economic challenges [17, 18, 19, 20]. Small Hydropower, run of the river (ROR) also has similar significant impact as the maximum portion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (penstock) that delivers it to a waterwheel or turbine for electricity generation with minimum releasing of water to the downstream. During this type of development, there is usually a long distance or gap between the diversion weir and power generation house to attain more power head and energy. During dry periods, the river in this section remains dry creating various ecological and environmental consequences.

In general, in the natural unregulated river when there is no any obstructions such as weir or dam, fishes can easily move upstream without giving much attention to the flow direction and other factors. However, construction of instream barriers and the subsequent impacts on migration is one of the major threats to freshwater fish diversity worldwide [21, 22]. Barriers restrict access to spawning grounds and preferred habitats, thus preventing dispersal and recolonisation [23, 24]. Providing passage for both small and large fish requires specific engineering solutions. The appropriateness of any solution is largely dependent on what direction fish are attempting to move. River regulation is also a key process that effects ecological connectivity and so the integrity of river floodplain systems [25]. River regulation also affects fish movement and community structure as many fish species need to move to complete various aspects of their life cycle [22, 26]. Altered flow delivery can also decouple the natural cycle between water temperature and flooding, both of which affect fish spawning and movement [22, 26, 27].

Run of river scheme, which generally have small impoundment weirs can also cause ecological impacts, as the reaches between water diversion and release from power generation house have a reduced flow. This may affect the ecology of the depleted flow reaches, including an altered availability of habitat features [28], a reduction of fish biomass

[29], loss of river continuity and impediment to fish movements [30]. Habitat complexity increases with water depth, water velocity and cover [31], resulting in increases in richness of aquatic fauna. A complex array of riverine habitats such as pools, riffles and backwater areas are preferred by fish [32], but these habitats can be lost or damaged in depleted reaches, such as those in run of river schemes. Regulated flows that maintain a minimum flow regime and reduce peak flows may improve habitat conditions depending on the channel morphology and modified flow dynamics. Reductions in flow can result in shallow areas and side channels drying out, thus reducing the amount of potential spawning and/or nursery habitat. Diverting weirs forced migration barriers for resident fish in 30% of small hydropower stations. Low-flow periods altered fish communities by ultimately reducing water depth and wetted area, causing an increase in fish density, which in turn can leads to a decreased production. Many authors have reported that reduced stream fish populations in response to reduced flows and it had the most substantial reductions in fish abundances.

In addition to downstream water release, fishway structure also plays a key role to enhance the local ecosystem. It allows the fish to migrate easily for their spawning and other activities. Properly designed fishway system and its position in the natural river direction have significant impact on mitigating the migration problem of fish and helping them to meet their life cycle’s basic requirements, especially the spawning activities while enhancing the local ecosystem [33]. Any reduction in fish passage may cause deterioration in ecological class under the EU water Framework Directive. Fish passage facilities are the key part of the Green Hydro Certification in many countries, including France and Germany.

Water flow velocity is another important factor governing the upstream movements of migrating fish [34, 35], and the provision of suitable flow conditions to the downstream of a dam is an effective method of improving passage [36]. Fish passage efficiency is influenced by discharge when the water level in the river is comparatively lower or excessively higher than the swimming capabilities of the fish in general [37]. Consequently the effectiveness of fishway may decrease during such events. It is observed that very few papers have discussed about the downstream fishway designing compared with the fishway in upstream migration. Likewise, all management efforts are on promoting upstream migration than downstream movement, however, fish passage requirements within river channels are bidirectional and equally important in all directions [38]. As every type of species has its important role in ecosystem, the fishway design research has found to be carried out mostly with economically significant species like salmonids while the species considered to be of low commercial value have been generally ignored may be due to limited information available of such species. Most of the researchers have only emphasized on the importance of fish passage efficiency, i.e., number of fish passes through the fishway but limited researches tend to carry out on fish mortality rate after passing through the fishway as this factor can also guide the real design effectiveness of the fishway. Hydraulic factors like discharge, velocity and flow patterns of the river are found to be an integral part of the fishway. The importance of fish behavior on encountering conditions associated with fish passes is also significant when facilities fail to sufficiently attract fish to their entrance and in some cases may actually repel those from the inlet [39]. Hence, improve fish pass design with quantifying the behavioral response to factors, such as prevailing discharge and temperature regimes that are likely to affect the degree to which structures impede fish movements.

1.4 Fishway Design

Fishways have a long history, with the earliest one recorded more than 300 years ago in France when the southern province of France, Bearn, made it mandatory that weirs and dams construction must take into consideration of a passage for fish for their smooth movement [40, 41, 42]. Since the fishway construction in different countries including China has a long history but the real status and construction scenario are looking different comparing to its total number and the effectiveness given in Table 4 [43].

Table 4 Fishway Research Status

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

Since 1930, physical and numerical hydraulic studies and improved biological assessments have provided a more comprehensive scientific knowledge and a more reliable basis for designing and operating fish passage systems. Current development in biology, particularly with enhanced understanding of fish behavior, advanced hydraulic concepts, more nature-like solutions, improved interdisciplinary or eco-hydraulic approaches. Further field assessments in fish passage efficiency indicate effective and adaptable fish passages for small and large fishes, as well as other freshwater species [44, 45, 46]. However, the earliest fish bypass structures were generally poorly designed for local hydraulic conditions and fish species. Thus, it is required to focus more on the importance of design parameters that will enhance the effectiveness and efficiency of fishway in coming future.

1.4.1 Overview of Fishway Designing

In general, most papers have discussed the fishway design used in upstream migration compared to the downstream. However, the design of downstream passage also needs to take swimming ability, behavior of target species, physical and hydraulic conditions at the water intake as in case of upstream fish passes in to consideration [47]. Fishways success depends on the interaction of fish behavior and swimming ability with hydraulic characteristics as illustrated in Table 5 below [33].

The performance of fishway varies greatly with their type, design, operating regime, the species concerned, and it is often the product of experience in dealing with these variables [48]. Construction of instream barriers and the subsequent impacts on migration are the major threats to freshwater fish diversity worldwide [21, 22]. Barriers restrict access to spawning grounds and preferred habitats, thus preventing dispersal and recolonisation [49, 50]. Providing passage for both small and large fish requires specific engineering solutions. The appropriateness of any solution is largely dependent on what direction fish are attempting to move. Biologically oriented fishway research has focused mostly on anadromous fish species (e.g. salmonids) [51, 52]. Therefore, considerably limited information on coarse species has been available. Studies have proven that these species can travel considerable distances for reproduction, refuge and feeding purposes [37, 52, 53]. Study of swimming energetics and kinematics of juvenile S. chongi at a single temperature provide useful data for the design of fishways [54]. Likewise, Chinese sturgeons conserve energy by swimming efficiently and have high fatigue recovery capability which will be important during fishway designing [55]. Therefore, there is an increasing need to conduct many studies to accommodate movements and behavior of different kinds of fishes within the fishway and to assess the effect of potential key-variables that require to be considered for the successful development of future fishway designs.

Table 5 Different Fishway Structures and Effectiveness

Type	Dimensions and discharge	Range of application	Advantages and disadvantages	Effectiveness
Slot passes	Pool dimensions: lb > 1.90 m; b > 1.20 m; h > 0.5 m; Slot width: s > 0.17 m. Discharge can be from Q = 140 l/s up to several cubic metres per second.	Generally used for small and medium heads including variable impounding heads. Can be used for small streams and large rivers. The minimum tailwater depth must be h > 0.5 m.	Relatively high discharges can be sent through, thus good attraction currents can form. More reliable than conventional pool passes because of the lower risk of clogging of the slots.	They are currently the best type of technical fish pass, being suitable for all species of fish and are passable for invertebrates if a continuous bottom substrate is built in.
Pool passes	Pool dimensions depend on the river zone; lb > 1.4 m; b > 1.0 m; h > 0.6 m. Submerged orifices: b_S/h_S > 25. 25 cm. Discharge Q = 80 to 500 l/s.	Generally used for small and medium heads, at melioration dams and at hydroelectric power stations.	Only relatively low discharges allowed; there is great risk of clogging with debris.	Suitable for all species of fish if the dimensions of the pools and orifices are chosen as a function of the fish size that can be expected to occur. There might not be sufficient attraction current at low discharges.
Denil passes	Channels: b = 0.6 to 0.9 m; h > 0.5 m; < 1:5; Q > 250 l/s. Channel lengths can be 6 to 8 metres; resting pools are required for heights > 1.5 to 2 m.	Generally suitable for small heads, particularly for retrofitting of old milldams when there is not much space.	Relatively high discharges; should not be used for variable headwater levels; not sensitive to varying tailwater levels; need little space; cheap; good formation of attraction current.	According to present knowledge, less suitable for weak swimmers or small fish. Selective. Benthic fauna cannot pass.

Q: Discharge or flow. h: Water level difference. b: Pool width. lb: Pool length. b_S: Submerge orifice width. h_S: Submerge orifice height.

A number of studies have addressed the flow circulation patterns, the jet characteristics and the turbulence generated by the energy dissipation in pools for different configurations, and their relevance to the development of suitable hydraulic criteria for passage of salmonid species [56, 57, 58]. The modification of internal flow characteristics in the pools by placement of submerged structures to examine the extent of the turbulence, particularly the horizontal Reynolds shear stress component can be reduced, and thus facilitate and shortening the passage time of small individuals, should be considered. To improve the effectiveness of fish passage for larger species, it can be modified by incorporating orifices into the traditional pool and weir design, which is reported in the studies of swimming behavior for sturgeon [59, 60, 61]. Likewise, other important design considerations are appropriate flow speed, passage time [62], maximum speed for sustained swimming [63], hydraulic conditions [64], and swimming performance [65]. Similarly, protocols for testing swimming performance shall be well-established and the results are of interest to fish physiologists as they provide design criteria for construction of fishways [66, 67, 68]. The relevance of swimming behavior and performance to fishway issues is a motivated work in this field [60].

1.4.2 Correlation Between Effective Fishway and the Design Parameters

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

1.4.2.1 Suitable Position for a Fish Pass

In general, in natural rivers when there are no obstructions such as weir and dams, fish can easily move upstream without giving much attention to the flow direction and other factors. However, a barrier across the river creates the difficulties to fish movement towards the upstream. Similarly the possible dimensions of any fishways are usually severely limited by engineering, hydraulic and economic constraints, particularly in larger rivers. Thus, the position of fishway at the dam plays a significant role. Fish usually migrate upstream following the path in or along the main current possibly the bank of the river where the water current is the maximum [33]. A fish pass, which extends far into the tail water below the dam, considerably limits the possibility that fish can find the entrance. Thus, a design fault that has been responsible for the failure of many fish passes. In places where dams or weirs are placed diagonally across the river and overflow along their entire crest, upstream migrating fish usually concentrate at the upstream, narrow angle between the weirs and banks. Therefore, the fish pass should clearly be sited in this area. Facilitating movement of fish back to mainstream habitats can be achieved through the construction of specialist floodplain fishway or potentially by manipulating the river hydrograph [69]. Improving lateral connectivity not only benefits native species, but also facilitates the movement of non-native species utilizing floodplain habitats [70, 71].

In the case of a wide river it may be necessary to provide the several entrances and more than one fish pass to attract certain species from the opposite bank. Migrating fish may arrive either at the bank where the powerhouse is located or at the opposite bank where the spillway is discharging water with more current and suggests to design two separate fish passes, each with one or more entrances wherever required [72].

1.4.2.2 Fish Pass Entrance and Attraction Flow

For the efficient fish pass, the entrance must be designed so that fish find the inlet with a minimum time and pass the fishway comfortably [34]. It is explained that the perception of the current by aquatic organisms plays a decisive role in their orientation in rivers. Fish that migrate upstream as adults are usually swim against the main current. However, they do not necessarily migrate within the maximum flow but, depending on their swimming abilities, they may swim along its edge. If migration is blocked by an obstruction, the fish will seek onward passage by trying to escape laterally at one of the dam's sides. In such case they continue to react with positive rheotaxis and, in perceiving the current coming out of a fishway, fish are guided into the fish pass. The properties of the tailrace below a dam where water velocity and degree of turbulence influence the attracting current that forms at the entrance to the fish pass. The velocity at which the attracting current exits in the fish pass should be within the range of 0.8 to 2.0m s^{-1}. Particularly where the tailwater level fluctuates, a special bypass can be used to channel additional flow directly from the headwater to the entrance of the pass in order to boost the intensity of the attracting current. The bypass can be in the form of a pressure pipe, but it is usually better to have an open channel. Except for special cases, flow velocity should not exceed 2m s^{-1}. In many cases, this is directly below the weirs or dams, at the foot of the barrage or at the turbine outlets. A critical problem is how to construct the fish pass entrance so that fish can swim into the fishway even at low water levels. Entry into the fish pass can be made, even for bottom-living fish species, by linking the fish pass to the bottom of the natural river [33].

Overall passage effectiveness is determined by properly utilizing the method of attracting fish to locate systems for upstream movements. No fish passage system, will work successfully if fish cannot find, or are not attracted to the entrance regardless of types, configuration or internal passage efficiency. Proper flow management at a hydroelectric project is an important method that can be used to attract fish and flow released near a fishway entrance which helps the migrants to locate it effectively. Approaches to attracting fish to passage systems need to consider species, hydraulics and site-specific conditions. Usually site-specific biological and hydraulic studies are needed to develop concepts into effective fish passage [35]. New Technologies like tracking fish through telemetry have been helpful in quantification of fish guidance, attraction and fish passage efficiencies mainly for upstream fish passage systems [35, 36, 52].

1.4.2.3 Fish Passage Exit and Exit Conditions

When designing th fish passage, its water inlet (exit into the headwater) must be located far enough from the weir or turbine intake to prevent the fish coming out of the passage from swept into the turbine from the water current. At least 5m distance should be kept between the fish passage and the turbine intake or trash rack [33].

1.4.2.4 Discharge and Velocity Conditions in the Fish Pass

The discharge required to ensure optimum hydraulic conditions for fish within the pass is generally less than that is needed to form an attracting current. However, during dry period when the availability of water is less, subsequently the total discharge available should be used in the fish passage to allow unhindered passage of migrants. This method is used for the dams that are not used for hydropower generation. If more water is available to supply the fishway than that is needed for the hydraulically sound functioning of the existing or planned fish pass, alternative designs should be carried out. In general, current velocity in fish pass should not exceed 2.0 m s^{-1} at any narrow point such as in orifices or slots and the limit of this velocity should be assured by the appropriate design of the pass. The pass should incorporate structures that form sufficient resting zones to allow weak swimming fish to rest during their upstream migration [33]. Water flow velocity is an important factor governing the upstream movements of migrating fish, and the provision of suitable flow condition at the downstream of a dam has been identified as an effective method of improving passage. For fish to be attracted towards a fishway, it is generally believed that flows originating from a point near the fishway entrance should be highly relative to those released elsewhere along the dam face [73].

1.4.2.5 Dimensions, Slopes, Resting Pools

Proper dimensions of fishway include information on such features as slope, width, length and water depth as well as the dimensions of orifices and resting pools. These parameters depend mainly on the particular type of fish pass including the available discharge. The body length of the biggest fish species that occurs or could be expected to occur in accordance with the concept of the potential natural fish fauna is an important consideration in determining the dimensions of fish passes. However, the maximum sizes, such as that of the size of sturgeon that can grow to 6.0 m in length, are not used. The average body length of the largest fish species expected in the river as well as the permissible difference in water level must be considered in defining the dimensions of a fish pass. For constructions that are more technical, the maximum permissible slope ranges from 1:5 to 1:10, depending on the construction principle chosen, while close-to-nature constructions should show maximum slopes less than 1:15 corresponding to the natural form of rapids. The fishway has a bed slope of 10% is typical [42, 74]. In any case, the requirements of the weakest species, or of the weakest life stages, must be considered when defining the dimensions of a pass. Resting zones or resting pools should be provided in fishways at intervals of such lengths as defined by the difference in level of not more than 2.0 m between pools [33]. The turbulence of the flow through the fish pass should be as low as possible so that all aquatic organisms can migrate through the pass independently of their swimming ability. The volumetric energy dissipation in each pool of a fish pass should not exceed 150 to 200 Watt per cubic meter, of pool volume [33]. Turbulence is frequently identified as the major factor limiting the passage of small-bodied species and can be manipulated in a fishway pool [75], either by: (i) improving dissipation of energy in the pool, or (ii) reducing the amount of energy entering the pool [76, 77].

1.4.2.6 Effectiveness and Efficiency

The concept of effectiveness and efficiency is to clarify the percentage of mitigation provided by a fish pass. Effectiveness is a qualitative concept, which checks that the fish pass is suitable for all target species passes through within the range of environmental conditions mainly observed during the specific migration period. Effectiveness can be measured through visual inspection, trapping and video checks [78]. The efficiency of a fish pass is a more quantitative description of its performance. It may be defined as the number of fish present at the dam which then enters and successfully pass through the fish pass an acceptable length of time. The methods which give an insight into the efficiency of a pass are more complicated than those for effectiveness. Specially, marking and telemetry are useful techniques to check the overall efficiency of fish passes and the cumulative effect of various dams along a migration path [72]. Effective passage systems for both upstream and downstream movements have three basic characteristics i.e., (i) fish passes are easy to be located by the fish community, (ii) fish passes have hydraulic conditions that match biological needs and that species seek rather than avoid, and (iii) fish passes provide suitable and efficient transport. However, attraction and passage efficiencies are associated mainly with upstream fish passage systems. Attraction efficiency refers to the probability that fish approaching the barrier will locate the fishway entrance, while passage efficiency refers to the probability they will move through the fishway and pass upstream [35]. Effectiveness and efficiency may be limited by how easily fish can locate or be guided to upstream or downstream fish passage systems. Fish passage system choice basically depends on species type and fish habitat management objectives including site conditions, fish attraction and guidance, water level difference, hydraulic characteristics, operational constraints, construction materials, maintenance, and economics. Fish attraction and guidance aspects, biological requirements, and hydraulics are the most critical aspects for effectiveness and efficiency. Efficiency of fish movement at an area of difficult passage involves knowing how many fish of a particular species attempt to pass upstream relative to the number of fish that successfully pass through [79, 80]. Attraction efficiency was defined as the proportion of fish tagged and released during the study that were subsequently located within less than approximately 3m from a fishway entrance [81] or at the base of a barrier to fish movement and near enough to a fishway entrance for fish to detect fishway attraction flow [82].

Passage efficiency was calculated by dividing the number of fish of a particular species that exited a fishway by the number that was detected at the fishway entrance [81, 82]. Passage efficiency may relate to the types of fish passage, its slope and hydraulic head, while attraction efficiency may relate to biological factors such as migratory characteristics and temperature tolerance of the fish species present [83]. The topology of the flow also influences the fish passage efficiency [84, 85, 86]. Three sequential components of fish passage relevant to both up and downstream migrations are attraction, passage itself, and post passage effects [87], which are very important during design. Fishway entrance, i.e. attraction is a two-step process, consisting of guidance to the fishway entrance and actual entry into the fishway [88]. Indeed, this distinction may be important, as some studies have reported fish approaching the entrance but failing to actually enter [89, 90]. Since guidance, attraction, or passage can independently limit fishway efficiency, evaluating these different components of passage is necessary to understand mechanisms of passage failure, and identify potential mitigation measures. It is highlighted the importance of assessing physiological consequences of passage that may not only affect the efficiency at the barrier but affect survival or reproduction [91, 92].

1.5 Hydroelectric Engineering Design based on Eco-environment Protection

Design of hydropower dam is very important as all the eco-environment issues raised from the hydropower development are quite concerned with the efficient design. During eco-environmental friendly design, it is necessary to consider the key factors, which are related to socio-economic and environmental benefits. During the design of the river hydrology, proper site selection is very important because all the benefits depend on it. Consequently, during hydropower development power optimization is equally important.

Hence, balance between the power generation and environment protection is very important for the sustainable hydropower development. Otherwise, if there is just the simple design used for power generation only, then after sometime of operation, it starts to visualize the severe impacts on freshwater ecosystems causing several ecological and environmental problems that will lead to social and economic challenges. It is believed that mostly the large hydropower has significant impact on the environment and river ecosystem due to its huge quantity of storage water. However, small Hydropower, Run of River (ROR) also has similar impact as the maximum portion of a river’s water which is diverted to a channel, pipeline, or pressurized pipeline (penstock) that delivers it to a waterwheel or turbine for electricity generation with minimum releasing of water to the downstream. During dry period, usually the river to the section between diversion weir and the power generation house remains dry followed by many ecological and environmental consequences due to minimum releasing of flow. Hence, this depleted dry section and other related impacts are needed to be considered very seriously during Small Hydropower, Run of River (ROR).

Small -scale hydropower plants are generally of the run-of-river type, which exhibit differences in design, appearance and impact from conventional large hydroelectric schemes. In general, however, many of the characteristics of large impoundment hydropower schemes and run-of-river schemes are similar and this is more a question of scale in terms of potential impacts. Essentially, the issues and impacts of these smaller developments are poorly understood and have not been adequately studied [93]. Two basic conditions must be met for run-of-river schemes to work effectively, namely: a change in elevation (known as head), and a volumetric flow rate running through the turbine [94]. Run-of-river schemes have been thought to essentially maintain a natural flow regime [95], and consequently allow for a biologically friendly flow scenario, especially with regard to migratory species. However, this is not accurate although they usually do not impound the system, they modify flow regimes, and abstraction by run-of river schemes which results in flow-depleted stretches of river between the intake and outfall. Therefore, it is commonly misunderstood that hydropower is harmless to the environment. The question remains, however, about how much flow can be diverted from a river before the ecology is damaged [94]. This is considered to be the primary impact of run-of-river schemes, as the hydraulic regime over the abstracted reach is without doubt altered, experiencing lower flows than normal. Run-of-river schemes can only operate when there is sufficient flow in the river. However, the amount of water available for power generation is not only determined by the discharge of the river [62], but is dependent upon the abstraction regime of individual schemes, which relates to the discharge. Consequently, run-of-river schemes are thought to cause lower disturbance and impact to stream ecology [8]. Additionally, impacts are considered to be less dam aging as they do not lead to fragmentation of riverine habitat, with the condition that instream flows remain sufficient to protect river characteristics and ecology [96]. Nevertheless, run-of-river schemes generally require an impounding structure, and many are re-developments of existing sites, such as old mills, which are located on existing structures or require construction of small weirs, the impacts of which on fish communities are poorly understood [97, 98].

Hence, if the design is improved more carefully by effectively managing downstream river flow, regular sediment release with properly designed fishway can reduce negative impact of hydroelectric projects on natural rivers. Moreover, it will improve the socio-economic condition of the affected areas with the enhancement in river ecosystem and environment. Therefore, efficient hydropower designing is the backbone of the sustainable hydropower development. Following are some important factors needed to be concerned during eco-environment friendly hydropower design.

