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Retrofitting of Non-Hydro Reservoirs and Dams in Menderes River Basin, Turkey

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MSc. Hydropower Development
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Abstract

An increasing global concern on water scarcity, climate change and energy transition has placed a focus on the hydropower industry for the role it plays in managing these problem. While water impoundment by dams create problems of water scarcity, energy produced from hydro dams have a low carbon footprint and possibly provide a huge force to phase out nonrenewable energy systems. Hydropower development is tagged with a lot of environmental and social challenges which have become bottlenecks, reducing its attractiveness as an investment choice for the global energy transition. Retrofitting of non-powered dams, however provides an opportunity to add power production function to non-powered dams with minimal environmental impact and cost. Hydropower retrofitting provides a new wave of green energy production but it's prudent to note that the retrofitting potential of non-powered dams pivots around their technical and economic feasibility.

The aim of this study is to demonstrate the environmental, technical and economic feasibility of hydropower retrofitting projects in the Buyuk Menderes basin in Turkey. The study investigated the retrofitting potential of 11 non-powered dams within the Buyuk Menderes basin without compromising on the economic feasibility and environmental sustainability. The study commenced with an introduction on water resource management, climate change and their connection to the energy field, hydropower and hydropower retrofitting. A review of literature on the energy situation in Turkey and Buyuk Menderes basin preceded a theoretical introduction of the concept of hydropower generation and retrofitting. The methodology of this study commenced with an input data refinery process. A quick description of the study area was done to ascertain the reason for its choice for this project. The Buyuk Menderes basin was modelled with the WEAP software with a simulation period from 1964 to 2010 matching the duration of available data. To ensure that the model was very representative of the basin, the established model was regionally calibrated with the aid of catchment parameters and stream flow data. The Percent BIAS was used as the main model evaluation criteria for this study. Energy production simulation for the 11 dams was performed and the corresponding output recorded. An estimation of the capital cost involved in the execution of these projects was performed to reflect current prices. Economic indicators were used to assess the economic feasibility of these hydropower retrofitting projects. The levelised cost of electricity was calculated and used to assess the competitiveness of electricity produced from these hydropower retrofitting project to other emerging renewable forms of energy. Results from energy simulation revealed that the 11 non powered dams had a total annual energy output of

38.737GWh at a total capacity of 4.42MW. The total estimated capital investment cost of the 11 retrofitting projects was computed as \$ 7,892,166. The total NPV of the 11 non-powered dams was \$ 25,576,000. The average LCOE of the 11 non powered dams was \$0.061/kWh. The average unmet demand within the basin stood at a value of 78,736,387.5 m^3 translating to 16587.71 hectares of unirrigated land in a year. The implications of these results have been properly discussed in the discussion chapter of this study. The findings of this study indicate that retrofitting of non-powered dams could be an untapped opportunity to support the global energy transition by providing a cheaper and environmentally friendly option to spearhead rural electrification.

Preface

First and foremost, I would like to thank the Almighty God for his blessings and divine provision throughout this research work.

My sincerest gratitude goes out to Professor Tor Bakkon Haakon who supervised this research with a priceless level of guidance and patience. His honesty and inspiration motivated me to keep working hard to the end. It was a great privilege sharing moments of brainstorm and laughter with him.

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Quentin Adjetey Okang

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List of Abbreviations

WEAP	Water Evaluation and Planning
PBIAS	Percent BIAS
NPV	Net Present Value
LCOE	Levelised Cost of Electricity
KWh	Kilowatt hour
DSI	General Directorate of State Hydraulic Works
GHG	Green House Gas
ICOLD	International Commission on Large Dams
TWh	Terawatt hour
CO2	Carbon Dioxide
IEA	International Energy Agency
IHA	International Hydropower Association
MW	Megawatt
MGM	State Meteorology Affairs
HEPP	Hydroelectric Power Plant
NPD	Non Powered Dam
ET	Evapotranspiration
PET	Potential Evapotranspiration
FAO	Food and Agriculture Organization
Kc	Crop Coefficient
DWC	Deep Water Conductivity
SWC	Soil Water Capacity
HGF	Hydro Generating Factor
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return

Chapter 1: Introduction

1.1 Background

The earth is endowed with many natural resources which support the existence of life and biodiversity. Among these natural resources, water plays a very essential role in human survival and well-being. The application of water in industry, agriculture, and household activities is very crucial, and its availability can easily determine the economic progress of a community or a group of people (Akhmouch et al., 2018). Water resources exist in different forms and location (surface, air and underground) with surface water forming a total of 70 percent of the coverage of the earth. Despite this huge water potential of the earth, only 2.5 % is present as freshwater sources while the remaining fraction is stored as ice caps and frozen glaciers. Freshwater is spatially and temporally distributed around the world due to the geographical and climatic setup of different parts of the earth. The phenomena of spatial and temporal distribution of water around the world often plays a key role in determining the economic prowess of a community since water availability is an important factor in industrialization, agricultural production and basic life activities. The hydropower industry, known for several instances of river fragmentation has been labelled as a major cause of water scarcity in many river basins (Zhongming et al.,2022). This is because dams impound water at the upstream section and alter the natural flow of water at their downstream sections. The risk of water scarcity in communities located at the downstream section of hydropower reservoirs is slowly dampening the reputation of the industry as a major green energy source which can contribute to the battle against climate change and greenhouse gases (Opperman et al.,2022). According to a study by UNICEF an estimated 260 billion dollars is lost annually due to unproductive time spent traveling to get water for household activities (Water & The Economy, 2022). Research has shown that the world's population under water scarcity moved from 0.24 billion people in the 1900s to 3.8 billion people in the 2000s and this is mainly due to reasons like population growth, overexploitation of water resources and anthropogenic climate change activities (World Health Organisation,2021). While it might be quite easy to handle population and water exploitation issues, climate change has been a major challenge over the past decades. Burning of fossil fuels (coal oil and gas) to provide energy for industrialization has led to the release of several tons of greenhouse gases which have destroyed the earth's ozone layer, increased earth temperature, altered the hydrological and climatic regimes leading to severe droughts and floods. According the UN, the energy sector is the largest contributor to global greenhouse gases (GHG), accounting for about 35% of total emissions (United Nations, 2022). About 84.3% of the world's energy mix is provided by fossil fuels (United Nations, 2022) and this means that the energy sector plays a pivotal role if global warming has to be reduced to the barest minimum. Following the dictates of the Paris agreement to end GHG emissions by 2040 and a motivation to reduce the environmental impacts from non-renewable energy sources, the concept of an energy transition was developed to replace all non-renewable energy supply systems with renewable energy. World leaders under the Glasgow climate summit (COP26) have agreed to raise a total amount of 100 billion USD to exploit the potential in renewable energy sources like hydropower, wind energy, solar energy, geothermal and tidal energy, in order to achieve the target of zero-carbon economy by 2040. Among these renewable sources of energy production, hydropower with its water storage and regulation potential provides a very realistic energy supply mode that can serve all load demands from energy consumers. Compared to hydropower, the other sources of renewable energy are very reliant on weather conditions such as cloud cover, wind speed, solar radiations, tidal wave properties and are often difficult to regulate to meet irregular and realistic demands from consumers. Despite the strong contribution that the hydropower industry can play in the success of the energy transition, hydropower development is faced with grave environmental and socio-economic challenges, spanning from the high cost of initial investment, land inundation, river fragmentation, fish migration, loss of economic sources, alteration of river flow, and destruction of habitats, etc. These challenges related to the hydropower industry is gradually reducing the interest in hydropower development projects and consequently dampening the competitiveness of hydropower production to other renewable energy sources. Despite these major bottlenecks in the hydropower industry, an opportunity lies in the retrofitting of non-powered dams to produce clean power which can support the global energy transition goal at a minimum cost without further damage to the environment. The latest database of dams from ICOLD indicates that the globe is endowed with 57,985 dam out of which 29,163 are non-powered dams (ICOLD, 2019). Since ICOLD considers only dams with a height above 15 meters in their database, the available data shows that there is a potential to generate energy from 29,163 dams without compromising their main purpose.

While this global hydropower retrofitting potential looks very interesting to invest in, it must be ensured that these projects are economically, environmentally and technically feasible and competitive with other renewable sources of power production. There is, therefore, a pressing need for an in-depth investigation and research into the retrofitting potential of these non-powered dams in order to verify their environmental friendliness and cost effectiveness. Without compromising on the current water use and outflow from non-powered dams, water balance models can be developed to simulate the effect of different reservoir operational strategies and their impact on water availability in the reservoir and its retrofitting potential. This thesis seeks to investigate the hydropower generation potential of retrofitting non-powered dams within the Buyuk Menderes river basin in Turkey paying close attention to current water use, environmental and economic feasibility.

1.2 Objectives

The objectives of this study are as follows:

1. Carry out a literature study on the current state of retrofitting of non-hydropower dams and reservoirs.
2. Apply a method (WEAP) to calculate the retrofitting potential in the Buyuk Menderes river basin.
3. Demonstrate the proposed methodology by simulating the hydropower production for a time period matching the available data.
4. Provide a rough estimate of costs of retrofitting, the revenue of the possible hydropower production, and compare to other sources of renewable energy production.
5. Identify potential environmental, social, or other types of barriers in the realization of the concept.
6. Assess the assumptions, limitation and uncertainties in the methodology and calculations

1.3 Structure of the report

This master’s thesis begins with an introduction on water resources and it relation to the hydropower and the global energy sector. The study continues with a literature review on the energy situation of Turkey and how hydropower retrofitting stands a chance to close the energy gap when non-renewable energy sources are phased out. The thesis further delves into a theoretical breakdown of the principles governing hydropower production, the concept of retrofitting and the description of the Buyuk Menderes basin. The methods and materials used in the research are explained in the methodology section. The findings of this study are then presented in the results sections. Following the results section, is a full analysis of the results, a presentation of limitations of the work and the proposed prospective topics which could be interesting to venture into. The report ends with a conclusion on the study, references and appendices.

Chapter 2: Literature Review

With a yearly production of about 300 TWh, electricity production in Turkey is mainly generated from coal, gas, and hydropower (Rodriguez et al,2020). The country's electricity mix is dominated by its coal-fired power stations and the carbon footprint of electricity production is 400g of CO_2 per kilowatt-hour, a little below the global average (Rodriguez et al.,2020). The emission intensity of non-renewable sources of energy production in Turkey is however 393grams of CO2 per kilowatt hour (Transparency Climate, 2019). Turkey currently has an annual energy per capita value of 2,740 kWh/year (Energy Consumption in Turkey, 2022 and an energy price of $0.09/kWh (Daily Sabah, 2022)

With a rapidly growing population and economy, Turkey's energy demand has increased by almost six times between the period of 1970 and 2010, making the country a strong demand point for energy (Atilgan et al, 2016). As predicted by the IEA, the country's energy demand has seen a very fast growth and this is partly associated to its increase in population (Bayraktar,2018). Apart from an increase in population, Turkey has had to deal with a high energy import ratio because it imports nearly 70% of its energy (Bayraktar, 2018). In a bid to achieve an appreciable level of energy security within an increasing energy demand and current global calls for an energy transition, Turkey launched the National Energy and Mining Policy(NEMP) which had a renewable energy resource zone (RE-zone) framework to channel investment into the renewable energy space and consequently increase the contribution of carbon-neutral energy to the national energy mix. Under the RE- ZONE action plan, Turkey plans to increase an existent 28,133 MW hydropower capacity to 34000MW (Bayraktar, 2018). Turkey happens to be endowed with an average of 186 km^3/year discharge of water flowing through its 177,000 km of rivers (Ağiralioğlu, 2016). The country benefits from a landscape of mountains with an average elevation of 1100 meters above sea level (Ağiralioğlu, 2016). These natural features of the Turkish terrain provide good head and volume of water and therefore makes it easy for hydropower to be developed. Looking through literature, there is little research done on the retrofitting potential of already existing non-powered dams within Turkey, and this knowledge gap may easily drive investors into building new hydropower stations which are relatively expensive and carry huge social and environmental burdens. In order to optimize investments within the hydropower space to increase capacity as proposed by the plan of the RE-ZONE framework, Turkey requires a series of studies/research into the retrofitting potential of non-powered dams paying closer attention to the competitiveness of electricity generated from retrofitting these dams with emerging renewable technologies. The aim of this study is to use a water balance model to assess the hydropower generation potential of non-powered dams in the Buyuk Menderes Basin without compromising on environmental sustainability, economic viability and current water use. It is expected that the findings of this study will initiate action for further pre-feasibility studies in the different river basins in Turkey.

2.1 Hydropower

Production of power with water is the simplest definition of hydropower. The technology has seen different phases of development in the past centuries spanning from when the concept was first conceived in 202 BC till date (IHA, 2022). Hydropower has been closely related to economic development as it played a very vital role in providing power to pound and hull grains, break ore and spin cotton at the onset of the industrial revolution (IHA,2022). According to a report by IEA (2020), Hydropower production stands at an annual production of 4,418 TWh and remains the highest source of renewable electricity production globally (IEA, 2022).

Development of hydropower involves a very detailed process of planning which includes a very careful assessment of the capacity and head of the chosen site. Water availability and the elevation difference are the two most important features that define the hydropower potential of a given terrain. The technology uses the falling force of water from a given elevation to mechanically move a turbine connected to rotors. As the turbines rotate, the rotors also rotate within an electromagnetic generator connected to the turbine and this leads to the production of electricity. Hydropower production can be established with dams which enhance the storage of water over specific time periods or as run of river projects which require no storage of water. As water flows from a higher elevation to rotate turbines at lower elevations, the roughness, size, length, contractions, bends, and expansions of the waterway create singular and frictional head losses which decrease the level of power produced. The net effect/power produced from hydropower operations is directly related to the density of water, capacity, gravitational force, net head, and the overall system efficiency which is a function of the turbine, generator, and transmission efficiency. The net effect from hydropower production can be calculated with equation 1, 2 and 3

$$P = \eta \cdot \rho \cdot g \cdot H \cdot Q \text{— (1)}$$

$$\eta = \eta t . \eta g . \eta t \text{— (2)}$$

$$H = Hg - Hf - Hs \text{— (3)}$$

Where η-System efficiency, η_t - Turbine efficiency, η_g - Generator efficiency, η_t- Turbine efficiency, ρ=Density of water (kg/m^3), g-Gravitational force (m/s^2), Hg- Gross head loss (m), Hf- Frictional Head loss (m), Hs-Singular losses(m), H-net Head (m) and Q-Water discharge (m^3/s). (Fjøsne,2020)

In hydropower production, energy is defined as the amount of power that can be produced from a particular scheme over a period. The energy equivalent is also defined as the energy potential of 1m^3 of water. The energy and energy equivalent of a hydropower scheme can be calculated using the following formulas

$$E = P * t \text{— (4)}$$

$$E_{e=} \frac{E_a}{Q_a} - (5)$$

Where P= Power/Effect [W], t= time(hours), Ea=Annual energy(Wh), Qa= Annual inflow(m^3), E=Energy(Wh) and Ee=Energy Equivalent

With information of energy equivalent and total inflow of a hydropower scheme, the potential energy that can be produced from the scheme can be calculated. Most often than not, hydropower schemes are not able to totally reap all of their potential energy and this is often due to the capacity factor of the scheme. The capacity factor describes how much of the installed capacity in a hydropower scheme is utilized. The capacity factor is highly influenced by unpredictable variation in flow, water scarcity, head loss and operational losses. The capacity factor for a hydropower scheme is expressed in equation 6.

$$\frac{Actual\ energy\ output\ of\ a\ power\ plant(Wh)}{Potential\ energy\ output\ at\ full\ name\ plate\ capacity(Wh)} \text{—(6)}$$

Typically, the capacity factor for run of the river hydropower plants ranges from 0.4-0.5. Introduction of dams in hydropower schemes creates reservoirs that store water for a specific period and increase the scheme's capacity factor to about 0.6-0.8. Another way to increase the capacity factor of a hydropower scheme is by waterway optimization. Waterway optimization is done to ensure that the cross-sectional area of the waterway is designed with the average discharge in the terrain. Large waterway areas come with a huge construction cost but are very efficient in reducing frictional losses in the system. To find the optimized waterway dimension which optimizes cost and frictional losses control, hydropower engineers rely on the continuity equation which is expressed in equation 7

$$Q=A\cdot v — (7)$$

$$A = \pi * \frac{D^2}{4} - \ (8)$$

$$v = C * \sqrt{2} * g * H - - \ (9)$$

$$Q = \pi * \frac{D^2}{4} * C * \sqrt{2} * g * H \quad --(10)$$

$$D = \sqrt{\frac{4*Q}{Cmax*\pi}} \qquad --(11)$$

Where, A- Cross-sectional area of water way (m2), V- the flow velocity [m/s],
D -waterway diameter (m), C- contraction coefficient, H – height distance between the center of the intake and the water level (m) and Cmax - Maximum flow velocity water way (m) (Fjøsne,2020).

2.2 Retrofitting

Every hydropower project typically goes through four main stages, namely, the reconnaissance study, pre-feasibility study, feasibility study and project implementation stage. These project phases collectively add up to almost four to five years of time and come at a huge investment cost to developers. In the current global quest for greener energy production mainly spearheaded by United Nation's sustainable development goal 7, time and cost friendliness is a major mark for all sources of renewable energy production.

Globally, many dams have been developed with reservoirs for the sole purpose of irrigation, water supply, navigation, recreation, and flood control. If these dams satisfy certain technical and economic criteria, an additional purpose of power production could be added to their primary purposes. To ensure that hydropower is very competitive in providing the current renewable energy needs, retrofitting of non-powered dams could be a very relevant agenda to invest in. In line with the global energy transition goal, the coming decades will experience an energy mix with a lot renewable energy (wind, solar, geothermal, bioenergy etc.). Many dams with hydropower purposes will be needed at different and remote locations to create hybrid power systems. These powered dams could possibly supply energy in cases when other renewables (wind, solar etc.) can't respond to energy demands. Hydropower retrofitting is one of the surest ways to achieve energy security for both remote and urban communities once all non-renewable sources of energy generation are phased out.

Retrofitting of non-powered dams is defined as the set of engineering works performed to add hydroelectric capabilities to an existing non-powered dam (Fjøsne,2020). In this report, retrofitting for non-powered dams will be referred to as retrofitting. Non powered dams may also be referred to as reservoirs.

In addition to the fact that retrofitting saves a lot of time in the provision of renewable energy, the engineering technology is also cost-friendly and flows with minimal environmental impacts (Fjøsne,2020). With retrofitting, turbines and other electromechanical equipment are installed onto the already existing dam structure, ensuring that there is limited construction cost and environmental impacts.

Despite the fact that retrofitting has a lot of advantages, the technology also flows with some disadvantages which has to be taken into consideration if success has to be achieved. From the onset of the study of retrofitting potential, developers and researchers often make a mistake of not highlighting the competitiveness of energy produced to other cheaper renewable energy sources (Hansen et al., 2021). Another critical problem associated with retrofitting is the allocation of water. Retrofitting should be done without compromising on the ability of the existing dam to perform its primary function (irrigation, water supply, etc.) even within periods of high energy demand. To ensure that turbine cost recovery is not outstretched, it is prudent to invest into multiple turbines with different capacities to ensure a good level of power production during low and high flow seasons.

To manage the risks involved in retrofitting projects, it must be ensured that a properly integrated water resource management system that identifies and considers the demands of different water users in the river basin is used for priority setting. To enhance the profitability of retrofitting projects, attention should be paid to the economic viability of running a hydropower scheme with the new turbine installations.

2.2.1 Technical requirement

Retrofitting provides an economic advantage that allows dam owners to increase the profitability of owning a non-powered dam, but not all non-powered dams can be retrofitted(Fjøsne,2020). For a dam to undergo successful retrofitting, it must have an exploitable head and available flow. The existence of a good topography, waterway and easy connection to the grid are other relevant technical requirements that contribute to the success of retrofitting non-powered dams.

Though retrofitting involves a minimal level of civil work to the dam structure, the safety and structural integrity of the dam should never be taken for granted, because it poses a threat to life. It must be ensured that overturning forces acting on the dam after its structural modification never exceeds the stabilizing forces. A good factor of safety should be a serious consideration before dams are structurally modified for the purpose of retrofitting. In analysing the factor of safety, it must be ensured that the retrofitted dam can support the new hydrostatic conditions introduced.

The hydropower industry has over the years suffered a reputational risk of water consumption as it is seen to be a large consumer of water (Bakkenet al., 2013). Water consumption in the hydropower field is highly related to evaporation. A buildup of reservoir volume and surface area increases the evaporation losses from the reservoir. In cases of retrofitting where hydropower production is added to dams which serve an existing water demand, developers must be extra strategic in minimizing the water consumption associated with power production. It is prudent that retrofitting projects have an operation scheme that allows power production with water releases for the dam's original purpose. This operation scheme ensures that water consumption allocation to hydropower is minimized.

Demand for electricity, and the proximity of a power station to the electricity grid are very vital factors that determine the essence and profitability of a retrofitting project. Many non-powered dams were built without hydroelectricity, mainly because the power demand and grid connection as at the time of construction were low and unavailable respectively (Hansen et al., 2021). Retrofitting projects should never commence without a careful assessment of the need for power and proximity to the electricity grid. Since retrofitting involves water allocations, it would also be prudent to delve into the water demand periods of the original purpose of the dam and the electricity demands within the terrain of interest. Knowledge of the timing of water demand, for different purposes of the non-powered dam can help developers and operators to strategically allocate water and ensure that an optimal rule which allows water allocated for the dam's primary purpose is also passed through a turbine for power production.

Turbine technologies for the purpose of retrofitting have been developed over the years, ensuring that retrofitted dams are safer and more ecofriendly. Turbine selection is a key technical consideration, and a function of the design discharge, water availability and head specifications of the dam to be retrofitted. Laying a focus on environmental sustainability, auto venting Kaplan turbines, which have the capacity of increasing dissolved oxygen levels of water exiting the runners, is one of the turbine choices for good retrofitting works (Brookshier et al.,1999). Another interesting turbine solution for retrofitting is the straflomatrix technology which ensures that cost and space is optimized in the installation of the turbines to the dam structure. The straflomatrix turbines are axial straight flow turbines where the upstream and downstream sections of the reservoir are connected by a straight tube and the generator is placed directly on the periphery of the turbine runners (ANDRITZ, 2022).

2.3 General Description of Buyuk Menderes River Basin

The Buyuk Menderes River basin is located in the south-western part of Turkey as shown in figure 1. The basin shares a boundary with the Aegean Sea to the west, the West Mediterranean and Region of Lakes to the south, the Kuçuk Menderes and Gediz basins to the north, and the Akarcay basin to the east. The river basin covers ten cities and 185 municipalities and lies between latitudes 37° 6’- 38° 55’ North and longitudes 27° 15'- 30° 36' East. As shown in figure 1, elevation within the basin ranges from sea level at the western coastal area to more than 2,400 m at the southern and northern mountains, and the mean elevation of the region is nearly 850 m (Ortigara, 2022). The river empties into the Aegean Sea and creates a delta that provides a very important bio-habitat for the breeding and wintering of water birds. Noted for its meandering nature, Akcay, Cine, and Çuruksu are the most relevant tributaries within the basin (Ortigara, 2022). These three rivers have a hydraulic relation with the main Buyuk Menderes rivers as they flow into it. The Akcay and Cine rivers contribute about 30% and 12% of flow respectively to the main Buyuk Menderes river (Durdu, 2010).

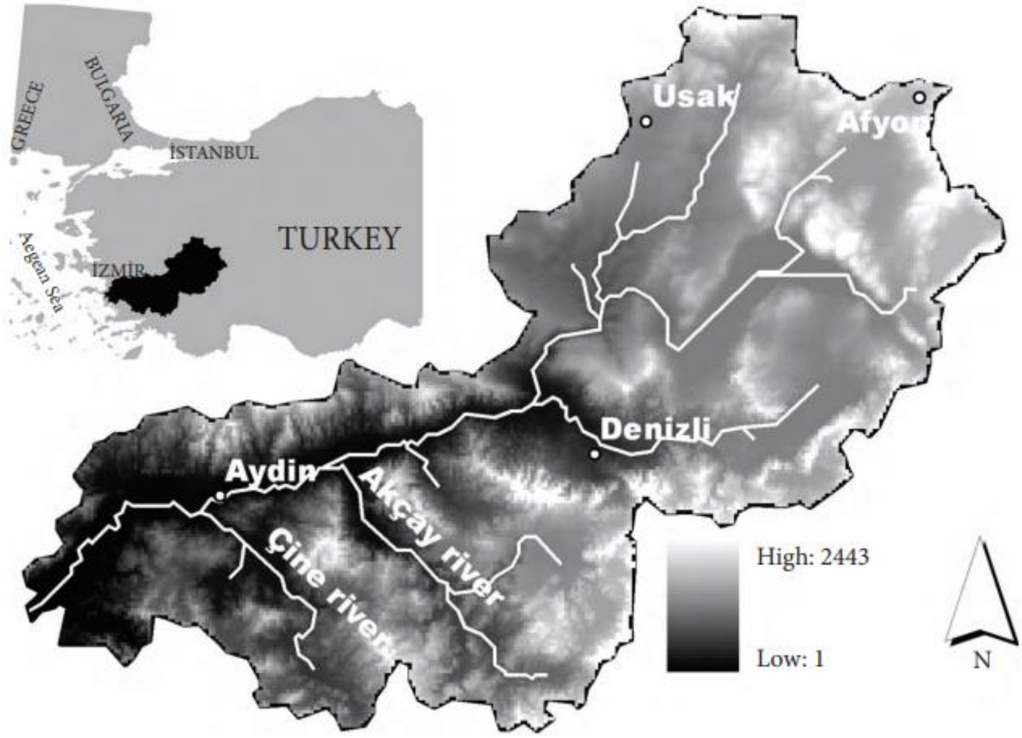

Figure 1: Map of Buyuk Menderes River Basin (Durdu, 2010).

With a population of 2.5 million people and a total land area of 24,873 km^2, the borders of the Buyuk Menderes river basin falls within ten provinces. The basin's characteristic natural water potential of 3,047 hm^3 and specific discharge of 3.72 lt/s/km^2, enables it to provide water to drive the textile, leather, and agricultural industries. The basin is endowed with a very lengthy irrigation network spanning from the very upstream sections to the downstream section and irrigation flow is released to serve agricultural demands for a total of 20-24 hours in a day (DSI, 2018) Irrigation in the basin supports the production of cotton, vegetables, fruits, maize, and wheat in the plain areas, as well as figs, olive trees, oranges, peaches, and plums in the foothill of the mountainous areas (Durdu, 2010).

The basin records an annual average precipitation and temperature of 624mm and 15.6°C respectively (Durdu, 2010). The water demand distribution in the river basin lies at 78%,2%and 6% for agriculture, industry and drinking purposes respectively. A total of 33 hydropower plants with an installed capacity of 351 MW and an annual potential energy production of 913.3GWh have been developed in the river basin. A review of plans to renew some irrigation networks in the lower Buyuk Menderes plains has threatened the existence and operation of some of these hydropower plants located upstream and this has led to a decline of the annual energy potential to a value of 862GWh. Table 1 presents the list of planned hydropower projects within the Buyuk Menderes basin and their corresponding capacities

Table 1: List of Planned Hydropower Projects

HEPP NAME	STAGE	PROVINCE	INSTALLED POWER(MW)	ENERGY(GWh)
BEYAGAC HEPP	PLANNING	DENİZLİ	1.43	7.31
EGE HEPP II	PLANNING	DENİZLİ	0.72	3.22
EGE HEPP III	PLANNING	DENİZLİ	1.28	5.49
EGE HEPP IV	PLANNING	DENİZLİ	1.87	8.13
ERENLER HEPP	PLANNING	DENİZLİ	7.21	36.53
HOROZ I HEPP	PLANNING	DENİZLİ	0.48	3.14
KOVANBURNU HEPP	PLANNING	AYDIN	5.4	25
SÜLEK1 HEPP	PLANNING	DENİZLİ	3	11.3
AKBAS DAM	PLANNING	DENİZLİ	2.50	6.77
AKCAY REG HEPP	PLANNING	DENİZLİ	2.40	8.41
AKHAN HEPP	PLANNING	DENİZLİ	0.72	2.10
AHLISAR HEPP	PLANNING	AYDIN	4.22	8.87
SULEKI 2 HEPP	PLANNING	DENİZLİ	1.7	5.38

To manage sediment accumulation, the basin is endowed with several check dams and ground sills which reduce the rate of sedimentation of major reservoirs in the basin. Cleaning of check dams coupled with a lot of watershed management practices reduce the rate of erosion in the basin. These continuous sediment handling practices boost the flood dampening integrity of the dams within the basin.

Research conducted within the basin shows that rivers in the basin are endowed with about 39 species of fish, whose habitats span from the most upstream section of the basin to the most downstream section. These fish have migratory patterns largely connected to flow characteristics within the rivers. Migratory patterns are intended to satisfy the feeding, wintering, breeding and growth needs of the fish. Due to river fragmentation effect of dams, migration of some of these fish species are limited, leading to an increase in the number of endangered species within the basin. As a mitigation measure, release of minimum flow and construction of fish ladders should be given critical attention when dams are being constructed or retrofitted. (Güçlü et al., 2013)

The hydrology of the of the basin changes from year to year. In typical dry years, research has shown that most of the irrigation dams on the brook of the main Buyuk Menderes basin are not able to satisfy all their demand points (DSI, 2018). Adiguzel–Cindere dams are however endowed with a huge inflow of water regardless of the year. To cater for these unmet demands during typical dry years, water is released from the Adiguzel-Cindere dams to support irrigation and other purposes in the areas with water starved dams.

2.4 Climate

The Buyuk Menderes basin experiences a combination of the Mediterranean and continental climate partly because it is located between the Aegean, Central Anatolian, and Mediterranean regions of Turkey (DSI, 2018). Continental climates have very cold and snowy winters with arid and hot summers while the Mediterranean climates experience rainy and warm winters with dry and hot summers. Provinces like Denizli, Afyon and Usak located in the upper section of the Buyuk Menderes basin experience the continental climate, while provinces located in the southwestern section of the basin experience the Mediterranean climate (DSI, 2018).

Meteorological parameters like temperature, relative humidity, evaporation, precipitation, wind direction, and speed are very relevant in determining the overall climatic conditions of a basin. In the Buyuk Menders basin, these parameters are measured with established meteorological stations operated by the General Directorate of State Hydraulic Works, Turkey (DSI, 2018) and State Meteorology Affairs (MGM). A good analysis of meteorological data offered by these institutions reveals that July and August are months that record the lowest precipitation values in the basin (DSI, 2018). Precipitation values recorded in the basin, are relatively higher from November to April. Annual precipitation values recorded by different regions in the basin are displayed in table 2.

Table 2: Annual Precipitation Value for Regions in Buyuk Menderes Basin

Region	Annual precipitation (mm)
Dinar	445
Usak	533
Denizli	555
Nazilli	586
Aydın	628
Muğla	1146

From a total of 73 meteorological stations spread across the basin, analysis conducted on precipitation data shows that the average annual precipitation in the Buyuk Menderes basin stands at a value of 624 mm (DSI, 2018).

Moving from the coastal to the mid and upper section of the basin, the average recorded temperatures reduce across the basin. The basin records its highest temperatures in July and August while its lowest temperatures are normally recorded in January and February (DSI, 2018). Evaporation in the basin has its peak recording in the month of July which is normally dry.

2.5 Dams

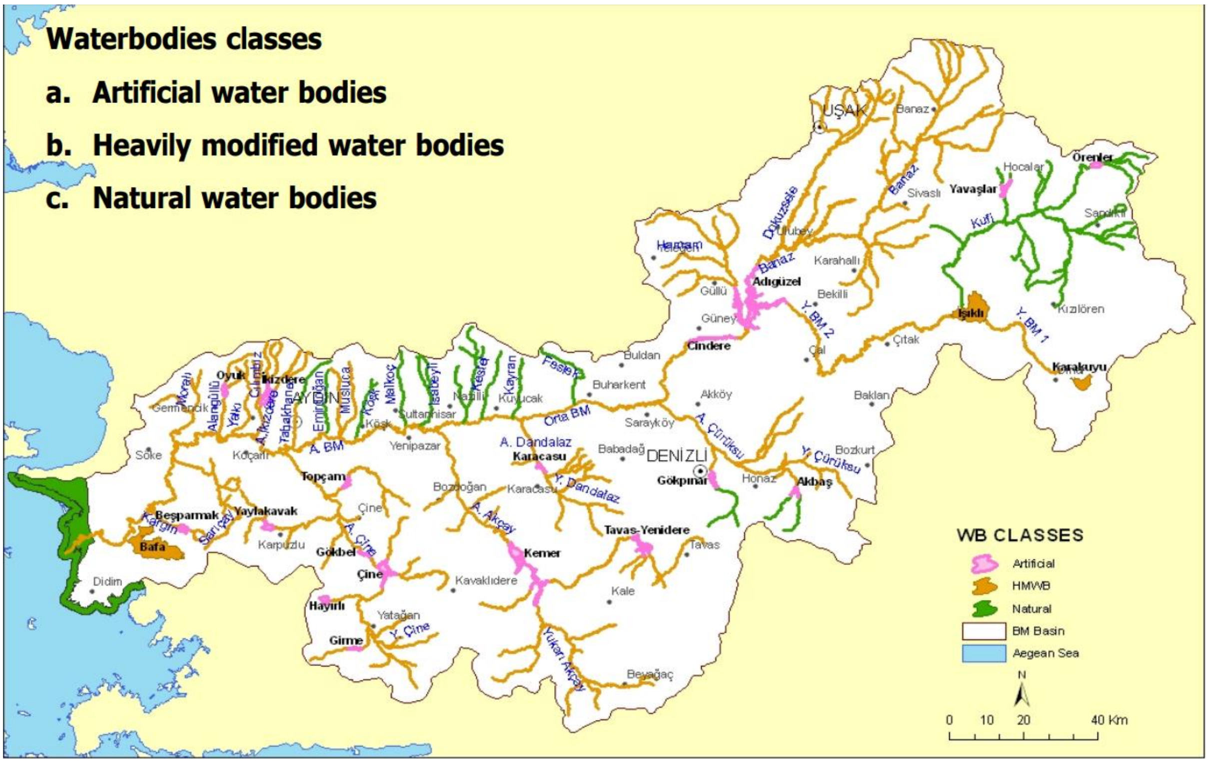

Figure 2: Layout of dams in the Buyuk Menderes basin (Sterk, 2022)

As shown in table 3, the Buyuk Menderes basin has a total of 25 dams, developed for the purpose of irrigation, water supply and industry. Out of this heavy investment of dams, only 14 are currently functional and this is displayed in table 3. Eleven out of the 14 functional dams are non-powered and currently serving irrigation, water supply, and industrial demands within the basin. All 11 non powered dams (NPD) have a total potential annual inflow capacity of 845.32 hm^3 and a gross head above 6.4 meters. Adiguzel- Cindere, Kemer and Cine are the major dams in the basin and they collectively hold an annual water potential of 1,239.16 hm^3. These dams are powered irrigation dams with an annual irrigation and power potential of 718 hm^3 and 355 GWh respectively. Due to a renewal of irrigation networks in the lower section of the basin, the Akcay Hydro Electric Power Plant (HEPP) which is in line with Kemer reservoir will have to reduce its regulation and allow more water to flow downstream for irrigation purpose. A total of 13 new hydroelectric power plants have been planned for development in the basin and this will provide a total capacity of 32.93MW. Figure 2 shows a layout of the dams in the basin

Table 3: Operational Status of Dams in the Buyuk Menderes Basin.

DAM	STATUS	PURPOSE
ADIGÜZEL DAM	OPERATIONAL	IRRIGATION /POWER
KEMER DAM	OPERATIONAL	IRRIGATION /POWER
ÇİNE DAM	OPERATIONAL	IRRIGATION /POWER
YENİDERE DAM	OPERATIONAL	IRRIGATION
GİRME DAM	IDLE	IRRIGATION
HAYIRLI DAM	IDLE	IRRIGATION
YATAĞAN DAM	IDLE	IRRIGATION
BAYIR DAM	IDLE	IRRIGATION
TOPÇAM DAM	OPERATIONAL	IRRIGATION
YAYLAKAVAK DAM	OPERATIONAL	IRRIGATION
CİNDERE DAM	OPERATIONAL	IRRIGATION /POWER
GEVENEZ DAM	IDLE	IRRIGATION
GÖKPINAR DAM	OPERATIONAL	IRRIGATION
KARACASU DAM	OPERATIONAL	IRRIGATION
BAHADIR DAM	IDLE	IRRIGATION
IŞIKLI LAKE RESERVOIR	OPERATIONAL	IRRIGATION
KARAKUYU LAKE	IDLE	IRRIGATION
YAVAŞLAR DAM	OPERATIONAL	IRRIGATION
KONAK DAM	IDLE	IRRIGATION
ÖRENLER DAM	OPERATIONAL	IRRIGATION
İKİZDERE DAM	OPERATIONAL	IRRIGATION
OYUK DAM	IDLE	IRRIGATION
AKBAŞ DAM	OPERATIONAL	IRRIGATION
GOKBEL	OPERATIONAL	IRRIGATION
SERBAN POND	IDLE	IRRIGATION

2.5.1 Orenler Dam

Operation of the Orenler dam started in 1985 and is located on the Kufi stream within the Buyuk Menderes basin. It has an irrigation potential of 2,777 hectares when pressurized irrigation schemes are used. It has a gross head of 20 m and an average annual water input of 19.16 hm3. The specifications and operational data of the Orenler dam are displayed in table 4

Table 4: Operational Specification of Orenler Dam

Location	Kûfi (Karadirek) brook
Purpose	Irrigation
Thalweg elevation of the dam location	1153.50 m
Precipitation area	206.8 km^2
Annual average input flow (1980-2013)	19.16 hm^3 (developing state)
Lowest Regulated Water Level	1163.91 m
Highest Regulated water level	1173.35 m
Reservoir volume at LRWL	4.70 hm^3
Reservoir volume at HRWL	26.28 hm^3
Active volume	21.58 hm^3
Annual water amount allocated for irrigation	11.36 hm^3
Irrigation water planned percentage	59.3 %
Type and area of the existing irrigation network	Conventional; 3784 ha
Type and area of the new network	Pressure piped; 2777 ha
Annual irrigation water needs for unit area	4481 m^3/ha
Irrigation flow rate	1.75 m3/s

2.5.2 Yavaslar Dam

Located on the Kufi brook (Komi stream), the Yavaslar dam commenced operations in 1985 mainly for irrigation purposes. With an annual average water input of 11.84 hm3 and a gross head of 37.0 m the dam irrigates a total of 1,493 hectares. The operational specifications of the Yavaslar dam is displayed in table 5

Table 5: Operational Specifications of Yavaslar Dam

Location	Kufi brook
Purpose	Irrigation
Thalweg elevation of the dam location	1003.0 m
Precipitation area	263.5 km^2
Annual average input flow	11.84 hm^3
Dam minimum water level	1017.67 m
Dam normal water level	1040.00 m
Reservoir volume at minimum water level	2.71 hm^3
Reservoir volume at normal water level	27.38 hm^3
Active volume	24.67 hm^3
Annual water amount allocated for irrigation	4.18 hm^3
Irrigation water planned percentage	35.3 %
Type and area of the existing irrigation network	Conventional; 1493 ha
Type and area of the new network	Pressure piped; 1060 ha
Annual irrigation water needs for unit area	4508 m^3/ha
Irrigation flow rate	1.50 m^3/s

2.5.3 Isikli reservoir

The Issikli reservoir has a total surface area of 64 km^2 and was developed in 1,953 by the General Directorate of State Hydraulic Works in Turkey mainly for the purpose of irrigation. The reservoir has a gross head of 6.4 meters and an annual average inflow of 250 hm^3. It's able to irrigate a total area of 50,811 hectares and its operational specifications are listed in table 6.

