OPERATION OF CASCADE DAMS CONSIDERING VARIOUS SCENARIOS AND FINANCIAL ANALYSIS OF SCENARIOS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

BERKER YALIN İMAMOĞLU

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

JANUARY 2013

Approval of the thesis:

**OPERATION OF CASCADE DAMS
CONSIDERING VARIOUS SCENARIOS
AND FINANCIAL ANALYSIS OF SCENARIOS**

submitted by **BERKER YALIN İMAMOĞLU** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen _____________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Ahmet Cevdet Yalçıner _____________________
Head of Department, **Civil Engineering**

Assoc. Prof. Dr. Zuhal Akyürek _____________________
Supervisor, **Civil Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. A. Melih Yanmaz _____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Zuhal Akyürek _____________________
Civil Engineering Dept., METU

Assist. Prof. Dr. Şahnaz Tiğrek _____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Nuri Merzi _____________________
Civil Engineering Dept., METU

Ayşe Soydam Baş, M. Sc. Civil Engineer _____________________
Temelsu International Engineering Services Inc.

Date: 15.01.2013

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name : BERKER YALIN İMAMOĞLU

Signature :

ABSTRACT

**OPERATION OF CASCADE DAMS
CONSIDERING VARIOUS SCENARIOS
AND FINANCIAL ANALYSIS OF SCENARIOS**

İmamoğlu, Berker Yalın
M.Sc., Department of Civil Engineering
Supervisor: Assoc. Prof. Dr. Zuhal Akyürek

January 2013, 158 pages

In assuring the energy supply of Turkey, hydroelectric energy plays one of the most important roles in plans formulated to realize equilibrium between energy production and consumption. Hydroelectric power plants' development on Murat River, a tributary of Euphrates, is a part of the development plan for energy production.

Operation of four dams in cascade on Murat River are simulated by using program package HEC-ResSim. For this purpose, ten scenarios are formulated to utilize the hydraulic potential of Murat River between the elevations of 870 m – 1225 m. This study provides detailed financial analyses of scenarios and shows how HEC-ResSim program can be used in formulation of alternative scenarios.

Electric energy storage requirement due to the rising demand for peaking power is creating a completely new market value, which is also increasing the attractiveness of pumped storage power plants. The results of the simulation performed in Scenario 10 in which two pumped storage power plants are considered have 15% higher internal rate of return value than the other scenarios with conventional turbines. Results demonstrate the increasing attractiveness of the cascade system with reversible pump turbines.

Keywords: HEC-ResSim, Reservoir Operation, Simulation, Pumped Storage Hydropower Plants

ÖZ

ARDIŞIK BARAJLARIN ÇESİTLİ SENARYOLAR DÜŞÜNÜLEREK İŞLETİLMESİ VE SENARYOLARIN FİNANSAL ANALİZİ

İmamoğlu, Berker Yalın
Yüksek Lisans, İnşaat Mühendisliği Bölümü
Tez Yöneticisi: Doç. Dr. Zuhal Akyürek

Ocak 2013, 158 sayfa

Hidroelektrik enerji; arz ve talep arasındaki dengeyi sağlamak için yapılan planlamalarda, Türkiye'nin enerji arzını güvence altına alarak en önemli rollerden birini oynar. Fırat Nehri'nin bir kolu olan Murat Nehri üzerindeki hidroelektrik santraller enerji üretimi için yapılan kalkınma planlamasının bir parçasıdır.

Murat Nehri üzerindeki ardışık dört barajın işletilmesi HEC-ResSim paket programı kullanılarak benzeşimleri sağlanmıştır. Bu amaçla, Murat Nehri'nin 870 m - 1225 m kotları arasındaki hidrolik potansiyelini kullanmak için on senaryo tasarlanmıştır. Bu çalışma senaryoların detaylı bir finansal analizini sunmakta ve HEC-ResSim programının alternatif senaryoların formülasyonunda kullanılabileceği anlatmaktadır.

Pik güç talebinde olan artış nedeniyle doğan elektrik enerjisi depolama ihtiyacı tamamen yeni bir piyasa değeri yaratarak, pompaj depolamalı santrallerin çekiciliğini arttırmaktadır. İki pompaj depolamalı santralin modellendiği Senaryo 10'nun diğer depolamalı santralli senaryolara kıyasla %15 daha fazla bir iç karlılık oranına sahip olduğu görülmüştür. Sonuçlar pompa türbinlerine sahip ardışık sistemin cazibesinin arttığını göstermektedir.

Anahtar Kelimeler: HEC-ResSim, Baraj İşletmesi, Benzeşim, Pompaj Depolamalı Hidroelektrik Santraller

To My Parents...

ACKNOWLEDGEMENTS

I would like to state that I am grateful to my advisor **Doç. Dr. Zuhal AKYÜREK** for her contributions, support from the initial to final level, who influenced and reshaped my career, future plans and expectations by her perfectionism, motivation of achievement and positive reinforcements.

I am also grateful to my dear wife, **Esen İMAMOĞLU** for her encouragement, positive motivation and endless support in hard times.

I owe my deepest graditute to my dear mom, **Canan İMAMOĞLU** and to my dear dad, **Cemal İMAMOĞLU** for their patience, endless support, interest and encouragement.

The assistance of the Temelsu Inc. staff is gratefully acknowledged. In addition to the information furnished, the employees officials of Temelsu were particularly helpful in suggesting and arranging meetings and in providing advice and background information.

Finally, I would like to thank to my friend and manager, **Ayse SOYDAM BAŞ** for all her best wishes. This study could not be completed without you. I am so grateful to you.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURES

LIST OF TABLES

TABLES

CHAPTER 1

INTRODUCTION

Water and energy are two main resources which are required for humankind and are tightly connected. As water flows from highlands to a lower elevation, its potential energy is reduced by drop in elevation, and other causes. A part of this potential energy may be converted to mechanical energy and used to generate hydropower.

During the nineteenth century, hydropower became a source of electrical energy. In the 1900s, the generation of electricity expanded the need for larger hydroelectric plants because the transmission of power over long distances became economical by the installation of alternating current equipments (Gulliver and Arndt, 1991).

The first benefit of the hydropower is that no air or water pollutants are produced. Since fuel is not burned, there is minimum pollution. Hydropower also reduces greenhouse gas emissions. Relatively low operation and maintenance costs are other advantages of hydropower (International Energy Agency, 2012).

In assuring the energy supply of Turkey, all industrialized and developing nations adopt the principle that a suitable mix of different energy resources must be relied upon in meeting the energy consumption with acceptable economy and supply security. It is well-known that hydroelectric power plays one of the most important roles in plans formulated to realize an equilibrium between energy production and consumption. Alternatives to hydroelectric power generation include nuclear power plants, thermal power plants, and relatively new technologies relying on geothermal, wind and solar energy. Import of electric power, which has been practised in the past, could also meet the domestic electricity demand.

The feasible hydroelectric energy potential of Turkey is estimated to be about 140 GWh/year and as of year 2011, only 38% of this is generated recently, as the other portion is lost because of incomplete development of dams and their hydropower plants (Energy Market Regulatory Authority, 2012). However there is a speedy pace of on-going construction of hydropower plants all over Turkey including many run-of-river types.

Demand forecast is the essence of decision making processes in market activities. Demand for electricity is basically affected by economic growth, increase in population and urbanization as well as energy efficiency applications and factors related to climate change (Deloitte Financial Advisory Services LLP, 2010).

Turkey will likely see the fastest medium to long-term growth in energy demand among the International Energy Agency member countries. Turkey has a young and urbanising population and energy use is still comparatively low. Therefore, ensuring sufficient energy supply to a growing economy remains the goverment's main energy policy concern (International Energy Agency, 2012).

Although Turkish electricity demand forecast should be based on the cumulative demand forecast of each regional distribution company by virtue of the Electricity Market Grid Regulation and Regulation Concerning Electricity Demand Forecast, currently it is still calculated by Ministry of Energy and Natural Resources by using Model for Analysis of Energy Demand (MAED). According to the latest "Turkish Electrical Energy 10-Year Generation Capacity Projection 2011-2020 Report" published by Turkish Electricity Transmission Company, total electricity demand is expected to reach 398 TWh with 6.7% compound annual growth rate in base scenario and 434 TWh with 7.5% in high scenario in 2020 (Turkish Electricity Transmission Company, 2011).

