APPRAISAL OF ENVIRONMENTAL FLOWS DOWNSTREAM GHAZI BARRAGE

By

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THESIS ACCEPTANCE CERTIFICATE

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Dedicated to my parents for their immense faith in me and for their unwavering support in all my life's endeavors

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"…and ***my success can only come from Allah****: in Him I trust and unto Him I look."*

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ABREVIATIONS LIST

ADB	Asian Development Bank
EFA	Environmental Flows Assessment
EFR	Environmental Flows Requirement
FDC	Flow Duration Curve
GBHP	Ghazi-Barotha Hydropower Project
HEC-RAS	Hydrologic Engineering Centre- River Analysis System
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
LFI	Low Flow Index
MAF	Mean Annual Flow
MMF	Mean Monthly Flow
MMTM	Monthly Modified Tenant Method
TDP	Tarbela Dam Project
WAPDA	Water and Power Development Authority

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Due to exploding population growth, urban sprawl, and economic development, Pakistan’s freshwater supplies have become highly stressed. As the competing water needs for various sectors such as agriculture, domestic, energy and industrial sectors is increasing, it has resulted in drastic decrease of water availability per capita water to less than 1000m3/person in the country of 220 million. Consequently, the mainstream water management in the country has dictated river water for anthropogenic needs, thus silently compromising the needs of the freshwater ecosystems. In order to reap benefits of healthy rivers and their ecosystems,

river flows must meet environmental flow requirements. Environmental flows, or E-flows, are a management concept that determine the flow regimes required to maintain

a river’s ecosystems in a desired state. There is a dire need of studies to cater for the assessment of environmental flows.

The aim of the present study is to assess environmental flows and provide values of minimum water flows on the downstream side of Ghazi Barotha Hydropower Project (GBHP). This project aimed to generate electricity started in 1995. It diverts water from the River Indus at Ghazi to a power channel. It was thought to be an environmentally friendly project with least social impacts. Over the years it has been observed that downstream ecosystem is affected due to no release of water there instead diverting all the water into power channel. The industrial waste being thrown there, and absolute diversion water has caused devastating impacts on the downstream side at Ghazi Barrage. To make this project sustainable several methods for evaluating environmental flows are employed in this study. In the first part of this study, pre- and post-dam analysis is conducted. In the second part, environmental flows for downstream Ghazi are calculated by different methods and their comparisons are made. Obtaining the most advantageous releases and notifying policy are the prime focus. The results of this study showed that environmental flows determined by different hydrological methods could be used to maintain flow during the months of

low flow season to make GBHP sustainable. The inflection points and the flow against them could also be used, derived from HEC-RAS in wetted perimeter method as hydraulic methods are usually site specific. As far as ecological analysis is concerned, there should be a flow of minimum 3653 cumecs for fish species to survive there in affected reach.

Chapter 1

INTRODUCTION

1.1 BACKGROUND

One of the main hurdles in the industrial and economic sector of Pakistan is the paucity of electrical power. The demand for electricity is increasing day by day and for economic growth it is essential that rate of power production must meet the increasing demands of industrial sector. In the beginning of 21^{st} century Pakistan has gone through economic crises due to shortage of power. Due to short supply of electricity an effective approach was needed to get certain issues like energy consumption to be addressed. Over the years there is increase in electricity production and major contributor in power generation is Ghazi Barotha Hydropower Project-GBHP. The GBHP was established by Water and Power Development Authoriy-WAPDA, a Pakistan's government owned organization. This project was first named as Ghazi-Gariala hydropower project, but the name was changed to Ghazi Barotha Hydropower Project by WAPDA in the late 1991 upon the request of the people(Consultants).

The GBHP is situated in the eastern side of province Khyber Pakhtun Khuwa and the northern part of the province Punjab, Pakistan(Jager and Smith 2008). The

Ghazi Barotha Hydropower Project-GBHP was designed to overcome the power shortage in Pakistan and it has an installed capacity of 1450 MW. It utilizes the available head between tailrace at Tarbela and the confluence of River Indus and Haro River. From Ghazi to Barotha reach River Indus provides a head of 76m(Technology). It's a runoff river type power plant(Botelho, Ferreira et al. 2017). The runoff river GBHP is located just about 100km from Islamabad(Technology).

The run-of-the-river hydropower project is freshly developed technology and fittingly incorporated for river having low flows. In this river type, comparatively low volume of flow is stored and sends off through channels into the turbine(Karakoyun, Dönmez et al. 2018).

The GBHP comprises of three key components, (i) A barrage – which is about 7km downstream of tarbela dam (ii) a power channel- having a capacity of 1600 cumecs (56,500 cusecs) and a concrete lined trapezoidal structure (iii)and a power complex- which is placed on Indus river's left bank with generation capacity of 1450 MW. (specie wala). The barrage conveys water to a concrete lined channel which is about 52km and then send it to the power complex at barotha(Technology).

In the past rivers have been used by the people to get utmost gains when it comes to power generation, agriculture, or water supply in urban areas. It is evident that construction of large dams on rivers induces severe environmental and ecological problems especially in low flow season when there is not enough water to release downstream. To address these ecological issues, in early 70's the concept of environmental flows arisen to mitigate the adverse impact caused by hydraulic structures. An environmental flow is the minimum quantity of water that is needed to maintain ecosystem's healthy growth and the species dependent on the river water. The provision of environmental flows is very important in maintaining water quality, providing sufficient water for aquatic species, preserving the functioning of riverine ecosystem and helping communities residing downstream the hydraulic structure and the people who are dependent on river's water.

1.2 STATEMENT OF PROBLEM

Water promises to be a limited reserve worldwide in the new era. Pondering on this assessment, there is an urgent need of an effective resolution for inter-provincial water rights because a delay in this declaration might give rise to controversial issue over water in South Asia as Pakistan is already struggling to get its lower riparian constitutional rights from India. Amidst the global skirmish for water, WAPDA perpetrated injustice to the people living downstream on the bank of this river by diverting all the water to power project and making them deprived of water. The complete diversion of water is a violation against the basic rights of the people living on the bank of river. The GBHP has alarming impacts on the downstream of the Ghazi

Barrage by being responsible for drying up wells, turning the green banks of the Indus into parched lands and changing the waterway into stagnant and dead river of stones. Despite protests by the affected people during mid-nineties the conflict between the rights of people and Ghazi Barotha Project remains unresolved. Currently the implementation of project cuts off water release on the downstream side for seven months during the year. During low flow season, the flow is reduced to less than 10% of water in the river(Moore 2004). In GBHP with some modifications, sustainability can be achieved while protecting the rights of the people living downstream. Currently, the inflow to Ghazi Barrage is almost all the water that is being released by Tarbela Dam. The much-dreaded diversion to power channel leaves negligible amount of water as compared to pre-project flows for downstream of barrage. According to the current execution of plan, no matter what the releases are the total volume of water that is ought to be released in single day will be released all at once during an hour thus there will be no flow during the rest of the day. The sort of the alteration in flow regime will have extensive impact on ecological and social conditions.

The water quality of Indus is affected due to contaminants that come from Gadoon-Amazai in the river-because of braided nature of riverbed it will cause more wreckage to the area where it is being released as compared to the rest of the river and for future reference erratic release of water during low flows will result in permanent ecological damage and high pollution concentration.

Top of all, the two notable adverse outcomes caused by the diversion are, (i) water resources future use whether it is for power generation, fishing, or tourism. (ii) picturesque beauty of area representing quality of life of that area. The access to natural watercourse to people is the base on which Pakistan demands water from India. The struggles over water resources are the cause of many conflicts all over the world. Pakistan is blessed to have plenty of freshwater resources however their proper management remains a challenge for our strategists. Ghazi Barotha is vital nationwide project in the advancement of cost-effective energy sources, but it must be operated in such a way that it must avoid unnecessary burden on any sector of our society. Thus, environmental flows are believed to be vital means for sustainable development of aquatic ecosystems downstream river.

1.3 RESEARCH HYPOTHESIS

In developing countries, numerous proposed dams especially for hydropower are menacing world's river systems. Worrying over their social and environmental impacts has resulted in their omission from the term sustainability. Improved study in planning, designing, and operating the hydropower dams could help us in finding where to build and not to build, and to lessen the adverse impacts it could have(King and Brown 2018).Ghazi Barotha thus meets need for economic development by overcoming power shortage problem but with little adaptations the feasibility of the project can be kept while safeguarding the civil rights of the affected people. Thus, environmental flows are very important for sustainability. Hydrologic methods, hydraulic methods and ecological methods are used to determine environmental flows for sustainable development of riverine ecosystem. Hydrologic methods are the simplest and oldest, historic records of flow for subjective stream are used as an input.

1.4 OBJECTIVE OF THE STUDY

- To assess Environmental Flow Releases (EFR) for the affected reach by using hydrological methods and hydraulic methods.
- To make comparison of these methods.
- To make comparison of pre- and post-dam flow regimes

1.5 SCOPE OF THE STUDY

The execution of GBHP has drastically changed the pre-project flow pattern of river Indus. During low flow months the water is completed diverted from Tarbela to Ghazi Barotha power complex with leaving no flows for downstream side negatively affecting the sustainable growth of riverine ecosystem, survival of fish and human being living nearby the riverbanks. To lessen these negative impacts caused by the GBHP project, environmental flows are essential because by making comparison of environmental flows estimated by different methods, we will able to get a single minimum value of flow that is required to avoid this misfortune.

1.6 ORGANIZATION OF THE THESIS

Chapter 1 comprises of background of Ghazi Barotha Hydropower Project and its impact on sustainable development. The problem statement, hypothesis of research, objectives, and scope of study.

Chapter 2 has detailed literature review.

Chapter 3 describes the study area.

Chapter 4 has the calculations of environmental flows made by different methods.

Chapter 5 contains the detailed comparison of inflows outflows of Tarbela Dam and Ghazi Barrage

Chapter 6 consist of conclusion and recommendations.

Chapter 2

LITERATURE REVIEW

Research work formerly conducted in the area of environmental flows across the world with specific focus on Pakistan has been discussed in this chapter. General overview of the hydropower and environmental flows studies carried out are discussed. The gaps in the research are also covered.

2.1 WHAT ARE ENVIRONMENTAL FLOWS?

According to the Brisbane Declaration (2007) environmental flows are the fresh water’s quantity, quality and timing which is required for sustaining ecosystems of all living things (Brisbane declaration). Environmental flow assessment can be taken as detailed approximate of environmental water requirements and the impacts of altered flows on ecosystems and human beings, to advise decisions such as

- Whether we ought to reserve some portion of water from the total flow for environmental uses and if yes, how much water should be retained and based on what schedule it must be put into effect.
- How the impacts of present ventures on rivers can be lessen? Whether by releases of environmental flows or by putting controls on water withdrawals.

- How the amendments can be made on already executed projects to increase environmental conditions for good.
- How and where to construct a new water project

2.2 HISTORICAL BACKGROUND OF ENVIRONMENTAL FLOWS

The history of environmental flows is associated with the increase in dam-building that begun to increase noticeably in the middle of 20th century. River ecosystems are affected by dam construction at the local and regional level. As there are more dams on river, the damaging impacts by these structures will be ever more recognizable(Poff and Matthews 2013).

The term environmental flow came into light in contemporary times when human induces activities like flow regulations and overuse of water resulted in the degradation of aquatic ecosystems. Biodiversity of freshwater ecosystems is considerably degraded due to alteration in flow regimes by human intrusions(Reporter 2018). To benefit aquatic species like fish there is a need of minimum amount of water that must remain in the river which gave rise to terms like low flows, fish lows and minimum flows.(Tegos, Schluter et al. 2018). In 1990's the all-inclusive method to environmental flow assessment (EFA) was not just confined to in-stream activities, but covered all facets of a running water system, comprising floodplain, estuaries and groundwater bodies. This methodology also considered all aspects of a flow regime like quality, quantity, duration, frequency, and rate of change. There are several interpretations for EFA. For example, Tharme described it as an estimation of the original flow that is supposed to go on to flow down the river and onto its floodplains to retain the valued characteristics of the ecosystem (Tharme 2003). Nowadays, many terms like environmental flows, ecological flow, and environmental water requirement are used to describe the amount of water that is reserved to fulfill requirement of environmental flows needed by water ecosystems. Over the last decade, the connection amongst livelihoods and river flows was viewed by taking human aspect as an element of a holistic approach for covering issues like aesthetics, public dependency on river ecologies, economic benefits, leisure activities and connection to morphological methods. Now the notion continues to improve and is moving from the conventional stance of bare minimum water quantity to a more comprehensive understanding. It is acknowledged that wellbeing and sustainability of river ecologies hinge on multiple factors comprising river hydraulics, barrier existence to connectivity, flow regime, exploitation extent etc(Acreman and Dunbar 2004).Consequently, it entails several biological, physical, chemical, and morphological processes in a river to form aquatic ecosystems and to maintain it (Suen and Eheart 2006). In addition to this, modern approaches require involvement of stakeholders and experts of different disciplines to address socioeconomic issue. Though to incorporate all the factors mentioned above within an EFA study is extremely difficult. Even though the methodological advances provide modern modelling tools and framework for computing the complex interactions, but the key limiting factor is the time and amount of the required information. Thus, the problem is addressed in the light of limited data availability in most applications around the world. In such cases, it is necessary to look for those EFA methods that are parsimonious when it comes to time, data, and expertise knowledge(Tegos, Schluter et al. 2018).

In developing nations, the major task is establishing the environmental flow policies due to clashes occurring between the conservation of riverine ecosystem and the requirement of infrastructure for water resource exploitation.

2.3 WHY TO MAINTAIN ENVIRONMENTAL FLOWS

Water has been used by human beings since very early times. With the passage of time freshwater resources are depleting and it is of utmost concern on the global scale. The water availability for future as well as present use is decreasing day by day which in turn is responsible for the disturbing impacts on the functioning of freshwater ecosystems as well as for their healthy growth. Water resources must be allocated to different sectors depending on their need of use and keeping in view the depleting water resources we must look into this matter and make it sustainable so that our present and future generations may get benefit from it. Environmental flows play vital role in encouraging sustainable development and sharing benefits to lessen poverty. However, apportioning water for environmental uses is still questioned. For economic development water resources infrastructure ventures like dams for water storage, water supply in cities, flood protection and drought alleviation are necessary but when they are not properly planned and managed, they can be a source of problems in downstream ecosystems and neighborhood due to their effect on quality and quantity of flow. Water is used for energy generation since long time as well as in the current era. The stored water's potential energy is used to produce electricity from hydropower. Among other renewable resources hydropower is the highly used renewable energy resource. Fang et.al stated that the hydraulic benefit rates of rivers must be scientifically defined as it is as important for the sustainability as for the avoidance of environmental challenges that may be initiated by the significantly emerging hydropower plants.(Fang, Wang et al. 2010). Botelhoa et.al explored hydropower plants influence on environment and conducted case studies in Portugal.(Botelho, Ferreira et al. 2017). Jager and smith talk about whether the production of electricity and ecosystems can be conserved at the same time(Jager and Smith 2008). Piman et.al explored the dam impacts on three distinct rivers in Mekong basin(Piman, Cochrane et al. 2016). Moore's did research with some researchers of 64 countries and revealed that environmental flow assessment is very important for the water resources to be sustainable(Moore 2004).

2.4 ENVIRONMENTAL FLOW ASSESSMENT (EFA) APPROACHES

There are many methods for environmental flow assessment. Variations amongst streams and rivers and the conditions of their evaluations are the reasons for the development of new methods. By Tharme it is reported that early EFA approaches were originated in the USA from the end of 1940s(Tharme 2003). Now a days, several methods incorporating all levels of complexity exist. They can be classified into four groups namely hydrological, hydraulic, habitat simulation and holistic. Brief reviews of these approaches are given by Acreman et.al(Acreman, Overton et al. 2014), petts(Petts 2009) and Tharme. Gopal has described different methodologies for the assessment of environmental flows(Gopal 2013).

The hydrological methods are the oldest and consist of several methods ranging from simple to much refined techniques, the only input is stream flow data in all these methods considering it as river identity.