Table 6: Operational Specifications of Issikli reservoir

Location	Kufi brook-Isikli brook
Purpose	Irrigation
Thalweg elevation of the reservoir location	815.00 m
Precipitation area	2957.0 km^2
Annual average input flow	250.0 hm^3
Reservoir minimum water level	817.00 m
Reservoir normal water level	821.00 m
Reservoir maximum water level	821.40 m
Reservoir volume at minimum water level	27.30 hm^3
Reservoir volume at normal water level	237.50 hm^3
Reservoir volume at maximum water level	263.50
Active volume	210.20 hm^3
Annual water amount allocated for irrigation	136.55 hm^3
Irrigation water planned percentage	54%
Minimum pond area	31.81 km^2
Maximum pond area	63.97 km^2
Type and area of the existing irrigation network	Conventional; 50811 ha
Type and area of the new network	Pressure piped; 29360 ha
Annual irrigation water needs for unit area	5403 m^3/ha
Irrigation flow rate	20.0 m^3/s

2.5.4 Gokbel Dam

The Gokbel dam is found a few kilometers downstream the Cine dam. It was constructed by DSI for the purpose of irrigation in the Cine and Soke area within the Buyuk Menderes basin. Water released from the hydroelectric power plant of Cine is regulated in the Gokbel dam. Hydropower production during flood control months when the Cine reservoir level is reduced and when the ecological flow is increased would be interesting to investigate. The Gokbel dam has a gross head of 37 meter and has its operational specifications listed in table 7

Table 7: Operational Specification of Gokbel dam

Thalweg (shaft) elevation of the dam location	68.50 m
Annual average flow	246.6 hm^3
Minimum water level	103.60 m
Normal water level	105.60 m
Average water level	105.00
Active volume (daily regulation)	1.30 hm^3
Full annual water amount allocated for irrigation	150.0 hm^3
Full annual water amount allocated for irrigation	3.18 hm^3
Type and area of the network (Gross)	Pressure piped; 26400 ha
Irrigation flow rate (Çine+Koçarlı+Söke)	16.0 m^3/s

2.5.5 Akbas Dam

Akbas dam is located on the left bank of the Curusku brook of the Buyuk Menderes sub basin and it’s originally developed for irrigation and drinking water supply purpose. The dam has an annual average inflow of 16 hm^3 and an irrigation potential of 492 hectares of agricultural land. It also supplies Denizli province with drinking water. The gross head of the dam is 68.25 meters and it operational specifications are listed in table 8.

Table 8: Operational Specifications of Akbas Dam

Location	Curusku brook
Purpose	Drinking+Irrigation
Thalweg elevation of the dam location	860.0 m
Precipitation area	175 km^2
Annual average input flow	16.00 hm^3
Dam minimum water level	890.00 m
Dam normal water level	923.88 m.
Dam maximum water level	928.25 m
Reservoir volume at minimum water level	2.55 hm^3
Reservoir volume at normal water level	24.35 hm^3
Active volume	21.80 hm^3
Annual water amount allocated for irrigation	2.20 hm^3
Annual water amount allocated for drinking water	8.76 hm^3
Annual total regulated water	10.96 hm^3
Annual total regulation rate	70%
Type and area of proposed irrigation network	Pressure piped; 492 ha
Annual irrigation water needs for unit area	5286 m3/ha
Irrigation module	0.60 l/s/ha
Irrigation flow rate	0.400 m3/s
Drinking Water flow rate	0.350 m3/s

2.5.6 Gokpinar Dam

Gokpinar dam is sited on the left bank of the Curusku brook in the Buyuk Menderes basin. The dam was developed by DSI for the purpose of irrigation and drinking water supply. Water inflow into the Gokpinar dam is mostly from its springs which are located at the upstream section of the dam. With a flow capacity of 1.10 m^3/s these springs are able to provide about 34.7 hm^3 of water annually to the dam. Most of the water regulated by this dam is released for irrigation purposes. The dam has a gross head of 41.2 meters and its operational specifications have been detailed in table 9.

Table 9:Operational Specification of Gokpinar Dam

Location	Curusku Gokpinar brook
Purpose	Drinking+Irrigation
Thalweg elevation of the dam location	295.0 m
Precipitation area	212 km^2
Annual average input flow	45.22 hm^3
Dam minimum water level	317.00 m
Dam normal & maximum water level	336.20 m
Reservoir volume at minimum water level	4.50 hm^3
Reservoir volume at normal water level	28.20 hm^3
Active volume	23.70 hm^3
Annual water amount allocated for irrigation	14.62 hm^3
Annual water amount allocated for drinking water	3.00 hm^3
Annual total regulated water	17.62 hm^3
Annual total regulation rate	56%
Type and area of the existing irrigation network	Conventional; 5824 ha
Type and area of the new network	Pressure piped; 2700 ha
Annual irrigation water needs for unit area	6397 m^3/ha
Irrigation flow rate	2.65 m^3/s
Drinking Water flow rate	0.12 m^3/s

2.5.7 Karakasu Dam

Karakasu dam is sited exactly on the Dandalas brook of the Buyuk Menderes basin. The dam was purposely developed for drinking water and irrigation purposes. It has a potential to provide irrigation water for about 840 hectares of agricultural land. The dam has an annual average water inflow of 30 hm^3 and a gross head of 48 meters. The operational specifications of the dam have been listed in table 10. Most of the water allocation for this dam is delivered for irrigation purposes.

Table 10:Operational Specification of Karakasu Dam

Location	Dandalas brook
Purpose	Drinking+Irrigation
Thalweg elevation of the dam location	245.0 m
Precipitation area	537 km^2
Annual average input flow	30,0 hm^3
Dam minimum water level	273.50 m
Dam normal & maximum water level	298.20 m
Reservoir volume at minimum water level	3.50 hm^3
Reservoir volume at normal water level	22.94 hm^3
Active volume	19.44 hm^3
Annual water amount allocated for irrigation	5.06 hm^3
Annual water amount allocated for drinking water	8.71 hm^3
Annual total regulated water	13.77 hm^3
Annual total regulation rate	46%
Type and area of the existing irrigation network	Conventional; 2200 ha
Type and area of the new network	Pressure piped; 840 ha
Annual irrigation water needs for unit area	7112 m^3/ha
Irrigation flow rate	1.00 m^3/s
Drinking Water flow rate	0.100 m^3/s

2.5.8 Tavas Yenidere Dam

Tavas Yenidere dam is sited on the right bank of the Akcay brook within the Buyuk Menderes basin. Located on the Yenidere brook, the dam has an irrigation potential of 588 hectares of agricultural land when irrigation is delivered with a pressurized piping system. The dam has a gross head of 40.62 meters with an annual average inflow of 15 hm^3. The operational specifications of this dam is detailed in table 11.

Table 11: Operational Specifications of Tavas Yenidere Dam

Location	Akcay
Precipitation area	739.2 km^2
Thalweg elevation	842.18 m
Annual average flow (1980-2013)	15.00 hm^3
Minimum water level	866.00 m
Maximum and normal water level	882.80 m
Volume at minimum water level	10.08 hm^3
Volume at maximum and normal water level	61.60 hm^3
Active volume	51.52 hm^3
Pond Area at minimum operational level	1.341 km^2
Pond Area at maximum operational level	6.613 km^2
Annual irrigation water need	4822 m^3/ha
Annual water amount to be allocated for Yenidere irrigation (pumping)	2.40 hm^3
Regulation rate	58.68 %
Net irrigation area	2973 ha
Water pumping elevation for the right bank	951.50 m
Water pumping elevation for the left bank	952.00 m
Total pump flow rate	2.18 m3/s
Total pump power	2593 kW
Irrigation water flow rate	2.18 m^3/ s

2.5.9 Topcam Dam

Topcam dam is located at the right bank of the Cine brook. This dam was developed to serve irrigation and flood control functions. The Topcam dam has the potential of irrigating 2,866 hectares of agricultural land with high pressured irrigation schemes. The dam has an annual average inflow of 28 hm^3 and a gross head of 54 meters. The operational specification of the dam is listed in table 12.

Table 12: Operational Specification of Topcam dam

Location	Madran brook(Cine)
Purpose	Irrigation + flood control
Thalweg elevation of the dam location	61.50 m
Precipitation area	274 km^2
Annual average input flow	28.00 hm^3
Dam minimum water level	81.70 m
Dam normal water level	113.90 m
Dam maximum water level	115.65 m
Reservoir volume at minimum water level	9.80 hm^3
Reservoir volume at minimum level of flood control	83.50 hm^3
Flood control volume	14.2 hm^3
Reservoir volume at normal water level	97.70 hm^3
Active volume	87.90 hm^3
Annual water amount allocated for irrigation	15.82 hm^3
Annual regulation rate	56%
Type and area of the existing irrigation network	Conventional; 4983 ha
Type and area of the new network	Pressure piped; 2866 ha
Annual irrigation water needs for unit area	6520 m^3/ha
Irrigation flow rate	3.00 m^3/s

2.5.10 Yaylakavac Dam

Yaylakavac dam is located on the Karpuzlu brook of the Buyuk Menderes basin. It has a sole purpose of irrigation and is quite close to the Aydin province in Turkey. The reservoir has an annual average water inflow of 48.8hm^3. Operation of this dam began in 1997 and it has the potential of irrigating 2,938 hectares of agricultural land when pressurized irrigation systems are engaged. The dam has a gross head of 68.5 meters and its operational specifications are detailed in table 13.

Table 13:Operational Specifications of Yaylakavac Dam

Location	Karpuzlu brook
Purpose	Irrigation
Thalweg elevation of the dam location	91.0 m
Precipitation area	183 km^2
Annual average input flow (1980-2013)	48,8 hm^3
Dam minimum water level	109.00 m
Dam normal water level	159.50 m
Reservoir volume at minimum water level	2,00 hm^3
Reservoir volume at normal water level	31.40 hm^3
Active volume	29.40 hm^3
Annual water amount allocated for irrigation	14.63 hm^3
Annual regulation rate	36%
Type and area of the existing irrigation network	Conventional; 3123 ha
Type and area of the new network	Pressure piped; 2938 ha
Annual irrigation water needs for unit area	5882 m^3/ha
Irrigation module	075 l/s/ha
Irrigation flow rate	2.90 m^3/s

2.5.11 Ikizdere Dam

Ikizdere dam serves the purpose of drinking water supply and irrigation. Under highly pressurized modes of irrigation, the dam can serve about 99.70 hectares of agricultural land. Most of the water allocation from this dam is for drinking water supply purposes and the drinking water is supplied to the Aydin province. The dam has a gross head and annual average inflow of 96 meters and 134.7 hm^3 respectively. The operational specification of the Ikizdere dam is presented in table 14 The dam has a good head and water availability which could be exploited provided the water demand from the Aydin province is satisfied.

Table 14: Operational Specification of Ikizdere Dam

Location	İkizdere brook
Purpose	Drinking+Irrigation
Thalweg elevation of the dam location	81.00 m
Precipitation area	279.6 km^2
Annual average input flow (1980-2013)	134.7 hm3
Dam minimum water level	107.50 m
Dam normal water level	176.80 m
Reservoir volume at minimum water level	6.92 hm3
Reservoir volume at normal water level	194.90 hm3
Active volume	188,0 hm3
Annual water amount allocated for drinking water	48,60 hm3
Annual water to be given for ecological water	10.10 hm3
Annual total regulated water	99.7 hm3
Annual total regulation rate	74%
Drinking Water flow rate	2.00 m3/s

2.5.12 Energy potential of the dams

Research from the available data on non-powered dams within the Buyuk Menderes basin suggest that an average of 43.87% of the total annual inflow into the reservoirs is not regulated for their intended purposes and is therefore available for power production. This indicates that about 370 hm^3 of water could be made available for power production in the various reservoirs. Table 15 reveals key components for the computation of energy potential of each dam.

Table 15: Energy Specifications of 11 Non Powered Dams

Dam	Outflow (m^3/s)	Head (m)	Energy Equivalent(kWh/m^3)	Annual average flow(hm^3)	Potential energy Production (GWh)
Yavaslar	1.5	37	0.091	11.84	1.074
Orenler	1.75	19.85	0.049	19.16	0.933
Issikli	20	6.4	0.016	250	3.924
Tavas Yenidere	2.18	40.62	0.100	15	1.494
Topcam	3	54.15	0.133	28	3.718
Gokbel	16	37.1	0.091	246.6	22.438
Yaylakavak	2.9	68.5	0.168	48.8	8.198
Ikizdere	2	95.8	0.235	134.7	31.648
Gokpinar	2.77	41.2	0.101	45.22	4.569
Akbas	0.75	68.25	0.167	16	2.678
Karakasu	1.1	53.2	0.130	30	3.914

2.6 WEAP

WEAP software has a graphical user interface with a menu that changes depending on the view activated. As displayed in figure 3, the Schematic, Data, Results, Scenario Explorer and Notes view are components of the menu bar in WEAP. In the schematic view we have the WEAP elements (Diversions, Reservoir, groundwater, etc.) and the quantity of each element is shown in parenthesis. In the WEAP model, the components of a water shed or basin are converted into WEAP elements. The river, diversion, reservoir, groundwater, other supply, demand site, catchment, wastewater treatment, runoff/infiltration, transmission link, return flow, run of river hydro, flow requirement and stream flow gauges are the 14 elements of the WEAP model as shown in figure 3

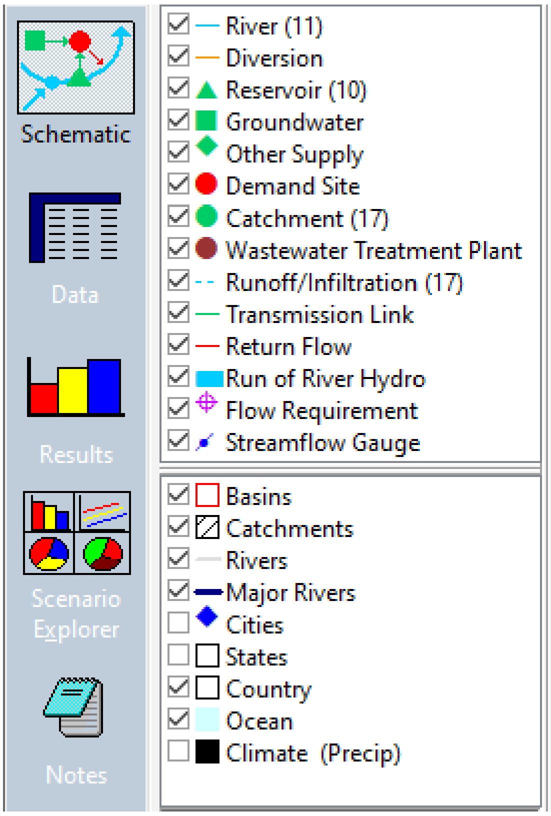

Figure 3: WEAP Menu bar and Elements

The river, diversion, reservoir, groundwater and other supply elements are used to represent any source of water inflow within the basin being modelled. The stream flow in the model needs to reflect reality.

To do this, a stream flow time series can be entered from any hydrological model to show the flow in the river element. Another way is by building the hydrological model in the WEAP software (WEAP, 2022). To build a hydrological model within WEAP, there is a need to add a catchment element which represents the entire basin or sub basins of interest. The catchments developed is divided into different elevations and connected to the river element with the run off infiltration link (WEAP, 2022). When this is done, the model estimates the water-balance(inflow-outflow) of the catchment and then transfers the outflow to the river through the transmission link. In a water shed system, hydrology is not the only simulation which occurs, we can also have supply and demand interactions. Demands in the water shed system could be related to population, industry and agricultural demands and this is represented in a model by the demand sites as shown in figure 3. The demand site element is often placed on a known demand site and the transmission link element is used to connect the river to the demand site. The demand sites receiving water from the river normally don't consume all the water they receive. There is often a return flow back into the supply source and this is represented with a return flow element as shown in figure 3 (WEAP, 2022). The return flow element is often located at the downstream section of the transmission link element. Two types of reservoirs can be represented in the WEAP model and these are the off stream and on stream reservoirs. While the on stream reservoirs are sited on the river and can be filled with flow from the river, off stream reservoirs are off the stream and normally need a diversion from the river to be filled up (WEAP, 2022). Hydroelectric power plants in the model can be run by a reservoir if it involves water regulation or impoundment and also as a run of river plant, if it is operated with the available water from the stream. Operation rules are required to enable proper functioning of the model and the flow requirement element is one of these operational rules (WEAP, 2022). The flow requirement element ensures that the model meets the flow rate conditions at the point of interest while considering the set demand priorities in the model. To evaluate the performance of the model we need to include a stream flow gauge element which allows us to compare simulated flow to observed streamflow and verify the goodness of fit with an objective function (WEAP, 2022). The input for a streamflow element is discharge data. Ground water element can also be added to the model if there is a demand for it. The transmission link element can be connected from the supply to the demand site for ground water. Water quality can also be modelled by including the wastewater treatment plant element in front of the discharge point in the model (WEAP, 2022).

2.6.1 Water Balance in WEAP

The soil moisture method, which is one of the five methods of simulating a catchment's water balance in WEAP has been chosen for this study. This mode of simulating runoff ensures that, inbuilt processes are used in the calculation of runoff and evapotranspiration within a given catchment. In the calculation of runoff within a basin, this method accounts for the initial moisture content and the soil infiltration processes for each time step of the simulation (Fjøsne,2020). The hydrological model within the WEAP software is semi distributed in nature and therefore receives input data and distributes them between different elevations within a catchment(Fjøsne,2020).

To be able to run simulations with the WEAP model, there is a need for climatic data input. Climatic data input to this model includes time series of temperature and precipitation, wind velocity, freezing point, melting point, relative humidity, albedo and initial snow volume.

Evapotranspiration(ET) is defined as the process through which water is lost from the soil and plant surfaces into the atmosphere. These climatic data inputs play a huge significance on the level of evapotranspiration a catchment experiences (Allen et al., 1989). The theoretical value of evapotranspiration for a given catchment is often referred to as its potential evapotranspiration(PET) and this can be determined with the Penman Monteith equation expressed in equation 12. Equation 12 has temperature, humidity, albedo, and several other climatic factors as input.

$$ETo = \frac{0.408\Delta(Rn-G)+\gamma\left(\frac{Cn}{T+273.16}\right)u^2(e_a-e_s)}{\Delta+\gamma(1+C_d u_2)} \text{------(12)}$$

Where, ETo- Potential evapotranspiration (mm.d^{-1}), Rn- Net Radiation at crop surface (MJ.$m^{-2}d^{-1}$), U_2-Mean daily wind speed(ms^{-1}), T- Mean daily temperature(ºC),G-Soil heat flux density at soil surface ($MJm^{-2}d^{-1}$), e_s-daily saturation vapour pressure (kPa), e_a- daily mean actual vapour pressure(kPa), Δ-slope of saturation-vapour pressure curve(kPa$^o C^{-1}$),γ-Psychometric constant(kPa$^o C^{-1}$), C_n and C_d –constants (Cai et al., 2007)

To determine the actual evapotranspiration values for specific crops within a terrain, the value for the potential evapotranspiration (ETo) has to be adjusted with the crop coefficient values for the crop of interest. The formula to determine the actual evapotranspiration is displayed in equation 13

$$E_a = ET_o * K_c - (13)$$

Where Ea – Actual Evapotranspiration, ETo- Potential evapotranspiration and Kc- Crop coefficient

With the provided climatic data input, WEAP calculates the potential evapotranspiration for a given catchment using the Penman Monteith equation and further adjusts it with provided crop coefficient data to produce the actual evapotranspiration of crops within a catchment.

Crop coefficient values differ from one crop to another and is normally given a default value of 1 in the WEAP software. The crop coefficient has a significant influence on the level of evapotranspiration from a catchment and can vary for different months in a year. The Kc values are dependent on the level of exposure of the leaves of crops, as agricultural production moves through the bare, planting, mid and harvest seasons. With the automatic catchment delineation mode of the WEAP software, the area and composition of different land uses such as agriculture, forest, urban, barren, grassland etc. can be determined for every catchment. Kc values for the determined land cover can be determined from the FAO report 56 (Allen et al. 1998) and served as input in the different elevation bands within the catchment. Within the WEAP software, demands for irrigation water use can be made with the integrated methods by simply instructing the software to include all irrigated areas once a catchment is created. Another objective way to handle irrigation demand is to use the artificial irrigation demand method which creates an irrigation demand site and serves it with water withdrawals from the catchment. Within the irrigation demand node, the startup year, annual activity level, water use rate, monthly variation and consumption has to be served as input. These input describes the nature of the irrigation water demand site in the model. Aside irrigation, other demand nodes for water supply, channel withdrawal etc., can also be established within the model.

As illustrated in figure 4, the soil moisture method chosen for this study illustrates the basin or catchments as by a two bucket system. This bucket system divides the soil within the various catchments into an upper and lower layer. The upper bucket shown in fig 4 represents the layer of the soil within the catchment which has a direct contribution to surface runoff, interflow and percolation. As shown in figure 4 the upper bucket has precipitation, snowmelt and irrigation as its main input while its outputs are evapotranspiration, percolation, interflow, direct and surface runoff. The level of water in the upper bucket has a very significant influence on the level of evapotranspiration which comes out of the catchment. Within the upper bucket, the parameters which influence the ET, surface runoff, direct runoff, interflow and percolation are soil water capacity(SWC), soil moisture content(Z1), runoff resistance coefficient and preferred flow direction. Parameters like the deep water capacity(DWC) and deep conductivity also have a great influence on the runoff from this model.

In the model setup, net evaporation from the surface of the reservoirs is the difference between the evaporation and precipitation for each time step (WEAP,2022). This is served as input when a reservoir element is introduced into the WEAP model. Positive net evaporation values represent a lot of water loss from the surface of the reservoir and vice versa.

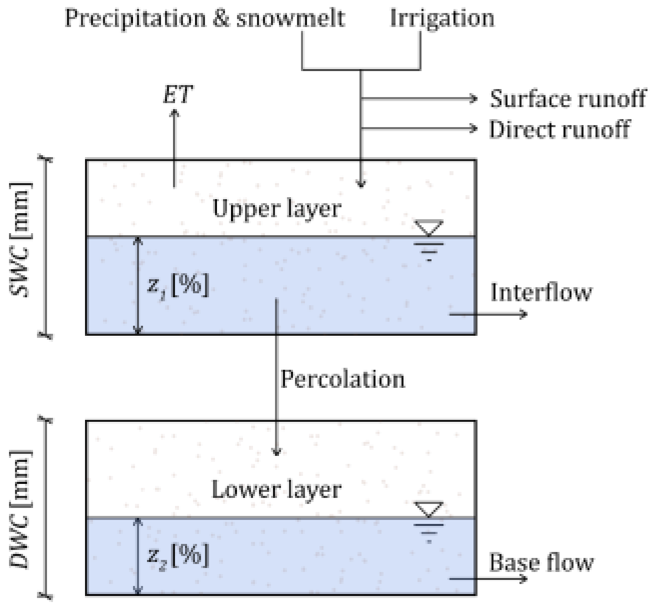

Figure 4: Illustration of Bucket scheme in the Water Balance Method of WEAP (WEAP, 2022)

2.6.2 Catchments and reservoirs

With WEAP's integrated automatic catchment delineation function, basins and sub basins often referred to as catchments can be easily developed in the model. To demarcate a catchment with WEAP's catchment delineation mode, a point is chosen in the modelled basin, and WEAP employs Hydro SHEDS, which is an in built digital elevation model, to produce a boundary around all areas that have water sources draining to the chosen point. The generated catchment, displays the main river within the catchment, the catchment node and the runoff infiltration link. Princeton data center, HydroSHEDS and ESA-CCI-LC are inbuilt data source which supply each delineated catchment with climatic, elevation and land cover data. To simulate the operation of a reservoir, it is required to know the exact location of the reservoir on the globe. HydroSHEDS has a latitude and longitude indicator which aids users to position WEAP elements at their correct geographical location. After the reservoirs have been positioned correctly, there is a need to serve WEAP with data on the physical and operational structure of the reservoir. Physical structure of the reservoir has to do with information on its storage capacity, volume elevation curve, net evaporation, maximum hydraulic outflow, loss to groundwater and observed volumes. The operational data has to do with information on the top of conservation, top of buffer, top of inactive and the buffer coefficient as displayed in figure 5. Availability of water in the reservoir is highly influenced by the operational data served as input and this information ensures that management of regulation is controlled to satisfaction. As shown in figure 5 the volume of water in the inactive zone is not available for simulations regardless of the demand or priority of the water demand node. Above the inactive zone, is the buffer zone which has water that can be regulated. When water reaches the top of buffer level, the percentage of water in the buffer zone to be used for regulation can by served as operational input to the model.

Above the buffer zone is the conservation zone which is the main water supply zone for all demand nodes located at the downstream section of the reservoir. This zone is normally free of restriction and is normally available to serve all demand. Above the conservation zone is the flood control zone, which ensures that the probability of occurrence of a flood is almost zeroed. The distance from the top of conservation to the level of total storage is also known as the freeboard of the dam. When the available water volumes within these zones are not verified in WEAP, the model treats the total reservoir storage capacity as a conservation zone with unlimited restrictions to water withdrawals.

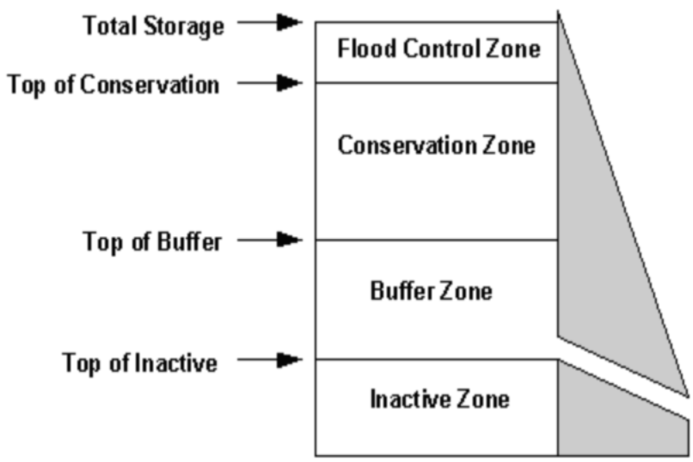

Figure 5 : Illustration of Operational structure of Reservoir Element in WEAP (WEAP, 2022)

Reservoir elements planted into WEAP models serve several purposes ranging from irrigation, flood control, water supply, hydropower production etc. The physical and operational input for each reservoir is customized in accordance to its purpose.

Once a reservoir is assigned a power production function, it becomes very relevant to introduce the requisite hydropower data into the model. Hydropower data which is fed as input into the WEAP model includes the maximum turbine flow, tail water elevation, plant factor, generating efficiency, hydropower priority and energy demand. WEAP calculates the hydropower for each reservoir based on the available water in the reservoir and the different priorities set for other demand nodes.

In a situation where hydropower is given the least priority, a full reservoir will serve and meet all the water needs of demand nodes before considering power production. If water is available for energy production, the WEAP model calculates the energy output with information on the volume of flow through the turbine at each given time step and the Hydro generating factor(HGF) which is also a function of water density, plant factor, available head, plant efficiency and acceleration due to gravity (WEAP, 2022). The available head is recognized as the difference between the water level at each point and the thalweg elevation. The combination of the turbine, generator, and transmission efficiency represents the total plant efficiency. The plant factor is a representation of all the capacity factors within the power generating station. The hydrogenating factor for each time step can be defined by equation 14 (WEAP, 2022).

Equation 15, defines the energy generated from the WEAP model

$$\text{HGF (GJ m3)} = \rho * \text{H} * \text{PF} * \eta * \text{g} * \text{ 1 000 000 000} \text{ ---(14)}$$

Where H- Available Head (m), g - gravitational force (9.81 m/s^2), ρ -density of water (1000 kg/m^3), PF - plant factor,

$$\text{E } (GJ) = \text{HGF} \cdot \text{V} – (15)$$

Where E- Energy generated(GJ), V – Flow volume through turbine at each time step (m^3/time step)

2.7 Economic Analysis

The economic viability of every hydropower retrofitting project is very pivotal in determining its feasibility. After determining the technical feasibility of a project the next stage is to subject it to economic scrutiny, to determine whether it makes economic sense to qualify the project to implementation stage. In full-scale hydropower projects, costs can be classified into initial investment cost and the operation and maintenance cost. Initial investment costs related to full-scale hydropower projects involves cost of civil works for dam, water way and access road constructions.

For retrofitting projects however these initial investment costs are normally excluded. The initial investment costs for retrofitting projects are mainly related to the purchase of electromechanical equipment, minimum pipe works, transmission lines and project management costs. Operating and maintenance cost in retrofitting projects mainly involve management costs and replacement of worn-out equipment. According to IRENA (2012) , the operating and maintenance cost is normally estimated as a percentage of the overall investments. The economic benefits of retrofitting projects can be obtained after electricity produced is offered to a market at a profitable price. An economic analysis subjects the cost and revenue of the retrofitting projects to economic tools like the net present value, benefit-cost ratio, internal rate of return and levelised cost of electricity production, ensuring that the project's cost doesn't outweigh its benefit.

2.7.1 Net Present Value, Internal Rate of Return and Levelised Cost of Electricity

The main indicators for determining the economic viability of engineering projects are the net present value and the levelised cost of electricity. The NPV compares the present value of the total cost incurred on a project to the present value of the benefit to be reaped from the project in order to determine the true value of the project. With the application of a discounting rate, the present value of future amounts can be found. In project analysis , the net present value must be positive for the project to be labelled as attractive and viable for investments. Equation 16 gives a good definition of the Net Present Value.

$$NPV = \sum_{t=0}^{n} \frac{(Cost-Revenue)_t}{(1+r)^t} \quad \text{–(16)}$$

Where r - Discounting rate, t- year number, and n-total number of years for the project. (Žižlavský, 2014).

The project with the highest net present value should always be chosen when compared to a group of projects with positive values. Since engineers often rely on financial institution for loans to execute projects, it will be good to have a fair idea of the interest rate at which to borrow money for project financing. The internal rate of return is the interest rate at which the net present value is zero. Project investment risks are acceptable if the internal rate of return is greater than the current interest rate. The formula for the internal rate of return is displayed in equation 17

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_o \text{— (17)}$$

Where Ct- Net Cash Inflow During Period t, r-Discount rate, t-Number of time period and Co- Total Initial Investment Cost (Hartman et al., 2004)

The levelised cost of electricity is a constant unit price for comparing the cost of power production plants. The LCOE is used to find the cheapest energy supply sources to push investments into. It also represents the electricity pricing for hydropower/retrofitting projects to be considered as profitable in the space of several alternative power producing sources. Projects with higher LCOE than the future prices of electricity are considered as economically risky.

To obtain the LCOE, the total cost over the lifespan of the projects is discounted to the present value and then divided by the total electricity generation over the lifespan of the project. No revenues are included in this calculation so this makes it fair to compare different energy provision sources. Equation 18, clearly defines the levelised cost of energy

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \text{---(18)}$$

Where r - discount rate, n - number of years in the lifetime, I - Investment costs, M -operation and maintenance costs, F-fuel costs, and E – Electrical Energy generation(kWh), t- time step (IRENA, 2012).

Chapter 3: Materials and Methods

This chapter reveals the methods that have been employed in this study. It begins with a data quality check and then delves into the main expectation established for the estimation of the hydropower retrofitting potential. This chapter further describes how the WEAP model was established for this study, its input data and how the calibration process was executed. The chapter also gives a description of the methods involved in the costs and revenue estimation for the various retrofitting projects and the modules of economic analysis that were used to verify the economic integrity of these retrofitting projects.

3.1 Data Refinery

The WEAP model is deterministic in nature and will therefore produce erroneous results if it's fed with faulty data. For this reason, data quality checks were very relevant in this study. Hydrological and meteorological data from several stations within the Buyuk Menderes Basin was received from the Turkish General Directorate of State Hydraulic Works and the directorate of Electrical Power Resources. With the exception of relative humidity and the cloudiness fraction, all climatic data in this study was obtained from the Princeton data center. Data for relative humidity and cloudiness fraction was obtained on a monthly resolution from the FAO's AQUASTAT Climate Information tool.

Available discharge data was organized into a WEAP friendly format (csv) in an excel spreadsheets. To assess the continuity of available discharge data, the gap chart displayed in figure 6 was developed. This chart helped in identifying which gauging station possessed an appreciable level of continuity of available discharge data. In figure 6, the red and black marked cells represent available and missing data respectively. The column on the left section of the red and black markings represents the names of the gauging stations, while the row on top represent the year for which data was available or not.

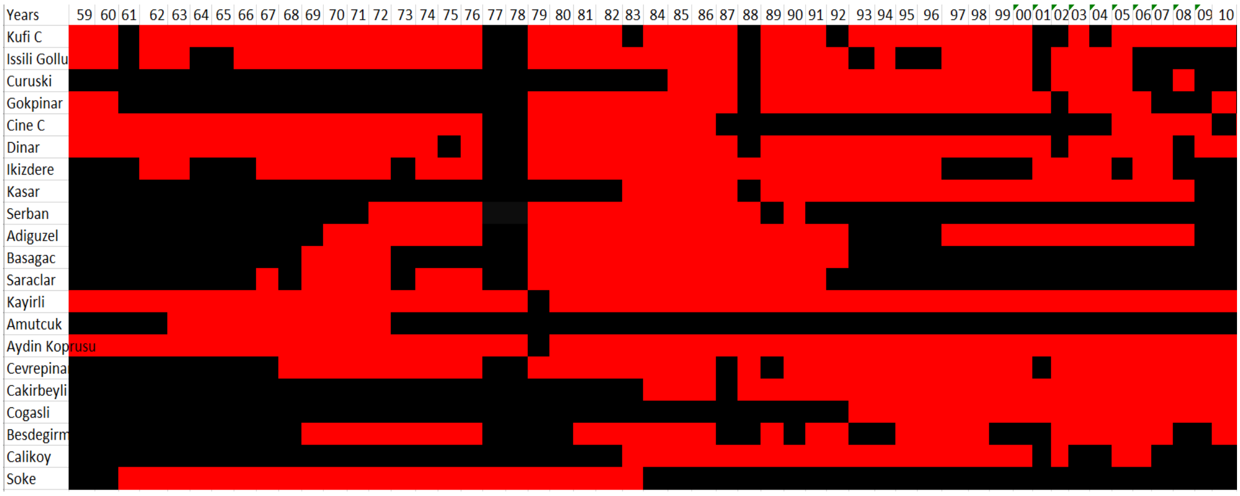

Figure 6: Illustration of Gap Chart of Discharge Data from Gauging Stations

A plot of the cumulative discharge for each station was made to check for possible breach of homogeneity. On this plot, a line of best fit was generated and its coefficient of regression (R^2) was used to identify stations with good and bad data set. Figure 7 and figure 8 show a sample of the generated plots for the various gauging station.

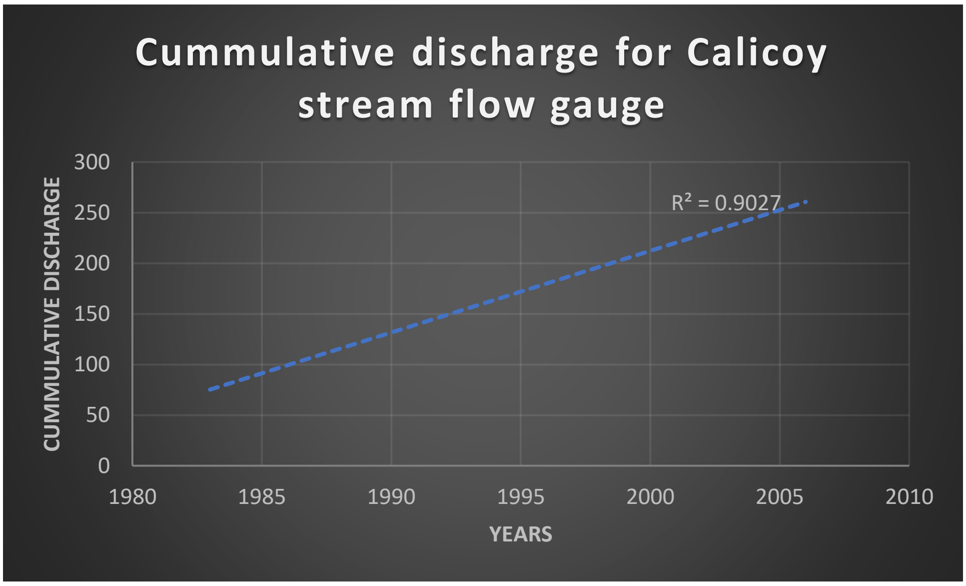

Figure 7 : Data Quality Check Plot for Calikoy Gauge

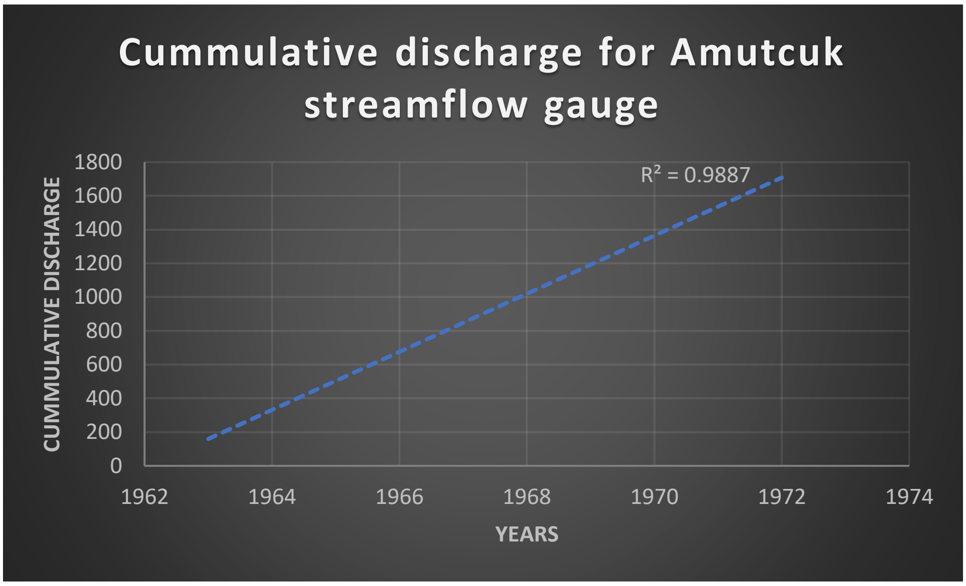

Figure 8: Data Quality Check Plot for Amutcuk Gauge

3.2 Method for Estimation of Retrofitting Potential

3.2.1 Main Expectation

A major expectation in this study is that energy production through retrofitted dams must not compromise on the ability of the dams to perform their primary purpose. Another important expectation requires that retrofitting of these dams must introduce environmental sustainability within rivers. The study also expects that turbines for the power station are placed at the foot of the dam, giving no room for the construction of tunnels. Hydropower generation simulation shall be run for the different catchments, ensuring that years with no data in all months are excluded from the simulation.