Directive 2001/77/EC concerning Encouragement of Electricity Production from Renewable Energy Resources in the Internal Market of Electricity aims at producing 22.1% of the electricity consumed by the Europian Union member countries from the renewable energy resources (Energy Market Regulatory Authority, 2011). This provision will require European Union countries to import energy from abroad. It will be possible to export part of the hydroelectric energy to be produced in Turkey at convenient prices. However, energy to be produced at thermal or nuclear power plants can also be imported at cheaper prices. For this reason, surplus supply has to be aimed in the production of green energy in our country.

Accordingly, development of all hydroelectric capacity in the shortest period of time is required regarding national interest.

With the recent liberalization, the appearance of Turkish electricity energy sector has been changing significantly, the level of competition increasing and more and more players have been entering into the market every day. 4628 numbered Electricity Market Law and the following Electricity Market License Regulation have paved way to private entrepreneurs for electricity generation, and granted them in establishing the power and operating hydroelectric power plants.

Cascade reservoir systems may be complex. Because of the complexity, computer based simulation programs can be used to provide and perform different scenarios easily. One can use computer based simulation programs extensively to solve problems with operation rules or operation limitations. Simulation is a modelling technique that is used to predict the behaviour of the system under a given set of conditions, representing all the characteristics of the system largely by a mathematical or algebraic description.

HEC-ResSim is a general-purpose reservoir simulation model developed by the Hydrologic Engineering Center to evaluate a wide variety of flood control and conservation storage projects, including hydropower analysis. The program can be used efficiently for single reservoirs or for complete reservoir systems on either critical period or period of record studies.

Upper Fırat Valley of Turkey is the least developed area in terms of the potential value of its water and land resources. Development of the region over a period of two to three decades would make a major contribution to Turkey's energy supplies. On the other hand, without development of the region it is doubtful whether any of these future requirements can be achieved.

The study conducted by Pöyry and Temelsu International Engineering Services Inc., was presented as a feasibility report for water resources management in the Lower Murat basin between 870 m – 1225 m. The feasibility report was carried out in 2011. Maximization of firm energy and operation of reservoirs in peak mode was studied in the feasibility study. The main goal of this thesis is to improve the feasibility report by considering different operation scenarios and pumped storage alternatives. In addition to this, financial analysis has been carried out considering the revenues, the operation and maintenance costs as well as the capital expenditures.

The objective of this study is

i) to estimate the hydropower potential of the Murat river between 870 m – 1225 m. Various operation rules and ten different scenarios are performed to investigate the energy generation potential,

ii) to provide information for long-term planning on the capacity of Kaleköy reservoir system and respective reservoirs, Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2,

iii) to reduce spillway losses, such that a higher fraction of runoff is used for energy generation,

iv) to maintain high heads and preferentially produce energy when prices are high. This is also achieved by using the operation guide curves and operation rules,

v) to investigate if the pumped storage applications on the system is feasible or not,

vi) to get information for future investments. Financial analyses are presented for the comparison of the scenarios.

In order to fullfill these objectives, this thesis has seven main chapters including this chapter.

Chapter 2 contains a general information about mathematical formulation of the model, a literature review section and a brief information about reservoir simulation models.

Characteristics of Kaleköy reservoir system and Lower Murat basin are summarized in Chapter 3.

The results of ten scenarios have been presented to utilize the hydraulic potential of the Murat River between the elevations of 870 m – 1225 m in Chapter 4.

According to the results of each scenario, the financial anaylses of the scenarios are described in Chapter 5.

Finally discussion of results and conclusion of the thesis is given in Chapter 6 and Chapter 7, respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 Water Power Equation

The amount of power that a hydraulic turbine can develop is a function of the quantity of water available, the net hydraulic head across the turbine, and efficiency of the turbine (Doland, 1954).

The power output of a hydroelectric plant is given by the equation (Yanmaz, 2006):

$$P(kW) = e.\gamma.Q.H \tag{2.1}$$

where

P = generator output in kW

e = overall plant efficiency (a fraction)

γ = specific weight of water in (kN/m³)

Q = flow through the turbine (m³/s)

H = net head on the turbine (m).

Following is a brief description of the sources of the parameters that make up the power equation. The source of the flow for hydroelectric plants is snowmelt and rainfall. Since rainfall is quite variable in quantity and occurence, the resulting runoff is by no means constant. Figure 2.1 shows the gross head as the difference between the reservoir and tailwater (elevation plus velocity head and head loss) for any given discharge. The net head on the turbine is the difference between the energy grade line elevations at the entrance to the turbine case and at tailwater. The efficiency term is the combined efficiencies of the turbine, transformer and generator.

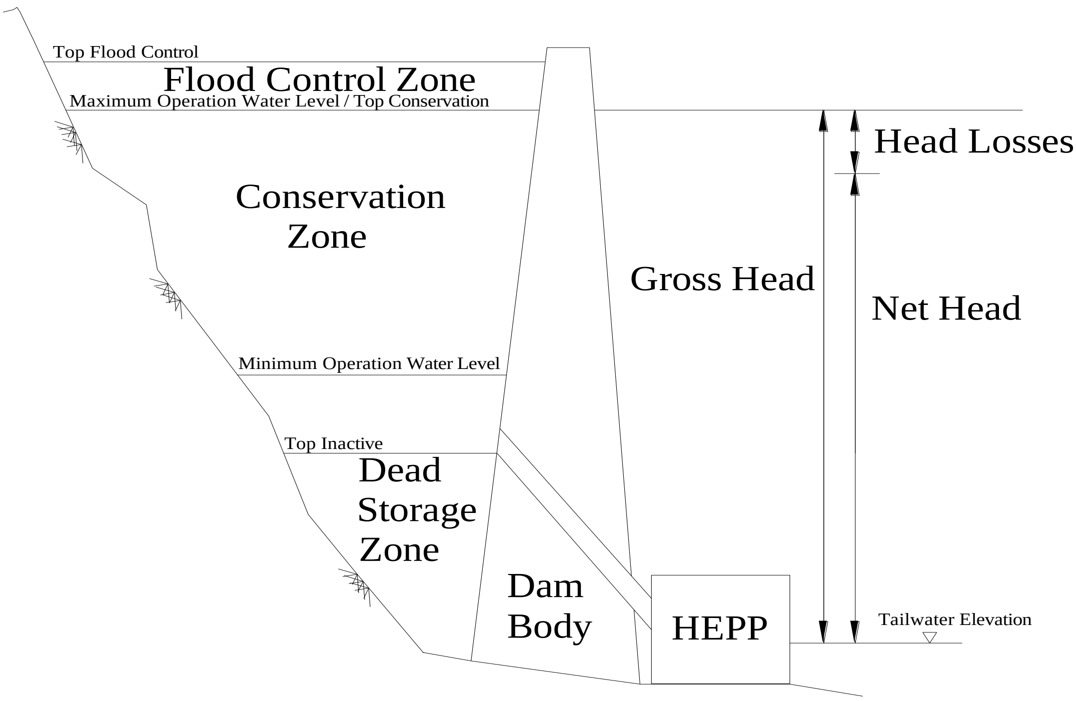


Figure 2.1 Storage zones

2.2 Storage Zones

The storage in a reservoir is composed of flood control zone, conservation zone and dead storage zone. Flood control zone provides space for flood regulation. Conservation zone is the storage between maximum operation water level (top of the guide curve) and dead storage zone. Energy is produced in conservation zone. No reservoir releases can be made when the pool level drops below the top-of-dead storage zone (Figure 2.1).

2.3 Hydropower Potential of Turkey

The Turkish electric power industry and its present plans for meeting the future demand in the country have been reviewed in this section. Turkey, which has one of the fastest growing energy markets in the world, has significant growth potential in this area going forward as shown in Figure 2.2.