Lots of studies have been carried out worldwide to estimate environmental flows at various rivers and streams using several methods, tools, and datasets. Some of the related ones are, Combined use of the hydraulic and hydrological methods to calculate the environmental flow: Wisloka river, Poland: case study (2019) and this study proposes a two-step method, in first step calculate EF range using tenant method and then limit the inflection points in WPM to that range which fits in the tenant range. The resulting EF would be supported by the river’s morphological conditions(Książek, Woś et al. 2019). In Assessment of Environmental Flows from Complexity to Parsimony—Lessons from Lesotho (2018), the aim of this study was to recommend an environmental flow policy at three sites in Lesotho by using DRIFT method and it provides specific flow values for fish by relating it with hydraulic characteristics allowing to quantify the impacts of the chosen policy to the aquatic environment (Tegos, Schluter et al. 2018). In the paper, Comparison of environmental flow assessment methods with a case study on a runoff river-type hydropower plant using hydrological methods (2018), comparison of pre- and post-dam flow analysis with widely used EFA methods is made. Pre and post dam flow regimes are investigated by flow duration curve and dramatic difference is observed between flow characteristics which in turn affects aquatic life in the long run (Karakoyun, Dönmez et al. 2018). The paper Global Trends in Environmental Flow Assessment: An Overview (2018) studies several methods for evaluating environmental flow (EF) and gives global trends. It examines that different methods require different data sets and time requirements. And no approach is superior to other. The challenging part in implementation of environmental flows is the estimation of most suitable value for water allocation and preserving required discharge during low flow times (Baghel, Gaur et al. 2019). A review of environmental flow assessment: methodologies and application in the Qianhe River (2016) assesses present-day approaches for the assessment of environmental flows based on hydrological methods, hydraulic methods, and habitat simulation model. And recapitulates the benefits and shortcomings of different methodologies and their applicability requirements (Hao, He et al. 2016). The study Hydrologically based environmental flow methods applied to rivers in the maritime provinces (Canada) illustrates the importance of hydrological flow regime as it relates to base flow component as a vital element in the level of instream flow protection. The river hydrology and corresponding base flow conditions are crucial aspects in environmental flow assessments and enormously significant in the safety of fish habitation (Caissie, Caissie et al. 2014). Five different hydrological methods were tested for their applicability and were found that VMF and tessman methods to be effective and easy to be implemented in Accounting for environmental flow requirements in global water assessments (Pastor, Ludwig et al. 2014).

The relevant work in Pakistan includes the study of Environmental flow requirements and impacts of climate change-induced river flow changes on ecology of the Indus delta, Pakistan, which concludes that if existing decline of aquatic ecology lasts it will be perplexing to retain present or improving the ecological management class irrespective of the changes in the river flows in future (Salik, Hashmi et al. 2016). Environmental flows were estimated by different methods and their comparison is made. Socio-economic survey and water quality tests are performed to show adverse impacts on downstream communities and deterioration of water quality during low flows (Kareem). The paper on Evaluating impacts of Ghazi barotha hydropower project on re-settlers at barotha model village, attock, Pakistan (2011) assesses the impacts of GBHP on the lives of people living on downstream side and how they are affected ever since displacement. Results of the study shows that unfavorable impacts by GBHP were not precisely anticipated during project development and it causes unrest among resettlers (ZULFIQAR ALI1). The report on Ghazi Barotha Hydropower project- Environmental studies provides information on the description of the project and ecological aspects of river indus. According to this report a minimum release of 28 cumecs will be supplied from the barrage during all project life (Botelho, Ferreira et al. 2017). And the study on Environmental flows downstream of Kotri Barrage reveals that due to increase in temperature, water requirements are more now than the estimation made two decades ago. Environmental flows are required as more freshwater is required to reverse the process of sea intrusion downstream of Kotri barrage (Mughal 2013).

The natural environment gives benefits to humans when it comes as a function of ecosystem such as provision, regulation, and cultural services (Costanza, d'Arge et al. 1997). When it comes to water resources it relates to the generation of electricity (Operacz 2017) , rivers that provides location for fish breeding and helps in the movement of water from soil into the plants, navigation and recreation purposes. Water resources availability and the threats for flood protection and water insufficiency are associated to ecological wellbeing. By taking environmental flows into consideration, it may limit the amount of water for consumptive water users. For water managers it is of great challenge to have a balance between services that river provides and protection of freshwater biodiversity. Water management must not only be seen from economic point of view instead it must be inculcated in the minds of people in a way that it becomes part of human consciousness that water management is important.

2.5 ENVIRONMENTAL FLOW ASSESSMENT METHODS

There are number of approaches that have been classified in different ways as shown in Table 2.1

Table 2.1 Classification of EFA methods(Gopal 2013)

Organisation	Categorization of Methods	Sub-category	Examples
IUCN (Dyson et al. 2003)	Methods	Look-up tables	Hydrological (e.g. Q95 Index)
			Ecological (e.g. Tennant Method)
		Desk-top analyses	Hydrological (e.g. Richter Method)
			Hydraulic (e.g. Wetted Perimeter Method)
			Ecological
		Functional analyses	BBM, Expert Panel Assessment
			Method, Benchmarking Methodology
		Habitat modelling	PHABSIM
	Approaches		Expert Team Approach
			Stakeholder Approach (expert and non-expert)
	Frameworks		IFIM, DRIFT
World Bank (King and Brown 2003)	Prescriptive approaches	Hydrological Index Methods	Tennant Method
		Hydraulic Rating Methods	Wetted Perimeter Method
		Expert Panels	
		Holistic Approaches	BBM
	Interactive approaches		IFIM, DRIFT
IWMI (Tharme 2003)	Hydrological index methods		Tennant Method
	Hydraulic rating methods		Wetted Perimeter Method
	Habitat simulation methodologies		IFIM
	Holistic methodologies		BBM, DRIFT, Expert Panels, Benchmarking Methodology

Stalkner grouped them as standard methods and incremental methods. Standard methodologies are those that give a value of flow that is intended to maintain aquatic life and incremental methodologies are considered to be repeated process in which fish habitat-river flow relation and the hydrology of river is transformed into habitat time series, proposes water management options simulation(Gopal 2013).

Dunbar et.al kept these groupings but names the incremental approaches as Empirical technique. According to them standard setting approaches are office-based approaches that use existing information and predict a suitable schedule of instream flow requirements. Whereas empirical techniques are based on physical and biological data to plan flow requirements(M J Dunbar) - dunbar 1998

King and Brown differentiate the methods as interactive and prescriptive approaches as tabulated in Table 2.2. The prescriptive methods focus on a particular objective and purposed a single value of flow for the flow regime. The interactive methods are based on relationships between flow changes and some part of the stream that is considered for establishing the flow based on the required river condition(Davis and Hirji)

Table 2.2 Characteristics of prescriptive and Interactive Approaches

Prescriptive Methods	**Interactive Methods**
Provides single flow value to	Gives a range of flow values,

maintain desired objective	each value associated to a distinct river condition
Not favorable for discovering options	Favorable to delve into options
Preferred where objectives are clear, and likelihood of controversy is insignificant	Suitable where the eventual outcome is Environmental flow

Tharme (Tharme 2003) and Tharma And Smakhtin (Management) have a preference to classify the approaches into four groupings i.e. hydrological methods, hydraulic methods, habitat simulation methods and holistic methods.

2.6 HYDROLOGICAL METHODS

In hydrological models, long term data usually about 30 to 50 years are used to estimate environmental flows. Because these methods rely on past data there are also known as historical flow methods. The benefit of using this method is that it is continuously measured at different locations and it can be available easily from dam authorities. Hydrological methods are the oldest and easiest and used widely. About 30% of all methods under this classification are normally region specific and comparatively utilize little biological and morphological information on rivers(Tharme 2003). Hydrological methods are mostly used in that area where this is less conflict and other assessment methods cannot be implemented due to lack of data and resources.

2.6.1 Tennant Method

The tenant method is also known as the Montana method and is one of the oldest methods developed for the requirements of fish. Its foundation was Tennant's 17 years of experience on many streams and on field testing of 11 streams in Nebraska, Montana and Wyoming. Tenant method is simple in applicability as it entails no field work out. Tennant method requires historical data of daily discharges flow records. Mean annual flow is calculated from daily flow records. Environmental flows recommended by this method are based on the fact that some percentage of Mean annual flow is necessary for a sustainability of river ecosystem. Tennant suggested two sets for recommending a flow comprising six months of winter and six months of summer. And the hydrologic data collected for this method mainly consist of depth, width and velocity of stream and the correlation amongst the variables changing and different values of Mean annual flow as shown in Figure 2.1

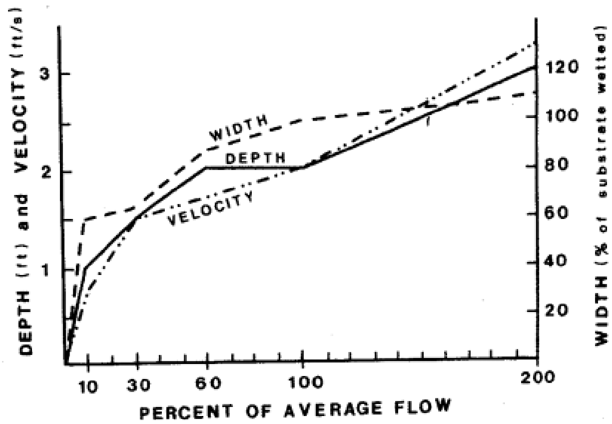

Figure 2.1 Relationship of flow(%) with depth, width and flow velocity(Gopal 2013)

As the graph shown in Figure 2.1, he mentions that instream habitat qualities like width, depth, and velocity increases from no flow to 10% of the flow and then starts decreasing. Tenants concluded that riffles are too shallow for larger fish to move when stream flow was 10% of the MAF and they move into deeper pools. The lower limits for the average depth and velocity for the short-term survival of fish are observed to be 0.3m and 0.25m/s respectively. And when the levels of mean annual flow are 30% the average depths range is 0.45m to 0.6m and range of velocity is 0.45m/s to 0.6m/s and it is considered to be optimal for fish survival. When the mean annual flow is 60% it provides excellent to outstanding habitat and the flushing flows are provided at the mean annual flow of 200%. Base flow regimes are proposed for summer and winter season on the basis of percentages of the average yearly flow which will yield corresponding aquatic habitat conditions. The environmental flow requirements suggested by tenant method is given in Table 2.3

Table 2.3 EFRs by Tenant method (Gopal 2013)

Description of general condition of flow	Recommended flow regimes (% of MAF) Nov-Apr	Recommended flow regimes (% of MAF) May-Oct
Flushing or maximum	200%	200%
Optimum range	60-100%	60-100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	<10%	<10%

For the determination of Mean annual flow tenant's method relies on historic flows, its one if the limitation of this method as it does not require any sort of ecological data for environmental flow assessment. The other limitation in tennant's method is it does not account for monthly flow. Tennant method was developed for the streams having same hydrological regimes and it cannot be used for streams having different flow patterns. Several amendments were proposed. Mathews and Bao observed in Texas that annual mean discharge is not suitable for fish as flow of river varies. So, they recommended to replace average annual discharge with median yearly discharge(Gopal 2013).

2.6.2 Tessman Method

Fraser proposed that tenant method could be expanded by stating monthly minimum lows for featuring seasonal variation(Jowett 1997). Tessman tracked it up by studying natural flow variations monthly to find out the thresholds of flow. The flow for every month is determined by considering tessman advised low flow standards which necessitate variation for each month. Environmental flow requirements suggested by Tessman is shown in Figure 2.2

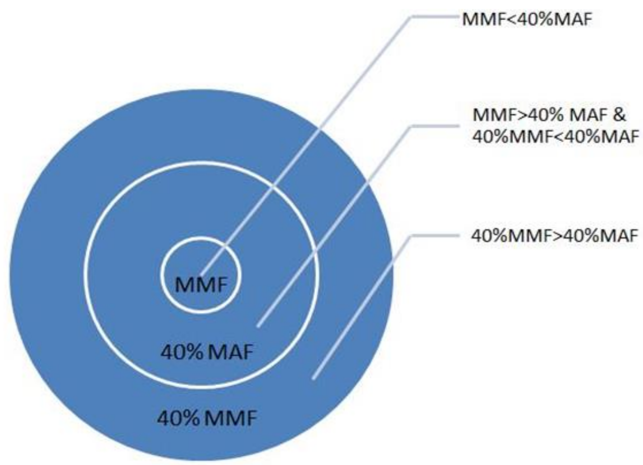

Figure 2.2 Tessman recommendation for EFRs

2.6.3 Monthly Modified Tenant Method

As discussed earlier, Fraser put emphasis on alteration in tenant method (Jowett 1997). This method is reviewed by Hughes and Hannart and was formed through quantitative analysis in a several trainings concentrating on rivers environmental flow assessment took place in South Africa(Kareem). To estimate environmental flows for each month three values of minimum flows were produced and tenant own conclusion which states short term survival of fish, good survival of fish and excellent aquatic habitat exits at 10% MMF, 30% MMF and 60% MMF is also employed in this method as shown in Figure 2.3

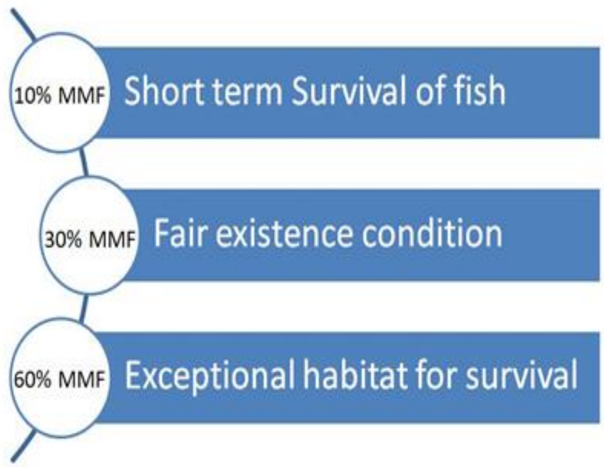

Figure 2.3 EFR recommendation by Monthly Modified Tenant Method

2.6.4 Low Flow Indices

Low flow indices were then implied as environmental flows for protecting aquatic life. 7Q10 is the generally suggested hydrological index. It is defined as lowest recorded value of flow within a return period of 10 years for seven consecutive days(Caissie and El 2003). 7Q2 uses a return period of 2 years for seven consecutive days of low flows.

7Q10 is most used in low flow indices for environmental flows, globally. The other hydrological indices used as EFR are 7Q2, 7Q20, 30Q10 and 1Q10.

2.6.5 Flow Duration Curve Method

A flow duration curve is classified as a cumulative distribution of flows representing the percent of time over a specific period of observations. FDC representing values of discharge could be daily, weekly or fortnightly. It basically represents the variability and range of flow data when there is daily flow data used. The flow data is generally plotted as percentages of total flow or on a log scale. Long term data is useful in evaluating the accessibility of water at specific point. Q_{95} exceedance percentile can be described as the discharge which is equal or more for 95% of the time. The exceedance percentile commonly used as environmental flows are Q_{90} and Q_{95} (Pyrce).

2.7 HYDRAULIC METHOD

It is a hydraulic rating method based on the relationship between wetted perimeter of river and flow at chosen cross section of the river reach. Wetted perimeter is that part of stream's bottom and sides who are in contact with water. This method was unveiled by Montana Department in 1970s. The critical flow requirement for the representation of habitat is represented by inflection point below which the conditions become unfavorable for aquatic life. The breakpoint in a relationship of discharge versus wetted perimeter is known as inflection point.

These methods rely on convenience of aquatic habitation and believe that it's closely related with definite hydraulic indicators for instance, width, depth, discharge velocity, hydraulic radius and wetted perimeter. The response curves between discharge and particular hydraulic indices are acquired from data of hydraulic or hydrologic computation based on theoretical formulations. These approaches employ a quantifiable correlation between the quality and quantity of studied river to evaluate discharge recommendations. Even though river reaches features, slope and transection are taken into consideration by hydraulic methods but the exact and direct effects of discharge on particular ecosystem functions and cyclic variabilities are still not reviewed. The characteristic method of this categorization is Wetted perimeter method.

2.8 OTHER METHODS

The utilization of wetted perimeter method and hydrological methods as distinctive indicators of river and to define ecological flows is limited. For this purpose, hydrological methods and hydraulic methods are used in combination with other methods that also include quality of water and biological conditions. Habitat simulation models could be used for illustration of this point as they evaluate environmental flow values based on comprehensive evaluation of the quantity and pertinency of physical habitat requirements of aimed species that are being monitored under various flow regimes. They used hydrological, hydraulic as well as biological data for the representation of habitat conditions at representative sites within hydraulic simulation tool to establish relation between habitat and discharge. Instream flow incremental Methodology-IFIM is used to assess environmental flows in the standpoint of management decisions. Generally, the lowest acceptable value of flow is determined by predicting availability of instream habitat that matches the preference of few fish by using Physical habitat simulation model PHABSIM software, being key component of IFIM.

Then there are holistic methods(Arthington A.H.1), necessarily used for decision making practices allowing the stakeholders and scientist of different disciplines to share their knowledge and data thus making a move from prescriptive to interactive approaches. As the aim of these methods are to address all the needs of whole riverine ecosystem they include all the main biotic and abiotic elements thus their data requirements, time resources and human resources are more in demand (King, Brown et al. 2003). These approaches emphasize on choosing the consequences of water resources management circumstances rather than addressing ecological requirements. Over the last two decades, several methods have been established and employed in South Africa, Australia, and UK. The mostly used method is Building block method (BBM)(King and Louw 1998) and the downstream response to imposed flow transformation framework (DRIFT).

