Abstract

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), close to 90% of the dams in Africa, 75% of the dams in Asia and 60% of the European large dams are presently not used for hydropower production. 'Retrofitting for hydropower production' describes the addition or expansion of an existing dam not used for hydropower with hydroelectric power generation capabilities.

This study intends at demonstrating the hydropower potential of non-powered dams following the current water regulation. In order to quantify the hydropower potential of retrofitting non-powered dams, the study is based on a case study of the Büyük Menderes River basin in Turkey including 6 non-powered dams. The entire basin is simulated period is from 1975 to 2010 using the software WEAP. Parameters are calibrated by using catchments which already have gauging station. Climate data such as relative humidity fed in to WEAP by averaging 17 points which is taken along the whole basin.

An economic analysis of the retrofitting potential is done to compare retrofitting of existing dams, with new hydropower projects and other renewable energy. There are costs which is included in the analysis such as construction cost, operation and maintenance, equipment cost. Levelized cost of electricity is calculated for the retrofitting of all the non-powered dams and compared to other renewable energy sources, whereas the net present values are calculated to measure the economic viability of the retrofitting considering the future electricity rate.

The results show a retrofitting potential of 20 MW for the one non-powered dams in Büyük Menderes. There are 6 NPDs are in the river basin but due to the availability of reliable data the software only simulates one dam, which also economically feasible when it is compared with other renewable energies. Summarized, the case study presents important results that indicate the hydropower potential and demonstrates the economic viability of retrofitting existing non-powered dams.

Preface

This study is submitted in partial fulfillment of the requirements for a Master of Science in Hydropower development at Norwegian university of science and technology. This study has been performed between February 2021 and July 2021. Professor Tor Haakon Bakken has supervised the work.

This study needs field visit to have better understanding of the area but because of COVID – 19 outbreak it makes it difficult to travel. Some lockdowns in between also make the working environment difficult.

First and the most I want to thank God for helping me with everything through the process, and There are many people who have contributed to this work. I want to thank my supervisor Tor Haakon Bakken for his support during the entire semester. For your valuable advice, quick responses and positive feedbacks have been highly appreciated. I also want to thank my mom Sosina and all my friends who have been with me throughout the process by motivating me to reach the final stage.

Trondheim, 15.07.2021

Rediet Tsegaye Hagos

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DC	Deep Conductivity
SWC	Soil Water Capacity
DW	Deep Water Capacity
RRF	Runoff Resistance Factor
Kd	Deep Conductivity
F	Preferred Flow Direction
Ks	Root Zone Conductivity
POWER	
NPDs	Non- power dams

1 Introduction

1.1 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), close to 90% of the dams in Africa, 75% of the dams in Asia and 60% of the European large dams are presently not used for hydropower production. 'Retrofitting for hydropower production' describes the addition or expansion of an existing dam not used for hydropower with hydroelectric power generation capabilities.

Compared to the construction of a new dam, retrofitting could pose a cost-effective way to increase electricity production, which was proven a case study in Spain as part of a master thesis in 2020 (Rydland Fjøsne, 2020). Impacts related to the retrofitting on the environment are basically negligible as the dam has been built and the flow regulation has already been made. The mere addition of turbines and other electromechanical equipment usually requires little additional construction and limited degradation of an already impacted river basin. 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. Based on the study carried out, and former similar studies, the global potential shall be assessed.

1.2 Objectives

The main objectives of this study are the following:

- Identify a region/river basin of demonstrating the retrofitting potential of non-hydro reservoirs.
- Develop/apply a method to calculate the retrofitting potential in a basin with non-hydropower dams/reservoir (in the region/river basin identified under 1)
- Demonstrate the proposed methodology for instance with use of WEAP or any other suitable tool for the purpose.
- 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.

- Assess the assumptions, limitation and uncertainties in the methodology and calculations.

1.3 Structure of the report

This thesis starts with a theory section covering the principles of hydropower used in this study, the concept of retrofitting challenges and technical considerations and practical solutions, and a description of the chosen river basin for the study area. A presentation and explanation of all the materials and methods are included in Method section. The outcomes of the study are presented in the Results section which is followed by a discussion. The Discussion covers the limitations, uncertainties, results. Last section is the conclusion, the references, and the appendices.

2 Theory

This section starts by describing the basic principles of hydropower generation and the concept of retrofitting challenges and technical considerations and practical solutions. The second part is a description of the chosen study area and its characteristics such as background of study area, climate, description of dams and reservoirs. Following to that there is WEAP section describes the WEAP software with its most relevant integrated functions and calculation systems for this study, the last section is about the basis for the economic assessment of retrofitting projects.

2.1 Hydropower

Hydropower is the energy extracted from the natural potential of usable water resources. It is the capture of the energy of moving water for some useful purpose. When the energy of flowing water is used to run turbines, then the electricity generated is called Hydroelectric power. The head causing flow, runs the turbine blades, and thus producing electricity from the generator coupled to the turbine. Principal parameters necessary in making hydro- power studies are water discharge (Q) and hydraulic head (H). since the energy production is dependent on Q and H, there are some conditions that affect the head(H) are head loss such as expansion, contraction, friction loss in waterways and bends. Equation listed below describes the energy production of hydropower.

$$E = P \,.\, t$$

Whereas P = Generated hydropower in watt (W)

$$P = \eta \,.\, g \,.\, H \,.\, Q$$

Whereas $\eta =$ Efficiency factor

ρ = Density of water (kg/m^3)

g = gravitational force (m/s^2)

H = the effective head (m)

Q = water discharge (m^3/s)

2.2 Retrofitting

Retrofitting could propose a cost-effective way to increase electricity production. Retrofitting describes the addition or expansion of an existing dam with hydroelectric power generation capabilities. According to ICOLD less than 20% of world's large dams are used for hydroelectric generation. Compared to the construction of a new dam, and under certain conditions, impacts on the environment are less severe as most substantial impacts have already been caused. The mere addition of turbines and other electromechanical equipment usually requires little additional construction and limited degradation of an already disturbed waterway. Wide public support is thus more likely as well. But in the search for such potentials for additional power generation it always must be asked why these uses have not been obvious before, in particular taken during the construction of the plant.

2.2.1 Challenges and Technical solutions

Retrofitted dams technically are always multipurpose dams and share the same set of challenges. One main challenge can be the priority setting for water allocation, for instance if there is a high energy demand and therefore claims are voiced for higher water releases. In case that previous water release patterns are retained, the main challenge will be the high capital costs of the turbines and the question how to unlock investment sources. Further key issues for retrofitting are the grid integration and the harmonization with a given tariff system.

During operation, a main challenge are the revenues, their allocation and the question who will benefit. Those economic aspects carefully need to be negotiated during the planning process already. A further big challenge during operation is, that there is an economic motivation to reallocate water resources towards the purpose with the highest marginal revenue. For a dam originally managed for agricultural irrigation, e.g., there might be moments where peak demand of electricity will encourage discharge of water although not scheduled for irrigation purposes in that exact moment.

To minimize risks in the context of a retrofitting project the general requirements of transparent and democratic processes need to be respected, involving all relevant public and private stakeholders. The diverse demands of various sectors at the water resources thoroughly have to be analyzed and incorporated into the consideration and weighting process. Sound economic concepts need to be developed beforehand, including cost-benefit-analysis to allocate investment costs and returns, gains from power purchase, infrastructure maintenance costs etc. Responsibilities, accountability and the distribution of gains and duties must be determined in detailed and binding contractual agreements.

2.2.2 Practical considerations

Even if retrofitting is done on existing dams but there are some practical considerations, we should take to assure the safety of dam and environment.

A thorough review of potential impacts of retrofitted hydropower was conducted. The basic areas of consideration include: The actual use of land and the impact of construction processes, The impacts of river diversion, both temporary and permanent on the downstream channel characteristics , Type of power that will be generated and hence the type of releases that are required, The impact on aquatic fauna and flora, Increased noise levels occurring during the construction and operational phases, Visual impacts of the final product after construction, The impact on residents in the area by altering the flow of water they receive, destroying land that they deem culturally significant, or altering the natural habitat in a way that they find unacceptable. Most of the environmental impacts are less in retrofitting than new hydropower project if diversion of flow or construction of tunnel or pipes are done to improve the head but sometimes the impact can be negligible if no changes have made to improve hydropower generation.

2.3 Description of the case of the study of Büyük Menderes basin

2.3.1 Geography and history

The Büyük Menderes River is located in South-Western part of Turkey, in Western Anatolia. The basin covers ten cities and 185 municipalities. The basin covers catchment area of 24,873 km^2 with total inhabitant of 2.5 million peoples. The Büyük Menderes River is the main river in the basin, with a length of 584 km, drains an area of about 24,873 km^2, parts of 5 provinces, namely Aydin, Mugla, Denizli, Usak and Afyon, which corresponds 3.2 % of Turkey. It raises near Dinar County of Afyon province and discharges into Agean Sea within the boundaries of Aydin province. Its major tributaries are Kufi, Banaz, Dokuzsele, Curuksu, Dandalaz, Akcay and Cine streams. Major cities in the basin are Usak, Denizli, Saraykoy, Nazilli, Aydin and Soke.

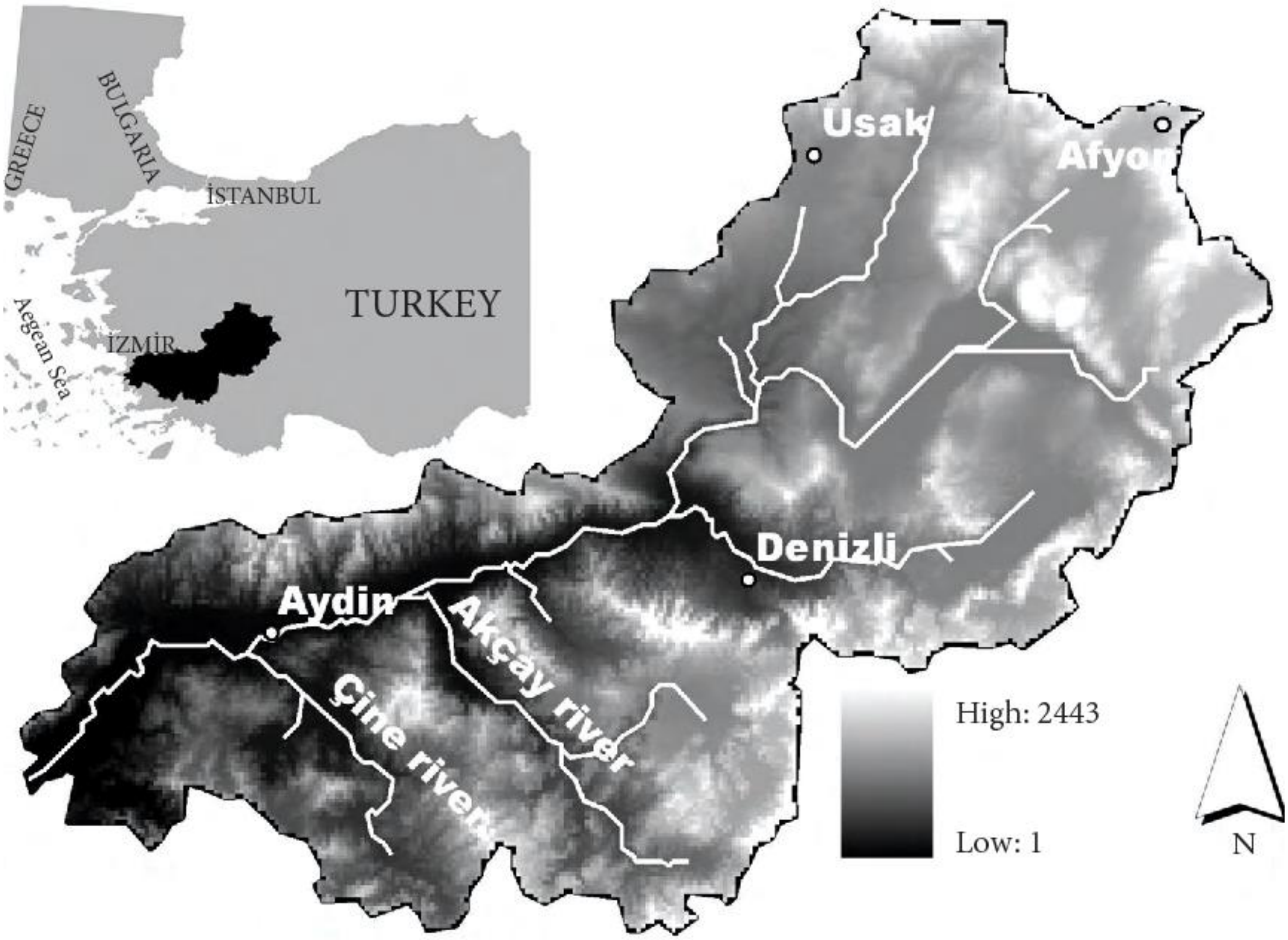

Figure 1:Buyuk Menderes river basin

2.3.2 Dams and reservoirs

There are 10 official dams in the Büyük Menderes River basin. the total reservoir capacity of the dams in the basins is 2232.05 MCM. from 10 dams four of them are hydropower dams with total hydropower capacity for hydropower dams is 187.2 MW and the rest six dams are irrigation, industrial and flood control dams. The reservoir capacity of six non-hydropower dams in the basins is 642.2MCM and the total reservoir capacity of the dams in the basins is 2232.05 MCM.