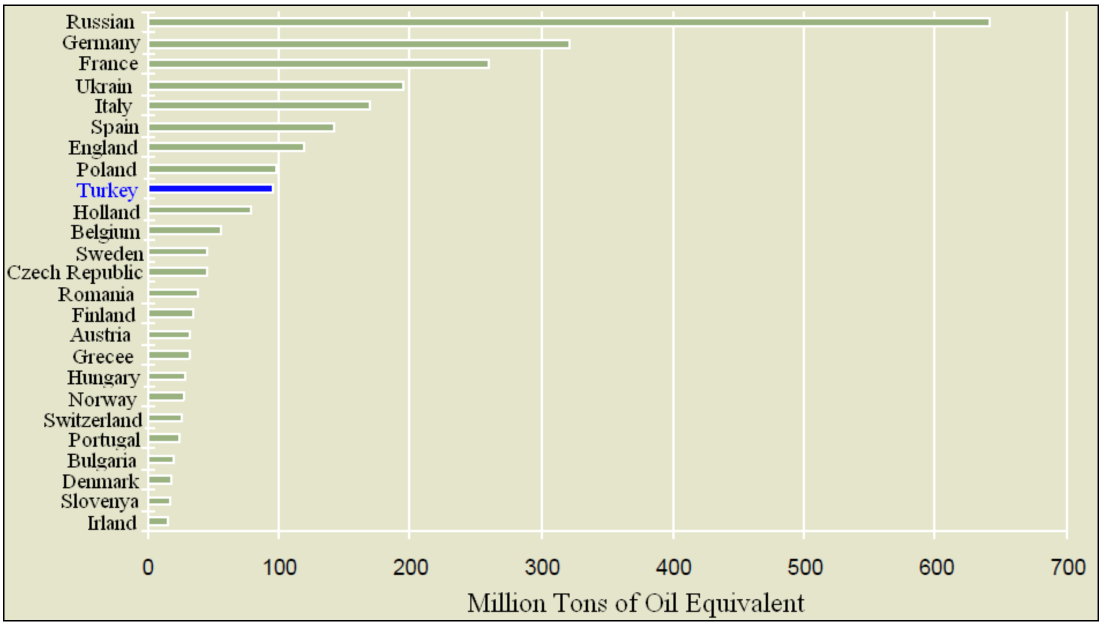


Figure 2.2 Energy generation of European countries, 2009 (Investment Support and Promotion Agency, 2010)

As shown in Table 2.1, there is a considerable increase in the average of the recent years production and consumption values. Increase in installed capacity and peak demand are 8.9% and 8.2% respectively while the rate of increase in production and consumption are 9.1% and 9.0% respectively. It can be understood the increase in production and consumption values were parallel in the year 2011.

Table 2.1 General energy production and consumption of Turkey (Energy Market Regulatory Authority, 2012)

	Unit	**2009**	**2010**	**2009-2010 (% change)**	**2011**	**2010-2011 (% change)**
Installed capacity	MW	44 761	48 591	8.6	52 911	8.9
Peak demand	MW	29 870	33 392	11.8	36 122	8.2
Production	GWh	194 813	210 182	7.9	229 395	9.1
Import	GWh	812	1 883	131.9	4 556	142.0
Export	GWh	1 546	2 675	73.0	3 645	36.3
Consumption	GWh	194 079	210 434	8.4	229 319	9.0

It is seen from Figure 2.3 that the proportion of natural gas as a source in energy generation is almost 50%. The figure reveals that the share of energy produced from natural gas has increased in recent years, whereas, the share of hydropower energy has decreased. To tell the truth, this is not a desirable situation. This fact implies that dependency on foreign resources has increased.

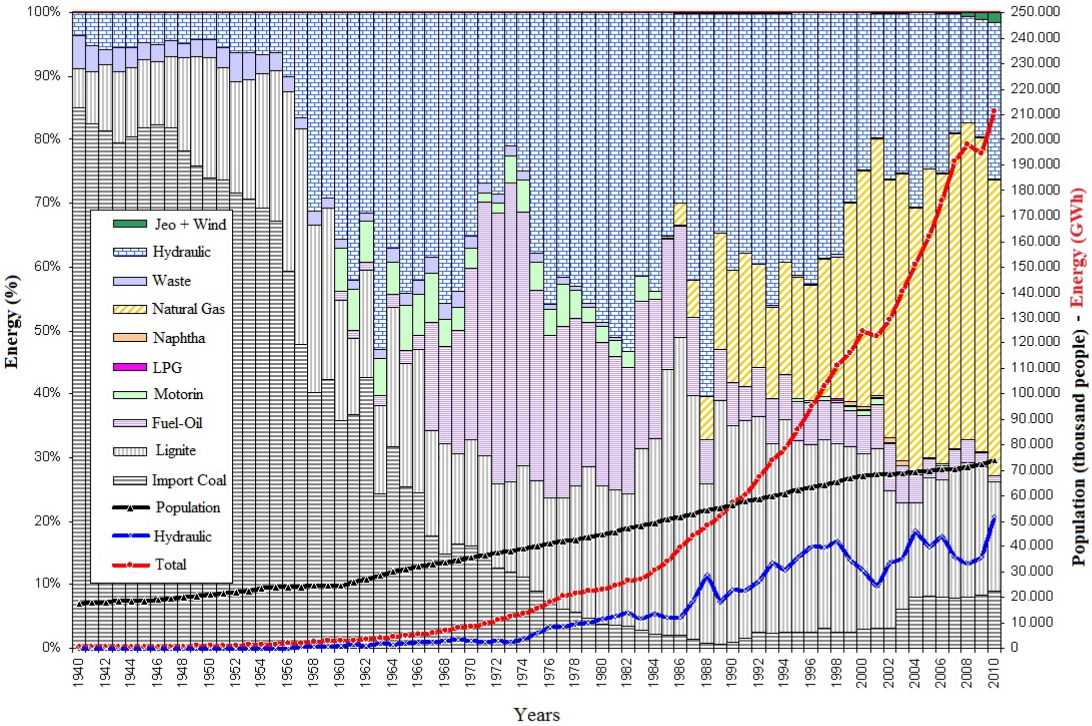


Figure 2.3 Development of Turkey's electric generation and distribution of sources (Saraç, 2012)

Theoretical hydropower potential of Turkey is 433 billion kWh, only 30% of theoretical hydropower potential is economically and technically feasible as shown in Figure 2.4. Today 37% of economically and technically feasible hydropower potential is under operation.

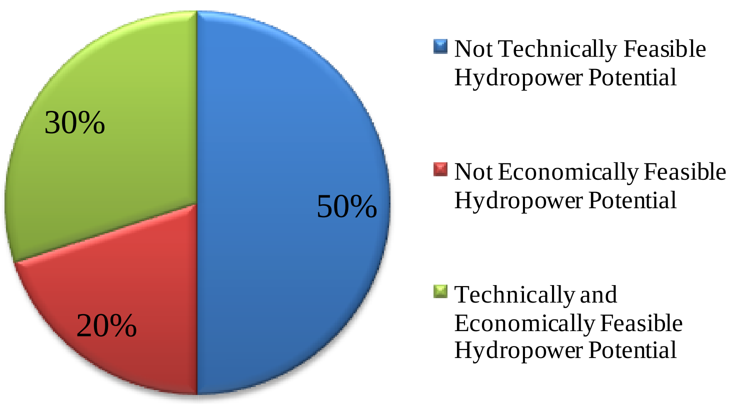


Figure 2.4 Hydropower potential of Turkey (General Directorate of Renewable Energy, 2012)

Dams in operation in Turkey as of 2011 according basins are shown in Figure 2.5. 267 dams which have active volume of more than 3 hm^3 have been considered.

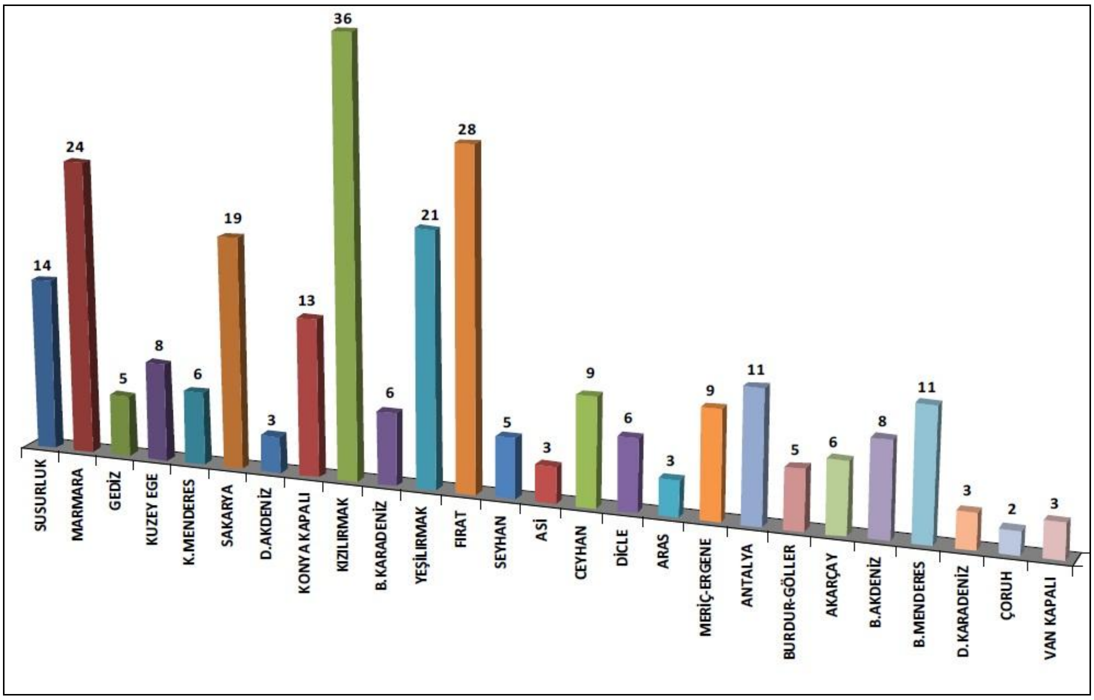


Figure 2.5 Number of dams under operation in Turkey's basins (Alantor et al., 2012)