Generally, there is no single method or combination of methods that is recommended for the assessment of environmental flows for all rivers as every method has its own advantages, disadvantages, and limitations. The research gap exits as there is absence of understanding between functions of ecosystem and environmental flows. The dominant holistic EFA methods are intensive in time, data and money resource and it's the major limitation in developing countries for carrying out environmental flow assessments. Outcomes from existing methods cannot provide inputs to the studies associated to economic appraisal. Hence, there is gap among different disciplines i.e. ecology, hydrology, geography etc. To overcome this gap there is dire need to focus on ecosystem services recognized by environmental flows.

Chapter 3

STUDY AREA

3.1 SITE DESCRIPTION

3.1.1 Location

The project Ghazi Barotha Hydropower project is located on the River Indus in the northwest part of Pakistan, downstream of Tarbela Dam. The project is introduced for the generation of power to meet power demands in Pakistan by utilizing the hydraulic head available between Tarbela and the convergance of rivers namely Indus and Haro as shown in Figure 3.1 and 3.2. This project encompasses of three essential components:

1. a barrage, sited at 7 km downstream of Tarbela Dam as shown in Figure 3.3 and it is just at upstream side of village Ghazi and it regulates every day discharges from Tarbela and redirects the flows into the power complex. During the low flow season, compensation water and during the high flow season the excess water is released on the downstream side of barrage.

2. a concrete -lined power complex of about 52 km in length having a capacity of 1600 cumecs as shown in Figure 3.2 and a bed slope of 2 in 9600, base breadth of about 58.4 m, a velocity of 2.33m/s and water depth of 9m.
3. a power channel of generation capacity 1450MW is located in the vicinity of village Barotha as shown in figure 3.4. It comprises of two headponds, five pen stocks, a siphon spillway, a forebay, a power intake structure and a power complex with five turbo generators of capacity 290MW each. Maximum electricity will be available during the months of high lows

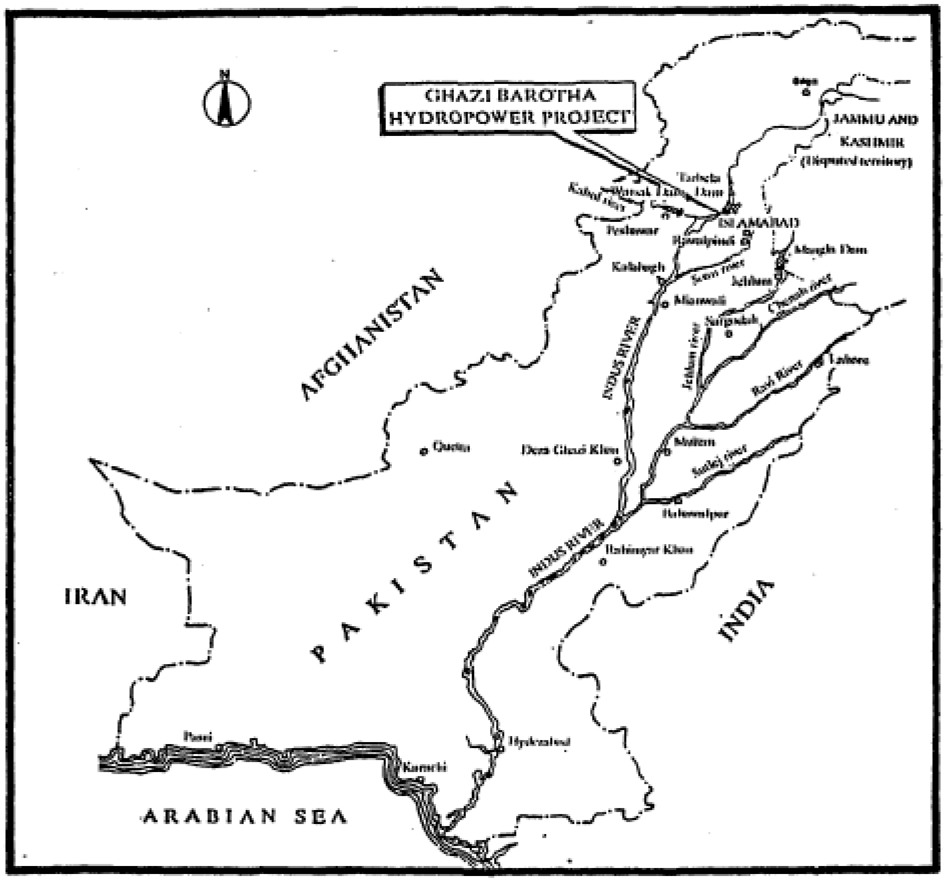

Figure 3.1 Location plan of project(WAPDA)

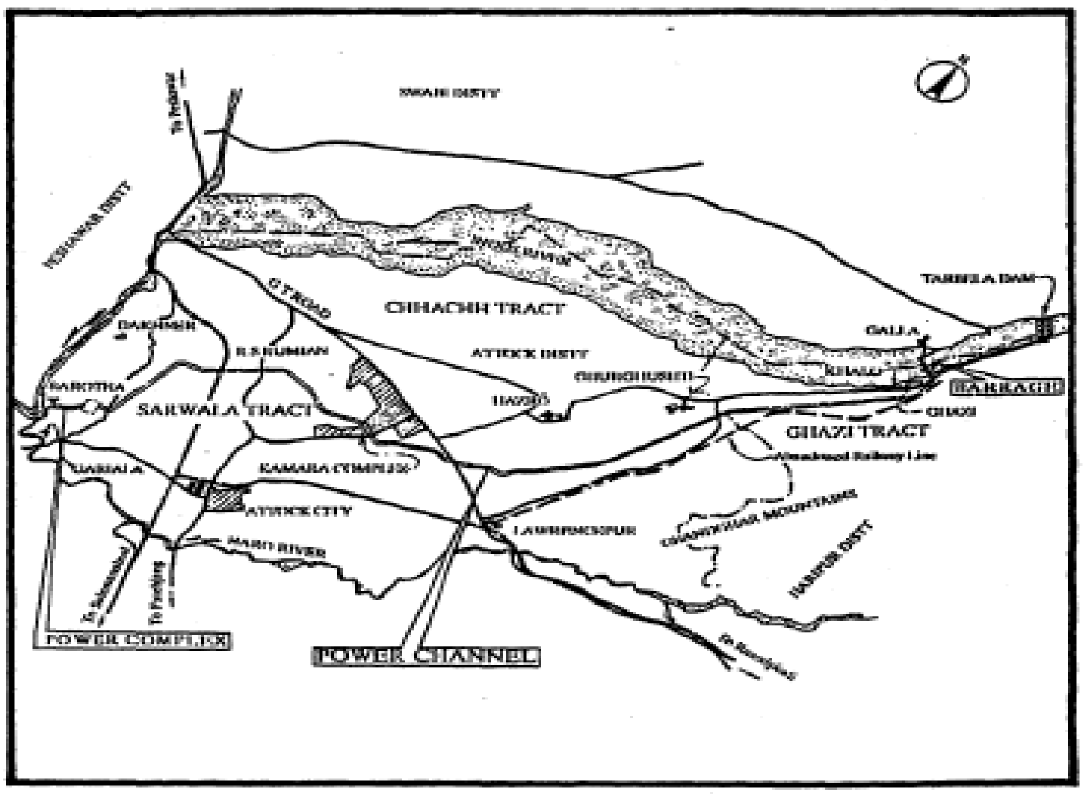

Figure 3.2 Project layout plan(WAPDA)

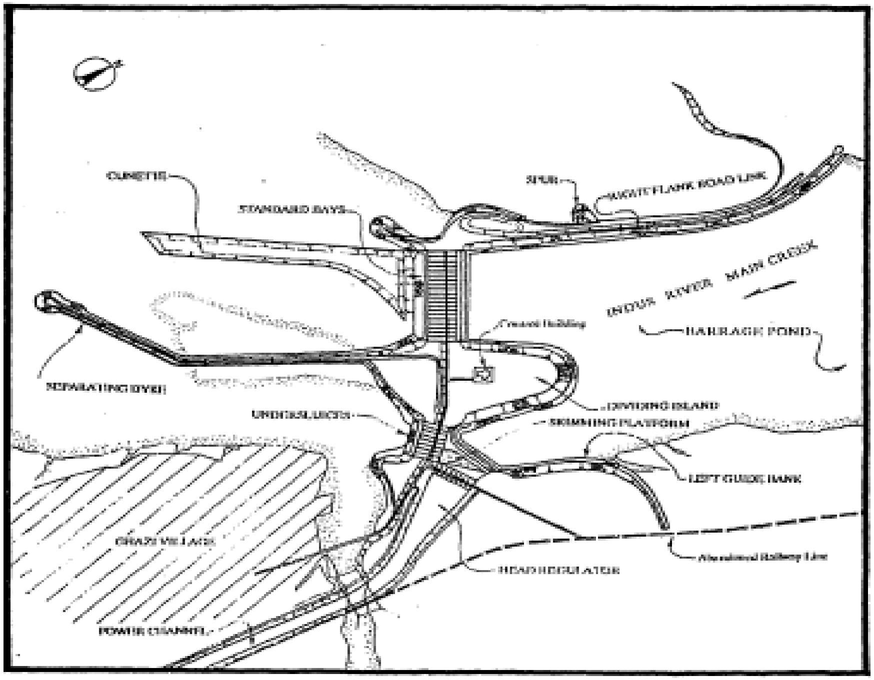

Figure 3.3 Barrage layout plan(WAPDA)

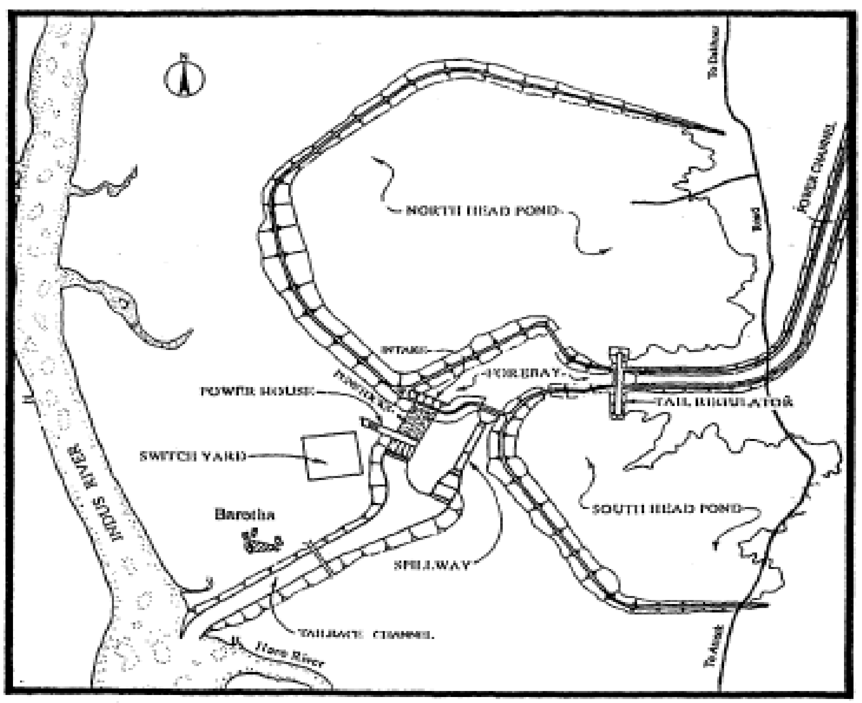

Figure 3.4 Power complex layout plan(WAPDA)

The zone of project entails the reach of Indus river which is affected and is part of Ghazi Barotha Hydropower Project. It is found downstream of Ghazi Barrage up to the convergence of Kabul waterway near Attock Bridge. On the Downstream side of Ghazi Barrage the Indus River flows in a wide and interwoven channel for a length of 48km before its union with Kabul River as shown in Figure 3.2. Topi Khwarh and Badri Khwarh are the two small streams that conveys urban sewage and minor floods from Khyber Pakhtunkhwa throughout monsoon and entering the affected reach.

3.1.2 Climate

The climate in this area is hot in summer season having temperature between 38^0C and 46^0C. the winters are cold here having temperature 3^0C and 14^0C. the coldest months are December and January.

3.1.3 Rainfall

The area is under the effect of the southeast monsoon causing July and August to be the wettest months having an average precipitation of 313mm and 173mm, respectively. The dry period ranges from October to December having an average precipitation of 10-35 mm/month.

3.1.4 Air

There are several industries, but area is not heavily crowded. Air is usually of good quality. Emissions in this area are attributed to traffic and the increased in concentration of dust is because of inadequate state of roadways over there. There is no station for environmental monitoring but for project monitoring of air quality is conducted and it was found out that quality parameters (NO_x, SO_2 and CO) concentration is in limits of NEQS and World Bank. Though the level of fine dust was surpassing the world bank recommended limits but are within NEQs limits.

3.1.5 Natural Water Resources

There is a cycle of low flow and high flow season throughout the year as reflected in the current flow pattern of the Indus river. The period of low flow generally varies from the mid of October to April. There is no main tributary in the concerned reach. In dry season, the low flow in the Indus is mostly what is released from Tarbela Dam all through the irrigation and power tunnels and the volume of this flow is regulated in correspondence with irrigation requirements at the downstream of barrages. In wet season, the high flows are discharged from above the spillways of the dam, in addition to the releases from power passageways. Little contributions in erratic form are also taken from little rivers runoff for the period of high flow season.

The mean daily minimum outflows that are mostly released during the month of January varies from 4202 to 22106 cusecs (average 13772 cusecs) as of 1976 to 1990.

The concerned reach of the Indus is having a length of about 41 km and stretch out amongst the Ghazi Barrage and the Kabul River. The mean value of Indus plain slope is about 1m/km (1:1000) and the width of river bottom is 2.2 to 4.5 km with tiny channels convoluted within it.

3.1.6 Topography

Khalo and Ghazi have a topography rolling with a mild slope in the direction of river Indus. The slope dramatically escalates beyond Ghazi Hamlet due to closeness of Ghandghar mountains on the side of southeast. From the run off from mountains three nullahs are produced, one passing to the north of Ghazi, the second divides the Khalo and Ghazi whilst the third one passes to the south of Khalo.

3.1.7 Area

The total area of Khalo and Ghazi have been estimated as 16 and 55ha respectively. These areas are based on data regarding the confining borders of these town given to the consultants.

3.1.8 Population

According to the report of WAPDA, the population of Khalo and Ghazi in 1991 were assessed to be 8255 persons and there was a growth rate of 3% annualy.

Chapter 4

METHODOLOGY

4.1 MATERIALS AND METHOD

The data which is required for this study is obtained from Tarbela Dam Authorities, WAPDA and Provincial Fishery Department KPK. Historic flows were needed for Hydrological methods, Cross Sections of river reach are required for Hydraulic methods and desirable water depth range of common fish species in Tarbela is required for Ecological analysis. The 45 years (1974-2019) records of inflows and outflows are used for the assessment of environmental flows in hydrological methods. The tarbela dam inflows are noted at upstream gauging station of Besham. Comparison of assessed environmental flow values by inflows are made with outflows released by the bays of Tarbela dam. Then for Post dam analysis, assessed environmental flow values by using data of outflows of Tarbela dam is compared with the 15 years (2004-2019) record of daily outflows that are released on downstream side of Ghazi Barrage. For the assessment of Environmental flows by hydraulic methods i.e. wetted perimeter method, comprising graphs of wetted perimeter versus discharge are used for the determination of inflection point. HEC-RAS is used for different River Stations (RS) of affected reach for calculation of wetted perimeters against different flow profiles. Then for ecological analysis we have linked fish species with the cross-section properties of affected reach.