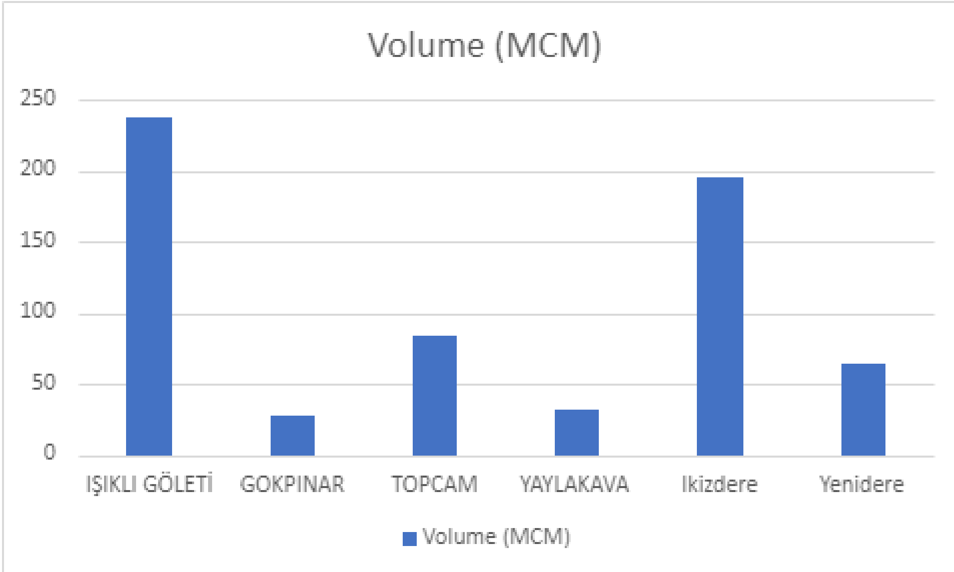

Figure 2:Reservoir Capacity

2.4 WEAP

WEAP (Water Evaluation and Planning system) is a Windows-based decision support system for integrated water resources management and policy analysis. WEAP is a model-building tool, used to create simulations of water demand, supply, runoff, evapotranspiration, infiltration, crop irrigation requirements, instream flow requirements, ecosystem services, groundwater and surface storage, reservoir operations, and pollution generation, treatment, discharge, and instream water quality, all under scenarios of varying policy, hydrology, climate, land use, technology, and socio-economic factors. WEAP can dynamically link to the USGS MODFLOW groundwater flow model and the US EPA QUAL2K surface water quality model.

WEAP was created in 1988 and continues to be developed and supported by the U.S. Center of the Stockholm Environment Institute, a non-profit research institute based at Tufts University in Somerville, Massachusetts. It is widely used for climate change adaptation studies and has been applied by researchers and planners in hundreds of organizations worldwide.

2.4.1 Water Balance

There are five methods in WEAP to simulate catchment processes such as evapotranspiration, runoff, infiltration, and irrigation demands. These methods include.

- Rainfall Runoff
- Irrigation Demands Only versions of the Simplified Coefficient Approach

- Soil Moisture Method
- MABIA Method
- Plant Growth Method or PGM.

Rainfall Runoff Method (Soil Moisture Method)

In this specific study the rainfall runoff method (soil moisture method) is selected. The Soil Moisture method is more complex, representing the catchment with two soil layers, as well as the potential for snow accumulation. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow, and changes in soil moisture. This method allows for the characterization of land use and/or soil type impacts to these processes. Baseflow routing to the river and soil moisture changes are simulated in the lower soil layer. Correspondingly, the Soil Moisture Method requires more extensive soil and climate parameterization to simulate these processes.

Note that the deeper percolation within the catchment can also be transmitted directly to a groundwater node by creating a Runoff/Infiltration Link from the catchment to the groundwater node. The method essentially becomes a 1-layer soil moisture scheme if this is link is made.

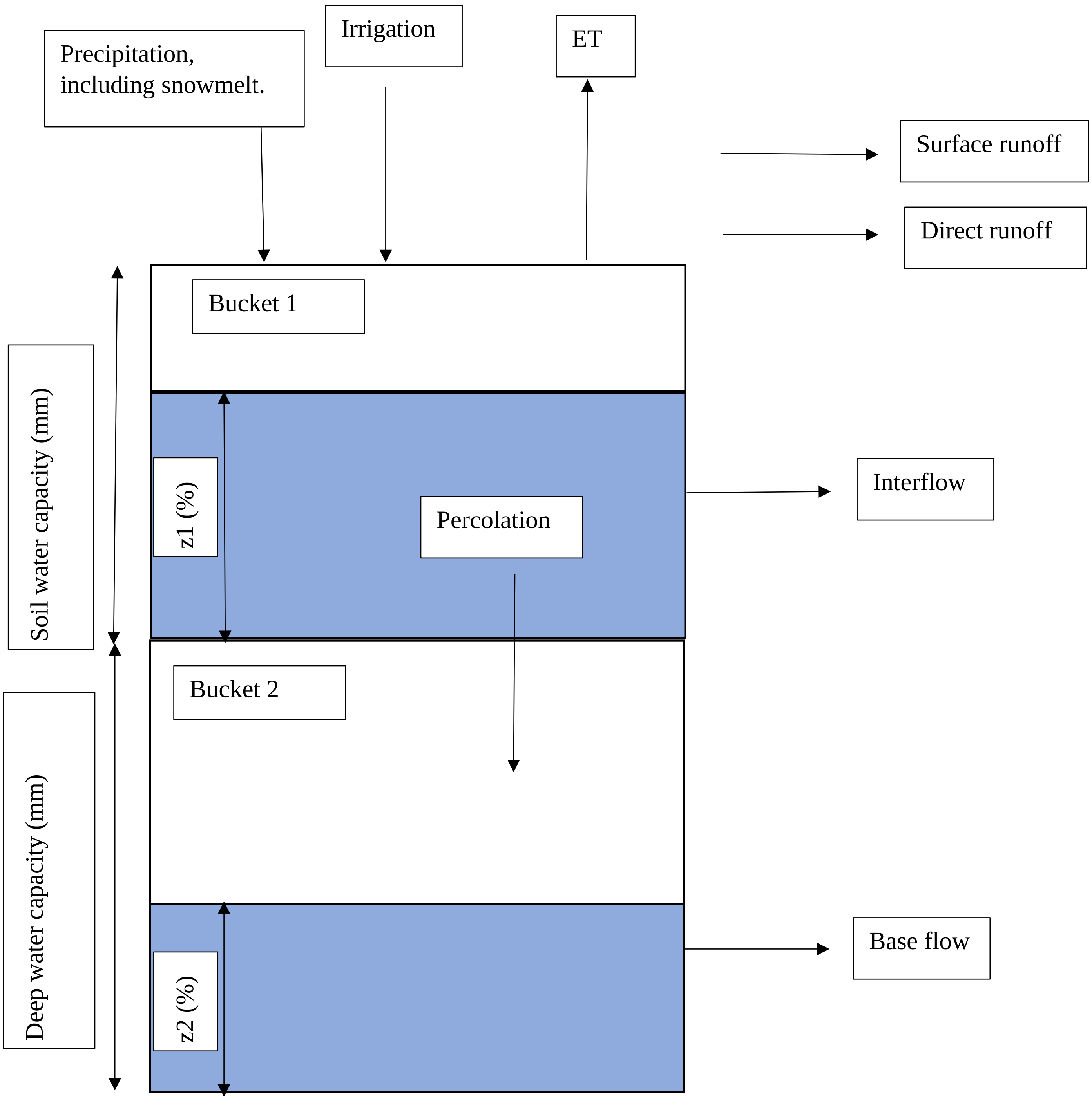

Figure 3: different parameters in soil moisture

Deep Water Capacity is Effective water holding capacity of lower, deep soil layer (bottom "bucket"), represented in mm. This is given as a single value for the catchment and does not vary by land class type. This is ignored if the demand site has a return flow link to a groundwater node.

Initial Z1 is Initial value of Z1 at the beginning of a simulation. Z1 is the relative storage given as a percentage of the total effective storage of the root zone water capacity.

Initial Z2 is Initial value of Z2 at the beginning of a simulation. Z2 is the relative storage given as a percentage of the total effective storage of the lower soil bucket (deep water capacity). This parameter is ignored if the demand site has a runoff/infiltration link to a groundwater node. This rate cannot vary among the land class types.

Beside these variables mentioned above there are parameters such as crop coefficient (Kc), Deep conductivity (Kd), Runoff resistance factor (RRF), Root Zone conductivity (Ks) and preferred flow direction (F).

2.4.2 Catchments and Reservoirs

WEAP classify areas into big catchments and sub catchments and automatically delineate and gives information about the data like precipitation, temperature, and wind. WEAP have also a function to categorize the catchments based on the land cover and elevation bands.

Reservoir storage is divided into four zones, or pools. These include, from top to bottom, the flood-control zone, conservation zone, buffer zone and inactive zone. The conservation and buffer pools, together, constitute the reservoir's active storage. WEAP will ensure that the flood control zone is always kept vacant.

WEAP allows the reservoir to freely release water from the conservation pool to fully meet withdrawal and other downstream requirements, and demand for energy from hydropower. Once the storage level drops into the buffer pool, the release will be restricted according to the buffer coefficient, to conserve the reservoir's dwindling supplies. Water in the inactive pool is not available for allocation, although under extreme conditions evaporation may draw the reservoir into the inactive pool.

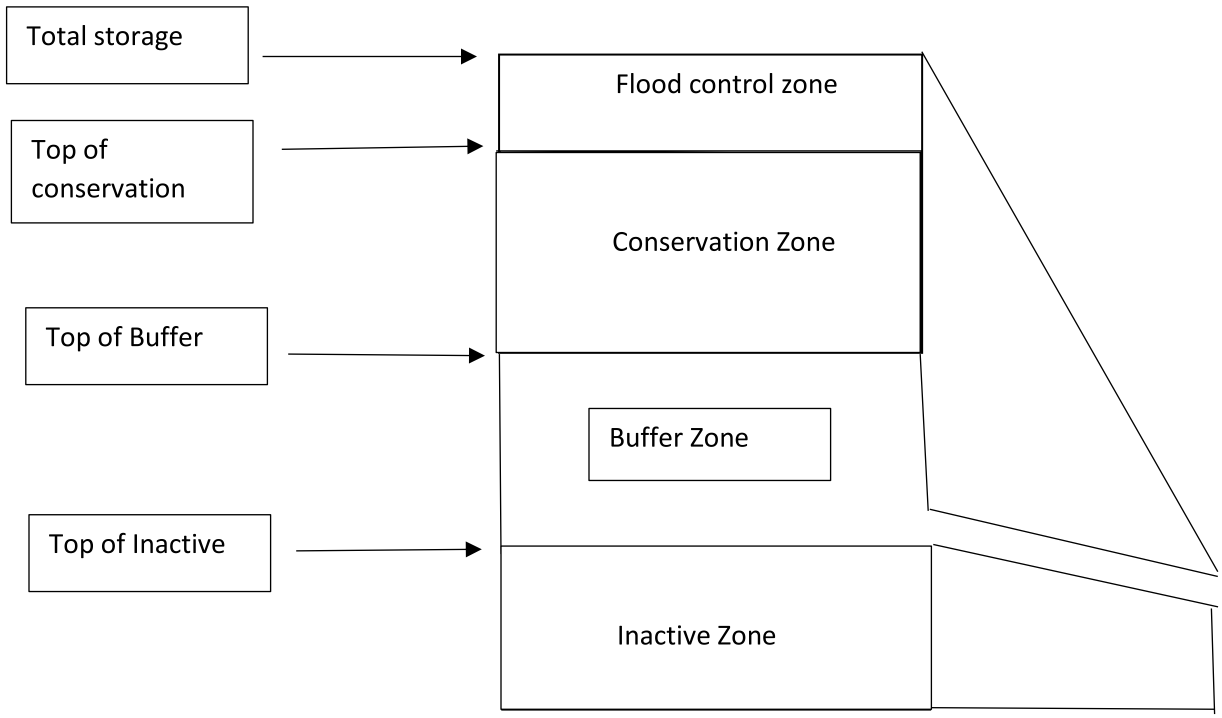

Figure 4:Reservoir zone definition in WEAP.