1.5.1 Downstream Release

The downstream environmental flow refers to the quantity, time and quality of water flow necessarily meet the human needs while maintaining the process essential to a healthy river ecosystem. Environmental flow maintains the well-functioning of the river ecosystem including support of downstream habitat and sediment transport to flood plains and estuaries [99, 100]. Once the instream environmental flow requirement has been met, the basic ecological process in a river can be maintained [101]. Dams and other river structures affect the river morphology and alter downstream flow patterns, which in turn will have adverse impacts on water quality, temperature, sediment movement and deposition, fish and wildlife, and the livelihoods of people who depend on healthy river ecosystems [102]. Similarly, according to the report published by ECRR [17], the increasing exploitation of hydropower is significantly changing the discharge and water temperature, disturbing matter and energy balances, and consequently changing river morphology. Large flow fluctuations, especially during the periods of low flow, can have great negative impacts on instream fish and wildlife, and will create water supply problems for downstream as well as upstream users. It further explains ROR operations are managed properly during the periods of low flow to minimize artificial flow fluctuations and protect the aquatic resources [103]. Reduction in flow causes water temperature to rise in summer and decline in winter, and the concentration of some solutes can be elevated as the groundwater input increases relatively compared with the surface water [104, 105]. The environmental flow will vary from river and management objectives. Basic challenge confronting the environmental flow proponents is the difficulty of determining how much alteration from the natural flow can be tolerated without compromising ecological health [106]. An environmental flow assessment (EFA) for a river may be defined simply as an assessment of how much of the original flow regime of a river should continue to its floodplains in order to maintain specified and valued features of the ecosystem [107, 108]. The minimum instream flow requirement is the flow regime (including floods, average flows and droughts) for a river that maintains desired ecological conditions, including physical, chemical and biological components and their interactions [109]. Several methods are available to estimate the minimum ecological instream flow requirement MEIFR. However, available techniques for assessing the MEIFR tend to be difficult and cumbersome. The simplest Tennant method is uncertain for the determination of the percentage to determine MEIFR [110]. Similarly, the complicated habitat techniques, such as in-stream flow incremental methodology [111], building block methodology [112] and holistic method [113] need detailed ecological data and have limited applications in practice.

Hydropower projects have gone through the capacity maximization phase and are now moving towards a more environmentally friendly phase informed by ecology. Various environmental assessment methodologies take the downstream flow necessary to protect basic requirements of aquatic and human life. However, at present there are no widely accepted criteria on the quantity of water required for downstream release that will mitigate the ecological impacts.

There are different methods for determining minimum percentage of downstream water release. Tennant, 1976, stated that 10% of the mean annual discharge (MAD) would be the minimum to sustain life whereas Alves and Henriques [114], reported that in Spain, 10% of the mean annual flow (MAF), and in Portugal, 2.5–5% of MAF, are used to set environmental flows. According to United Nations Food and Agriculture Organization [115], compensation flow for conserving microflora, aquatic insects and fish in the dewatering zone should be within 10-20% of the normal flow. According to Tharme [116], common percentiles and indices recorded in several countries for use as minimum flow recommendations, include Q_{95} (United Kingdom, Bulgaria, Taiwan and Australia) and Q_{90}

(Brazil, Canada, and United Kingdom). Fang et al also described different instream flow release methods used in different countries, providing details for downstream releasing mechanism in use [117]. While understanding the reasoning behind previous flow releasing methodologies is important for guidance, flows for improving river ecology must be determined based on local conditions. There is a risk of downstream dehydration if more focus is given to maximum power generation without maintaining downstream ecology demands with minimal water flow. Ecological compliance and power generation should be optimized when generating hydropower [118].

1.5.2 Sediment Release

Sediment release improves substrate stability and fish habitat, and reduces soil and bank erosion by preventing increased channel depth. Nutrients associated with sediment are also important for improving the soil fertility of the agriculture land. However, dam/ weir control the sediment release to downstream by trapping it at the upstream face of the dam which creates lots of consequences related to soil stability, fish habitat and many others. Weirs reduce access to shelter because the backwater acts as a sediment trap. Sediment can act as an indirect indicator of fish-habitat quality by integrating other physical-habitat variables; depth, velocity, and cover. Sediment type and size often reflect previous rather than present hydraulic conditions, and fish move continuously to find and exploit zones of preferred depth, velocity, shear stress, and turbulence [119, 120]. Bed sediment influences fish habitat suitability [121]. Removal of weirs may also improve downstream spawning conditions, provided that natural gravel transport processes are restored [122]. Mostly during wet period when the river discharge is very high, flushing of sediments is carried out in hydropower projects but it may have negative impacts on downstream river and aquatic animals due to heavy flow with maximum bedload impact.

1.5.3 Changes in Habitat Characteristics

Habitat complexity increases with water depth, water velocity and cover [123], resulting in increases in the richness of aquatic fauna. A complex array of riverine habitats such as pools, riffles and backwater areas are preferred by fish [124], but these habitats can be lost or damaged in depleted reaches, such as those in run-of-river schemes. Flow reductions affect the physical habitat characteristics of rivers, such as water velocity, sediment transport, turbidity, bed and bank stability [125], wetted width, water depth and water temperature. Many of the changes experienced will depend on the channel morphology but flow modifications have the potential to alter the quantity and quality of available aquatic habitat

[126], which subsequently influences stream biota [127]. Reductions in flow can result in shallow areas and side channels drying out, thus reducing the amount of potential spawning and/or nursery habitat. Anderson et al characterized reaches with artificially reduced discharge as having slower velocities, increased water temperatures and shallower habitats compared with upstream and downstream of the depleted reach [127].

1.5.4 Changes in Water Quality

Reductions in flow can also influence water temperature, both of which are important abiotic factors that change after the regulation of rivers [128]. When flows are reduced, such as in depleted stretches of river, temperatures can increase due to a reduction in wetted area and increase in shallower water, as well as a reduction in hyporheic flows, all of which may have consequences for the development and reproduction of aquatic organisms that are influenced by temperature [129].

1.5.5 Hydro Peaking

Release of water in mostly larger schemes is generally related to demands of electricity, thus water discharge is maintained at a regulated minimum and rapidly increased to meet the demands [127], and however there are some effects in small hydropower run of river scheme as well. This is known as hydro-peaking, and such fluctuations in water flow are generally frequent, rapid and large [129]. Hydro peaking caused by dramatic fluctuations in discharge, change the availability and suitability of aquatic habitat for use by fish [127], which can lead to negative impacts on both habitats and organisms [130].

1.5.6 Passage of Fish Species

Many fish species require passage along the length of rivers during at least short periods of their life-cycle. In many places the migration of fish is an annual event while dams and other instream structures constitute the major barriers to their movement. In some cases the long-term sustainability of fish populations depends on this migration and in developing countries local economies can be heavily reliant on this as a source of income. The passage of fish is an issue that must be considered during the design and planning stage of proposed developments (dam site selection) and adequate consideration should be given to appropriate mechanisms for their transfer (eg. Fish ladders, mechanical elevators, guidance devices and translocation programs). Large-scale downstream migration of some species may require mitigation measures to reduce mortality by passage through turbines.

Appropriate and feasible options for facilitating passage are also an issue for existing developments.

Hence, downstream water and sediment release, changes in habitat characteristics, changes in water quality and fish passes are the important factors during eco-environment protection hydropower designing.

1.6 Economic Analysis of Sustainable Green Hydropower

Sustainable development is difficult without the demonstration of effective and equitable distribution of economic benefits. An economic consideration plays an important role in the decision-making processes associated with hydropower projects. The use of economic resources in an effective manner requires the selection of the best options to evaluate the projects, so that there will be no hidden and unforeseen costs that emerge in the future. All the hydropower project costs generally come at the construction stage. Once the projects are constructed, project get the further pressures and has a very long economic life. Hydropower projects generally have good energy payback periods. The high level of service obtained from the hydropower projects combined with its other different character is driving forces for the regional development. Due to this, hydropower can be taken as a tool for economic development. As per the new developments, capital and operating costs need to be considered into account over the lifetime of a project. All the direct and indirect costs, benefits should be identified during economic analysis. The following principles are basically required in economic analysis process.

1.6.1 Costs and Benefits

Generally, economic sustainability decisions are based on a comprehensive evaluation of resources affected with the project costs and benefits. The following parameters should be taken into account during analysis:

1.6.1.1 Benefit Cost Ratio (B/C Ratio)

Costs

1) Construction, operations and maintenance costs should be finding out in a detailed manner. Foreign and local currency, financing options and exchange rate variation need to be analyzed.
2) Land acquisition costs should be evaluated considering the actual economic value of land.

3) The costs of environmental and social mitigation plans should be identified.
4) Consider the replacement of the main equipment after a defined period, and for the maintenance and rehabilitation of civil works where there is necessary.

Benefits

1) Accrued benefits at a national or regional level, including any additional taxes, industrial development and other multiple use benefits that could be important to the project.
2) Consider the savings from greenhouse gas emissions, and improved local air quality.
3) Benefits that provide to local communities including job creation, local industry, recreation, skill enhancement training, health care and sanitation, environmental benefits and other income generating activities.
4) Quantification of the energy and power benefits (calculate in terms of the displaced alternative energy) and other benefits such as spinning reserve, system regulation including improved thermal efficiency.
5) Multiple benefits to the downstream users including irrigation, water supply, flood mitigation, aquatic life, water-based transport based on socio-economic and environmental benefits.

1.6.1.2 Internal rate of return (IRR): This is also one of the indicators to evaluate the project. It is the interest earned on the portion of the project that is internally invested.

1.6.1.3 Net present value (NPV): Under the NPV criterion, the present worth of all cash inflows is compared against the present worth of all cash outflows associated with an investment project. The difference between the present worth of these cash flows, which is referred to as the Net Present Value (NPV), and it determines whether or not the project is an acceptable investment. When two or more projects are under consideration, NPV analysis further allows us to select the best project by comparing their NPV figures [131].

Chapter 2 Green Hydropower Engineering Standards and Evaluation research

In this chapter, we discuss about the green hydropower standards existing at present along with the new findings of this research which can be an additional benefit to the existing sustainable green hydropower development. Based on our research design results, we have we have divided our evaluation criteria into three; technical, environmental and socio-economical.

The essence of green and sustainable hydropower is to keep the structure and function of the river eco-system in the standard frame. Whether the condition of river eco-system under the influence of hydropower project meets requirements depends on a comprehensive assessment of all ecological factors in line with relevant technical standards. The Green Hydropower standard offers operational criteria and guidelines to improve the ecological status of rivers affected by the use of Hydropower [8]. Indicators and standards are key components of green hydropower certification system. Green Hydropower Certification, Low Impact Hydropower Certification and International Hydropower Association (IHA) have been used to ensure environmentally compatible hydropower production by issuing guidelines to electricity facilities. Three of them include a set of credible and objective standards aiming to guarantee that no major environmental problems persist after the corresponding criteria are fulfilled. In addition to eco-environmental friendly and socio-economic standards, technical standards are equally important to make the hydropower development completely clean, green and sustainable.

2.1 General Basic Criteria Used for the Green Hydropower Standard

2.1.1 Minimum Flow Criteria

The downstream environmental flow refers to the quantity, time and quality of water flow necessary to meet the human needs while maintaining the process essential to a healthy river ecosystem. Environmental flow provide the following benefits explained below and maintains the well-functioning of the river ecosystem including support of downstream habitat and sediment transport to flood plains and estuaries.

1) Moderated, natural discharge regime.
2) Minimum, seasonally adjusted base flow level varying with natural discharge conditions
3) Interconnection between water course, groundwater, riparian zone and flood plains
4) Adequate water depth for fish migration.
5) Coordination with bed load management
6) Preservation of habitats requiring protection and retaining function of landscape features.
7) Preservation of natural biodiversity, particularly the native fish species and rare and endangered biocoenoses.
8) No critical temperature conditions and oxygen concentrations.

2.1.2 Hydro Peaking Criteria

Release of water in mostly larger schemes is generally related to demands for electricity, thus rapidly increasing the minimum amount of water discharge to meet the demands listed below. This is known as hydro-peaking,

1) Attenuation of discharge fluctuations.
2) No dry-out in the return flow section.
3) Avoidance of critical temperature variation.
4) No isolation of fish and benthic fauna outside the main channel.
5) Preservation of habitat diversity and characteristic landscape features.
6) Preservation of fish habitats, particularly spawning grounds.

2.1.3 Reservoir Management Criteria

This following criterion represents the flow management timing during flushing to reduce the ecological consequences may happen to the downstream river.

1) Management program for reservoir flushing (annual or seasonal storage).
2) No permanent damage through un-natural flushing.
3) Flushing procedures of sand traps.
4) The Raising and lowering of reservoir water levels.

5) Ecologically based reservoir design and connectivity with tributaries (river impoundments, seasonal- or annual storage).
6) Ensuring bed load transport (river impoundments).
7) Scheduling of flushing with respect to times of reproduction (seasonal or annual storage, river impoundments).

2.1.4 Bed Load Management Criteria

Mostly during wet periods where the river discharge is very high, flushing of sediments is carried out in hydropower projects but it may have negative impacts on downstream river and aquatic animals due to heavy flow with maximum bed load impact. Sediment release improves substrate stability and fish habitat, and reduces soil and bank erosion by preventing increased channel depth. Nutrients associated with sediment are also important for improving soil fertility of the agriculture land.

1) Bed load transport during flood periods.
2) Preventing bed erosion through adequate influx of bed load.
3) Solid material budget for run of the river power plants.
4) Solid material budget in diverted river reaches caused by storage power plants.
5) Formation of natural lateral stream inlets.

2.2 Proposed Additional Green Hydropower Evaluation Standard

During this research work, the main objective is to develop new design concept for the sustainable green hydropower development to improve the shortcomings of the existing green hydropower concepts. Hence, to develop the new research concept, we mainly focused on the improvement of dam designing by following the basic standard of green hydropower concept. The new conceptual design can be further applied as a green design model and utilized in many local and international projects in the future. The newly designed concepts provide some additional evaluation standards considering technical, environmental, social and economic factors which are discussed below.

Indicators used for Evaluation:

The comparison between an indicator and its targets is a pre-requisite for evaluating development in reference to sustainability. In our research, following key indicators were used for the evaluation purpose.

1) Power generation scenario as per downstream flow
2) Fish migration
3) Temperature effect
4) Soil stability and land erosion
5) Agriculture growth
6) Height of dam

2.2.1 Technical Standard (45)

1) Position of fishway i.e., the proper selection of fishway position according to the natural river flow direction across the full section of the river width, to attract more fishes to the fishway.
2) This research with two fishways can help to improve the fish migration throughout the year at fluctuating water level during wet as well as dry period. With this design, fishes can migrate during flood period when the river flow is very high 0.5 m over the weir crest and even during dry period when there is very minimum flow of 0.5 m at the upstream face of the weir.
3) New design with 1:1 slope was created at the upstream face of weir to minimize the sediments deposition at the upstream face of the dam and improve the fish exit efficiency.
4) Open channel designed between the sluice gate and weir will help to maintain continuous release of downstream environmental flow and sediments. It will further help in downstream fish migration. It creates the extra discharge needed for the attraction velocity required in fishway.
5) Design of spillway structure at two different positions; i) At the upstream side before the weir section ii) After intake position, is used to control and maintain the required flow in fishway during high flow period.

2.2.2 Environmental Standard (30)

1) Improve water quality with maintaining the optimal dissolved oxygen (DO) and normal temperature required for the aquatic life by continuous downstream flow and improving the water depth at downstream river and maintain the normal temperature
2) Fish population growth due to improving the fish migration.
3) Agriculture growth due to more irrigated land; nutrient release along with trapped sediments make the soil more fertile.

4) Improve the landscape

2.2.3 Socio-Economical (25)

1) Increased fish population can improve the income generating activities of local people by improving fishing job and market.
2) Due to more irrigated land and nutrient release with trapped sediments can develop the good market for the agriculture products.
3) Improved landscape will develop the local tourism. Energy saving and emission reductions with the utilization of energy from micro hydropower development which in turn control the firewood collection for cooking and stop deforestation. This will further contribute to controlling green house gas (GHG) emission in long run.

Table 6 Additional Evaluation Standard

Item	Type of Evaluation	Index	
Technical Standard (45)	Fishway design	*Fishway position*	5
		Two Fishway	10
	Weir design	*1:1 upstream weir slope*	5
		Open channel (Environmental flow)	10
		Power generation	10
		Spillway	5
Environmental Standard (30)	Water quality	*Temperature*	5
		Dissolved oxygen	5
	Fish population growth	*Impact on fish*	10
	Agriculture growth	*Impact on agriculture land*	5
	Landscape	*Impact on landscape*	5
Socio-Economical Standard (25)	Income generation	*Fish job and market*	10
		Agriculture and market	5
		Tourism development	5
	Energy saving and emission reduction	*Substitution effect*	5

Comparison between the Foreign Green Hydropower Certification & Evaluation Approaches with the New Proposed Evaluation Standard explained in Table 7.

Table 7 Comparison between the Foreign Green Hydropower Certification & Evaluation Approaches

Name	Main function	Basic content	Feature of the evaluation
Certification of Green Hydropower in Switzerland	To set up certification standard and economic incentive mechanism, so as to encourage the hydropower owners to actively protect the	Impact of the hydropower project on the environment	To be applied for project operation period, and refer to the implementation condition of related management for the qualitative evaluation
Certification of Low-impact Hydropower in USA	To set up certification standard and economic incentive mechanism, so as to encourage the hydropower owners to actively protect the ecological environment	Impact of the hydropower project on the environment	To be applied for project operation period, and refer to the implementation condition of related management for the qualitative evaluation
Evaluation Standard of Hydropower Sustainability of IHA	To comprehensively evaluate the sustainability of hydropower	Environmental, economic and social impacts of hydropower project, and setting up of an integrated evaluation tool	To be applied for the early stage, and the preparation, execution and operation periods of the hydropower project, and refer to the descriptive standards for the qualitative evaluation
Evaluation Standard of Green SHP in China	To comprehensively evaluate the sustainability of hydropower	Ecological protection is given high priority, auxiliary with the social, economic and management means	To be applied for project operation period, and the qualitative and quantitative evaluations combined
New Proposed Evaluation Standard for the Run of River Small Hydropower projects	To set up the technical standard to encourage the hydropower developers and policy makers to develop the Sustainable Green Hydropower Development	Technical design is given high priority, supported with environmental and socio-economical means	To be applied for the early stage of planning and preparation to execution and operation periods. Qualitative and quantitative evaluations combined.

2.3 Summary

The new findings in the technical design improvement shall be used as key evaluation criteria along with environmental standards including socio-economic benefits. For evaluation purpose, Technical Standard has been given the maximum weightage value of 45 marks while environmental and socio-economic standards receive 30marks and 25marks respectively. The technical design is prioritized in our research, and has been given the maximum weightage value. These technical findings which are carried out with detail hydraulic calculations are required for the optimal power generation at the maximum downstream water release and discharge required for the fishway as well. Compared to the existing design, new design will improve minimum monthly discharge to the downstream from 10% to 30% throughout the year with reaching 63.9% downstream water release during maximum dry period. This design can increase the downstream water depth from 30cm to 60cm, so there will be normal temperature and dissolve oxygen maintain for the aquatic life. It will further improve the socio-economic and environmental condition of the downstream effected region between the diversion weir and the power generation house with creating fish and agriculture market, improve landscape and tourism, consumption of micro hydropower energy for their daily activities such as study, lighting, cooking and control the green house gas (GHG) emission.

Chapter 3 Migratory Fish Swimming Behavior and Capability Study

In this chapter, we will discuss about the acute temperature effect on the fish. This study is helpful to find out changes of fish behavior in downstream river at fluctuating water level during wet as well as in dry period, when there usually occurs a different temperature occurred due to a sudden change in water depth. This experiment is useful for fishway designing. Fish behavior experiments at different velocities and temperature changes are conducted to support in fishway designing. Critical swimming speed (U_{crit}), oxygen consumption rate (MO_2), tail beat frequency (TBF) and tail beat amplitude (TBA) of fish behavior are carried out through the experiment in different swimming speeds and different acute temperatures at 5^{o}C and 25^{o}C. Juvenile sterlet sturgeon fish was taken for the experiments to find out the effect of the change of acute temperature change on the swimming ability and metabolism of the fish. The sterlet sturgeon, *Acipenser ruthenus* (Linnaeus, 1758), is a fresh water fish that lives in habits large rivers in Eurasia and is the only sturgeon native to both Asia and Europe [132]. It is a small sturgeon, weighing up to 20 kg with a standard length not exceeding 1m [133]. The sturgeon prefers the deep depressions of riverbeds lined with sand, gravel and stone and it avoids turbid water. During spring floods, it makes short migrations upstream for spawning. Due to over fishing, pollution and dams, the sturgeon has declined throughout its native range and anadromous populations have been affected greatly. The IUCN Red List classifies the sterlet as the endangered.

Construction of dams and other hydraulic structures across rivers have substantial effects on fish physiology and the spawning migration and acutely low or high temperature change is stressful. Low temperatures result from hypolimnetic release of water from upstream reservoirs [134] and the use of ice prior to fish release by the aquaculture industry [135]. High temperatures are caused by thermal pollution in discharges from power plants and factories [136] and the release of water from the epilimnion of reservoirs. Temperature change also accompanies the tidal cycle in estuarine reaches of rivers that discharge to the sea.

Acute temperature change produced by anthropogenic activities is typically more severe than the routine change of temperature in the nature. Thus, the acute temperatures resulting from human activity alter fish swimming behavior, muscle performance and metabolism more than naturally occurring temperature changes [137]. Temperature change has large impacts on aquatic organisms, particularly the ectotherms. Aerobic swimming performance is also strongly dependent on temperature [138, 139, 140]. During fishway designing, attraction efficiency may relate to biological factors such as migratory characteristics and temperature tolerance of the fish species present [81]. Water temperature and temperature variations play a fundamental role in migratory behavior of fish [141]. Investigators have reported effects of temperature change on various aspects of aerobic swimming performance, but it has been reported that anaerobic exercise in fish is not generally dependent upon temperature [138, 142, 143].

Previous studies on the effect of temperature have focused primarily on swimming capability [144, 145, 146]. However, there is little information available on swimming capability at acute temperatures following sudden temperature change. This new study on fish bahavior provides information on the effect of acute temperature change on the swimming ability and metabolism of juvenile sterlet sturgeon. Changes in critical swimming speed (U_{crit}, i.e. the maximum prolonged swimming speed, it is calculated as described by Brett at 1964, oxygen consumption rate (MO_2), tail beat frequency (TBF), and tail beat amplitude (TBA) during swimming are measured at 15^{o}C (near optimal), at the acutely low temperature of 5^{o}C and the acutely high temperature of 25^{o}C.

3.1 Materials and method

3.1.1 Test fish

Juvenile sterlet sturgeon with standard length, 13.7 ± 0.3 cm and body weight, 17.3 ± 0.8 g (mean ± S.E., n = 24) were obtained from the Yichang Three-Rivers Fishery Limited Company, China. The fish were maintained in a glass holding tank (850 L, 15°C controlled by an aquarium heaters, DO > 7.0 mg/L) and the fish were acclimated for one week. They were fed at 12:00 a.m. with compound forage (5% body weight per day). Forty-eight hours prior to the experiment, feeding was interrupted to avoid the increased metabolic rate caused by digestion. Then fish were transferred from the holding tank to the respirometer with water at one of three test temperatures; 15 ± 0.5°C (near optimal), 25 ± 0.5°C (acutely high temperature) or 5 ± 0.5°C (acutely low temperature) for testing.

3.1.2 Respirometer

Fish were tested in a 14L sealed Steffensen-type swimming respirometer [146] submerged in a 55.7L tank to maintain a controlled temperature (5 ± 0.5°C, 15 ± 0.5°C, 25 ± 0.5°C) by ice or an aquarium heaters. The respirometer has a 4.5L rectangular swimming chamber (35.5cm L × 11.0cm W × 11.5cm D). In the chamber, a flow rectifier maintains laminar flow and a grid at the end prevents fish from being swept away. Water flow in the swimming section is generated by a variable-speed motor with attached propeller and flow rate was calibrated against voltage. A CCD video camera was placed above the swimming chamber so that swimming behavior could be analyzed. The video was manipulated with SWISTrack software.

Swimming speed (U) was assumed to equal water velocity as measured with an Acoustic Doppler Velocity Meter (NortekAS, Oslo, Norway). The rate of oxygen consumption (MO_2) was calculated from the change in dissolved oxygen during the stepped velocity test, which was measured with an oxygen electrode (Hach HQ30d, Loveland, USA).