4.2 ASSESSMENT OF ENVIRONMENTAL FLOWS

Prior to estimation of environmental flows, there is a comparison of the average monthly values of naturally existing inflows and regulated Tarbela Dam outflows as presented in Table 4.1

Table 4.1 Comparison of inflows and outflows of Tarbela dam

Months Wet season	Inflows (cusecs* 1000)	Outflows (cusecs* 1000)	Months Dry Season	Inflows (cusecs * 1000)	Outflows (cusecs* 1000)
May	75.7	69.7	Nov	25.7	50.6
Jun	157.0	127.6	Dec	19.7	33.1
Jul	238.5	180.0	Jan	16.7	18.5
Aug	224.8	194.5	Feb	18.3	36.3
Sep	104.6	120.6	Mar	23.4	30.9
Oct	41.0	59.7	Apr	34.6	33.5

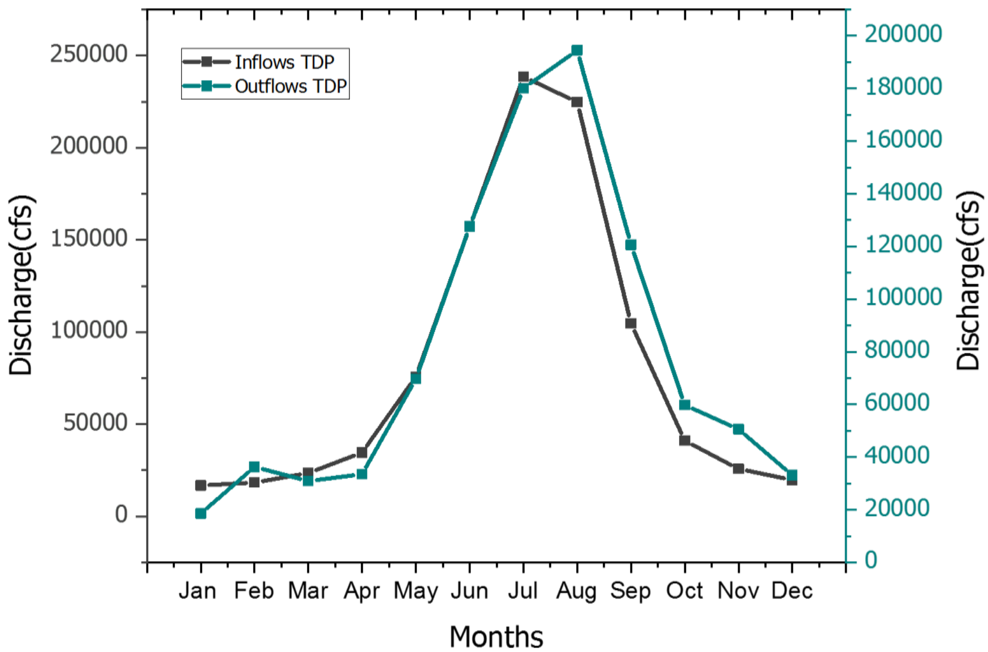

Figure 4.1 Comparison of Inflows and Outflows of Tarbela Dam

The comparison of average monthly values of naturally existing inflows at Tarbela dam and outflows released on the downstream side of Ghazi Barrage are presented in Table 4.2 and its graphical representation in Figure 4.2

Table 4.2 Comparison of Inflows of Tarbela dam and Outflows at Ghazi barrage

Months Wet season	Inflows at Tarbela (cusecs)	Outflows at Ghazi (cusecs)	Months Dry Season	Inflows at Tarbela (cusecs)	Outflows at Ghazi (cusecs)
May	75700	23782.77	Nov	25700	5872.14
Jun	157000	82028.26	Dec	19700	1397.06
Jul	238500	126648.3	Jan	16700	994.49
Aug	224800	140621.7	Feb	18300	1172.28
Sep	104600	65660.4	Mar	23400	1164.96
Oct	41000	7459.58	Apr	34600	1553.60

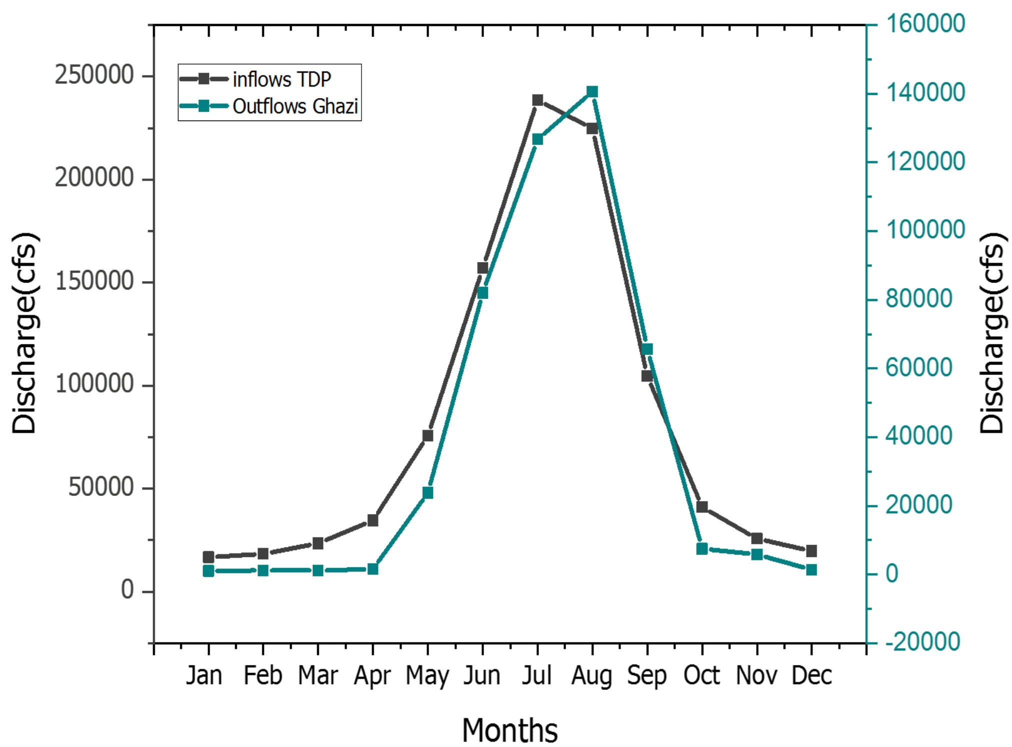

Figure 4.2 Comparison of Inflows of Tarbela Dam and Outflows at Ghazi Barrage

The quantity of outflows released downstream of ghazi barrage during dry season are very low as compared to the naturally available inflows. The difference in the flows can easily be seen in tabulated form in Table 4.2 above as well as from hydrograph showing comparisons in Figure 4.2.

In the Figure 4.3, we can see the comparison between naturally available inflows of Tarbela Dam, regulated outflows of Tarbela Dam and outflows released downstream of Ghazi Barrage.

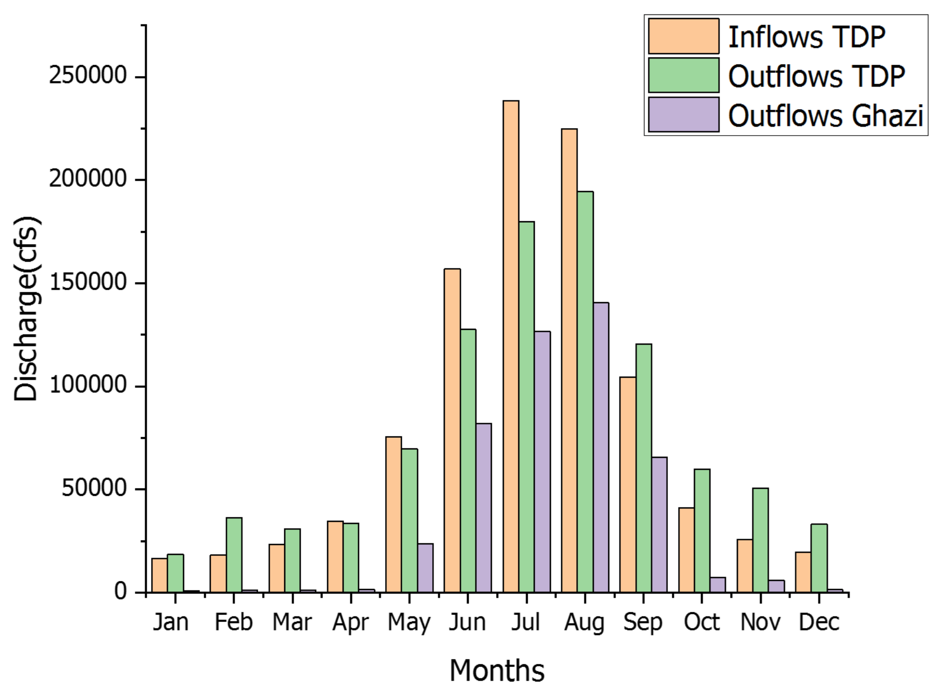

Figure 4.3 Comparison of Inflows and outflows of Tarbela Dam and outflows released at Ghazi Barrage

4.2.1 Tenant Method

This mean annual flow is calculated by using data of about 45 years. The calculated mean flow value of Indus river at upstream side of Tarbela dam is 82600 cubic feet per second-cusecs. The environmental flow requirements based on this value using tenant approach for dry season is presented in Table 4.3 and for wet season in Table 4.4

Table 4.3 EFR calculation for Dry Season using Tenant approach

Description of general condition of flow	Recommended flow regimes (% of MAF) Nov-Apr	Calculated Values of EFR (cusecs)
Flushing or maximum	200%	165200
Optimum range	60-100%	49560-82600
Outstanding	40%	33040
Excellent	30%	24780
Good	20%	16520
Fair or degrading	10%	8260
Poor or minimum	10%	8260
Severe degradation	<10%	< 8260

Table 4.4 EFR calculation for wet season using Tenant approach

Description of general condition of flow	Recommended flow regimes (% of MAF) May-Oct	Calculated Values of EFR (cusecs)
Flushing or maximum	200%	165200
Optimum range	60-100%	49560-82600
Outstanding	60%	49560
Excellent	50%	41300
Good	40%	33040
Fair or degrading	30%	24780
Poor or minimum	10%	8260
Severe degradation	<10%	< 8260

Table 4.5 Different riverine ecosystem conditions corresponding varies base flows

Description of river ecosystem condition corresponding to flow	Calculation of environmental flows			
	November-April		May to October	
	%MAF	Calculated EFRs (cusecs)	%MAF	Calculated EFRs (cusecs)
Excellent to outstanding habitat	40%	33040	60%	49560
Able to sustain fair survival conditions	10%	8260	30%	24780
Minimum for short term fish survival	10%	8260	10%	8260

Tennant has concisely decided that for the short-term survival of fish the minimum requirement of flow is 10% MAF, for the fair survival of fish the requirement of flow is 30% MAF and for optimum habitat of fish the requirement of flow is 60% MAF as shown in Table 4.5. These valued of environmental flows are used worldwide regardless of hydrologic and physical background owing to ease of using average values of historical flow.

Now for post Tarbela Dam and post Ghazi Barrage analysis, same approach is employed, and the calculations are for the mean annual flow of Indus river at downstream side of Tarbela Dam is 80790 cubic feet per second-cusecs. The environmental flow requirements based on this value using tenant approach for dry season is presented in Table 4.6 and for wet season in Table 4.7.

Table 4.6 EFR Calculation for dry season by Tenant method

Description of general condition of flow	Recommended flow regimes (% of MAF) Nov-Apr	Calculated Values of EFR (cusecs)
Flushing or maximum	200%	161580
Optimum range	60-100%	48474-80790
Outstanding	40%	32316
Excellent	30%	24237
Good	20%	16158
Fair or degrading	10%	8079
Poor or minimum	10%	8079
Severe degradation	<10%	< 8079

Table 4.7 EFR Calculation for wet season by Tenant method

Description of general condition of flow	Recommended flow regimes (% of MAF) May-Oct	Calculated Values of EFR (cusecs)
Flushing or maximum	200%	161580
Optimum range	60-100%	48474-80790
Outstanding	60%	48474
Excellent	50%	40395
Good	40%	32316
Fair or degrading	30%	24237
Poor or minimum	10%	8079
Severe degradation	<10%	< 8079

Table 4.8 Different riverine ecosystem conditions corresponding varies base flows

Description of river ecosystem condition corresponding to flow	Calculation of environmental flows			
	November-April		May to October	
	%MAF	Calculated EFRs (cusecs)	%MAF	Calculated EFRs (cusecs)
Excellent to outstanding habitat	40%	32316	60%	48474
Able to sustain fair survival conditions	10%	8079	30%	24237
Minimum for short term fish survival	10%	8079	10%	8079

4.2.2 Tessman Method

This method recommends three different situations for the estimation of environmental flows. The main reason of using these conditions is to include season variation in determination of environmental flows. For the evaluation of environmental flow requirements using tessman method, recommended flows are shown in Table 4.9

Table 4.9 Tessman Method for evaluating environmental flow requirements

Situation	Recommended EFR
1. MMF < 40% MAF	MMF
2. MMF > 40% MAF and 40% MMF < 40% MAF	40% MAF
3. 40% MMF > 40% MAF	40% MMF

In Table 4.9, MAF represents mean annual flow and MMF represents mean monthly flow. For flushing purpose, tessman prescribed a 14-day period of 200% during the month of highest flow.

The calculated MAF is 82600 cusecs and 40% MAF is 33040 cusecs. These values are employed in assessing environmental flows by tessman method. Table 4.10 shows values of MMF and 40% of MMF for each month

Table 4.10 MMF and 40% MMF

Months	MMF (cusecs)	40% MMF (cusecs)	Months	MMF (cusecs)	40% MMF (cusecs)
Jan	16700	6680	Jul	238500	95400
Feb	18300	7320	Aug	224800	89920
Mar	23400	9360	Sep	104600	41840
Apr	34600	13840	Oct	41000	16400
May	75700	30280	Nov	25700	10280
Jun	157000	62800	Dec	19700	7880

Keeping in view the values of MAF, MMF, 40% MAF and 40%MMF, environmental flows estimated for each month by tessman method are tabulated in Table 4.11

Table 4.11 Calculation of EFR by Tessman Method

Month	Situation	EFR (cusecs)
Jan	MMF (16700) < 40% MAF (33040)	16700
Feb	MMF (18300) < 40% MAF (33040)	18300
Mar	MMF (23400) < 40% MAF (33040)	23400
Apr	MMF (34600) > 40% MAF (33040) & 40% MMF (13840) < 40% MAF (33040)	33040
May	MMF (75700) > 40% MAF (33040) & 40% MMF (30280) < 40% MAF (33040)	33040
Jun	40% MMF (62800) > 40% MAF (33040)	62800
Jul	40% MMF (95400) > 40% MAF (33040)	95400
Aug	40% MMF (89920) > 40% MAF (33040)	89920
Sep	40% MMF (41840) > 40% MAF (33040)	41840
Oct	MMF (41000) > 40% MAF (33040) & 40% MMF (16400) < 40% MAF (33040)	33040
Nov	MMF (25700) < 40% MAF (33040)	25700
Dec	MMF (19700) < 40% MAF (33040)	19700

The discharge of 165200 cusecs which is 200% MAF must be upheld for a 14-day period during the month of July i.e. highest flow, for flushing purpose.

Now for post Tarbela Dam and post Ghazi Barrage analysis, same approach is used, and the calculations are for the value of MAF of Indus river at downstream side of Tarbela Dam is 80790 cubic feet per second-cusecs and 40% MAF is 32316 cusecs. Table 4.12 shows values of MMF and 40% of MMF for each month.

Table 4.12 Mean Monthly Flows (MMF) and 40% of MMF

Months	MMF (cusecs)	40% MMF (cusecs)	Months	MMF (cusecs)	40% MMF (cusecs)
Jan	18500	7400	Jul	180000	72000
Feb	36300	14520	Aug	194500	77800
Mar	30900	12360	Sep	120600	48240
Apr	33500	13400	Oct	59700	23880
May	69700	27880	Nov	50600	20240
Jun	127600	51040	Dec	33100	13240

Keeping in view the values of MAF, MMF, 40% MAF and 40%MMF, environmental flows estimated for each month by Tessman method are tabulated in Table 4.13

Table 4.13 Calculation of EFRs using Tessman's method

Month	Situation	EFR (cusecs)
Jan	MMF (18500) < 40% MAF (32316)	18500
Feb	MMF (36300) > 40% MAF (32316) & 40% MMF (14520) < 40% MAF (32316)	32316
Mar	MMF (30900) < 40% MAF (32316)	30900
Apr	MMF (33500) > 40% MAF (32316) & 40% MMF (13400) < 40% MAF (32316)	32316
May	MMF (69700) > 40% MAF (32316) & 40% MMF (27880) < 40% MAF (32316)	32316
Jun	40% MMF (51040) > 40% MAF (32316)	51040
Jul	40% MMF (72000) > 40% MAF (32316)	72000
Aug	40% MMF (77800) > 40% MAF (32316)	77800
Sep	40% MMF (48240) > 40% MAF (32316)	48240
Oct	MMF (59700) > 40% MAF (32316) & 40% MMF (23880) < 40% MAF (32316)	32316
Nov	MMF (50600) > 40% MAF (32316) & 40% MMF (20240) < 40% MAF (32316)	32316
Dec	MMF (33100) > 40% MAF (32316) & 40% MMF (13240) < 40% MAF (32316)	32316

4.2.3 Monthly Modified Tennant Method

This method uses historical data of flows for each month of the year to calculate mean monthly flows. Different percentages of environmental flows are then calculated by using MMF as shown in Table 4.14

Table 4.14 Calculation of EFRs using monthly modified Tenant method

Month	Calculated EFRs for each month (cusecs)		
	10% of MMF	30% of MMF	60% of MMF
Jan	1670	5010	10020
Feb	1830	5490	10980
Mar	2340	7020	14040
Apr	3460	10380	20760
May	7570	22710	45420
Jun	15700	47100	94200
Jul	23850	71550	143100
Aug	22480	67440	134880
Sep	10460	31380	62760
Oct	4100	12300	24600
Nov	2570	7710	15420
Dec	1970	5910	11820

Now for post Tarbela Dam and post Ghazi Barrage analysis, same approach is used, and the calculations are for the value of MAF of Indus river at downstream side of Tarbela Dam is 80790 cubic feet per second-cusecs and the estimated values of EFR are given in Table 4.15

Table 4.15 Assessment of EFRs using monthly modified Tenant method

Month	Calculated EFRs for each month (cusecs)		
	10% of MMF	30% of MMF	60% of MMF
Jan	1850	5550	11100
Feb	3630	10890	21780
Mar	3090	9270	18540
Apr	3350	10050	20100
May	6970	20910	41820
Jun	12760	38280	76560
Jul	18000	54000	108000
Aug	19450	58350	116700
Sep	12060	36180	72360
Oct	5970	17910	35820
Nov	5060	15180	30360
Dec	3310	9930	19860

4.2.4 Low Flow Indices

Low flow indices were then implied as environmental flows for protecting aquatic life. 7Q10 is the generally suggested hydrological index. It is defined as lowest recorded value of flow within a return period of 10 years for seven consecutive days (Caissie and El 2003). 7Q2 uses a return period of 2 years for seven consecutive days of low flows.