2.4.3 Hydropower generation

To accommodate situations in which you want to prioritize reservoir releases to generate hydropower, there are two methods for specifying hydropower energy demands in WEAP: as individual energy demands for each reservoir, or as an aggregate energy demand at the system level. You can choose either method, or even use both at the same time, even setting different priorities for the system demand and the individual demands.

Hydropower generation is computed from the flow passing through the turbine, based on the reservoir release or run-of-river streamflow, and constrained by the turbine's maximum flow capacity. Note that the amount of water that flows through the turbine is calculated differently for local reservoirs, river reservoirs and run-of-river hydropower. For river reservoirs, all water released downstream is sent through the turbines, but water pumped from the reservoir to satisfy direct reservoir withdrawals is not sent through the turbines.

2.5 Economic analysis

2.5.1 Cost of retrofitting and hydropower revenue

Retrofitting hydropower is the most cost-effective way of generating electricity compared to the construction of a new dam, and under the following conditions, retrofitting could pose a cost-effective way to increase electricity production. The mere addition of turbines and other electromechanical equipment usually requires little additional construction and limited degradation of an already disturbed waterway. Impacts on the environment are less severe as most substantial impacts have already been caused Wide public support is thus more likely as well.

2.5.2 NPV and LCOE

The net present value is an indicator used in economic analysis. It gives an idea of how much 'actual' money will return to the investors, especially in the case of long-term project for which the inflation has huge impact on the value of the money. This indicator calculates indeed the cumulative cash flow corrected by the inflation rate, giving hence the actual value of the benefits according to the economic situation. This value is calculated as following.

$$NPV = \sum_{k=0}^{n} cost - revenue/(1 + r)$$

Whereas *r* is the discounting rate

k is the year number.

n is the total number of years accounted for in the lifetime.

For the project to be economically feasible the value of NPV must be greater than 0 or positive value. For different projects, the one with highest NPV values is the preferred one.

The levelized cost of energy represent the price at which the producers should sell their electricity so that it covers all the costs generated by the building and the operating of the system over its lifetime. Knowing this value is very relevant. If the future price of energy can be predicted, the investors will indeed immediately be known whether their projects are profitable or not. In this case, the lower the levelized costs of energy, the better the project.

$$LCOE = \frac{\sum_{K=0}^{n} costk/(1+i)^k)}{\sum_{k=0}^{n} Ek/(1+i)^{k}}$$

Whereas LCOE is the levelized costs of energy

k is the k-th year.

n is the expected lifetime of the project.

Costs k are the costs generated over the k-th year.

Ek is the energy produced during the k-th year.

i is the discount rate.

3 Materials and methods

This section mainly describes in detail how the study is performed such as methodologies used, reason for choice of this specific basin as case of study, main key assumptions taken, tools that are used for the study area and explains the different types of scenarios in the study area.

3.1 Method for estimation of retrofitting potential

3.1.1 Main assumptions

The potential of retrofitting in this specific study is restricted to the potential that can be generated with a minimum of negative impacts on the existing water uses and the environment. This indicates that there are some assumptions to consider, such as the water used for hydropower generation cannot reduce the consistency of water supply for the existing water uses and avoiding any kind of construction of tunnels and pipelines in order to avoid the disturbance of the environment. to assess the potential of the study area with respect to the main assumptions, it is considered essential to perform a simulation of the water balance of an entire river basin on the specific study area. The simulation helps to analyzing and evaluation of different scenarios such as identifying different capacities of turbines to estimate ideal potential over realistic potential, application of different turbine capacities and alterations on the water demands, However the scenarios with altered water demands are used to investigate the possible effects that such amendments may have on the potential of retrofitting.

3.1.2 Choice of case study

The choice of River basin for use in the case study is based on the reservoir capacity of the dams in the basin and the availability of water in the basin also the main reason for selecting the basin in order to generate power without affecting the existing water supply uses. In Tukey there are 286 NPDs listed in the ICOLD World Register of Dams (ICOLD, 2019). Among this NPDs 6 are located in the Büyük Menderes basin. These 286 NPDs dams which is located in turkey are ranked based on the capacity of reservoir and the study area is selected based on the first high-capacity reservoir dam. The first ranked dam based on capacity named Isikli Göleti and have a reservoir capacity of 237.8MCM, the purpose of dam is for irrigation. There are totally 10 dams located in Büyük Menderes River basin, out of 10 dams 4 of them are existing powered dams and the rest of 6 are NPDs.

3.1.3 Tools

In this study software WEAP (Water Evaluation and Planning system) is found suitable for this study because, it provides a program for the modelling of basins including reservoirs and hydropower generating units and, it has different methods for the implementation of water withdrawals and irrigation water are integrated in the software or made possible to enter the data manually. In addition, it can create different scenarios and link it with the data, gives the result how it works in different condition by changing the parameters. ArcMap 10.3 is used for delineation of catchments in order to illustrate figure on the study area description and also to show the points that are taken for relative humidity.

The datasets used in these studies are:

- ❖ A Study on Importance and Role of Irrigation and Hydropower Plant Operation in Integrated River Basin Management (Cengiz Koç,2016)
- ❖ The Natural Conditions of the Işıklı Lake Watershed and its Reflection on Land Use (Dr. Muhammet BAHADIR)
- ❖ the prediction of worldwide energy resources (POWER)
- ❖ GRDC portal data

3.2 WEAP setup

The hydrological years in the model setup are defined from January to December. The start year is 1975. The simulation period is chosen to start from January 1975. The climate data from Princeton which is found from WEAP for specific study area ends in 2010 so this year is marks as the end of simulation period.

3.2.1 Climate data

Data for relative humidity is gathered from the prediction of worldwide energy resources (POWER) tool. These data are monthly average from the period of 1981-2019 with spatial resolution of 10 minutes. To represent the whole basin, 17 random points inside the basin averaged and used for the whole basin. The random 17 points are presented below in figure 5 and the averaged value of wind speed and relative humidity are presented in table 1.

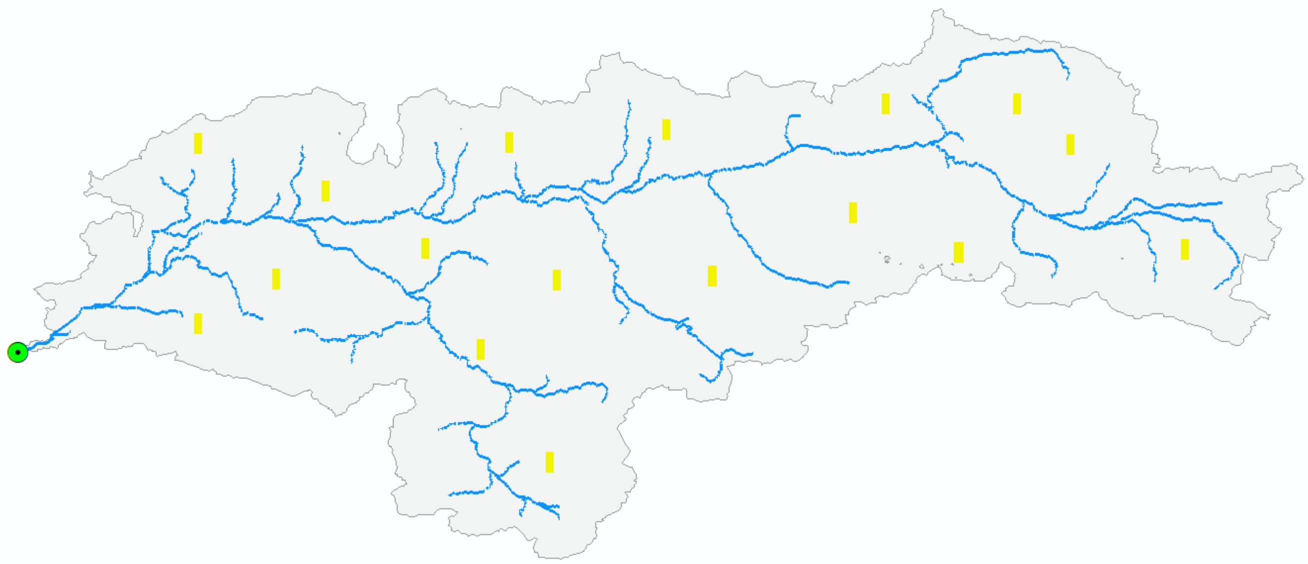

Figure 5: Placement of 17 points of Relative Humidity from POWER data.

Table 1: Averaged value of Relative Humidity.

Month	Relative Humidity (%)
January	80.88
February	77.85
March	72.68
April	67.15
May	60.08
June	47.91
July	37.96
August	36.99
September	41.88
October	54.48
November	68.50
December	79.85

For climate data such as precipitation, temperature, and wind WEAP is used. WEAP by itself have the command called catchment delineation mode to store these climate data in the system. For this specific study resolution of 3 second used. The Princeton data that is available in WEAP system is from 1948 to 2010.

3.2.2 Catchments and reservoirs in current state

The WEAP function for automatic catchment delineation is used to create the framework of the Büyük Menderes basin and its sub catchments. The basin is first divided into five sub catchments named Sub catchment one, two, three, four and five, starting at the most downstream part. For each of the 10 of the dams that are in the river basin, a sub catchment is generated from the point where the water course from each dam meets the main river in the Büyük Menderes basin. All the main rivers in the basin are created by the automatic catchment delineation mode and named after the dam in the catchment. Therefore, including the main big catchment menders, five sub catchments, six catchments based on NPDs and 4 catchments based on rest of dams which is used for hydropower and one sub catchment created around stream flow gauge located to compare the observed and simulated flow, totally there are 17 catchments in Büyük Menderes River basin. there are an overview of how the model is set up is presented in Figure 6

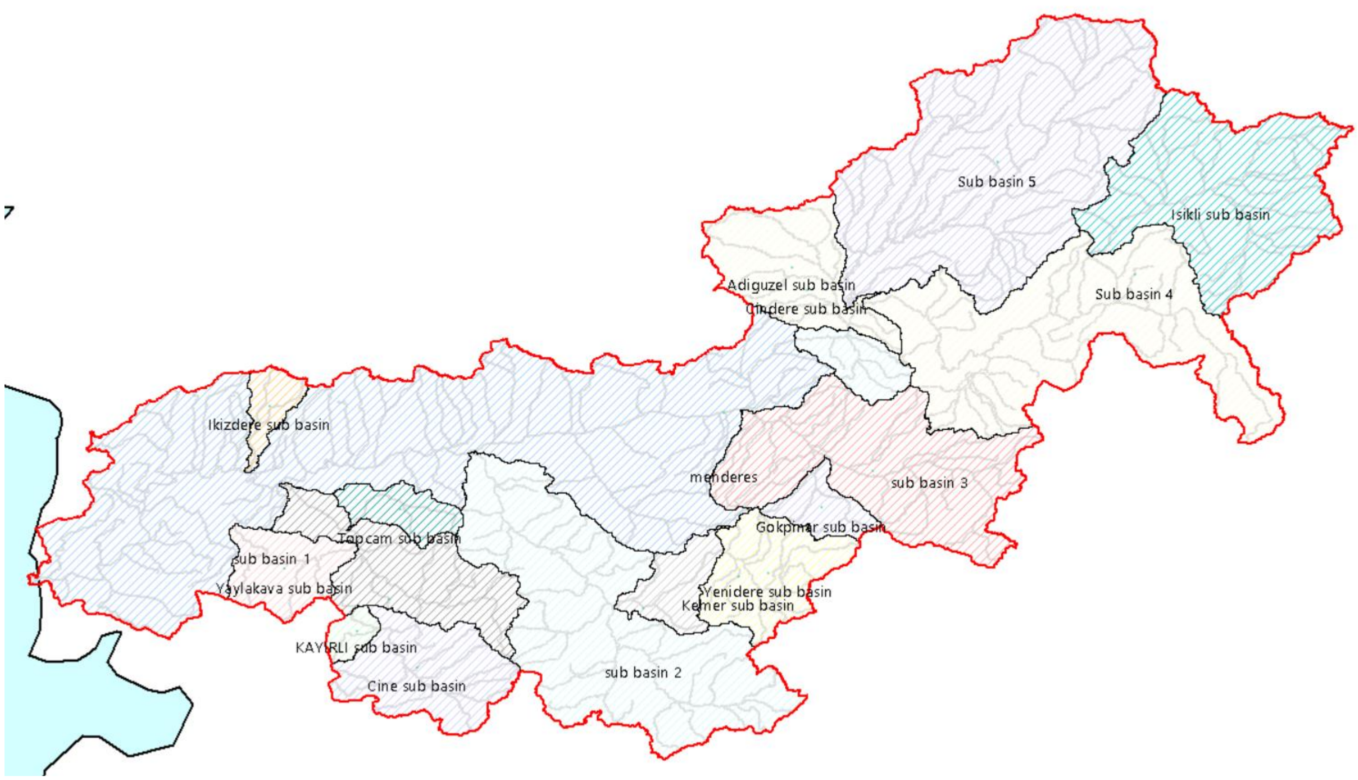

Figure 6:Catchments from WEAP.