3.1.3 Protocol for stepped velocity test

A total of 24 sturgeon, eight for each of three temperatures (5ºC, 15ºC, 25ºC), were tested. Prior to testing, the standard length (SL) and mass (m) of each fish was measured, and the fish swam at 0.5 SL s^{-1} for one hour at test temperature. Then, water velocity was increased by 0.5 SL s^{-1} in every 20 min and dissolved oxygen was measured at 5 min intervals. When the fish was exhausted (swimming ceased and the fish rested against the wire grid for 20s).

3.1.4 Data collection and analyses

All experimental data were expressed as mean ± S.E. and data analysis and fitting was carried out by using Origin (Version 8.1) software. Based on data from the stepped velocity test, the oxygen consumption rate (MO_2) was calculated using Equation1:

$$MO_2 = (d(DO)/dt - d(DO)'/dt) \times V/m \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

Where, V is respirometer volume (L), m is body mass (kg), d (DO)/dt is the rate of change of DO ($mgO_2L^{-1}h^{-1}$) and d (DO)'/dt is the rate of change of DO in the control (respirometer with no fish). Critical swimming speed (U_{crit}) was calculated by using the flow velocity (U) and step intervals were recorded during the test by using Equation 2 as described by Brett (1964).

$$U_{crit} = Up + (tf / ti) \times Ut \quad \text{(2)}$$

Where, Up (SL s^{-1}) is last velocity recorded before exhaustion, Ut (SL s^{-1}) is the velocity increment, tf (min) is the time elapsed at fatigue velocity and ti (min) is the time interval.

During the test, fish were videotaped (25 frames s^{-1}) and the recordings were manipulated with SWISTrack software. TBF (beats s^{-1}) was the number of complete tail beat cycles per minute and TBA (SL) was obtained by measuring the maximum distance that the tip of the tail moved from one lateral extent to the other. The statistical comparisons were made by parametric analysis of variance (ANOVA, Fisher LSD).

3.2 Results

3.2.1 Variation of U_{crit} and MO_2 with temperature

The values of U_{crit} for the juvenile sturgeon at the three test temperatures as shown in Figure 2, are such as, at 15°C (close to the optimal swimming temperature), U_{crit} was 3.39±0.21 SL s^{-1} (0.456±0.028 m s^{-1}); at 25°C (acutely high), U_{crit} was 3.13±0.23 SL s^{-1} (0.440±0.032 m s^{-1}) and at 5°C (acutely low), U_{crit} was 1.93±0.29 SL s^{-1} (0.264±0.040 m s^{-1}).

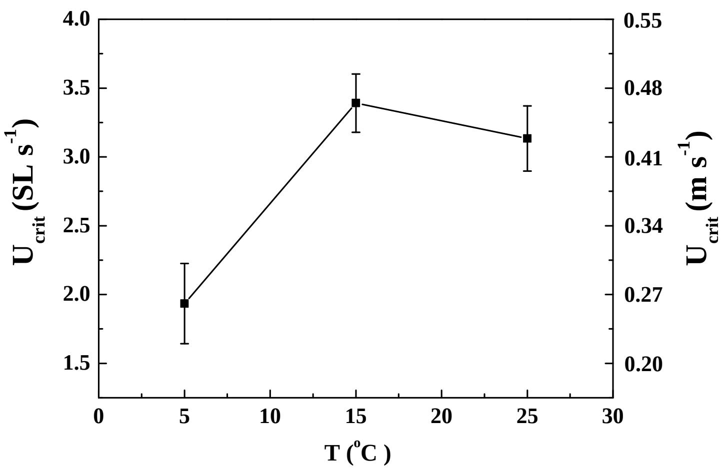

Figure 2 Relationship between Critical Swimming Speed vs. Temperature

The values of MO_2 for the juvenile sturgeon at the three test temperatures as shown in Figure 3, such as, at 15°C, MO_2 increased from 318.43 $mgO_2kg^{-1}h^{-1}$ (0.5 SL s^{-1}) to 481.45 $mgO_2kg^{-1}h^{-1}$ (3.5 SL s^{-1}); at 25°C, MO_2 decreased from 612.66 $mgO_2kg^{-1}h^{-1}$ (0.5 SL s^{-1}) to

245.93 $mgO_2kg^{-1}h^{-1}$ (3 SL s^{-1}); at 5^{o}C, MO_2 decreased from 169.20 $mgO_2kg^{-1}h^{-1}$ (0.5 SL s^{-1}) to 45.34 $mgO_2kg^{-1}h^{-1}$ (2.5 SL s^{-1}).

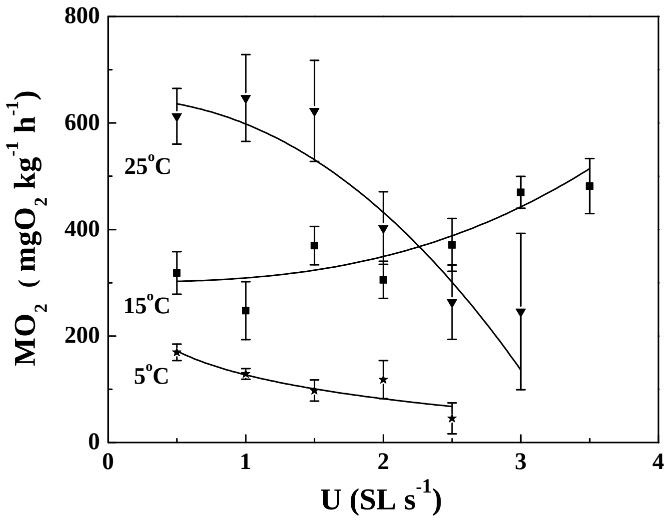

Figure 3 Oxygen consumption rate (MO_2, mean± SEM) as a function of swimming speed

3.2.2 Variation of TBA and TBF with temperature

The values of TBA for the juvenile sturgeon at the three test temperatures shown in Figure 4, are such as, at 15^{o}C, TBA decreased from 0.105 SL (0.5 SL s^{-1}) to 0.096 SL (4 SL s^{-1}); at 25^{o}C, TBA increased from 0.055 SL (0.5 SL s^{-1}) to 0.074 SL (3.5 SL s^{-1}); at 5^{o}C, TBA decreased from 0.077 SL (0.5 SL s^{-1}) to 0.068 SL (2.5 SL s^{-1}).

The values of TBF for the juvenile sturgeon at the three test temperatures as shown in Figure 5 are such as, at 15^{o}C, TBF increased from 0.79 beat s^{-1} (0.5 SL s^{-1}) to 2.98 beat s^{-1} (4 SL s^{-1}); at 25^{o}C, TBF increased from 0.78 beat s^{-1} (0.5 SL s^{-1}) to 2.45 beat s^{-1} (3.5 SL s^{-1}); at5^{o}C, TBF increased from 0.82 beat s^{-1} (0.5 SL s^{-1}) to1.83 beat s^{-1}(2.5 SL s^{-1}). The slopes of the regression lines (ΔTBF/ΔU) at 5^{o}C, 15^{o}C and 25^{o}C were 0.64, 0.79 and 0.59, respectively.

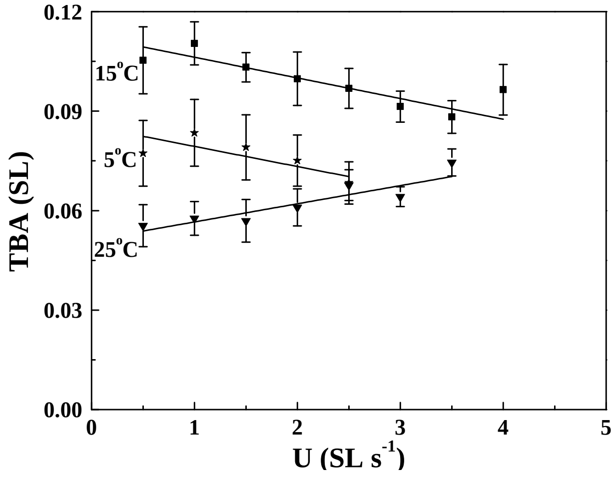

Figure 4　Tail beat amplitude (TBA, mean± SEM) as a function of swimming speed

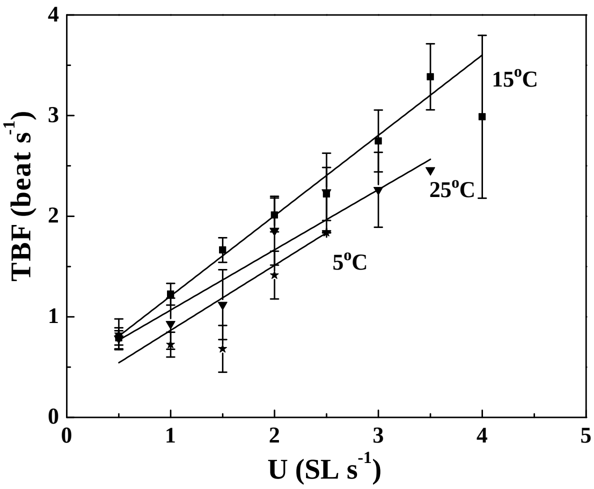

Figure 5　Tail beat frequency (TBF, mean± SEM) as a function of swimming speed

3.3 Discussion

3.3.1 U_{crit} and MO_2

Critical swimming speed, U_{crit} [147] is an indicator of swimming capacity and physiological condition [148]. In this study, U_{crit} was the highest at 15°C and decreased with acutely higher (25°C) or lower (5°C) temperature (Figure 2). The acutely low temperature affect U_{crit} was significant ($p<0.05$), 5°C group versus 15°C; but the difference between 25°C group and 15°C group was not significant ($p=0.48$). Muscle activity of fish decreases at low temperatures [145]. Similarly, at the high temperatures fish diminish its muscle and cardio vascular function [149]. Review of the videos recorded during the test revealed that the sturgeon displayed station holding behavior mostly at both 5°C and 25°C. Station holding behavior has been reported as an energy saving strategy and been observed at acutely low temperatures [145]. At acutely high temperature, station holding behavior is caused by lowered muscle performance [149]. At Speeds above 0.4 m s^{-1} shovelnose sturgeon (Scaphirhynchus platorynchus) at 16°C alternated between active swimming and substrate appression to conserve energy which is enhanced by sturgeon morphology of streamlined body shape, flat rostrum, and large pectoral fins [150]. U_{crit} of the juvenile Lake sturgeon (Acipenser fulvescens) at 14°C and at 15°C, was 0.261 m s^{-1} (1.74 SL s^{-1}) and 0.386 ± 0.042 m s^{-1} (2.45 ± 0.23 SL s^{-1}), respectively [151, 152] which is lower than U_{crit} of this study of sterlet sturgeon (0.456±0.028 m s^{-1}, 3.39±0.21 SL s^{-1}).

At 15°C, MO_2 was directly proportional to swimming speed ($p<0.001$) but at 5°C and 25°C the relationship was inversed ($p<0.05$) (Figure 3). Additional energy is required to increase swimming speed and, at 5°C and 25°C, the additional energy must come from anaerobic metabolism. The lower temperature dependence of anaerobic metabolism was reported in the introduction and is supported by data [138]; temperatures above optimal reduce the oxygen-carrying capacity of the blood and limit oxygen delivery to tissues. At acutely high or low temperatures, white muscle contributes to swimming at a lower speed and fatigue occurs sooner as a result of lactic acid accumulation [138]. Jones et al. [153] reported that acutely high temperature affect swimming performance in bluegill sunfish (Lepomis macrochirus) due to low cardiac output; others have reported that the function of cardiovascular system function is not sufficient to meet the increased metabolic demand of muscle at high temperature [154, 155, 156, 157]. Our data and the work of others indicate that acutely low temperatures lower muscle activity and acutely high temperatures decrease the function in muscle and cardiovascular system. As temperature moves away from the optimum, the onset of anaerobic metabolism and use of white muscle fiber begins at lower swimming speeds. As a result, aerobic metabolism, MO_2, decreases rather than increases with increased swimming speed and swimming performance (U_{crit}) declines.

3.3.2 TBA and TBF

TBA increased with speed at 25°C, but decreased with swimming speed at 15°C and 5°C ($p<0.05$) (Figure 4). The maximum TBA (TBA_{max}) of juvenile sterlet sturgeon (0.105 SL) provides an important criterion for fishway design; the minimum slot width should be no less than TBA_{max} to avoid disturbing normal gait [54]. The change in TBA with temperature was not significant but decreased at both low and high temperatures. The decrease in TBA_{max} was 32% at 25°C and 24% at 5°C.

TBF increased linearly with swimming speed at all three temperatures ($p<0.05$) (Figure 5), consistent with other reports [137, 158]. The slopes of the regression lines ($\Delta TBF/\Delta U$) at 5°C, 15°C and 25°C were 0.64, 0.79 and 0.59, respectively. This slope has been reported for other species at near optimal temperatures: 0.33 for Schizothorax chongi [54]; 0.56 for Oncorhynchus mykiss (rainbow trout); 0.96 for Acipenser schrenckii [159]; 1.31 for Cyprinus carpio (carp) [160] and 1.30 for *Rutilus rutilus* (roach) [161]. Fish species exhibiting a lower slope expend less energy (lower MO_2) at a given swimming speed [54]. In this investigation, the slopes at 5°C and 25°C were lower than at 15°C. The decrease in slope was 27.5% at 25°C and 45.85% at 5°C. The temperature stress seems to increase swimming efficiency, perhaps to compensate for lowered performance of muscles and/or cardiovascular function. At a given swimming speed, TBF was lower at 5°C than at 15°C, probably due to reduction in myotomal muscle contraction rate [137, 162]. TBF did not change in bluegill sunfish Lepomis macrochirus (Rafinesque, 1819) at temperatures above the acclimation temperature, though there was potential for increased rate of myotomal muscle contraction [153]. Whereas in our case TBF was lower at 25°C compared to 15°C, possibly due to increased rate of myotomal muscle contraction.

3.4 Summary

This research on effects of acute temperature changes may give some contribution in conservation of the sterlet sturgeon and help to improve the design of fishways when there is temperature variation due to water level fluctuation during wet and dry periods basically concerned with downstream release of water. This experiment has guided to maintain the normal temperature throughout the period to obtain the natural fish behavior. Hence, during fishway designing, open channel concept with continuous flow of water found to be considered following one of this reasons.

Chapter 4 Design of Small Hydropower Project Considering Migratory Fish Protection

This chapter will discuss the new conceptual dam design considering fishway. Here it is more emphasized on the hydraulic design calculation to get maximum possible downstream release with very minimum effect on the power generation. Furthermore, the river flow management methodology will be discussed to explain on how to get the comprehensive benefits from the optimization of power generation, fish migration and sufficient downstream river flow simultaneously.

Hydropower is generally termed as a clean and green source of energy; however, there are significant socio-economic and environmental impacts on downstream reach due to diverting more water for power generation and releasing insufficient downstream water, thus leading to fewer priorities. The largest hydropower schemes invariably use a dam to store a reservoir of water for electricity generation. By contrast, run of river schemes simply divert a proportion of the river flow through turbines and return the water downstream. Most of the research on the impact of hydropower development on river ecosystems has been carried out for the large schemes storage projects compared to the impacts of small-scale, run off river hydropower schemes. However, it needs to be noted that hydropower schemes, regardless of whether they are run of river or large storage schemes, are characterized by the similar structural elements and thus may have the same impacts. Moreover, after an initial rush for small-scale hydropower schemes in USA, other European countries in the past, these schemes have largely been abandoned because of their potential impacts on the environment and their failure to deliver economically viable power production. Essentially, the issues and impacts of these smaller developments are poorly understood and have not been adequately studied and designed.

Despite having several benefits of hydropower projects, hydropower production also has severe impacts on freshwater ecosystems such as causing several ecological and environmental problems, which will lead to social and economic challenges. Nevertheless, if the design is improved more carefully by effectively managing downstream river flow, sediment flow and improving the fishway design, the negative impact of hydroelectric projects on natural rivers can be significantly reduced. Moreover, it will improve the socio-economic condition of the affected area with the enhancement in river ecosystem and environment.

4.1 Methodology

4.1.1 Case Study

An existing small run of river (ROR) Sanjen (Upper) Hydroelectric Project (SUHEP) located at the Rasuwa district, of Central Development Region of Nepal has been taken as a case study of this research. It is s small hydropower run of river (ROR) scheme project. It has a capacity of 14 MW and the project site is situated at the altitude of 2345m. Sanjen River is one of the tributaries of Bhote Koshi River in Gandaki Basin. It is a snow fed stream, which originates from the Salasungi Himalaya Range. Because of the seasonal variation of the river flow, there is an excess power supply during the monsoon high flow season (July-September) and shortage in the dry season (December-May), which is the general river hydrology scenario existing all over Nepal [163]. Most of the developed hydropower projects in Nepal are small run of river hydropower focusing more on hydropower generations with giving very minimum priority in fishway design.

River hydrology data and other necessary available field data were collected with the help of personnel from local hydropower project and the government of Nepal. Year-round discharge records were available for the project site and it had a minimum flow of 2.33m^3/sec in the dry season, a maximum flow of 42.49m^3/sec during the wet season (Figure 6) and a gross head difference of 150m over a distance of about 3km from dam to power station. For design purposes, the six months from December to May were considered as the low flow period, with the high flow period from June to November. A 40% flow exceedance (Q40) and 11m^3/sec design discharge were assumed for power generation. Necessary hydraulic calculations such as velocity and discharge were calculated for the fishway design and other hydraulic structures.

4.1.2 Fishway design

The fishway design was carried out by considering both native fish and other important species in order to be used in a broad manner for the development of future hydropower. In this design, two fishways such as weir fishway (during wet period) and sluice fishway (during wet period) were considered along the main river stream. Similarly, additional open channel was designed between the two fishways, which is used for the multiple purposes such as environmental flow release, downstream fish migration and sediment release. The weir fishway uses the entire weir crest length and sluice fishway follows the natural channel, so fish encounter the fishway directly as they migrate upstream which may help to improve the efficiency of the passage. River hydrology (Figure 8) shows that the month when the river flow is high, extra water obtained after diverting the water for power generation and fishway utilization, shall be spilled through two-spillway structure located at upstream of weir and after intake (Figure 9). Additional flow for the attraction velocity, which is created just adjacent to the both fishway inlets at the main stream of the river, may help the fish to be attracted more easily to find the fishway inlet with very minimum time lapse.

Following the existing river hydrology, hydraulic calculations were carried out for slot design, volumetric power dissipation (E), open channel design, discharge from weir fishway, discharge from sluice fishway, velocity inside the pool and exit velocity, minimum water depth and attraction velocity were carried out for the fishway design. Similarly, the intake design with power generation calculations was also conducted.

The following formulas were used for calculations.

4.1.2.1 Slot design

$$Q = (2/3) * \mu r * s * (2*9.81)^{\wedge}0.5 * ho *^{\wedge}1.5 \text{......................(3)}$$

Where, Q is the discharge (m^3/sec), μr is the coefficient of discharge, s is the slot width (m), and h_o is the maximum water height of pool (m).

4.1.2.2 Volumetric power dissipation (E)

$$E = ((\rho * g * \Delta h * Q)/(b * hm * (Lb - d))) \text{......................... (4)}$$

Where, E is the volumetric power dissipation; ρ is water density (1000kg/m^3); g is gravitational acceleration (9.81m/sec^2); Δh is the minimum head difference in the pool; Q is discharge (m^3/sec); hm is minimum water depth in both fishways pool; Lb is pool length (m); b is pool width (m) and d is the cross wall distance for both fishway (m).

4.1.2.3 Open channel design

The size and flow velocity of the open channel were calculated using the following formulas,

$$Q = V * A \text{ ....} \quad (5)$$

Q = V*A
V = 1/η*R^(2/3)*S^(0.5)*W*D

Where, Q is the design (Environmental) flow discharge (m^3/sec) in the open channel, A is the cross sectional area of the channel, W is channel width (m), D is water depth (m), η is Manning's Roughness Coefficient for Concrete (0.014), R is the hydraulic radius, S is the slope of the channel and the V is the open channel velocity.

4.1.2.4 Discharge from weir fishway(During wet period)

Discharge at the weir was calculated using the following formula,

$$Q = C * L * H \wedge (3/2) \text{ ....} \quad (6)$$

$C = (2/3)^{3/2}(g)^{1/2}$
Gravitational acceleration g: 9.806 m s^{-2}
Discharge coefficient C: 1.704 $m^{1/2}$ s^{-1}

Where Q is discharge (m^3/s), C is the discharge coefficient ($m^{1/2}$ s^{-1}), L is length of weir (m) and H is normal flow height of water over weir crest (m).

4.1.2.5 Discharge from sluice fishway (During dry period)

Discharge and velocity under the sluice gate were calculated using the following formulas:

$$Discharge(Q) = (V * h2 * L) \text{ ....} \quad (7)$$

Where, normal discharge (Q); V is the velocity (m/sec), L is the length of the gate opening (m), h_2 is the height of the gate opening (m)

4.1.2.6 Flow Simulation

ANSYS Fluent 14.5 software was used to simulate flow pattern and velocity inside the fishway at different upstream water levels during dry as well as in wet periods. Since our objective was to find out the velocity at each and every section inside the fishway, hence, we used computer simulation based model design. Otherwise, it was difficult to obtain the velocity at every section manually from the prototype physical model. The maximum velocity obtained inside the fishway's slots and pools is being used to calculate the pool dimensions, minimum water head along with volumetric power dissipation. During weir fishway design, flow simulation was carried out by considering upstream fihway's inlet and exit invert level. Accordingly, as per the available river hydrology, maximum velocity inside the fishway was calculated at different water head over weir crest such as 0.15m, 0.5m, 1m, and 1.5m. Similarly, in case of sluice fishway, maximum velocity inside the fishway was calculated at different water depth occurs in upstream river such as, 0.5m, 0.8m, 1m and 1.5m.

In addition, the open channel between weir and under sluice portions at a slope of 1:500 was used for the continuous environmental flow. This open channel can be further used for downstream fish migration and continuous sediment release. Moreover, environmental flow can be further used to create an attraction velocity required for the fishway at the end of the channel.

ANSYS Fluent is ideally suited for incompressible and compressible fluid-flow simulations in complex geometries. ANSYS Fluent provides complete mesh flexibility, including the ability to solve the flow problems using unstructured meshes that can be generated about complex geometries with relative ease. Initially the geometry was created according to the fishway model scale and mesh was generated accordingly. Using the Volume of Fluid, VOF formulation, open channel flows is modeled in ANSYS Fluent. To start using the open channel flow fishway simulation, velocity inlet, pressure inlet, outflows are selected as boundary condition. At operating condition gravitational acceleration 9.81m/sec^2 was considered. For pure open channel flow applications, the inlet and outlet boundary conditions are controlled by the Froude number. Velocity inlet boundary conditions are used to define the velocity and scalar properties of the flow at inlet boundaries. Pressure inlet boundary conditions are used to define the total pressure and other scalar quantities at flow inlets. Velocity inlet boundary conditions are used at an inlet and it will fix the mass flow. Outflow boundary conditions are used to model flow exits where the details of the flow velocity and pressure are not known prior to solution of the flow problem. k- Epsilon(ε)Model is used for the fluent solution. K and Epsilon in the turbulence specification method was chosen and selected the appropriate profile names in the lists next to turbulent kinetic energy and turbulent dissipation rate. For this calculation, the convergence tolerance on the continuity equation is kept at 0.001. The solution begins with an estimated pressure profile at the outlet boundary.The initialization procedure was selected as it is very important in the open channel analysis. For the initial stability of the solution, a smaller time step is selected.

ANSYS Fluent is ideally suited for incompressible and compressible fluid-flow simulations in complex geometries. Flow equations utilized during fluent analysis are explained below.

Navier-Stokes Equations of Fluid Flow

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{v}) = 0 \qquad (8)$$

Momentum Equation

$$\rho\left(\frac{\partial \vec{v}}{\partial t} + \vec{v}.\nabla\vec{v}\right) = \nabla.\vec{\sigma} + \vec{f} \qquad (9)$$

Where, ρ is fluid density, $\vec{v}$ is flow velocity vector, $\vec{\sigma}$ is stress tensor

is body forces and ∇ is del operator.