7Q10 is most used in low flow indices for environmental flows, globally. The other hydrological indices used as EFR are 7Q2, 7Q20, 30Q10 and 1Q10. The values of environmental flow requirements suggested by using low flow indices are given in Table 4.16

Table 4.16 Values of EFR by Low flow indices

Low Flow Index	EFR (cusecs *1000)
7Q10	11.69643
7Q20	11.32143
7Q2	13.55929
1Q10	10.875
30Q10	12.6325

Now for post Tarbela Dam and post Ghazi Barrage analysis, same approach is used, and the calculations are for the value of MAF of Indus river at downstream side of Tarbela Dam is 80790 cubic feet per second-cusecs. The calculation for estimating environmental flow requirements by low flow indices based on this mean annual flow is given in Table 4.17

Table 4.17 Values of EFRs using Low flow Indices

Low Flow Index	EFR (cusecs *1000)
7Q10	3.65
7Q20	2.292857
7Q2	8.001056
1Q10	3.125
30Q10	4.947333

4.2.5 Flow Duration Curve Method

A flow duration curve (FDC) is classified as a cumulative distribution of flows representing the percent of time over a specific period of observations. FDC representing values of discharge could be daily, weekly or fortnightly. It basically represents the variability and range of flow data when there is daily flow data used. The flow data is generally plotted as percentages of total flow or on a log scale. Long term data is useful in evaluating the accessibility of water at specific point. Q_{95} exceedance percentile can be described as the discharge which is equal or more for 95% of the time. The exceedance percentile commonly used as environmental flows are Q90 and Q95 (Pyrce). Environmental flow requirements estimated by using exceedance percentile method Q_{95} for each month is given in Table 4.18

Table 4.18 Assessment of EFR using Exceedance percentile method for each month

Month	Monthly Q_{95}	Month	Monthly Q_{95}
Jan	12300	Jul	123560
Feb	11600	Aug	123640
Mar	13280	Sep	51680
Apr	20400	Oct	26900
May	33150	Nov	18900
Jun	73180	Dec	15100

Now for post Tarbela Dam and post Ghazi Barrage analysis, same approach is used, and the calculations are for the value of MAF of Indus river at downstream side of Tarbela Dam is 80790 cubic feet per second-cusecs. Environmental flow requirements based on this mean annual flow value estimated by using exceedance percentile method Q_{95} for each month is given in Table 4.19

Table 4.19 Assessment of EFR using Exceedance percentile method for each month

Months	Monthly Q_{95}	Month	Monthly Q_{95}
Jan	3000	Jul	34490
Feb	1910	Aug	46170
Mar	7000	Sep	46890
Apr	8829	Oct	15950
May	19260	Nov	15000
Jun	30910	Dec	8036

4.3 HYDRAULIC METHOD

4.3.1 Wetted Perimeter Method (WPM)

This method(Gippel and Stewardson 1998) calculates environmental flows based on correlation between discharge and river cross section. It is a hydraulic rating method based on the relationship between wetted perimeter of river and flow at selected cross section of the river reach. The roughness of river reach, slope of riverbed, transection profiles acquired by hydrological data series or by on ground surveys are essential components. Wetted perimeter is that portion of particular river reach whose cross section is in contact with water. Rendering to the response curve of discharge and wetted perimeter, the critical flow requirement for the representation of habitat is represented by inflection point below which the conditions become unfavorable for aquatic life. The breakpoint in a relationship of discharge versus wetted perimeter is known as inflection point. There are several ways to identify the inflection point on wetted perimeter-discharge curve. When environmental flows are assessed by WPM fitting functions are used often. Fitting functions of this curve (i.e. wetted perimeter-discharge curve) differ with different transection sections. For triangles and parabola transections, power function is used while for rectangle and trapezoidal transections, exponential function is used.

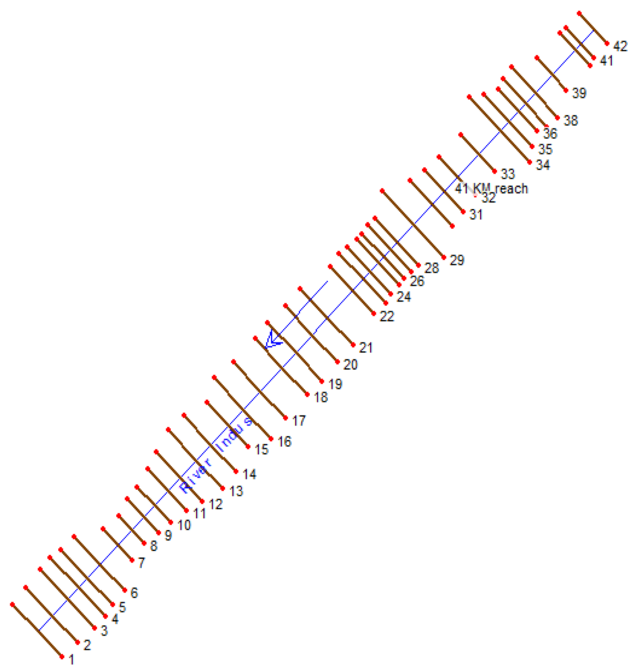

Figure 4.4 Details of 42 river station points of considered affected reach of River Indus

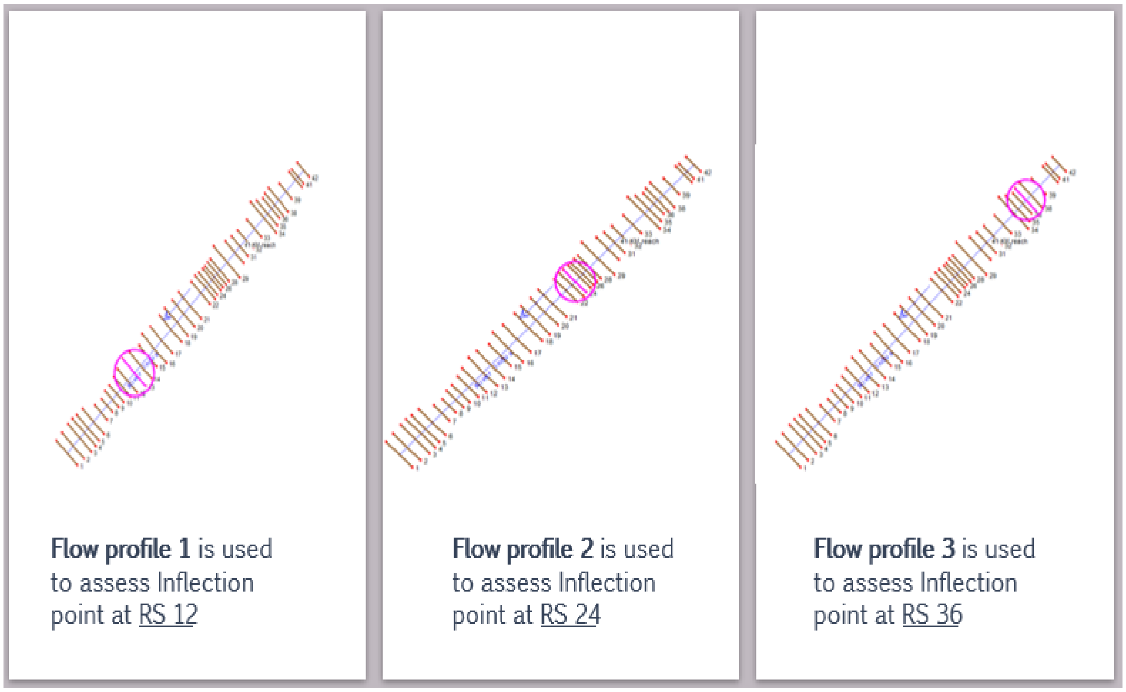

Figure 4.5 River Stations

RS 42 is on Upstream side and RS01 is located near the confluence of River Indus and River Kabul as shown in Figure 4.4. In Figure 4.5, three different river stations considered for finding the inflection point is indicated.

4.4 ECOLOGICAL MODULE

Field surveys are important to find out the ecological necessities for characteristic fish species and development stages known to occur at this site. According to the report by WAPDA, the key species included Mahseer, Challi, Shooondal, Common Carp, Silver Carp, Sheer Mahi, Sulemani, Daula and Dauli. According to the KPK Fishery Department, the commercial fish species found in

Tarbela Dam are Grass Carp, Silver Carp, Rohu Carp, Common Carp, big head Carp and Mahseer. The scientific name of these species is Ctenopharyngodon Idella, Hypopthalmichthvs molitrix, Labeo rohita, Cyrpinus carpio, Hypophthalmichthys nobilis and Tor putitora respectively. The preferences of fish species were enumerated by means of river habitation features which include width, depth, velocity, substrate characteristics, instream cover and bank cover as well as parameters of water quality which includes temperature, pH, dissolved oxygen and conductivity. A summary of the above information in terms of desirable water depth range is shown in Table 4.20

Table 4.20 Fish and their desirable water depths

Fish Species	Scientific name	Desirable Water depth (m)
Grass carp	Ctenopharyngodon idella	1.75
Silver carp	Hypopthalmichthvs molitrix	0.9
Rohu carp	Labeo rohita	0.75
Common carp	Cyrpinus carpio	1.75
Big head carp	Hypophthalmichthys nobilis	1.75
Mahseer	Tor putitora	1.25

Chapter 5

RESULTS AND DISCUSSION

In this chapter, environmental flows calculated by different methods are now compared with upstream inflows of Tarbela Dam, regulated outflows from Tarbela Dam and the outflows released at the downstream of Ghazi Barrage. Bar chats are plotted to compare the different values of EFR with inflows and outflows.

Pre-Dam Analysis

Environmental flows calculation is carried out on the inflows of Tarbela Dam.

Before discussing hydrological methods, here is the comparison of naturally available inflows of Tarbela Dam, regulated outflows of Tarbela Dam and outflows at downstream side of Ghazi Barrage in Figure 5.1

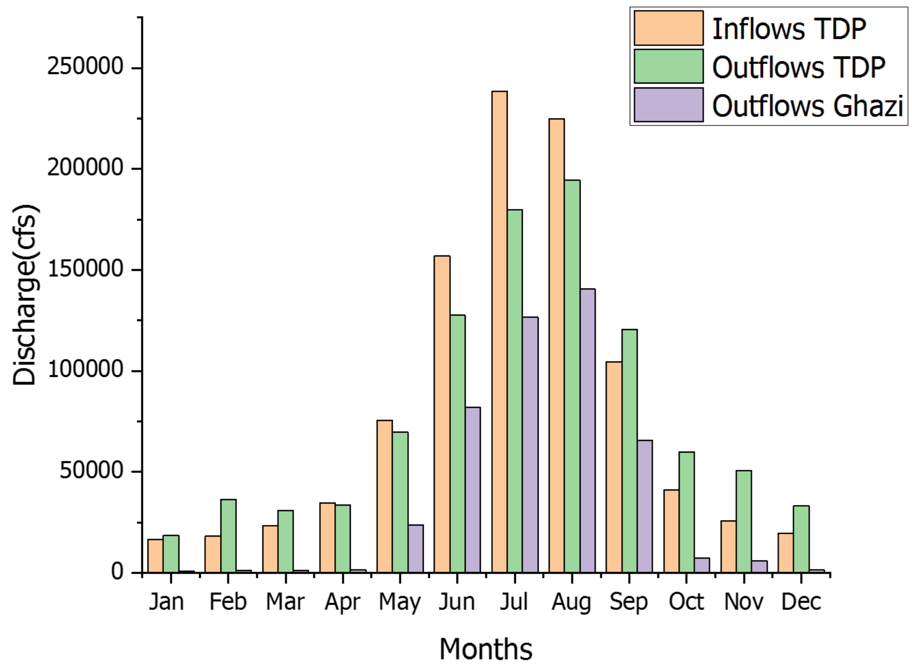

Figure 5.1 Comparison of inflows and outflows from Tarbela Dam and outflows at Ghazi Barrage

5.1 COMPARISON OF ENVIRONMENTAL FLOWS CALCULATED BY TENANT METHOD WITH INFLOWS AND OUTFLOWS

Figure 5.2 shows the comparison of outflows at Tarbela Dam, calculated EFR by tenant method and outflows at Ghazi Barrage.

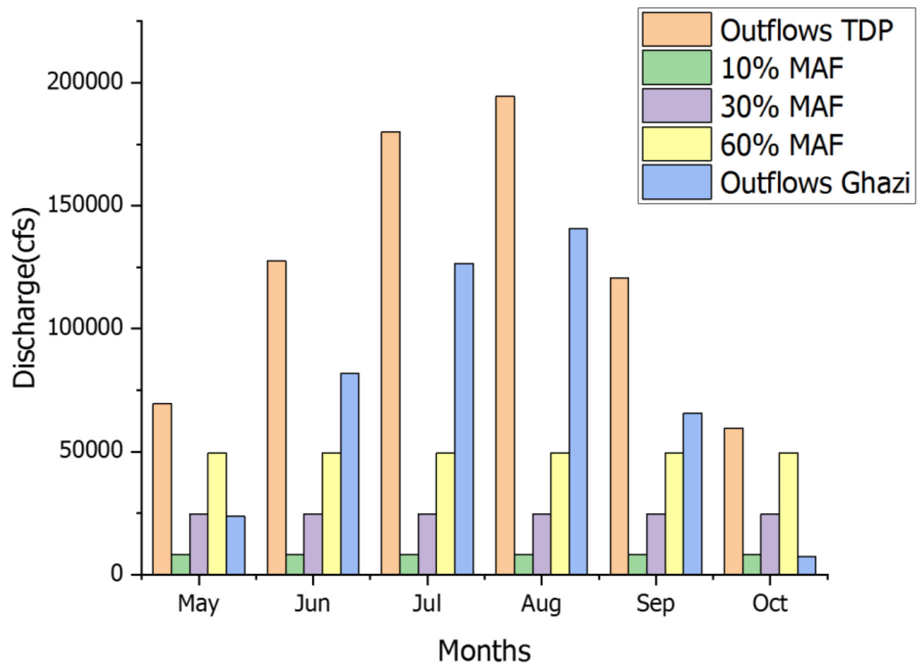

Figure 5.2 Comparison of EFR by Tenant Method with outflows of Tarbela Dam and Ghazi Barrage during wet season

It is evident from Figure 5.2 that quantity if outflows released from Tarbela Dam are greater than the recommended values of EFR during wet season.

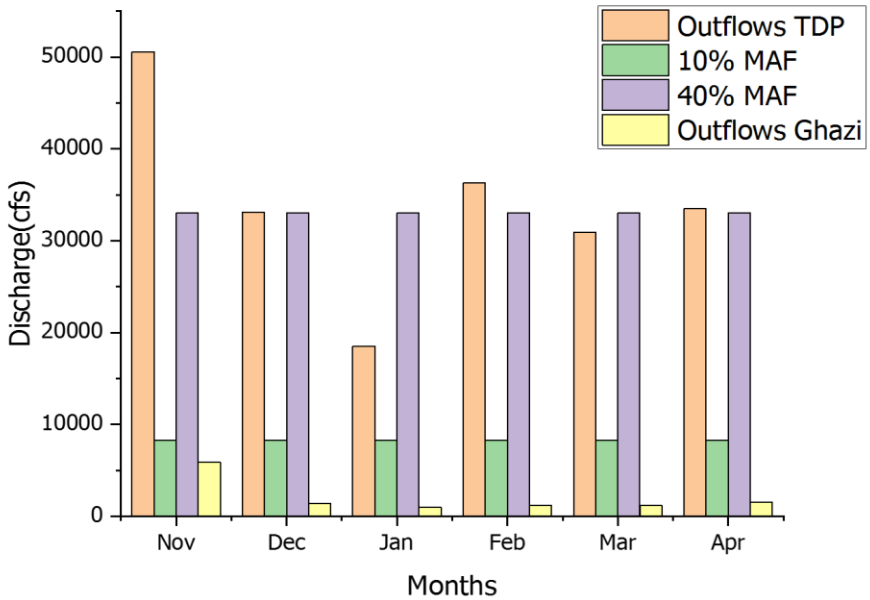

Figure 5.3 Comparison of EFR by Tenant Method with outflows of Tarbela Dam and Ghazi barrage during dry season

From Figure 5.3 in dry season, Tarbela Dam outflows are meeting the minimum values of EFR recommended by Tenant method. From above graph, it is shown that outflows of Tarbela Dam are greater than 40% MAF for the months of November and February and the outflows of Tarbela Dam are slightly greater than 40% MAF for the month of December and April. In January and March, outflows are less than 40% MAF.