Our country is poor in primary energy resources as petroleum and natural gas. Accordingly, the primary energy requirement has to be purchased greatly from abroad. This fact increases the dependency of our country abroad. Major part of the utilized energy is consumed as electrical energy. İnci (2012) presented the installed power capacity of Turkey below in Table 2.2.

Table 2.2 Installed power capacity of Turkey – September 2012 (İnci, 2012)

Source	**Installed Capacity (MW)**	**Ratio (%)**
Natural gas	19 558	35.3
Hydro	18 811	33.95
Coal	12 522	22.6
Wind	2 001	3.61
Fuel-Oil	1 948	3.52
Biogaz	115	0.21
Geotermal	114	0.21
Others	332	0.6
Total	**55 401**	**100**

The development of installed capacity in Turkey according to primary energy resources is given in Figure 2.6, as well.

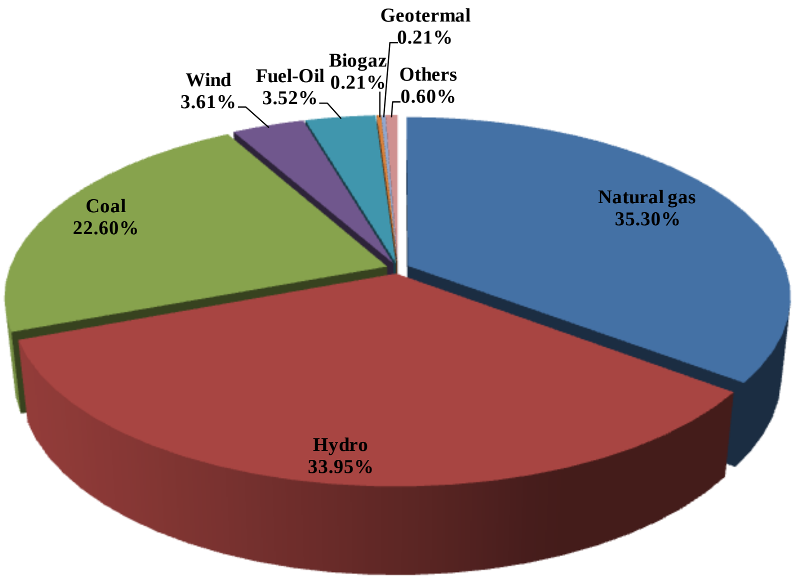


Figure 2.6 Turkey's installed capacity ratios according to sources – September 2012 (İnci, 2012)

Turkey will have to purchase extra 65-70 million tons of imported coal or 30-35 billion cubic meters natural gas if the remaining economically and technically feasible hydropower potential is produced by thermal plants. The annual additional fuel cost for Turkey will be 6-7 billion dollars for coal, 9-11 billion dollars for natural gas. Burning fossil fuels is adding extra carbon dioxide to the greenhouse gases in the atmosphere, much more than the normal carbon cycle can manage. The quantities are 120-200 million ton/year for coal plants and 60 million ton/year for natural gas (Bakır, 2013).

In Turkey, in the recent 20 years or so, the electric distribution companies have been applying the so-called 'wise -hours-schedule' system of pricing on voluntary basis. The energy-consumption gauges at houses and industrial buildings measure and record separately the energy consumed at three distinct periods defined by the Turkish Electric Energy Distribution Company, known as TEDAS in Turkey, as 'day period' which is between 06-17 hours, 'peak period' which is between 17-22 hours, and 'night period' which is between 22-06 hours. Development of the peak demand by years is shown in Figure 2.7.

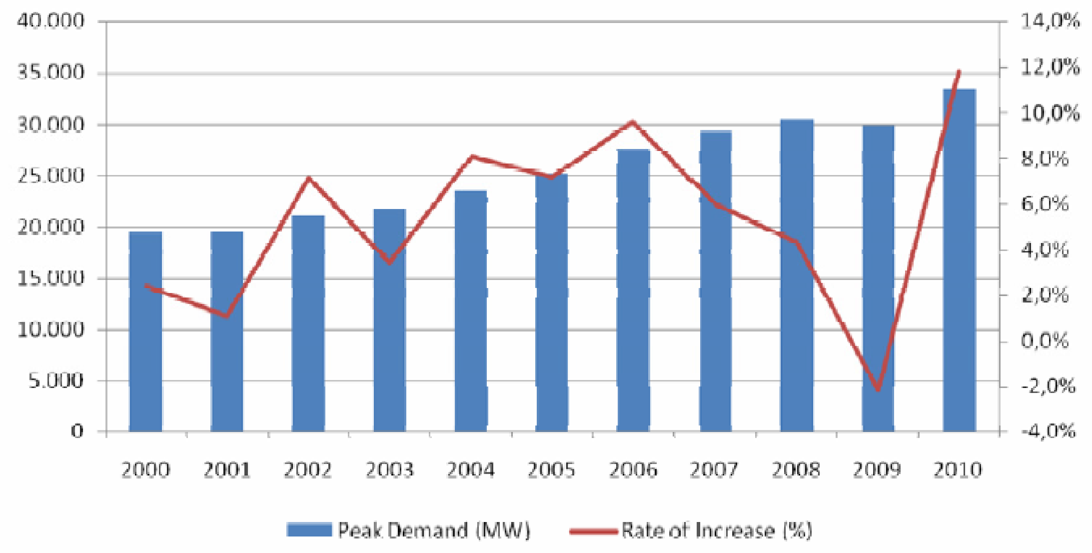


Figure 2.7 Development of the peak demand by years (Energy Market Regulatory Authority, 2011)

In September 1996 the Ministry of Energy, recognizing the future need for additional generating capacity to meet increasing demands for power and energy in the Turkish electrical system, invited bids for construction of a number of hydroelectric projects under the provisions of the Turkish Build Operate Transfer Law.

10 years electrical energy generation capacity projection in Turkey is investigated by Turkish Electricity Transmission Company between 2011 and 2020. The purpose of this study is to be helpful to the decision makers, investors and all market participants on the timing, number and configuration of the generation facilities to be installed in order to meet the electrical energy demand safely. Estimated projection of two series of high and low demand scenario is created. According to the high demand scenario, energy demand and peak demand are increased 86% and 91% respectively, from 2011 to 2020. In the low demand scenario, the increase in energy demand and peak demand are 75% and 70% respectively. Rate of increase in energy demand and peak demand projection for the years is shown in the Table 2.3. An average of 7.5% for the High Demand Scenario and an average of 6.7% for the Low Demand Scenario were estimated.

Table 2.3 Estimated peak demand and energy demand according to the high and low scenarios (Energy Market Regulatory Authority, 2012)

Years	High Demand				Low Demand			
	Peak Demand		Energy Demand		Peak Demand		Energy Demand	
	MW	Increase (%)	GWh	Increase (%)	MW	Increase (%)	GWh	Increase (%)
2011	36 000	7.81	227 000	7.87	36 000	7.81	227 000	7.87
2012	38 400	6.67	243 430	7.24	38 000	5.56	241 130	6.22
2013	41 000	6.77	262 010	7.63	40 130	5.61	257 060	6.61
2014	43 800	6.83	281 850	7.57	42 360	5.56	273 900	6.55
2015	46 800	6.85	303 140	7.55	44 955	6.13	291 790	6.53
2016	50 210	7.29	325 920	7.51	47 870	6.48	310 730	6.49
2017	53 965	7.48	350 300	7.48	50 965	6.47	330 800	6.46
2018	57 980	7.44	376 350	7.44	54 230	6.41	352 010	6.41
2019	62 265	7.39	404 160	7.39	57 685	6.37	374 430	6.37
2020	66 845	7.36	433 900	7.36	61 340	6.34	398 160	6.34

In order to satisfy demand on the supply side of these scenarios, the two scenarios are created by Energy Market Regulatory Authority. Based on these two scenarios, development of installed power, firm energy and total energy are shown in the following Table 2.4.