3.2.2 Choice of case study

Endowed with an energy potential of 913.3 GWh and an average annual flow potential of 3047 hm^3, the Buyuk Menderes basin is one of the most important basins in Turkey (Kaynak, 2022). The basin occupies about 3.2 % of the entire land area of Turkey and supports the agricultural and textile industry significantly (Kaynak, 2022). According to a publication by the International Water Association (Kaynak, 2022), it has been projected that by 2050, the basin will experience a reduction in annual precipitation by 10 % and a 20% decrease in the flow rate due to high evapotranspiration. This problem calls for serious action from all stakeholders of water use in the basin. For the hydropower sector, efficient utilization of water should be the hallmark to optimize power provision in the basin. Building of new dams as planned by managers of water resources in the basin might increase river fragmentation which could consequently deepen problems related to water scarcity by 2050. The basin is endowed with several non-powered dams which could be retrofitted to produce energy without introducing further environmental issues. These reasons informed the decision to choose Buyuk Menderes basin for this study.

3.2.3 Tools

The main software used for this study is the Water Evaluation And Planning(WEAP) software. This software provides a platform that enables its user to create virtual versions of naturally existing basins. With WEAP elements, climatic data from Princeton data center, elevation data from HydroSHEDS and land use data from ESA-CCI-LC, the Buyuk Menderes basin was developed with ease. The model's flexibility with input data, enables users to create scenarios by changing data in the main elements of the model setup. WEAP has a user-friendly interface that allows analysis of results in different units and time steps. The 2021 version of WEAP was used for this study and this easily computes and displays all objective functions used for model evaluation. The excel spreadsheet software was also used to organize the discharge data in an acceptable format(csv) for model input.

3.2.4 WEAP Setup

Positioned at the most downstream section of the Buyuk Menderes river, the catchment delineation function in WEAP was used to outline the entire Buyuk Menderes basin. WEAP automatically generated the main Buyuk Menderes river and its major brooks which are Kufi, Curusku, Akcay, Cine, Dandalas and Banaz as illustrated in figure 1. The basin generated by the model has a total land area of 2,439,232 hectares and an elevation distribution ranging from -8 to 2,521 meters. The mean elevation within the model was 791 meters. The current year for model simulation was chosen from 1964-2010 matching clear available data. With the catchment delineation mode in WEAP, the river detail function was tuned to display a total of 269 rivers. As shown in figure 9, the main elements in the model for this study consists of 15 reservoirs, 16 rivers, 18 catchments, 27 demand sites (irrigation, drinking water supply, surrounding and channel withdrawal), 16 stream flow gauges, 26 runoff infiltration links , 36 transmission links, 26 return flow links and 13 flow requirement nodes.

Figure 9: Main WEAP Elements For the Study (WEAP,2022)

Elements within WEAP that required exact geographic positioning were introduced into the model with the aid of the decimal coordinate system incorporated in the catchment delineation mode of the software. In order to reflect reality within the modelled basin, it was a key requirement that all the WEAP elements were fed with quality basin representative data set. Climatic data within the basin and its catchments were retrieved from the Princeton data center and the AQUASTAT Climate Information tool from FAO. Data on the physical and operational characteristics of the various reservoirs within the model was obtained from Directorate of State Hydraulic Works (DSI), Turkey. Ground and surface water irrigation demands within the modelled basin were fed with irrigation demand data from DSI. In-built land use data from ESA. CCI- LC was employed in determining the various land covers within the basin and its catchments. Streamflow data serving as input to the stream flow gauges was provided by DSI and EIE.

3.3 Model Schematization

3.3.1 Sub basin set up

The Buyuk Menderes basin has five main brooks namely Kufi, Banaz, Cine, Akcay, and Curusku, which drain into the main Buyuk Menderes river. Positioned at the drainage point of these brooks, sub basins were generated with the aid of the catchment delineation mode in WEAP. Other sub basins were also developed for minor brooks like Karpuzlu, Dandalas and Ikizdere which had reservoirs located on them. Figure 2 gives a good description of the various brooks in the basin. Within the WEAP model, these sub-basins are noted as catchments and the finalized model had a total of 18 catchments. Once a catchment is created in WEAP, its catchment node is automatically generated and positioned at the geometric center of the catchment. The catchment node is connected to the river with the runoff infiltration element which directs all runoff generated/simulated from the catchment to a set position within the main river.

Depending on the water demands within the catchment, the surface runoff fraction was used to distribute the total runoff from the catchment to different positions in the main river of the catchment. Within each catchment, the catchments nodes carry relevant data on the land use, climate, flooding, yield and cost for the different elevation bands in the basin. For the purpose of this study, critical attention was paid to land use and climate leaving the flooding, yield and cost components which were not under the scope of this study. The climatic data set determines the level of runoff generated by the model and includes catchment information of precipitation, temperature, humidity, cloudiness fraction, melting point, albedo and snow. Inbuilt land use data from ESA-CCI-LC shows that all the catchments under investigation in this study, did not have snow and ice present, so the snow parameters (albedo, snow accumulation, freezing point etc.) were left at their default values.

The land use section, provides information on the area of land within the different elevation bands in the catchment. It also shows the percentage of land allocated to agricultural activities, forest cover, grassland, wetland, urban development, shrub land, barren or sparse vegetation, open water, snow and ice.

Information on land use was left at its default values for all catchments within the model. This data on land use is normally useful for calibration purposes and aided in identifying the most relevant elevation bands and land use for calibration. The other parameter within the land use section are the crop coefficient (Kc), soil water capacity, deep water capacity, runoff resistance factor, root zone conductivity, deep conductivity and preferred flow direction. These parameters are characteristics of the catchment that influence the amount of runoff generated within the catchment for each time step. They are therefore used for calibration purposes to ensure that the generated runoff from the catchment is a true reflection of the observed runoff. Data on these parameters was changed during the calibration stage after schematization of the model was complete.

3.3.2 Reservoir Set Up

Data presented by the DSI, shows that the Buyuk Menderes basin is endowed with a total of 25 dams with reservoirs. Eleven of these 25 dams fall into the category of non-powered dams in operation. These non-powered dams in operation are the main structures of relevance for assessment of retrofitting potential in the basin. Information on the geographical location of the various dam was needed to properly position then in the WEAP model. Dam location information available in the degree-minute-second format was converted to the decimal degree system (DDS) which can be used in WEAP's catchment delineation mode.

Switching to the catchment delineation mode, the in-built digital elevation model within WEAP, aided in the location and proper positioning of the reservoir elements in the model. The startup year for each reservoir was served as input into the model to enable the model to identify when each reservoir became active. If the startup year of the reservoir is not designated, the model assumes that the reservoir is active in the current account (1964-2010) and thus simulates regulation throughout the period of the current account. After the startup year for each reservoir was established, the physical characteristic of the reservoir was served as input into the model. The physical characteristics include storage capacity, volume elevation curve, net evaporation, maximum hydraulic outflow and observed volume. Data on these physical characteristics from DSI was served as input into the required field in the model. It was assumed that all the reservoirs were completely sealed and had no water losses to the ground so the field for loss to groundwater was not populated with data. Monthly evaporation and precipitation data within the catchment of the various. reservoirs was obtained from DSI and used to determine the net evaporation for each time step. The net evaporation data was prepared in an excel spreadsheet with a csv format and served as input into WEAP for all the reservoirs under investigation. Regulation in the reservoir is highly dependent on its operational data input. Operational data for each reservoir included data on the volume of water available at the top of conservation also referred to as the highest regulated water level, the top of buffer which is also known as the lowest regulated water level, the top of inactive which is the dead volume in the reservoir and the buffer coefficient. This information on operational volumes for the various reservoirs within the model was acquired from DSI and served as input into their rightful fields within the data section of the model. It was assumed that the entire volume of water in the buffer zone could be released/regulated so the buffer coefficient for all the reservoirs was set at 1.

The Hydropower data input in the model consists of information on the maximum turbine flow, tail water elevation, plant factor, generating efficiency, hydropower priority and energy demand. The model utilizes this hydropower data to simulate hydropower production from the non-powered reservoirs for each time step. Data used to populate the required fields within the Hydropower section of WEAP was obtained from DSI.

Since a major priority of this study is to assess the hydropower retrofitting potential without compromising on the current use of the reservoir, the maximum turbine flow was set as the irrigation flow rate instead of subscribing to the rule of thumb that states that the turbine capacity should be twice the annual average discharge within the catchment. Hydropower priority for all the reservoirs was also set as 2 so as to prevent water use competition with irrigation and drinking water demand. The data needs of the reservoir element in WEAP has a cost section which ensures an easy assessment of the economic viability of retrofitting the non-powered dams. The cost section includes information on capital cost, variable cost, fixed operating cost, variable benefit, fixed benefit and electricity revenue. For the purpose of this study however, the cost function in the reservoir data needs was not used. The IRR, NPV and LCOE were used for economic analysis in this study. The priority section of the reservoirs data needs enables users to set a priority for filling of the reservoir to the top of conservation before serving other demands in the model. For the purpose of this study, this priority was left as its default value of 99.

3.3.3 Demand Node Set

The basin in this study is endowed with 3,047 million cubic meters of water which is served to several water demands within the basin. The Buyuk Menderes basin is an industrial hub for textile production and a very significant agricultural basin for cotton, wheat and maize production (Durdu, 2010). Competing water uses within the basin spans through hydropower generation, irrigation, water supply, and industrial usage. In order for the model to reflect reality of water availability and allocation, it is important that all the competing water demands are properly schematized in the model. The demand site element in the WEAP model ensured that all the competing water uses were well represented in the model. The irrigation demand nodes were first established in the model using data from DSI the irrigation map of the basin shown in figure 10

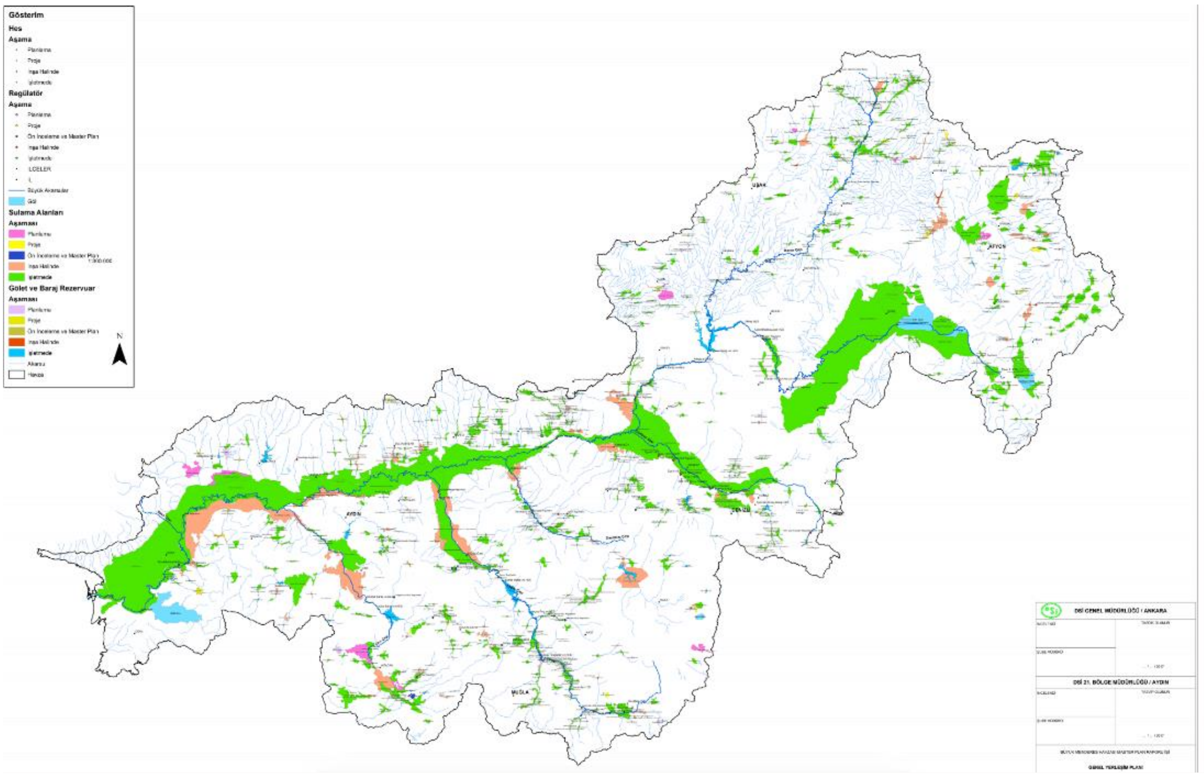

Figure 10: Irrigation Map of Buyuk Menderes Basin (DSI, 2018)

Irrigation data provided by DSI did not include the geographical location of the demand points. The available irrigation demand data was divided into surface and ground water irrigation. Surface irrigation was further divided into public and privatized irrigations. To ensure that the model schematization was as simple as possible, these demands were lumped into total ground and surface water irrigation demand nodes. Using the irrigation map as shown in figure 10, all surface irrigation demand nodes were further divided into left and right river bank irrigation demand nodes. The irrigation demands were positioned at the downstream section of the reservoirs and runoff infiltration node so as to ensure that the set demands are met.

Drinking water demand in the respective catchments were also represented with the demand site elements in WEAP. After mounting all the demand site elements in WEAP, the startup year was served as input into the model. This is done to prevent the model from allocating water to demand sites during years when they were not in existence. Because many irrigation demands were lumped into one, the startup year for the lumped irrigation nodes was assumed as that of the single irrigation node with the highest contribution to the lump. After the start-up years for the various demands were established, their respective annual activity level was then served as input. The annual activity level in this study indicates the population and land area to be served by available water supply. While population was chosen as the unit for drinking water demand, land area (hectares) was chosen for irrigation water demand. The annual water use rate describes the annual rate at which water is allocated to each unit (population or land area). The monthly variations for allocating water to each demand site was given as input data into the model. The monthly variation of drinking water was equal for each month. Irrigation water demand, however responds to the structure of the agricultural year and the hydrological settings of the terrain under consideration. For the purposes of this study, the monthly variation for irrigation demand was set to reflect rainfall pattern in the basin. It was revealed by DSI, 2018 that precipitation in the basin is generally higher from November to April and possibly implies that irrigation could be rain fed during November to April. With this in mind the monthly irrigation flow variation displayed in table 16 was set for model input.

Table 16: Monthly variation in Irrigation and drinking water demand

Month	Irrigation Demand (%)	Drinking Water Demand (%)
January	0	8.33
February	0	8.33
March	0	8.33
April	6.7	8.33
May	9	8.33
June	20.4	8.33
July	30.3	8.33
August	25.2	8.33
September	7.4	8.33
October	1.0	8.33
November	0	8.33
December	0	8.33

Demand nodes have a consumption data input which describes the percentage of the allocated water that is consumed by each demand site. For the purpose of this study it was assumed that each demand site consumes 80% of all water allocated to it. Demand site data input sections like loss and reuse, demand management, cost and advanced were left unpopulated with data because their data requirement were detailed and not relevant to the scope of this study. All drinking and irrigation water demands within the catchment were set to a priority value of 1 while the hydropower demand had a priority of 2. These set priorities allow the model to serve all irrigation and drinking water needs before attending to water needs for hydropower production.

After water use data has been fed into the demand nodes, the transmission link element in WEAP was used to connect water from the available water source (river, aquifer) to the demand site. The return flow link element in WEAP was also used to transfer all unconsumed water from the demand site/node back to the available water source.

3.3.4 Ground Water Nodes

Within the Buyuk Menderes basin, a total of 18,857.4 hectares of irrigated land are supplied with irrigation water from aquifers.

The ground water element in WEAP allows users to represent flow from aquifers to ground water irrigated sites in the basin. The ground water elements for each catchment were placed within their respective catchment after which its data requirements were supplied. The main ground water data needs are the startup year, the physical and the cost component. The startup year indicates which year the aquifer was connected as an irrigation water supply point to the to the demand nodes. For the purpose of this study the startup year for each ground water node was chosen as that of the irrigation demand node it supplies water to. This was to ensure that the ground water systems provide water only for the period of existence of the irrigation demand. The physical data needs of the ground water nodes include storage capacity, initial storage, maximum withdrawal, natural recharge and method. The storage capacity input gives the total theoretical capacity of the aquifer. In this study, it was assumed that the storage capacity for all the groundwater nodes is unlimited, thus the field was left blank. The initial storage is the quantity of water stored in the aquifer at the beginning of the simulation. In this study, the initial storage was assumed to be 20 times the annual demand from the ground water irrigated sites. The maximum withdrawal data input determines the maximum monthly withdrawal from the aquifer for irrigation supply. In the model, the maximum annual ground water released was distributed across the various months with the same monthly variation percentage for surface irrigation. The cost component of the ground water data requirements measures the economic benefits of introducing aquifers into an irrigation scheme. The scope of this study does not cover an analysis into the economic benefit of introducing an aquifer into an irrigation scheme so the fields within the cost section were left unpopulated.

3.3.5 Stream Flow Gauge

Stream flow gauges are fairly distributed at different locations within the basin in order to observe the behavior of flow for different time steps. Data from stream flow gauges guide decisions on calibration, minimum flow and turbine choice. The stream flow gauge element within WEAP enables users to include the discharge stations in the model. Relevant discharge station information for this study were provided by DSI and EIE. Observed runoff data within these discharge stations were obtained on a monthly resolution and organized into a WEAP friendly format (csv) for input. In the catchment delineation mode, the stream flow gauges were placed at their rightful positions within the basin. Prepared discharge data were then served as input into their respective streamflow gauges.

3.3.6 Flow Restriction for Minimum Flow

Minimum flow is normally released to the downstream end of reservoirs to ensure that flow connectivity and sustenance of biological life. In this model, the dammed water for irrigation purpose is released from the outlet of the reservoir during the peak irrigation months which is from April to October. No irrigation water release has however been scheduled from November to March for each of the reservoirs. For all the irrigation dams within this study, the period from November to March is a critical period for minimum flow release. During the peak irrigation release periods (April- October), no minimum flow is released when the irrigation flow far exceeds the minimum flow value. If the minimum flow requirement during the peak irrigation period is however higher than the irrigation flow, the flow difference between the irrigation and minimum flow is set as the minimum flow release.

The flow restriction element in WEAP is normally used to set minimum flows requirements in WEAP. In this study all flow restriction elements were positioned at the downstream end of the reservoir to ensure that minimum flow is released to those position even when there is no irrigation and power production flow release from the dams. The flow restriction element, requires data on the minimum flow as a single value over the year, or as monthly variations in a year. In this study, the monthly variation of minimum flow was served as input to all the flow restriction elements. To obtain this monthly variation in minimum flow, pre-regulation discharge data of downstream gauges were selected, and split into the various quarters in a year to ensure that the computed minimum flow, supports spawning, egg survival, fry displacement, migration and other fish habitat-specific conditions. Quarterly flow data was sorted, ranked and subjected to the probability of exceedance formula in equation 19

$$P = \frac{r}{n+1} \text{----(19)}$$

Where P- Probability of exceedance, r- rank , n- total number of data

Duration curves for the respective quarters were generated and used for the determination of minimum flow values. From these duration curves, the flow value which has the probability of being exceeded 95% of the time was set as the minimum flow for the quarters. Figure 11 show the finalized schematic illustration of the Buyuk Menderes River basin.

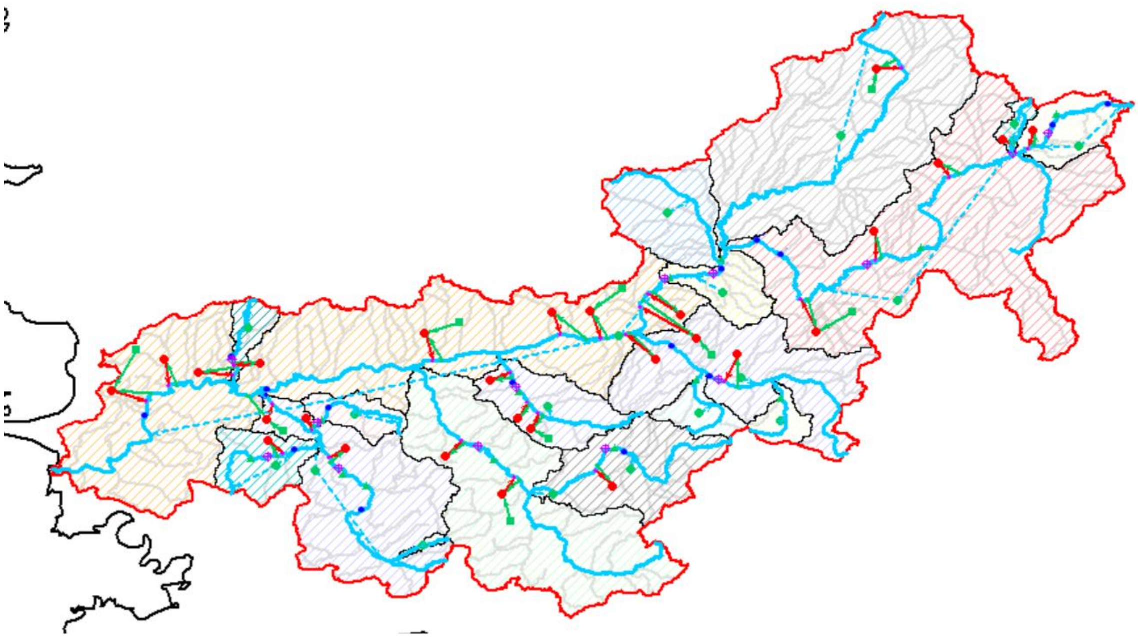

Figure 11 :Finalised Scheme of Buyuk Menderes River Basin

3.3.7 Model Calibrations

After the model is properly schematized, calibration is needed to ensure that simulated flow is almost equivalent to the observed flow from in the stream flow gauges. When a good calibration is achieved we can trust the results from the model as very representative of the basin and a good source of information planning. Regional calibration was done for all the catchments in this model. Independent calibration parameters were used to ensure that the deviation between observed and simulated flow was minimized. The main calibration parameters used for the calibration were the crop coefficient (Kc), soil water content (SWC), deep water capacity (DWC) and the runoff resistance (RRF). A yearly time step was adopted for the calibration. Before calibration, the model was switched to the catchment delineation mode to have a fair idea of the dominant land uses and elevation bands in the catchment. This gave a good idea of the specific land uses and elevation bands which will be sensitive to the calibration process.

The PBIAS was the main objective function used to assess the performance of the calibration. Calibration in each catchment commenced with the Kc value which is a very important water balance parameter due to its direct correlation to the crop evapotranspiration in the basin as shown in equation 13. The crop coefficient varies over the different months in a typical agricultural year. At the beginning of the agricultural year when the soil is bare, evapotranspiration is very low. After planting and sprouting, the leaf covered area increases and this is followed by a consequent increase in the crop coefficient because increased leaf cover raises the level of evapotranspiration losses. After harvesting, the Kc values dips because the leaf covered area is reduced. Kc values also vary for different crops and land use. As described by Durdu, (2010) in the paper title " Effects of climate change on water resources of the Büyük Menderes river basin, western Turkey" the main crops grown at the mountain foots of the basin are cotton, vegetables, fruits, maize, and wheat while figs, olive trees, oranges, peaches, and plums are grown at the mountainous part which are higher in elevations. For the purpose of this study the Kc values for the various land uses in the catchments were obtained from FAO report 56.

The Kc value for urban areas was obtained by finding the average of the monthly Kc values for grassland and bare land. These Kc parameters were served as input into the relevant fields within the data section of the software. With a good understanding of the trend of Kc values across the various months in the agricultural year, small changes were effected to the monthly Kc values to bridge the gap between the annual observed and simulated runoff in the catchment. These changes continued till the sensitivity of changes in Kc value to the calibration was lost. For each catchment within the basin, calibration with the soil water capacity follows that of Kc.

The soil water capacity is the size of the upper bucket in the soil moisture method illustrated in figure 4. The higher the capacity of the upper bucket, the lower the runoff generation within the catchments and vice versa. The soil water capacity of a typical catchment is not constant but varies over the agricultural year. At the beginning of the agricultural season when the soil is bare the water holding capacity of the soil is high because the irrigation flow to the field is at its minimum. After crops have sprouted however the irrigation water needs increase, causing more water to be released to the field. This reduces the water holding capacity of the soil and increases the runoff within the catchment. The monthly variation in the soil water capacity was served as parameter input to the rightful fields in the data section and further explored to bridge the gap between annual observed and simulated runoff in the catchments of the model. Calibration with the SWC continues till its sensitivity to the calibration process is lost. Calibration with the runoff resistance factor follows that of soil water capacity.

The runoff resistance factor is the measure of how runoff is impeded within a catchment. Higher runoff resistance factors flow with consequently low runoff generation and vice versa. The RRF is directly linked to the level of leaf cover in the catchment. Less leaf cover increases the runoff generation within the catchments because precipitation interception and evapotranspiration losses are reduced. When the leaf cover is higher, the interception of precipitation is high while evapotranspiration losses are higher, this consequently leads to lower runoff generation. With this analogy, the RRF values for each land use within the different elevations was served as input into the model and varied over the years to obtain the best fit for the observed and simulated annual flow. The RRF was a very sensitive parameter and ensured that a good level of ease was injected into the quest to bridge the gap between observed and simulated flow. Because equifinality in model calibration is permitted, all other calibration parameters with the exception of Kc, SWC and RRF were left at their default values once a good value for the objective function(PBIAS) for model evaluation was achieved.

3.3.8 Model evaluation criteria

To ensure that the model is functioning good and reflecting reality within a catchment, several model evaluation criteria (objective functions) can be employed. Objective functions normally used for model calibration evaluation are, the Nash Sutcliffe Efficiency(NSE), Pearson's correlation coefficient(r), Coefficient of determination (R^2), Prediction efficiency(Pe), Performance virtue statistics(PVk) and the error indices which are the Mean absolute error (MAE), Mean square error(MSE), Root mean square error(RMSE) and Percent bias (PBIAS) the coefficient of regression (Moriasi et al., 2007). For the purpose of this study the PBIAS was the main objective function used for evaluation of the model because of its ability to clearly indicate poor model performance. The percent bias (PBIAS) is a measure of the percentage by which the simulated annual flow generated from the model differs from the observed annual flow (Moriasi et al., 2007)

The PBIAS objective function is expressed in equation 20.

$$PBIAS = 100 * \frac{\sum_{i=1}^{n}(Q_{i\,obs} - Q_{i\,sim})}{\sum_{i=1}^{n} Q_{i\,obs}} \text{---(20)}$$

Where Qi, obs- the observed flow (m3/s) at time step i and Qi, sim - the simulated flow(m^3/s) at time step i.

When PBIAS is used as the main objective function for calibration, the main aim is to minimize it to the least value as possible. The best value for PBIAS in any calibration is 0% and this is achieved when the simulated and observed flow are the same throughout the time steps under consideration. When the calibration is very good the model and its results can be trusted to reflect reality. To interpret what each PBIAS value means for the calibration, the work of Moriasi (Moriasi et al., 2007) as displayed in table 17 was used.

Table 17: Table of Interpretation for PBIAS values

PBIAS value	Model Performance
0-10	Very good
10-15	Good
15-25	Satisfactory
25-∞	Unsatisfactory

3.4 Cost of Retrofitting

The cost engineering equipment and materials required to retrofit these non-powered dams involved the cost of complete electromechanical equipment, power house construction, penstock pipes, transportation, installation and civil works. The prices of these components were retrieved from the NVE cost base for small hydropower project. The prices of equipment in the NVE cost base were prices as at the year 2010, so the rightful inflation and exchange rates were applied to convert them to their current values in US dollar for the purpose of this study. The planned scheme for retrofitting was established to have pipes which tap water from the intake position, runs water down and through turbines in the power house located at the foot of the dam, and releases the same water into the irrigation channel for irrigation purposes. To minimize head losses related to the use of the pipes in the scheme, a pipe diameter optimization was performed to select pipes with optimum diameters and cost. Table 18 displays the selected pipe diameters for the different retrofitted dam.

Table 18: Optimised Penstock Diameter, Capital Cost and Turbine Type for NPDS

Dam	Optimised Penstock Diameter(m)	Capital Cost(Mil $)	Turbine Type
Yavaslar	0.840	0.294	Francis
Orenler	1.020	0.361	Kaplan
Issikli	3.000	0.705	Kaplan
Tavas Yenidere	1.100	0.928	Francis
Topcam	1.280	0.657781	Francis
Gokbel	2.750	1.82068	Francis
Yaylakavak	1.210	0.7562	Francis
Ikizdere	0.900	0.8715083	Francis
Gokpinar	0.660	0.544	Francis
Akbas	0.680	0.41	Francis
Karakasu	0.800	0.544	Francis

Based on the head and outflow requirements as shown in table15, the turbine application chart in figure 12 was used to select turbines for the various retrofitting projects. The selected list of turbine for each dam is shown in table 18. The capital investment cost for retrofitting of the 11 dams is displayed in table18. Operating and maintenance cost for running of power production business was assumed to be 4% of the capital investment cost. At the current energy of $0.09/kWh (Daily Sabah, 2022), the annual revenue was generated as the product of the current energy price and the annual energy produced by each dam A combination of natural resource and income tax for power production was assumed at 35% of revenue generated form power production.

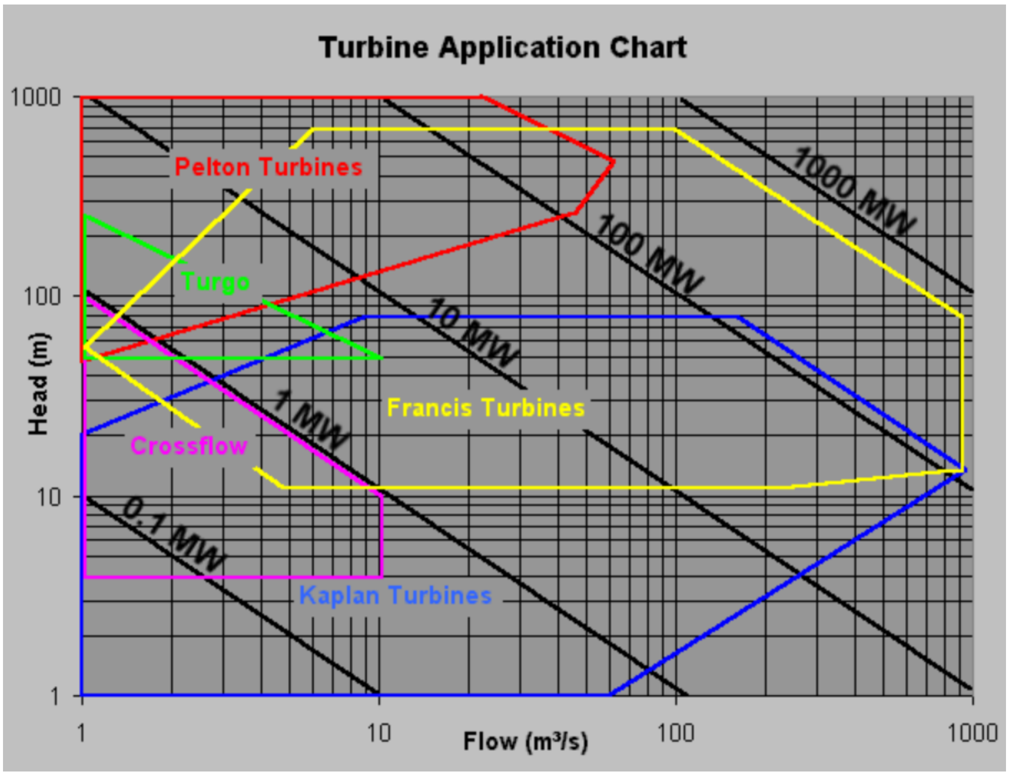

Figure 12 : Turbine Application Chart

3.4.1 Economic analysis

From the estimated values of cost and revenues, economic analysis was conducted to verify the economic viability of running the power production business for a period of 40 years at a discounting rate of 5%. The projects benefit-cost ratio was also assessed over the 40year period. The internal rate of return was used to determine the level of return on investment for each retrofitted dam. The levelised cost of electricity was also generated for each retrofitting project and compared to LCOE values of other emerging renewable energy sources (IRENA, 2021) displayed in table.

Table 19: Levelised Cost of Electricity for Emerging Renewables

Renewable Energy Source	LCOE($/kWh)
Bioenergy	0.076
Geothermal	0.071
Solar PV	0.057
Concentrated Solar Power	0.108
Onshore wind	0.039
Offshore wind	0.084

Chapter 4: Results

4.1 Calibration Results

4.1.1 Kufi Catchment Calibration results

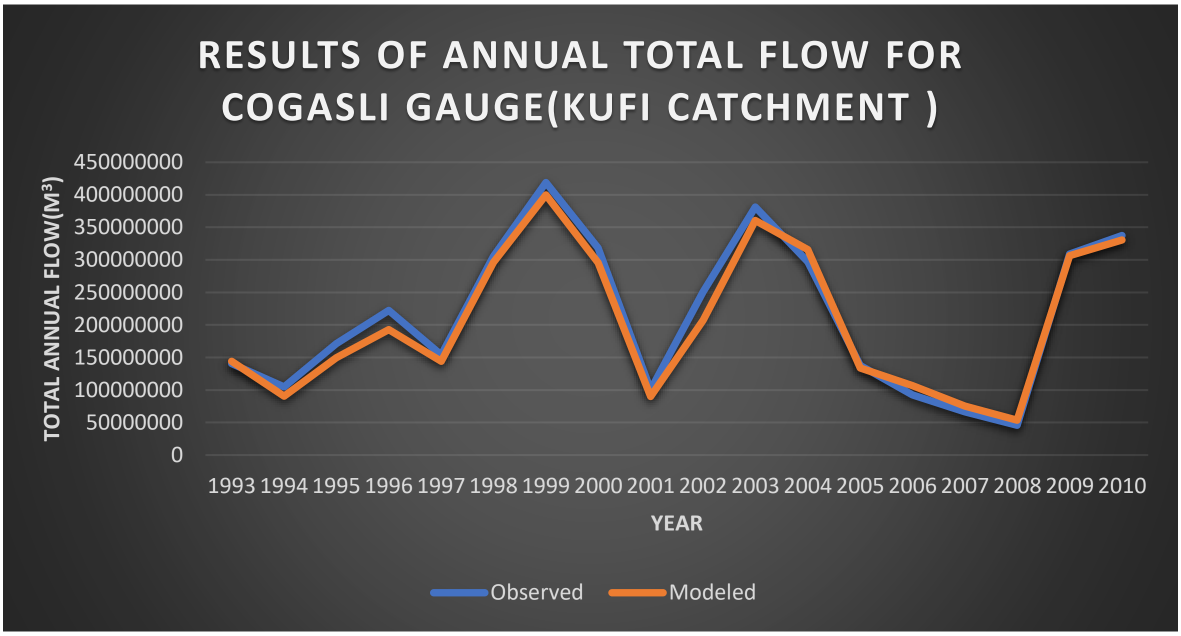

Figure 13: Calibration Results of Kufi Catchment

Results of calibration within the Kufi basin in figure 13 shows a percent BIAS of 1.6%. The simulated annual total flow closely follows all the peaks and recessions of the inter-annual hydrograph shown in figure 13. The deviation between observed and simulated flow for both dry and wet years is very minimal. It can however be observed in figure 13 that the modelled total annual flow in 1996 is slightly lower than the observed. The total observed flow for all the years under study was 3,852,351,619 m^3 while the total simulated flow was 3,692,660,623 m^3. The total observed and simulated flow differs by a value of 159,690,996 m^3. The total observed flow was 1.6% higher than the simulated flow from the model.

4.1.2 Curusku Catchment Calibration Results

Results of calibration for Curusku catchment as shown in figure 14 generated a percent BIAS of 3.4 %. It is seen from figure 14 that the simulated annual total flows for this catchment follows the peaks and recessions in the inter-annual hydrograph. The annual total simulated and observed flow for 1968 and 197 however recorded the highest deviation. In both years, the simulated total annual flow exceeded that of the observed. The total of all observed flows for the years under study was recorded as 7,973,624,361 m^3 while the total simulated flow value was 8,205,354,839 m^3. The total simulated flow was 231,730,478 m^3 higher than the observed flow. The simulated flow was 3.4% higher than the observed flow.