Conservation of mass equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho \omega)}{\partial z} = 0 \qquad (10)$$

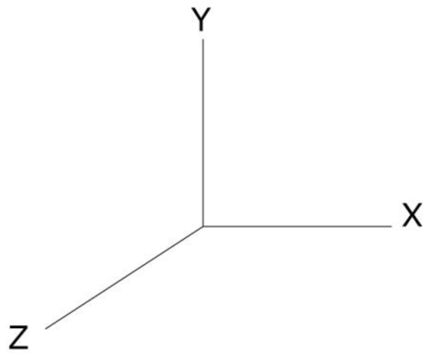

Figure 6　XYZ coordinates

where ρ is the density of the fluid, t is time and u, υ and w are the components of the velocity vector in x, y and z coordinates.

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+\omega\frac{\partial u}{\partial z}\right)=\frac{\partial\sigma_{xx}}{\partial x}+\frac{\partial\tau_{yx}}{\partial y}+\frac{\partial\tau_{zx}}{\partial z}+\rho g_x \text{............}(11)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+\omega\frac{\partial v}{\partial z}\right)=\frac{\partial\tau_{xy}}{\partial x}+\frac{\partial\sigma_{yy}}{\partial y}+\frac{\partial\tau_{zy}}{\partial z}+\rho g_y \text{..............}(12)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+\omega\frac{\partial w}{\partial z}\right)=\frac{\partial\tau_{xy}}{\partial x}+\frac{\partial\tau_{yz}}{\partial y}+\frac{\partial\sigma_{zz}}{\partial z}+\rho g_z \text{............}(13)$$

Where, gx, gy and gz are gravitational acceleration along x, y and z axes. The terms σ and τ are normal and shear stresses acting on the fluid, respectively. The first subscript in the notation indicates the direction of the normal to the plane on which the stress acts, and the second subscript indicates the direction of the stress.

Where,

$$\sigma_{xx}=-P+2\mu\frac{\partial u}{\partial x}-\frac{2}{3}\mu\nabla\vec{v} \qquad \tau_{xy}=\tau_{yx}=\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)$$

$$\sigma_{yy}=-P+2\mu\frac{\partial v}{\partial y}-\frac{2}{3}\mu\nabla\vec{v} \qquad \tau_{yz}=\tau_{zy}=\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)$$

$$\sigma_{zz}=-P+2\mu\frac{\partial w}{\partial z}-\frac{2}{3}\mu\nabla\vec{v} \qquad \tau_{zx}=\tau_{xz}=\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)$$

Navier-Stokes Equations of Fluid Flow Substituted and simplified

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+\omega\frac{\partial u}{\partial z}\right)=\frac{\partial P}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\frac{1}{3}\mu\left[\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)\right]\text{......}(14)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+\omega\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial y}+\rho g_y+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\frac{1}{3}\mu\left[\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)\right]\text{......}(15)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+\omega\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial z}+\rho g_z+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\frac{1}{3}\mu\left[\frac{\partial}{\partial z}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)\right]\text{......}\ (16)$$

Incompressible Newtonian Fluid

Generally, most fluids having practical importance such as water are incompressible, that means their densities are constant for a wide range of flows. This is a reasonable assumption except for certain extreme situations such as the cases where the fluid is under profound pressures. Since the density of fluid is constant, then the continuity equation for incompressible flows can be simplified with the following equation.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0\ \text{...}(17)$$

Navier-Stokes Equations (Incompressible Flow of Newtonian Fluids)

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+\omega\frac{\partial u}{\partial z}\right)=\frac{\partial P}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)\text{..........}(18)$$

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+\omega\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial y}+\rho g_y+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)\text{..........}(19)$$

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+\omega\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial y}+\rho g_z+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)\text{...........}(20)$$

RNG k- ε Model

The RNG k- ε model was a statistical technique called renormalization group theory. The RNG model has an additional term in its ε equation that improves the accuracy for rapidly strained flows.

- The effect of swirl on turbulence is included in the RNG model, enhancing accuracy for swirling flows.
- The RNG theory provides an analytical formula for turbulent Prandtl numbers, while the standard k- ε model uses user-specified, constant values.
- While the standard k- ε model is a high-Reynolds number model, the RNG theory provides an analytically-derived differential formula for effective viscosity that

accounts for low-Reynolds number effects. Effective use of this feature does, however, depend on an appropriate treatment of the near-wall region.

The RNG-based k- ε turbulence model is basically derived from the instantaneous Navier - Stokes equations, using a mathematical technique called “renormalization group” (RNG) methods.

The RNG k- ε model has a similar form to the standard k- ε model

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(a_k \mu_{eff}\frac{\partial k}{\partial x_j}\right)+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad \text{.....................(21)}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left(a_\varepsilon \mu_{eff}\frac{\partial \varepsilon}{\partial x_j}\right)+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon\rho}\frac{\varepsilon^2}{k}-R_\varepsilon+S_\varepsilon \quad \text{.........(22)}$$

In these equations, G_k represents the generation of turbulence kinetic energy due to the mean velocity gradients. G_b is the generation of turbulence kinetic energy due to buoyancy. Y_M represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate. The quantities a_k and a_ε are the inverse effective Prandtl numbers for k and ε respectively.

Solve control equation:

When control equation is dispersed to algebra group, it needs to solve according to order. Figure 7 shows the control equations solving process along with fluent simulation method given in a flow chart.

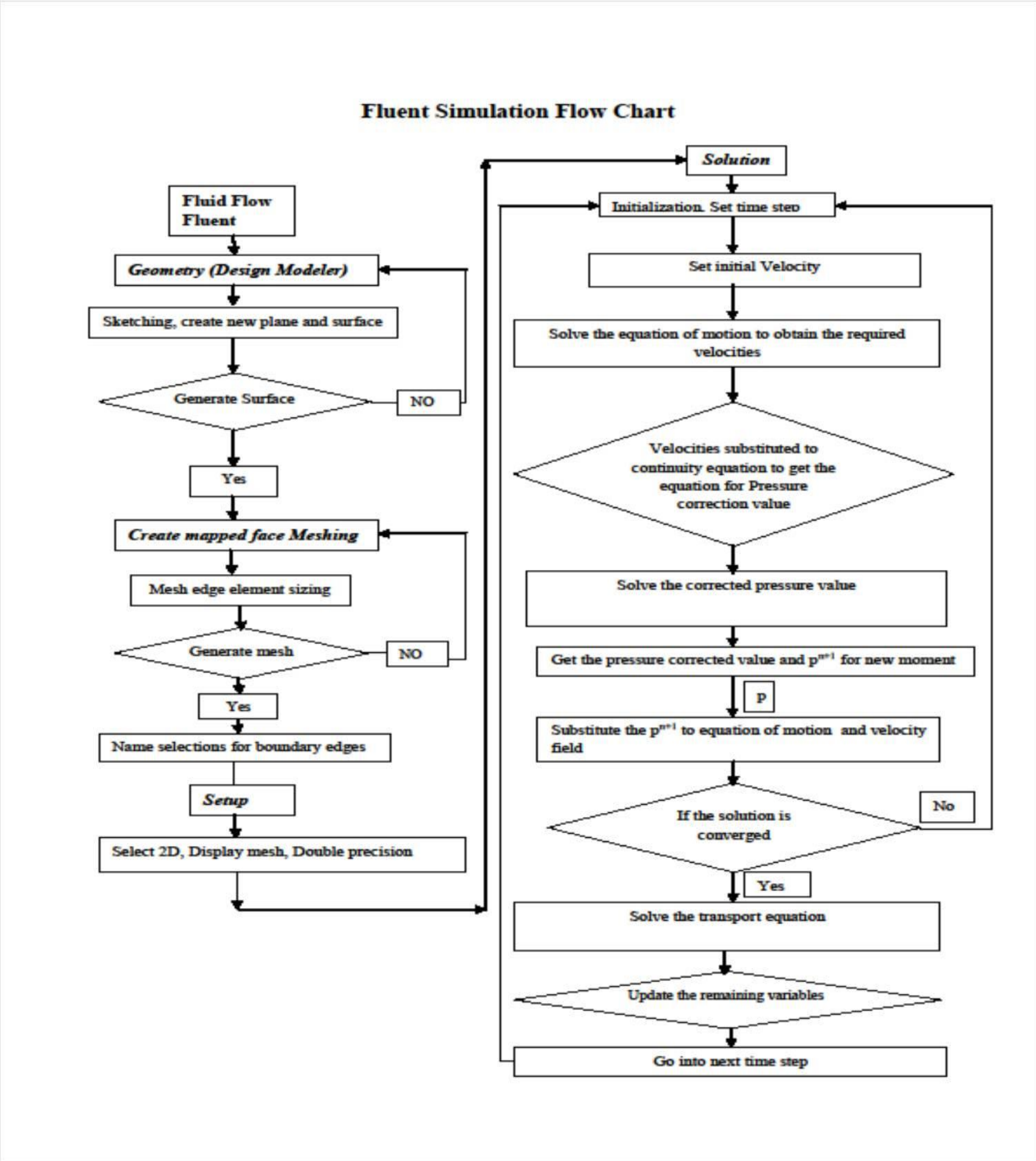

Figure.7 Fluent simulation flow chart

4.1.2.7 Vertical slot Fishway

The single vertical slot [42] design was chosen for the fishway as it maintains an average velocity at each slot over a large fluctuation in water depth [48, 74]. Two fishways at different locations were designed according to different river flow depth during wet and dry period (Figure 9). During low flow, in a dry period a 32m fishway with 7 pools (length 4.5m, width

1m, height 1m) was designed to run under the sluice at a slope of 1:20. During high flow, in a wet period also 32m in length fishway with 18 pools (length 1.7m, width 6m, height 1m). was designed along the weir facing downstream at a slope of 1:10.

Fishway length was calculated according to the available head obtained between the weir crest level, 2347.5m and the downstream river bed level 2344.0m. Downstream bed level was selected by considering the bottom-living fish along with others species. Minimum depth of water inside the pool was selected as 0.6m. All these dimensions were finalized depending on the result of volumetric power dissipation inside the pool which needs to be less than 200 watt/m^3 [164].

4.1.3 Energy calculation

For design purposes, the six months average monthly flow discharge from December to May was considered as the low flow period, with the high flow period from June to November (Figure 8). A 40% flow exceedance (Q40), 11m^3/sec design discharge and gross head difference of 150m over a distance of about 3km from dam to power station were assumed for power generation.

4.1.3.1 Intake design

$$Q = Cd * V * A \quad (23)$$

Where, Q is design discharge (11 m3/sec), V is velocity (m/sec) and A is cross section area of intake opening (m^2)

4.1.3.2 Power generation

Power and energy generation were calculated using the formula:

$$P: \eta * Q * g * h \quad (24)$$

Where, P is the power generated (MW), η is the efficiency (92%), Q is the design discharge (11m^3/sec), g is gravitational acceleration (9.80 m/sec^2) and h is the total net head available after losses from weir to turbine axis (144m).

E = P*t where, E is energy (MWh), P is power (MW) and t is generation time (h).

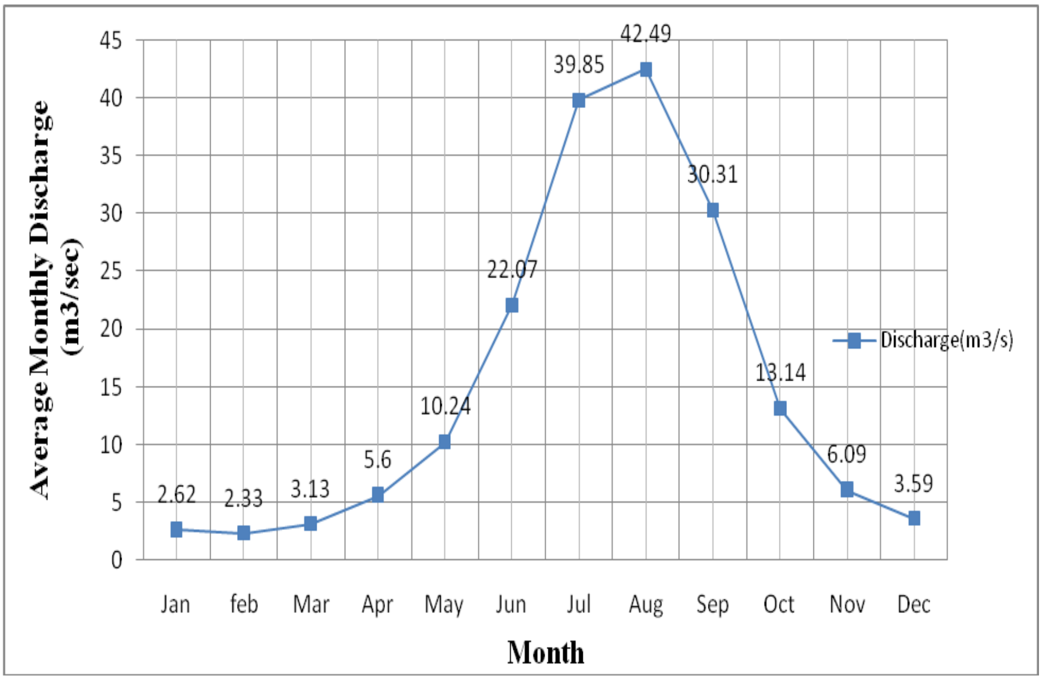

Figure 8　Average monthly discharge of river at the study site

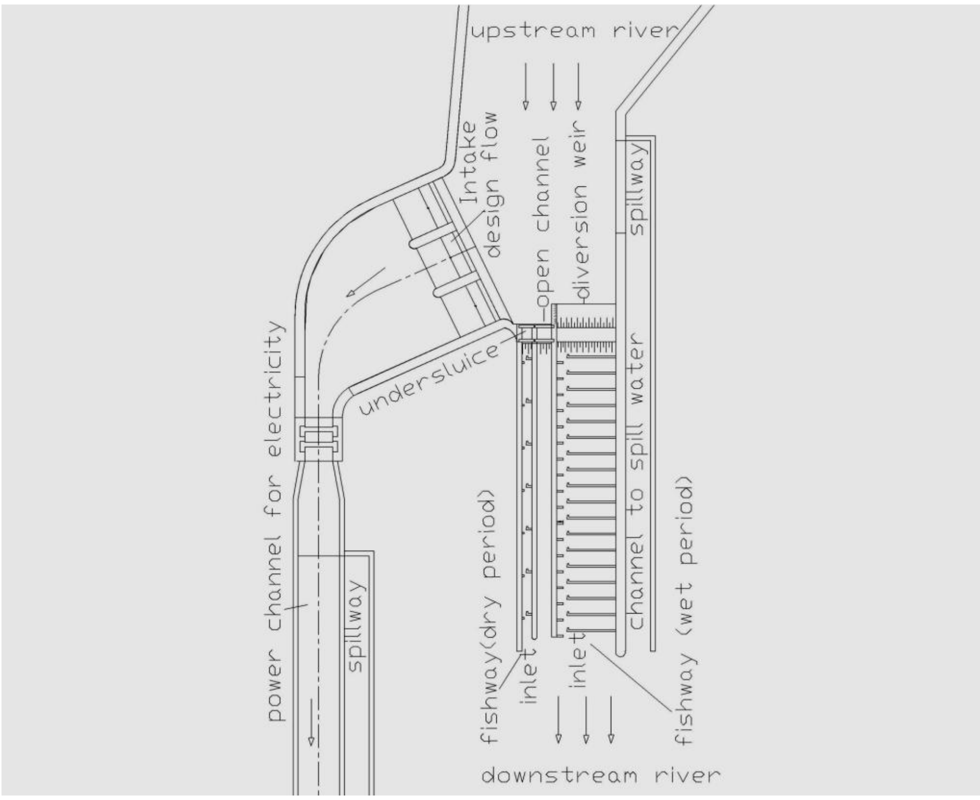

Figure 9　Project schematic showing the diversion weir with fishway

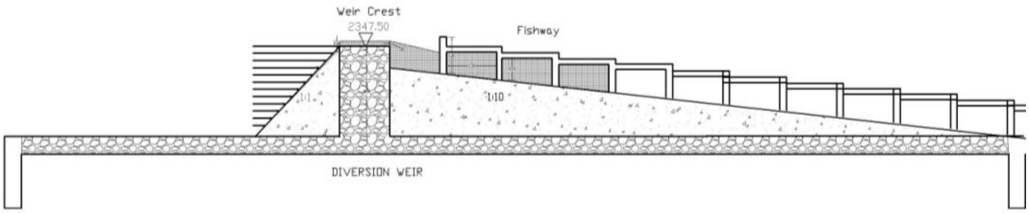

Figure 10　Longitudinal section of diversion weir

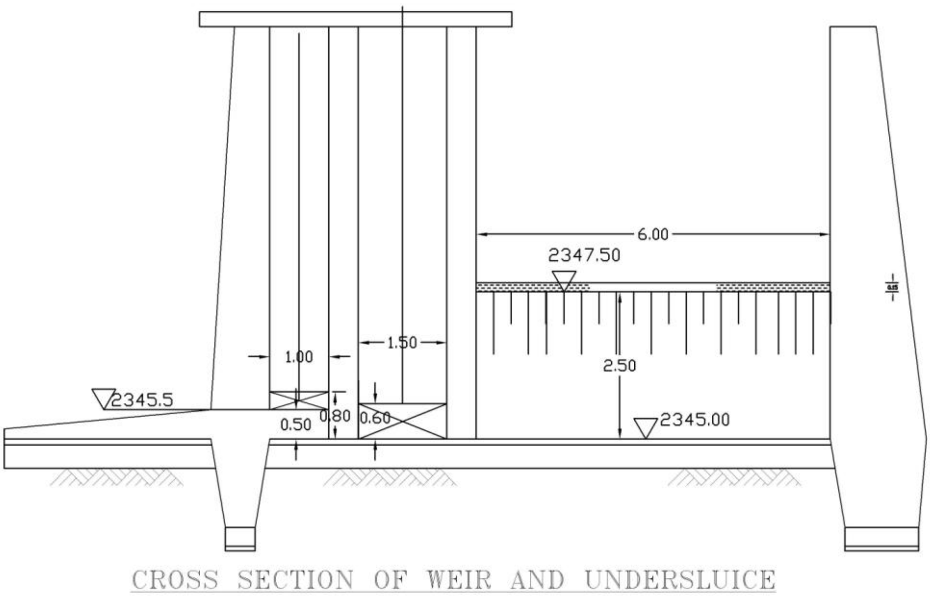

Figure 11　Cross section of weir and under sluice

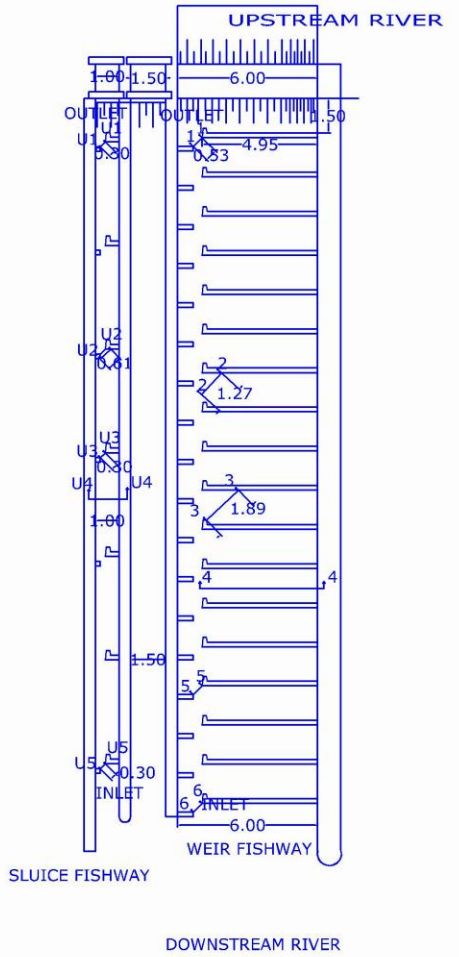

Figure 12 Sectional plan of Fishway

4.2 Results

Simulated results of the ANSYS Fluent 14.5 software are explained below, when the flow through the proposed hydropower station passes inside the weir fishway (wet period) and sluice fishway (dry period).

4.2.1 Weir Fishway (Wet Period)

The fishway running along the weir is designed for the wet period. During flood period there may be sufficient water in the river, however due to maximum discharge occurring in the weir section, it is very difficult for fish to move upstream as the exit velocity at the weir section exceed to the permissible velocity of 2m/sec. This configuration gives a maximum inside velocity of 0.76m/sec during normal operation of the fishway with a flow discharge of 0.59m^3/sec at the minimum flow height of 0.15m over the weir crest. The maximum fishway inside velocity varies from 0.76m/sec to 2.65m/sec according to flow height varying from 0.15m to 1.5m over the weir during the flood period. Similarly, exit velocities from the fishway corresponding to the different flow height are explain in Table 8. Consequently, during flood period when the water level increased to 1.5m, the fishway's maximum inside velocity and exit velocity both exceed to the permissible velocity of 2m/sec [33] as seen in Figure 13. Whereas, maximum inside fishway velocity (1.21m/sec) and the exit fishway velocity (1.3m/sec) which are within the permissible velocity of 2m/sec reached at the maximum over flow height of 0.5m (Explain in Figures 14, 15). Inside velocity at different sections (at 0.5m overflow height) i.e., slot, resting pool and other sections are explained in figure 14, 15 and 16.