Table 2.4 Development of the installed capacity and energy production for High and Low Demand Scenarios (Energy Market Regulatory Authority, 2012)

Years	Installed Capacity (MW)		Firm Energy (GWh)		Total Energy (GWh)	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
2011	53 035	52 596	253 817	253 289	295 806	294 915
2012	55 322	54 586	266 768	265 082	308 894	306 495
2013	62 380	59 592	290 605	283 261	333 648	325 046
2014	65 207	63 393	312 660	301 745	356 130	343 658
2015	66 407	64 593	324 866	315 408	368 975	358 220
2016	66 407	64 593	326 011	316 553	370 831	360 076
2017	66 407	64 593	325 362	315 904	369 660	358 905
2018	66 407	64 593	325 640	316 182	370 460	359 705
2019	66 407	64 593	325 696	316 238	370 235	359 479
2020	66 407	64 593	325 696	316 238	370 235	359 479

Taking into account the installed capacity, change in the reserve margins on the basis of different scenarios are shown in Figure 2.8. In 2011, reserve margin is approximately 45%. Reserve margin with a new capacity expected to be installed will increase until 2013, than it is expected to decrease. In the event of Scenario 2- High Demand, reserve margin decreases to negative by 2020.

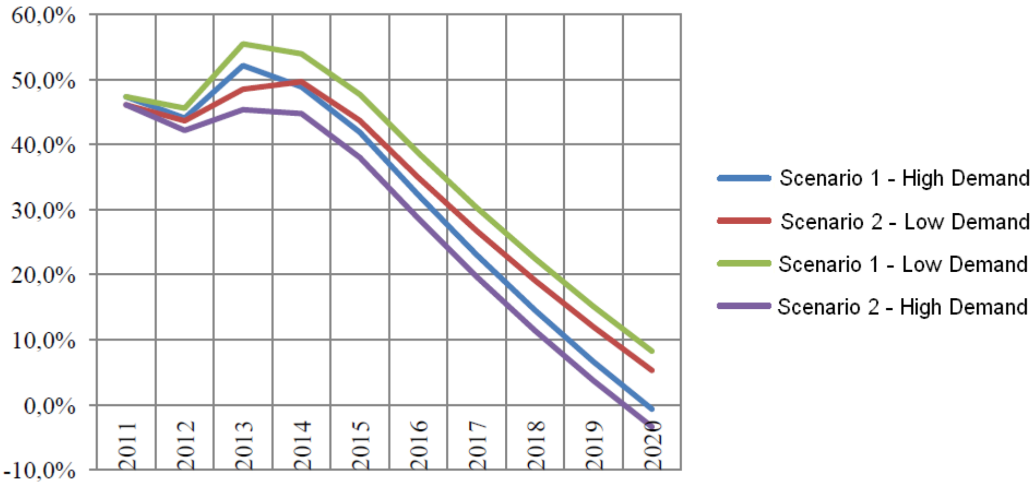


Figure 2.8 Development of reserve margins according to installed capacities (Energy Market Regulatory Authority, 2012)

Given the power generation capacity of power plants, the development of reserve margin is shown in Figure 2.9. Reserve margin is approximately 30% as of 2011, with the activated capacity in Scenario 1 reserve margin increases until 2013.

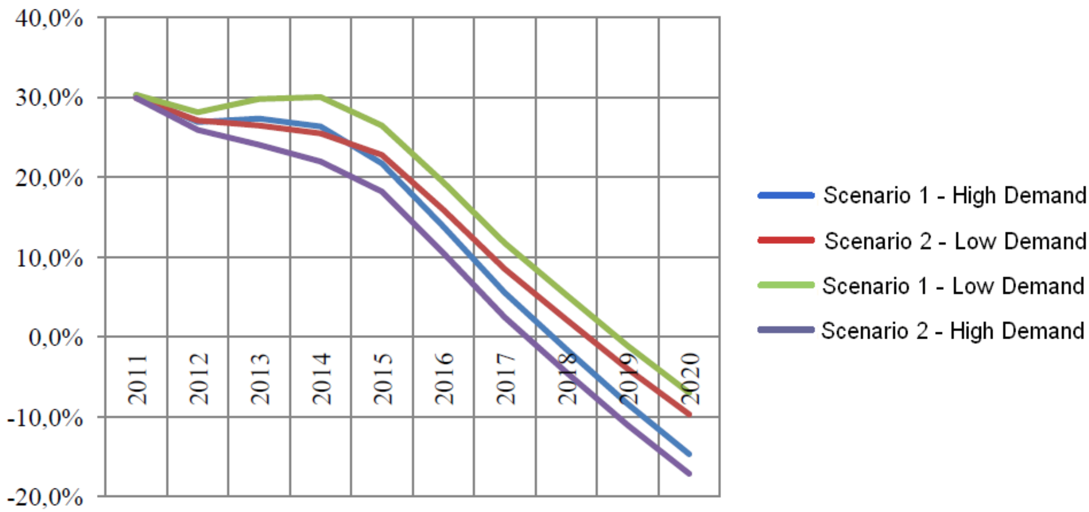


Figure 2.9 Reserve margins according to total and firm energy generation capacities (Energy Market Regulatory Authority, 2012)

Under these circumstances, a serious shortage of electric power supply could be encountered in the near future. In meeting the energy demand under the circumstances discussed above, it is indispensable and imperative for Turkey to create additional generation capacity.

2.4 Pumped Storage

Pumped storage hydroelectric projects have been providing valuable storage capacity, transmission grid ancillary benefits and renewable energy in the United States and Europe since the 1920s (Miller, 2010). In other words, pumped storage is a type of hydroelectric power generation that stores energy in the form of water in an upper reservoir, by pumping from a lower reservoir.

In the power-supply chain, pumped power plant fulfills several important functions as static, dynamic and compensational (Oliveira, 2011).

i) The static role of the pumped power plant is fulfilled through transformation of surplus energy in the network into peak energy. At the time when there is a surplus of energy in the network mostly during the night, the water is pumped from the lower reservoir into the upper one, and in peak periods, when a shortage of energy occurs, the plant is switched to a turbine mode and it produces electricity.

ii) The dynamic function of the pumped storage power plant means that the plant functions as a backup output for the system, it can produce regulatory output and energy and thus it contributes to the administration of the network frequently.

iii) The compensational mode of operation serves for regulating the voltage of the system.

The extend of pumped storage use is very widespread as shown in Figure 2.10, and almost every industrialized nation can boast at least one such installation.

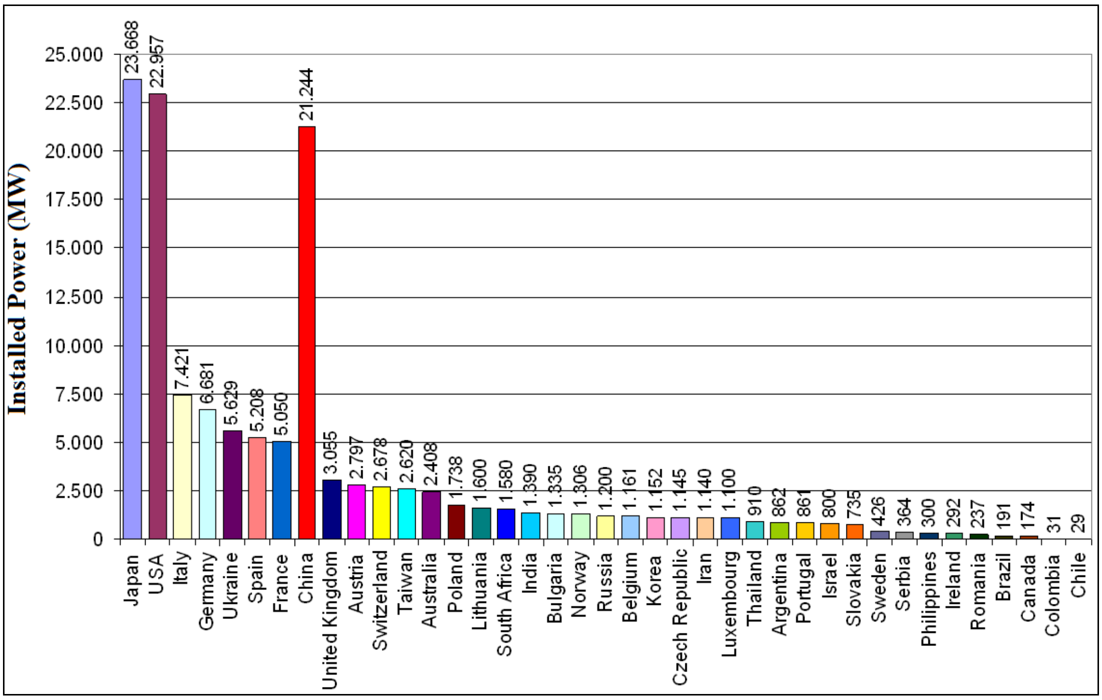


Figure 2.10 World Pumped Storage Potential (Saraç, 2012)