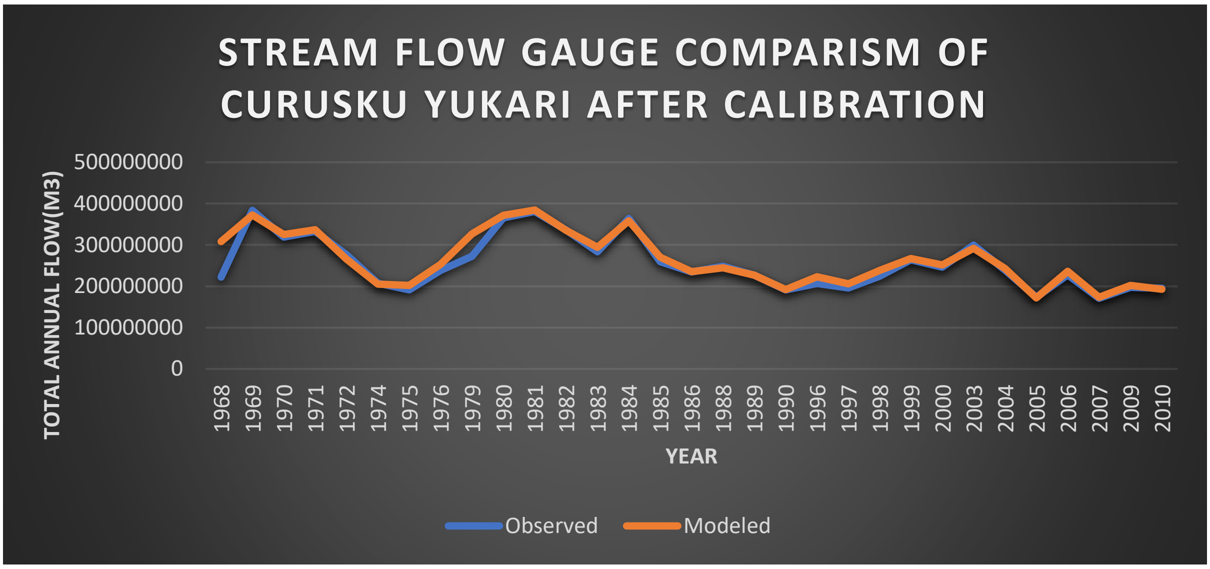

Figure 14: Calibration Results for Curusku Basin

4.1.3 Dandalaz Catchment Calibration Results

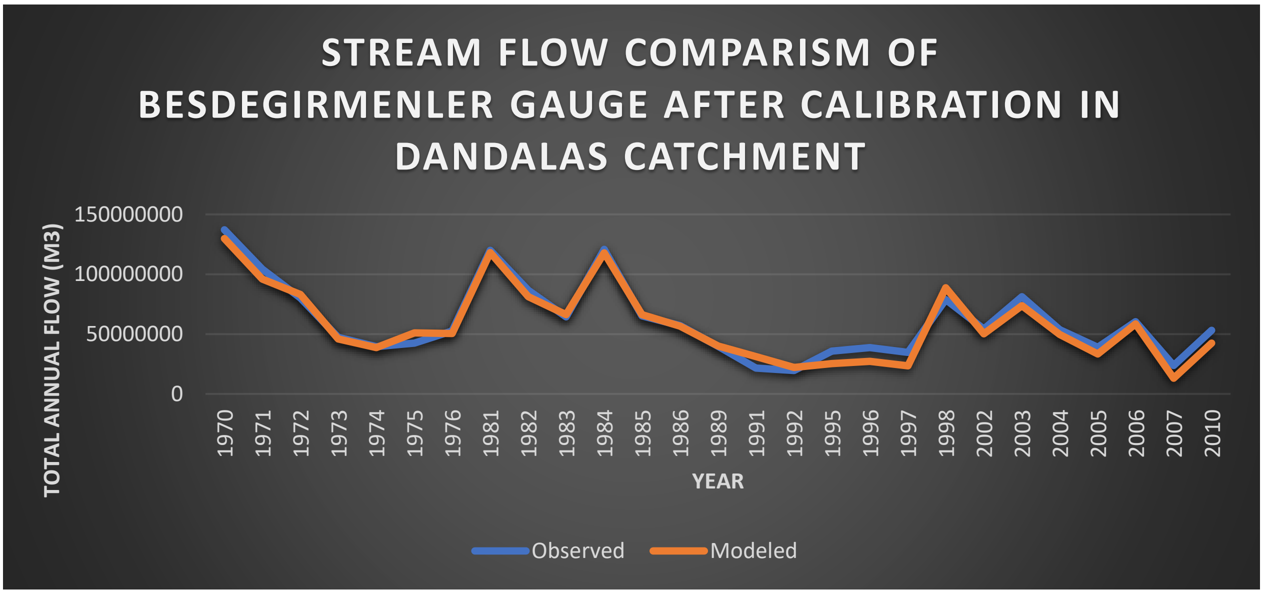

Figure 15 : Calibration Results for Dandalas Catchment

Results of the calibration in the Dandalas basin displayed a percent BIAS value of 4.3%. Figure 15 shows that the simulated flow closely follows the observed peaks and recession in the inter-annual hydrograph. The drop of total annual flow from 1970 to 1974 is well reflected by the simulated flow. The deviation between the simulated and observed total annual flow is however high for 1975, 1995,1996 and 1997. The total of all observed total annual flow was recorded as 1,651,344,106 m^3 while the model's simulated value was 1,580,142,91.5 m^3. The overall simulated total annual flow was lower than the observed by a flow value of 71,201,191 m^3 representing 4.3% of the total observed value for all the years.

4.1.4 Cine Catchment Calibration Results

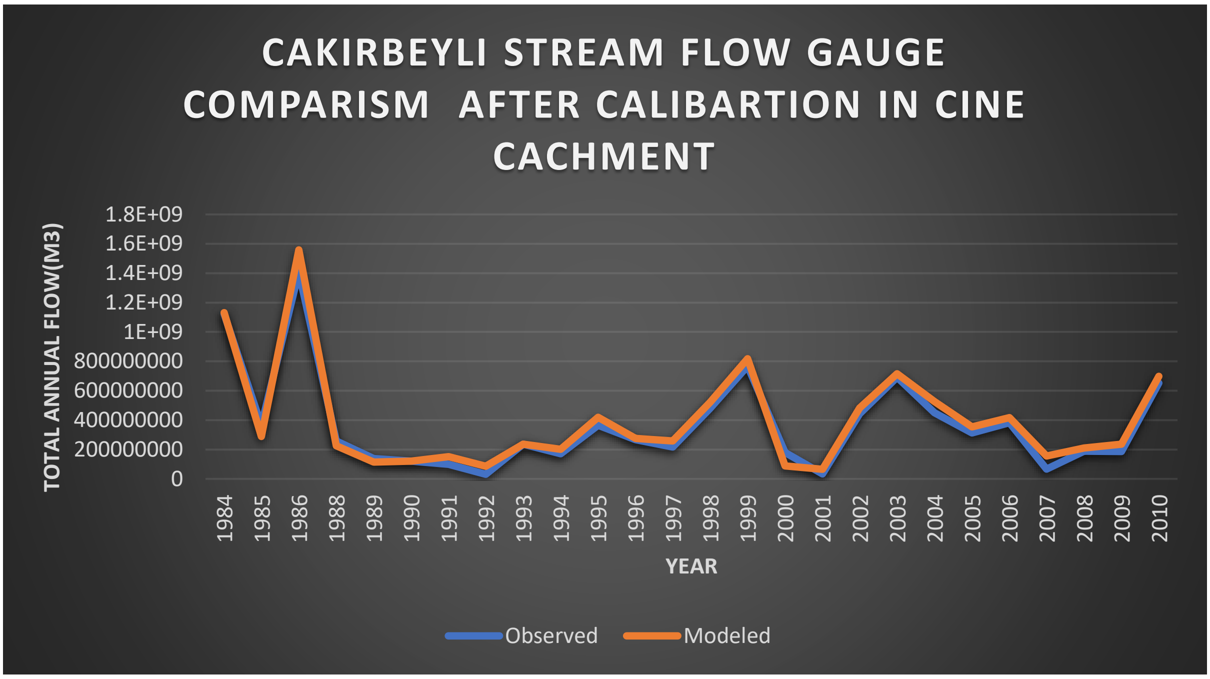

Figure 16: Calibration Results for Cine Catchment

Results of calibration in the Cine catchment as shown in figure 16 displays a percent BIAS value of 7.6 % From figure 16 the simulated flow is seen to closely follow the recessions of the inter-annual hydrograph with the exception of year 1992, 2000 and 2007. The total observed flow for all the years under study was recorded at the value of 9,629,593,114 m^3 while that of the total simulated flow was 10,352,457,502 m^3. The total modelled flow was higher than the observed flow by a flow value of 722,864,388 m^3.

4.1.5 Ikizdere catchment calibration results

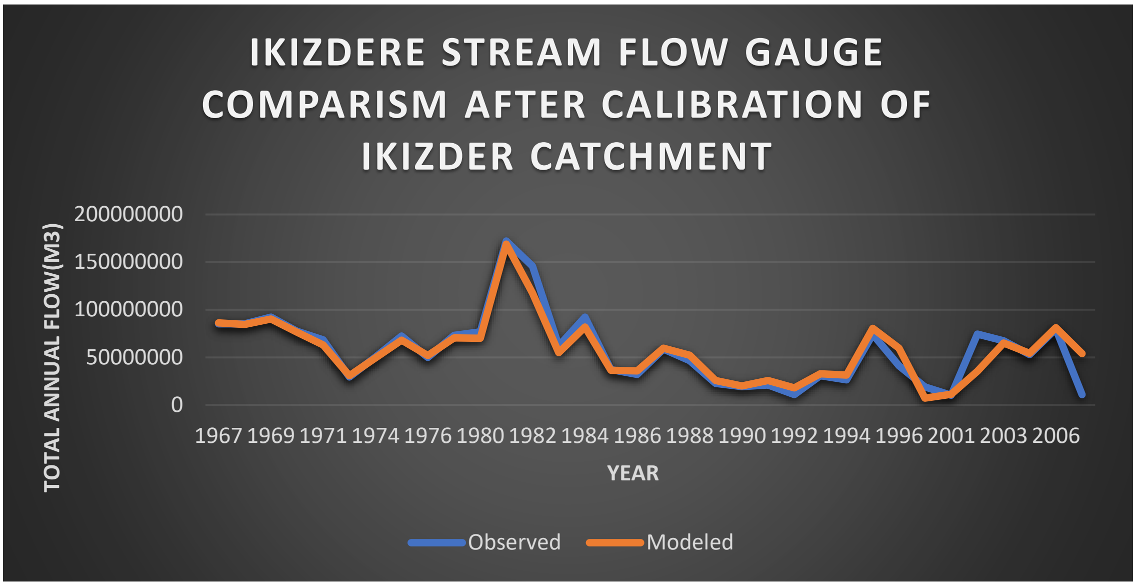

Figure 17: Calibration Results for Ikizdere Catchment

Results from calibration in the Ikizdere catchment is displayed in figure17. The percent BIAS value obtained from calibration was 0.86 %. As shown in figure 17, the deviation between the observed and simulated flow from 1967 to 1995 looks minimal. The period from 1996 to 2006 however recorded high deviations between the observed and simulated flow. The modelled flow misses the peaks and recessions of the observed flow from 1996 to 2006. The total observed flow for all the years was recorded as 1,966,025,524 m^3 while the total simulated flow was 1,949,021,143m^3. The total observed flow is higher than total simulated flow by a value of 17,004,381 m^3.

4.1.6 Tavas Yenidere Catchment Calibration Results

Results from the calibration of Tavas Yenidere catchment is displayed in figure18. The Percent BIAS generated from calibration was 2.5%. From a high annual total value recorded in 1984, a fast recession followed and remained constant from 1985 to 1998. The modelled flow was able to closely follow this peak and recession in observed flow. At a value of 678,578,084 m^3 the total annual simulated flow was recorded as higher than the total annual observed flow by a flow value of 16,824,673 m^3.

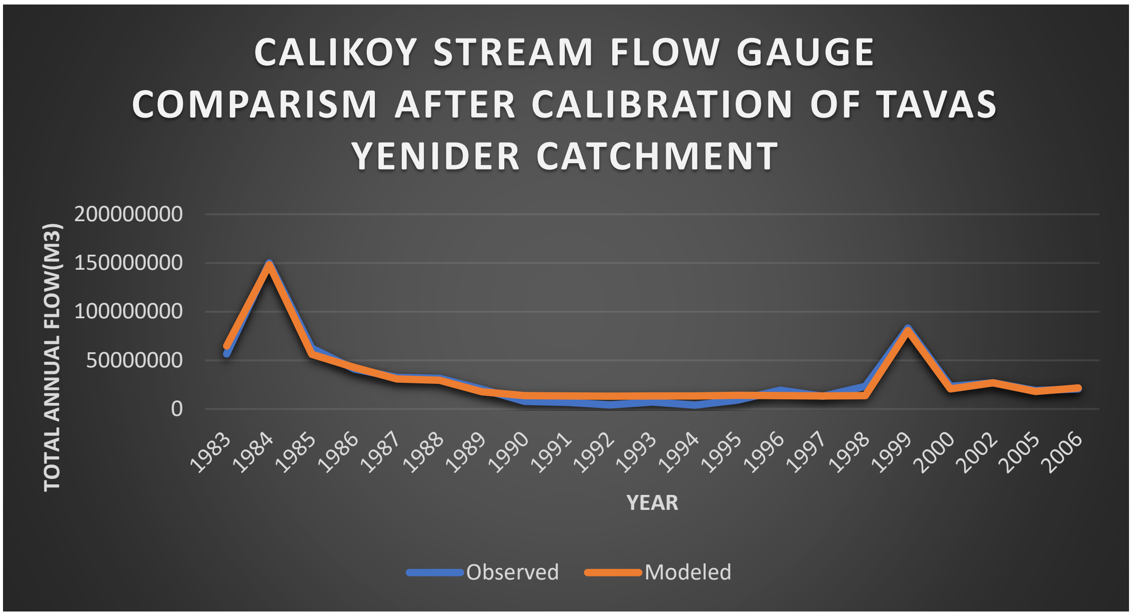

Figure 18 : Calibration Results for Tavas Yenidere Catchment

4.2 Minimum Flow Results

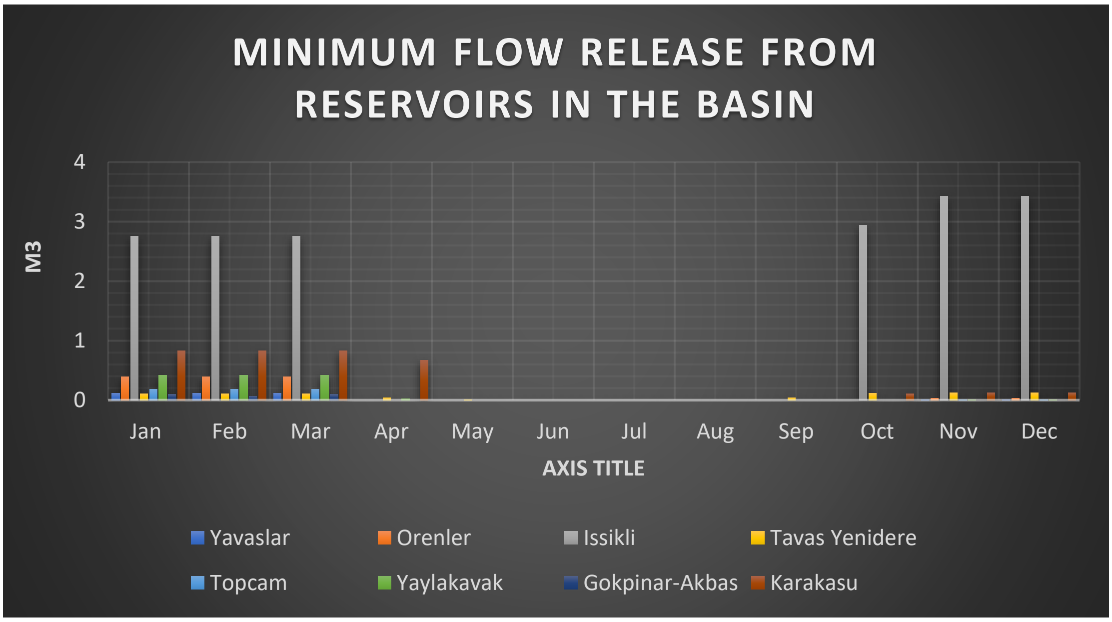

Figure 19 : Minimum Flow Results for the Non Powered Dams

The minimum flow values set for each dam under investigation is displayed in figure 19. From figure 19 it is realized that the minimum flow values for all the non-powered dams are generally higher from January to March. From May to August, all the dam release very little or no minimum flow. Apart from Issikli dam, all minimum flow releases from September to December are generally lower than the values from January to April. Issikli dam recorded the highest minimum flow release at a flow value of 3.428 m^3/s from September to December. The least minimum flow release was recorded by Topcam dam with a flow value of $0.01m^3/s$ in November and December. The average minimum flow release for all the dams over all months was $0.567m^3/s$. Due to the nature of the monthly variation in irrigation flow release, river connectivity and aquatic life sustainability would have been a serious environmental bottleneck in this project. The release of minimum flow from the dam in this critical months as shown in figure 19 Injects some level of environmental sustainability into the project.

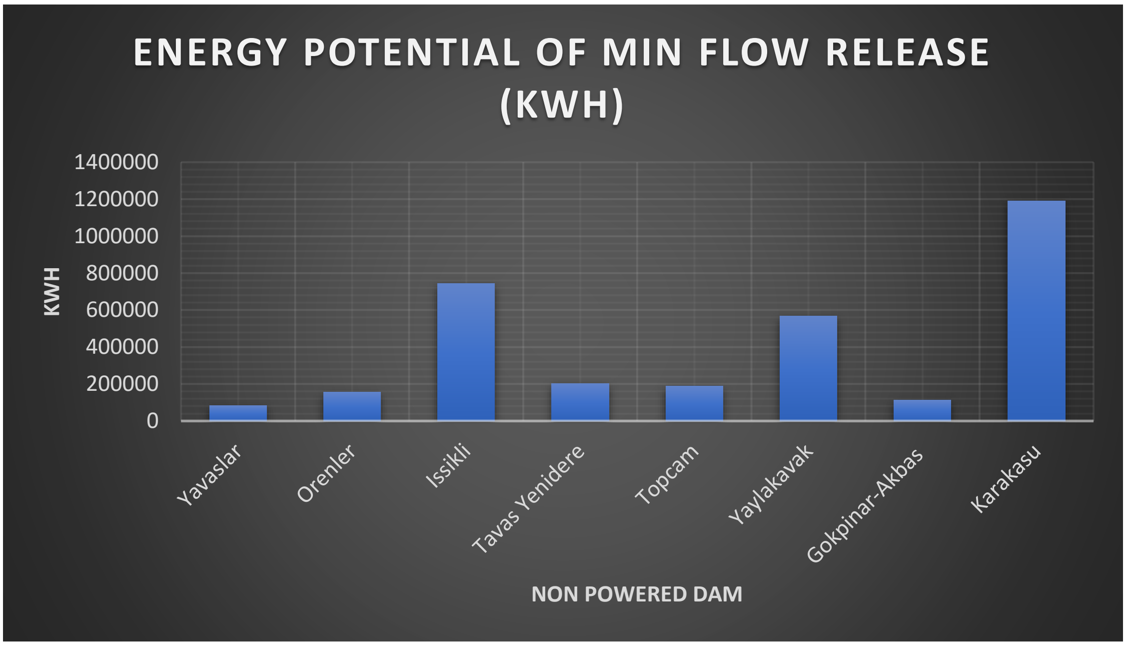

Figure 20 : Energy Potential of Minimum Flow Release

Figure 20 shows the annual energy production potential of minimum flow release through the installed turbines of each dam. Karakasu dam recorded the highest potential annual energy production from minimum flow release at an energy production value of 1,192,016 kWh. The minimum potential annual energy production from minimum flow release was recorded by Yavaslar dam in the Kufi basin. The average annual energy potential from the minimum flow release in the basin was recorded as 406,356.5 kWh

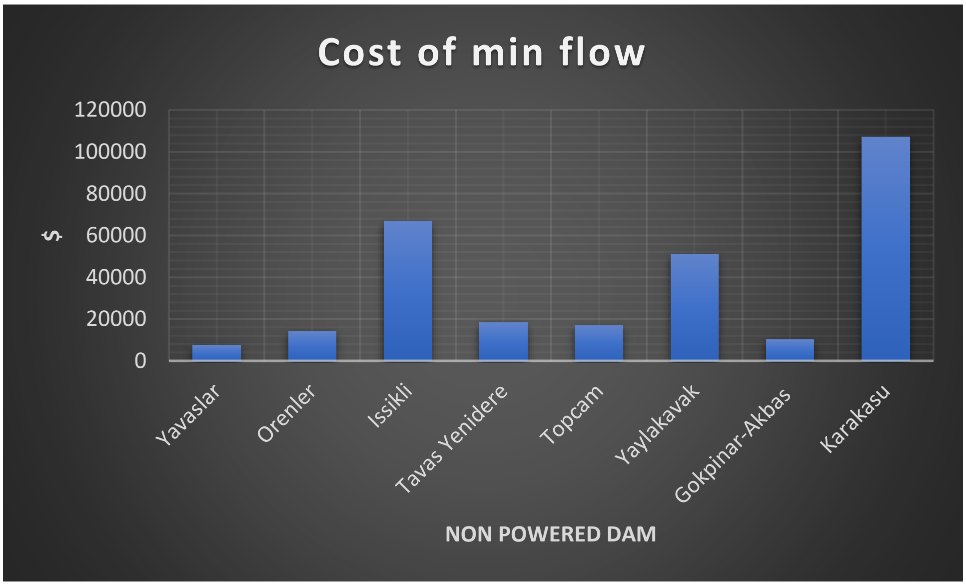

Figure 21: Cost of Minimum Flow Release

Because all of the proposed turbines for the dams will operate at extremely low efficiencies when operating with the minimum flow discharge, minimum flow is considered as a loss to the hydropower business and a gain to the environmental sustainability. Figure 21 shows the cost of releasing minimum flow into the river at the downstream section of the dam without allowing it to run the turbines. At an energy cost of $ 0.09/kWh, Karakasu recorded a loss of $ 107,281.4 which was the highest loss from minimum flow release in the basin. The lowest loss from minimum flow release was recorded by Yavaslar at a value of $7,584.394. The annual average loss from minimum flow release from all the non-powered dams was recorded as $ 36,572.09.

4.3 Results for unmet demand

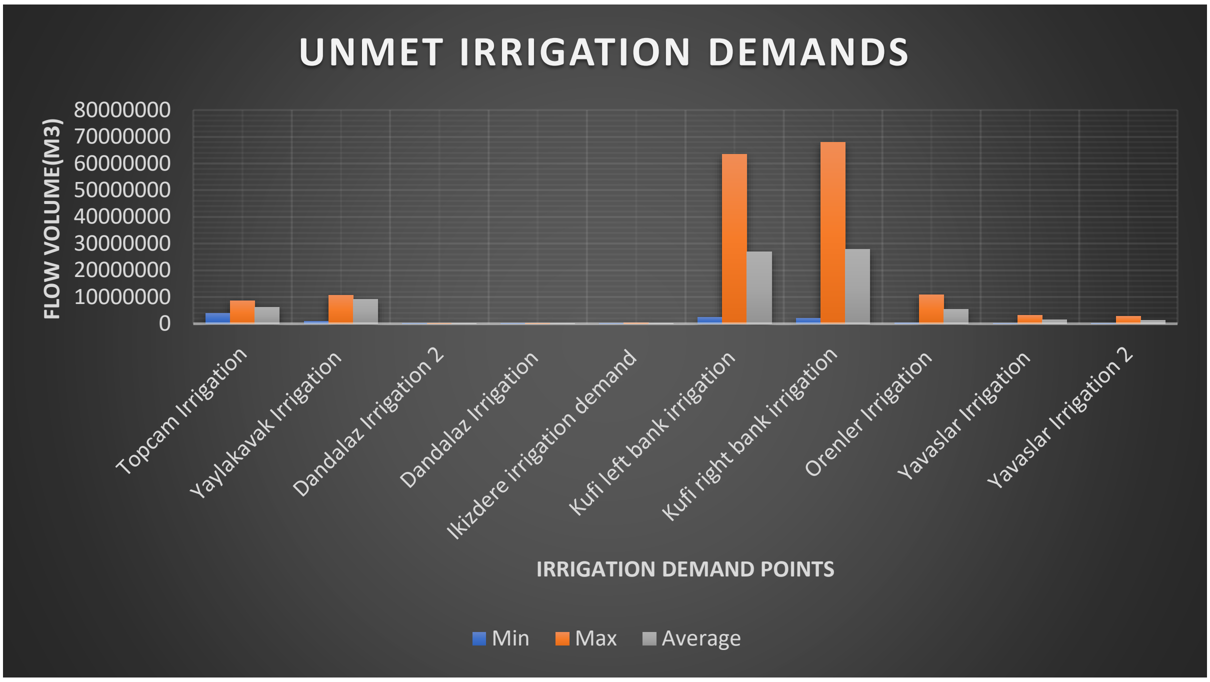

Figure 22: Results of Unmet Irrigation Demand

To assess the impact of water scarcity on the basin, figure 22 and figure 23 were generated. Figure 22 shows the results of unmet irrigation demands within the basin after the model has been schematized and calibrated. The chart in figure 22 shows the minimum, maximum and average value of unmet demand for each irrigation demand node. From the result, Dandalas Irrigation 2 recorded the least unmet irrigation demand at an average annual irrigation flow deficit of 7433.186 m^3. Kufi right irrigation was the most critical irrigation demand node with the highest unmet demand. Over the years of investigation, Kufi Right Bank Irrigation node recorded an average annual irrigation flow deficit of 27,880,950.4 m^3. Throughout the basin, the average annual irrigation flow deficit was recorded as 7,873,638.75 m3.

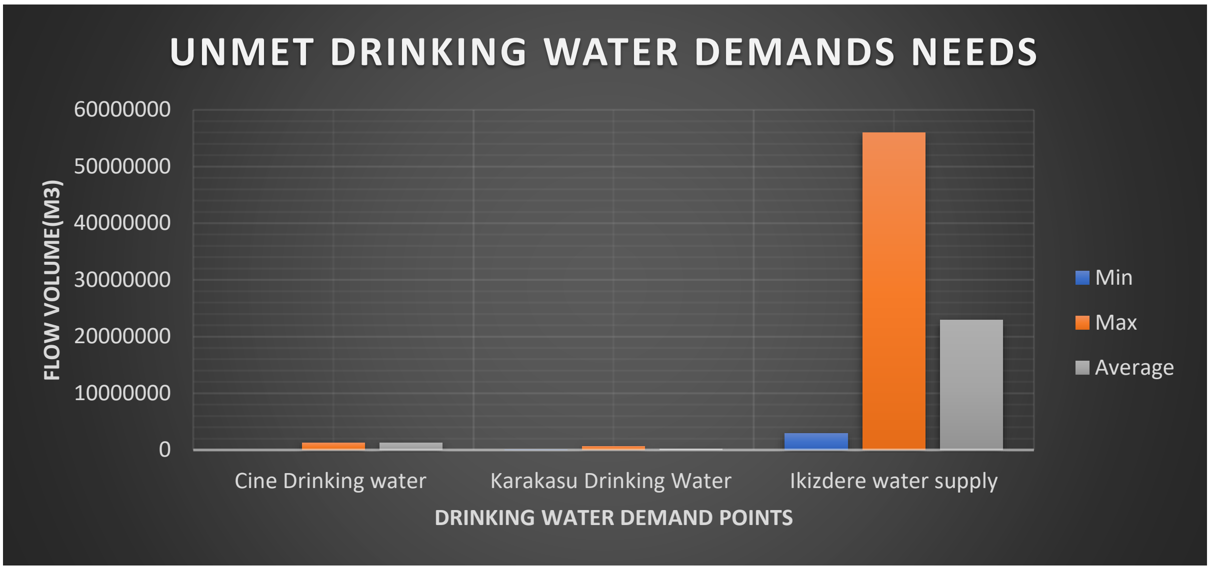

Figure 23 : Results of Unmet Drinking Water Demand

Figure 23 shows the unmet demands for the drinking water demand nodes within the basin. From figure 23, Karakasu drinking water demand recorded the least drinking water deficit with an annual average value of 180,319.1 m^3. Ikizdere drinking water supply was the most critical in terms of unmet water demands. The Ikizdere water demand node recorded an annual average drinking water deficit of 22,944,488 m^3. The average annual drinking water deficit in the basin was recorded as 8,139,926 m^3.

4.4 Energy Production Results

After complete schematization and calibration of the model, the simulated energy production from the various dams is displayed in figure 24. The results from energy production as displayed in figure 24 shows that Gokbel dam has the highest energy production potential. The Gokbel dam recorded an annual average energy production of 12,499,158.5 kWh. Yavaslar on the other hand recorded the lowest annual average energy production with a value of 350,232.868 kWh. The average annual energy production within the basin was recorded as 3,516,414.26 kWh. In total, the energy production from hydropower retrofitting in the basin is 38,680,556.8 kWh equivalent to 38.7 GWh of energy on an annual basis. Figure 24 shows the annual average energy production from all the dams under investigation in GWh. Figure 25, also shows the monthly trend of energy production in GWh

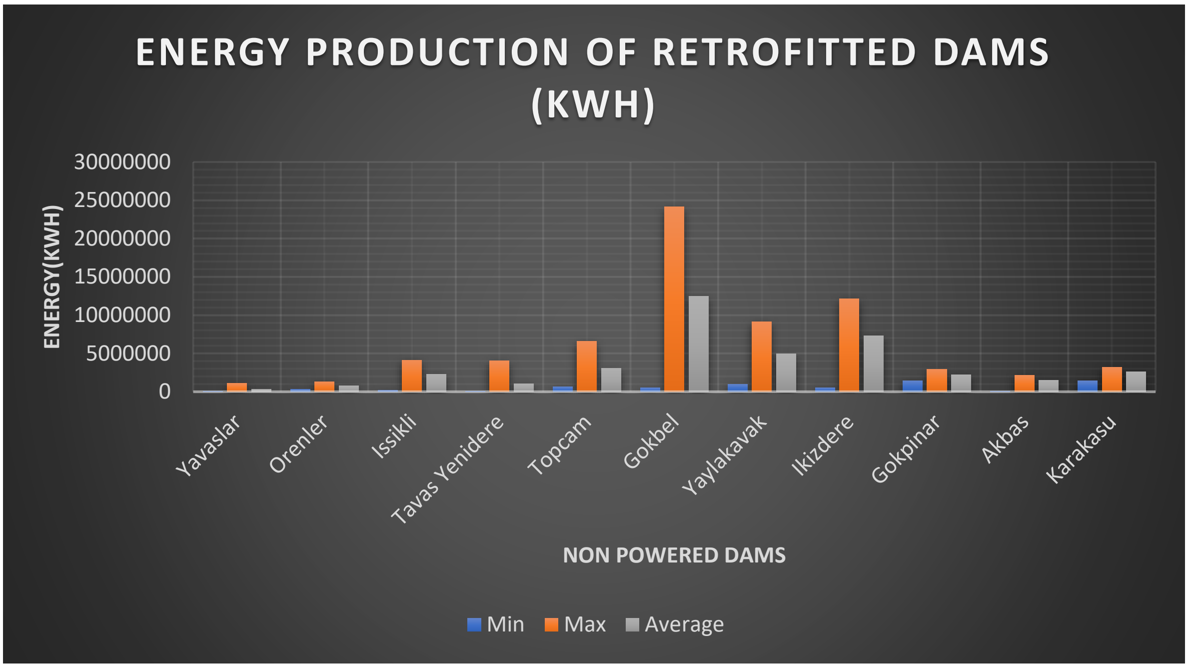

Figure 24: Energy Production from Retrofitted Dams

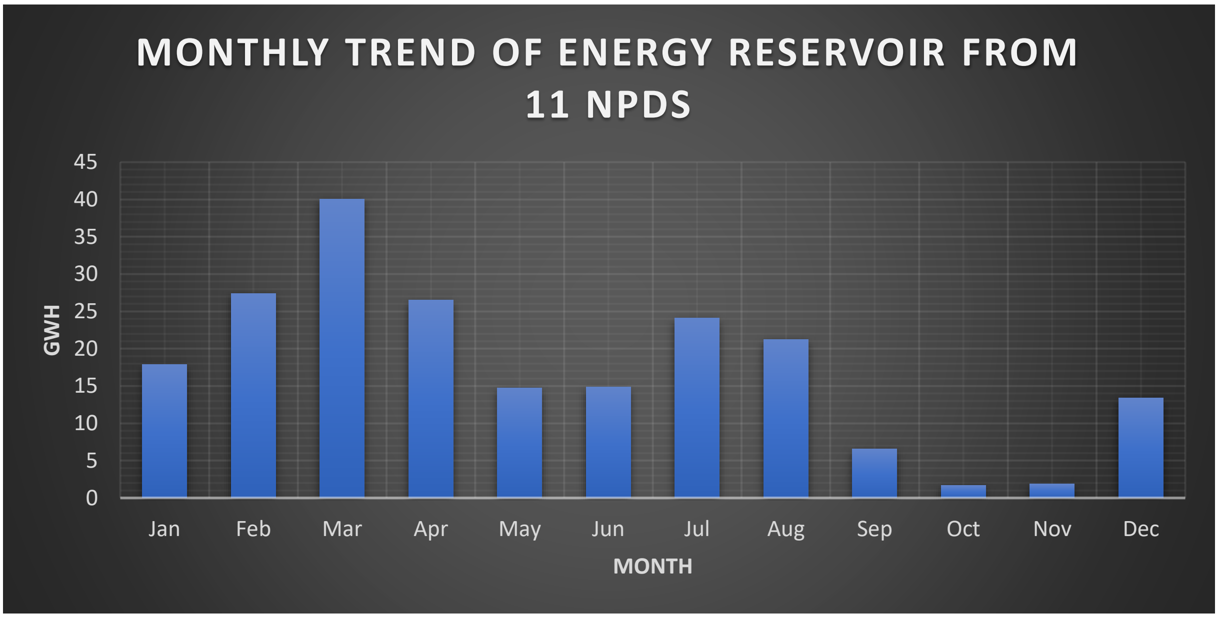

Figure 25Monthly Trend of Energy Production from 11 NPDS

The average power production in the basin is displayed in figure 26. Following the trend of energy production in figure 24, Gokbel recorded the highest power production at an annual production value of 1426.941 kW. Yavaslar also recorded the least power production from the basin with an annual production value of 39.977 kW. Average annual power production from all the dams within the basin stands at a value of 402kW. The total capacity of all hydro power retrofitted dams within the basin stands at 4422.032 kW.

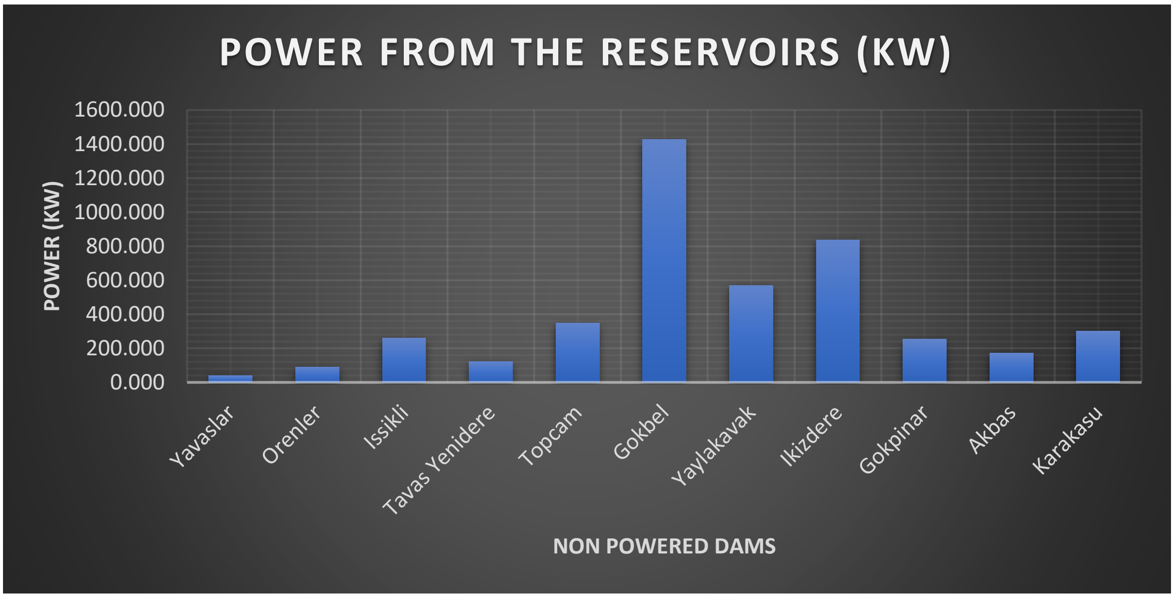

Figure 26 : Power Production from the Non Powered Dams

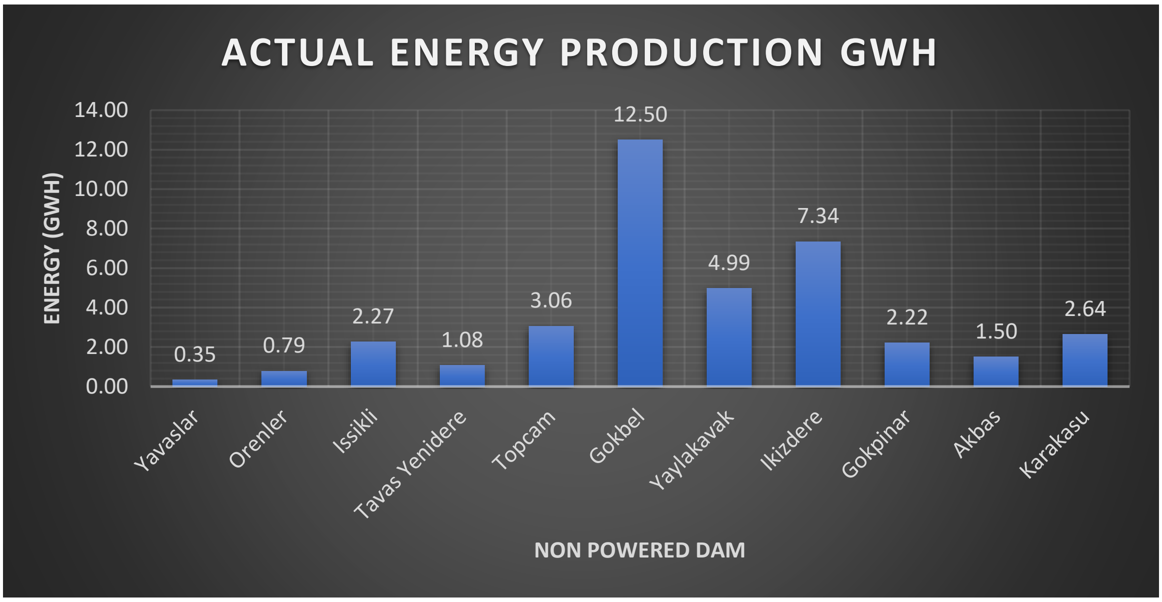

Figure 27 : Actual Energy Production from Non Powered Dams (WEAP Simulated)

From the technical specifications of the dams under this investigation the potential energy production was generated. Figure 28. compares the potential energy production to the actual average energy production from the dams under investigation. Figure 28 show that the potential energy production generally exceeds the actual energy production from the non-powered dams. This comparism gives an idea of the capacity factors of the various non-powered dams in this study.