3.2.3 Water demands

Data from scientific paper in a Study on Importance and Role of Irrigation and Hydropower Plant Operation in Integrated River Basin Management are used to estimate the water withdrawals from the catchments for the main purpose of domestic use and irrigation. The dataset consists of Net irrigation area (ha), Actual irrigated area (ha), Water use per unit area (m^3 /ha), Crop net irrigation water requirement (m^3/ ha), Irrigation rate (%), Irrigation efficiency (%), Total water used (m^3 /year). The location of demands is determined based on the irrigation schemes which is listed in scientific paper. Each of water withdrawal for irrigation and domestic uses are added as "Demand Sites" in WEAP with a connected "Transmission Link" and "Return Flow". The transmission links identify the placement of the extractions, and the return flows identify the amount and location of the returning unconsumed withdrawals. The withdrawal points are shown on WEAP in figure

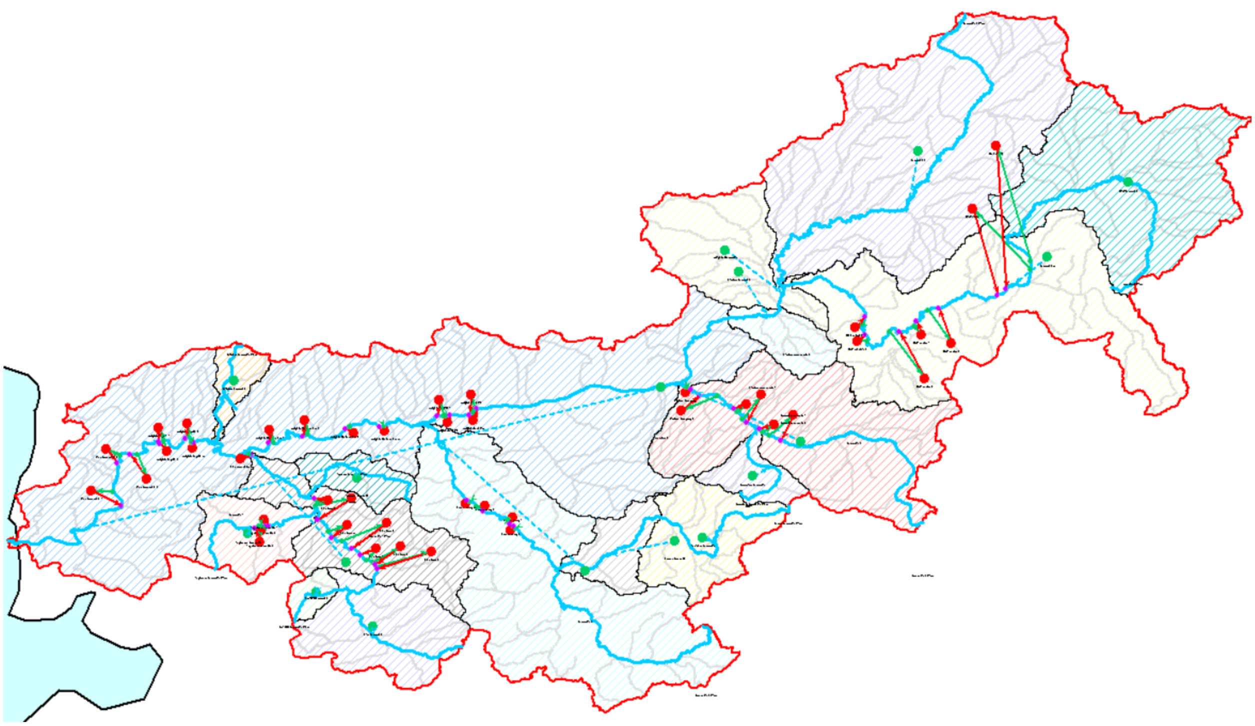

Figure 7: Location of water withdrawal point WEAP.

3.2.4 Calibration

There is only two-gauge station which is found along all study area. Those two sub catchments with gauging station are selected as calibration catchments. The main aim of the calibration is minimizing the difference between observed and simulated streamflow. From the catchments in the basin there are only two sub catchments which have a gauge station along the river basin. These two sub catchments named Menderes River and KAYIRLI sub basin River, and the gauging station names are Sokele and Kayrli, respectively.

Relative humidity data extracted from prediction of worldwide energy resources (POWER) tool, 17 points taken along the basin then from 17 points average value is calculated and used as input in WEAP.

Gauging station data are extracted from GRDC portal data, there are only two gauges present in Büyük Menderes River basin and the gauging station data are not much when it compared with the simulated data available in WEAP and there is error in the observation data in one gauge its high flow when it is compared to the precipitation in the time and in other gauge less flow registered. For the Kayrli catchment, a recorded extreme discharge value of 11.5 m3/s for the year 1981 which is too high when it compared with the simulated one. For the Menderes extremely small value on the year 1978.

The parameters chosen for calibration are:

- ❖ Soil Water Capacity (SWC)
- ❖ Deep Water Capacity (DW)
- ❖ Runoff Resistance Factor (RRF)
- ❖ Deep Conductivity (Kd)
- ❖ Initial Z1
- ❖ Initial Z2
- ❖ Preferred Flow Direction (F)
- ❖ Root Zone Conductivity (Ks)

Based on the parameters which is listed above calibration will be done by adjusting each of the parameters.

Table 2:Calibrated parameter values.

Parameters	Values
SW	1000
DW	1000
RRF	2
F	0.15
Kd	20
Ks	20

3.2.5 Model evaluation criteria

There are different ways to evaluate the goodness of fit of a calibration of water balance such as the percent bias (PBIAS), Nash-Sutcliffe efficiency criteria and Low flow index, but from the methods listed above the common method used to evaluate goodness of fit is the percent bias (PBIAS). The PBIAS Useful to assess the long-term bias in water balance, it represents the deviation of the simulated flow values from the observed flow values in percentage, and is calculated using the following equation:

$$PBIAS = \frac{\sum_{i=1}^{n}(Qiobs - Qi\ sim)}{\sum_{i=1}^{n}(Qi\ obs)}$$

Whereas Qi, obs is observed flow in (m3/s)

Qi, sim is simulated flow in (m3/s)

3.2.6 Scenario definition

There are three scenarios which is defined in this specific study.

- Scenario 1 is when the potential of all the water released from the dams.
- Scenario 2 is when the potential of the water flowing through turbines designed according to historical discharge observations.
- Scenario 3 is when the potential of the water flowing through the turbines from Scenario 2, with water demands reduced by 10, 20, 30, 40, and 50% For all the scenarios,

The assumptions that are listed above is for NPDs and existed hydropower dams which is in the WEAP model.

the following assumptions apply to all the NPDs and the currently powered dams implemented in the model. The hydraulic head is calculated based on the given tailwater elevations and reservoir elevations for each timestep.

Based on three different scenarios we analyze and see how much hydropower we can generate when the water balance is changed.

3.3 Economic analysis

In the economic analysis the following elements are included for the cost estimation.

- Civil work cost
- Water way
- Powerhouse
- Mechanical and electrical equipment
- Transportation and power during construction
- Transmission lines
- Unforeseen cost
- Administration and planning cost
- Financing cost
- Tax and subsides.

In this case only the following costs are calculated

- Mechanical and electrical equipment
- Operation and maintenance
- Control system

Table 3:Levelized cost of energy (LCEO).

Technology	LCEO(USD/Kwh)2010	LCEO(USD/Kwh)2020
Bio energy	0.076	0.076
Geothermal	0.049	0.071
Hydropower	0.38	0.044
Solar Pv	0.381	0.057
Offshore wind	0.162	0.084

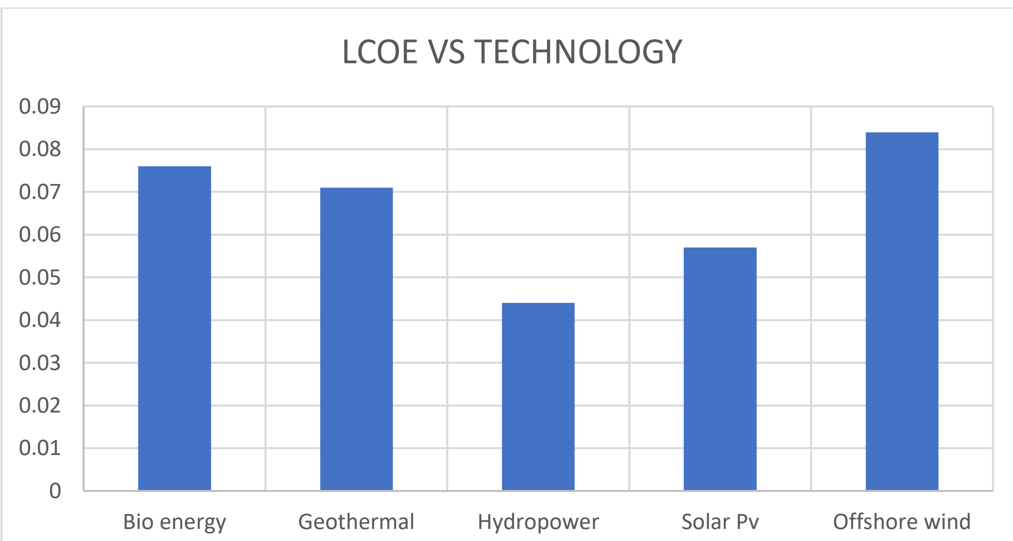

Figure 8:Comparision of Costs with other Renewable Energy.

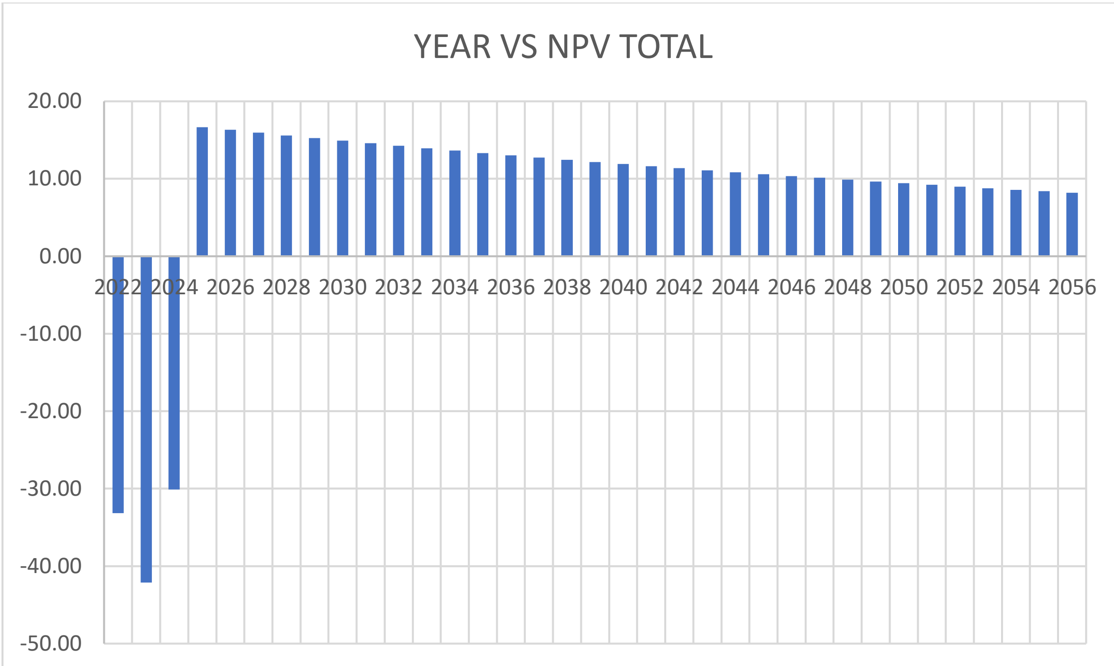

Figure 9:NPV Total.