Turkey needs pumped storage power plants (PSPP) which are all in energy portfolio of developed countries in a large extend more than any time as parallel to steps taken forward in development of nuclear power plants and renewable energy generation (Saraç, 2012).

In regards to this, General Directorate of Electrical Power Resources Survey and Development Administration planned and designed 18 PSPP projects in reconnaissance level and two at pre-feasibility level in 2011. Gökçekaya PSPP, at pre-feasibility level, is planned to be on the Sakarya River, and Gökçekaya Dam Reservoir is thought to be lower reservoir with an installed capacity of 1400 MW (Saraç, 2012).

Mid century, half of the world energy needs may be supplied at an acceptable cost by wind and sun but this requires electric energy storage close to 3 000 GW for 50 000 GWh. Pumped storage plants appear the best relevant solution (Lempérière, 2011).

Lempérière (2011) presented two options below for the future of world energy :

i. Huge utilization of coal, limited however end of the century by the coal availability as shown in Table 2.5.
ii. Huge utilization of wind and solar energies; it is possible but requires storages of electric energy as shown in Table 2.5.

Table 2.5 Sources of energy utilization (Lempérière, 2011)

Sources of Energy	**2010 (TWh/year)**	**2050 (option 1) (based on coal) (TWh/year)**	**2050 (option 2) (based on renewable) (TWh/year)**
Nuclear	3 000	5 000	7 000
Hydro	3 000	5 000	8 000
Biomass, Geotermy, Miscellaneous	4 000	10 000	15 000
Oil and Gas	40 000	25 000	15 000
Coal	10 000	50 000	15 000
Wind and Solar	-	25 000	60 000
Total of Energy Utilization	60 000	120 000	120 000

There are two types of turbines used in pump storage projects as shown in Figure 2.11. Firstly, the classic concept with separate machines may be used due to the need for extremely rapid switching time between turbine and pump operation. As two separate hydraulic machines, the rotational direction of the motor generator can be the same in both operational modes and this solution may add commercial value to today's utility operators (Mitteregger, 2008). Secondly, characteristic of reversible pump-turbines is the longer switch-over time from turbine to pump operation and vice versa. This is down to the air being used to expel the water in the turbine for restarting under pump operations, as the start-up equipment for the motor would not be in a position to do so with water. The rotational direction must also be changed, as this reversible machine operates in both, pump and turbine mode. In both cases, the selected design for the pumped storage arrangements should be chosen as an optimum technical solution that results in the best possible return for the operating utility (Jefferies, 1990).

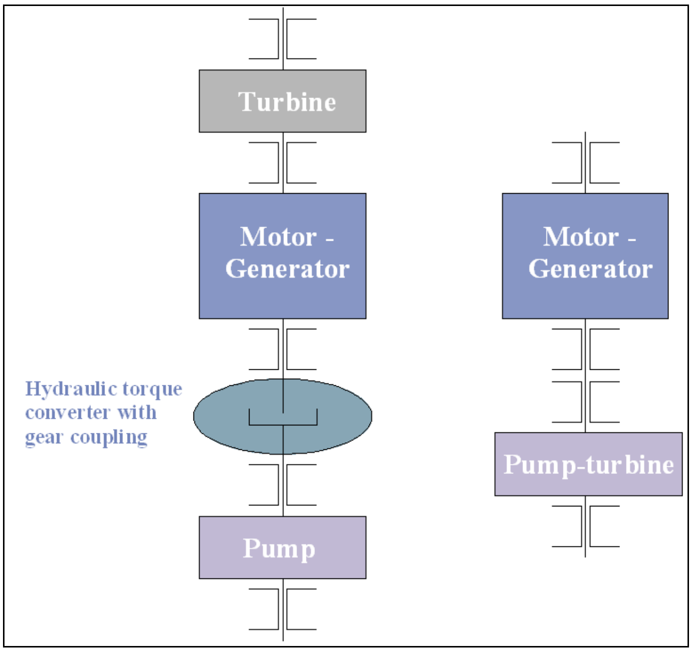


Figure 2.11 Types of pumped turbines (Voith, 2009)

The principal types of pumped storage schemes known today can be classified under four headings, as shown in Figure 2.12.

i) Pure pumped storage
ii) Multi-use type
iii) Water-transfer type
iv) Tidal type

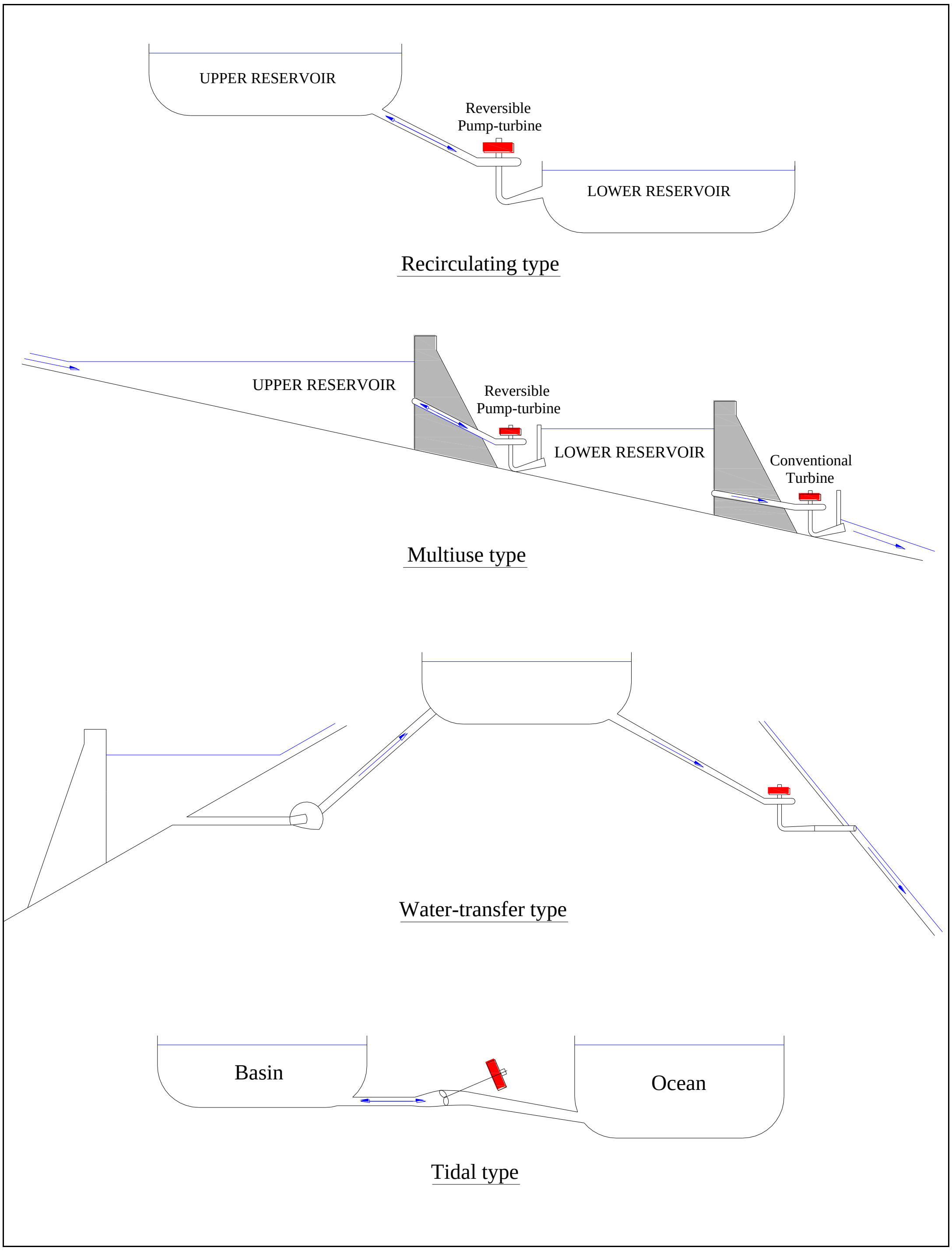


Figure 2.12 Types of pumped storages development (Voith, 2009)