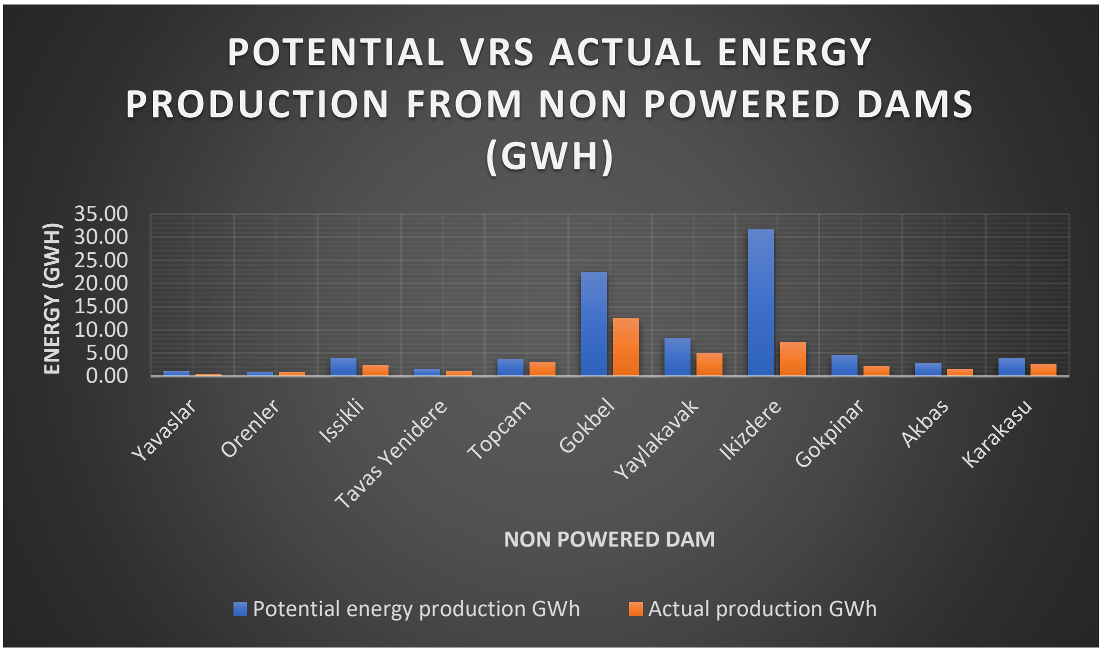

Figure 28 : Comparism of the Potential and Actual (Simulated) Energy from Non Powered Dams

The capacity factor is the ratio of the actual energy production to the potential energy production. Figure 29, displays the capacity factors of the various reservoirs under investigations. From figure 29, Orenler dam with a capacity factor of 0.845 recorded the highest capacity factor. Ikizdere dam with a capacity factor of 0.232 recorded the least capacity factor. The average capacity factor of all the reservoirs within the basin was 0.583. The basin's annual total hydropower retrofitting potential of 4422.032 kW flows with an average capacity factor of 0.583.

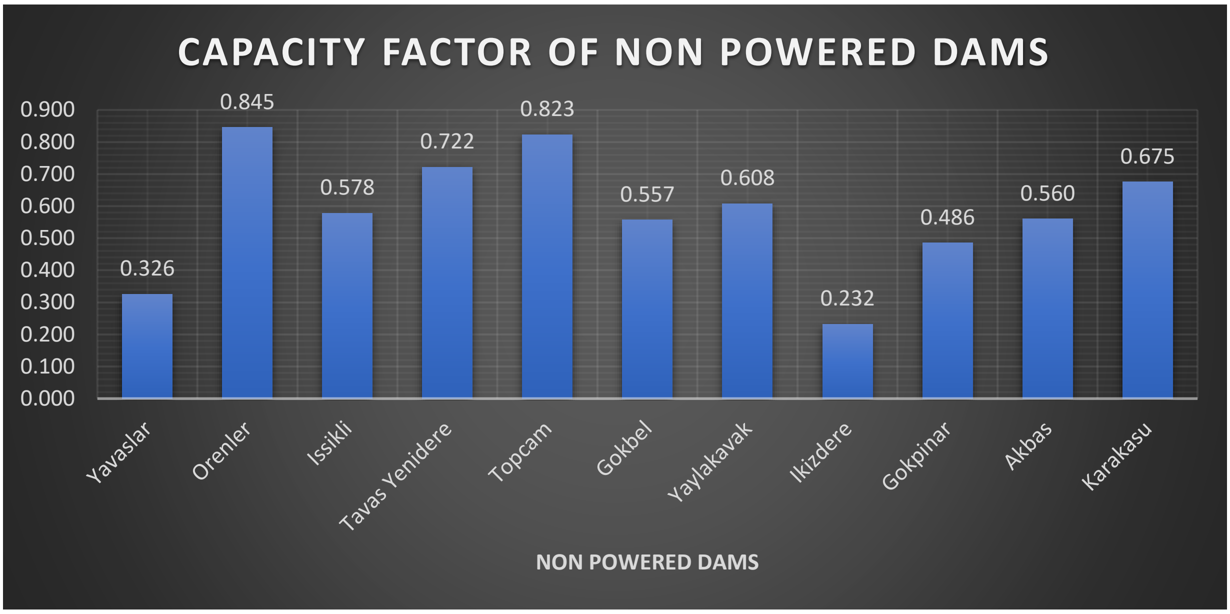

Figure 29: Capacity factor of Non-Powered Dams

4.5 Results of Cost Estimation and Economic Analysis

4.5.1 Capital Cost Estimation

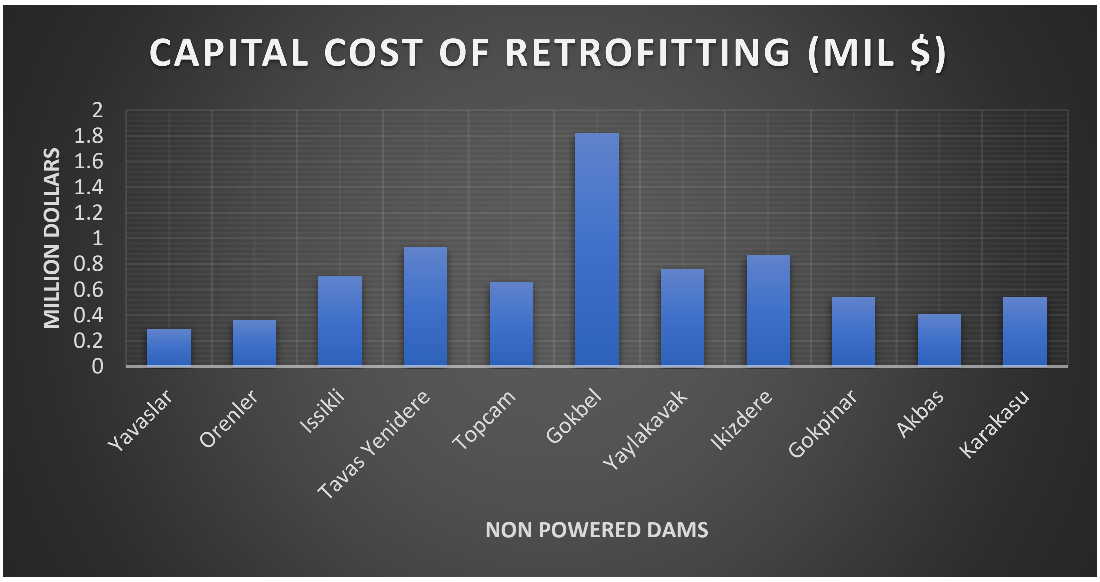

Figure 30 : Capital Cost of Retrofitting

Results from the capital investment required to execute the retrofitting project of all the dams is displayed in figure 30. At an estimated amount of $657,781, Gokbel recorded the highest capital investment requirement for its retrofitting project. The lowest capital investment cost was recorded by Yavaslar at an estimated amount of $294,000. The total estimated investment cost required to execute the retrofitting projects for all 11 non powered dams was $7,892,169.3

4.5.2 Operation and Maintenance Cost

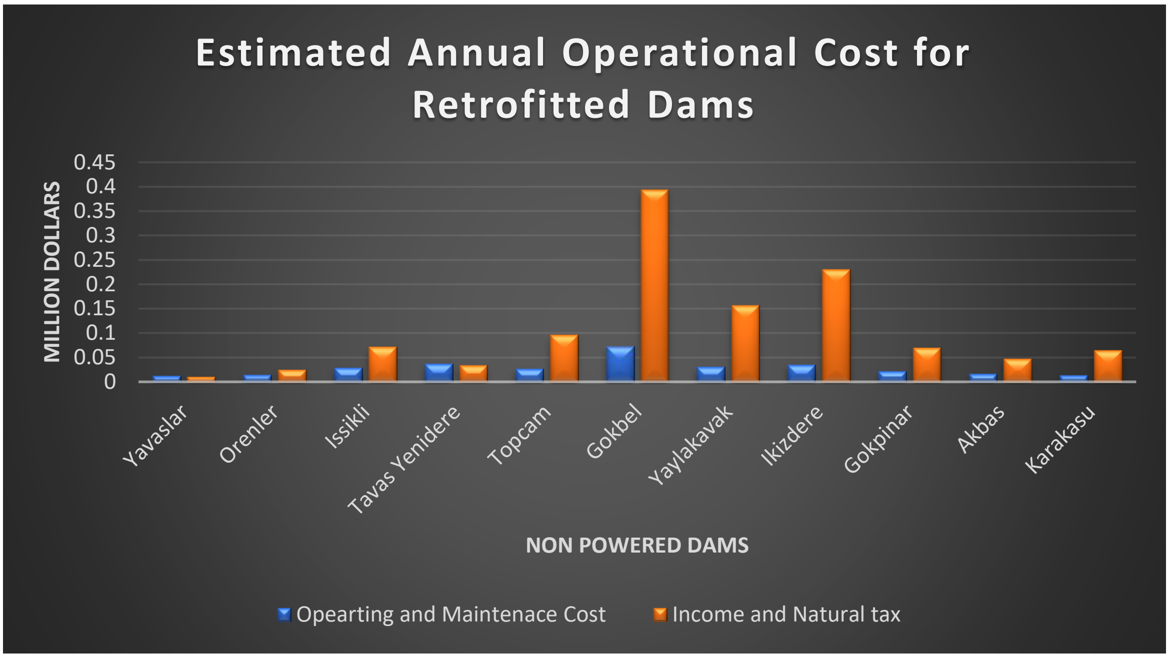

Figure 31 : Estimated Annual Operational Cost for Retrofitted Dams

The estimated operational costs for running power production business with the 11 retrofitted dams is displayed in figure 31 As shown in figure 31, Gokbel dam recorded the highest annual estimated operation and maintenance cost at a value of $72,827. The highest estimated income and natural tax cost was also recorded by Gokbel dam at a value of $393,750. With a value of $11,760 Yavaslar recorded the least estimated annual operating and maintenance cost as shown in figure 31, Yavaslar also recorded the least annual income and natural resource tax at a cost of $11,025. Results from the operation and maintenance cost estimation shows that the total annual operation and maintenance cost for all the 11 dams was $307,527. The total annual income and natural resource tax for all the retrofitted dams was $1,201,476.2.

4.5.3 Power Production Revenue

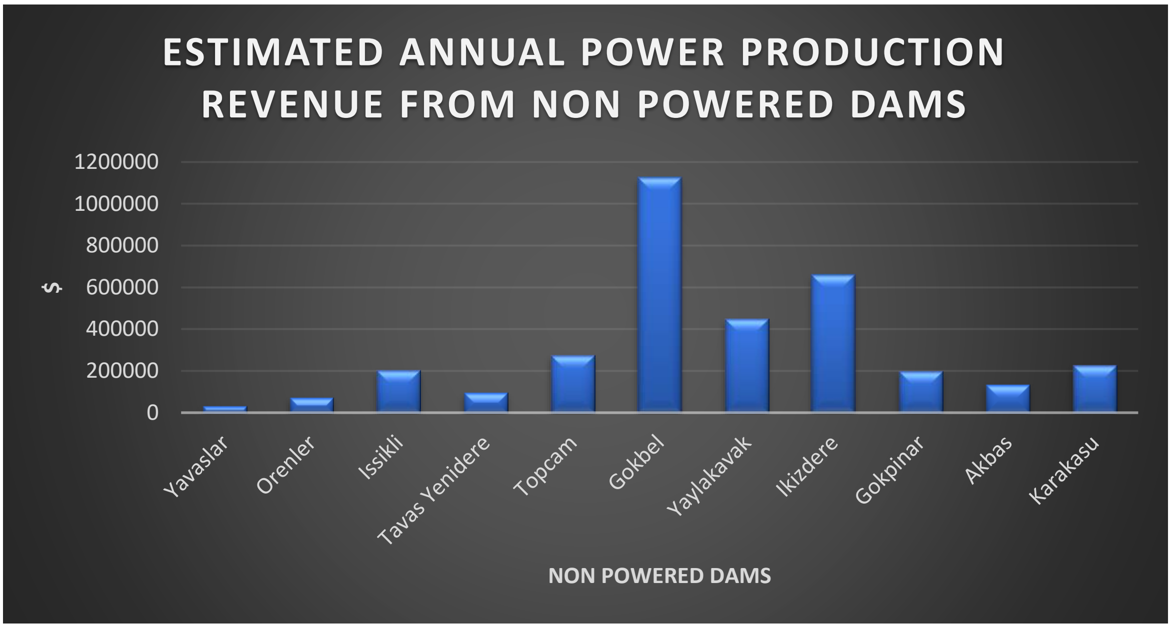

Figure 32 : Estimated Annual Power Production Revenue from NPDs

Revenue from power production is displayed in figure 32. At an estimated value of $1,125,000, Gokbel dam recorded the highest annual revenue from energy production. The dam with the least estimated revenue was Yavaslar which recorded an annual energy production revenue of $31,500. The total estimated annual energy production revenue from all 11 retrofitted dams was $347,432.

4.5.4 Economic Analysis

The simulated energy production potential of the non-powered dams was subjected to economic feasibility tests with the net present values, internal rate of return and benefit cost ratio employed as the major economic indices for decision making. Figure 33 shows the results of the NPV of the net cash flow after running the power production business from all the retrofitted dams for a total of 40 years at a discounting rate of 5% and an energy price of $0.09/kWh. Figure 33 shows that Gokbel dam recorded the highest NPV at a value of $ 9.477 million. Yavaslar dam was the reservoir with the least NPV, recording a value of $ -0.144 million. The average NPV was for all retrofitting projects in the basin was $ 2.32 million. The total NPV of all hydropower retrofitting projects within the basin was however recorded as $ 25.576 million. Results of the net present value show that 9 out of the 11 hydropower retrofitting projects under investigation have a positive NPV.

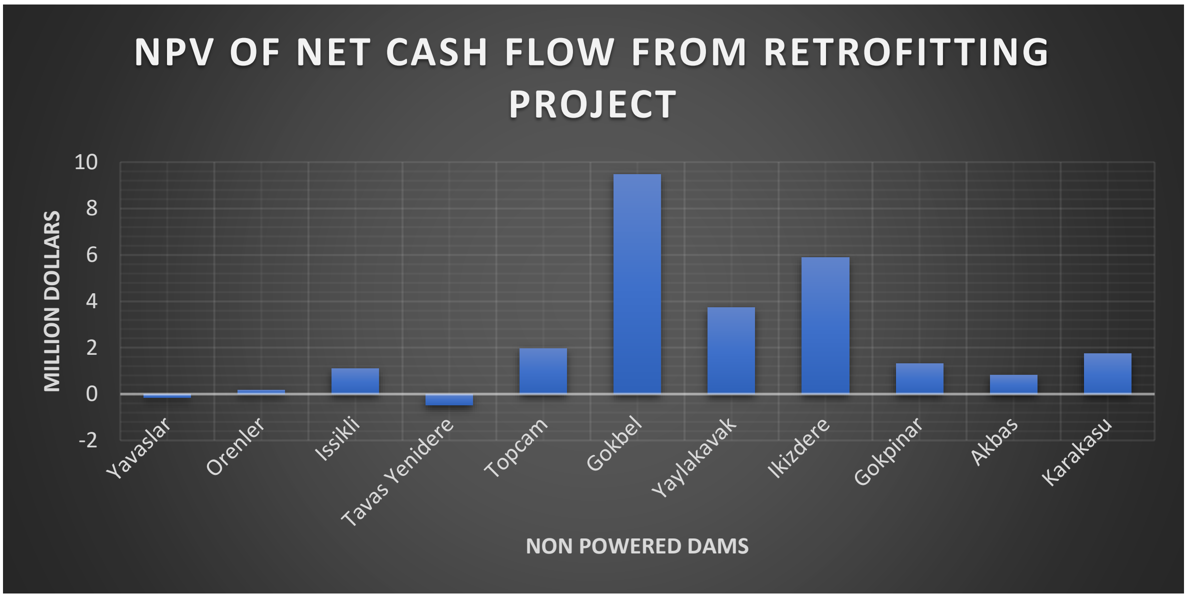

Figure 33 : Net Present Value of Net Cash Flow for the Retrofitting Projects

Figure 34 shows that internal rate of return of all the hydropower retrofitting projects. From figure 34, Ikizdere dam is seen to have the highest internal rate of return with a value of 38%. The least internal rate of return was recorded by two dams namely Tavas Yenidere and Yavaslar. Both dams recorded an IRR of -4%. The average IRR for all hydropower retrofitting projects in the basin was 14.72%. The results of the IRR show that 2 out of the 11 hydropower retrofitting project have negative IRR values.

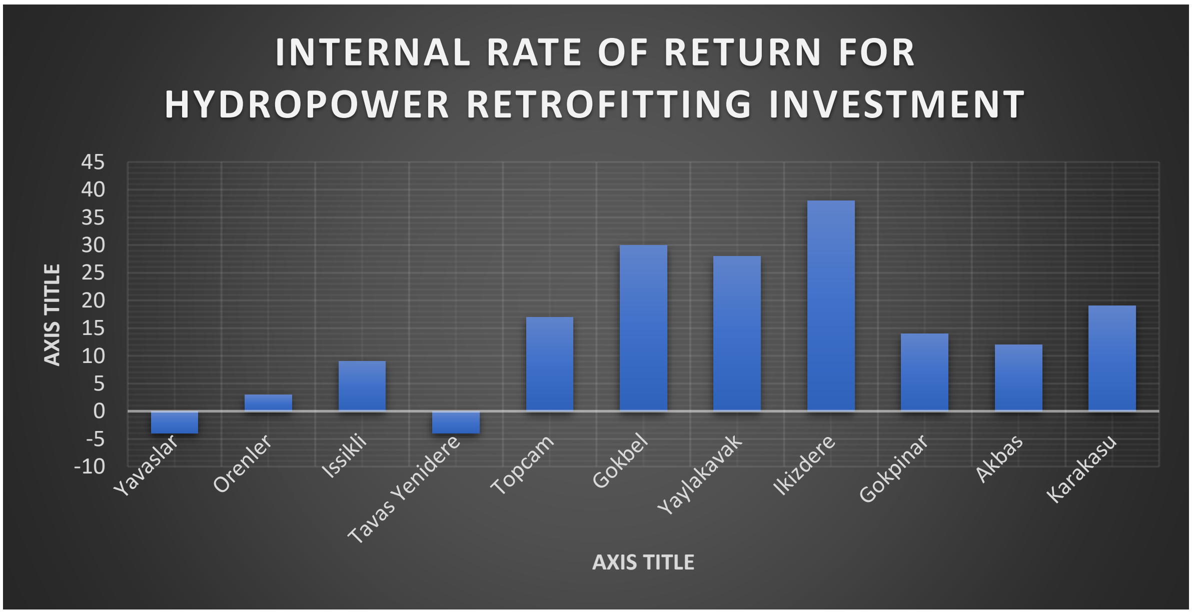

Figure 34: Internal Rate of Return for Retrofitted Dams

The benefit cost ratio is the ratio of the total benefit to the total cost of the hydropower retrofitting projects within the basin. Figure 35 shows results of the B/C ratio for all hydropower retrofitting projects under this study. Figure 35, indicates that Ikizdere has the best B/C ratio with a recorded B/C ratio value of 1.654. Tavas Yenidere however recorded the least B/C ratio with a value of 0.615. The average B/C ratio for all hydropower retrofitting projects in the basin was 1.21. The B/C ratio resulst indicates that the Tavas Yenidere, Orenler, and Yavaslar reservoirs recorded values below 1.

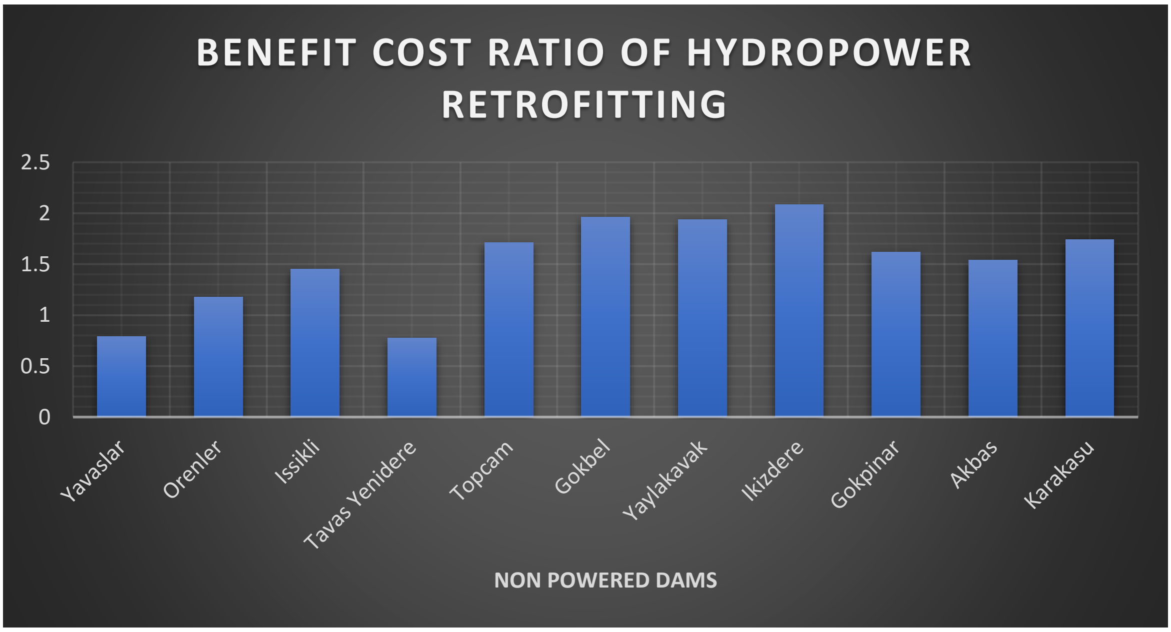

Figure 35: Benefit- Cost Ratio of Retrofitted Dams

4.5.5 Levelised Cost of Electricity

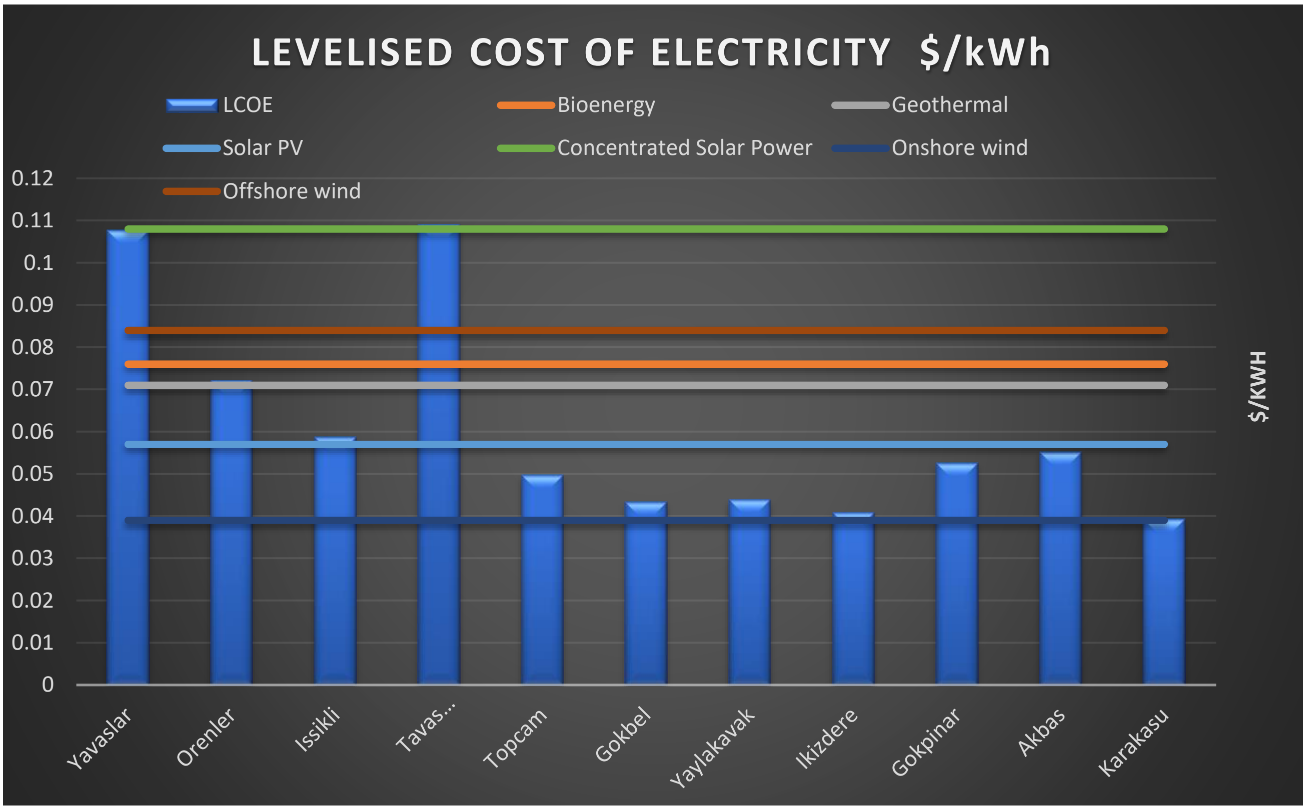

Figure 36: Levelised Cost Of Electricity for Retrofitted Reservoirs

Results from levelised cost calculation is displayed in figure 36. The levelised cost of electricity computed for the retrofitted dams shows that Yavaslar dam recorded the highest levelised cost of electricity at a value of $0.1077/kWh. With an LCOE value of $0.03926/kWh, Karakasu dam recorded the least levelised cost of electricity production. The average levelised cost of electricity for all the 11 retrofitted dams generated a value of $ 0.061/kWh. The average LCOE for the 11 retrofitted projects was lower than LCOE values of renewables like bioenergy, geothermal energy, concentrated solar power, and offshore wind whose values retrieved from the IRENA, 2021, report titled “Renewable Power Generation Cost in 2020” were $0.076/kWh, $0.071/kWh, $0.108/kWh and $0.084/kWh respectively. Renewables sources of energy like solar PV and On-shore wind energy, however have lower LCOE values of $0.057/kWh and $0.039/kWh respectively.

Chapter 5: Discussion

5.1 General Overview of Study

As described in the introduction, this study seeks to use the available data and tools to develop a methodology that calculates the retrofitting potential of non-powered dams within the Buyuk Menderes basin. With this methodology, a simulation of the hydropower production for the period of available data is to be completed and presented for each of the non-powered dams. An economic analysis involving a rough estimate of the cost of retrofitting and the possible revenue generation from hydropower production needs to be conducted to verify the economic feasibility of hydropower retrofitting in this basin. The cost of producing electricity from these non-powered dams must be compared to emerging renewable energy systems. The study identifies possible social and environmental bottlenecks which could impede the progress of the hydropower retrofitting projects. All assumptions, limitations and uncertainties in the methodology must be presented as part of the study.

From the study, the soil moisture method was employed in WEAP to develop a model of the Buyuk Menderes basin. In order for the model to reflect reality, all physical components in the basin were schematized with WEAP elements. The schematized model was regionally calibrated with catchments characteristics like the crop coefficient, SWC and RRF which have a direct influence on the water balance within the catchments. Results of calibration of the various catchments produced PBIAS values ranging from 0.86% to 7.6% suggesting that all of the catchments have been well calibrated and properly reflect the water balance within the respective catchments. Energy production simulation from the model suggest that the all non-powered reservoirs in the Buyuk Menderes basin have an average annual energy potential of 38.74 GWh. and a total capacity of 4.42 MW. The average levelised cost of energy production with the retrofitted dams was $0.061/kWh and generally lower than that of bioenergy, geothermal, concentrated solar power, and offshore wind energy. With the proposed monthly irrigation flow variation, power production is dominant between November and March when irrigation is zeroed. The recharge volume of the reservoir for irrigation in the next planting season is therefore reduced and this was evident in the unmet demands for the different irrigation demands in the various catchment. The average unmet irrigation demand within the basin stood at a value of 78,736,387.5 m^3 translating to 16,587.71 hectares of unirrigated land in a year. The economic implications of agricultural losses linked to water scarcity caused by hydropower retrofitting could be a possible bottleneck to the successful implementation of these retrofitting projects. The economic side the results suggest that the total cost of executing these retrofitting projects could be $ 7,892,169. The capital cost for the most and least expensive retrofitting project were about $1,820,680 and $294,000 respectively. The net present value of all the retrofitting projects when operated for a 40-year period at a discounting rate of 5% was $ 25,576,000. The average internal rate of return and benefit- cost ratio for all the retrofitting projects was 14.72% and 1.53 respectively.

5.2 Discussion of Calibration Results

5.2.1 Calibration of Kufi Catchment

Calibration results in the Kufi catchment, produced a percent BIAS of 1.6%. From table 17, the PBIAS value represents a very good calibration with minimum deviation between the observed and simulated total annual flow in the catchment. The simulated flow closely follows the observed flow and replicates its peaks and recessions suggesting that the model will be able to reflect the annual water balance for all the years of the calibration. From the results, the observed flow was higher than the simulated flow by a percentage of 1.6. This suggests that the model underestimates runoff generation in the Kufi catchment by 1.6%. Underestimation of runoff in the Kufi catchment could mean that all runoff related results such as power production simulation in Orenler, Yavaslar and Issikli as well as irrigation unmet demands in Kufi left and right irrigation demand nodes, could be underestimated by a margin of 1.6%. It may therefore be prudent to treat all result-based planning in the Kufi catchment with an underestimated error margin of 1.6%. The results of the calibration also suggest that the model can be trusted to reflect reality by a 98.6% margin.

5.2.2 Calibration of Curusku Catchment

Results from calibration in the Curusku catchment presented a PBIAS value of 3.4% which suggest that the calibration performed was a very good one according to the standards presented in table 17. The results of calibration indicate that simulated flow deviates from the observed value by a percentage of 3.4%. From the results it could be suggested that the model is able to produce a simulated flow which is a good reflection of the water balance for each year under study in this catchment. The deviation in the simulated and observed hydrographs of years 1968 and 1979 indicates that the calibration performed poorly within those years. Within the Curusku catchment, the total simulated runoff exceeded the observed value. This suggests that runoff generation in the Curusku basin is overestimated by a margin of 3.4%. All results related to the runoff in the Curusku basin could possibly flow with an overestimation margin of 3.4%. This suggest that power simulation from the Akbas and Gokpinar dams may be overestimated by 3.4%. In case that planning should be done with the results related to runoff generation from the Curusku basin an overestimation error margin of 3.4% could be expected. Nonetheless the calibration result indicates that the simulated results from the Curusku basin can be trusted to reflect reality by a margin of 96.4 %.

5.2.3 Calibration of Dandalas Catchment

Calibration results from the Dandalas ended with a PBIAS value of 4.3% which indicates that the calibration in the catchment was a very good one according to the model evaluation criteria listed in table 17. The graphical results shown in the inter-annual hydrograph in figure 15 suggest that, the calibration has enabled the model to simulate a total annual flow which has minimal deviation from the observed flow. This suggest that the simulated flow to a good extent reflects the original water balance in the Dandalas catchment. Total observed flow in the model is higher than the total simulated flow. This suggest that the model's simulated runoff is underestimated by a margin of 4.3%. Underestimation of runoff generation within the catchment could possibly mean that power simulation from Karakasu dam has also been underestimated by a margin of 4.3%. The underestimated simulated flow could also suggest that unmet irrigation demands in the Dandalas catchment have been over estimated by a margin 4.3%. For all runoff related planning in the Dandalas catchment, it would be prudent to include an underestimation error margin of 4.3%. The PBIAS value however indicates that results from the Dandalas catchment can be described as reliable by a percentage of 95.7.

5.2.4 Calibration of Cine Catchment

In accordance to the model evaluation criteria in table 17, the PBIAS value obtained at the end of calibration within the Cine catchment is very good. The PBIAS value suggest that the Cine catchment has been properly calibrated to reflect reality in both dry and wet years. The calibration results indicate that the simulated flow produced by the model deviated from the observed flow by a margin of 7.6%. This is the largest deviation in the calibration results for all regionally calibrated catchments in the Buyuk Menderes basin. The simulated flow from the model was higher than the observed flow by a percentage of 7.6. This suggest a possible overestimation of the runoff by the model. The model's overestimated runoff indicates that power simulation from Gokbel, Topcam and Yaylakavac dams and their related revenue might also be overestimated by a margin of 7.6%. This could also mean that water scarcity related to unmet irrigation and drinking water demands within the Cine catchment could be higher by a margin of 7.6 percent. It will be prudent to expect an overestimation error margin or 7.6% from all runoff related results from the Cine catchment. Results generated from the Cine catchments could be described as reliable by a margin of 92.4 %.

5.2.5 Calibration of Ikizdere Catchment

Calibration results from the Ikizdere catchment displayed a PBIAS of 0.86 which indicates a very good calibration in accordance to the model evaluation criteria in table 17 A PBIAS value of 0.86% is very close to the ideal PBIAS value which indicates perfection of model calibration. The simulated runoff from the model is very reflective of the observed runoff and deviates from it by a margin of 0.86 %, indicating that the simulated flow is able to reflect the water balance of the catchment for the years in the period of study. The observed total runoff is higher than the simulated total runoff, suggesting a possibility of runoff underestimation from the catchment. Underestimation of simulated runoff from the Ikizdere catchment indicates a possibility energy simulation underestimation from the Ikizdere dam. Flow underestimation indicated by the calibration results suggest that unmet irrigation demand in the Ikizdere catchment has been overestimated by a margin of 0.86%. It will be prudent to attach an underestimation error value of 0.86% to all results related to runoff generation from the Ikizdere catchment. The PBIAS results from calibration suggests that results generated from the Ikizdere catchment can be trusted to reflect reality by a percentage of 99.14.

5.2.6 Calibration of Tavas Yenidere Catchment

A calibration percent BIAS value of 2.5% was obtained at the end of calibration of the Tavas Yenidere catchment. From the model evaluation criteria listed in table 17, it can be suggested that the calibration for the Tavas Yenidere catchment is a very good one. The simulated runoff from the model deviates from the observed flow by a margin of 2.5 %. The calibration results show that the simulated flow from the catchment exceeds the observed flow by 2.5 %. This deviation between observed and simulated flow suggest a possibility of overestimation of runoff by the model. Simulated runoff overestimation from the model indicates that power production in the Tavas Yenidere reservoir could be overestimated by a margin of 2.5%. The overestimation of power simulation could trickle into the revenue generation from the retrofitting project of the reservoir. It could be prudent to expect an overestimation error of 2.5% from all results generated from the Tavas Yenidere catchment. Results from the Tavas Yenidere catchment could however be trusted to reflect reality by a percentage of 97.5.

5.2.7 General Discussion of Calibration in the Basin

In general, all the calibration results suggest that all of the catchments have been properly calibrated to produce results which are very representative of the respective catchment. The average PBIAS value of all the catchments was 3.37 which indicates that all the catchments have a very good calibration. The average PBIAS value for all the catchments suggests that power production simulation, a core element of this study, could be trusted with a good level of reliability.

5.3 Discussion on Minimum Flow

Minimum flow values were set to enhance river connectivity during different seasons in the basin. Some of the fish species within the basin are identified as critically endangered species and must be protected from extinction. River flow connectivity between the upstream and downstream section of all dams is relevant to ensure that fish life is sustained. Flow levels which trigger spawning, feeding, migration and other time related fish activities should be maintained at the correct time of year. Setting the right flow requirement at the right time is very necessary in ensuring connectivity, continuity of fish species and sustenance of fish life. For each dam, minimum flow values were set for the three quarters in a year. The flow values with the probability of being exceeded 95% of the time in the respective quarters of the year was chosen as the minimum flow for the dams. This values ensure that river connectivity is enhanced throughout the year. The irrigation flow release pattern allows a lot of irrigation release from April to October and no irrigation release from November to March. The irrigation flow rates during the period of irrigation, far exceed the set minimum flow values. Due to the lengthy nature of irrigation networks within the basin, it is assumed that irrigation flow is meted out 24 hours a day (DSI, 2018), serving the most upstream demand points first, followed by the downstream demand points. Continuous release of irrigation flow during peak season of irrigation explains why minimum flow values for the peak irrigation period were low as shown in the results. Continuous release of irrigation flow throughout the day ensures that the connectivity of the river is maintained. Hydropower production during the irrigation free months (November- March) is a secondary function of the dam and this purpose could be varied in response to power demand, power price and water availability. For any of these reasons, power production could be halted, resulting in no water release to the downstream section of the dam. This period could be critical for fish and aquatic life downstream and this explains why minimum flow values have been set for these months (November –March).