4 Results

4.1 Model calibration and evaluation

The final calibration catchment of Menderes catchment. Calibrated parameter results are shown below on the Figure 10.

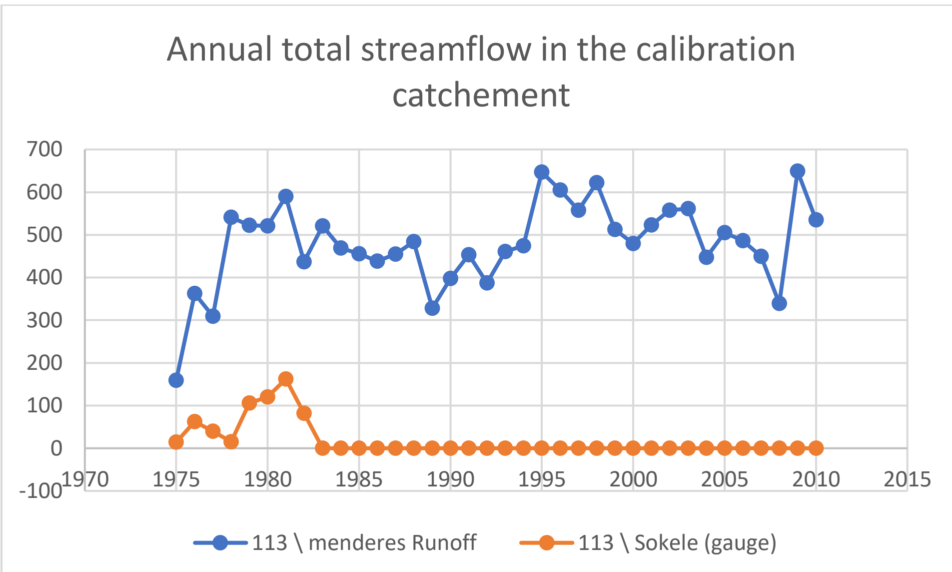

Figure 10:Calibration of Menderes catchment.

The final calibration catchment of KAYIRLI sub basin River. . Calibrated parameter results are shown below on the Figure 11.

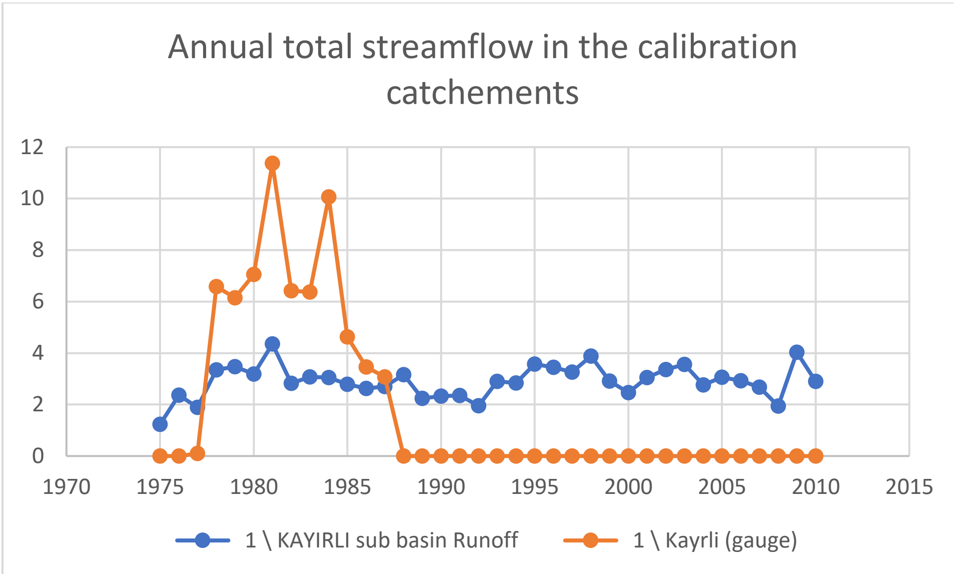

Figure 11:Calibration Result of KAYIRLI sub catchment.

5 Discussion

5.1 Limitations and uncertainties

5.1.1 Input data

There are a lot of limitations and uncertainties in this study in different aspects such as the reliability of existing data. Since the study is about retrofitting it is crucial to visit the study area to have better understanding of withdrawal of water, demand sites, water consumption but Due to corona makes it impossible for field visit and because of that a lot of initial data are taken from the previous studies, it was difficult to get the data which is needed for the project including most of the papers related to the study areas are written in Turkish language and was bit hard to translate and get the original information.

There are 17 catchments in the whole river basin but there is only two gauging station is found even these two gauging stations have year limited data with a lot of missing data that makes the study very difficult to calibrate with good value of PBIAS. Because of this limitation of important data, the software is limited to simulate the power production of all of NPDs which is located In the river basin. WEAP only able to calculate the hydropower generation of on NPDs which have high reservoir capacity in the river basin.

5.1.2 Method

5.2 Results of case study

The calibration of the software is not like expected because of the lack of more gauging station and even the gauging stations which are found have a lot of missing data. In result of this the PBIAS is very bad and not well calibrated

The result of this study is one dam from the whole basin can produce 20 MW of energy and it is economically feasible when it compared with other renewable energies. but the software failed to simulate other five NPDs because of the data availability.

6 Conclusion

This study has found the annual average hydropower potential for the selected non-powered dams in the Büyük Menderes River basin to be 20 MW. Out of 6 dams, only one dam can produce hydropower, availability of real data makes it difficult to determine the hydropower on the rest of the dams. The main strong point of this specific study is the consideration and analysis of the existing water uses on a whole basin to make it usable for multipurpose by including hydropower schemes into the existing dam and also identifying the economic limitations for the evaluation of the technical retrofitting potentials. Even if the simulation of software because of data availability fails to give the expected results on the other NPDs in the whole basin but modelling the entire basin are very useful for analysis of future scenarios such as change in the river basin activities, change in water management strategy, climate change, or other changes in the basin. it is economically feasible when it compared with developing new hydropower plant because in the case of retrofitting the main structures are already exist so no need to construct every component. Environmental wise it has less impact when it is compared to new projects and almost negligible if there is no headworks are done. Sometimes it can be challenging for example if the previous water withdrawal from the dam is taken in the upstream part that result to production of power which is less than the reservoir capacity of the existing dam. The weakness of this study is there is no much information about the existing dams and also problems of availability of gauges that really makes the study to get the deliverables like assessing the hydropower capacity all of NPDs which is located in the river basin.

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Appendices

APPENDIX A: DESCRIPTION OF THE MASTER THESIS

APPENDIX B: INCLUDED DAMS WITH CORRESPONDING STORAGE CAPACITIES

APPENDIX C: EXAMPLE OF THE DISCOUNTING OF THE COSTS, REVENUES, AND ENERGY FOR IŞIKLI GÖLETİ

APPENDIX D: DISTRIBUTION OF WATER WITHDRAWALS

APPENDIX E: VOLUME-ELEVATION CURVES FOR THE NPDs INCLUDED IN THE WEAP MODEL

APPENDIX F: SCREEN DUMPS FROM THE WEAP MODEL

APPENDIX A: DESCRIPTION OF THE MASTER THESIS

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: Rediet Tsegaye Hagos

Title: Retrofitting of non-hydro reservoirs and dams

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), close to 90% of the dams in Africa, 75% of the dams in Asia and 60% of the European large dams are presently not used for hydropower production. 'Retrofitting for hydropower production' describes the addition or expansion of an existing dam not used for hydropower with hydroelectric power generation capabilities.

Compared to the construction of a new dam, retrofitting could pose a cost-effective way to increase electricity production, which was proven a case study in Spain as part of a master thesis in 2020 (Rydland Fjøsne, 2020). Impacts related to the retrofitting on the environment are basically negligible as the dam has been built and the flow regulation has already been made. The mere addition of turbines and other electromechanical equipment usually requires little additional construction and limited degradation of an already impacted river basin. 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. Based on the study carried out, and former similar studies, the global potential shall be assessed.

2 MAIN QUESTIONS FOR THE THESIS

Key questions to be addressed in the thesis are;

1. Identify a region of demonstrating the retrofitting potential of non-hydro reservoirs
2. Develop/apply a method to calculate the retrofitting potential in a basin with non-hydropower dams/reservoir (in the region identified under 1)
3. Demonstrate the proposed methodology for instance with use of WEAP or any other suitable tool for the purpose.
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. Assess the assumptions, limitation and uncertainties in the methodology and calculations
6. Assess the global potential, based on the finding (in point 1-5) and previous studies carried out.

3 SUPERVISION, DATA AND INFORMATION INPUT

Professor Tor Haakon Bakken will be the main supervisor of the thesis work. 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, however, 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 2021.

Trondheim 15th of January 2021

Tor Haakon Bakken

Tor Haakon Bakken, Professor

APPENDIX B: INCLUDED DAMS WITH CORRESPONDING STORAGE CAPACITIES

NUMBER	CONTINENT	country	dam name	Purposes	Reservoir Capacity
1	EUROPE	Turkey	IŞIKLI GÖLETİ	I	237.8
2	EUROPE	Turkey	ADIGÜZEL	IHC	1076
3	EUROPE	Turkey	CİNDERE	IH	82
4	EUROPE	Turkey	GOKPINAR	I	28
5	EUROPE	Turkey	KEMER	HIC	431.5
6	EUROPE	Turkey	TOPCAM	IC	84
7	EUROPE	Turkey	YAYLAKAVA	I	31.4
8	EUROPE	Turkey	CINE	IHC	0.35
9	EUROPE	Turkey	IKIZDERE	I	196
10	EUROPE	Turkey	YENIDERE	I	65