2.5 Mathematical Formulation of the Model

Nandalal and Bogardi (2007) state that simulation is used to analyze the effects of proposed management plans: achievement regarding system performance is evaluated based on selected sets of decisions. Simulation model is based on the principle of continuity and solves the storage equation in a specific time. The state of the reservoir system is described by water available in the reservoir at the beginning of any time step. Consecutive time steps are identified as stages. The decision variable is water released from the reservoir.

2.5.1 Storage Volume Constraint

The model is operated on daily basis. Since operation policy is derived for annual cycles,

$$S_1 = S_{T+1} \tag{2.2}$$

where

S_1 = storage volume at beginning of the first period (first day)

S_{T+1} = storage volume at the end of the last period (last day)

T = total number of time steps (days)

For all other months reservoir storage belongs to the set of admissible storage volume:

$$S_{\min} \leq S_j \leq S_{\max} \tag{2.3}$$

where

S_j = storage volume at the beginning period j

S_{min} = allowable minimum storage volume, and

S_{max} = allowable maximum storage volume.

2.5.2 Release Constraint

The capacity of hydropower generators sets a maximum limit to reservoir release. If a minimum release request is not considered, the minimum release is set to zero. The release during any day should be within this feasible release range:

$$0 \leq R_j \leq R_{j,\max} \tag{2.4}$$

where

R_j = reservoir release during period j, and

$R_{j,max}$ = maximum allowable release through turbines in period j.

2.5.3 State Transformation Equation

The state transformation equation based on the principle of continuity is as follows:

$$S_{j+1} = S_j + I_j - E_j - R_j - Q_j \quad (2.5)$$

where

E_j = evaporation from reservoir during period j

I_j = inflow to the reservoir during period j, and

Q_j = spillage water during period j.

Other variables are as defined before.

2.6 Reservoir Simulation Models

Kansal (2005) states that the essence of simulation is to reproduce the behavior of the system from every point of view to investigate how the system will respond to conditions that may be imposed on it or that may occur in the future.

Özbakır (2009) made a simulation model of Seyhan and Ceyhan river basins by using the package HEC-ResSim. He had simulated both Seyhan and Ceyhan river basin models first for existing and planning scenarios and then for a search in excess water potential of each basin.

Rukuni's (2006) study is about the determination of the impact of small reservoirs on improved and sustainable rural livelihoods in semi arid regions of Zimbabwe. Water Evaluation and Planning (WEAP) system model is used to evaluate and simulate the various livelihood issues in the related subcatchment of the basins.

Growth in using simulation models in water management studies makes a good progress in computer based programs. In the following chapters some common computer based Decision Support Systems (DSS) are explained.

2.6.1 HEC-5

HEC-5 contains iterative search algorithms for making multiple-reservoir release decisions for each time interval during the simulation of a flood event. Program has optional economic analysis capabilities for computing expected annual flood damages for different operating plans. HEC-5 also has extensive capabilities for simulating reservoir operations involving hydroelectric power, water supply, and low flow augmentation.

2.6.2 WEAP

Water Evaluation and Planning system is a computer-based decision support system for integrated water resources management. Program was created by Stockholm Environmental Institute in Boston, Massachusetts. It is used to model simulations of water demand, energy demand, groundwater and water quality in a reservoir or river system. The analyst can create various models by using script editor as well (Figure 2.13).

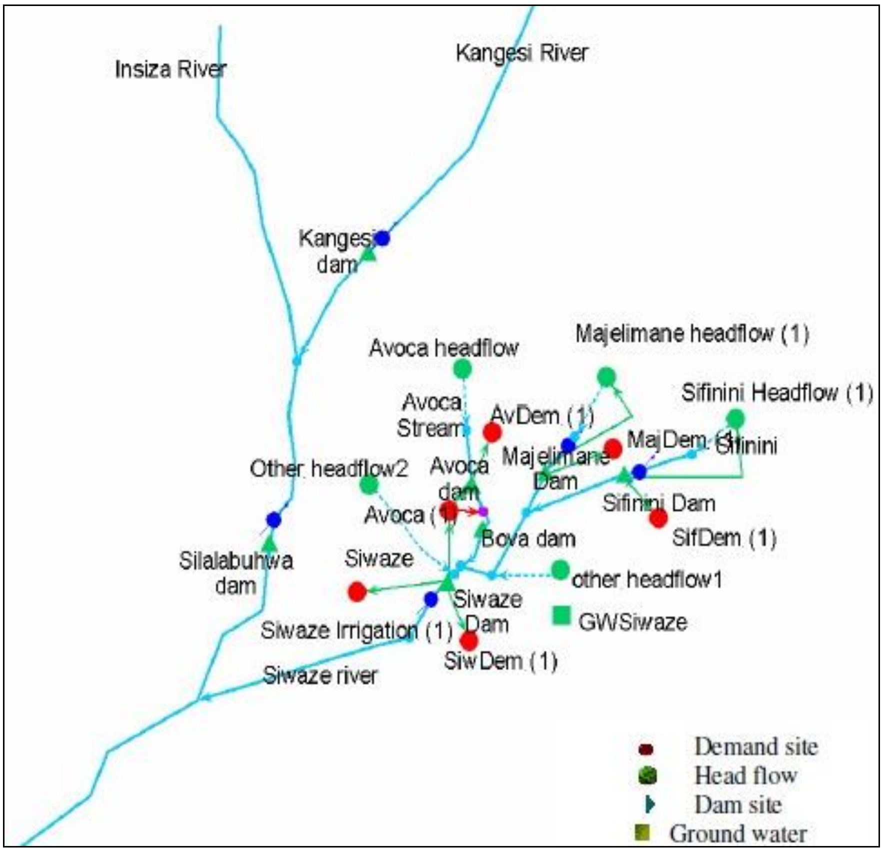


Figure 2.13 WEAP Network View (Rukuni, 2006)

2.6.3 MIKE BASIN

MIKE BASIN is a multi-purpose software to model integrated river basin planning and management. As shown in Figure 2.14 it has a river network which includes branches and nodes representing streams and important locations respectively. Program can store, analyse and visualize temporal data in Geographic Information System(GIS). MIKE BASIN is developed by a research and consulting organisation called DHI Water & Environment.

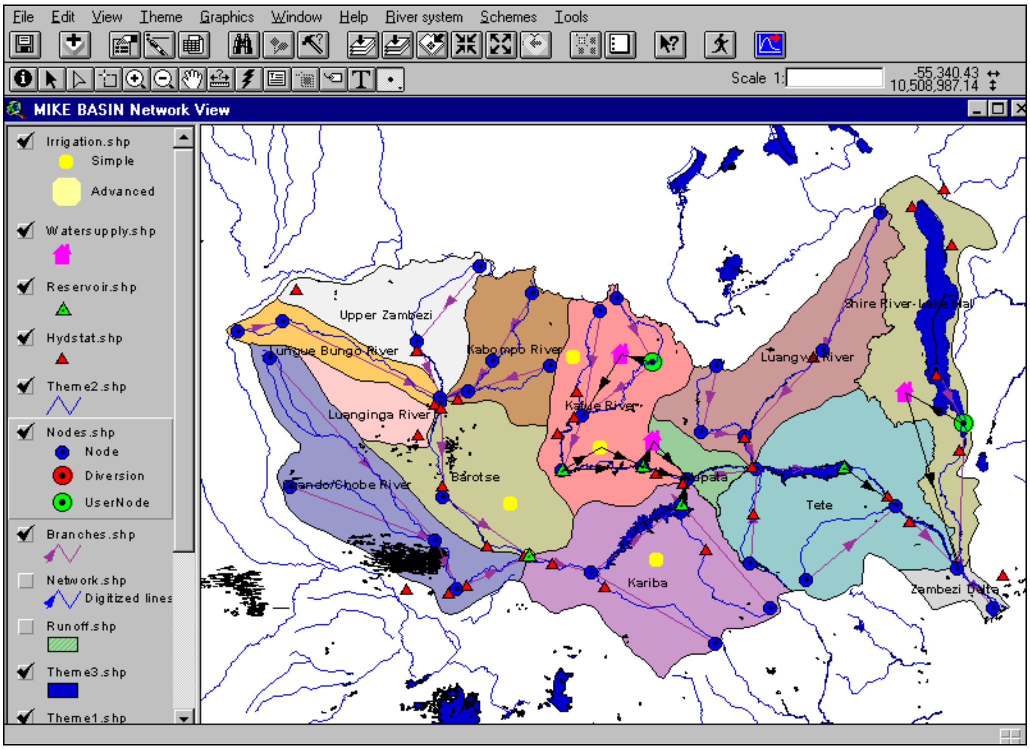


Figure 2.14 MIKE BASIN Network View (University of Texas, 2012)