Release of water from the reservoir is an economic loss to the hydropower generation business but a gain to environmental sustainability and river connectivity. The revenue which could have been made from power production with the minimum flow volume can be termed as the cost of minimum flow. The total minimum flow release from all the reservoirs was 68,171,381.2 m^3. With the different energy equivalents of the reservoir in the basin, the annual cost of releasing minimum flow was \$ 292,576. Comparing the cost of maintaining river connectivity (minimum flow release) to the total annual power production revenue of \$ 3,474,432 it can be suggested that minimum flow release will not have serious financial implications on the running of the retrofitting projects in the basin. It could therefore be suggested that of the cost of minimum flow is not an economic bottleneck to impede the execution of these retrofitting projects.

5.4 Discussion on Unmet Demands

All the catchments in the basin record different hydrology for different years. While some years are extremely wet others are dry and some are at the midpoint between wet and dry years. The natural hydrology affects the availability of water within the catchments. The different catchments have different water demand points with varying water needs. In a typical wet year when water is available in high quantities, all the water demands may be satisfied, however in a dry year when water availability is low, some of the demand nodes within the catchments register unmet demands of varying levels. The main unmet demands within the different catchments were irrigation and drinking water demands. Out of 27 demand points under this study, 13 points in a particular hydrological registered unmet demands. To properly analyse the registered levels of unmet demands within the basin, all irrigation unmet demands were separated from drinking water unmet demands.

5.4.1 Unmet Irrigation demand

Out of the 19 irrigation demand points in the basin, 10 of them experience some level of unmet demands throughout the different hydrological years. Aside natural factors like hydrology and climate, these unmet demands could also be man-made in nature. Cultivation of crops with high water demands within catchments that have an averagely low water availability, could possibly lead to issues of unmet irrigation demands. The regulations of reservoir could also be a possible cause of unmet irrigation demands. Within the model setup the irrigation flow release scheme was originally set to leave the period from November to March as the fallow period for the reservoir. During this period, the reservoir fills up for the next irrigation season. The scheme set in this model establishes hydropower production as a secondary function on these irrigations dams, and permits power to be produced only when all irrigation demands are satisfied. There is a possibility that this scheme exploits the monthly irrigation flow variation and allows power production to peak during the intended fallow period of the reservoir (November- March). There is also a possibility that water use for power production reduces the water recharge capability of the reservoir and consequently leads to unmet irrigation demands when the irrigation season is due. These climatic and anthropogenic reasons could be the possible cause of several irrigation unmet demands registered within the model. The sum of the average unmet water demand for the 10 irrigation nodes of concern was in the basin was 78,736,387.5 m^3. This unavailable volume of water suggests that in a typical dry year, 16,587.71 hectares out of a total of 55,626.6 hectares of land to be irrigated, will not be supplied irrigation water for the whole year. The results indicate that about 30 % of the land scheduled for irrigation will not be supplied with its irrigation water needs for a year. From the results it could be suggested that the catchments of these ten irrigation demand node are prone to water scarcity issues. An average water scarcity of 30% within these catchments could translate to serious agricultural economic losses that could be a possible bottleneck to impede the execution of the retrofitting projects. The retrofitting of Topcam, Yaylakavac, Karakasu, Ikizdere, Issikli, Yavaslar and Orenler reservoirs may be partly connected to this unmet demand experienced within the catchments of concern. An optimized power production scheme which minimizes power production water use and increases benefits could be put into play to make more water is available for the irrigation season. To combat unmet demand caused by hydrologically induced water scarcity, crops with lower irrigation water need but higher economic return could be cultivated in the water scarce areas. Developing genetically modified versions of the existing crops with lower crop water requirement could be a step in the positive direction to reduce the levels of unmet irrigation demands within the water scarce catchments.

5.4.2 Unmet Drinking Water Demands

The unmet drinking water demands simulated by the result of the model, suggest that drinking water demand in the Cine, Dandalas and Ikizdere catchments have unmet demand levels. This demand may be attributed to population size and water availability. The unmet drinking water demand is highest in Ikizdere and this suggests that the population being served is too high. Another reason could be that the water availability is averagely very low in the catchment. The total average volumes of unmet drinking water demands in the basin was 8,139,926 m^3. The absence of this volume of water suggest that about 413,195 out 1,154,323 people will not be privileged to have water for a year. Drinking water flow release is set as equal for each month of regulation. This means that drinking water is released to demand point every month. The continuous monthly release of drinking water supply suggests that hydropower production which is a second priority in the model will have minimum connection to these unmet drinking water demands. The drinking water scarcity of the three demand points translates to 36%. Results of drinking water scarcity indicates that the catchments are very critical and requires a high level of attention in water resource planning. The uncertainty in the population data input for each of the drinking water demand points could also be the reason for this high level of unmet demand. Possible mitigation measures to curb drinking water scarcity could be an investment into ground water schemes. While aquifers could present a good solution, attention should be given to the water stress index within the catchments.

5.5 Retrofitting and Energy from reservoirs

The processes involved in a typical Hydropower project is highly related to the specification of the site involved. All the dams to be retrofitted in this study have unique specification and thus require an independent discussion into their retrofitting potential, power simulation, cost component, revenue and economic viability with respect to other emerging renewable energy sources.

5.5.1 Hydropower Retrofitting of Orenler Reservoir

Orenler dam is an irrigation dam found within the Kufi brook within the Kufi catchment of the Buyuk Menderes river basin. The dam has a total annual average inflow of 19.16 million m3 and a head of 19.85m. The results indicate that Orenler dam's energy equivalent is 0.049kWh/m^3 suggesting that every cubic meter of available water in the reservoir can potentially produce 0.049kWh of energy. From the dam's specification, it was realized that energy production potential of the reservoir was 0.93 GWh. Results from average annual energy simulation from WEAP indicated an energy production simulation of 0.79 GWh. The results of energy simulation from WEAP, indicates that the capacity factor after retrofitting the Orenler dam could possibly be 0.85. The capacity factor suggest that Orenler reservoir will be able to averagely harness about 85% of its energy production capacity. With the Turkish energy per capita tagged at 2740kWh/year the results from energy simulation in WEAP suggests that the yearly energy needs of 288 people could be met by power generation from Orenler reservoir. To execute the retrofitting project for Orenler dam, the capital cost invested was $ 361,000. The capital cost included the cost of complete electromechanical equipment (turbine, transformer, generator, installation), power house and penstock cost. The result of economic analysis indicates that a sum of $14,400 was required annually for operation and maintenance of power production in the retrofitted Orenler dam. The income and natural resource tax from the results was presented as $ 24, 822. Total annual cost of operating hydropower production from Orenler was presented as $ 39,262 representing 10% of the capital cost. The total annual revenue from energy production from Orenler was $ 70,920 representing 19.6 % of the capital cost. At a discounting rate of 5% the net present value of the net cash flow from 40 years of power production with Orenler dam was $ 182,000. The NPV obtained suggest that at the end of running the project for 40 years, a profit of $182.000 could be possibly generated. The positive NPV results for running power production in Orenler indicates that the project will be profitable to invest in. The internal rate of return from economic analysis presented a value of 3% which suggest that the return on investment from the retrofitting project will be 3%. This therefore indicates that financing the project with a loan or financial instrument at an interest rate higher than 3% might reduce the economic viability of the project. It is also prudent to discard the execution of the retrofitting project if the current interest rate is higher than the IRR. Minimum flow release from Orenler to enhance environmental sustainability stands at a volume of 3,236,500.8 cubic meter translating to an annual cost of $ 14,180.38. The cost of minimum was 19.9% of the annual revenue from the reservoir's power generation. The ratio of annual cost of minimum flow to the annual revenue from power production in Orenler reservoir possibly suggest that minimum flow release won't be an economic bottleneck for the execution of the retrofitting project. Orenler recorded a levelised cost of energy of $ 0.072 /kWh indicating that it will not be an interesting investment to execute if its compared to other renewables like solar PV, geothermal and onshore wind energy which have lower LCOEs. If the Orenler project is however compared to bioenergy and offshore wind energy production, it could be a good venture to push capital into. At a discounting rate of 5%, results from computation of levelised cost of energy production for Orenler reservoir indicates that a total of 14,316,623.68 kWh of electricity could be produced over the 40-year period to replace nonrenewable sources of energy production in the Turkish energy mix. An investment in this project could possibly enable Turkey to offset about 5,626,433 kilograms of CO_2 emission throughout the 40-year period. This will be a positive mark in helping the world to achieve net zero emission by 2040.

5.5.2 Hydropower Retrofitting of Yavaslar Dam

Yavaslar dam is an irrigation dam within the Kufi catchment of the Buyuk Menderes basin. Yavaslar's dam specifications indicates that its energy equivalent and potential is 0.091 kWh/m^3 and 1.07GWh respectively. The results from annual average energy production simulation from WEAP presented the energy production from Yavaslar dam as 0.35GWh, indicating a capacity factor of 0.326. This capacity factor suggest that the reservoir will be able to harness about 32.6% of its potential energy production capacity. With an energy per capita value of 2740kWh/year, energy production results of Yavaslar reservoir from WEAP indicate that the energy needs of about 127 people could be met with Yavaslar's power production. Cost estimation results indicate that a total investment of \$ 294,000, relating to costs of turbine, transformer, generator, power house, and pipe will be required as capital investment into Yavaslar's retrofitting project. Annual operating and maintenance cost for running power production from Yavaslar was set as \$11,760. The income and natural resource tax from the results was presented as \$ 11,025. Total annual cost of operating hydropower production from the Yavaslar dam was \$ 22,785 representing 7.75% of the capital cost. The total annual revenue of energy production from Yavaslar reservoir was \$ 31,500, representing 10.7 % of the capital cost. At a discounting rate of 5%, the NPV of the net cash flow of power production from Yavaslar dam for a duration of 40 years was presented as - \$ 144,000. The NPV suggests that at the end of running the project for 40 years, a loss of \$144.000 could be incurred. The negative NPV results indicates that the project will not be profitable to invest in. The IRR results from the economic analysis presented a value of -4% which suggests that the project will not be profitable because a negative interest indicates loss to investment. Results from minimum flow release from Yavaslar reservoir displayed a total annual release volume of 92,868.36 cubic meters representing an annual cost of \$ 7,584.39. The cost of minimum was 24.1% of the annual revenue from the reservoir's power generation. The percentage of cost of minimum flow release to the annual revenue from power production in Yavaslar reservoir possibly suggests that minimum flow release won't be an economic bottleneck for the execution of the retrofitting project. Computation of levelised cost of energy from Yavaslar reservoir recorded a value of \$ 0.1077 /kWh, indicating that it will not be an interesting investment to execute when it is compared to renewable energy production sources like solar PV, geothermal, onshore wind energy, offshore wind, bioenergy, which have lower LCOEs. The Yavaslar reservoir retrofitting project might however be a little competitive when compared with renewable energy source like the concentrated solar power whose LCOE is higher. At a discounting rate of 5%, LCOE results for Yavaslar reservoir indicates that a total of 6,359,312.04 kWh of electricity could be produced over the 40-year period of the study to replace fossil fuel based electricity production sources in the Turkish energy mix. Working with a carbon footprint value of 0.393 kg CO_2/kWh for fossil fuel based electricity production sources, an investment in this project could possibly enable Turkey to offset about 2,524,646.88 kilograms of CO_2 emission throughout the 40-year period of operation of the reservoir. This can help dampen the carbon emission per capita in Turkey.

5.5.3 Hydropower Retrofitting of Issikli Dam

The Issikli dam is an irrigation dam found on the Kufi brook of the Buyuk Menderes basin. With total average annual flow of 250 million cubic meters and a head of 6.4 meters, the total energy equivalent and potential were recorded as 0.016 kWh/m^3 and 3.92 GWh. Energy simulation results from the Issikli dam for the given time period produced an output of 2.27GWh. The capacity factor for power production in the Issikli dam can be suggested as 0.578. This capacity factor suggest that Issikli reservoir will be able to averagely harness 57.8% of the potential energy production from the reservoir. With reference to an energy per capita of 2740kWh/year, the energy simulation results suggest that power production from the Issikli reservoir could possibly meet the annual energy needs of about 828 people living within the Buyuk Menderes basin in Turkey. The total cost of retrofitting of Issikli dam as displayed by the results shows a capital investment of $ 705,000. Results of cost estimation shows that a sum of $28,200 was required to operate and maintain power production annually with the Issikli dam. The income and natural resource tax from the results was presented as $ 71,505. The total annual cost required to run hydropower production from the Issikli dam was $ 99,705 representing 14.14% of the capital investment. The total annual revenue from energy production from Issikli was $ 204,300 representing 29 % of the capital cost. At a discounting rate of 5%, the NPV of the net cash flow from power production from the Issikli dam was $ 1,090,000. The NPV suggest that a profit of $ 1,090,000 could be made from running Issikli reservoirs power production project for 40 years. The positive NPV results indicates that the project will be profitable to invest in. The IRR from economic analysis presented a value of 9% which suggest that the project will be profitable with a 9%. return on investment. This indicates that financing the retrofitting project with a loan at an interest rate higher than 9% might reduce the economic viability of the project. A minimum flow volume of 47,346,278.5 cubic meters was released on an annual basis at a cost of $ 66,883.25 to ensure river connectivity and environmental sustainability. The annual cost of minimum represented 6.1% of the annual revenue from the reservoir's power generation. The annual cost of minimum as compared to the total annual revenue from power production in the Issikli dam, indicates that minimum flow could be exempted as a possible economic bottleneck for the execution of the retrofitting project. Results of the computation of the levelised cost of energy production for Issikli reservoir was $ 0.0586 /kWh indicating that it will not be a cost efficient project to execute when it's compared to renewable energy production sources like solar PV and on shore wind energy which have lower LCOEs. If the Issikli retrofitting project is however compared to concentrated solar power, geothermal, offshore wind energy and bioenergy, it could be a good venture to push some capital into. At a discounting rate of 5%, results from computation of levelised cost of energy production for Issikli reservoir indicates that a total of 41,221,126.02 kWh of electricity could be produced over the 40-year period to replace nonrenewable sources of energy production in the Turkish energy mix. An investment in this project could possibly enable Turkey to offset about 16,199,902 kilograms of CO2 emission throughout the 40-year period. Such an investment could possibly help reduce Turkey's carbon emission per capita and possibly champion the goals of the energy transition and United Nations Sustainable Development Goal(UNSDG) 7.

5.5.4 Hydropower Retrofitting of Gokpinar Dam

Gokpinar dam is an irrigation and drinking water supply dam found within the Curusku catchment of the Buyuk Menderes basin. With a total annual inflow and energy equivalent of 45 million cubic meter and 0.101 kWh/M3 respectively, the annual energy potential of the dam was recorded as 4.57 GWh. Energy production simulation results of the Gokpinar reservoir from WEAP displayed an annual average energy production of 2.22 GWh. The capacity factor determined for Gokpinar dam was 0.486 indicating that the Gokpinar reservoir could possibly harness 48.6% of its potential power production capacity. At an energy per capita of 2740kWh/year, the results from energy simulation from WEAP suggests that energy production from Gokpinar dam could serve the annual energy needs of 810 people within the basin. The capital cost of the retrofitting project for Gokpinar dam was $544,000. Results of economic analysis indicates that a sum of $21,760 was required annually for operation and maintenance of the power production of Gokpinar reservoir. The income and natural resource tax charged for running power production was $ 69,930. Total annual cost of operating hydropower production from Gokpinar reservoir was $ 91,690 representing 16.9% of the capital cost. The total annual revenue from energy production from Gokpinar dam was $ 199,800 representing 36.7% of the capital cost. At a discounting rate of 5%, the NPV of the net cash flow from power production from the Gokpinar dam was $1,311,000. This NPV value suggests that a total revenue of $1,311,000 could be generated at the end of running the power production project for 40 years. The positive NPV indicates that the project will be profitable to invest in. The IRR from economic analysis presented a value of 14% which suggest that the project will be profitable with a 14% return on investment. Securing a loan with an interest rate higher than 14% to finance this retrofitting project could reduce the project's economic feasibility. Minimum flow release from Gokpinar was 681,288 cubic meters representing an annual cost of $ 10,263.25. The cost of minimum flow release from the Gokpinar reservoir was 7.6 % of the annual revenue from the reservoir's power generation. The cost of annual minimum flow release as compared to the annual revenue from power production indicates that minimum flow release could possibly pose no threat to the economic viability of power production from Gokpinar reservoir. The levelised cost of energy production for Gokpinar was $0.05252 /kWh indicating that it will not be cost friendly to execute this project if it's compared to renewables energy production source like on shore wind energy. If the Gokpinar project is however compared to bioenergy, offshore wind, geothermal energy, solar PV and concentrated solar power, it could be a good venture to invest in. At a discounting rate of 5%, LCOE computation displays that a total of 40,313,171.71 kWh of electricity could be produced over the 40-year period to replace fossil fuel based energy production sources in the Turkish energy mix. Working with a carbon footprint value of 0.393kgCO2/kWh for fossil fuel based electricity production in Turkey, an investment in the Gokpinar dam's retrofitting project could enable Turkey to offset about 15,843,076.48 kilograms of CO2 emission throughout the 40-year period of power production.

5.5.5 Hydropower Retrofitting of Akbas Dam

The Akbas dam is an irrigation and drinking water supply dam found on the Curusku brook of the Buyuk Menderes basin. With a total average annual flow of 16 million cubic meters and a head of 68.25 meters, the energy equivalent and potential of Akbas was 0.167kWh/m^3 and 2.68 GWh. Energy simulation results of Akbas dam from WEAP produced an output of 1.5 GWh. The capacity factor for power production in the Akbas reservoir was computed as 0.560. This capacity factor indicates that Akbas reservoir can harness 56% of the potential energy production from the reservoir. With reference to an energy per capita of 2740kWh/year, the simulated energy production from Akbas reservoir can serve the annual energy needs of about 547 people within the Buyuk Menderes basin. The total capital cost of retrofitting of the Akbas dam was $410,000. Results of cost estimation indicated that a sum of $16,400 was required to operate and maintain power production on an annual basis with the Akbas dam. The annual income and natural resource tax paid for running power production from the Akbas dam was $ 47,250. Total annual cost required to run hydropower production from the Akbas reservoir was $ 63,650 translating to 15.5% of the capital investment. The total annual revenue from energy production from Akbas reservoir was $ 135,000 representing 32.9 % of the capital cost. At a discounting rate of 5%, the NPV of the net cash flow from power production from the Akbas reservoir was $ 811,000. The NPV value indicates that a profit of $ 811,000 could be generated from power production operation with the Akbas reservoir for a period of 40 years. The positive NPV results also indicates that the project will be profitable to invest in. The IRR from the economic analysis was 12% and this value suggests that the project will be profitable with a 12% return on investment. Project financing with an interest rate higher than 12% might reduce the economic feasibility of the project. The LCOE for the Akbas dam was $ 0.05515 /kWh indicating that it will not be a cost efficient project to execute when its compared to renewable energy production sources like on shore wind energy which has a lower LCOE. If the Akbas retrofitting project is however compared to concentrated solar power, solar PV, geothermal, offshore wind energy and bioenergy, it could be a good venture to push some capital into. At a discounting rate of 5%, results from computation of levelised cost of energy production for Akbas reservoir indicates that a total of 27,238,629.53 kWh of electricity could be produced over the 40-year period to replace nonrenewable sources of energy production in the Turkish energy mix. An investment in this project could possibly enable Turkey to offset about 10,704,781.41 kilograms of CO2 emission throughout the 40-year period. Such an investment could possibly help reduce Turkey's carbon emission per capita and champion the goals of the energy transition and UNSDG 7.

5.5.6 Hydropower Retrofitting Tavas Yenidere Dam

The Tavas Yenidere dam is an irrigation dam found within the Yenidere brook of the Buyuk Menderes basin. With an average annual inflow and energy equivalent of 15 million cubic meter and 0.1 kWh/m^3 respectively, the energy potential of the dam was computed as 1.49 GWh. Energy simulation from WEAP displayed that Tavas Yenidere dam generate an annual energy average of 1.08 GWh. The capacity factor determined for Tavas Yenidere reservoir was

0.722 indicating that the Tavas Yenidere dam can harness 72.2% of its potential power production capacity. At an energy per capita of 2740kWh/year the results from WEAP's energy simulation for Tavas Yenidere dam indicates that the reservoir can serve the annual energy needs of 394 people within the Buyuk Menderes basin. The capital cost of the retrofitting project for Tavas Yenidere dam was $928,000. Results of economic analysis from the retrofitting project of Tavas Yenidere's dam indicates that an annual sum of $37,120 was required for operation and maintenance of the power production from the Tavas Yenidere reservoir. The income and natural resource tax charged for running power production from Tavas Yenidere dam was $ 33,988. Total annual cost of operating hydropower production from Tavas Yenidere dam was $71,108.5 representing 7.6% of the capital cost. The total annual revenue from energy production from Tavas Yenidere dam was $ 97,110, representing 10.5 %of the capital cost. At a discounting rate of 5%, the NPV of the net cash flows from power production from the Tavas Yenidere reservoir was - $482,000. This NPV value suggests that a total loss of $482,000 could be incurred by running the power production project of the Tavas Yenidere dam for a period of 40 years. The negative NPV indicates that the project will not be a profitable venture to invest in. The IRR from running an economic analysis into Tavas Yenidere reservoir's retrofitting project presented a value of -4% which suggest that the project will not be economically feasible. Annual total minimum flow release from Tavas Yenidere dam was 20,44,172.18 cubic meters representing an annual cost of $ 18,327.74. The annual cost of minimum flow release from the Tavas Yenidere reservoir was 18.8% of the annual revenue from the reservoir's power generation. The annual cost of minimum flow release compared to the annual revenue is within a manageable margin, thus the economic losses from releasing minimum flow might not be a bottleneck in this project. The levelised cost of energy production for Tavas Yenidere dam was $0.109 /kWh indicating that the project will not be cost friendly when compared to all the emerging renewable energy sources with relatively lower LCOEs. At a discounting rate of 5%, LCOE computation displays that a total of 19,586,390.54 kWh of electricity could be produced over the 40-year period to replace fossil fuel based energy production sources in the Turkish energy mix. Working with a carbon footprint value of 0.393kgCO2/kWh for fossil fuel based electricity production in Turkey, an investment into the Tavas Yenidere retrofitting project could enable Turkey to offset about 7,697,451 kilograms of CO2 emissions throughout the 40-year period of power production.

5.5.7 Hydropower Retrofitting of Topcam Dam

The Topcam dam is an irrigation and flood control dam found within the Cine catchment the Buyuk Menderes basin. With a total average annual flow of 28 million cubic meters and a head of 54.15 meters, the energy equivalent and potential of Topcam was 0.133kWh/m3 and 3.72 GWh. Energy simulation results of Topcam dam from WEAP produced an output of 3.06GWh. The capacity factor for power production in the Topcam dam was computed as 0.823. This capacity factor indicates that Topcam dam can harness about 82.3% of the potential energy production from the reservoir. With reference to an energy per capita of 2740kWh/year, the simulated energy production from Topcam dam can serve the annual energy needs of about 1,117 people within the Buyuk Menderes basin. The total capital cost of retrofitting of the Topcam dam was $657,781. Results of economic analysis of running power production from the Topcam dam indicated that a sum of $26,311 was required to operate and maintain power production on an annual basis. The annual income and natural resource tax paid for running power production from the Topcam reservoir was $ 96,421. Total annual cost required to run hydropower production from the Topcam reservoir was $ 122,732 representing 18.7% of the capital investment. The total annual revenue from energy production from Topcam dam was $ 275,490 representing 41.88 % of the capital cost. At a discounting rate of 5%, the NPV of the net cash flow from power production from the Topcam dam was $ 1,963,000. The NPV value indicates that a profit of $ 1,963,000 could be made from power production operation from the Topcam dam for a period of 40 years. The positive NPV results also indicates that the project will be profitable to invest in. The IRR from the economic analysis was 17% and this value suggests that the project will be profitable at a 17% return on investments. Project financing with an interest rate higher than 17% might reduce the economic viability of the project. The LCOE for the Topcam reservoir was $ 0.04972 /kWh indicating that it will not be a cost efficient project to execute when it's compared to on shore wind energy production which has a lower LCOE value. If the Topcam reservoir's retrofitting project is however compared to concentrated solar power, solar PV, geothermal, offshore wind energy and bioenergy, it could be a better alternative to invest into. At a discounting rate of 5%, results from computation of levelised cost of energy production for Topcam dam indicates that a total of 55,581,331.51 kWh of electricity could be produced over the 40-year period to replace nonrenewable sources of energy production in the Turkish energy mix. An investment in this project could possibly enable Turkey to offset about 21,843,463.28 kilograms of CO_2 emissions throughout the 40year period.

5.5.8 Hydropower Retrofitting of Yaylakavak Dam

The Yaylakavak dam is an irrigation dam located on the Karpuzlu brook of the Buyuk Menderes basin. With an average annual inflow and energy equivalent of 48.8 million cubic meter and 0.168 kWh/m3 respectively, the energy potential of the dam was computed as 8.2 GWh. Energy simulation from WEAP displayed that Yaylakavak reservoir generates an annual average energy of 4.99 GWh. The capacity factor determined for Yaylakavak reservoir was 0.608 indicating that the Yaylakavak dam can harness about 60.8% of its potential power production capacity. At an energy per capita of 2740kWh/year the results from WEAP's energy simulation for Yaylakavak dam indicates that the reservoir can serve the annual energy needs of 1821 people within the Buyuk Menderes basin. The capital cost of the retrofitting project for Yaylakavak dam was $752,620. Results of cost estimation indicates that an annual sum of $30,248 was required for operation and maintenance of the power production from the dam. The income and natural resource tax charged for running power production from Yaylakavak dam was $ 157,027. Total annual cost of operating hydropower production from Yaylakavak reservoir was $187,275 representing 24.8% of the capital cost. The total annual revenue from energy production from Yaylakavak reservoir was $ 448,650 representing 59.6 % of the capital cost. At a discounting rate of 5%, the NPV of the net cash flows from power production from the Yaylakavak dam was $3,729,000. This NPV value suggests that a total profit of $3,729,000 could be generated by running the power production project of the Yaylakavak dam for a period of 40 years. The positive NPV value indicates that the project will be a profitable venture to invest in. The IRR from running an economic analysis into the Yaylakavak dam's retrofitting project was 28 %, which suggests that the project will be economically feasible with an investment return of 28%. If the project is executed with a loan or financial instrument which has an interest rate above 28%, the financial integrity of the project might be dampened. The annual cost of minimum flow release from the Yaylakavak reservoir was 11.4% of the annual revenue from the reservoir's power generation. The annual cost of minimum flow release compared to the annual revenue is within a manageable margin, thus the economic losses from releasing minimum flow might not be a bottleneck in this project. The levelised cost of energy production for Yaylakavak was $ 0.04385 /kWh indicating that the project will be cost friendly when compared to off shore wind, bioenergy, solar photovoltaic, concentrated plants and geothermal energy. When this project is compared to on shore wind, its competitive urge will drop because on shore wind energy has a lower LCOE. At a discounting rate of 5%, LCOE computation displays that a total of 90,523,054.47 kWh of electricity could be produced over the 40-year period to replace fossil fuel based energy production sources in the Turkish energy mix. Working with a carbon footprint value of 0.393kgCO2/kWh for fossil fuel based electricity production in Turkey, an investment into the Yaylakavak dam retrofitting project could enable Turkey to offset about 35,575,560.41 kilograms of CO2 emission throughout the 40-year period of power production.

5.5.9 Hydropower Retrofitting of Gokbel Dam

The Gokbel dam is an irrigation and flood control dam found within the Cine catchment of the Buyuk Menderes basin. With a total average annual flow of 246 million cubic meters and a head of 37.1 meters, the energy equivalent and potential of Gokbel dam was 0.091kWh/m3 and 22.4 GWh. Energy simulation results of Gokbel reservoir from WEAP produced an output of 12.5 GWh. The capacity factor for power production in the Gokbel dam was computed as 0.557. This capacity factor indicates that Gokbel dam can harness about 55.7% of the potential energy production from the dam. With reference to Turkey's energy per capita of 2740 kWh/year, the simulated energy production from Gokbel dam can serve the annual energy needs of about 4,562 people within the Buyuk Menderes basin. The total capital cost of retrofitting of the Gokbel dam was $1,820,680. Results of cost estimation indicated that a sum of $72,827 was required to operate and maintain power production in the Gokbel dam. The annual income and natural resource tax paid for running power production from the Gokbel dam was $ 393,750. Total annual cost required to run hydropower production from the Gokbel reservoir was $ 466,577 representing 25.6% of the capital investment. The total annual revenue from energy production from Gokbel dam was $1,125,000 representing 61.8 % of the capital cost. At a discounting rate of 5%, the NPV of all cash flow from power production from the Gokbel reservoir was $ 9,477,000. The NPV value indicates that a profit of $ 9,477,000 could be generated from power production operation of the Gokbel reservoir for a period of 40 years. The positive NPV results also indicates that the project will be profitable to invest in. The IRR from the economic analysis was 30% and this value suggests that the project will be profitable with a 30% return on investment. Project financing with an interest rate higher than 30% might reduce the economic viability of the project. The LCOE for the Gokbel reservoir was $ 0.04329/kWh indicating that the project will be very competitive when its compared to solar

PV, Concentrated Solar Plants, offshore wind, bioenergy and geothermal energy because its LCOE is lower than these renewable energy sources. The projects competitive urge is however lost when its compared to on shore wind which has a lower LCOE. At a discounting rate of 5%, results from computation of levelised cost of energy production for Gokbel reservoir indicates that a total of 226,988,579.42 kWh of electricity could be produced over the 40-year period to replace nonrenewable sources of energy production in the Turkish energy mix. An investment in this project could possibly enable Turkey to offset about 89,206,511.71 kilograms of CO_2 emissions throughout the 40year period.

5.5.10 Hydropower Retrofitting Ikizdere

The Ikizdere dam is a water supply dam located in the lower section of the Buyuk Menderes basin. With an average annual inflow and energy equivalent of 134 million cubic meter and 0.235 kWh/m3 respectively, the energy potential of the dam was computed as 31.65 GWh. Energy simulation from WEAP displayed that Ikizdere reservoir generated an annual energy average of 7.34 GWh. The capacity factor determined for Ikizdere reservoir was 0.235 indicating that the Ikizdere reservoir can harness 23.5% of its potential power production capacity. At an energy per capita of 2740kWh/year the results from WEAP's energy simulation for Ikizdere reservoir indicates that the reservoir can serve the annual energy needs of 2,679 people within the Buyuk Menderes basin. The capital cost of the retrofitting project for Ikizdere dam was $871,508. Results of cost estimation indicated that an annual sum of $34,860 was required for operation and maintenance of the power production from the Ikizdere dam. The income and natural resource tax charged for running power production from Ikizdere reservoir was $231,210. Total annual cost of operating hydropower production from Ikizdere reservoir was $266,070 representing 30.5% of the capital cost. The total annual revenue from energy production from Ikizdere reservoir was $ 660,600 representing 75.7% of the capital cost. At a discounting rate of 5% the NPV of the net cash flows from power production from the Ikizdere reservoir was $5,898,000. This NPV value suggests that a total revenue of $5,898,000 could be generated by running the power production project of the Ikizdere dam for a period of 40 years. The positive NPV results also indicates that the project will be profitable to invest in. The IRR from the economic analysis was 38% and this value suggests that the project will be profitable, producing a 38% return on investments. Project financing with an interest rate higher than 38% might reduce the economic viability of the project. The levelised cost of energy production for Ikizdere was $ 0.04079/kWh indicating that the project will be very competitive when compared to other renewable sources like geothermal, offshore wind, solar PV and Concentrated Solar plants which have higher LCOE values. The project will however not be competitive when it is compared to on shore wind energy which has a relatively lower LCOE value. At a discounting rate of 5%, LCOE computation displays that a total of 133,287,693.84 kWh of electricity could be produced over the 40-year period to replace fossil fuel based energy production sources in the Turkish energy mix. Working with a carbon footprint value of 0.393kgCO2/kWh for fossil fuel based electricity production in Turkey, an investment into the Ikizdere retrofitting project could enable Turkey to offset about 52,382,063 kilograms of CO2 emission throughout the 40-year period of power production.

5.5.11 Hydropower Retrofitting of Karakasu Dam

Karakasu dam is an irrigation and drinking water supply dam found within the Dandalas catchment of the Buyuk Menderes basin. With an average annual inflow and energy equivalent of 30 million cubic meter and 0.130 kWh/M3 respectively, the energy potential of the dam was computed as 3.91GWh. Energy simulation from WEAP displayed that Karakasu reservoir generate an annual energy average of 2.64 GWh. The capacity factor determined for Karakasu reservoir was 0.675 indicating that the Karakasu reservoir can harness 67.5% of its potential power production capacity. At an energy per capita of 2740kWh/year, the results from WEAP's energy simulation for Karakasu reservoir indicates that the reservoir can serve the annual energy needs of 963 people within the Buyuk Menderes basin. The capital cost of the retrofitting project for Karakasu dam was $544,000. Results of economic analysis from Karakasu's retrofitting project indicates that an annual sum of $13,600 was required for operation and maintenance of the power production from the Karakasu dam. The income and natural resource tax charged for running power production from Karakasu reservoir was $ 64,544. Total annual cost of operating hydropower production from Karakasu reservoir was $78,146.65 representing 14.4% of the capital cost. The total annual revenue from energy production from Karakasu reservoir was $ 226,062 representing 41.4% of the capital cost. At a discounting rate of 5%, the net presents value of all cash flows from power production from the Karakasu reservoir was $1,741,000. This NPV value suggests that a total revenue of $1,741,000 could be generated by running the power production project of the Karakasu dam for 40 years. The positive NPV indicates that the project will be profitable to invest in. The

IRR from running an economic analysis into Karakasu reservoir's retrofitting project presented a value of 19% which suggest that the project will be profitable with a 19% return on investment. Securing a loan with an interest rate higher than 19% to finance this retrofitting project could reduce the project's economic viability. Annual total minimum flow release from Karakasu was 9,136,108.8 cubic meters representing an annual cost of $ 107,281.4. The annual cost of minimum flow release from the Karakasu reservoir was 47.47 % of the annual revenue from the reservoir's power generation. The annual cost of minimum flow release is very high as compared to the annual revenue from power generation. This constraint could be a possible economic bottleneck preventing the release of the rightful amount to maintain river connectivity and environmental sustainability. The levelised cost of energy production for Karakasu was $ 0.03926/kWh indicating that the project will be more cost friendly than all other emerging renewable energy production sources. At a discounting rate of 5%, LCOE computation displays that a total of 48,012,624.32 kWh of electricity could be produced over the 40-year period to replace fossil fuel based energy production sources in the Turkish energy mix. Working with a carbon footprint value of 0.393kgCO2/kWh for fossil fuel based electricity production in Turkey, an investment into the Karakasu retrofitting project could enable Turkey to offset about 18,868,961.48 kilograms of CO2 emission throughout the 40-year period of power production.

5.6 Limitations and uncertainties

Data clarity happens to be one of the major limitations of this work. Discharge data from DSI was provided on a monthly resolution as scanned copies. Clarity of some of the numbers from older years in the data was poor and this could possibly lead to discharge data input that might not be very representative of the runoff series in the gauges of interest within the catchments. Data continuity was also an issue to deal with. Only few of the gauging station had continuous flow data for the years under study. Some of the gauging stations had several months of missing monthly data which were represented as zero values. Most of the relevant stations had some gaps which was difficult to fill with scaling because the nearby identical stations in terms of catchment area and specific discharge also had many years of missing data to a large extent.

With the exception of relative humidity and cloudiness fraction all climatic information was obtained from the Princeton data set. Relative humidity and cloudiness fraction was retrieved from the FAO's AQUSTAT Climate information tool. The representativeness of information from the FAO to the required points of interest was difficult to confirm. Data on irrigation demands within the various catchment were very many and not georeferenced, irrigation demand data was lumped into units to enable simplicity within the model. These different irrigation demands had different start up years so choosing one start up to represent all the irrigation demands in the lumped demand point was huge limitation which could probably inject some level of uncertainty into the model. Lack of specific information on the exact crops grown in the different areas within the Buyuk Menderes basin led to generalization of very key model input like the crop coefficient and irrigation release. The population of people reliant on the water demand was also difficult to ascertain. Several water demand assumptions were made with the population size of nearby communities. This could probably not be the original situation on ground and possibly lead to huge levels of unmet water demands. Information on the startups year of this water demand points was a limitation. The assumptions made with the start-up years of the demand nodes could possibly instruct the model to supply water to the nodes during years when they weren't in existence. Since the analysis is based on the periodic average this wouldn't be a very grave issue. The NVE cost base for small hydropower projects was used as the basis for cost estimation of the major components for the retrofitting projects. The interest, inflation and discounting rates applied to convert the costs in the NVE cost base from 2010 to 2022 and to test the economic feasibility of the project may not be reflective of the real situation. This could push some level of uncertainty into the estimated costs, possibly leading to over or underestimation of costs in the economic analysis.

5.7 Opportunities for further studies

In this study, the retrofitting potential of 11 non powered dams was computed as 38.737 GWh per year. Turkey has a total of 692 non powered dams. It would be an interesting study to measure the total energy potential which could be realized from retrofitting all of these non-powered dams, its environmental implications and the economic feasibility of embarking on such a project.

WEAP enables us to assess the retrofitting potential of non-powered dams with climatic and hydrological data. A study on how retrofitting of non-powered dams affect the stability and structural integrity of these dams would be a good path to gather information on dam safety and maintenance specification.

This study was conducted to assess the energy potential of a non-powered dam without changing the specifications of the dams and its intended purpose. Further studies could be conducted on the sensitivity of changes in turbine capacity to energy production and irrigation demands.