Table 8 Maximum velocity at exit section and inside the fishway at different overflow depth (Weir fishway)

Upstream overflow depth at Weir (m)	Maximum Velocity (Fishway Exit) in weir fishway at different height (m/sec)	Maximum Velocity inside the Fishway (m/sec)
0.15	0.66	0.76
0.5	1.21	1.35
1	1.7	2.06
1.5	2.02	2.65

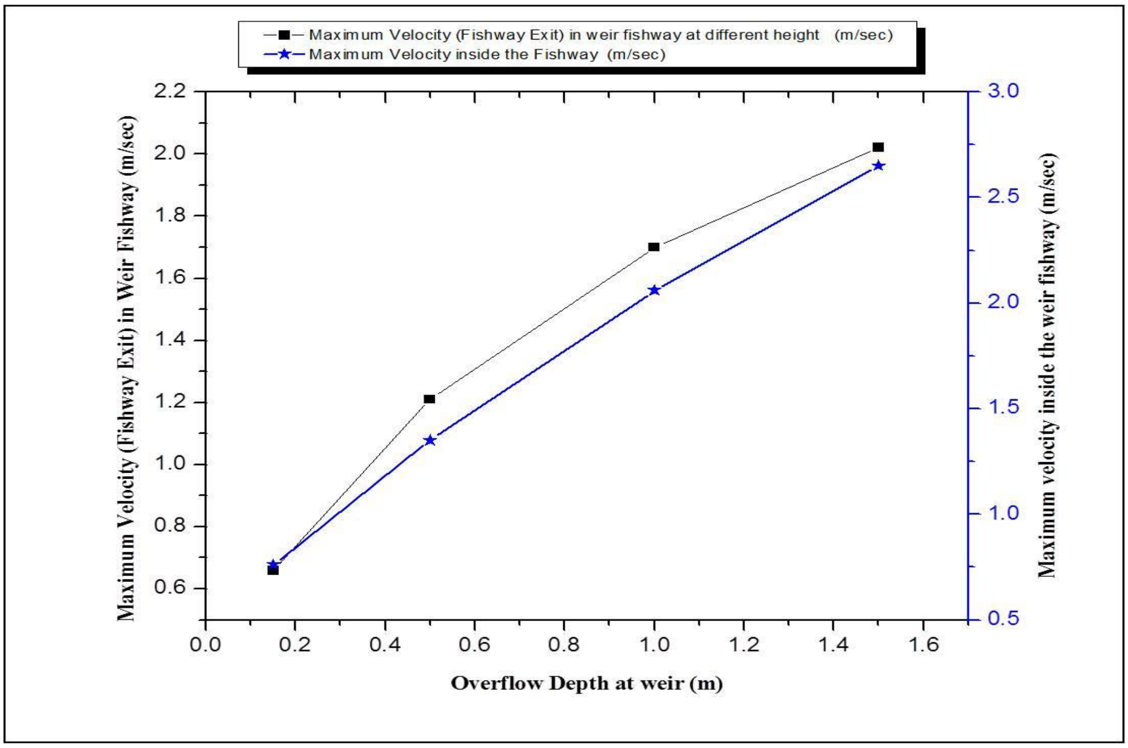

Figure 13 Maximum inside and exit velocity at different water levels in the weir fishway

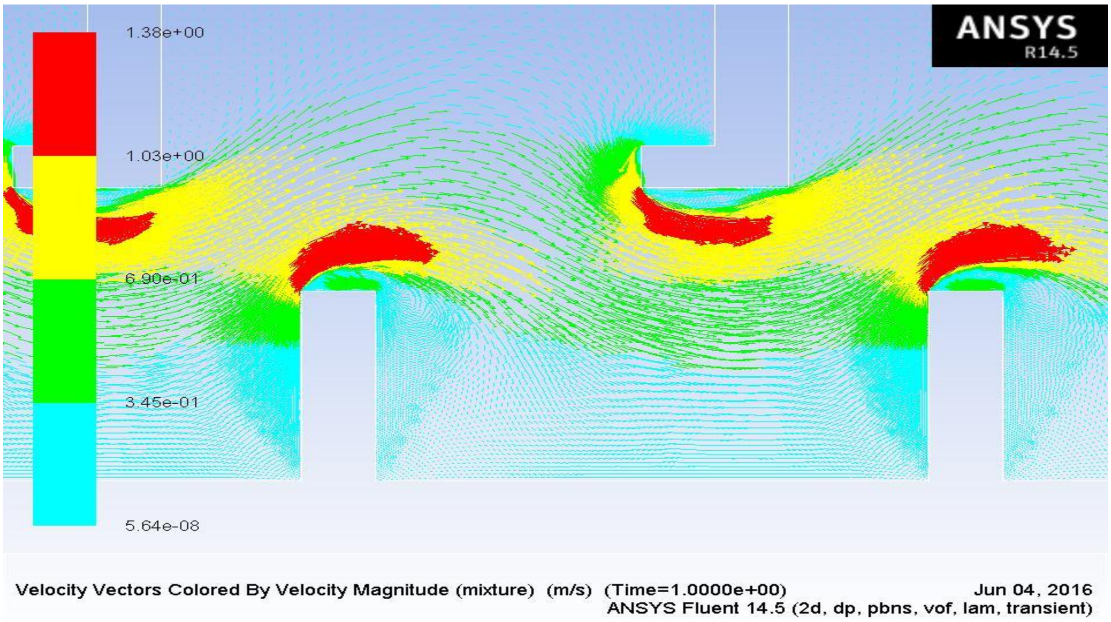

Figure 14 Velocity vectors in m/sec inside the weir fishway

(Enlarge view at the inlet section of fishway where the maximum velocity obtained, different color at Y-axis represents different velocity inside the fishway, Dark red color (maximum velocity, 1.3m/sec); symbol ⟶ represents flow direction)

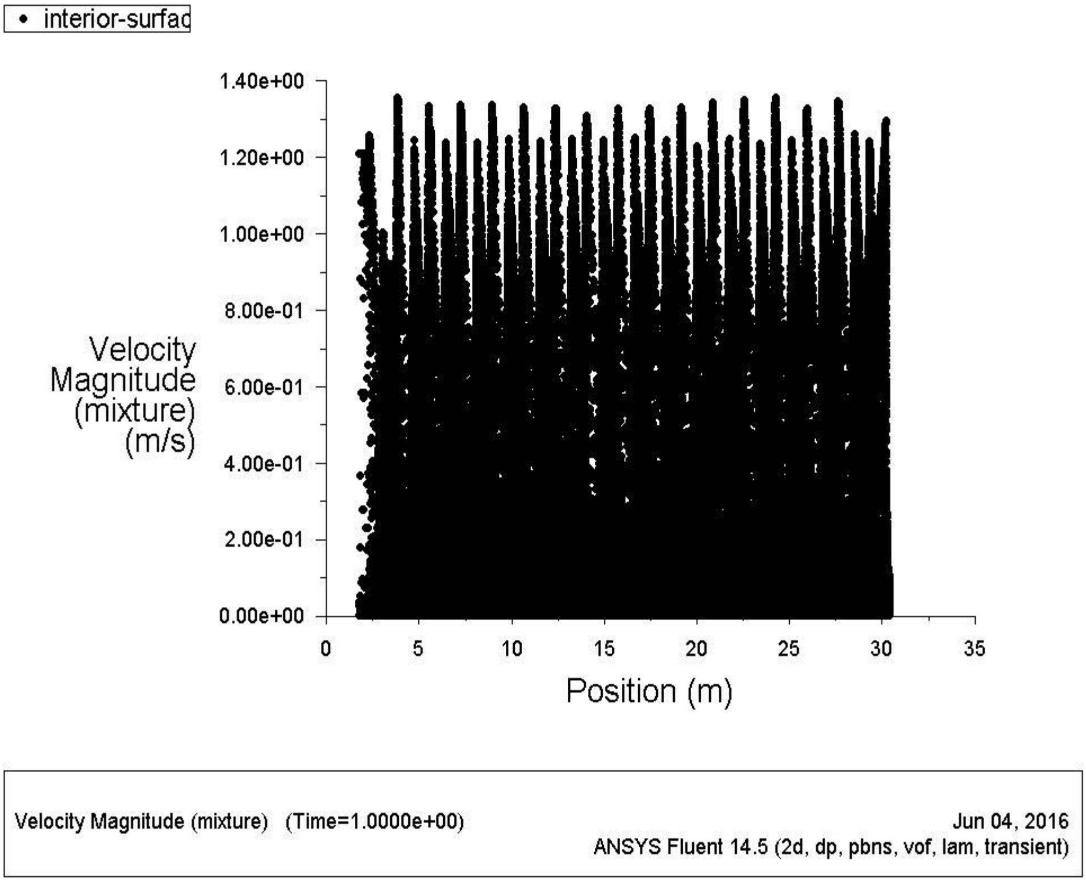

Figure 15 Velocity profile inside weir fishway

(Y-axis: Velocity Magnitude from (0.00e+00 to 1.40e+00) m/sec; X-axis: Position of different pool section in meter (m) starting from outlet of fishway towards inlet when water flow from upstream of weir towards downstream river during wet period)

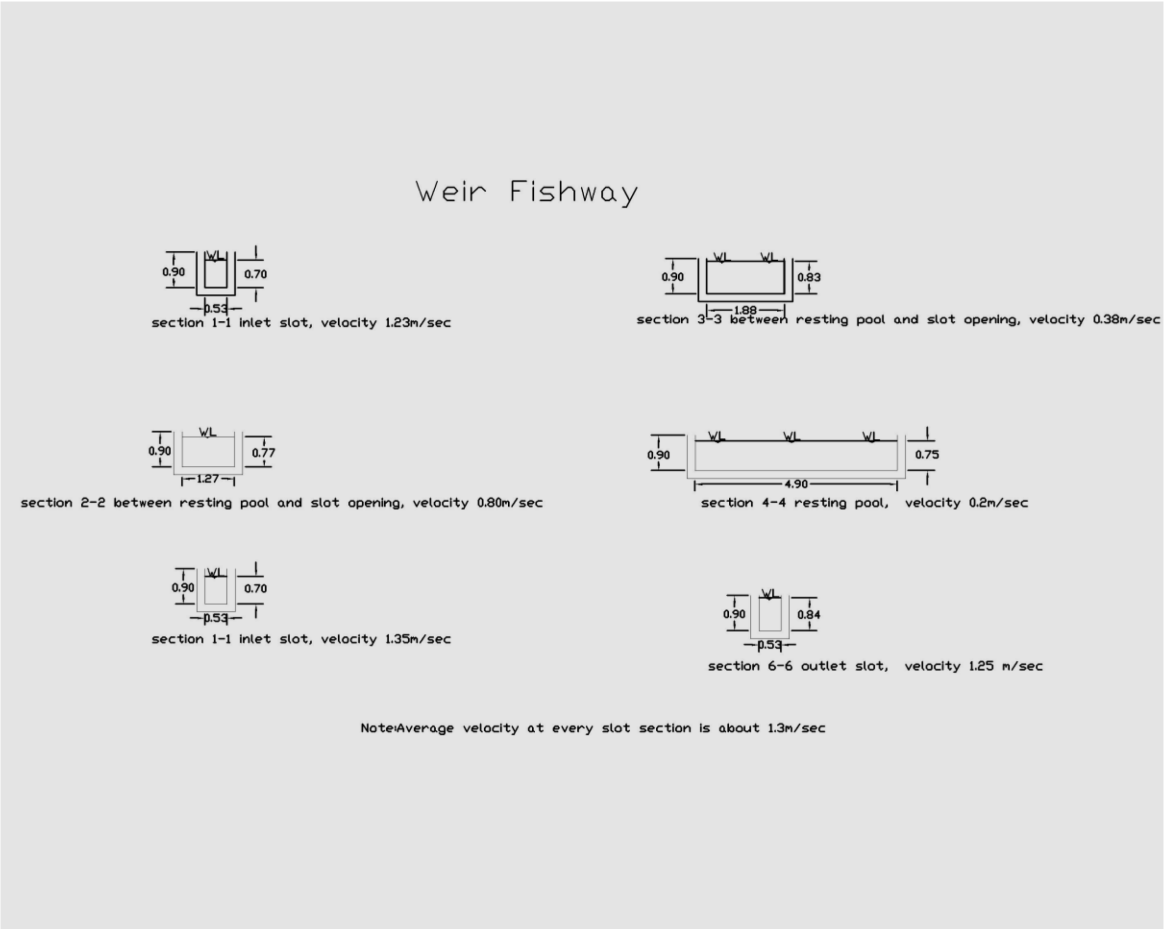

Figure 16 Velocity at different sections inside the weir fishway

4.2.2 Sluice Fishway (Dry Period)

The fishway running along under the sluice is designed for use during the dry period. It gives a maximum velocity of 1.125m/sec during normal operation of the fishway with a flow discharge of 0.338m^3/sec at the minimum flow height of 0.5m at upstream surface near to the sluice gate. The maximum fishway inside velocity varies from 1.12m/sec to 2.43 m/sec according to the flow height from 0.5m to 1.5m at the upstream surface during the dry period (Figure 17). Similarly, exit velocities from fishway taken at corresponding flow height are explained in Table 9. Consequently, when the flow height increased to 1.5m at the upstream surface, the maximum inside velocity and exit velocity both exceed to permissible velocity of 2m/sec [33] as seen in Figure 17. Whereas, maximum inside fishway velocity (1.96m/sec) and the exit fishway velocity (1.67m/sec) which are within the permissible velocity of 2m/sec reached at the maximum over flow height of 1m (Explain in Figures 17).

During 0.8m flow height, inside velocity at different sections i.e., slot, resting pool and other sections are explained in figure 18, 19 and 20.

Table 9 Maximum velocity at exit section and inside the fishway at different overflow depth (Sluice fishway)

Upstream Depth of Flow at sluice gate (m)	Maximum velocity (Fishway Exit) in Sluice Fishway at different height (m/sec)	Maximum Velocity inside the Fishway (m/sec)
0.5	1.1	1.12
0.8	1.47	1.65
1	1.67	1.96
1.5	2.05	2.43

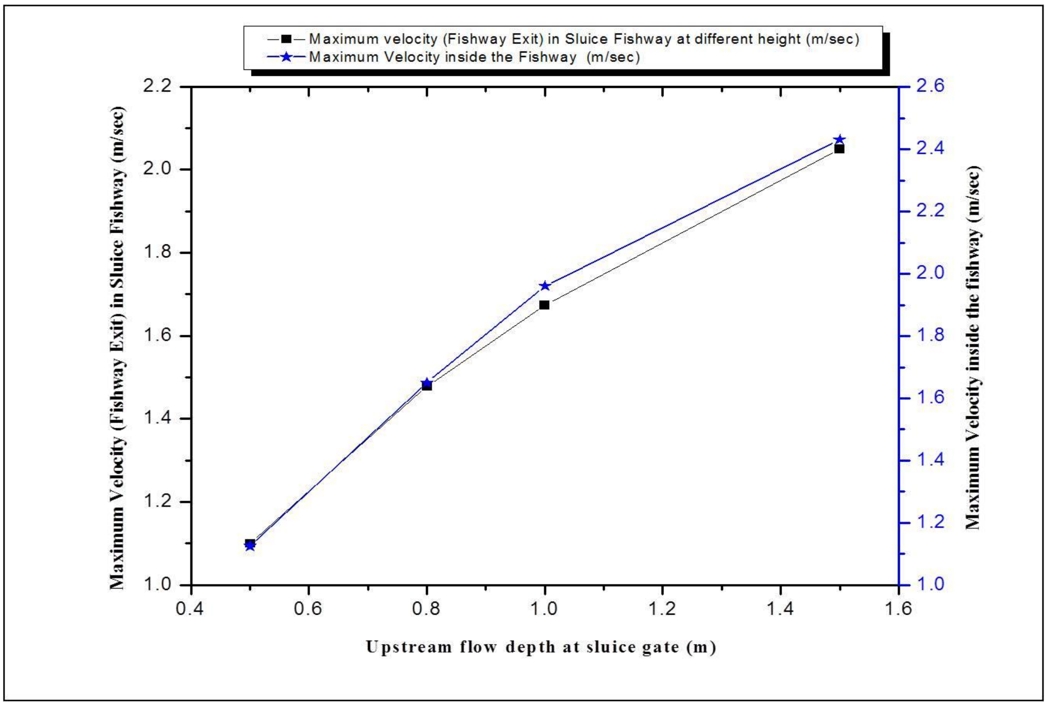

Figure 17 Maximum inside and exit velocity at different water levels in the sluice fishway

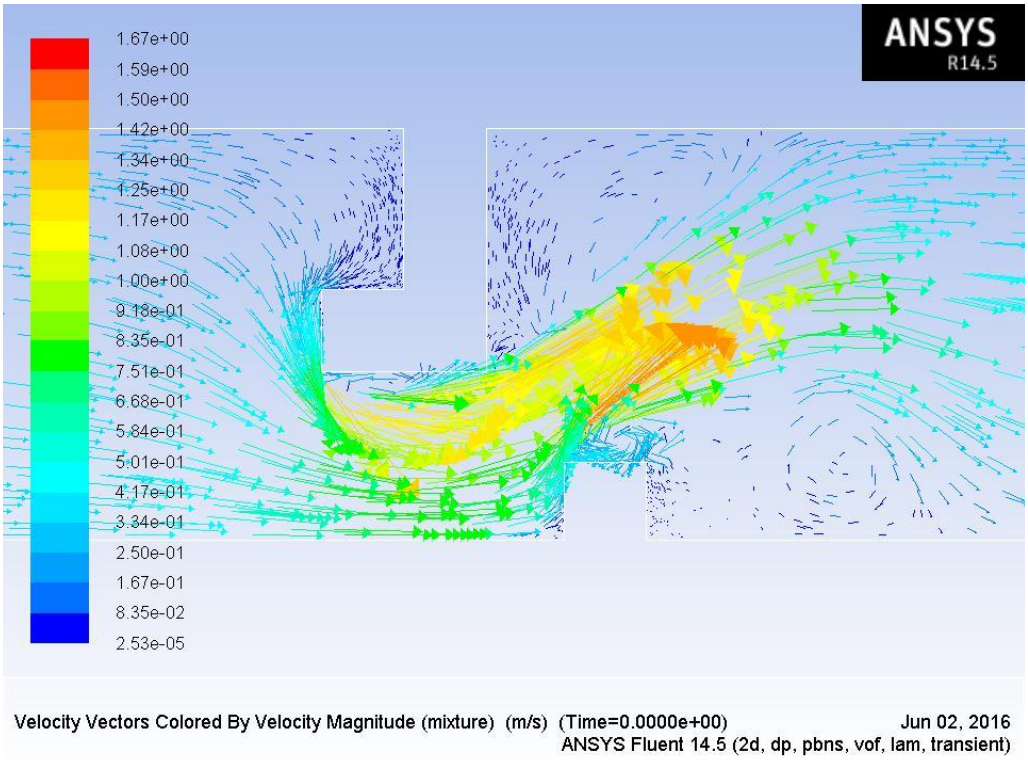

Figure 18 Velocity vectors (m/sec) in the sluice fishway

(different color at Y-axis represents different velocity inside the fishway, Dark red color represents maximum velocity, 1.67 m/s, symbol⟶ represents flow direction)

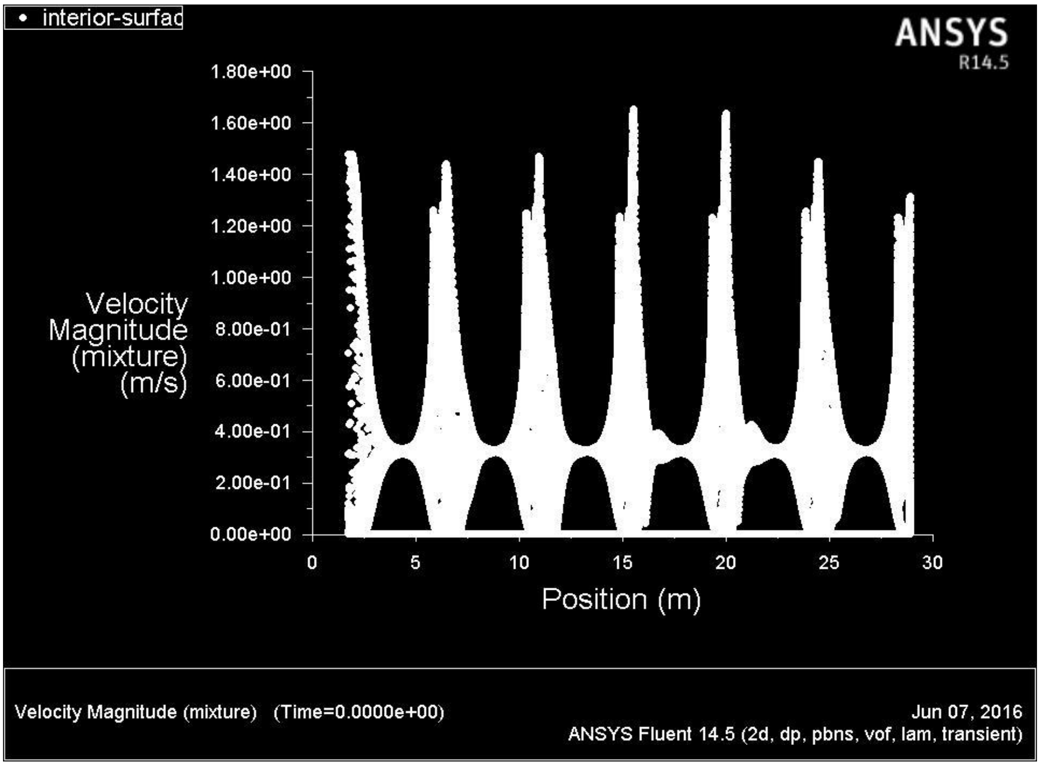

Figure 19 Velocity profile inside the sluice fishway

(Y-axis: Velocity Magnitude from (0.00e+00 to 1.80e+00) m/sec; X-axis: Position of different pool section in meter (m) starting from outlet of fishway towards inlet when water flow from upstream of sluice gate to downstream river during dry period)

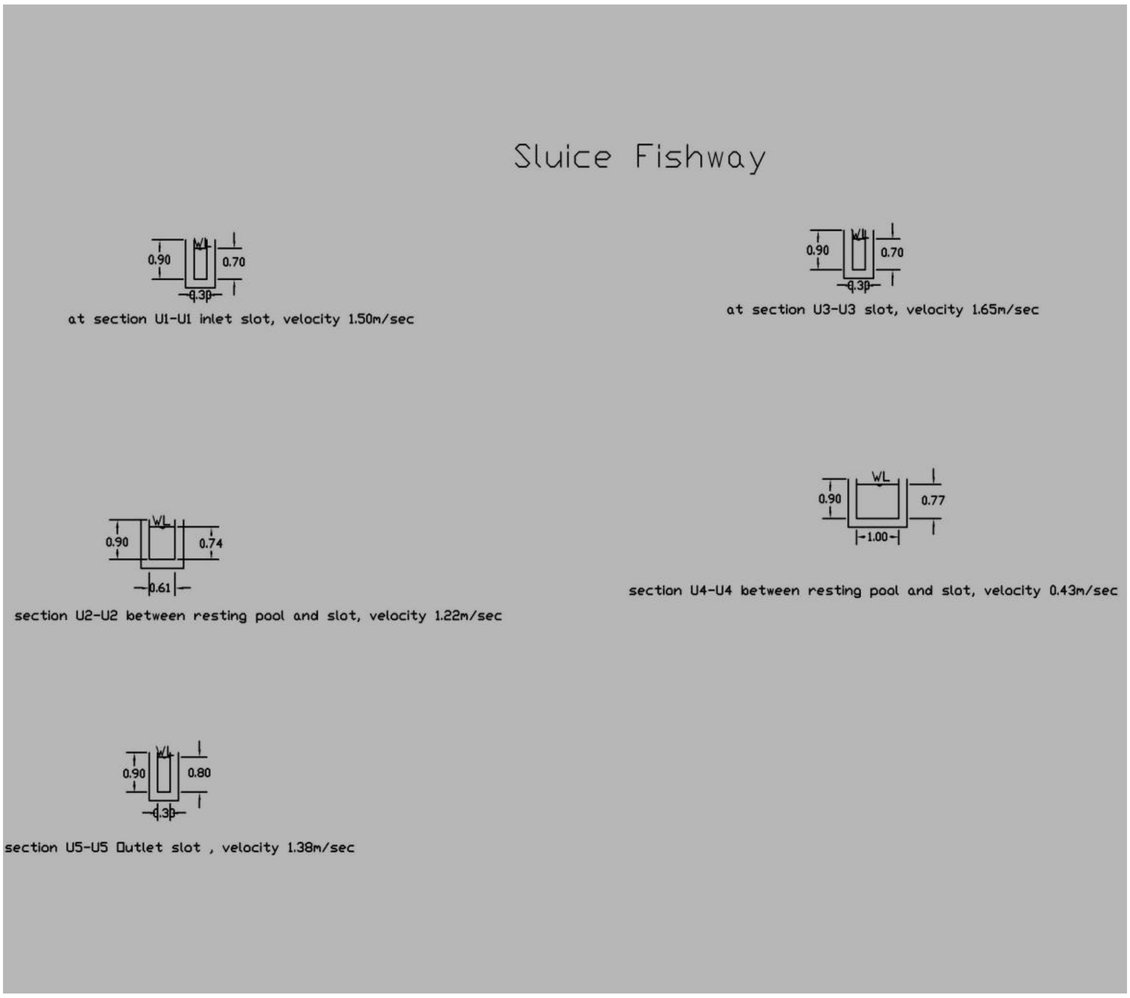

Figure 20 Velocity at different section of the sluice fishway

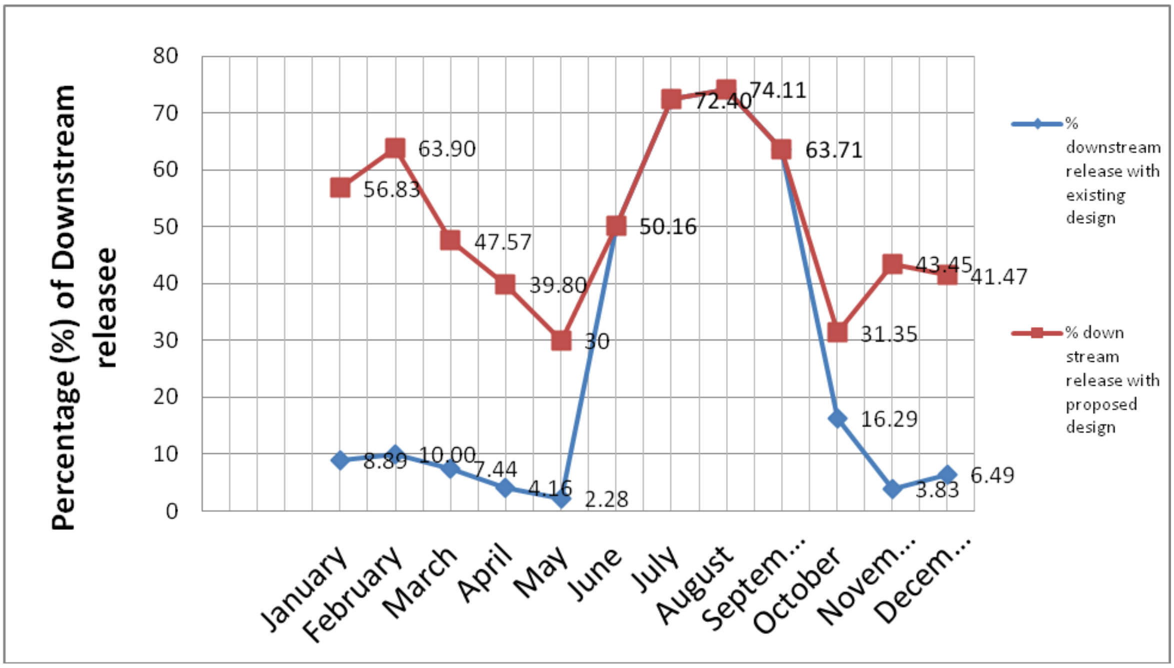

Figure 21 Comparison of downstream release between the existing design (10% of minimum average monthlydischarge) with the proposed design (minimum 30% average monthly discharge)

Figure 21 was obtained from the downstream release mechanism between the existing and the proposed design releasing methodology, following the available river discharge (Figure 8). In existing case, it only releases 10% of minimum monthly flow, i.e., 0.233 from the monthly discharge of February (2.33m^3/sec) throughout the year. Similarly, with new proposed design, we have managed to release the continuous flow 1.151m^3/sec i.e., 30% throughout the year with the same available discharge explained in Figure 8, which is used to improve the downstream benefits.