APPENDIX C: EXAMPLE OF THE DISCOUNTING OF THE COSTS, REVENUES, AND ENERGY FOR IŞIKLI GÖLETİ

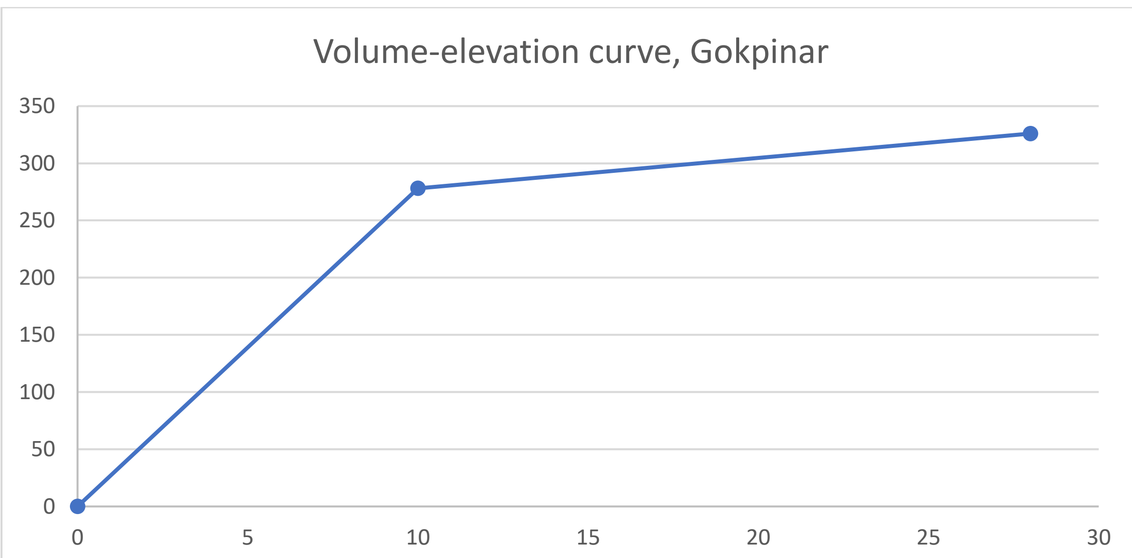
	Fiscal year	cost capital	INCOME TAX	NATURAL TAX	O&M(MIL USD)	TOTAL COST	NPV COST	REVENU ENERGY	NPV REVENUE	total NPV		NET CASH FLOW	IRR	BCR	SUM OF COST OVER LIFE TIME	SUM OF ELECTRIC ENERGYPRODUCED OVER LIFE TIME	0.00	It+Mt	Et	LCOE
	2022	34.83				-34.83	-33.17			-33.17	278.61	-34.83	17 %	2.96	34.15	19706.74		186.20	264.87	1
	2023	46.44				-46.44	-42.12			-42.12		-46.44			44.64	19320.33				
	2024	34.83				-34.83	-30.09			-30.09		-34.83			32.82	18941.50				
1	2025				2.67	-2.67	-2.20	22.94	18.87	16.67		20.27			2.47	18570.10				
2	2026				2.67	-2.67	-2.09	23.49	18.40	16.31		20.82			2.42	18205.98				
1	2027				2.67	-2.67	-1.99	24.05	17.95	15.95		21.38			2.37	17849.00				
2	2028				2.67	-2.67	-1.90	24.63	17.50	15.60		21.96			2.32	17499.02				
3	2029				2.67	-2.67	-1.81	25.22	17.07	15.26		22.55			2.28	17155.90				
4	2030				2.67	-2.67	-1.72	25.82	16.65	14.92		23.15			2.23	16819.51				
5	2031				2.67	-2.67	-1.64	26.44	16.23	14.59		23.77			2.19	16489.71				
6	2032				2.67	-2.67	-1.56	27.08	15.83	14.27		24.41			2.15	16166.39				
7	2033				2.67	-2.67	-1.49	27.73	15.44	13.95		25.06			2.11	15849.40				
8	2034				2.67	-2.67	-1.42	28.39	15.06	13.64		25.72			2.06	15538.63				
9	2035				2.67	-2.67	-1.35	29.07	14.68	13.34		26.40			2.02	15233.95				
10	2036				2.67	-2.67	-1.28	29.77	14.32	13.04		27.10			1.98	14935.24				
11	2037				2.67	-2.67	-1.22	30.49	13.97	12.74		27.82			1.95	14642.39				
12	2038				2.67	-2.67	-1.17	31.22	13.62	12.46		28.55			1.91	14355.29				
13	2039				2.67	-2.67	-1.11	31.97	13.28	12.17		29.30			1.87	14073.81				
14	2040				2.67	-2.67	-1.06	32.74	12.95	11.90		30.07			1.83	13797.86				
15	2041				2.67	-2.67	-1.01	33.52	12.63	11.63		30.85			1.80	13527.31				
16	2042				2.67	-2.67	-0.96	34.33	12.32	11.36		31.66			1.76	13262.07				
17	2043				2.67	-2.67	-0.91	35.15	12.02	11.10		32.48			1.73	13002.03				
18	2044				2.67	-2.67	-0.87	35.99	11.72	10.85		33.32			1.69	12747.09				
19	2045				2.67	-2.67	-0.83	36.86	11.43	10.60		34.19			1.66	12497.14				
20	2046				2.67	-2.67	-0.79	37.74	11.15	10.36		35.07			1.63	12252.10				
21	2047				2.67	-2.67	-0.75	38.65	10.87	10.12		35.98			1.60	12011.86				
22	2048				2.67	-2.67	-0.72	39.57	10.60	9.88		36.90			1.56	11776.34				
23	2049				2.67	-2.67	-0.68	40.52	10.34	9.66		37.85			1.53	11545.43				
24	2050				2.67	-2.67	-0.65	41.50	10.08	9.43		38.83			1.50	11319.05				
25	2051				2.67	-2.67	-0.62	42.49	9.83	9.21		39.82			1.47	11097.11				
26	2052				2.67	-2.67	-0.59	43.51	9.59	9.00		40.84			1.45	10879.51				
27	2053				2.67	-2.67	-0.56	44.56	9.35	8.79		41.89			1.42	10666.19				
28	2054				2.67	-2.67	-0.53	45.63	9.12	8.59		42.96			1.39	10457.05				
29	2055				2.67	-2.67	-0.51	46.72	8.89	8.39		44.05			1.36	10252.01				
30	2056				2.67	-2.67	-0.48	47.84	8.67	8.19		45.17			1.34	10050.99				

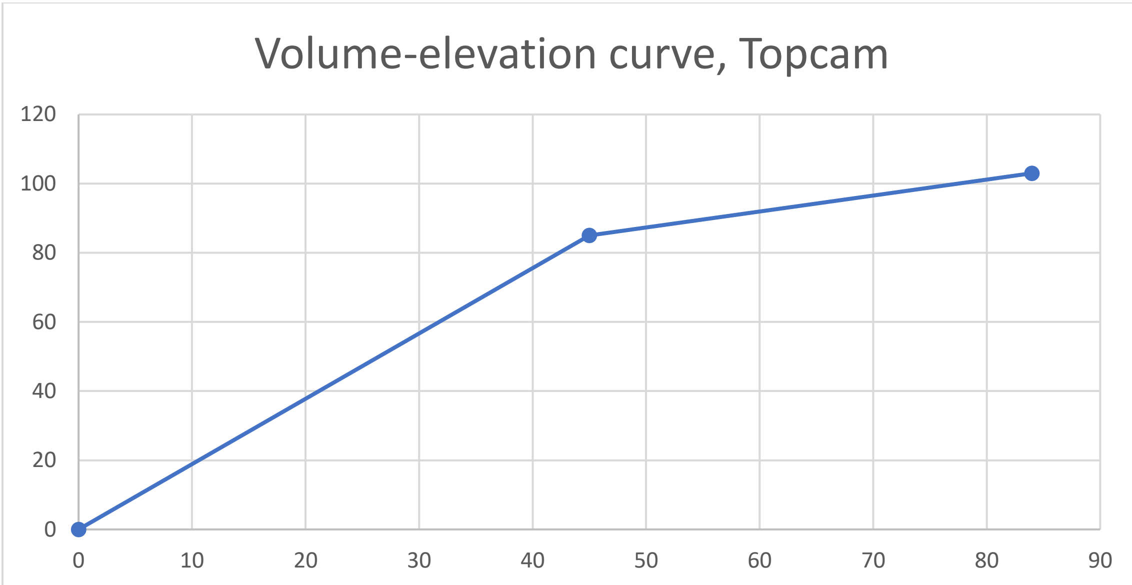
APPENDIX D: DISTRIBUTION OF WATER WITHDRAWALS

irrigation Name of scheme	net irrigation area	Actual irrigated area (ha)	water use per unit area(m^3/ha)	crop net irrigation water requirement (m^3/ha)	Irrigation rate (%)	Irrigation efficiency (%)	Total water used(m^3/year)
Aydın	18,500	21,992	6944	3573	119	51	152, 710,000
Söke	26,000	31,009	8374	4639	119	55	259,670,000
Sarayköy	8245	12,012	11,072	4496	146	41	133,000,000
Pamukkale	8593	5292	7937	4157	62	52	42,000,000
Nazilli	15,000	16,075	12,071	6442	107	54	193,180,000
Sultanhisar	4740	3014	11,077	6447	64	59	33,180,000
Akçay	14,900	12,306	10,642	5055	83	48	130,970,000
Karpuzlu	2750	1161	12,997	3161	42	24	15,090,000
Topçam	4300	1578	14,607	4081	37	28	23,050,000
Çürüksu	9212	9473	10,239	4437	103	43	96,990,000
Işıklı	1650	1550	6932	4573	94	66	10,750,000
Gümüşsu	1600	1000	3380	4940	63	-	3,380,000

Irgıllı	3920	1805	12,535	4271	46	34	10,750,000
Sütlaç	2820	1672	5353	4418	59	83	8,950,000
Çal	1730	675	7403	4370	39	59	5,000,000
Baklan	42,421	20,835	5915	4174	49	70	123,240,000

APPENDIX E: VOLUME-ELEVATION CURVES FOR THE NPDs INCLUDED IN THE WEAP MODEL




Volume-elevation curve, Topcam
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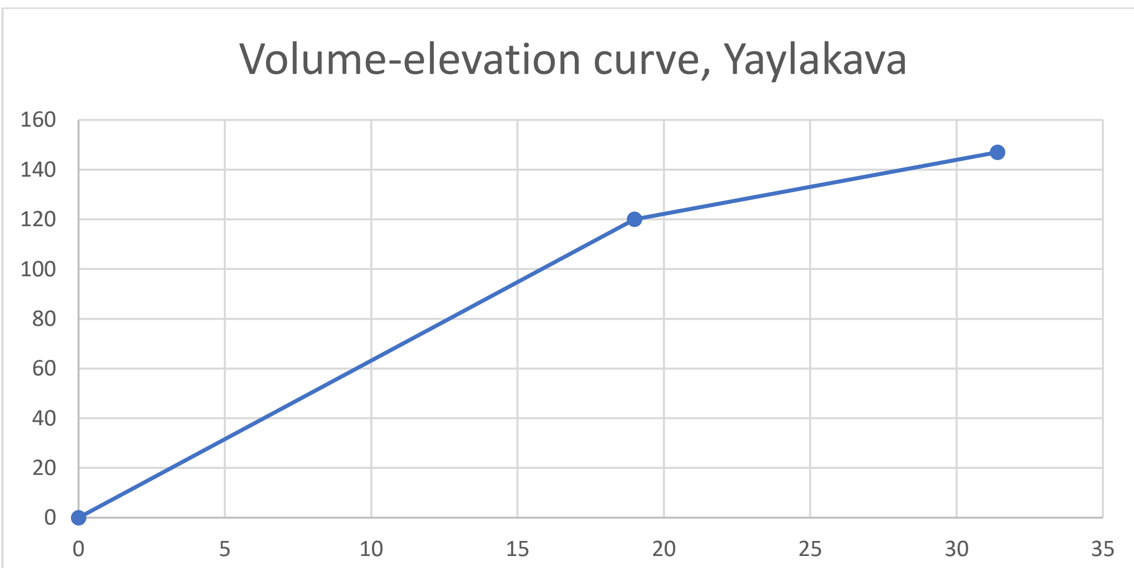
80
90


Volume-elevation curve, Yaylakava
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5
10
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20
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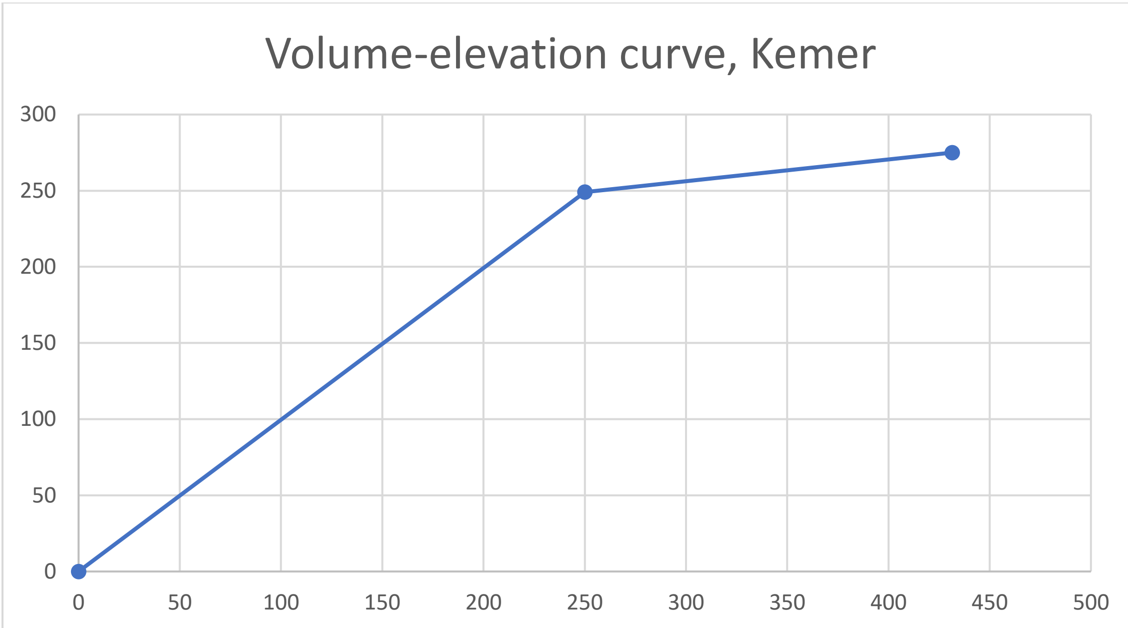
30
35