Chapter 6: Conclusion

This research aimed at demonstrating the environmental, technical and economic feasibility of hydropower retrofitting projects in the Buyuk Menderes river basin with available climatic data. Obtaining a good assessment of water availability for power production, the research sought to apply a method to calculate the retrofitting potential in the Buyuk Menderes river basin, simulate energy production from the available data of non-powered dams, estimate the cost and economic feasibility of these retrofitting projects, identify potential barriers to the realization of the concept of retrofitting and present all assumptions, limitations and uncertainties in the study.

Preliminary studies on the assessment of water availability for power production revealed that the Buyuk Menderes river basin is endowed with a total annual water potential of 3,047 million cubic meters. The 11 non-powered dams under study in this research, possessed a total annual water potential of 845 million cubic meters. From this potential, a total annual average of 496 million cubic meter is regulated to serve irrigation and drinking water demands. An annual total inflow volume of 349 million cubic meter for these 11 non powered dams therefore remains unexploited. This unexploited volume of water presents an appreciable level of water resource for power production. The soil moisture method in WEAP was used to generate a model of the Buyuk Menders basin to assess the energy potential of the 11 non powered dams. Results from the model indicates that the 11 dams can generate a total average of 38.737 GWh of energy. Relying on the annual energy per capita value for Turkey(2740kWh/year), the energy produced from all the retrofitting projects under this study can provide a total of 14,138 people within the basin with their annual energy needs. The total estimated capital investment cost of all the 11 retrofitting projects was computed as $ 7,892,166 and includes the cost of purchase and installation of complete electromechanical equipment, penstock, and power house. The annual estimated cost for operation and maintenance of all the 11 dams was $ 307,526, while the annual charge for income and natural resource tax was $1,201,476. The total estimated annual cost of operating the 11 retrofitted dams was $ 1,509,003. The estimated total annual revenue from operating these retrofitted dams was $3,474,432. The total NPV from operating these retrofitted dams for a period 40 years at a discount rate of 5 % was $ 25,576,000 indicating that it will be profitable if all the projects are executed together. The average estimated IRR for running these projects as a unit was 14.72% indicating that the project will be profitable with a 14.72% return on investments. For this reason, if a financial instrument or loan has to be secured to fund this project for the stipulated period, it should not have an interest rate greater than 14.72%. Any loan secured for the purpose of project execution which has an interest rate higher than 14.72% will dampen the economic viability of the retrofitting projects.

Total annual minimum flow release from the 11 dams was 68,171,381.2 cubic meters representing a loss of $ 292,576.7. Compared to the annual revenue of power production from the 11 retrofitted dams, it might be difficult to classify the annual cost of minimum flow release as a strong economic bottleneck that could compromise the environmental integrity of these projects. The average LCOE for retrofitting of all the reservoirs was 0,061$/kWh indicating that when the projects are completed as a unit it could be a better option when compared with other renewables like bioenergy, geothermal energy, concentrated solar power and offshore wind. The competitive urge of the project will however be lost when its compared to solar PV and on shore wind which have very low LCOEs. Computation of LCOE for all the reservoirs indicated that a total energy 703,428,528.09 kWh could be produced for the 40-year period under study. With reference to the carbon foot print of nonrenewable electricity in Turkey (0.393kg CO_2/kWh), retrofitting of these dams could provide competitively clean energy to replace fossil fuel based energy production sources in Turkey's energy mix. By investing in these retrofitting project, Turkey could avoid the release of about 276, 447,411 kg of CO_2 into the ozone layer over the 40-year period of operation. Though some of the individual retrofitting projects were not economically feasible, their impact on the protection of the ozone layer is very key. Some amount of green capital could be injected into these economically bad projects to offset some of the costs and possibly make them competitive. In accordance to a report by the DSI (2018), the Buyuk Menders basin has a power potential of 913.31GWh including existing and planned projects. Due to issues with regards to irrigation water distribution to the lower belts of the basin, some of the planned project have been called off, bringing the energy potential down to 862GWh. Energy provided by this retrofitting projects could replace the energy lost from the cancelled hydropower projects in the basin. The Energy potential in the basin could possibly move to 900.77 GWh if an investment is made in these projects. A total of 13 new hydropower projects have been planned at different locations within the Buyuk Menderes basin. These planned projects have a total energy production of 106.89 GWh and a capacity of 21.3 MW. An investment into these retrofitting project could provide the basin with 38.73 % of this planned energy supply, at a relatively cheaper cost and minimum environmental impact.

On a global level, the findings from this research indicate that the potential of retrofitting non-powered dams must not be overlooked in the world's quest to switch to a 100% renewable electricity grid. Data from the ICOLD database of dams reveals that at a total of 29,163 non-powered dams exist in different parts of the world (ICOLD, 2019). A global prefeasibility study and consequent investments on these dams can move the world closer to the targets of the energy transition. Further research in Africa and Asia could be very promising in bridging the global electrification gap with minimum financial resources and environmental impact.

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Appendices

APPENDIX A- Thesis Contract

NTNU
Norwegian University of Science and Technology

Faculty of Engineering

Department of Civil and Environmental Engineering

M.Sc. Thesis in

Water Resources Modelling and Engineering

Candidate: Quentin Adjetey Okang

Title: Retrofitting of non-hydro reservoirs and dams in Menderes river basin, Turkey

1 BACKGROUND

A large number of the world's large dams and reservoirs are built for other types of use than hydropower production. According to the statistics derived from the International Commission of Large Dams (ICOLD), the purpose of single purpose dams in Asia and Africa is dominated by irrigation, and only 14% and 7%, respectively, are used for hydropower. According to recent studies it is a technically possible and economically feasible to re-build (retrofit) some of these non-hydropower dams for the purpose of producing hydropower electricity, without affecting the existing purpose of the dams. The introduction of hydropower technology in these dams will neither introduce any additional environmental impacts. Retrofitting describes in this context the addition or expansion of an existing dam not used for hydropower with hydroelectric power generation capabilities.

The project aims at demonstrating the environmental, technical and economic feasibility of such a retrofitting in a river basin with climatic and water-use characteristics different than where it has been tested before, with a starting focus on analysing the availability of water resources for hydropower production. The study in Turkey will be based on a very preliminary model setup carried out in a master thesis in the Spring 2021. As the access to essential data now looks much more promising, the study is expected to provide a better basis for the evaluation of the concept in Turkey.

2 MAIN QUESTIONS FOR THE THESIS

Key questions to be addressed in the thesis are;

1. Carry out a literature study on the current state of retrofitting of non-hydropower dams and reservoirs.
2. Develop/apply a method (possibly WEAP) to calculate the retrofitting potential in Menderes river basin, a basin with non-hydropower dams/reservoir.
3. Demonstrate the proposed methodology by simulating the hydropower production for a time period matching the available data.
4. Provide a rough estimate of costs of retrofitting, the revenue of the possible hydropower production, and compare to other sources of (new) renewable energy production.
5. Identify potential environmental, social or other types of barriers in the realization of the concept.
6. Assess the assumptions, limitation and uncertainties in the methodology and calculations

3 SUPERVISION, DATA AND INFORMATION INPUT

Professor Tor Haakon Bakken will be the main supervisor of the thesis work, with Researcher Asli Bor Türkben as co-supervisor. Discussion with and input from colleagues and other research or engineering staff at NTNU, power companies or consultants are recommended, if considered relevant. Significant inputs from others shall be referenced in a convenient manner.

The research and engineering work carried out by the candidate in connection with this thesis shall remain within an educational context. The candidate and the supervisors are therefore free to introduce assumptions and limitations, which may be considered unrealistic or inappropriate in a contract research or a professional engineering context.

4 REPORT FORMAT AND REFERENCE STATEMENT

The report shall be typed by a standard word processor and figures, tables, photos etc. shall be of good report quality, following the NTNU style. The report shall include a summary, a table of content, lists of figures and tables, a list of literature and other relevant references. All figures, maps and other included graphical elements shall have a legend, have axis clearly labelled and generally be of good quality.

The report shall have a professional structure and aimed at professional senior engineers and decision makers as the main target group, alternatively written as a scientific article. The decision regarding report or scientific article shall be agreed upon with the supervisor. The thesis shall include a signed statement where the candidate states that the presented work is his/her own and that significant outside input is identified.

This text shall be included in the report submitted. Data that is collected during the work with the thesis, as well as results and models setups, shall be documented and submitted in electronic format together with the thesis.

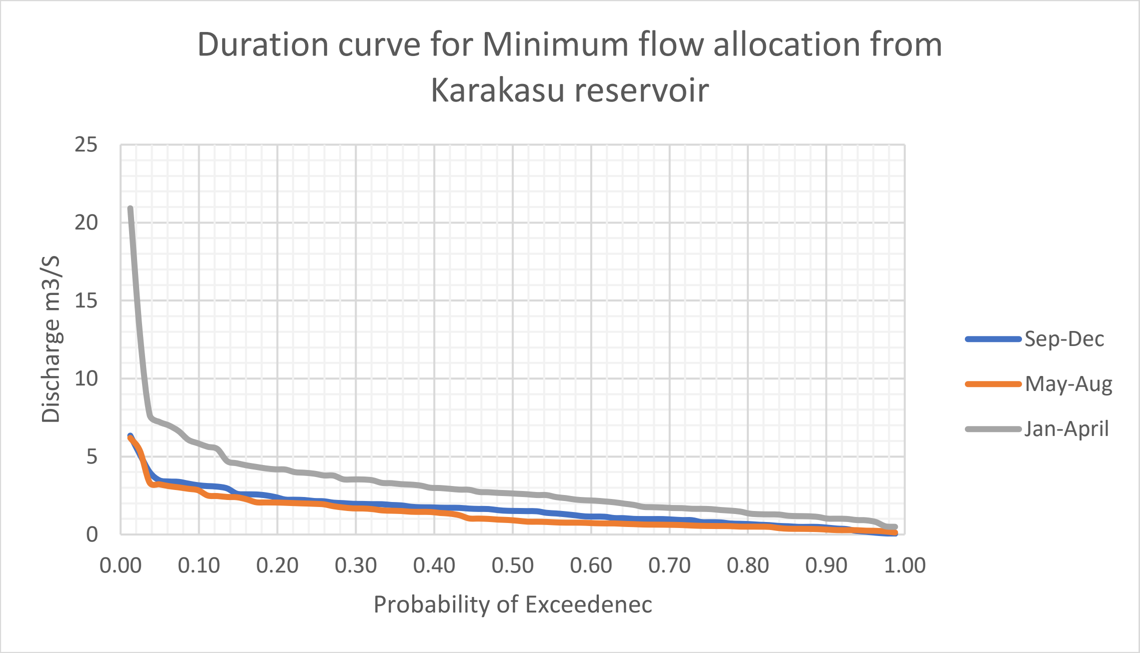
The thesis shall be submitted no later than 11th of June, 2022.

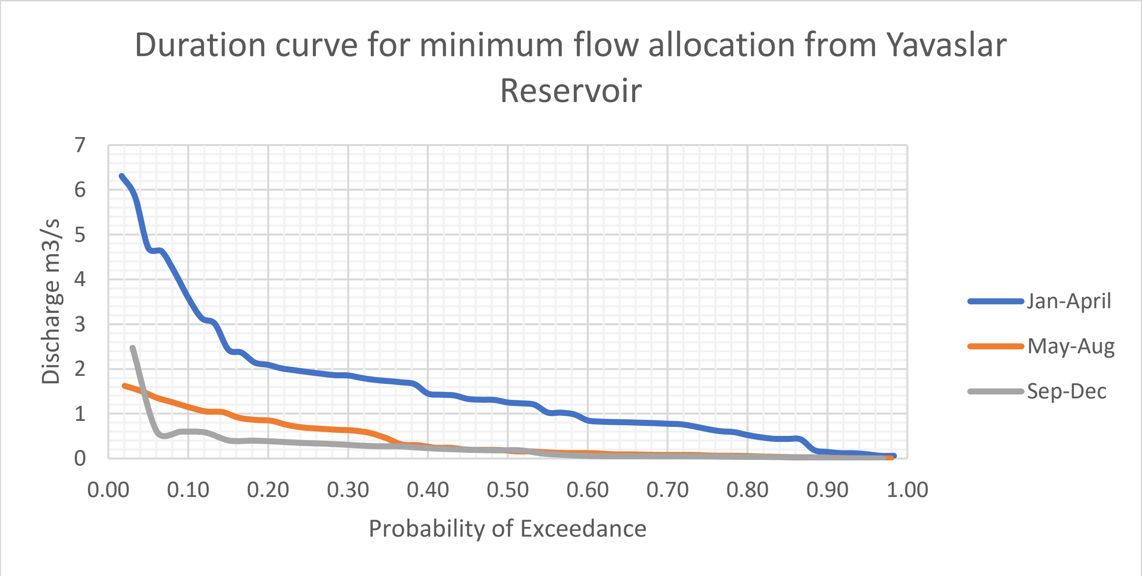
Trondheim 15th of January 2022

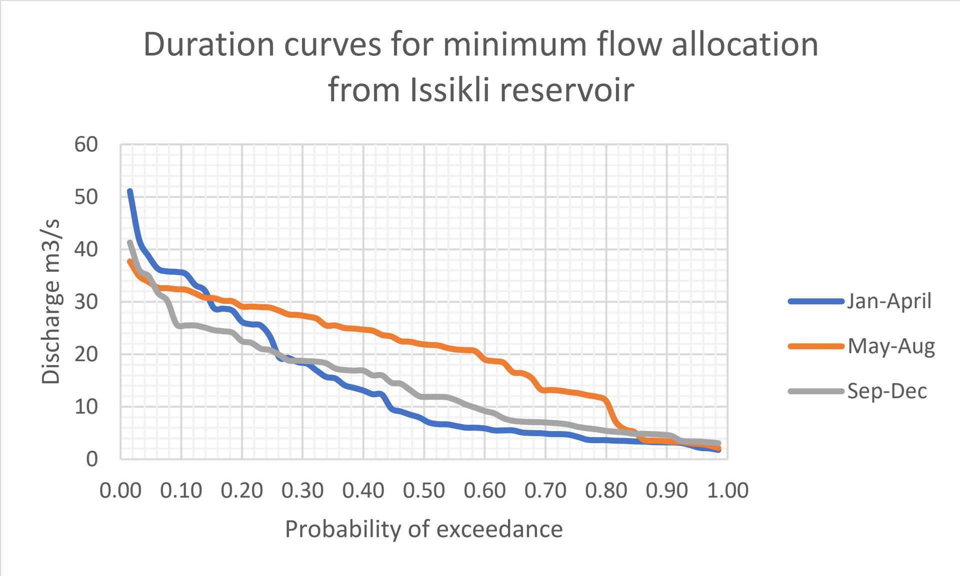
Tor Haakon Bakken

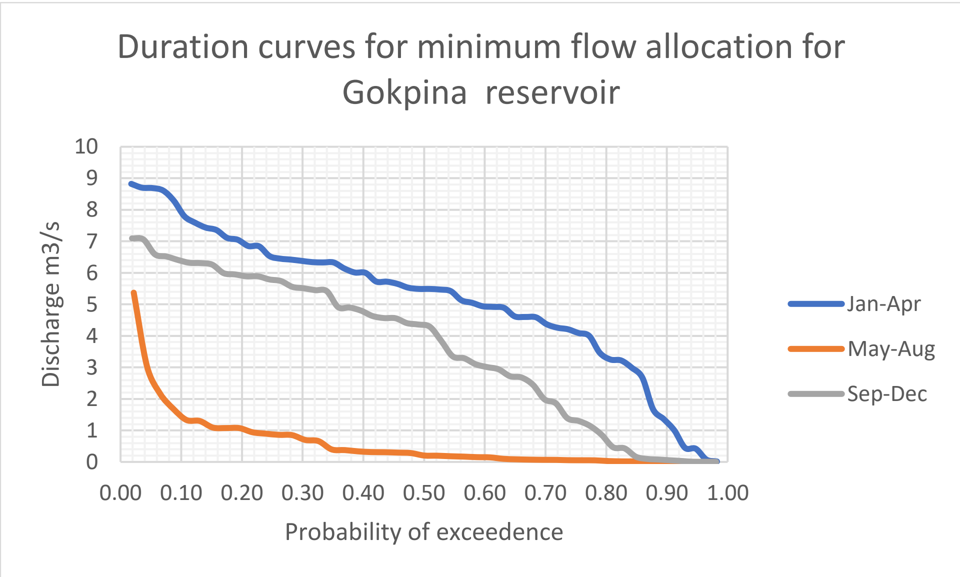
Tor Haakon Bakken, Professor

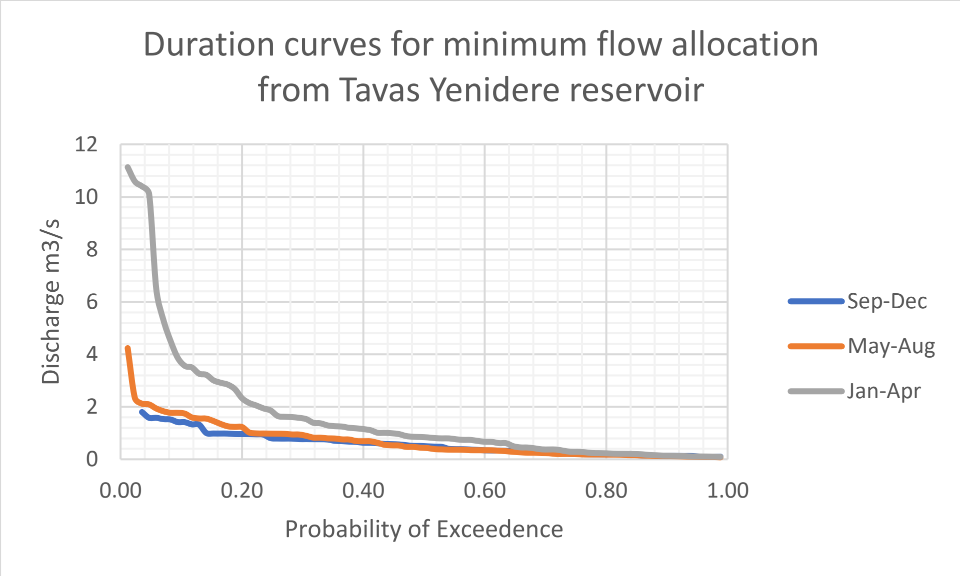
APPENDIX B- DURATION CURVES FOR MINIMUM FLOW CALCULATION

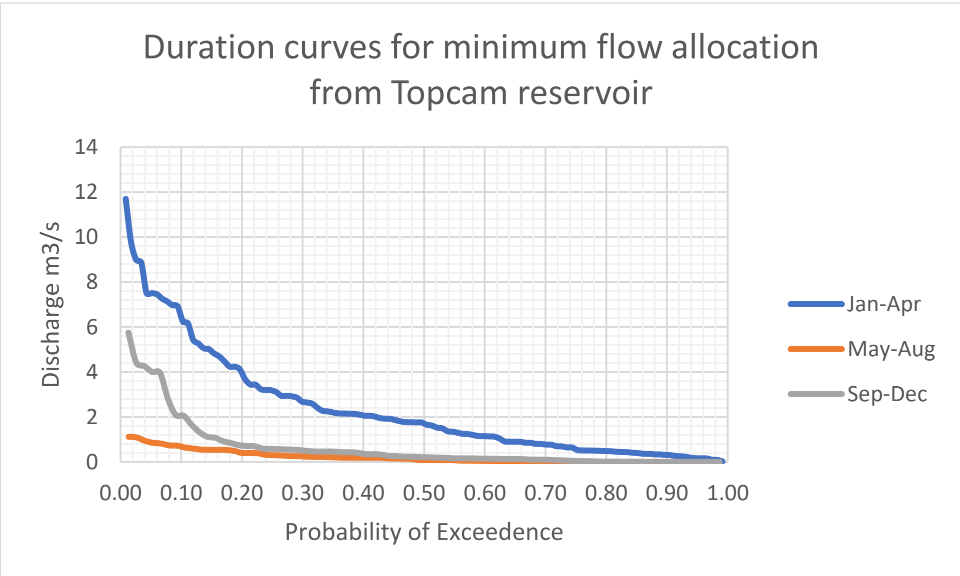


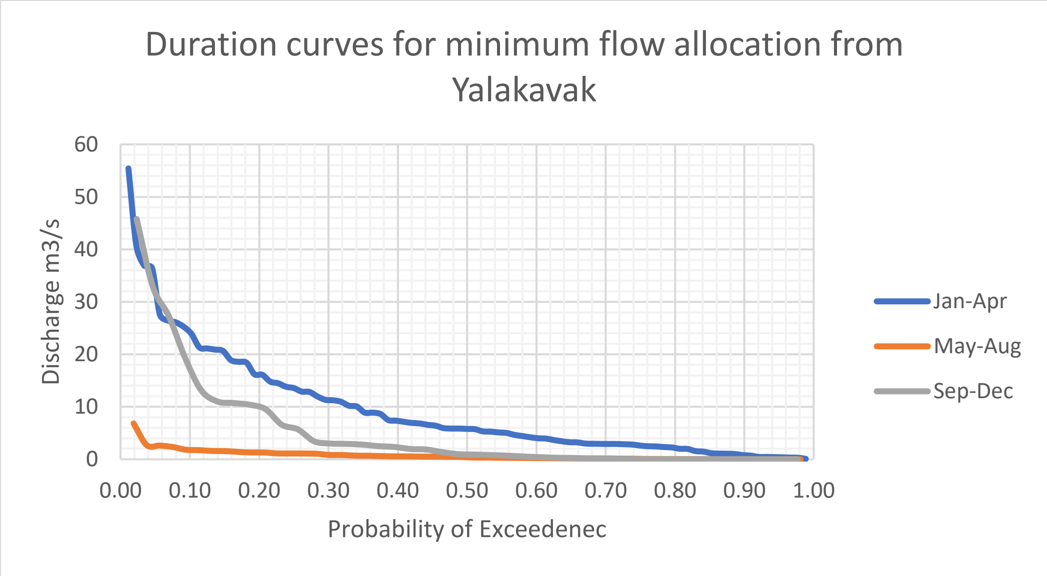


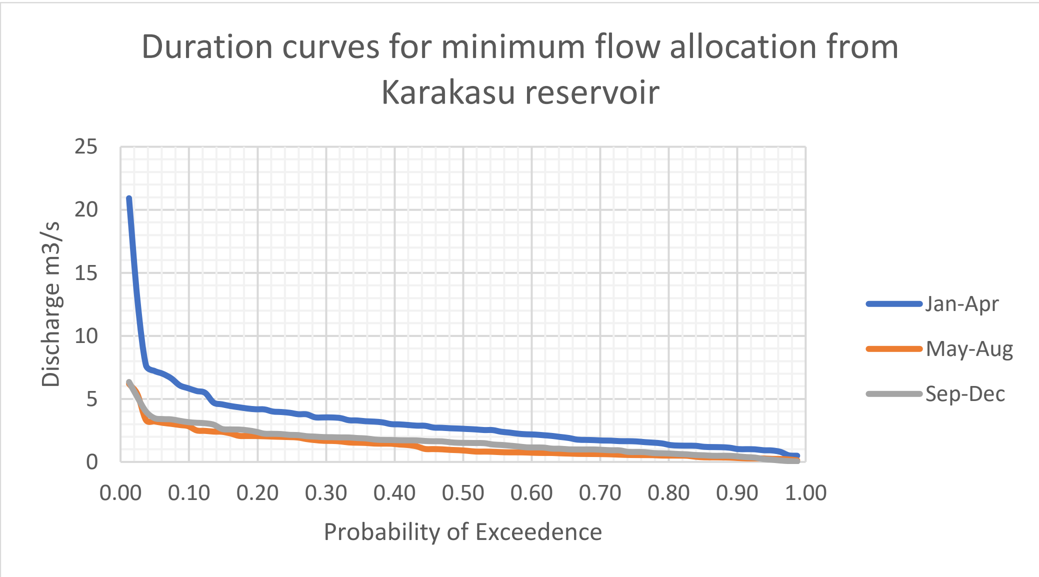

Duration curves for minimum flow allocation from Issikli reservoir
Discharge m3/s
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Probability of exceedance
Jan-April
May-Aug
Sep-Dec


Duration curves for minimum flow allocation for Gokpina reservoir
Discharge m3/s
10
9
8
7
6
5
4
3
2
1
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Probability of exceedence
Jan-Apr
May-Aug
Sep-Dec

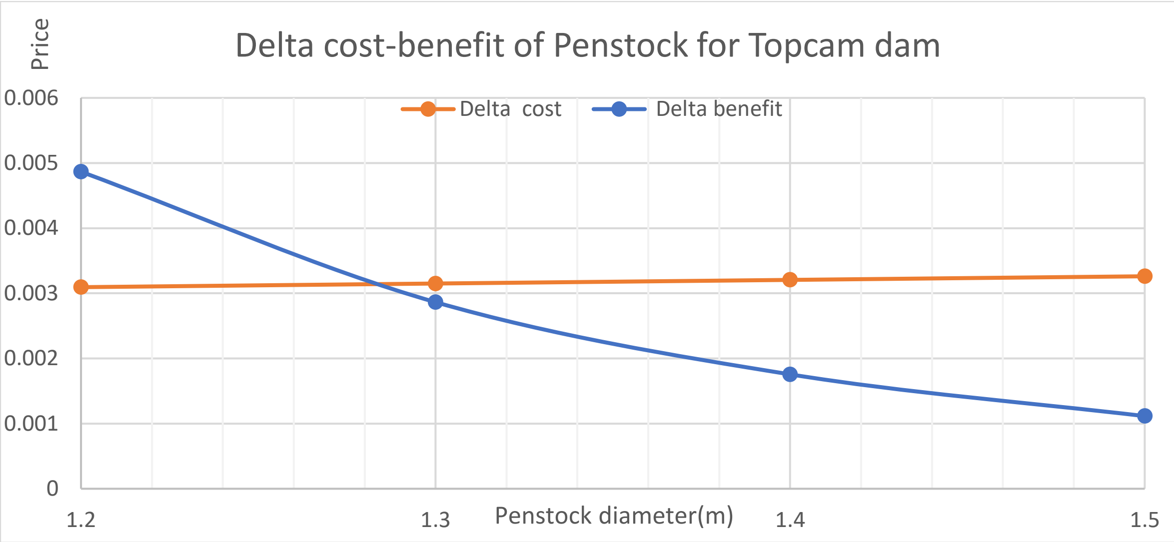

Duration curves for minimum flow allocation from Tavas Yenidere reservoir
Discharge m3/s
Probability of Exceedence
0
2
4
6
8
10
12
0.00
0.20
0.40
0.60
0.80
1.00
Sep-Dec
May-Aug
Jan-Apr

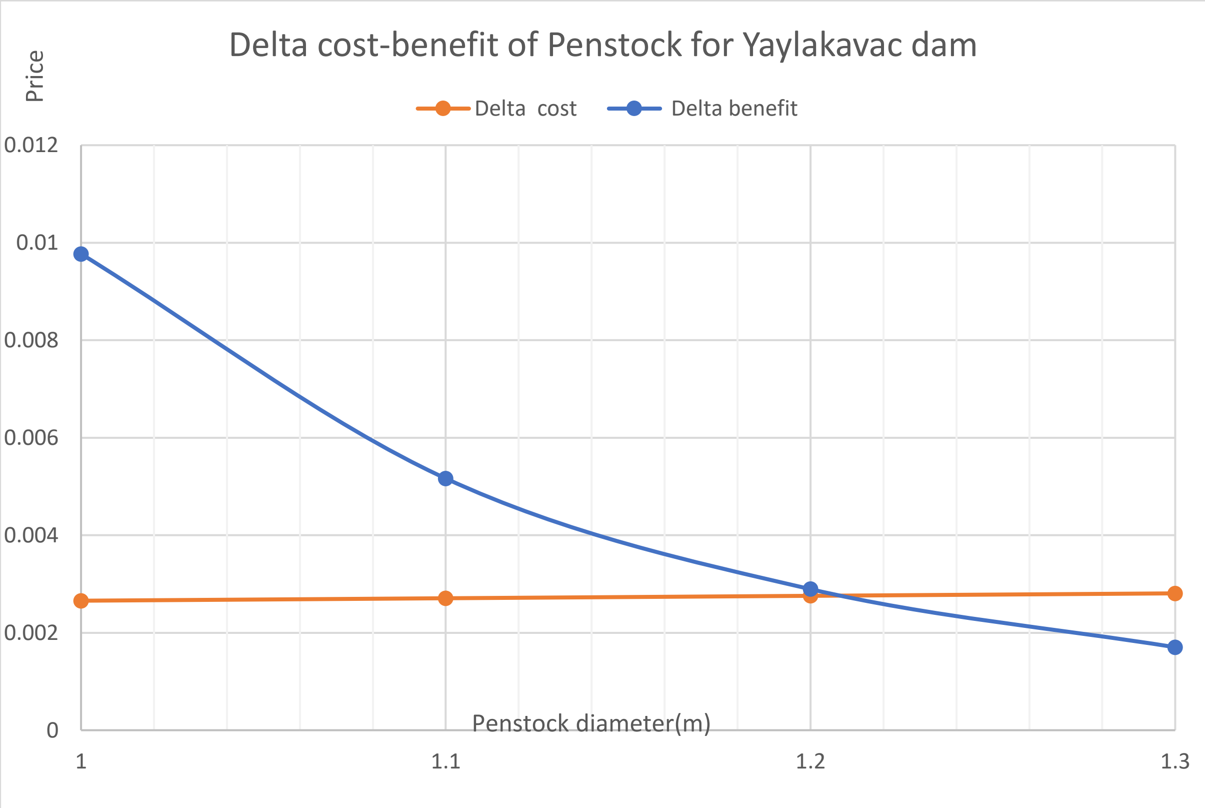

Duration curves for minimum flow allocation from Topcam reservoir
Discharge m3/s
Probability of Exceedence
0
2
4
6
8
10
12
14
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Jan-Apr
May-Aug
Sep-Dec

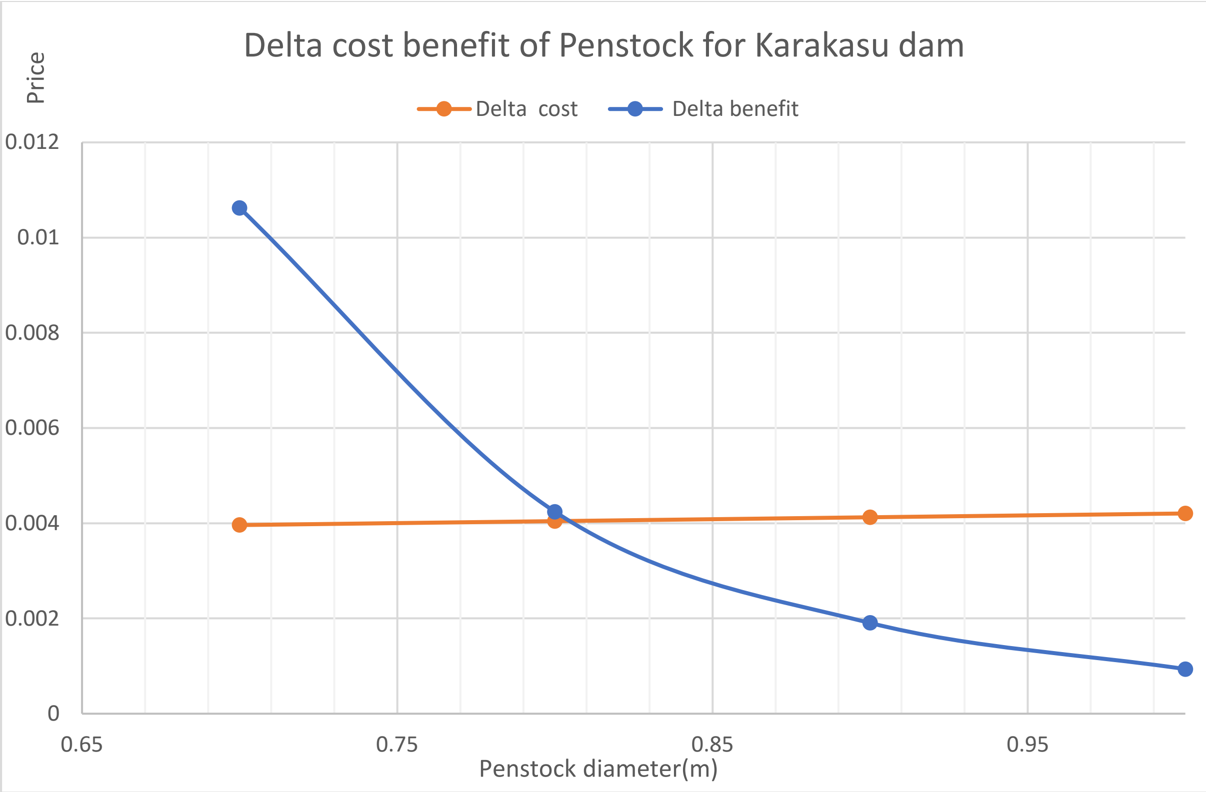

Duration curves for minimum flow allocation from Yalakavak
60
50
40
30
20
10
0
Discharge m3/s
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Probability of Exceedenec
Jan-Apr
May-Aug
Sep-Dec

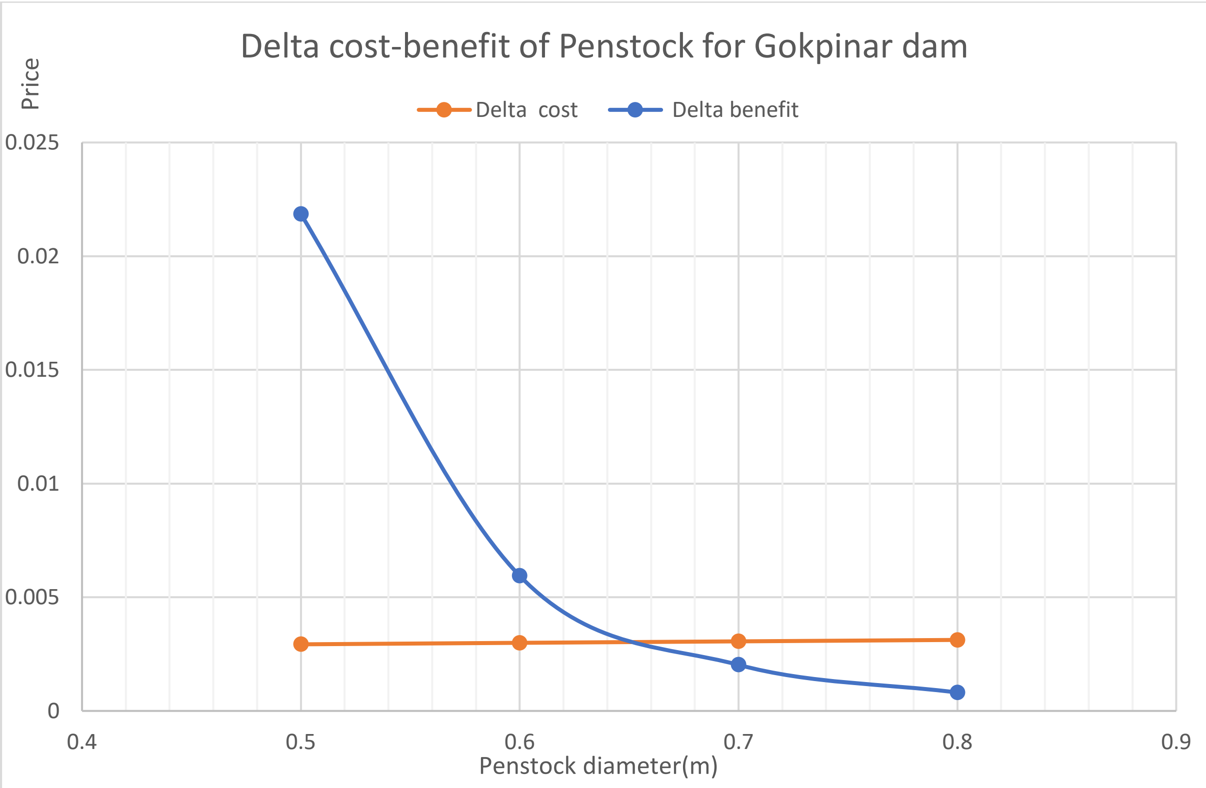

Duration curves for minimum flow allocation from Karakasu reservoir
25
20
15
10
5
0
Discharge m3/s
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Probability of Exceedence
Jan-Apr
May-Aug
Sep-Dec

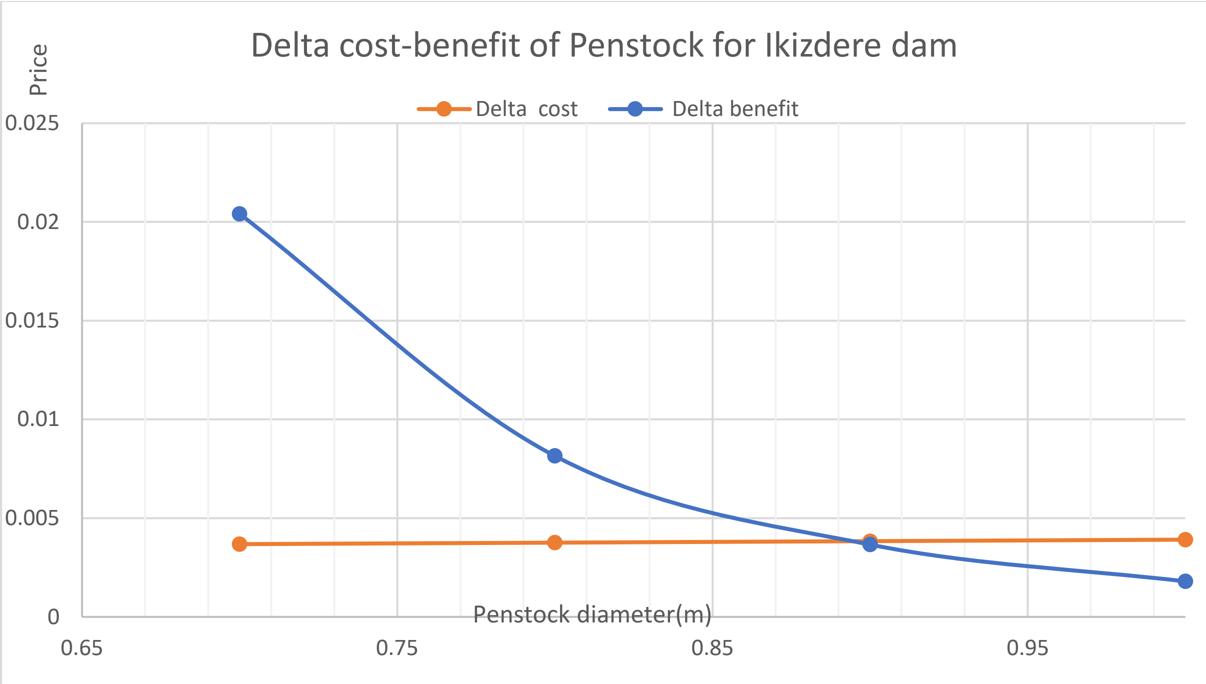
APPENDIX C – SAMPLE OF PENSTOCK OPTIMISATION CURVES