Environmental flow calculation carried out on the outflows of Tarbela Dam.

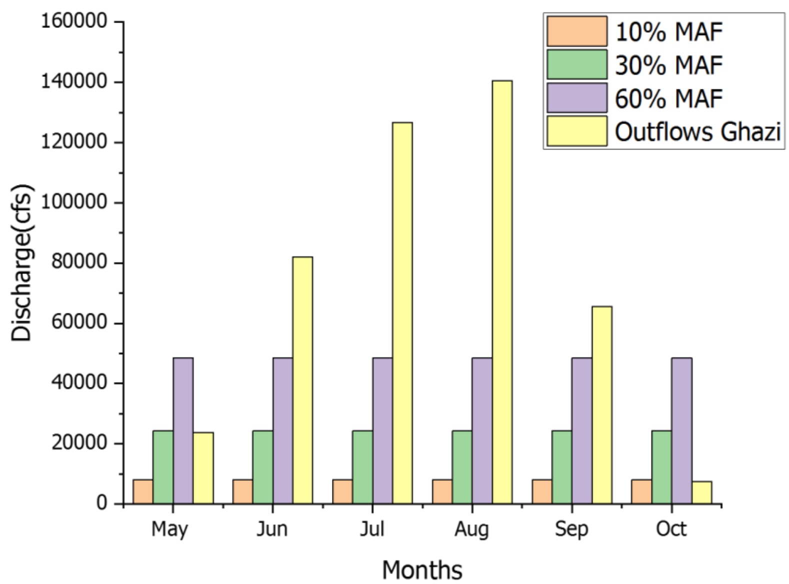

Figure 5.4 Comparison of EFR by Tenant Method with outflows at Ghazi Barrage during wet season

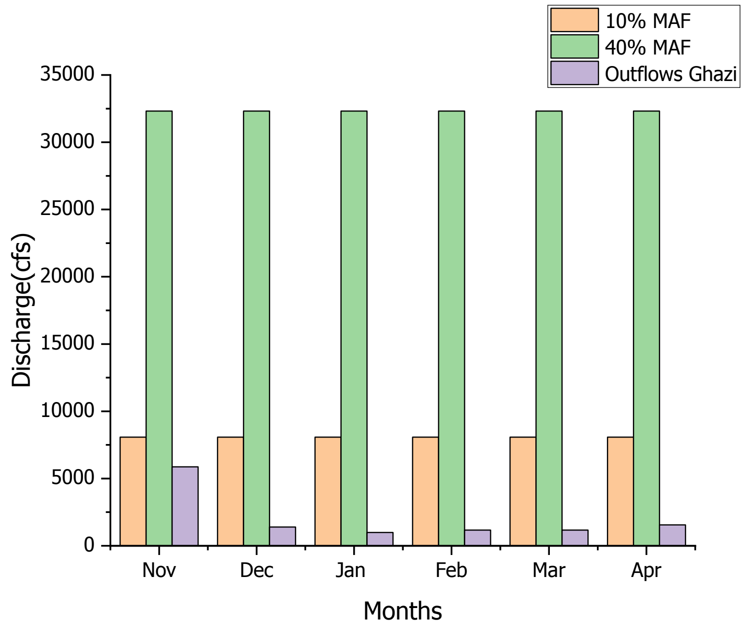

Figure 5.5 Comparison of EFR by Tenant Method with outflows at Ghazi Barrage during dry season

5.2 COMPARISON OF ENVIRONMENTAL FLOWS CALCULATED BY TESSMAN METHOD WITH INFLOWS AND OUTFLOWS

The main difference in Tenant and Tessman method is that Tessman method incorporates the seasonal variation of the natural flow regime of the River Indus. It can be seen from Figures 5.6 and 5.7 that the quantity of outflows released from Tarbela Dam are more than all the recommended values of EFR recommended by tessman during both the wet and dry seasons.

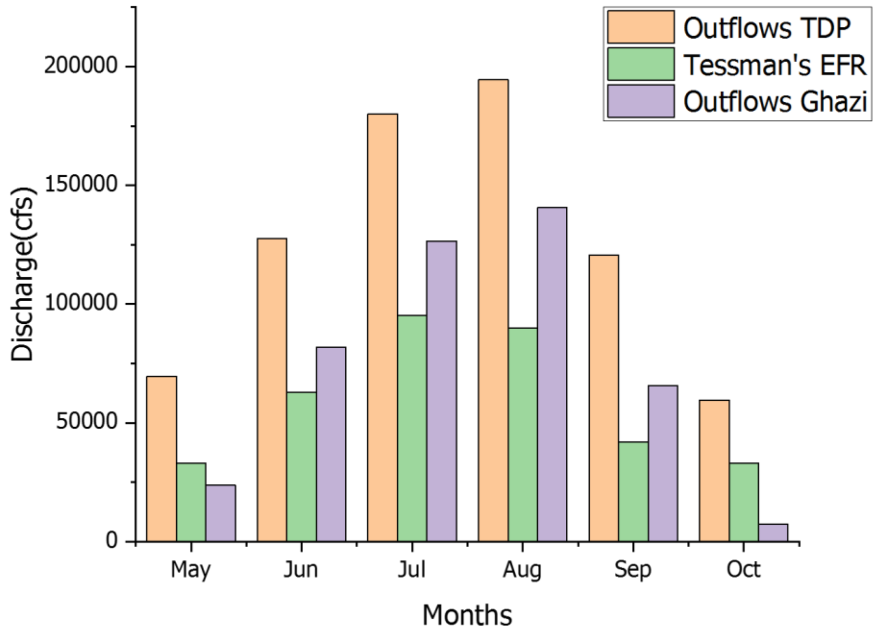

Figure 5.6 Comparison of EFR by Tessman Method with outflows of Tarbela Dam and Ghazi Barrage during wet season

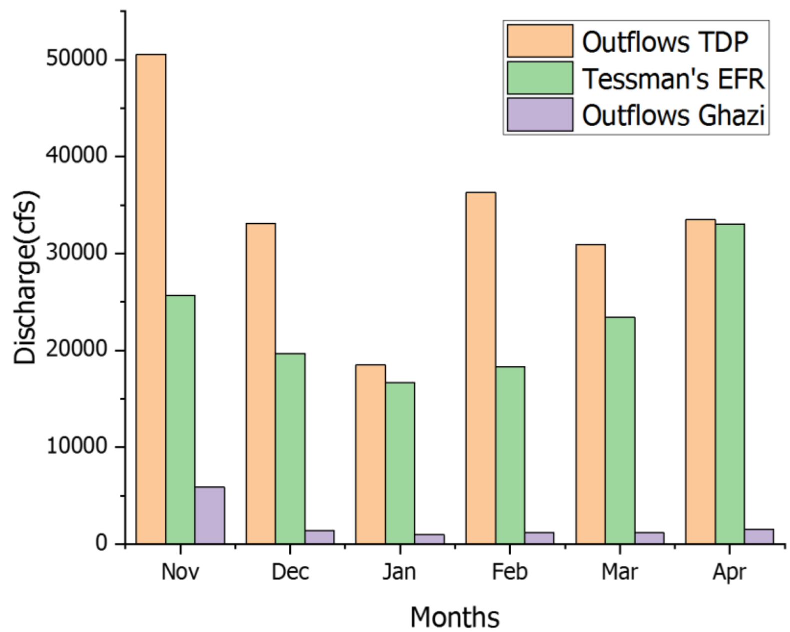

Figure 5.7 Comparison of EFR by Tessman Method with outflows of Tarbela Dam and Ghazi Barrage during dry season

From figures 5.6 and 5.7 the difference in the values of outflows from Tarbela Dam and EFR value recommended by Tessman method is very small for the months of January and April. Comparison by bar charts are plotted between regulated outflows of Tarbela Dam, EFR calculated by tessman method and outflows on the downstream side of Ghazi Barrage. It is evident from the bar charts that from October to May the average value of outflows released on the downstream side of Ghazi Barrage is much less than the suggested tessman's EFR. The reason at the back of this difference in the flows is that almost all the available flow is diverted into power channel of Ghazi Barotha for power generation. For June to September the average monthly outflows released at Ghazi Barrage are more than the recommended tessman's EFR.

Environmental flows calculation carried out on the outflows of Tarbela Dam.

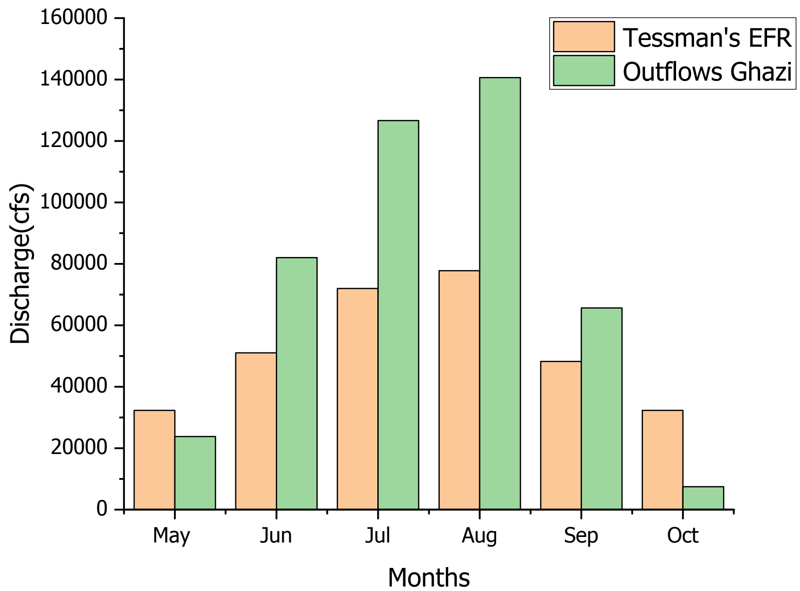

Figure 5.8 Comparison of EFR by Tessman Method with outflows at Ghazi Barrage during wet season

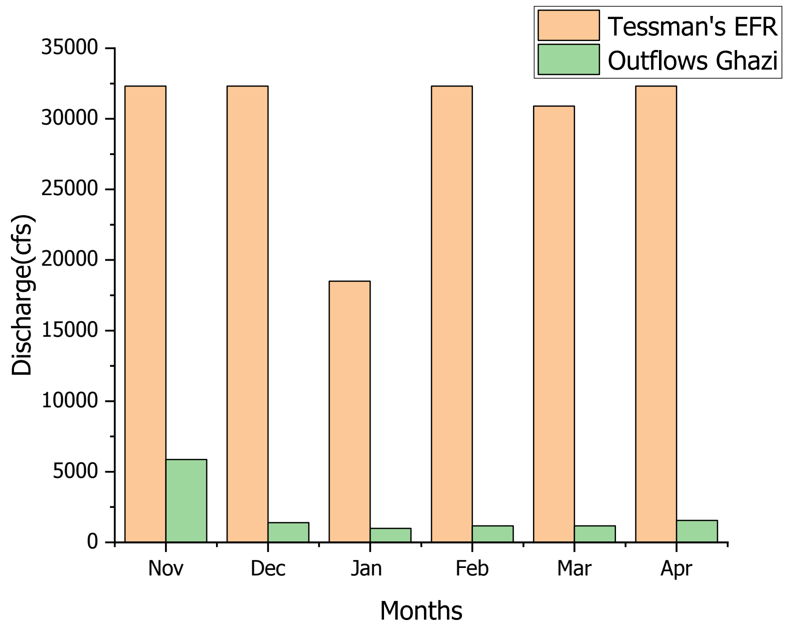

Figure 5.9 Comparison of EFR by Tessman Method with outflows at Ghazi Barrage during dry season

5.3 COMPARISON OF ENVIRONMENTAL FLOWS CALCULATED BY MONTHLY MODIFIED TENNANT METHOD (MMTM) WITH INFLOWS AND OUTFLOWS

Environmental flows are assessed by using the value of mean annual flow in original tenant method. The method is revised into new method named monthly modified tenant method to include the intra-annual variation in flow regime of river Indus in determining environmental flow values.

The comparison of outflows of TDP, EFR calculated by MMTM and outflows on the downstream side of ghazi barrage is shown in Figure 5.10. From both Figures

5.10 and 5.11 i..e wet season and dry season, it can be seen that quantity of outflows released from tarbela dam are more than the EFR defined by MMTM during whole year.

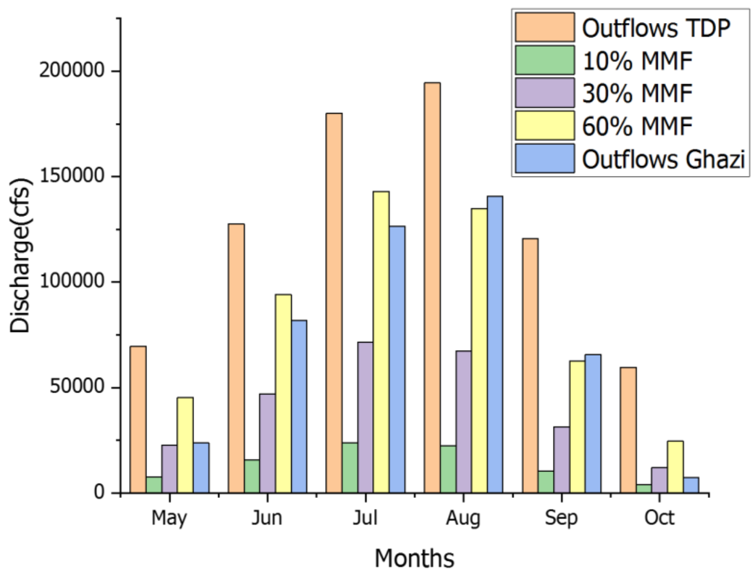

Figure 5.10 Comparison of EFR by Monthly Modified Tenant Method with outflows of Tarbela Dam and Ghazi Barrage during wet season

From Figure 5.10, it can be seen that during the months of May, June and July the outflows at the downstream side of Ghazi Barrage are fulfilling the requirement of the two out of three values of suggested EFR by Monthly Modified Tenant Method (MMTM) and the outflows at Ghazi Barrage are less than 60% MMF only during these months. In August and September, outflows at Ghazi Barrage are satisfying all the three values of recommended EFR but in October the outflows at Ghazi Barrage are very less that it is only suitable for the condition of short-term survival of fish.

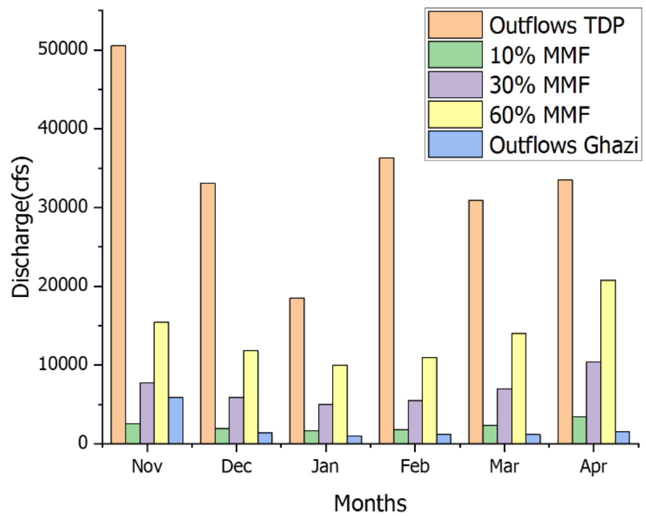

Figure 5.11 Comparison of EFR by Monthly Modified Tenant Method with outflows of Tarbela Dam and Ghazi Barrage during dry season

Now, when it comes to dry season, the outflows at the downstream side of Ghazi Barrage are very less during the months of December, January, February, March and April as they don't even satisfy any single value of EFR recommended by MMTM as shown in Figure 5.11. Only in November, it satisfies one value out of three of recommended EFR. During dry season, in most of the months the flow is very flow that it is not even satisfying the needs of short-term survival of fish.

Environmental flows calculation carried out on the outflows of Tarbela Dam.