Volume-elevation curve, Kemer
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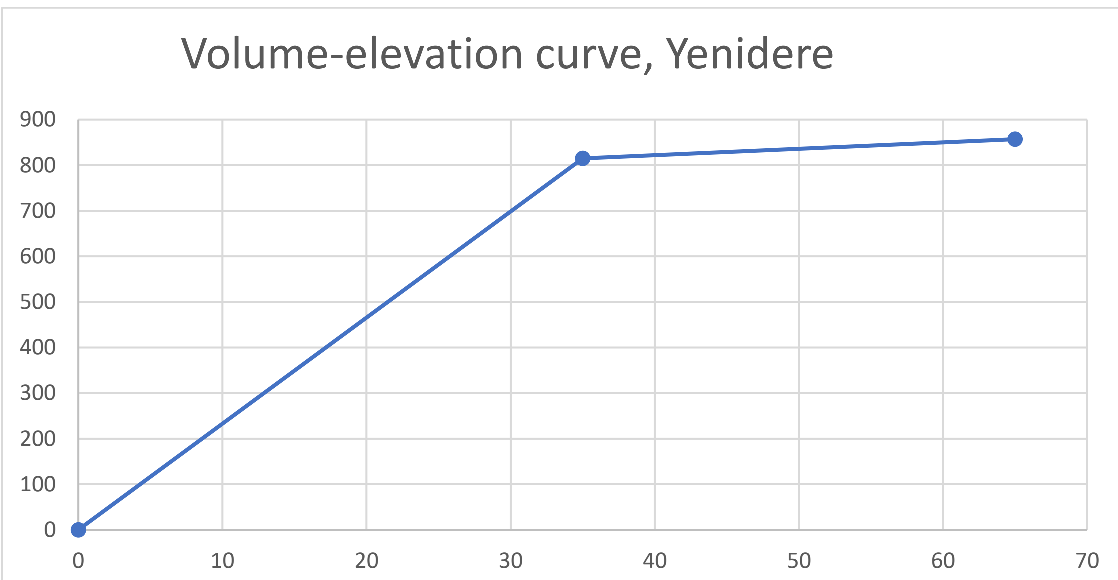
Volume-elevation curve, Yenidere
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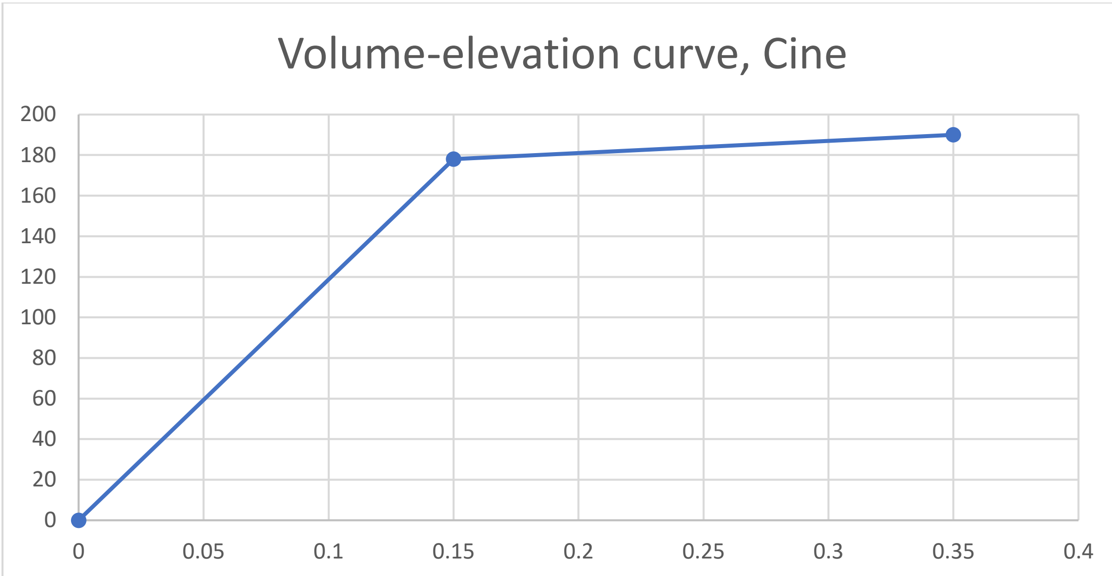
Volume-elevation curve, Cine
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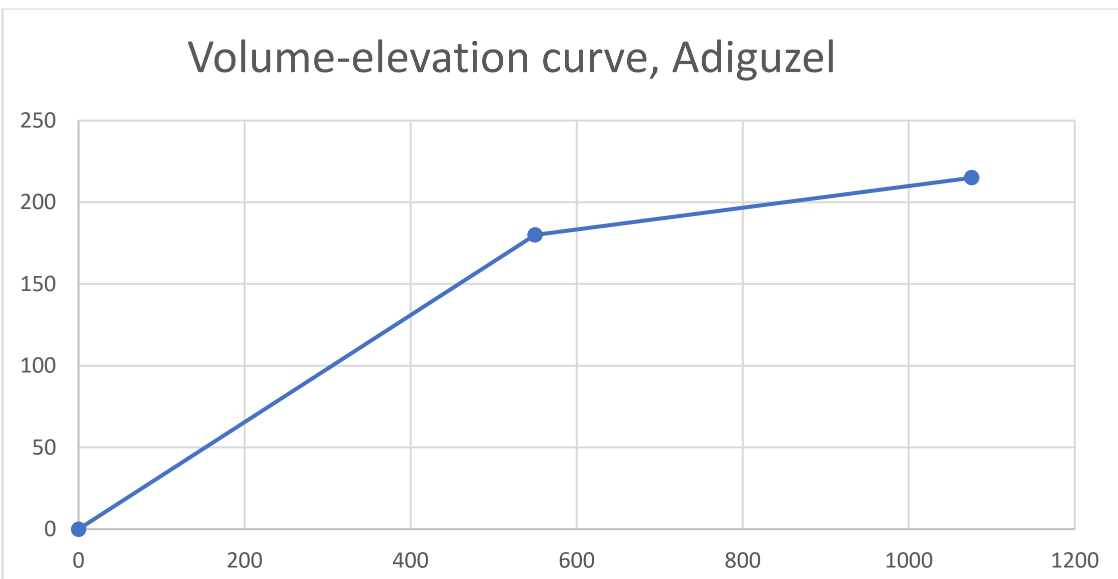
Volume-elevation curve, Adiguzel
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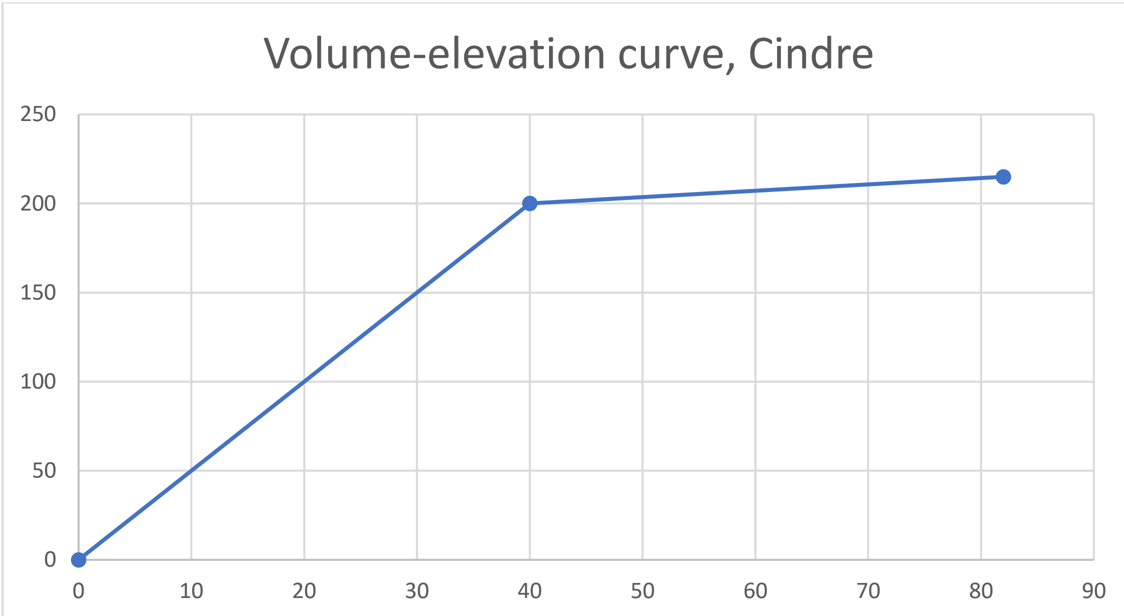
800
1000
1200