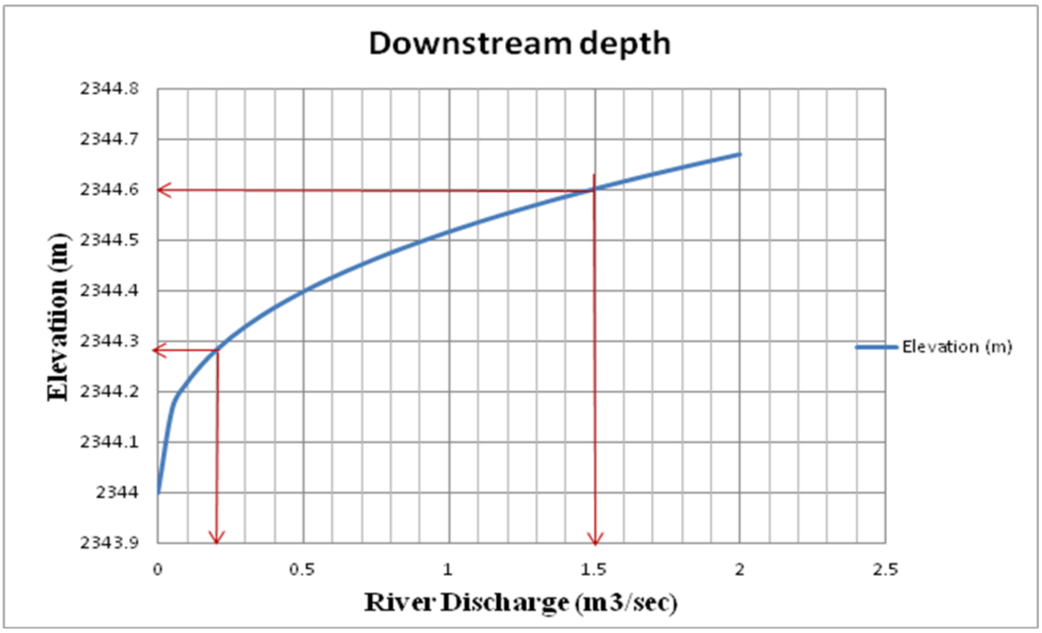

Figure 22 Comparison of downstream flow depth scenarios of the existing and proposed design

Figure 22 was obtained from the rating curve developed at downstream of river cross section.

4.2.3 Slot design

Slots were designed with the opening sizes of 0.525m and 0.30m for the weir fishway and the sluice fishway respectively. The height of 1m including 0.10m freeboard for both fishway ware calculated using the slot design equation-3. Detail calculations are explained in Appendix 4.

4.2.4 Volumetric power dissipation (E)

The maximum volumetric power dissipation (E) for the weir fishway pool is 100.28 watt/m^3 at the minimum pool head difference (Δh) of 0.09m, minimum water level inside the pool was maintained as 0.6m, with a discharge (Q) of 0.59 m^3/sec and the maximum designed velocity 1.35m/sec. Similarly, for the sluice fishway, the maximum volumetric power dissipation (E) is 178.08watt/m^3 at the minimum pool head difference of 0.14m. Minimum water level inside the pool was maintained as 0.6m, with a discharge (Q) of 0.338m^3/sec and a maximum designed velocity of 1.65m/sec. Volumetric power dissipation (E), shown in equation-4 was used for the calculation purpose. The minimum head difference (Δh) in the pool was calculated using the formula $V = (2g\Delta h)^{0.5}$; where V is the maximum velocity obtained from the ANSYS fluent 14.5 simulation , hm is minimum water depth in pool (0.6m); Lb is pool length (1.70m for weir fishway and 4.50m for sluice fishway); b is pool width (6m for weir fishway and 1m for sluice fishway) and d is the cross wall distance (0.2m). Length and width of the pool were selected considering different varying size of fishes from small to large. Moreover, the pool sizes are guided by the permissible volumetric power dissipation (E) value that should not exceed >200 watt/m^3. Detail calculations are explained in Appendix 4.

4.2.5 Open channel design

The size and flow velocity of the open channel are calculated using the formula explained in equation- 5. Q is the design (environmental) flow discharge (1.151m^3/sec) in the open channel, and it is calculated after managing the flow requirements for the power generation and the both fishways., W is channel width calculated as 1.5m, D is water depth was calculated as 0.54m, η is Manning's Roughness Coefficient for Concrete (0.014), R is the hydraulic radius calculated from the given mentioned formula (0.313), S is the slope of the channel (0.002) and the V is the open channel velocity calculated as 1.47 m/sec. Detail calculations are explained in Appendix 4.

4.2.6 Discharge from weir fishway

Discharge at the weir is calculated by using the formula given in equation -6. Where, C is the discharge coefficient (1.70), L is the length of weir (6m) and H is the normal flow height of water over weir crest (0.15m). The calculated normal discharge (Q) is 0.59 m^3/sec during the wet period. Detailed calculations are explained in Appendix 3.

4.2.7 Discharge from sluice fishway

Discharge and velocity under the sluice gate are calculated using the equation-7. Where, L is the length of the gate opening (1m), h_2 is the height of the gate opening (0.3m), h_1 is the normal upstream water level during the dry period (0.5m), Cd is the discharge coefficient (0.36). The calculated normal discharge (Q) is 0.338m^3/sec and the normal velocity (V) is 1.125m/sec during the dry period. Detailed calculations are explained in Appendix 3.

4.2.8 Intake design

The intake is designed with three openings, each 3.9m by 1.2m (W x D). The intake size was calculated for the design flow of Q=11m^3/sec following the equation -23.

4.2.9 Power Generation

Power and energy generation are calculated following the equation-24.

Where, P is the power generated (MW), η is the efficiency (92%), Q is the design discharge (11m^3/sec), g is gravitational acceleration (9.80 m/sec^2) and h is the total net head available after losses from weir to turbine axis (144m).

E = P*t; Where, E is energy (MWh), P is power (MW) and t is generation time (h). Detailed calculations are explained in APPENDIX 3.

Table 10 Comparison of energy generation by month for the existing and proposed designs

Month	Energy output (existing design) (MWh)	Energy output (proposed design) (MWh)
January	2401.43	1139.59
February	1906.28	765.56
March	2912.07	1652.67
April	5187.76	3276.55
May	9772.10	7118.52
June	10325.88	10332.46
July	10670.07	10676.87
August	10670.07	10676.87
September	10325.88	10332.46
October	10670.07	8864.96
November	5651.65	3346.83
December	3371.45	2114.77
Total Output	**83864.71**	**70298.12**

4.3 Discussion

4.3.1 Sustainable hydropower

This research contributes to the global effort to improve the design of hydropower projects in ways that meet social needs, such as providing electrical power and flood control, while reducing ecological impacts on fishery resources and other benefits deriving from downstream water flow. To advance sustainable hydropower in both theory and practice, a case study of an existing hydropower facility in Nepal is used to compare the existing facility with a proposed design that reduces ecological impacts. An innovative approach that improves fish passage and a site specific discharge policy is central to the sustainable design proposed here. This study explains the rationale and provides the technical details for a new design that would improve the downstream river flow pattern and minimize adverse ecological and environmental impacts. Although the sustainable design decreases power generation, it markedly increases the total socio-economic benefit of the hydropower facility.

4.3.2 Fishway design

This research tries to contribute to the global effort to improve the fishway design of hydropower projects in ways that meet social needs, such as providing electrical power and flood control, while reducing ecological impacts on fishery resources and other related benefits. An innovative approach that improves fish passage is central to the sustainable design proposed here. Since the design is based on the computer simulation by using ANSYS Fluent 14.5 software, the output of the simulation is quite reliable and important as it is widely used for different hydraulic design and calculations. Furthermore, using computer simulation based on model design will help to find out the velocity at each and every section of the fishway, which is generally very difficult to obtain from the prototype physical model. In fishway designing, one of the main important parameters is to find the velocity at different section of the pool in available flow discharge and varying water head. All other design parameters such as minimum head difference inside the pool, volumetric energy dissipation, and slot design also depend on the output results of velocity.

4.3.2.1 Fishway Position

This research focuses on the development of a new concept of fishway design by effectively managing downstream river flow with properly positioning the two fishway along the natural river flow direction. The weir fishway uses the entire weir crest length and sluice fishway following the natural channel, so fish may encounter the fishway with minimum stress. In general, if migration is blocked by an obstruction, the fish seeks onward passage by trying to escape laterally at one of the dam's sides. In such case, they continue to react with positive rheotaxis in perceiving the current coming out of a fishway, are guided into the fish pass [33]. Whereas, in our case, fish may encounter the fishways directly with minimum stress when they migrate upstream, as both the fishways are designed along the natural river direction following with continuous environmental flow between the two fishways along the same natural river flow direction and may improve the attraction efficiency comparatively more than the existing design.

4.3.2.2 Vertical slot design

Vertical single slot fishway is selected for the design purpose, as vertical slot fishways are capable of accommodating large changes in upstream water level provided that the downstream level varies in a similar manner. It provides a large range of water depth within the slot at which fish may choose to pass from one pool to another. It can also manage the large bed load if occurs. It is quite suitable for a wide range of fish species and fish sizes including snow trout available at the case study site, especially with full depth slot height. With Vertical slot, different size of fish with different leaping behavior can travel due to its slot opening design i.e., full throughout the depth of the pool. In Vertical slot type fishway, the slope of the structure can be maintained from 10-20% as per the different fish moving capabilities, for high performance and low performance fish as well [165]. Therefore, during our design vertical slot fishway is selected considering all these benefits discussed above.

4.3.2.3 Velocity, discharge and attraction velocity

Water flow velocity is an important factor for upstream fish migration [34, 35] and provision of suitable flow conditions downstream from dams improves passage [36]. According to the recommendation of the United Nations Food and Agriculture Organization [33], the current velocity in fish passages should not exceed 2m/sec at any narrow point, such as in orifices or slots, and this limit should be assured by appropriate design. Accordingly, in this design, during the wet period in the weir fishway (Figure 13), the maximum velocity was 0.76m/sec at a height of 0.15m (normal operation) and 1.35 m/sec at a height of 0.5m (high water). Therefore the design purpose, when the inside fishway maximum velocity (1.35m/sec) and the exit fishway velocity (1.21m/sec) at the flow height of 0.5m (Table 8), are taken into consideration as these velocities are within the fishway inside and exit permissible velocity of 2m/sec [33]. Consequently, the velocity (1.35m/sec) was taken for the calculations of minimum flow head, volumetric energy dissipation inside the fishway. At the overflow height of 0.15m, the maximum inside velocity is 0.76m/sec occurs in weir fishway (Explain in Figures 13). The continuous environmental flow (velocity 1.47m/sec at 1.151m^3/sec) released from the open channel design will used as the supplementary for the attraction velocity if there is insufficient flow at fishway inlet. Our design of releasing environmental flow is supported by the statement explained in DVWK [33], i.e., open channel option is suitable to pass the additional flow directly from the headwater to the entrance of the pass in order to boost the intensity of the attracting current when there is insufficient attraction velocity at fishway inlet. Similarly, it is further supported from the statement that when there is less attraction velocity at inlet of fishway, it is possible to increase the attraction flow, without the prior dissipation of its energy, and to create a high velocity jet issued adjacent to the fishway entrance [42]. Hence, in our design the open channel between two fishways is used to create attraction velocity of about 1.47m/sec by using the environmental flow discharge of 1.151m^3/sec, which will be quite supportive to migrate the fish even when the attraction velocity is minimum.

During the dry period, in the sluice fishway the maximum inside velocity varies from 1.12m/sec to 2.43m/sec according to the flow height from 0.5m to 1.5m at the bottom surface of the upstream diversion weir (Figure 17). When the flow height reaches to 1.5m at the upstream bottom surface of the diversion weir, the maximum inside velocity (2.43m/sec) and exit velocity (2.43m/sec) exceed the permissible velocity of 2m/sec. (Table 9). Therefore, the inside velocity (1.96m/sec) and the exit velocity (1.67m/sec) at 1m ht. is suitable for the design value but when the inside velocity (1.96m/sec) is used for the volumetric energy dissipation calculation, the output result exceed 200 watt/ m$^{3.}$ Hence, we used the maximum inside velocity 1.65m/sec at the height of 0.8m for the detail calculations.

4.3.2.4 Fishway exit design

The sighting of the pass entrance at an obstruction is not the only factor to be taken into account when positioning a fishway [40].Consequently, and the exit of the pass (exit for the fish, i.e. upstream end of the fishway) should not be situated in a fast flowing zone as well, where there is a risk of the fish being swept back downstream. This statement will further strengthen our design where the inside and exit velocity of fishway are near to the permissible velocity of 2m/sec. Moreover, according to the statement given in DVWK [33], linking the exit of the fishway with the natural bottom or bank substrate by means of a ramp facilitates improves the movement of migrant benthic organisms from the fish pass to the headwater, which will more reinforce the design. As in this design, there is 1:1 slope created at upstream face of the weir, i.e., from the weir crest (fishway exit) to the upstream bottom bed level which will help to maintain and control the flow velocity from weir crest to the river bed level gradually.

4.3.2.5 Fishway length and slope

In this design, fishway entrance is selected at the end of the 32m length by creating the slope of 1:10 at weir fishway and 1:20 at sluice fishway, to meet the natural river downstream minimum bed level of 2344m. Hence, the entry into the fishway can be made even proper for the bottom-living fish species. This design is supported by the statement that for several species whose swimming capabilities and migratory behavior are very different, or sometimes even unknown. For these species, it is better to have the entrance to the fishway further downstream, in a calmer and less turbulent zone [40].

4.3.2.6 Downstream migration and Environmental flow

In the present new design, there is a fishway facility for both upstream and downstream migration, which we generally do not find in existing design. Here in this design open channel situated between the two fishways (Figure 9) is designed for downstream migration. Open channel is designed in such a way that upstream river bed level and the open channel inlet invert level are maintained at the similar level of 2345m, with giving very mild slope at the inlet of the channel opening. The channel is designed at the slope of 1:500 to maintain the velocity (1.47m/sec) within the permissible limit.

Upstream fish migration is guided by the main current and fish swim up the zone of highest turbulence in the tailwater below a dam and for fish to be attracted towards a fishway. It is generally held that flows originating from a point near the fishway entrance should be highly relative to those released from elsewhere along the dam face [36].This statement supports our design as the open channel is designed to release an environmental flow of 1.151m^3/sec, which is higher than the normal flow at the weir and under sluice fishway i.e, 0.59m^3/sec and 0.338m^3/sec respectively.

4.3.2.7 Volumetric power dissipation

Turbulence in the fish passage should be as low as possible so that all the aquatic organisms can migrate through the pass regardless of swimming ability. The volumetric energy dissipation in each pool of a passage should not exceed 200watts/m^3 [33]. In this design, the maximum volumetric power dissipation is 100.28 watt/m^3 and 178.08 watt/m^3 in the weir and sluice fishways respectively. Hence, this new designed fishway can possibly pass the different fish species.

4.3.2.8 Slot Design and minimum depth

For fish such as brown trout, grayling, cyprinids and other small fish, slot widths of 0.15 to 0.17m are sufficient whereas for the large salmonids such as salmon, sea trout, and huchen, larger slot widths of 0.3m to 0.6m are recommended [164]. These standards support our design where the slot widths of the weir and sluice fishways are 0.525 and 0.3m respectively and are seem to be suitable for the different size of fish species.

4.3.2.9 Discharge range inside the fishway

Since in this new fishway design, weir fishway, used for the wet period and sluice fishway used for the dry period has the normal discharge of 0.59m^3/sec and 0.338m^3/sec respectively are within the 5-10% of the turbine discharge in respective of wet period (11m^3/sec) and dry period (about 6m^3/sec). The statement supports these discharge values that the fish pass discharge needs to be between 5-10% of maximum turbine discharge used in the hydropower project [165].

4.3.3 Power Generation

Pérez-Díaz and Wilhelmi, 2010 [166], stated that after maintaining downstream environmental flow, establishment of hydropower projects would suffer some economic loss because design capacity will not be met. Hence, there will be some power generation deficit as well with this new design (Table 10). However, the deficits are compensated by the additional socio-economic and environmental benefits, which are explained in chapter 5.

4.3.4 Sediment release

Weirs have resulted in reducing access to shelter because the backwater acts as a sediment trap. Forseth and Harby, 2014 [122] explained that sediment can act as an indirect indicator of fish-habitat quality by integrating other physical-habitat variables; depth, velocity, and cover. Hence, our design facilitates the continuous downstream release of sediments through regular channel flow. This design with continuous sediment releasing mechanism will further improve the downstream river bed stability and protect from improvement and the land erosion by increasing the channel depth. From this new design it is possible to release the sediment continuously even during low flow period as there is a provision of releasing the environmental flow throughout the year. Whereas, in case of existing design, sediment is generally released to downstream only in the high flow period, which may have significant impact in downstream river during dry period.

4.3.5 Downstream release

According to the river hydrograph (Figure 8), the average monthly minimum discharge is $2.33m^3$/sec in February and the maximum discharge is $42.49m^3$/sec in August. Based on the existing hydropower policy of Nepal, 10% of minimum monthly discharge release as an environmental flow [167], is not practically appropriate and remains arbitrary and minimal [168]. As per the existing design, 10% of minimum average monthly flow ($2.33m^3$/sec) comes around $0.23m^3$/sec, which seems very minimal and has many consequences mainly in the depleted region between diversion weir and power station. Considering this issue, the new design has conceptualized with continuous release of downstream flow ($1.151m^3$/sec) throughout the year with very minimum effect in regular power generation. According to the new design concept, it can increase the downstream flow from 10% of minimum discharge (exiting design) to at least 30% of the average monthly discharge throughout the year. Moreover this design improves the downstream release even in dry months i.e., December, January, February and March with significant release of 41.47%, 56.83%, 63.90%, 47.57% at optimal power generation (Figure 21). It further increases the downstream river depth from about 30cm (at $0.23m^3$/sec, existing design) to about 60cm (at ~$1.5m^3$/sec, proposed design, i.e., $1.151m^3$/sec from open channel and $0.338m^3$/sec from the sluice fishway) even in dry period (Figure 22). Hence, the continuous release of water of at least 30% throughout the year can further improve the downstream river stability, fish habitat due to continuous release of the sediment along with the downstream flow. It will also help to maintain the normal temperature. Similarly, due to continuous release of water, methane and CO_2 release in the downstream can be minimized in contrast to existing model. Due to this reason, it may help to maintain the optimal level of dissolved oxygen (DO) in the downstream river.

There are different methods available for determining minimum percentage of downstream water release. According to Tennant [169], 10% of the mean annual discharge (MAD) would be the minimum to sustain life. Whereas, Alves and Henriques reported that in Spain, 10% of the mean annual flow (MAF), and in Portugal, 2.5–5% of MAF, were used there to set environmental flows [170]. Similarly, according to United Nations Food and Agriculture Organization (http://www.fao.org) [115], compensation flow for conserving microflora, aquatic insects and fish in the dewatering zone should be within 10-20% of the normal flow. According to Tharme, several countries used the common percentiles method to determine the minimum flow such as, Q_{95} (United Kingdom, Bulgaria, Taiwan and Australia) and Q_{90} (Brazil, Canada, and United Kingdom) [116]. Fang et al., 2010, summarized different instream flow release methods used in different countries.

Our study has some similarity in terms of downstream release described above. However, according to Tharme, Q_{90} and Q_{95} percentile methods [116] along with the Tennant, 1976 methods [169] are contradictory. In our case there is only 2.33m^3/sec minimum discharge available at Q_{100} in the month of February, hence, it is not viable economically and technically to release the downstream flow following Q_{90} or Q_{95} percentile methods. As our main research objective is the sustainable hydropower design i.e., to get the regular optimized power generation following the maximum possible downstream water release. Similarly, Tenant stated that 30-50% of MAF is an excellent instream flow regime for fish, wildlife recreation and related environmental resources. However, in our case, the minimum average monthly discharge is 2.33m^3/sec and MAF is 15.12m^3/sec. Hence, if we follow the Tenant method, 30% of 15.12m^3/sec is 4.5m^3/sec but we have the minimum discharge of 2.33m^3/sec only. However, we try our best to give the optimum design with continuous release of about 1.5m^3/sec throughout the year to mitigate the impact concerning fish along with other socio-economic and environmental issues. Here, the downstream release flow of 1.5m^3/sec continuously is found to be at least 30% of the average monthly flow, which is about 10% of the MAF (Mean annual flow). Furthermore, this design can have significant result with 63.9% downstream release even in the driest month of February, which can contribute to obtaining the considerable downstream benefits (Figure 21). It is said that ecological compliance and power generation should be optimized when generating hydropower generation [118]. Therefore, as per our objective of proposed green sustainable hydropower design, it is not viable to release more than 10% of MAF, as that will affect the output power generation, which is an integral part of socio-economic development. This result shows that different river has different flow pattern and hydrology, and it is not always possible to get the same standard everywhere. However, the main objective concerning the downstream impact needs to be fulfilled every time.