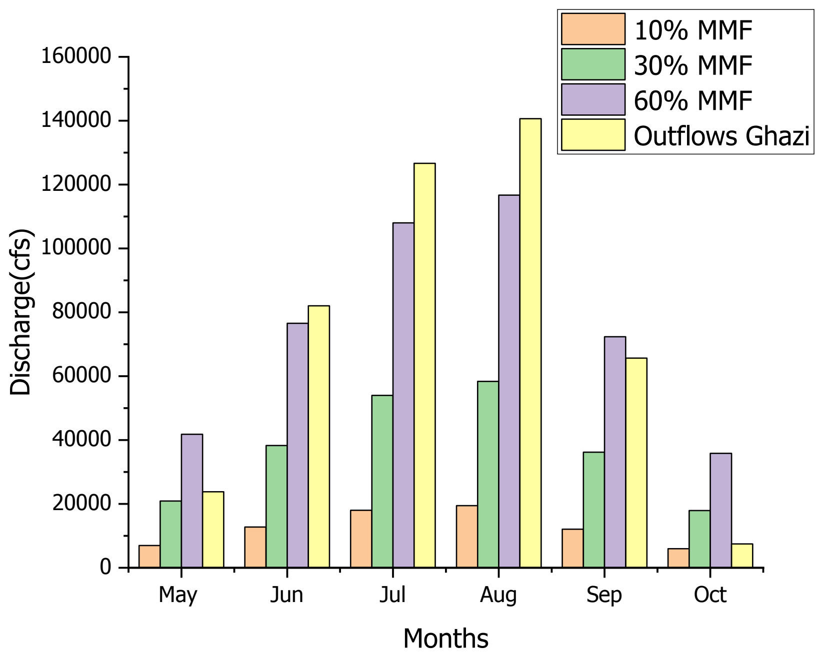

Figure 5.12 Comparison of EFR by Monthly Modified Tenant Method with outflows at Ghazi Barrage during wet season

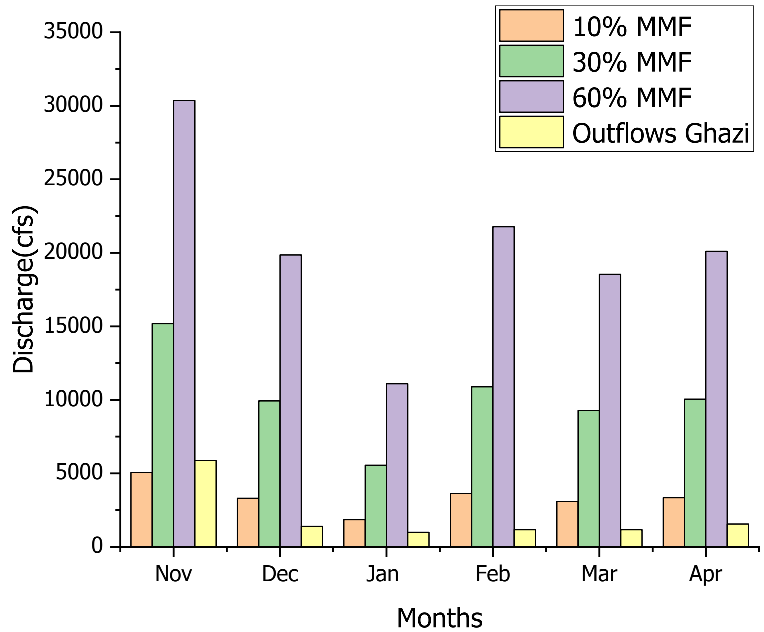

Figure 5.13 Comparison of EFR by Monthly Modified Tenant Method with outflows at Ghazi Barrage during dry season

5.4 COMPARISON OF ENVIRONMENTAL FLOWS CALCULATED BY LOW FLOW INDICES (LFI) WITH INFLOWS AND OUTFLOWS

By comparing the values of outflows of Tarbela Dam with different values of low flow, it is obvious that these outflows provide sufficient amount of water for the sustainability of riverine ecosystem.

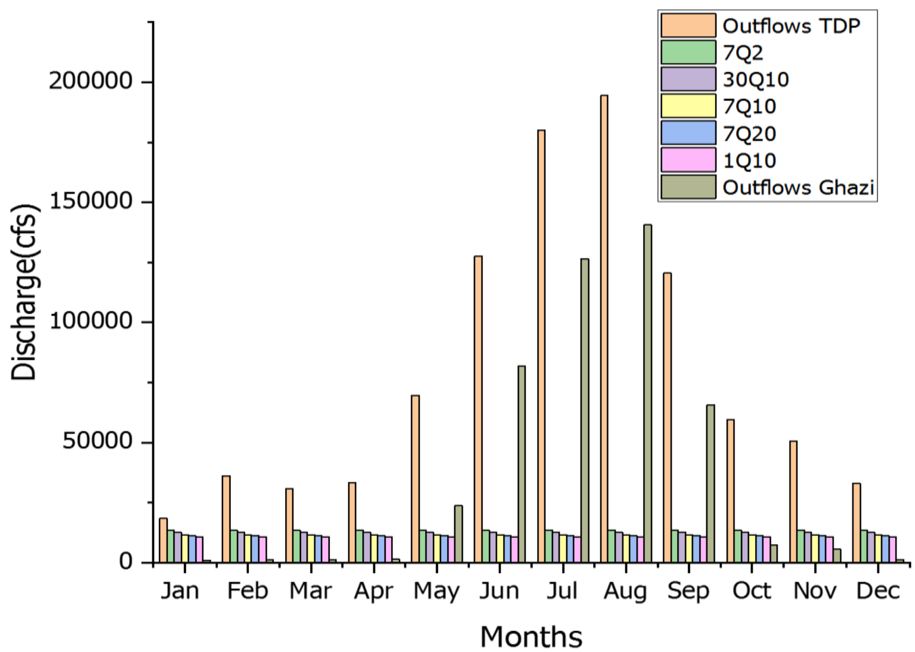

Figure 5.14 Comparison of EFR by Low flow indices with outflows of Tarbela Dam and Ghazi Barrage

Environmental flows are maintained during the five months i.e. May, June, July, August and September, as we can see through graph in Figure 5.14 that outflows at Ghazi Barrage are greater than the EFR values recommended by Low flow indices. Outflows released at the downstream side of Ghazi Barrage are very low in the rest of months.

The condition of the affected reach is not satisfying at all during the months of dry season as environmental flows are not maintained in any month of the dry season.

The difference in the values of outflows at Ghazi Barrage and recommended EFR values is very large in all months of dry season except November and from wet season the difference is very large for the month of October. The reason behind this large difference in the values could either be the storage in tarbela dam or diversion of available water in power channel.

Environmental flows calculation carried out on the outflows of Tarbela Dam.

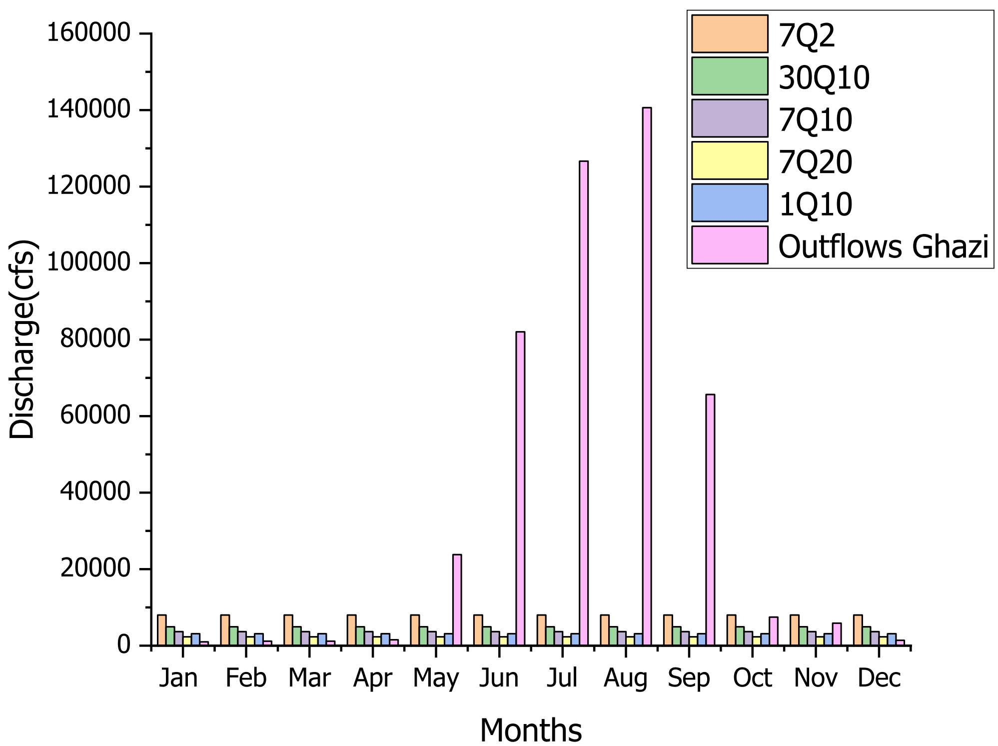

Figure 5.15 Comparison of EFR by Low flow indices with outflows at Ghazi Barrage

5.5 COMPARISON OF ENVIRONMENTAL FLOWS CALCULATED BY EXCEEDANCE PERCENTILE WITH INFLOWS AND OUTFLOWS

The exceedance percentile i.e. Q_{95}, is the most used flow duration index of this group and it recommends a single value of environmental flow for the whole year. As we can see in Table 4.1, the outflows of Tarbela Dam are large enough to provide water and maintain sustainability of riverine ecosystem.

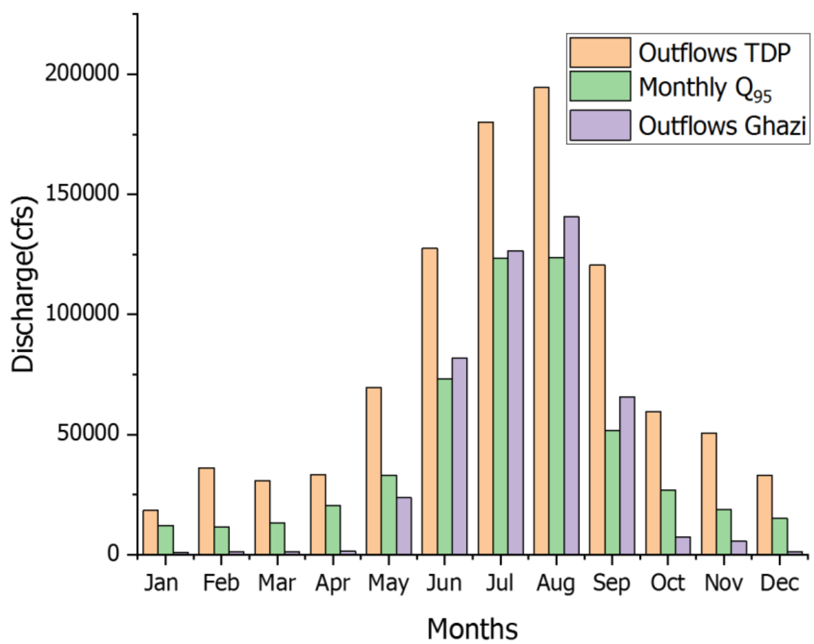

Figure 5.16 Comparison of EFR by Monthly Q95 with outflows of Tarbela Dam and Ghazi Barrage

It can be seen from the graph in Figure 5.16 that outflows released at the downstream side of the Ghazi Barrage in the months of October, November, December, January, February, March, April and May are less than the values of environmental flows suggested by the Q_{95} approach of flow duration indices. The reason of this very small flow could either be the storage at Tarbela Dam or the diversion into power complex.

The Q_{95} flow index is intended to incorporate the variation of flow regime throughout the year in River Indus by recommending environmental flows. It is obvious and clear from the graph in Figure 5.16 that outflows at Tarbela Dam are quite greater when it comes to comparison with the values of monthly Q_{95} so if outflows of Tarbela Dam were maintained at the downstream side of Ghazi Barrage, then there is no need for the assessment of monthly Q_{95} for the protection of ecosystem and sustainability purpose.

Environmental flows calculation carried out on the outflows of Tarbela Dam.

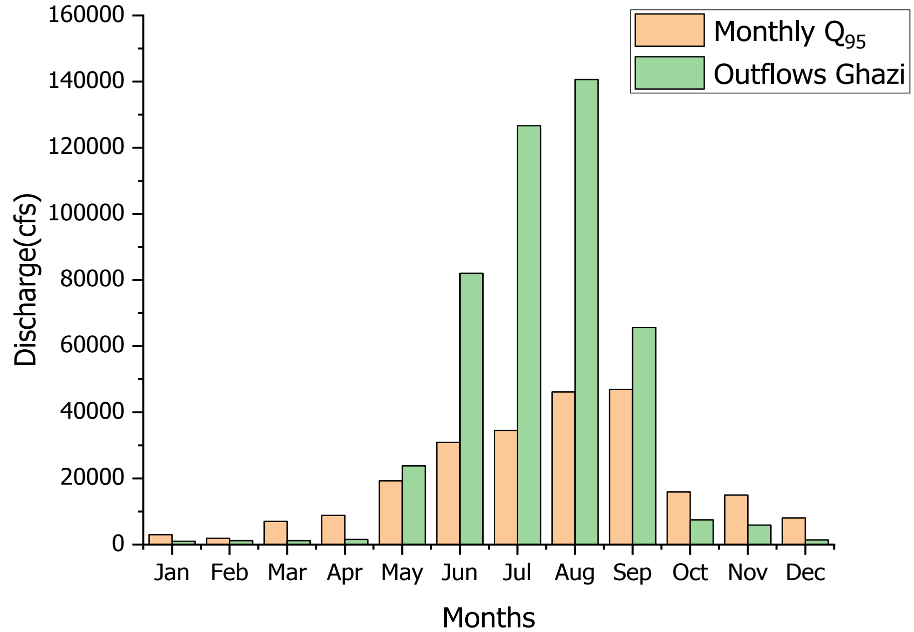

Figure 5.17 Comparison of EFR by Monthly Q95 with outflows at Ghazi Barrage

5.6 HYDRAULIC ANALYSIS

This step of modelling was at first intended to quantify the hydraulic characteristics at the affected reach by creating relationships of the discharge versus wetted perimeter and discharge versus water depth, the last one is used in ecological analysis. The calculation of this analysis is based on Manning's equation and we have used HEC-RAS. Following the methodology explained in the section 4.3. we find out the lowest breakpoint of the wetted perimeter discharge curve at the three-river station for the months of low flow.

This phase was primarily meant to compute the hydraulic characteristics at the three River Station beginning with analytical relationships of the discharge versus wetted perimeter and discharge versus water depth- the later is used in ecological analysis. The computations are based on the Manning's equation. Later, following the procedure of Section 2.7, we distinguished the lowest breakpoint (which is the first point on the curve where slope changes) of the wetted perimeter-discharge curve at the river stations of our interest. Figures 5.18, 5.19 and 5.20 shows the inflection point at three different river stations for the low flow months namely December, January, February, March and April.