Delta cost benefit of Penstock for Karakasu dam
Price
Delta cost
Delta benefit
0.012
0.01
0.008
0.006
0.004
0.002
0
0.65
0.75
0.85
0.95
Penstock diameter(m)


Delta cost-benefit of Penstock for Gokpinar dam
Price
Delta cost
Delta benefit
0.025
0.02
0.015
0.01
0.005
0
0.4
0.5
0.6
0.7
0.8
0.9
Penstock diameter(m)


Delta cost-benefit of Penstock for Ikizdere dam
Price
Delta cost
Delta benefit
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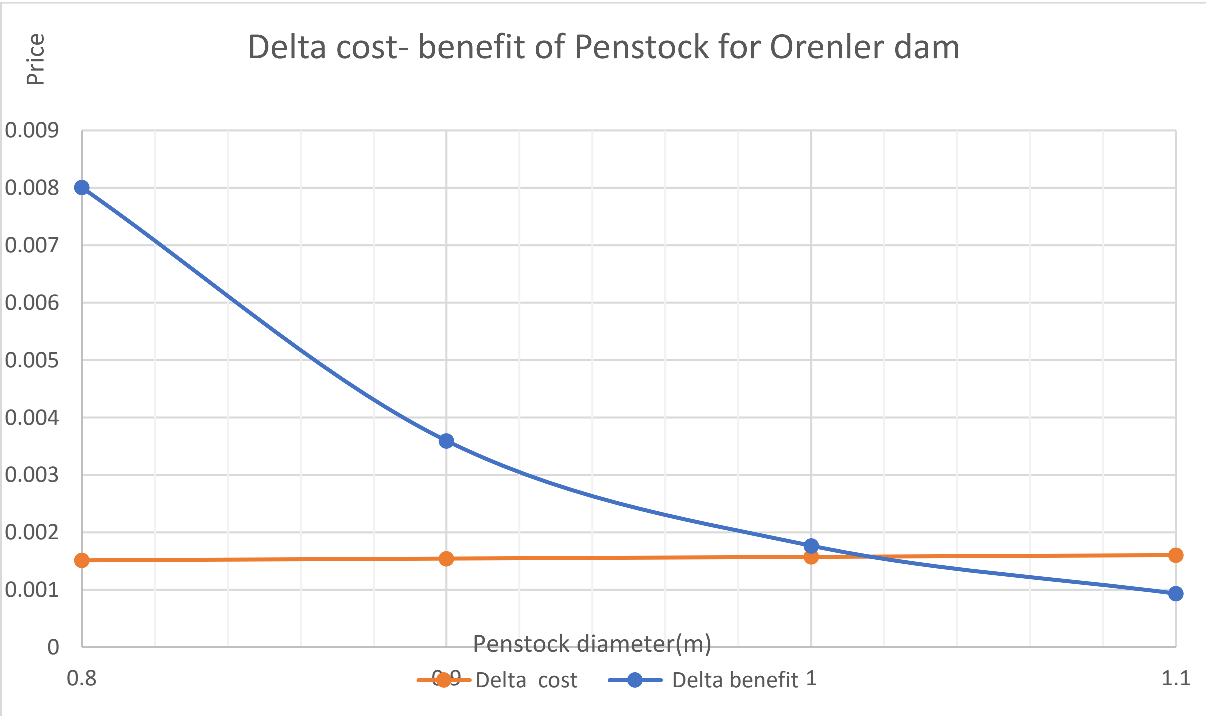
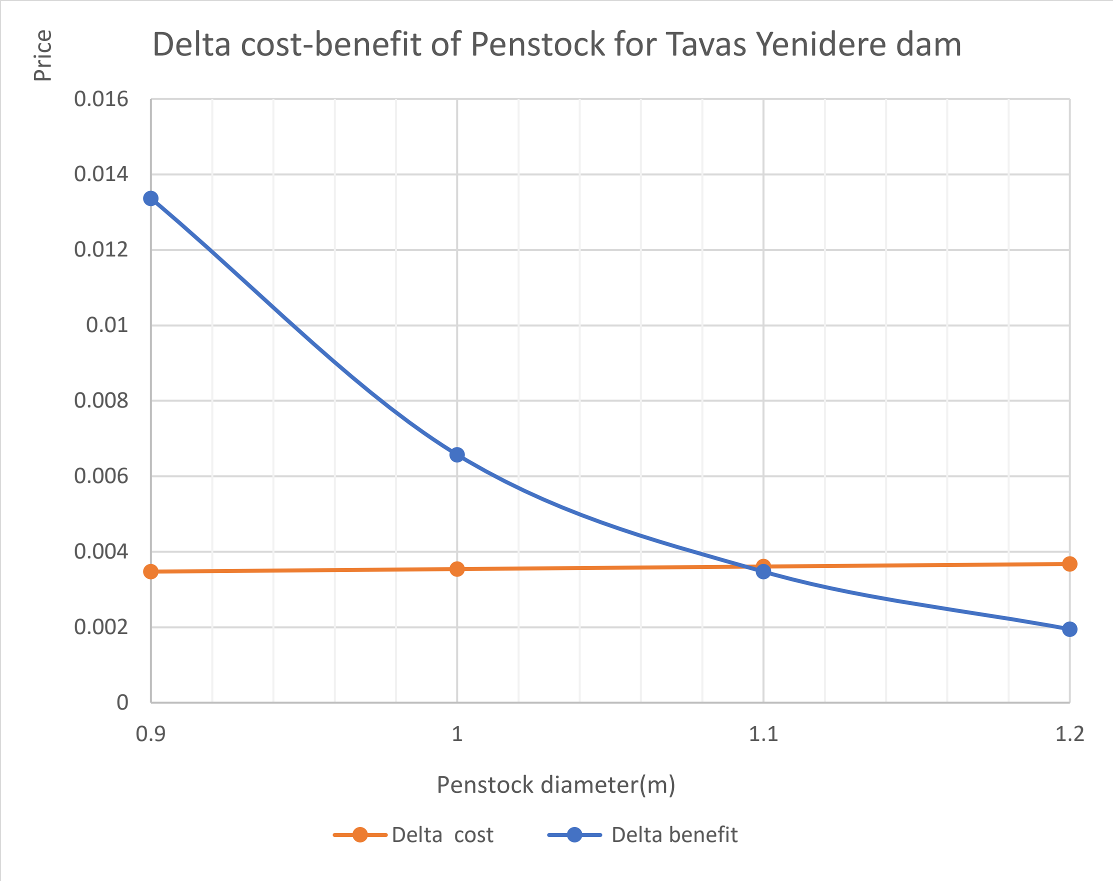
0.02
0.015
0.01
0.005
0
Penstock diameter(m)
0.65
0.75
0.85
0.95


Delta cost- benefit of Penstock for Orenler dam
Price
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Penstock diameter(m)
0.8
0.9
1
1.1
Delta cost
Delta benefit


Delta cost-benefit of Penstock for Tavas Yenidere dam
Price
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0.9
1
1.1
1.2
Penstock diameter(m)
Delta cost
Delta benefit

APPENDIX D- NON POWERED DAM SPECIFICATION SHEET

Reservoir	Outflow(m3)	Head(m)	Energy equivalent(KWh/m3	Annual average flow (hm3)	Potential energy production (GWh)	Actual production (GWh)	Capacity factor	Penstock length(m)	Penstock optimised diameter (m)	Turbine type
Yavaslar	1.5	37	0.091	11.84	1.07	0.35	0.326	22.000	0.840	Francis
Orenler	1.75	19.85	0.049	19.16	0.93	0.79	0.845	16.000	1.020	Kaplan
Issikli	20	6.4	0.016	250	3.92	2.27	0.578	3.000	3.000	Kaplan
Tavas Yenidere	2.18	40.62	0.100	15	1.49	1.08	0.722	36.000	1.100	Francis
Topcam	3	54.15	0.133	28	3.72	3.06	0.823	30.300	1.280	Francis
Gokbel	16	37.1	0.091	246.6	22.44	12.50	0.557	45.000	2.750	Francis
Yaylakavak	2.9	68.5	0.168	48.8	8.20	4.99	0.608	27.000	1.210	Francis
Ikizdere	2	95.8	0.235	134.7	31.65	7.34	0.232	39.750	0.900	Francis
Gokpinar	2.77	41.2	0.101	45.22	4.57	2.22	0.486	33.000	0.660	Francis
Akbas	0.75	68.25	0.167	16	2.68	1.50	0.560	45.000	0.680	Francis
Karakasu	1.1	53.2	0.130	30	3.91	2.64	0.675	42.755	0.800	Francis

Reservoir	Capital Cost(Mill $)	O&M/year (Mil $)	Income and Natural Resource tax (Mil $)	LCOE ($/kWh)	Annua Revenue(Mil $)	IRR	NPV	B/C ratio	Feasibility
Yavaslar	0.294	0.925	0.002269	0.1077	0.0315	-4	-0.144	0.789	Not Feasible
Orenler	0.361	0.49625	0.001217	0.072	0.07092	3	0.182	1.176	Feasible
Issikli	0.705	0.16	0.000392	0.05861	0.2043	9	1.09	1.451	Feasible
Tavas Yenidere	0.928	1.0155	0.002491	0.109	0.09711	-4	-0.482	0.776	Not Feasible
Topcam	0.657781	1.35375	0.00332	0.04972	0.27549	17	1.963	1.71	Feasible
Gokbel	1.82068	0.9275	0.002275	0.04329	1.125	30	9.477	1.964	Feasible
Yaylakavak	0.7562	1.7125	0.0042	0.04385	0.44865	28	3.729	1.939	Feasible
Ikizdere	0.871508	2.395	0.005874	0.04079	0.6606	38	5.898	2.085	Feasible
Gokpinar	0.544	1.03	0.002526	0.05252	0.1998	14	1.311	1.619	Feasible
Akbas	0.41	1.70625	0.004185	0.05515	0.135	12	0.811	1.539	Feasible
Karakasu	0.544	1.33	0.003262	0.03926	0.226062	19	1.741	1.744	Feasible

APPENDIX-E RESERVOIR INPUT DATA AND IRRIGATION WATER DEMAND

Catchment	Surface Irrigation Demand (ha)	Ground Water Irrigation Demand (ha)
Kufi	38679.97	11093
Banaz	4421.02	444.2
Buldan	16806	395
Curusku	12253.77	396
Dandalaz	461.474	442.65
Nazill	4449.776	1158.65
Akcay	17866	1990
Cine	26400	994.5
Soke	46834.93	1393.4

Reservoir	SUP	SC (hm3)	TC (hm3)	TOB (hm3)	TI (hm3)	BC	MTF (m3)	TW (m)	PF(%)	GE(%)	HP
Yavaslar	1985	27.38	27.4	0	2.71	1	1.5	1003	90	90	2
Orenler	1998	26.28	26.3	0	4.7	1	1.75	1153.5	90	90	2
Issikli	1980	237.8	238	0	27.3	1	20	815	90	90	2
Tavas Yenidere	1990	61.6	61.6	0	10.08	1	2.18	842	90	90	2
Topcam	1985	97.7	97.7	0	9.8	1	3	61.5	90	90	2
Gokbel	2000	24	24	0	22.8	1	16	68.5	90	90	2
Yaylakavak	1996	31.4	31.4	0	2	1	2.9	91	90	90	2
Ikizdere	2000	195	195	0	6.92	1	2	81	90	90	2
Gokpinar	2000	28	28	0	4.5	1	2.77	295	90	90	2
Akbas	2000	24.5	24.5	0	2.25	1	0.75	860	90	90	2
Karakasu	2000	22.94	22.9	0	3.5	1	1.1	245	90	90	2

Where

SUP –Start Up Year

SC- Storage Capacity

TC- Top of Conservation

TOB-Top of Buffer

TI-Top of Inactive

MTF- Maximum Turbine Flow

TW- Tailwater Elevation

PF-Plant Fcctor

GE- GenerationEfficiency

HP- Hydropower priority

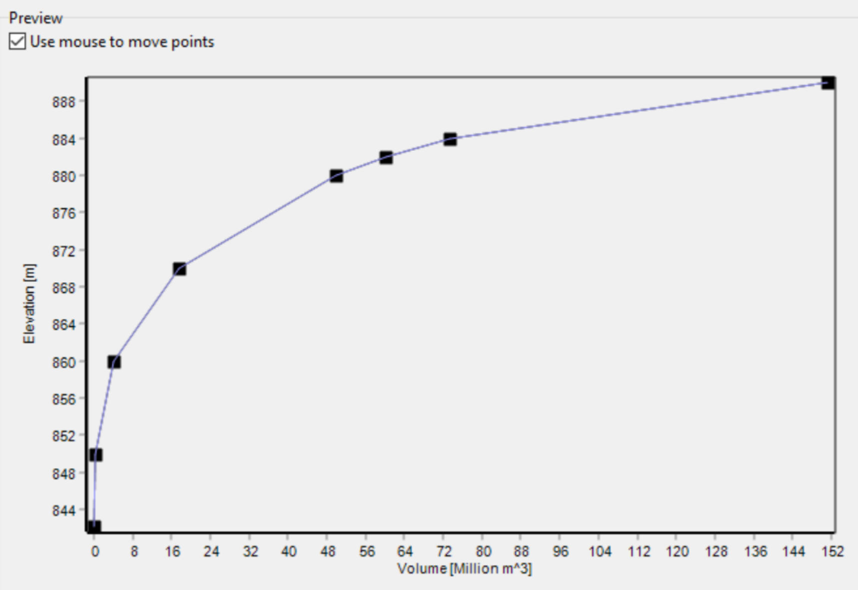
APPENDIX – F SCREEN DUMP OF VOLUME ELEVATION CURVES FOR NPD

Reservoir: Tavas Yenidere

Add | Delete | Export

Volume [Million m^3]	Elevation [m]
0	842.18
0.2275	850
4.1734	860
17.5228	870
49.8116	880
60.056	882
73.44	884
151.22	890

8 points | Delete All

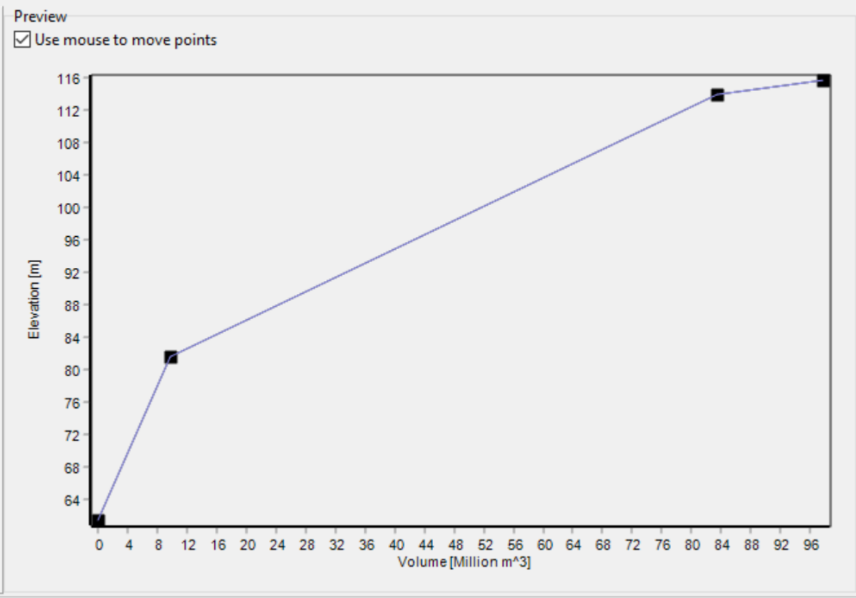


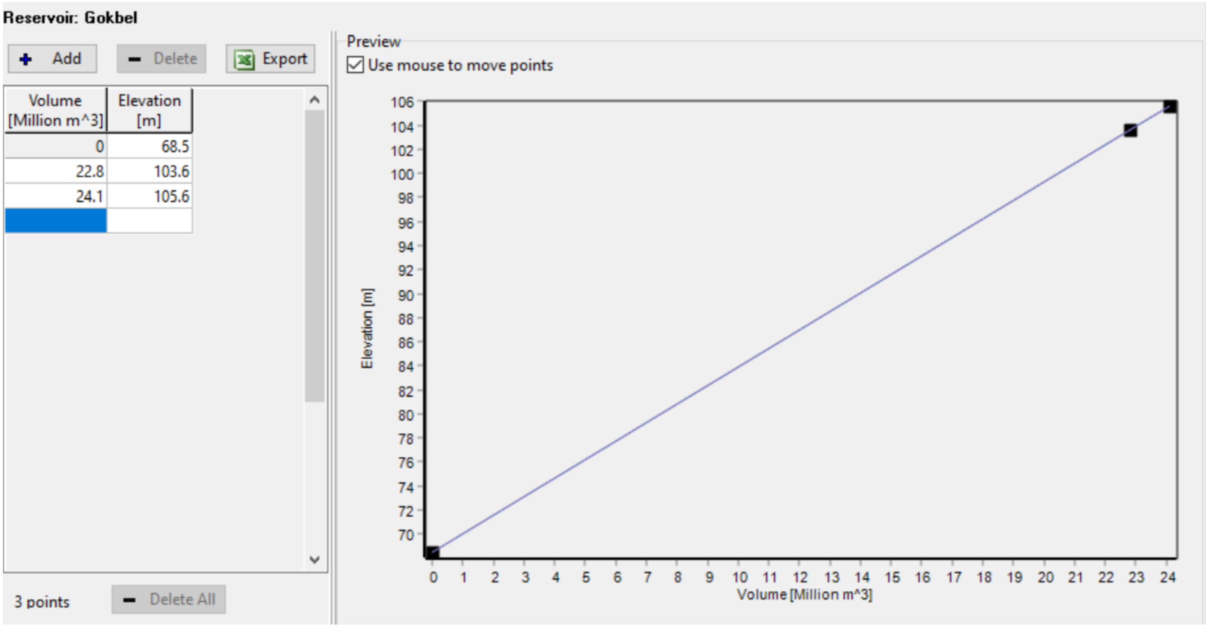
Reservoir: Topcam

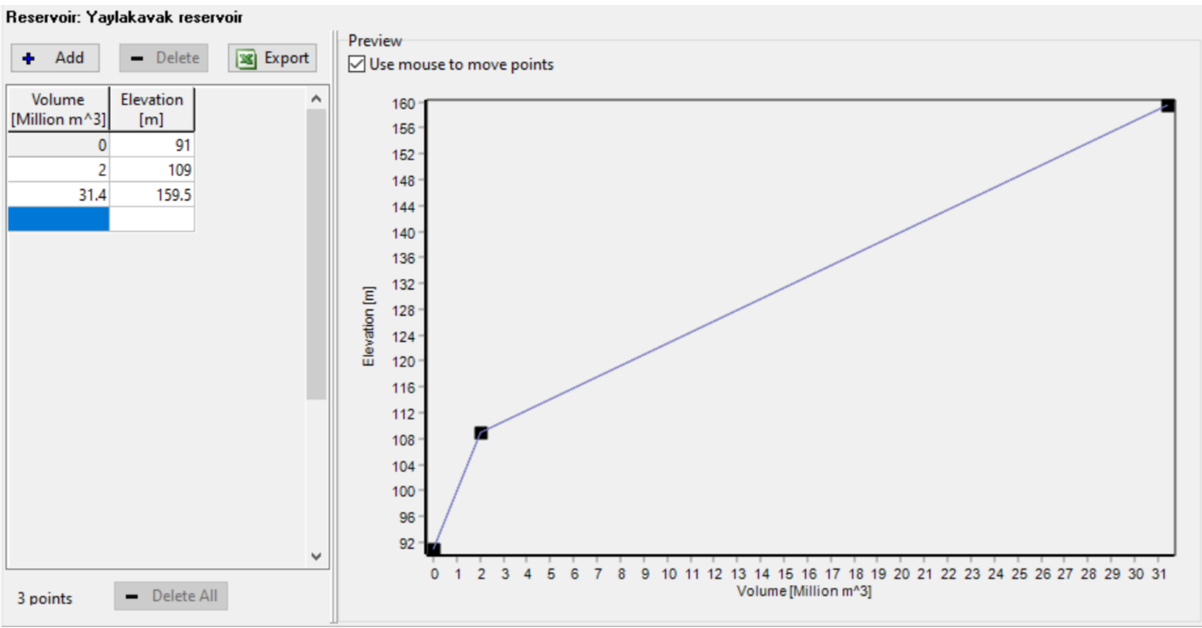
Add | Delete | Export

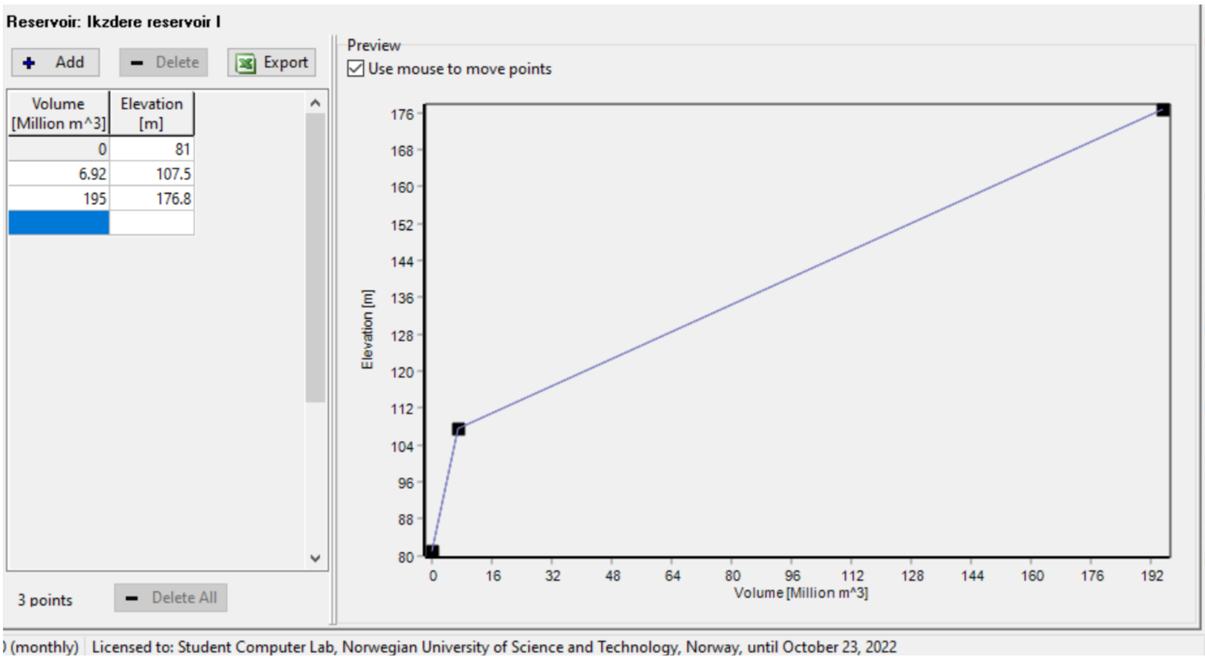
Volume [Million m^3]	Elevation [m]
0	61.5
9.8	81.7
83.5	113.9
97.7	115.65

4 points | Delete All




Reservoir: Gokbel
Add
Delete
Export
Volume [Million m^3]
Elevation [m]
0
68.5
22.8
103.6
24.1
105.6
3 points
Delete All
Preview
Use mouse to move points
Elevation [m]
Volume [Million m^3]


Reservoir: Yaylakavak reservoir
Add
Delete
Export
Volume [Million m^3]
Elevation [m]
0
91
2
109
31.4
159.5
3 points
Delete All
Preview
Use mouse to move points
Elevation [m]
Volume [Million m^3]


Reservoir: Ikzdere reservoir I
Add
Delete
Export
Volume [Million m^3]
Elevation [m]
0
81
6.92
107.5
195
176.8
3 points
Delete All
Preview
Use mouse to move points
Elevation [m]
Volume [Million m^3]
176
168
160
152
144
136
128
120
112
104
96
88
80
0
16
32
48
64
80
96
112
128
144
160
176
192
) (monthly)
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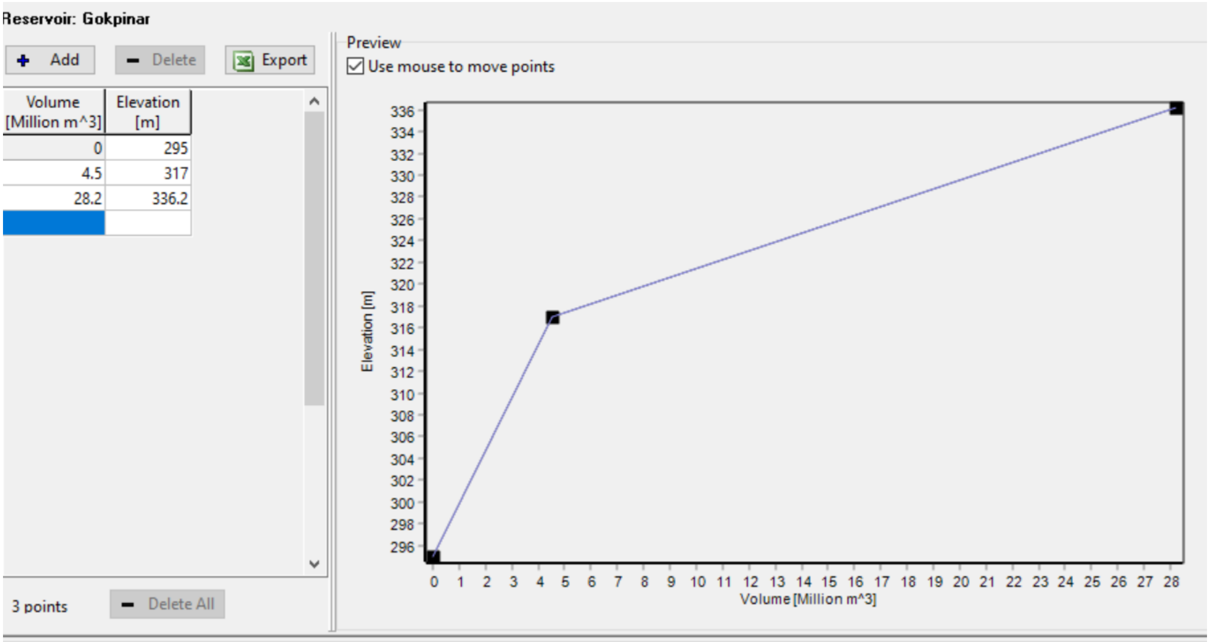
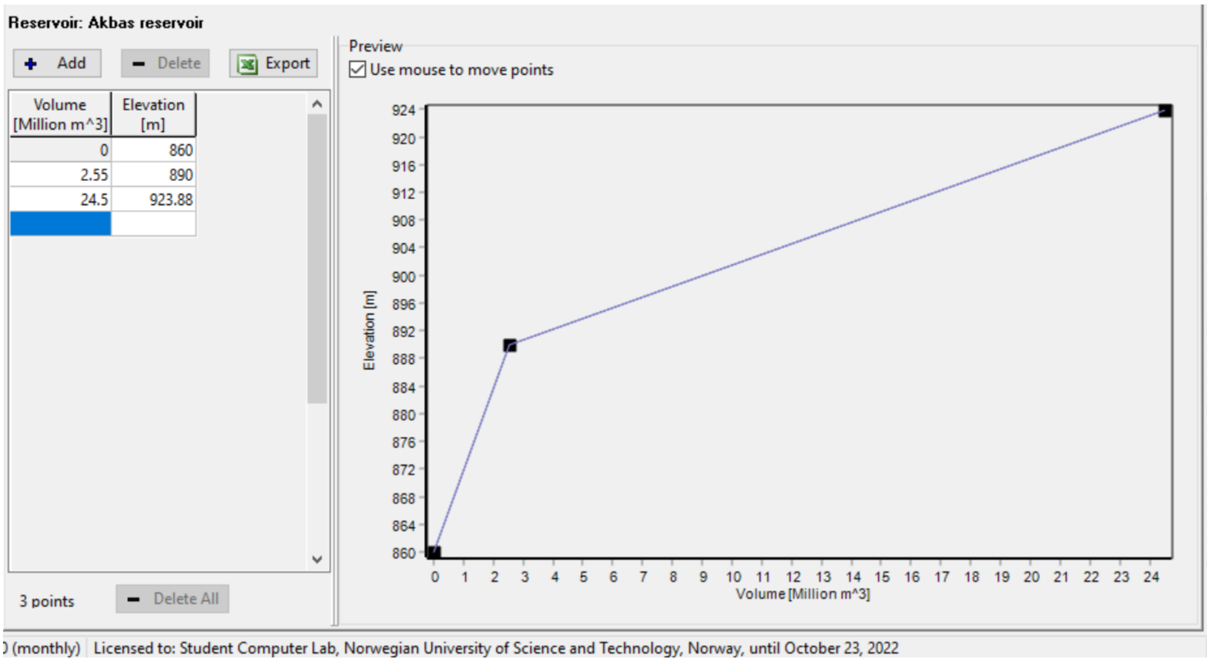
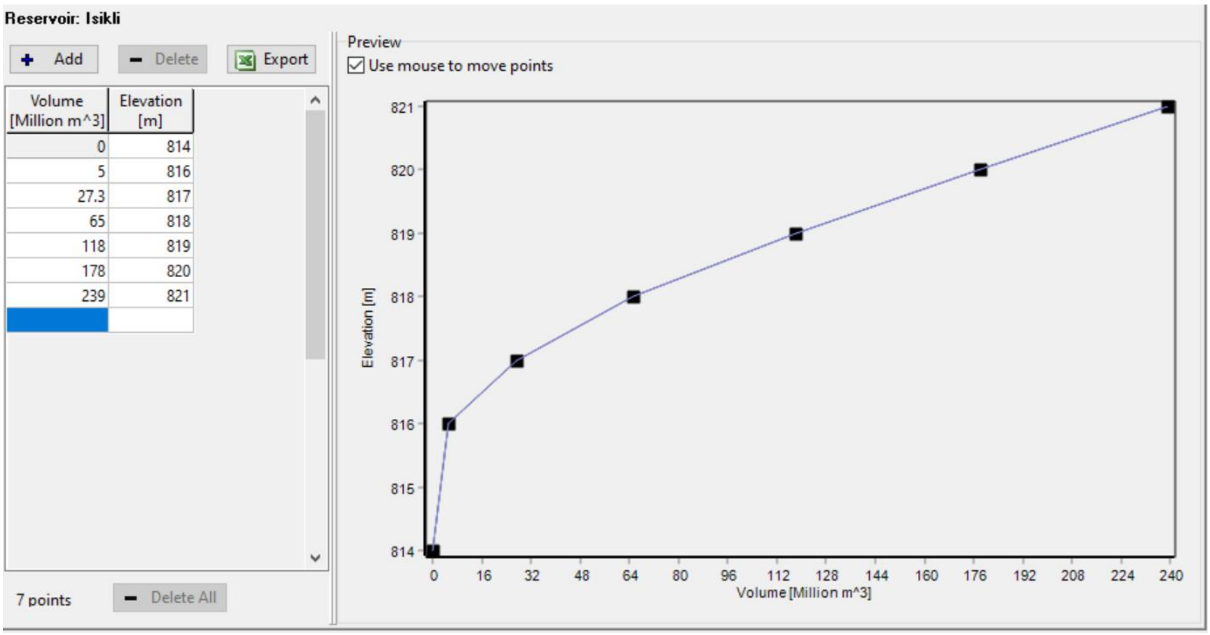
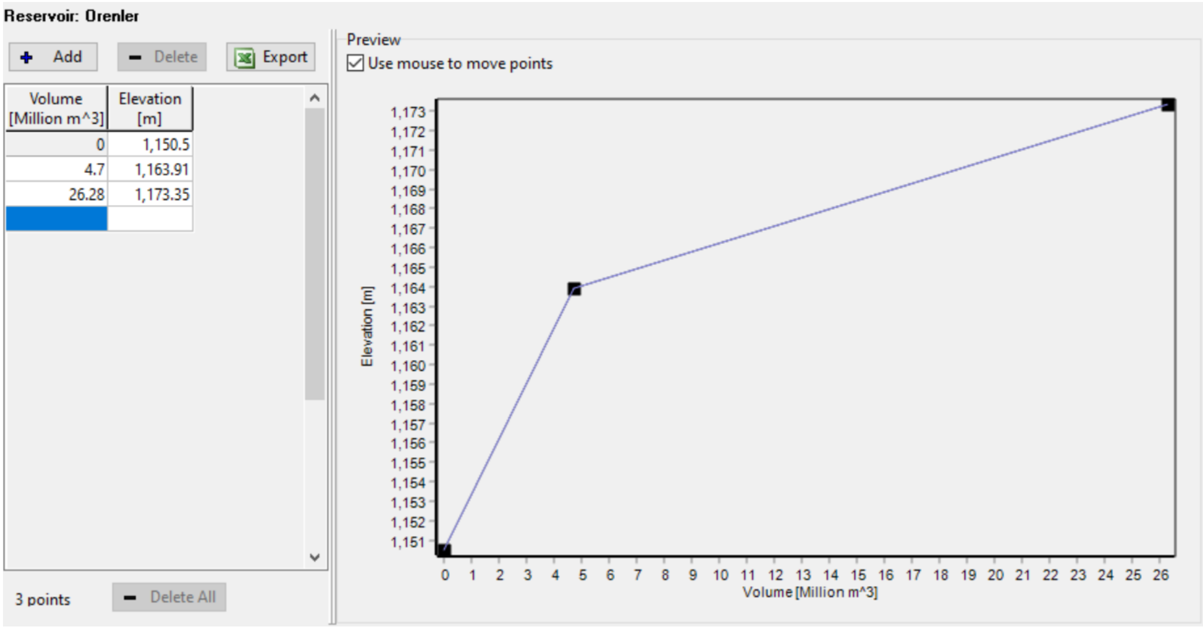
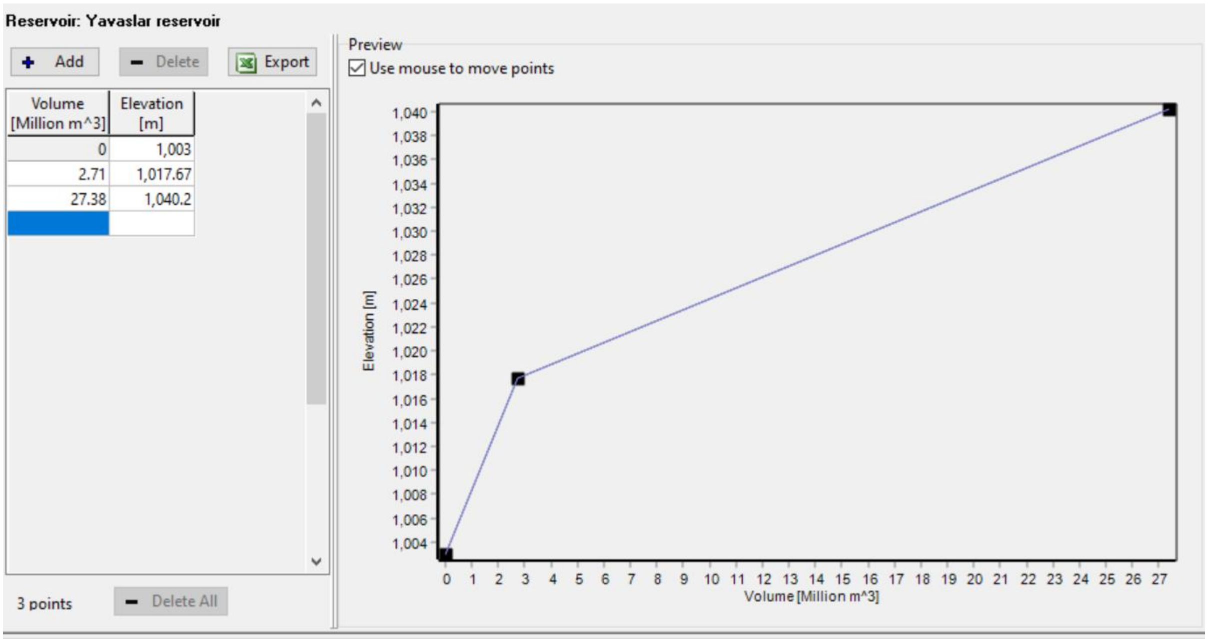

Reservoir: Gokpinar
Add
Delete
Export
Volume [Million m^3]
Elevation [m]
0
295
4.5
317
28.2
336.2
3 points
Delete All
Preview
Use mouse to move points
Elevation [m]
Volume [Million m^3]
336
334
332
330
328
326
324
322
320
318
316
314
312
310
308
306
304
302
300
298
296
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28


Reservoir: Akbas reservoir
Add
Delete
Export
Volume [Million m^3]
Elevation [m]
0 860
2.55 890
24.5 923.88
3 points
Delete All
Preview
Use mouse to move points
Elevation [m]
Volume [Million m^3]
) (monthly)
Licensed to: Student Computer Lab, Norwegian University of Science and Technology, Norway, until October 23, 2022


Reservoir: Isikli
Add
Delete
Export
Volume [Million m^3]
Elevation [m]
0 814
5 816
27.3 817
65 818
118 819
178 820
239 821
7 points
Delete All
Preview
Use mouse to move points
Elevation [m]
Volume [Million m^3]


Reservoir: Orenler
Add
Delete
Export
Volume [Million m^3]
Elevation [m]
0
1,150.5
4.7
1,163.91
26.28
1,173.35
3 points
Delete All
Preview
Use mouse to move points
Elevation [m]
Volume [Million m^3]


Reservoir: Yavaslar reservoir
Add
Delete
Export
Volume [Million m^3]
Elevation [m]
0
1,003
2.71
1,017.67
27.38
1,040.2
3 points
Delete All
Preview
Use mouse to move points
Elevation [m]
Volume [Million m^3]