4.4 Summary

The different projects have different downstream requirements and thus, the same standard is not appropriate and possible in every river and for all projects. In this research, the optimization of the power generation with releasing maximum possible water to the downstream has given more priorities. This design can release at least 30% of the average monthly flow throughout the year to downstream river along with the considerable releasing of 63.9% even in the driest month of February. This result seems to be considerably high and significant compared with the exiting design having 10% downstream water release policy in Nepal. Furthermore, with this design, it is possible to facilitate the continuous sediment release to downstream even during low flow period, which is another key factor to control the river stability and land erosion. Moreover, new fishway design can further improve the continuous fish migration throughout the river even during the dry period when the river has very minimum flow.

Chapter 5 The Green Benefit Evaluation of the Hydropower Station

This chapter discusses about the evaluation between the existing hydropower designs and the new developed research design based on green hydropower concept following an economic analysis carried out separately. Regarding existing hydropower, the same project is selected as discussed in chapter 4. Benefit Cost ratio (B/C), Internal Rate of Return (IRR) and Net Present Value (NPV) are taken as economic parameters during economic analysis. Energy rates and other parameters are taken as per the current standard of Nepal used in hydropower development.

5.1 Economic Analysis

The economic analysis of the project period is considered as 25-year and analysis is carried out with and without considering socio-economic and environmental benefits. Then the result has compared to evaluate the efficacy of the design. During economic analysis, the discount rate of 10% is assumed according to the present scenario of Nepal. Energy rate is considered as per the standard of power purchase agreement (PPA) upto the size of 25 MW project currently exists in Nepal i.e., Nepalese Rupees, 8.40 per KWh and 4.80 per KWh for dry period and wet period respectively (http://www.waterpowermagazine.com) [171]. One US dollar equivalent to Nepalese Rupees 102.00 is taken for the analysis purpose. Economic parameters such as Benefit-Cost ratio (B/C), Internal Rate of Return (IRR) and Net present value (NPV) are calculated as part of the economic analysis

During this study, it is observed that the 3km stretch in downstream area located between diversion weir and power generation house is directly affected. About 200 families reside there and the total land areas of around 534,368m^2 are mostly affected due to Natural River diverted for the power generation. The economic analysis is mainly concerned with, these affected area and other related socio-economic and environmental impacts. However, similar problem exists in most of the run of river projects due to river diversion, so this analysis can be useful in other project as well. Socio-economic and environmental indicators given in Table 11 are considered for economic analysis. Microsoft excel 2007 is used for the analysis as it is very reliable and easy to understand the results [172]. Following formulas are considered during the analysis.

5.1.1 Future Value

$$F = P * (1+i)^{\wedge} n \quad \text{...} (25)$$

Where, F represent as future value, P is Present value and "n" is number of years.

5.1.2 Net Present Value (NPV)

$$NPV = \sum_{n=0}^{N} An / (1+i)^{\wedge} n \quad \text{.....................................} (26)$$

Where,

An= Net cash flow at the end of period "n"

i= discount rate

n= service life of project

5.1.3 Benefit Cost ratio (B/C)

$$NPVBenefit(B) = \sum_{n=0}^{N} bn(1+i)^{\wedge}(-n) \quad \text{.............................} (27)$$

$$NPVCost(C) = \sum_{n=0}^{N} Cn(1+i)^{\wedge}(-n) \quad \text{................................} (28)$$

Where,

bn = Benefit at the end of period 'n'; bn>= 0

Cn = Expenses at the end of period 'n'; Cn>= 0

An= bn-Cn

N= Project period

5.1.4 Internal Rate of Return (IRR)

It is the interest earned on the portion of the project that is internally invested. IRR was calculated using Microsoft excel, spreadsheet using the following formula,

=IRR (range, guess)

Where, range represents the total period of cash flow and guess represents the discount rate percentage.

Table 11 Socio-economic and Environmental benefits from proposed design

Socio-economic and Environmental benefits	Annual Income (US$ 000)
Fish population and job	7.6
Irrigation/Agricultural growth	600
Energy from micro hydropower	50
Landscape, tourism	105
Protection from land erosion due to sediment release in downstream	300

5.2 Power generation

During power generation calculations, the four months from December to March were considered as the low flow period, with the high flow period from April to November. A 40% Flow Exceedance (Q40), 11m^3/sec design discharge and gross head difference of 150m over a distance of about 3km from dam to power station were taken for power generation.

5.3 Results

Detail economic analysis considering socio-economic and environmental benefits are explained in APPENDIX 1 and 2.

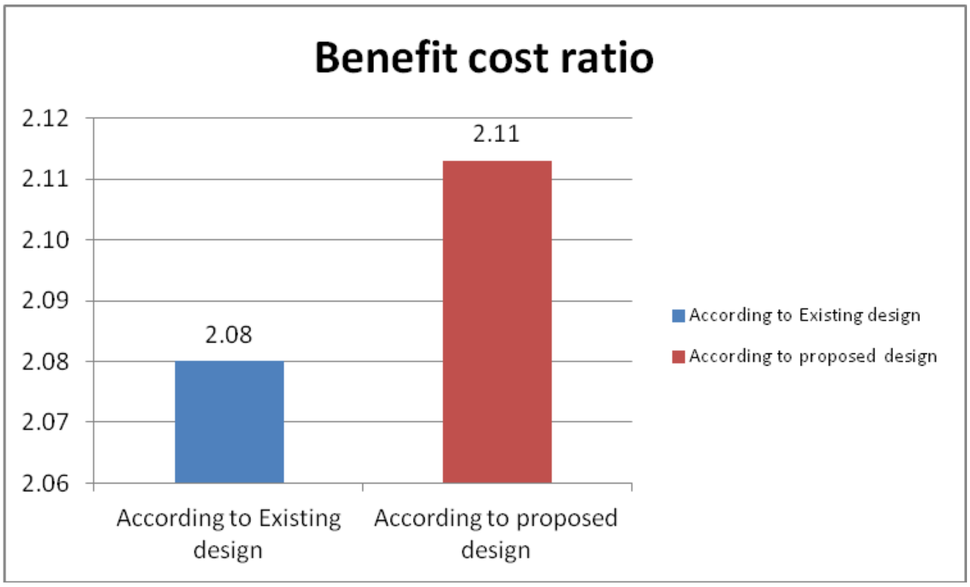

Figure 23　Comparison of Benefit Cost (B/C)

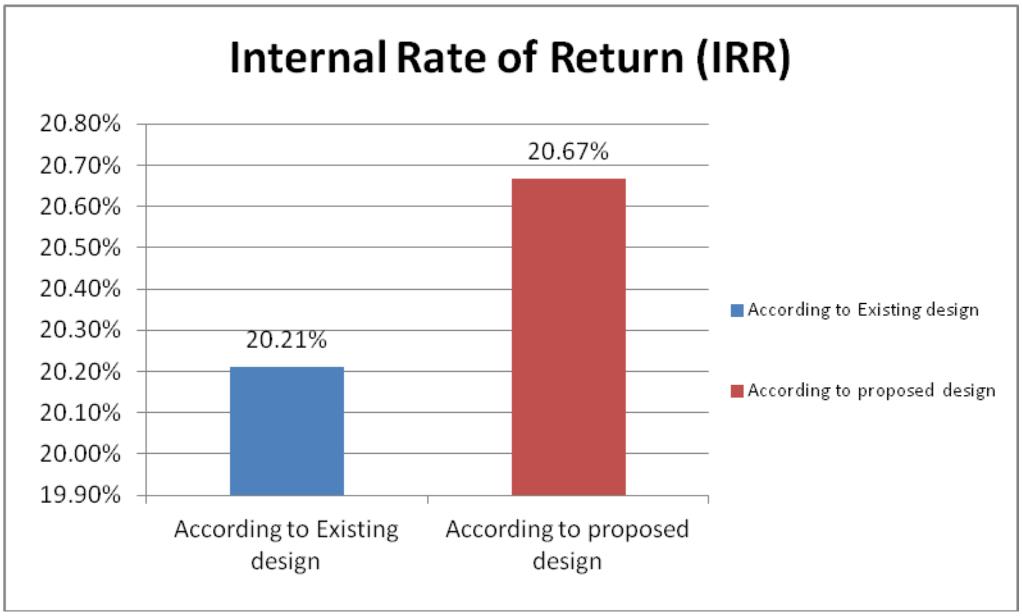

Figure 24　Comparison of Internal Rate of Return, IRR

Table 12 Comparison for Economic Values

Economic Indicators	Energy generation benefit without considering socio-economic and environmental factors (Existing design)	Energy generation benefit with considering socio-economic and environmental factors (Proposed design)
Net Present Value (NPV)	US $ 16,081,000	US $ 16,109,000
Benefit Cost Ratio (B/C)	2.08	2.11
Internal Rate of Return (IRR)	20.21%	20.67%

5.4 Summary

Existing design has more earning while considering the income from the power generation only. However, after maintaining downstream environmental flow, established hydropower projects may suffer some economic losses as design capacity would not be met [178]. According to the existing design, it will give the output generation of 10591MWh and 73273 MWh during dry and wet period respectively, i.e., in total 83864MWh. Whereas, from the new conceptual hydropower design, it will generate the electricity of 5673 MWh during dry period and 64626 MWh in wet period i.e, in total generation of 70298 MWh (Table 10). However, when the project is evaluated considering this new design concepts following socio-economic and environmental factors, the new developed hydropower design looks comparatively economically sound as it will improve the socio-economic status of the people. The comparison results of the economic values are explained in Table 12. The figure

(23, 24) shows that, with the proposed design, it is possible to get more economic benefits if the design is improved considering continuous fish migration, sufficient downstream water release at optimized power generation and other related socio-economic and environmental issues. Fish population growth can establish the fish market and per capita income of the people living at downstream affected area can be improved gradually. Downstream water released with sediments can improve the soil fertility with the collection of phosphorous, nitrogen associated with sediments, which can improve the agriculture growth. Releasing of sediments and bed load to downstream can protect the land from erosion. It can further improve the landscape of surrounding area with better plantation, increased river depth, growth in fish population, which can enhance the tourism in local sector and create more job opportunities in rural area.

Moreover, out of total downstream release of $1.5m^3/sec$, about $0.2m^3/sec$ water discharge can be further utilized for micro hydropower development with the generation of 90KW electricity which can be locally consumed for lighting, study, entertainment and other income generating activities like water mill for grinding wheat, rice and other agricultural products locally. It can further help the local people to improve their education and save their maximum time from firewood collection used for cooking. People can consume the locally available electricity for their energy resources, which in turn will minimize the deforestation and contribute to reducing the greenhouse gases effects. Hence, the new developed design can be used as a new conceptual model used for the development of clean, green and sustainable hydropower in future.

Chapter 6 Conclusion and Future work

This research will help to improve the existing green hydropower concepts with modifications and improvements in hydraulic design for sustainable hydropower development in a broad manner. In this research, it is focused on balance between the optimized power generation along with continuous downstream flow, improved fishway design and regular sediment release, which plays a significant role to obtain the green sustainable hydropower development. Even though the existing green hydropower concept has focused more on environmental issues concerned with downstream release and bedload management, it has not yet covered all the issues required for sustainable hydropower development in long run. It seems that they do not have sufficient design mechanism on releasing the flow considering the balance between power optimization and downstream release together. Consequently, they have sediment release mechanism only during high flow period, however with our new design it is possible to release the sediment continuously even during dry period as the new design has the facility to release downstream release of 1.151m^3/sec throughout the year. Furthermore, even though the existing green concept has focused on fish migration, but it seems lacking in their existing concept. According to their available standard there seems to be difficulties in fish migration while the river flow is very high during flood and the minimum during dry period. However, from our new design it is possible to migrate the fish throughout the year during wet as well as in dry period when there is lots of fluctuation in natural river flow.

Chapter 1: Different literatures are cited to find the requirements to design the effective fishway including the eco-environmental friendly hydropower projects. It is obtained that the downstream water release, sediment transportation, water quality and proper fish migration are the key factors needed to be considered. Accordingly, the new design has been conceptualized following the standard key factors to meet the optimize power generation for the sustainable hydropower development.

Chapter 2: Considering the green hydropower standards existing at present, we try to add some evaluation standard as per our new research findings for the future sustainable green hydropower development. Accordingly, we have divided our evaluation criteria into three divisions as technical, environmental and socio-economical. Since the technical design has been given the more priority in our research, the maximum value of 45 marks is allocated to technical along with 30marks and 25marks for environmental and socio-economical standard respectively. In this new research, all the environmental issues such as downstream environmental water release, sediment transportation, fish migration, water quality and other related socio-economic effects are based on our technical design improvement. Thus, this research tries to develop the new evaluation standards focused more on technical design for the future small hydropower development.

Chapter 3: When there is different flow arising during dry and wet period, it may change the downstream river temperature, which is directly concerned with fish behavior and movement. Hence, an effect of acute temperature change on fish behavior has been carried out, as it is very important during fishway designing. Results on acute temperature change effect on fish critical swimming speed (U_{crit}), oxygen consumption rate (MO_2), tail beat frequency (TBF) and tail beat amplitude (TBA) at 5°C(acute low temperature), 15°C (normal temperature) and 25°C (acute high temperature) are find out. Hence, it shows that if there is no sufficient regular water release to downstream river then acute change of temperature may occur during such period and have significant effects on fish behavior which will affects during migration. These results will help the designer to know the importance of temperature effect and consider related consequences during fishway designing.

Chapter 4: The new developed design of fishways used for dry as well as wet period can improve the fish migration even during fluctuating water level . The positions of the new fishways are selected according to the Natural River flow direction to attract more fish naturally. ANSYS Fluent 14.5 software is used to simulate the flow pattern and find the velocity in every section of the fishways. Discharge, velocity, attraction velocity, water depth and volumetric power dissipations, which are the key parameters in fishway designing, are calculated following the standards and formulas given in different literatures. Considering new design, fishways can work efficiently even during flood period when the overflow height raises to 0.5m more from the normal flow depth of 2.5m in upstream river at fish exit (weir crest) position. Consequently, when the river flow depth dropped from 2.5m to 0.5m at the bottom surface of upstream weir during dry period, the new design can further work effectively to migrate the fish.. Environmental flow release through open channel situated between the sluice fishway and weir fishway can help to create additional attraction velocity. Moreover, open channel can be further used as a fish passage for the downstream migration. Vertical slot fishway with slot opening size 0.525m (weir fishway) and 0.3m (sluice fishway) are designed, which is compatible for different sizes of species. Fishways were designed at the slope of 1:10 (weir fishway) and 1:20 (sluice fishway) connecting the fishway entrance at the end of 32m length to reach the downstream bed level, considering different fish to utilize the fishway including the bottom living fish. Therefore, the new conceptual design can help to improve the fish migration both in the upstream as well as in downstream river continuously. However, with the existing green hydropower concept, it is not possible to migrate the fish when there is minimum river flow during dry period as they do not have the proper mechanism or guideline to pass the fish in such a situation. Thus, our new design can make significant contribution in conservation to the endangered fish population as well.

From the new developed design, there will be at least 30% downstream flow throughout the year to a maximum of 63.9% during the driest month compared with the existing 10% downstream releasing hydropower policy of Nepal. The proposed design can thus minimize the negative downstream impacts with significant improvement of continuous downstream release by optimizing the power generation Furthermore, the continuous environmental release of the downstream river will help to increase the river depth to 60cm compared with the existing design having 30cm, even during the driest month of February. Increased depth will help to maintain the river's normal temperature and Dissolved Oxygen (DO) at required level. In this new design, the open channel used for environmental release can further improve the continuous release of sediments to downstream, which will protect the downstream riverbed stability and surrounding area from soil erosion and landslides. Moreover, the continuous release of sediment of different sizes can improve the fish habitats as well.

Chapter 5: When the power generation is taken into consideration to find out economic value, then the existing hydropower design has the more generation of 83864 MWh. compared to the new green conceptual design with total generation of 70298 MWh. This is because the existing design has used the maximum water for power generation, whereas, the new design has maintain the balance between power generation and downstream environmental flow. However, when the project is evaluated in terms of this new green hydropower concepts following socio-economic and environmental factors, then new developed hydropower design looks more economically sound as it has more annual income compared to that of the existing design. Economic analysis results have shown the new researched design get the Benefit Cost ratio (B/C ratio) of 2.11, an Internal Rate of Return

(IRR) of 20.67% and a Net Present Value (NPV) of US $16,109,000 compared to the existing design with (B/C ratio)=2.08, (IRR)=20.21% and NPV=US $16,081,000. An economic result explains that hydropower project will be more sustainable if it is designed by considering the socio-economic and environmental benefits together with optimal power generation.

Thus, the new developed hydropower design considering green concept, can improve the socio-economical and environmental condition of downstream effected reach between the diversion weirs to power station more effectively compared to the existing design concept. Moreover, the design is properly evaluated with the detailed economic analysis for 25 years, which can further make this research concept as a new finding used for the future clean, green and sustainable hydropower development. This design can further spread the new ideas .to the policy makers of the respective country in terms of future sustainable hydropower development. Although the case study is taken in Nepal, however, this design can be utilized in other countries with similar river hydrology as well.

Future work

1) This research is based on small dam height. It would be interesting to carry out further research considering dam with larger height.
2) This research has developed the design concept on sediment release mechanism. It would be suggested to have future work on the quantification of real volume of sediment release following this design.
3) In future, fishway design can be conducted in real structure following the natural river.
4) It would be interesting to carry out water quality test such as temperature, dissolved oxygen and other ecological parameters in coming future following this design.
5) In future work, economic analysis shall be carried out following different methods to compare the results.

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Academic works achievement during study period

1) Mandal P, Cai L, Tu Z., Johnson D., Huang Y. Effects of acute temperature change on the metabolism and swimming ability of juvenile sterlet sturgeon (Acipenser ruthenus, Linnaeus 1758). Journal of Applied Ichthyology, 2016, 32: 267-271

2) Mandal Prashant, Tu Zhiying, Yuan Xi, Gao Yong, Huang Yingping, Peng Hui. Importance of Design Factor in Improvement of Fishway Efficiency. *American Journal of Environmental Protection*, 2015, 4(6): 344-353

3) Mandal Prashant, Huang Yingping, Peng Hui, Yuan Xi, Tu Zhiying, Johnson David. Conceptual Fishway Design for Small Hydropower Development.
Submitted to *Sustainability*.

4) Mandal Prashant, Huang Yingping, Peng Hui, Yuan Xi, Tu Zhiying, Johnson David. The New Conceptual Design for Sustainable Hydropower Development.
Submitted to *Environmental Engineering Science*.

APPENDIX 1

ECONOMIC ANALYSIS

(With Existing Design)

Outputs

Economic Analysis	
BCR	**2.08**
IRR	**20.21%**
NPV Scheme (US$ 000)	**16,081**

Scheme details			**Programme**		
Installed capacity	14.30	MW	Construction start year	2015	year
Economic	25	years	Operating start year	2018	year
Energy production			**Capital costs**		
Dry season energy	10.59	GWh	Economic costs	23,212	US$ 000
Wet season energy	73.27	GWh	Per kW economic cost	1,623	per kW
Total energy production	83.86	GWh			
			Total cost	23,212	US$ 000
Selling rate					
Dry	8.40	NRs/kWh	Phased over	4	Years
	8.24	USc/kWh	Year 1 (%)	20.0	%
Wet	4.80	NRs/kWh	Year 2 (%)	30.0	%
	4.71	USc/kWh	Year 3 (%)	30.0	%
Assumed escalation rate	2.0%	per year	Year 4 (%)	20.0	%

Operational costs		
O&M costs % of economic	2.00%	
-		
Capacity benefit@ USD 100 per kW	1430	US$ 000
Economic factors		
Assumed currency rate (US$ to NRs)	102	
Discount rate	10%	

Socio-Economic and Environmental annual benefit

		Per month benefit
Fish population and job (US$ 000)	2.55	0.212
Irrigation/Agriculture growth/MARKET (US$ 000)	200.0	16.67
Microhydropower development (US$ 000)	16.67	1.389
Landscape,tourism (US$ 000)	35.00	2.917
Protection from land erosion due to sediment release in downstream (US$ 000)	100.0	8.333

PROGRAMME		Develop't year	Construction				Start operation																								
Years		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Years #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Year of Operation						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Year of environmental benefit						0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
INCOME																															
Tariff willingness to pay (USc)																															
Primary energy			8.24	8.74	8.91	9.09	9.27	9.46	9.65	9.84	10.04	10.24	10.44	10.65	10.87	11.08	11.31	11.53	11.76	12.00	12.24	12.48	12.73	12.99	13.25	13.51	13.78	14.06	14.34	14.62	14.92
Secondary energy			4.71	4.99	5.09	5.20	5.30	5.41	5.51	5.62	5.74	5.85	5.97	6.09	6.21	6.33	6.46	6.59	6.72	6.86	6.99	7.13	7.28	7.42	7.57	7.72	7.87	8.03	8.19	8.36	8.52
Total Electricity Revenues (US$ 000)			0	0	0	2385	4865	4962	5062	5163	5266	5372	5479	5589	5700	5814	5931	6049	6170	6294	6419	6548	6679	6812	6949	7088	7229	7374	7521	7672	7825
Capacity benefits						715	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430
Fish population and job(US$)						2.55	2.60	2.65	2.71	2.76	2.81	2.87	2.93	2.99	3.05	3.11	3.17	3.23	3.30	3.36	3.43	3.50	3.57	3.64	3.71	3.79	3.86	3.94	4.02	4.10	4.18
Irrigation/Agriculture growth/Market (US$)						200.0	204.0	208.1	212.2	216.5	220.8	225.2	229.7	234.3	239.0	243.8	248.7	253.6	258.7	263.9	269.2	274.6	280.0	285.6	291.4	297.2	303.1	309.2	315.4	321.7	328.1
Microhydropower development (US$)						16.7	17.0	17.3	17.7	18.0	18.4	18.8	19.1	19.5	19.9	20.3	20.7	21.1	21.6	22.0	22.4	22.9	23.3	23.8	24.3	24.8	25.3	25.8	26.3	26.8	27.3
Lanscape,tourism (US$)						35.0	35.7	36.4	37.1	37.9	38.6	39.4	40.2	41.0	41.8	42.7	43.5	44.4	45.3	46.2	47.1	48.0	49.0	50.0	51.0	52.0	53.0	54.1	55.2	56.3	57.4
Protection from land erosion due to sediment release in downstream (US$)						100.0	102.0	104.0	106.1	108.2	110.4	112.6	114.9	117.2	119.5	121.9	124.3	126.8	129.4	131.9	134.6	137.3	140.0	142.8	145.7	148.6	151.6	154.6	157.7	160.8	164.1
TOTAL INCOME (US$ 000)					0	3454	6656	6761	6868	6976	7087	7200	7316	7434	7554	7676	7801	7928	8058	8191	8326	8464	8605	8748	8895	9044	9196	9352	9510	9672	9836
COSTS																															
Initial																															
Economic cost (US$ 000)			4,642	6,964	6,964	4,642																									
Running costs																															
Annual O&M costs (US$ 000)						374	822	905	995	1,095	1,204	1,325	1,457	1,603	1,763	1,939	2,133	2,347	2,581	2,839	3,123	3,436	3,779	4,157	4,573	5,030	5,533	6,086	6,695	7,364	8,101
Replacement costs (US$ 000)						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total costs (C) (US$ 000)		0	4,642	6,964	6,964	5,016	822	905	995	1,095	1,204	1,325	1,457	1,603	1,763	1,939	2,133	2,347	2,581	2,839	3,123	3,436	3,779	4,157	4,573	5,030	5,533	6,086	6,695	7,364	8,101
CASH FLOW		0	(4,642)	(6,964)	(6,964)	-1562.18	5834.00	5856.28	5872.43	5881.67	5883.13	5875.86	5858.82	5830.84	5790.64	5736.81	5667.81	5581.91	5477.23	5351.68	5202.98	5028.58	4825.71	4591.30	4321.97	4014.00	3663.28	3265.32	2815.13	2307.24	1735.64
ECONOMIC INDICATORS																															
NPV benefits (US$ 000)	59399																														
NPV cost (US$ 000)	28546																														
NPV benefits-cost (US$ 000)	16081																														
Benefit cost ratio	2.08																														
IRR on the project	20.21%																														