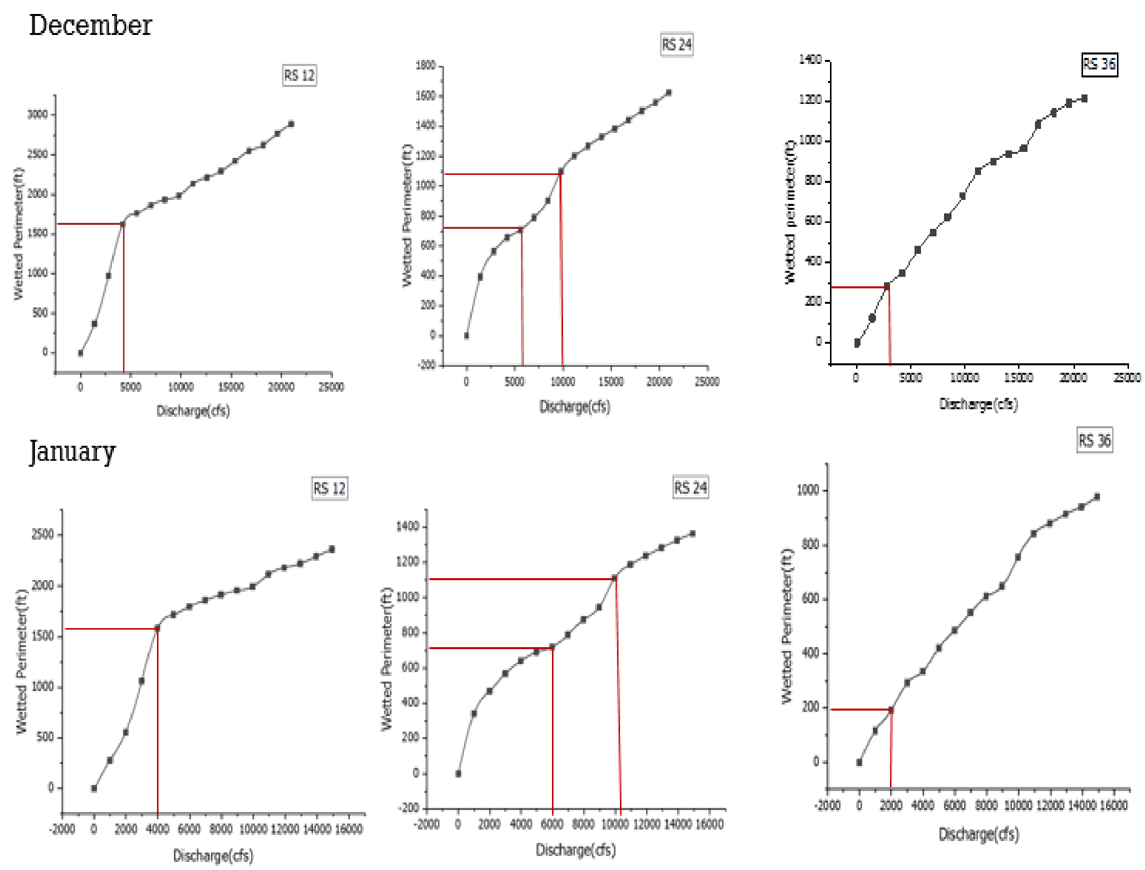

Figure 5.18 Inflection point for the month of December and January

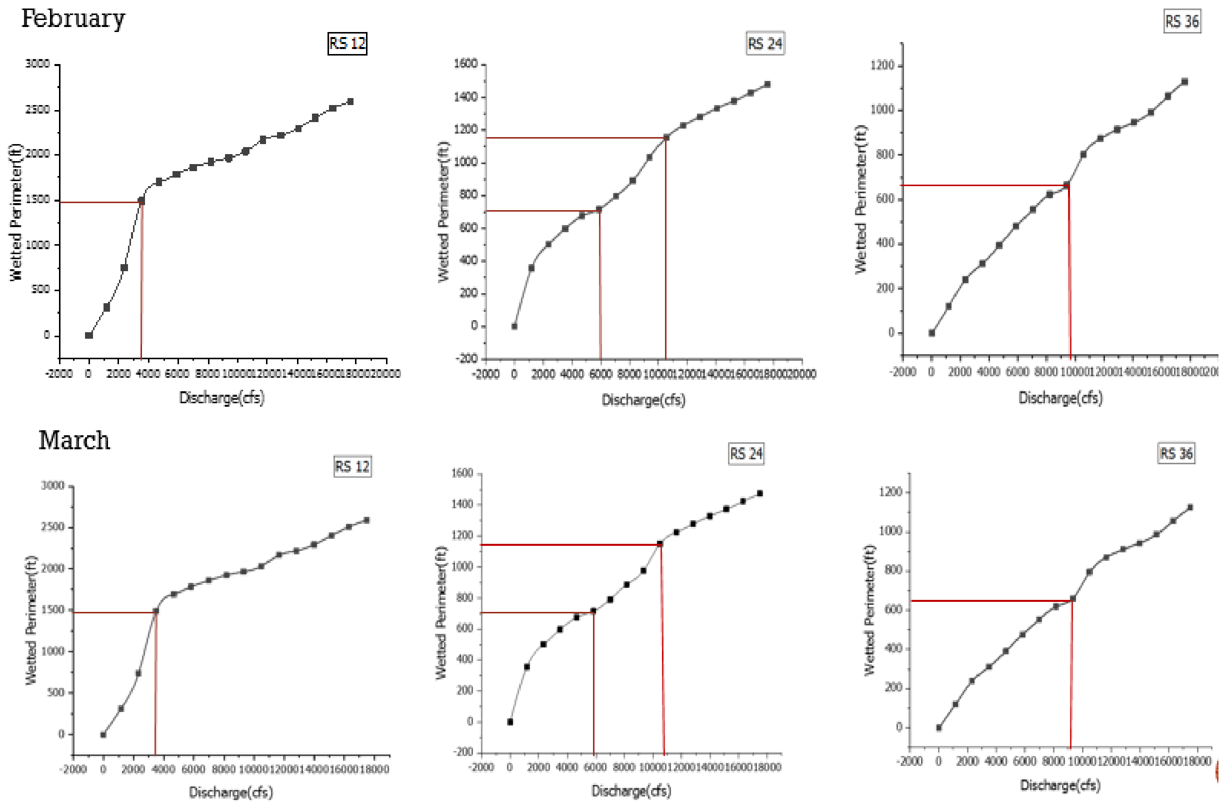

Figure 5.19 Inflection point for the month of February and March

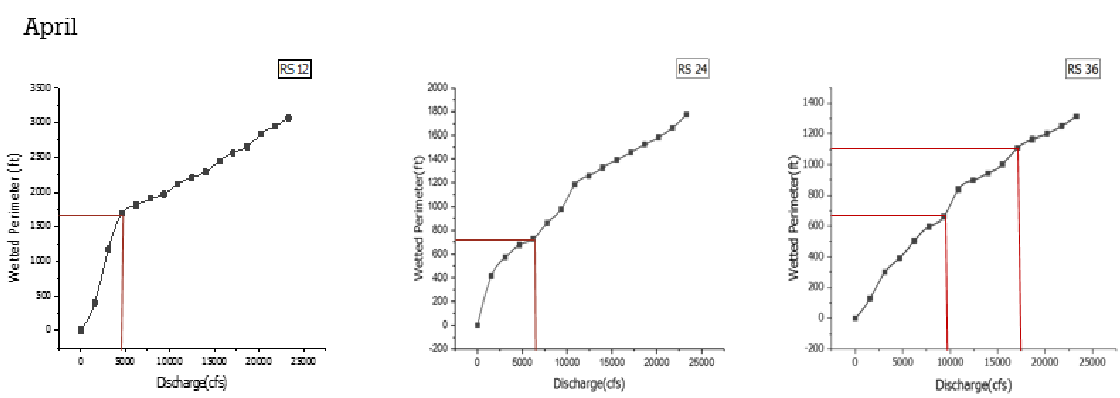

Figure 5.20 Inflection point for the month of April

The resulting targeted flows, wetted perimeter and hydraulic depths are given in Table 5.1, 5.2, 5.3, 5.4 and 5.5

Table 5.1 Details for the month of December

River Station	Discharge (cfs)	Wetted Perimeter (ft)	Hydraulic depth (ft)
12	4194	1625.3	1.06
24	5592	707.8	1.24
36	2796	283.63	1.43

Table 5.2 Details for the month of January

River Station	Discharge (cfs)	Wetted Perimeter (ft)	Hydraulic depth (ft)
12	3980	1584.71	1.02
24	5970	719.94	1.28
36	1990	191.34	1.50

Table 5.3 Details for the month of February

River Station	Discharge (cfs)	Wetted Perimeter (ft)	Hydraulic depth (ft)
12	3519	1496.62	0.94
24	5865	716.6	1.27
36	9384	663.67	1.84

Table 5.4 Details for the month of March

River Station	Discharge (cfs)	Wetted Perimeter (ft)	Hydraulic depth (ft)
12	3495	1492.39	0.94
24	5825	715.32	1.27
36	9320	660.02	1.83

Table 5.5 Details for the month of April

River Station	Discharge (cfs)	Wetted Perimeter (ft)	Hydraulic depth (ft)
12	4662	1695.55	1.13
24	6216	727.71	1.31
36	9324	660.21	1.84

According to the report by WAPDA, Ghazi Barotha Hydropower project-Environmental studies, it is stated that a minimum release of 28 cumecs (i.e. equivalent to 989cfs) will be supplied from the barrage during all project life and the hydraulic depth at this flow at three river stations of our interest is given in Table 5.6

Table 5.6 Hydraulic depth at discharge 989 cfs

River Station	Hydraulic depth (ft)
12	1.12
24	0.64
36	1.30

5.7 ECOLOGICAL ANALYSIS

Generally, this phase involves the analysis of several components of the ecosystem including, geomorphology, floodplain vegetation, macro vertebrates and fish etc as well as their effect counter to variations of the natural flow regime. For this reason, we examined the fish heath dynamics. The main result of this analysis was directly linking of fish requirements alongside water depths and discharge at each river station in the affected reach, for the considered fish species we estimated the flow requirement to make certain the required average depth values of table, through the discharge versus stage relationship.

5.7.1 Environment of River

The area of the affected reach, amid Tarbela Dam Project (TDP) and the convergence of the River Haro, the River Indus is split up into three different divisions

- From Tarbela to Khairabad, a braided channel
- From Khairabad to Darwazai, Attock gorge

- From Darwazai to the convergence with Haro River, an alluvial basin

The River Indus flows in a broad braided channel prior to merging the River Kabul and entering Attock gorge in the first zone. This zone has a range of morphological essentials at different phases of vegetation cover and formation. During season of low flows, this zone has isolated ponds and river creeks surrounded by bars and these elements are subjected to erosion and sedimentation during flood season. This zone is favorable for fishing due to morphological features. Below Khairabad, the Indus flows in a narrow and deep channel with rocky banks. Together with the strong currents, these features restrict fishing. Though in the first zone, the impacts of the development on fisheries in the River Indus will be limited between TDP and the convergence with River Kabul.

On average for about 49% of the time, 10 dallies flow released form TDP are above 1600 cumecs. Releases more than 1600 cumecs are spill out from the barrage pond into Indus river channel. During the period of low flows that starts from mid of October and lasts till early May, the average value of discharge in the downstream side of river channel is 28 cumecs and 7 cumecs for irrigation purposes. Good fishing conditions occurs during summer months i.e. mid of May to early October. During winter, most fishing take place in the barrage pond, the head ponds and in deep pools between the barrage and River Kabul.

5.7.2 Fish Species

The literature on fisheries relating to northern Pakistan was reviewed comprehensively. Table 5.7 presenting a list of all fish species that have been found in the affected reach is based on the provincial fishery department and existing literature.

Table 5.7 Tarbela reservoir's Fisheries(WorldBank)

Fish Species	Scientific name	Length (cm)	Weight (kg)
Mahseer	Tor putitora	60	2.5
Challi	Labeo dero	30	1
Shoondal	Recoma labiata	70	5-6
Common carp	Cyrpinus carpio	75	12
Silver carp	Hypopthalmichthvs molitrix	80	12
Sheer mahi	Clupisoma naziri	20	0.3
Sulemani	Glyptothorax puniabensis	20	0.5
Daula	Channa punctata	30	0.5
Dauli	Channa gachua	20	0.3

5.7.3 Tarbela reservoir's Fisheries

The challenging factor at Tarbela for the development of fishery is the temperature regime as it is intermediary between cold water and warm water conditions. Mostly, large cyprinids in south asia are cultured in warm water and these species have a range of 22^0C to 30^0C for temperature. This part of Indus has a temperature ranging from 17^0C to 20^0C in summers and 9^0C to 11^0C in winters. The limitation in fish production is due to V shaped bottom that restricts the infiltration of sunlight to the bottom (productive) area. About 60%, the shoreline is steep and rocky. The reservoir's maximum depth is 120m. About 90% of fishery in Tarbela is dependent on the Khalabat pocket, a narrow bay in southeast section of the reservoir which is fed by River Siran. The River Siran is expected to be the breeding field for mahseer, captured in Tarbela. Mahseer and Common Carp make up the most of fishery in Tarbela, with the later being the most common. Mahseer is the second most common specie and Silver Carp being the third common specie. Rohu make 5% of the catch. Mullah is common in upstream and downstream but not found in the Khalabat pocket.

5.7.4 Fish Ladder

In the locality of this project, Mahseer is the prime migratory fish. It occurs in River Indus as far off downstream as the Kalabagh vicinity and travels upstream for a significant distance for spawning. Spawning regions for Mahseer as stated in the report are from the River Siran, Haro, Dor Kabul and River Soan and its tributaries. Though, spawning is not reported from River Indus in between TDP and the convergence of River Kabul. Presence of TDP could have stopped mahseer migration on the upstream side if its not for fish ladder, because fish ladder are built to allow fish movement across a river and provide access to upstream areas for spawning and for migration provide routes for downstream side. Beyond TDP, Mahseer are recognized in the River Siran for spawning and it is the second most profuse fish to be found in Tarbela reservoir's Khalabat pocket. The power channel at Barotha poses no fish barrier for movement purposes as it is located off the river Indus.

According to the fishery department KPK, the species in Table 5.8 are found.

Table 5.8 Fish Species desirable water depth

Fish Species	Scientific name	Desirable Water depth (m)
Grass carp	Ctenopharyngodon idella	1.75
Silver carp	Hypopthalmichthvs molitrix	0.9
Rohu carp	Labeo rohita	0.75
Common carp	Cyrpinus carpio	1.75
Big head carp	Hypophthalmichthys nobilis	1.75
Mahseer	Tor putitora	1.25

All the bodily functions of fish are performed in water which implies fish is totally dependent on water to breathing, feeding, growing, excreting waste, maintaining a salt balance, and reproducing. Fish naturally incline towards the habitat that is most appropriate for their physiological requirements. This certain behavior is identified as habitat selection. The optimal fish production depends on biological, chemical, and physical water quality requirements. Successful aquaculture necessitates an understanding of water quality. Water quality significantly effects the rate of growth and survival on fish cultivation. Few researchers previously carried out several research about depth of water and effect of water quality on the rate of fish growth. Ali and coworkers stated that effect of water depth on Nile tilapia fingerlings and adults vividly affect the growth and survival rate (Ali, El-Feky et al. 2013).

Chapter 6

CONCLUSION AND RECOMMENDATIONS

This study comprises the assessment and categorization of environmental flow assessment methods. Five different hydrological methods were discussed among more than 200 environmental flow assessment methods due to their wide-ranging use. Hydrological methods were used for assessing the environmental flows at the downstream side of Ghazi Barrage. Historic flow records of inflows at upstream of Tarbela Dam and outflows released from Tarbela Dam were used for hydrological methods to estimate environmental flow requirements. The estimated environmental flows driven by hydrological methods were then compared with the outflows of Tarbela Dam and outflows released at the downstream side of Ghazi Barrage. After that hydraulic method was applied on the affected reach to find the inflection point. In Wetted perimeter method it may be difficult to obtain the proper geomorphology scale to concern about without having hydrologic attribute values of the river. In ecological analysis, one can use acceptable environmental flow values based on one specie, constrained spawning period and comparatively unlimited timely open criterion for migration.

6.1 Conclusions

1. It was noted that outflows released at the downstream side during the months of October, November, December, January, February, March,

April, and May are not satisfying the value of Environmental flow requirements calculated from tenant method. June, July, August, and September are the months in which environmental flow requirements are maintained.

2. Environmental flow requirements estimated by Tessman's method are not upheld in most of the months and are only maintained during June, July, August, and September.
3. Environmental flow requirements estimated from Monthly modified tenant method are maintained only in June, July, August and are not retained in December, January, February, March and April, and the outflows released during these months are less than 10% MMF. In May and September outflows released at the downstream side are less than 60% MMF and greater than 10% MMF and 30% MMF. In October and November, outflows released are less than 30% MMF.
4. Environmental flow requirements estimated by Low flow indices are only maintained in May, June, July, August, and September and are not retained during rest of months.
5. Environmental flow requirements estimated by using one of the most used flow duration indices i.e. Q_{95} are not maintained May, June, July, August, and September and are not retained during rest of months.

The months complying with environmental flow requirements are mostly the months of high flow season and the problem arises during low flow season.

6. In Hydraulic Method, namely Wetted Perimeter Method it might be difficult to find out the proper geomorphology to concern without having the hydrologic characteristic values of river. In this method, we have found the inflection points and determines the hydraulic depth and flow against that inflection point. Beyond which it causes detrimental effects on ecosystem.
7. The Ecological module utilizes the depth required by one species against the present values of flow at different river stations and gives acceptable Environmental flow values based on one species and their migration criteria. The hydraulic depth against various flows we have determined are very less than the one required by the species as stated in Table 5.8. The minimum flow required to achieve desirable water depths of fish species in Table 5.8 is 3653 cumecs approximately equals to 129000 cfs.

This study presents the various methods for determining the environmental flows including hydrological, hydraulic methods along with ecological analysis.

6.2 Recommendations

1. To mitigate the adverse effects of low flows released at the downstream side of Ghazi Barrage on ecosystem and make this GHBP

environmental friendly and sustainable, it is recommended to increase the quantity of flow following the recommendations of any methods.

2. Other methodologies can also be used to assess environmental flows, that could be habitat simulation methods or holistic methods.
3. During the low flow months, the water quality should also be monitored and examined.
4. Environmental flows should be a part of national policy to encourage the sustainability of development of water resource and healthy progress of river ecosystems.

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