Volume-elevation curve, Cindre
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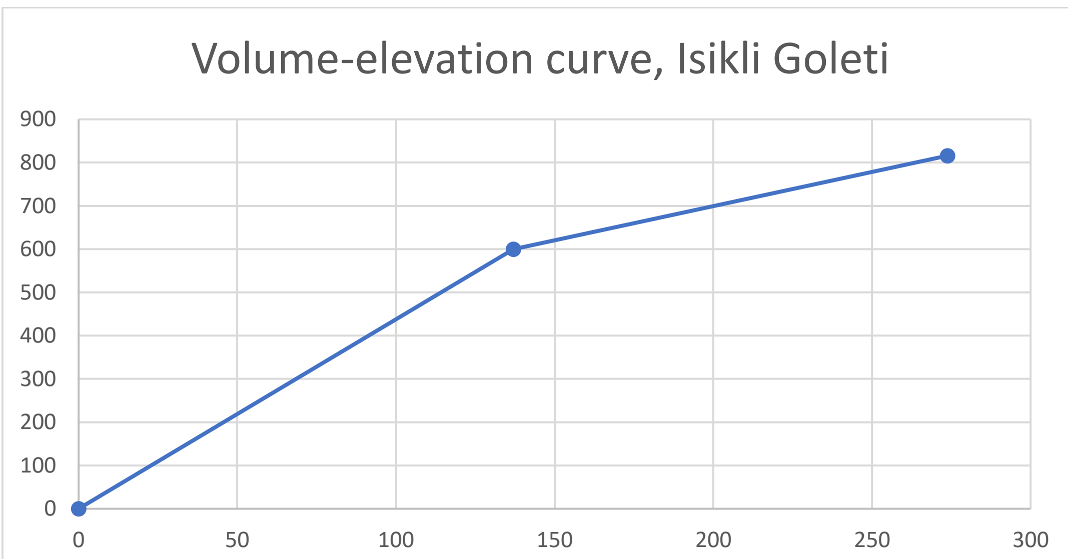
Volume-elevation curve, Isikli Goleti
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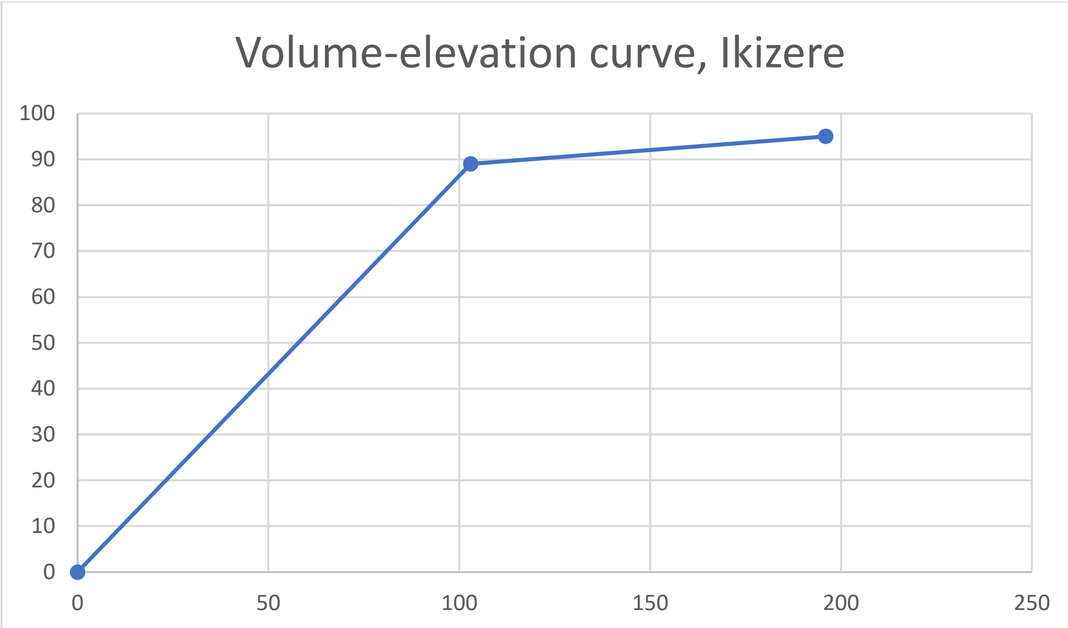
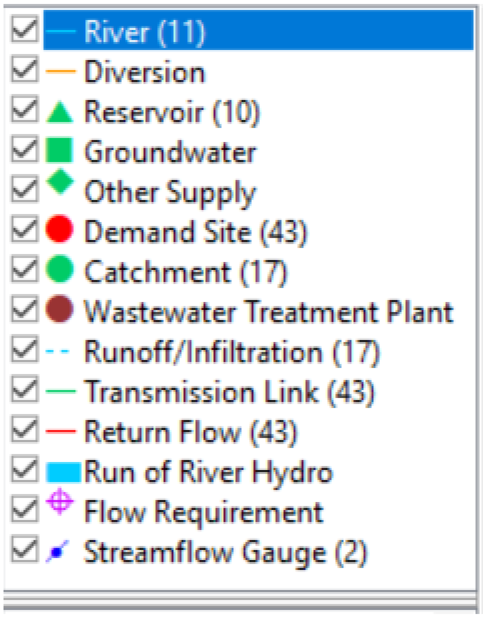
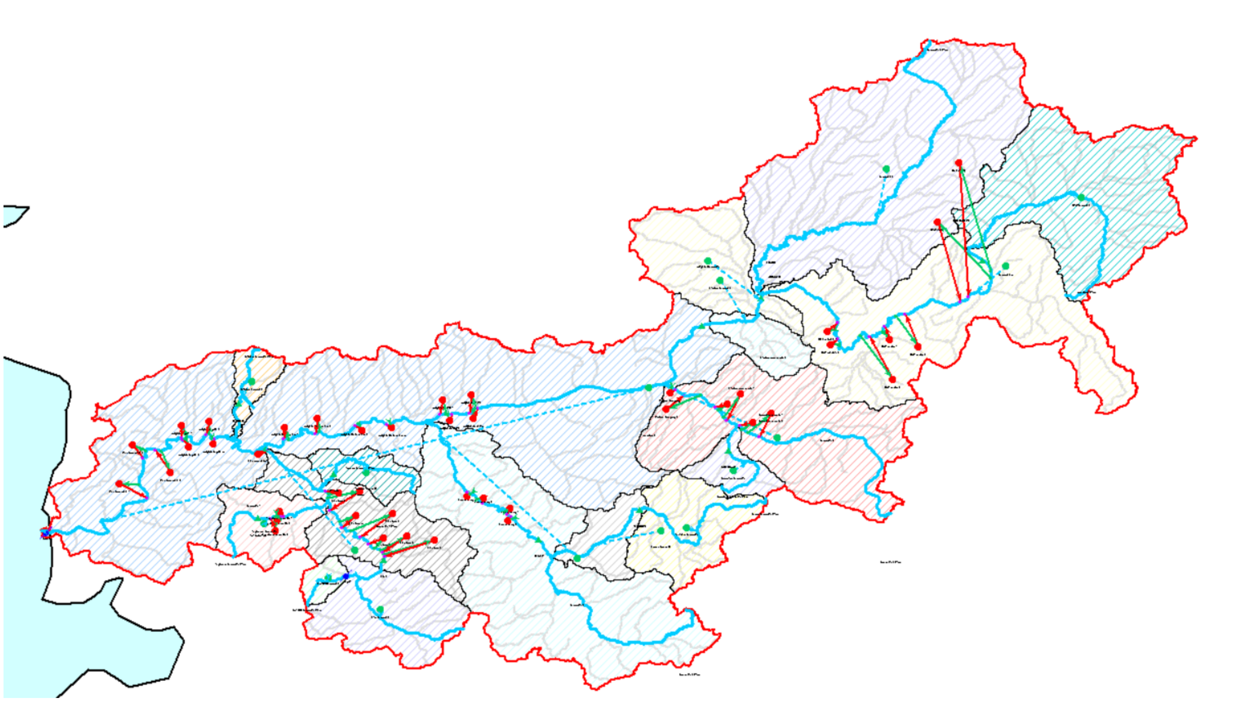
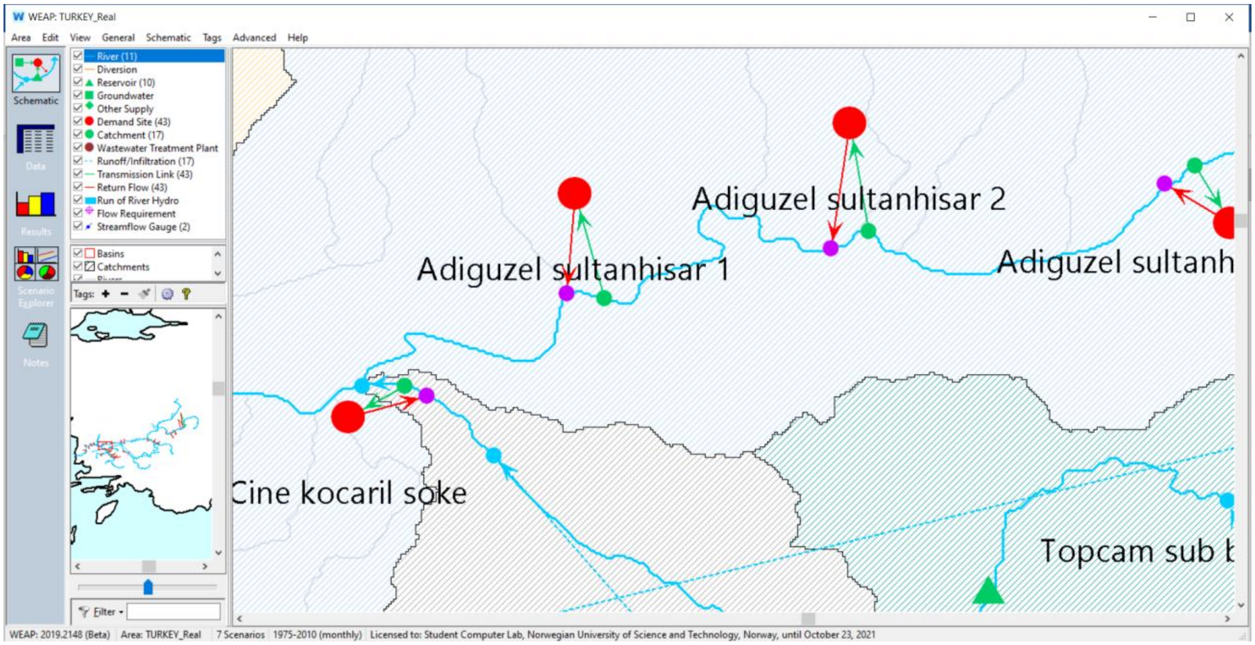
150
200
250
300



DIGIT APPENDIX F: SCREEN DUMPS FROM THE WEAP MODEL


River (11)
Diversion
Reservoir (10)
Groundwater
Other Supply
Demand Site (43)
Catchment (17)
Wastewater Treatment Plant
Runoff/Infiltration (17)
Transmission Link (43)
Return Flow (43)
Run of River Hydro
Flow Requirement
Streamflow Gauge (2)





Key Assumptions

These are user-defined variables that can be referenced elsewhere in your analysis. For monthly variation, use Monthly Time-Series Wizard.

Key Assumption	1975	Scale	Unit
Calibration	0		
F	0.15		
Kc	1.2		
RRF	2		
Sw	1000		mm
Z1	30	Percent	
Ks	20		mm
Z2	30	Percent	
Kd	20		mm
Dw	1000		mm
humidity	MonthlyValues(Jan,80.88,Feb,77.85,Mar,72.68,Apr,67.15,May,60.08,Jun,47.91,Jul,37.96,Aug,36.99,Sep,41.88,Oct,54.48,Nov,68.5,Dec,79.85)		
Wind	MonthlyValues(Jan,3.36,Feb,3.57,Mar,3.41,Apr,3.11,May,2.8,Jun,3.1,Jul,3.34,Aug,3.07,Sep,2.91,Oct,2.88,Nov,3.09,Dec,3.28)		
MonthlyVariataion	MonthlyValues(Jan, 1.2, Feb, 1.2, Mar, 1.2, Apr, 2.6, May, 8.3, Jun, 15.7, Jul, 27.6, Aug, 24.4, Sep, 11.5, Oct, 3.7, Nov, 1.3, Dec, 1.3)	Percent	
FreezingPoint	-5		C
MeltingPoint	5		C
ConsumptionRate	70	Percent	share
PrecipitationCorrect	1.18		
ReducedWithdrawals	1		

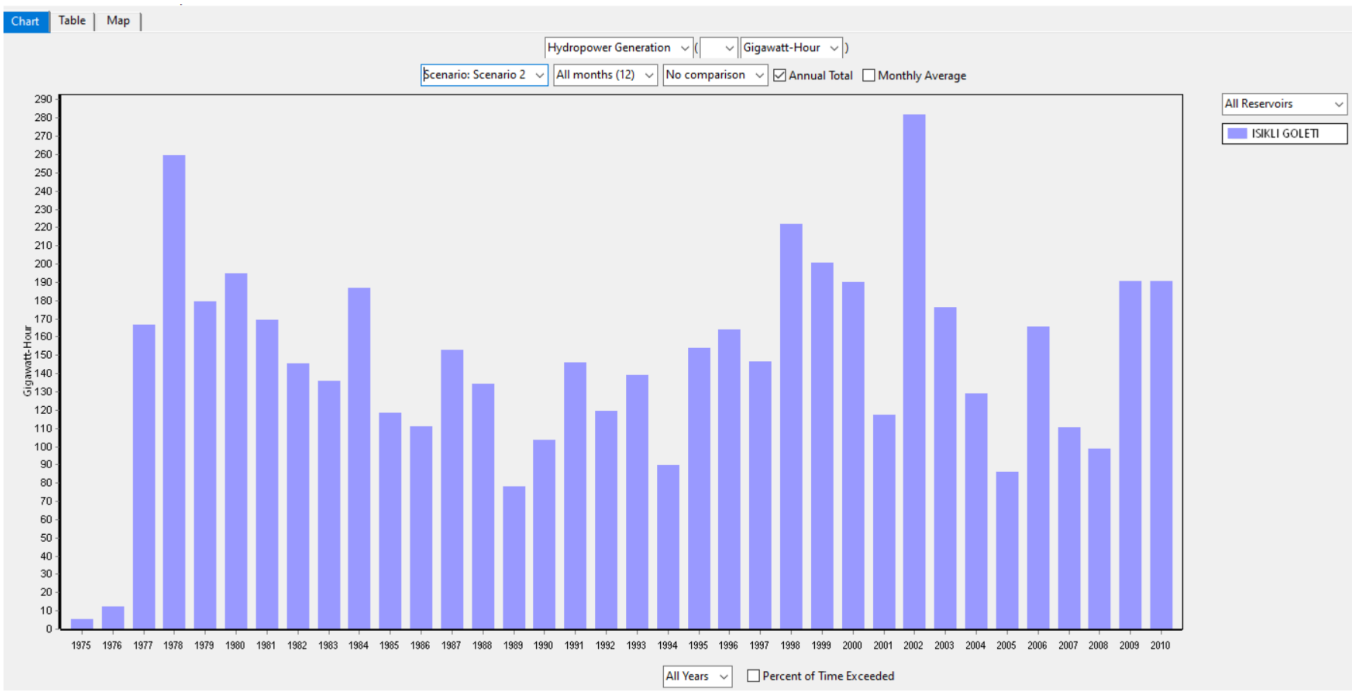


Chart
Table
Map
Hydropower Generation
Gigawatt-Hour
Scenario: Scenario 2
All months (12)
No comparison
Annual Total
Monthly Average
All Reservoirs
ISIKLI GOLETI
Gigawatt-Hour
All Years
Percent of Time Exceeded