ECONOMIC ANALYSIS (With Proposed Design)

Outputs

Economic Analysis	
BCR	**2.11**
IRR	**20.67%**
NPV Scheme (US$ 000)	**16,109**

Scheme details			**Programme**		
Installed capacity	14.30	MW	Construction start year	2015	year
Economic	25	years	Operating start year	2018	year
Energy production			**Capital costs**		
Dry season energy	5.67	GWh	Economic costs	22,295	US$ 000
Wet season energy	64.63	GWh	Per kW economic cost	1,559	per kW
Total energy production	70.30	GWh			
			Total cost	22,295	US$ 000
Selling rate					
Dry	8.40	NRs/kWh	Phased over	4	Years
	8.24	USc/kWh	Year 1 (%)	20.0	%
Wet	4.80	NRs/kWh	Year 2 (%)	30.0	%
	4.71	USc/kWh	Year 3 (%)	30.0	%
Assumed escalation rate	2.0%	per year	Year 4 (%)	20.0	%

Operational costs		
O&M costs % of economic	2.00%	
-		
Capacity benefit@ USD 100 per kW	1430	US$ 000
Economic factors		
Assumed currency rate (US$ to NRs)	102	
Discount rate	10%	

Socio-Economic and Environmental annual benefit

		Per month benefit
Fish population and job (US$ 000)	7.6	0.637
Irrigation/Agriculture growth/MARKET (US$ 000)	600	50
Microhydropower development (US$ 000)	50	4.167
Landscape,tourism (US$ 000)	105	8.75
Protection from land erosion due to sediment release in downstream (US$ 000)	300	25

PROGRAMME		Develop't year	Construction				Start operation																								
Years		**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**
Years #	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Year of Operation						**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Year of environmental benefit						**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
INCOME																															
Tariff willingness to pay (USc)																															
Primary energy			8.24	8.74	8.91	9.09	9.27	9.46	9.65	9.84	10.04	10.24	10.44	10.65	10.87	11.08	11.31	11.53	11.76	12.00	12.24	12.48	12.73	12.99	13.25	13.51	13.78	14.06	14.34	14.62	14.92
Secondary energy			4.71	4.99	5.09	5.20	5.30	5.41	5.51	5.62	5.74	5.85	5.97	6.09	6.21	6.33	6.46	6.59	6.72	6.86	6.99	7.13	7.28	7.42	7.57	7.72	7.87	8.03	8.19	8.36	8.52
Total Electricity Revenues (US$ 000)			0	0	0	1937	3951	4030	4111	4193	4277	4362	4449	4538	4629	4722	4816	4913	5011	5111	5213	5317	5424	5532	5643	5756	5871	5988	6108	6230	6355
Capacity benefits						715	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430
Fish population and job(US$)						7.65	7.80	7.96	8.12	8.28	8.44	8.61	8.78	8.96	9.14	9.32	9.51	9.70	9.89	10.09	10.29	10.50	10.71	10.92	11.14	11.36	11.59	11.82	12.06	12.30	12.55
Irrigation/Agriculture growth/Market (US$)						600.0	612.0	624.2	636.7	649.5	662.4	675.7	689.2	703.0	717.1	731.4	746.0	760.9	776.2	791.7	807.5	823.7	840.1	856.9	874.1	891.6	909.4	927.6	946.1	965.1	984.4
Microhydropower development (US$)						50.0	51.0	52.0	53.1	54.1	55.2	56.3	57.4	58.6	59.8	60.9	62.2	63.4	64.7	66.0	67.3	68.6	70.0	71.4	72.8	74.3	75.8	77.3	78.8	80.4	82.0
Lanscape,tourism (US$)						105.0	107.1	109.2	111.4	113.7	115.9	118.2	120.6	123.0	125.5	128.0	130.6	133.2	135.8	138.5	141.3	144.1	147.0	150.0	153.0	156.0	159.1	162.3	165.6	168.9	172.3
Protection from land erosion due to sediment release in downstream (US$)						300.0	306.0	312.1	318.4	324.7	331.2	337.8	344.6	351.5	358.5	365.7	373.0	380.5	388.1	395.8	403.8	411.8	420.1	428.5	437.0	445.8	454.7	463.8	473.1	482.5	492.2
TOTAL INCOME (US$ 000)					0	3714	6465	6566	6668	6773	6880	6989	7100	7213	7329	7447	7567	7690	7815	7943	8073	8206	8342	8480	8621	8765	8912	9061	9214	9369	9528
COSTS																															
Initial																															
Economic cost (US$ 000)			4,459	6,689	6,689	4,459																									
Running costs																															
Annual O&M costs (US$ 000)						359	790	869	956	1,051	1,157	1,272	1,399	1,539	1,693	1,863	2,049	2,254	2,479	2,727	3,000	3,300	3,630	3,993	4,392	4,831	5,314	5,846	6,430	7,073	7,781
Replacement costs (US$ 000)						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total costs (C) (US$ 000)		0	4,459	6,689	6,689	4,818	790	869	956	1,051	1,157	1,272	1,399	1,539	1,693	1,863	2,049	2,254	2,479	2,727	3,000	3,300	3,630	3,993	4,392	4,831	5,314	5,846	6,430	7,074	7,781
CASH FLOW		0	(4,459)	(6,689)	(6,689)	-1103.76	5674.90	5696.60	5712.42	5721.60	5723.32	5716.66	5700.62	5674.07	5635.80	5584.45	5518.53	5436.38	5336.21	5215.99	5073.54	4906.43	4711.97	4487.22	4228.94	3933.56	3597.13	3215.32	2783.36	2295.99	1747.43
ECONOMIC INDICATORS																															
NPV benefits (US$ 000)	**57934**																														
NPV cost (US$ 000)	**27418**																														
NPV benefits-cost (US$ 000)	**16109**																														
Benefit cost ratio	**2.11**																														
IRR on the project	**20.7%**																														

APPENDIX2

Socio-Economic and Environmental Benefits

During case study, it was observed that 200 families were living in the 3km stretch in downstream area located between diversion weir and power generation house are directly affected with their total land area of around 534,368 m^2. The new conceptual design developed with the fishway design improvement, downstream water and sediment release mechanism can improve the following activities of the people living in that the affected area, concerned with socio-economical and environmental issues.

From Proposed design

Socio-economic and Environmental benefits	Annual Income (US$ 000)	Monthly Income (US$ 000)
Fish population growth , fishing job and market	7.6	0.637
Agriculture growth and market	600	50
Micro hydropower development	50	4.167
Landscape and tourism development	105	8.75
Protection from land erosion due to sediment release in downstream	300	25

FromExisting Design (During four months June, July, August and September)

Socio-economic and Environmental benefits	Annual Income (US$ 000)	Monthly Income (US$ 000)
Fish population growth , fishing job and market	2.55	0.212
Agriculture growth and market	200	16.67
Micro hydropower development	16.67	1.389
Landscape and tourism development	35	2.917
Protection from land erosion due to sediment release in downstream	100	8.333

Fish population growth , fishing job and market

Fish Yield per km per year	400	Kg/km/year
Total Yield in 3km per year	1200	Kg/km/year
Rate/ kg fish	650	NRs.
Total income per year	7647.05	US$

Considered for economic analysis	7647	US$/year

Agriculture growth and market

Total affected agriculture land	534368	m^2
Income per square meter land per year From agriculture growth and selling due to sufficient water for irrigation, in Nepalese Rupees	120	NRs.
Total Income per year from 534,368 m2 land from agriculture growth and selling due to sufficient water for irrigation, in Nepalese Rupees	64124160.00	NRs.
Total income per year in US$	628668.2353	US$

Considered for economic analysis	~600,000	US$/year

Micro Hydropower Development

(Minimize deforestation and utilize more locally used electricity with the development of micro hydro power after more downstream water release with new design)

	Design Head	92	m
	Discharge	0.2	m^3/s
	Efficiency	50%	
	Acceleration due to gravity	9.81	m/s^2
	Power	90.252	KW
		0.090252	MW
	In 30 days		
For 200 family	in KWh	64981.44	KWhr/month
For one family		324.9072	KWhr/month

Energy Selling Rate per KWh (NRs)

Dry Period	8.4	0.0824	In US$
Wet Period	4.8	0.0471	In US$

Average Energy selling rate	0.0647	USD
200 families can use the total electricity of amount per month……………………………………..	4204.681	USD/month

200 families can use the total electricity of amount per year

50456.18 USD/ Year

Consider benefit amount for economic analysis ~ 50,000 US$ per year

Landscape and tourism development (climbing mountain, boating, fishing etc with more job creation through tourist guide, providing housing facilities for tourist)

No. of affected family	200	
per day average income	150	NRs.
Total 200 Families income per day in Nepalese currency	30000	NRs.
Total 200 Families income per day in US currency	294.1176	US$
Total 200 Families income in 30 days in US currency	8823.529	US$
Total 200 Families income in one year in US currency	105882.4	US$/ year
Considered for economic analysis	~105,000	US$/year

Protection from land erosion due to sediment release in downstream		
In general total protection and maintenance cost from the existing design	**300,000**	US$
Gabion retaining wall	8500000	NRs
Stone retaining wall	12000000	NRs
Other protection work	2000000	NRs
road maintenace	8500000	NRs
Total Maintenance Cost	**31000000**	**NRs.**
With the proposed design, regular release of sediments and gravel can improve the downstream affected area and save the amount which is generally used for the protection and maintenance work previously.	**303,921.6**	**US$**
Considered benefit amount per year for economic analysis	**300,000**	**US$**

APPENDIX 3

Flow and Energy Calculation (with new proposed design)

Under Sluice Gate		
Length of undersluice	1	m
y2	0.3	m
y1	0.5	m
y3	0.12	m
Cc	0.4	
Coefficient, Undersluice(Cd)	0.359	

Weir

Coefficient of Weir	1.705	
Length of weir	6	m
flow ht. over werir	0.15	
$C = (2/3)^{3/2}(g)^{1/2}$		
1.70		

Open Channel Gate
(Attraction Velocity)

y2	0.6	m
y1	0.7m	
Cc	0.4	
Coefficient Undersluice	0.359	
y3	0.24	m
Length of gate for attraction velocity		1.5m

Discharge under a sluice gate

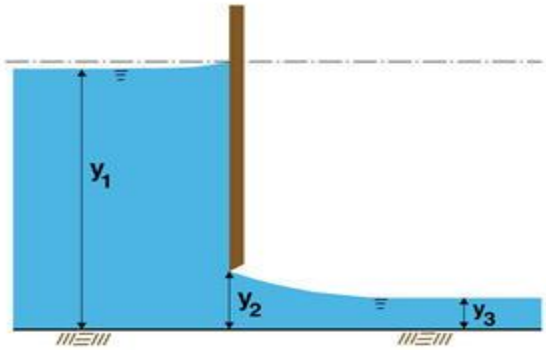
Equations:

$C_c = y_3/y_2$

$C_d = C_c/[1 + C_c\ (y_2/y_1)]^{1/2}$

$v_2 = C_d\ (2gy_1)^{1/2}$

$q = v_2\ y_2$



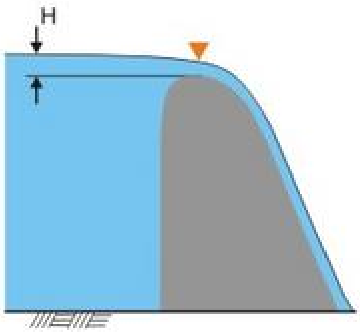
Discharge over a broad-crested weir

Gravitational acceleration g: 9.806 m s^{-2}

$C = (2/3)^{3/2}(g)^{1/2}$

$=1.70m^{1/2}\ s^{-1}$

$Q = CLH^{3/2}$



Month	Available Discharge(m3/s)	Actual Discharge from Undersluice (m3/s)	Downstream release (m3/s)	velocity at undersluice (m/s)	Attraction Velocity (<2 m/s)	Design Water flow from intake during wet period (m3/s)	minimum water height required for fishway at weir (m)	minimum discharge at weir fishway (m3/s)	velocity at weir(m/s)	water available after releasing the design discharge (m3/s)	Extra water need to be spilled from spillway (m3/s)	water flow through weir or undersluice	remaining flow discharge after passing through undersluice fishway for power generation (m3/s)
Jan	2.620	0.338	1.151	1.125	1.279	11			0.66	-8.72		Under sluice	1.131
feb	2.330	0.338	1.151	1.125	1.279	11				-9.01		Under sluice	0.841
Mar	3.130	0.338	1.151	1.125	1.279	11				-8.21		Under sluice	1.641
Apr	5.600	0.338	1.151	1.125	1.279	11				-5.74		Under sluice	4.111
May	10.240	0.338	1.151	1.125	1.279	11				-1.10		Under sluice	8.751
Jun	22.07	0.338	1.151	1.125	1.279	11	0.15	0.59		10.48	9.32	weir	19.987
Jul	39.85	0.338	1.151	1.125	1.279	11	0.15			28.26	27.10	weir	37.767
Aug	42.49	0.338	1.151	1.125	1.279	11	0.15			30.90	29.74	weir	40.407
Sep	30.31	0.338	1.151	1.125	1.279	11	0.15			18.72	17.56	weir	28.227
Oct	13.14	0.338	1.151	1.125	1.279	11	0.15			1.55	0.39	weir	11.057
Nov	6.09	0.338	1.151	1.125	1.279	11				-5.25		Under sluice	4.601
Dec	3.59	0.338	1.151	1.125	1.279	11				-7.75		Under sluice	2.101

ENERGY CALCULATION
(with proposed new design)

Gross Head = 150 m

Tunnel Length = 1295 m

Design Discharge = 11 m3/s

Excavated tunnel diameter = 3.5 m

X-section area of head race tunnel

Concrete Lining Section = 7.51 m2

Shotcrete Lining Section = 8.66 m2

Concrete Lining = 60%

Shotcrete Lining = 40%

Penstock Length = 425 m

Penstock Diameter = 1.6 m

No of days	River Discharge (m^3/s)	Available Design discharge (m^3/s)	Turbine Discharge (m^3/s)	difference	Downstream percentage % release	discharge used for power genration after maintaining at least 30 % d/s release (m^3/s)	At least 30 % release to down stream(%)	Actual d/s release quantity with new design (m3/s)	Velocity Shotcrete (m/s)	Velocity Concrete (m/s)	Headloss (m)	Power (MW)	Energy (MWh)
31	2.62	1.13	1.13	0.57	56.83	1.13	56.83	1.49	0.13	0.15	0.06	1.5	1140
28	2.33	0.84	0.84	0.64	63.90	0.84	63.90	1.49	0.10	0.11	0.03	1.1	766
31	3.13	1.64	1.64	0.48	47.57	1.64	47.57	1.49	0.19	0.22	0.12	2.2	1653
30	5.6	4.11	4.11	0.27	26.59	3.37	39.80	2.23	0.39	0.45	0.52	4.6	3277
31	10.24	8.75	8.75	0.15	14.54	7.18	29.92	3.06	0.83	0.96	2.36	9.6	7119
30	22.07	19.99	11.00	0.50	50.16	11.00	50.16	11.07	1.27	1.47	5.54	14.4	10332
31	39.85	37.77	11.00	0.72	72.40	11.00	72.40	28.85	1.27	1.47	5.54	14.4	10677
31	42.49	40.41	11.00	0.74	74.11	11.00	74.11	31.49	1.27	1.47	5.54	14.4	10677
30	30.31	28.23	11.00	0.64	63.71	11.00	63.71	19.31	1.27	1.47	5.54	14.4	10332
31	13.14	11.06	11.00	0.16	16.29	9.02	31.35	4.12	1.04	1.20	3.72	11.9	8865
30	6.09	4.60	4.20	0.31	31.03	3.44	43.45	2.65	0.40	0.46	0.54	4.6	3347
31	3.59	2.10	2.10	0.41	41.47	2.10	41.47	1.49	0.24	0.28	0.20	2.8	2115
365													70298

Capacity(MW)	Dry Energy (MWh)	Wet Energy (MWh)	Total Energy (MWh)
14.4	5673	64626	70298

Flow Calculation (with existing design)

Under Sluice Gate

Length of undersluice	1	m
y2	0.3	m
y1	0.5	
Cc	0.4	
Coefficient of Undersluice	0.359	
Coefficient of Weir	1.705	
Length of weir	6	m

$C = (2/3)^{3/2}(g)^{1/2}$
$=1.7044$

Q = (2/3)* μ * B * SQR (2 * g) * h ^(3/2)

Month	Available DIscharge(m3/s)	Actual downstream discharge from Undersluice (m3/s)	velocity at undersluice (m/s)	Attraction Velocity (<2 m/s)	Design Water flow from intake during wet period (m3/s)	maximum water height with no fishway at weir (m)	discharge at weir with no fishway (m)	velocity at weir(m/s)	remaining flow discharge (m3/s)
Jan	2.620	0.233	1.125	0.000	11			2.88	2.387
feb	2.330	0.233	1.125	0.000	11				2.097
Mar	3.130	0.233	1.125	0.000	11				2.897
Apr	5.600	0.233	1.125	0.000	11				5.367
May	10.240	0.233	1.125	0.000	11				10.007
Jun	22.07	0.233	1.125	0.000	11				21.837
Jul	39.85	0.233	1.125	0.000	11				39.617
Aug	42.49	0.233	1.125	0.000	11	2.46	42.49		42.257
Sep	30.31	0.233	1.125	0.000	11				30.077
Oct	13.14	0.233	1.125	0.000	11				12.907
Nov	6.09	0.233	1.125	0.000	11				5.857
Dec	3.59	0.233	1.125	0.000	11				3.357

ENERGY CALCULATION

(with existing design)

Gross Head = 150 m

Tunnel Length = 1295 m

Design Discharge = 11 m3/s

Excavated tunnel diameter = 3.5 m

X-section area of head race tunnel

Concrete Lining Section = 7.51 m2

Shotcrete Lining Section = 8.66 m2

Concrete Lining = 60%

Shotcrete Lining = 40%

Penstock Length = 425 m

Penstock Diameter = 1.6 m

Month	No of days	River Discharge	Available Design discharge	Turbine Discharge	Velocity		Headloss	Power	Energy
		(m^3/s)	(m^3/s)	(m^3/s)	Shotcrete(m/s)	Concrete(m/s)	(m)	(MW)	(MWh)
January	31	2.62	2.387	2.39	0.28	0.32	0.27	3.2	2401
February	28	2.33	2.097	2.10	0.24	0.28	0.20	2.8	1906
March	31	3.13	2.897	2.90	0.33	0.39	0.39	3.9	2912
April	30	5.6	5.367	5.37	0.62	0.71	1.34	7.2	5188
May	31	10.24	10.007	10.01	1.16	1.33	4.66	13.1	9772
June	30	22.07	21.837	11.00	1.27	1.47	5.63	14.3	10326
July	31	39.85	39.617	11.00	1.27	1.47	5.63	14.3	10670
August	31	42.49	42.257	11.00	1.27	1.47	5.63	14.3	10670
September	30	30.31	30.077	11.00	1.27	1.47	5.63	14.3	10326
October	31	13.14	12.907	11.00	1.27	1.47	5.63	14.3	10670
November	30	6.09	5.857	5.86	0.68	0.78	1.60	7.8	5652
December	31	3.59	3.357	3.36	0.39	0.45	0.52	4.5	3371
	365								83865

Capacity(MW)	Dry Energy (MWh)	Wet Energy (MWh)	Total Energy (MWh)
14.3	10,591	73,273	83,865

APPENDIX 4

Fishway Design Report

Sluice fishway

	E	((ρ*g*Δh*Q)/(b*hm*(Lb-d)))	
Water density	ρ	1000	Kg/m3
Acceleration due to gravity	g	9.81	m/s2
Minimum head difference in pool	Δh	0.14	m
Discharge	Q	0.338	m3/s
Width of Pool	b	1	m
Minimum water level in pool	hm	0.6	m
Length of Pool	Lb	4.50	m
Crosswall Thickness	d	0.2	m
Velocity (Fluent)	V	1.65	m/s
E (volumetric power dissipation)	=	**178.08**	**Watt/m3**

Calculation of minimum head difference (Δh)

	V	(2*9.81*Δh)^0.5	
	V^2	2*9.81*Δh	
Now,	Δh	V^2/(2*9.81)	
		0.14	m

Weir Fishway

	E	((ρ*g*Δh*Q)/(b*hm*(Lb-d)))	
Water density	ρ	1000	Kg/m3
Acceleration due to gravity	g	9.81	m/s2
Minimum head differnece in pool	Δh	0.09	m
Discharge	Q	0.59	m3/s
Width of Pool	b	6	m
Minimum water level in pool	hm	0.6	m
Length of Pool	Lb	1.70	m
Crosswall Thickness	d	0.2	m
Velocity (Fluent)	V	1.35	m/s
E (volumetric power dissipation)	=	**100.28**	**Watt/m3**

Calculation of minimum head difference (Δh)

	V	(2*9.81*Δh)^0.5	
	V^2	2*9.81*Δh	
Now,	Δh	V^2/(2*9.81)	
		0.09	m

SLOT DESIGN

Sluice Fishway

Discharge (Q)	2/3*μr*s*(2*9.81)^0.5*ho^1.5		
μr	Coefficient of discharge	0.45	
s	Slot width(m)	0.3	m
ho	Water height at the end of each pool that is maximum height of pool	0.9	m
Q	0.340	m3/s	
Actual Discharge from under sluice gate (Q)		0.338	m3/s
From the slot discharge formula			
Q	2/3*μr*s*(2*9.81)^0.5*ho^1.5		
Since, Q	0.338	from hydraulic calculations	
Therefore, 0.338	=	2/3*μr*s*(2*9.81)^0.5*ho^1.5	
0.338	~	0.340	m3/s
Thus, Slot width	=	0.3 30	m cm
Slot Height	=	0.9 90	m cm
Free Board		0.1	m
Slot maximum height:		1 100	m cm

Weir Fishway

Discharge (Q)	2/3*μr*s*(2*9.81)^0.5*ho^1.5		
μr	Coefficient of discharge	0.45	
s	Slot width	0.525	m
ho	Water height at the end of each pool that is maximum height of pool	0.9	m
Q	0.596	m3/s	
Discharge from Weir section (Q)		0.594	m3/s
From the slot discharge formula (Q)			
Q	2/3*μr*s*(2*9.81)^0.5*ho^1.5		
Since,			
Q	0.594	from hydraulic calculations	
Therefore,			
0.594	=	2/3*μr*s*(2*9.81)^0.5*ho^1.5	
0.594	~	0.596	m3/s
Thus,			
Slot width	=	0.525	m
		52.5	cm
Slot Height	=	0.9	m
		90	cm
Free Board		0.1	m
Slot maximum height:		1	m
		100	cm

OPEN CHANNEL DESIGN

Manning's Roughness Coefficient for Concrete (η) = 0.014

Gradient of Head Race Canal (s) = **0.002**

Hydraulic Radius (R) = 0.313

So,

The Discharge Passing Through the Head Race Canal From the Intake,:

Q = 1.125 m3/sec

or,

Therefore,

Q = V*A

= 1/η*R^(2/3)*S^(0.5)*W*D

Let,

W = D

0r

1.125 = 1/η*((W*D)/(W+2*D))^(2/3)*S^(0.5)*W*D

Trial:

D = 0.540 m

And,

W = 1.500 m

or,

<u>1.125</u> <u>=</u> <u>1.195</u>

Final Dimensions of Head Race Canal

D	=	0.540	m
W	=	1.500	m
Freeboard	=	0.1	m
Final D	=	0.64	m
V	=	Q/A	
	=	1.476	m/sec

指　导　教　师 ____________________

学 科(系) 主 任____________________

院 分 管 领 导____________________