2.6.4 HEC-ResSim

HEC-ResSim is a freely available reservoir simulation software developed and maintained by the US Army Corps of Engineers, Hydrologic Engineering Center. The latest release version 3.0 is used world-wide in many applications, but especially by US environmental and water management agencies. The software is based on earlier versions of HEC, but now makes use of Java code and graphical user interfaces.

The basic purpose of the HEC-ResSim model is to simulate the operation of single or multiple (interconnected) reservoirs. As input, the model requires inflow data to the system. Such data can represent measurements at stream gauges or be outputs of e.g. precipitation-runoff models. The HEC-ResSim model is able to handle in an efficient way the analysis of several alternative scenarios. Such scenarios may differ in the inflow data, the operation rules, reservoir characteristics or the general reservoir network.

Detailed documentation of the model is available from the HEC-ResSim website which has a manual consisting of 500 pages. It is recommended to check the website for model updates (Klipsch, 2007).

CHAPTER 3

KALEKÖY CASCADE RESERVOIR SYSTEM

3.1 Description of Watershed

The past three decades have seen a renaissance in the development of the land and water resources of the anciently civilized river basins of the Middle East. In recent years the Indus Valley of Pakistan, the Nile Valley of Egypt, the Khuzestan of Iran, and the Lower Mesopotamian region of Syria and Iraq have benefited from river projects on a massive scale which will promote as much economic growth in present generation as has been achieved in the past four thousand years.

There are two major rivers in the eastern region of Anatolia, the Euphrates and the Tigris. The valley of these two rivers encompasses the northern portion of the famed and fertile crescent of the Mesopotamia.

The Fırat (Euphrates) River, the largest river in the Middle-East, originates in the high mountains of Eastern Turkey at an elevation of over 3,000 meters above sea level. The Fırat River has the largest catchment area of all Turkish rivers, and is composed of two distinct parts: The upper basin and the lower basin. The upper basin is mountainous and lies above the confluence of the Fırat and the Murat rivers. The project area is within the catchment area of Murat River which is a tributary of Fırat River.

The principal tributary, the Murat, originates from the skirts of Aladağ in the vicinity of Diyadin District within the province of Ağrı. As the river continues its flow towards the west, it runs through the province of Ağrı. At the end of Ağrı Plain, Şeryan Creek joins the river, fed by various tributaries. Thereafter, Murat River runs through a valley for about 70 km towards the south and passes Malazgirt and Bulanık plains. The tributaries as Nadirşeyh, Hınıs and Patnos join the river branch. Running through Alpaslan I dam site where construction was completed, the river is joined by Bingöl Creek. Then it reaches Alpaslan 2 dam site. In Muş plain, it confluences with Karasu and runs into a deep valley. Göynük Creek joins the river branch in the vicinity of Genç District. The river continues its flow through the valley and reaches the reservoir of Keban Dam, close to Palu District.

The development of the water resources of the Murat River, has been investigated by the state agencies through its agencies over many years. The authorities under consideration have developed projects aimed for irrigation, water supply and energy utilizing the flow data of these stations in order to develop the water and land resources of Murat River Basin. Some of these projects are under operation, whereas, some are under construction or in final design, planning, and reconnaissance stages.

Kaleköy reservoir system lies immediately upstream of Keban, and, from the point of view of size and cost of power and energy production, it is one of the most attractive hydroelectric projects not only on the Murat River but in Turkey as a whole. The reservoirs and their locations are given in Figure 3.1.

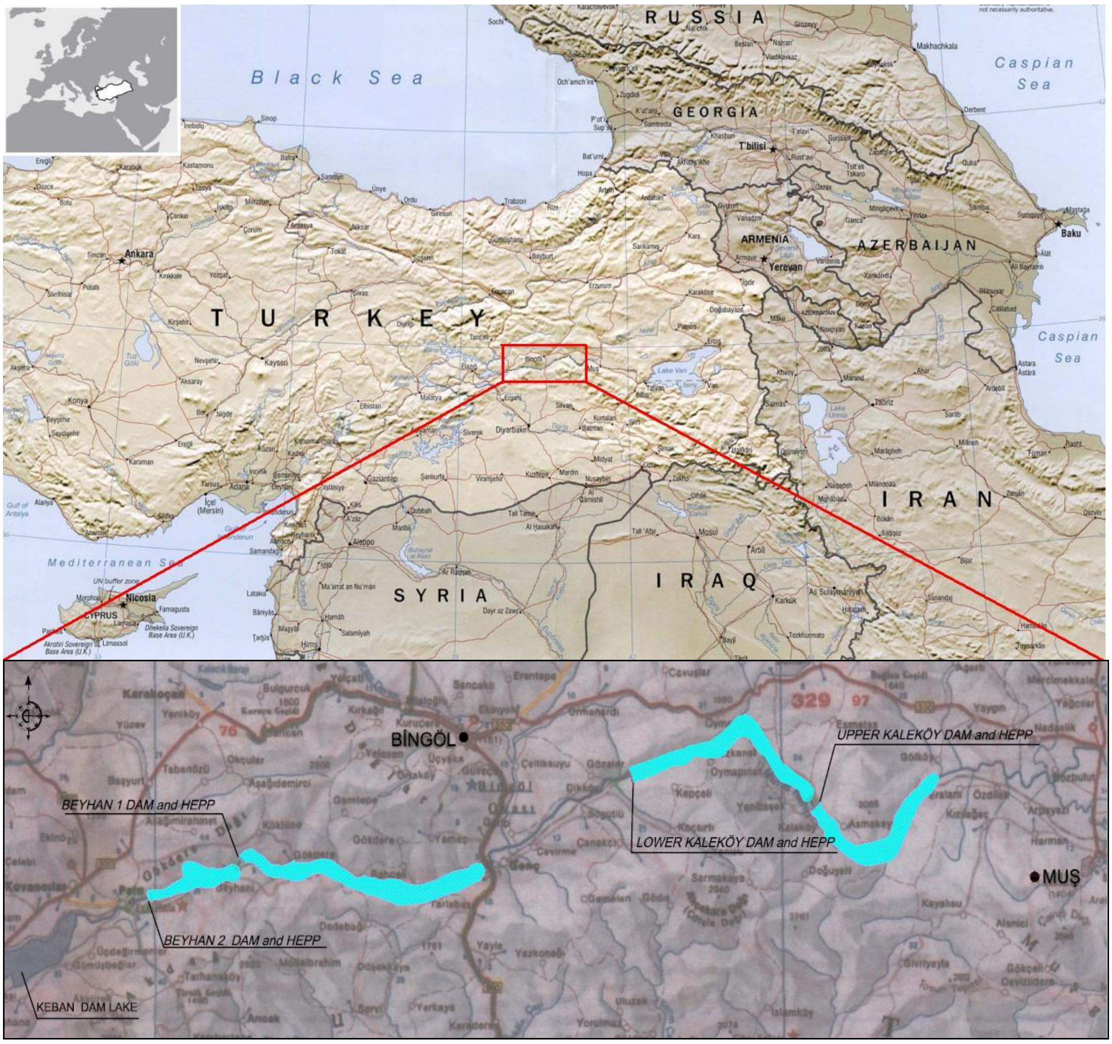


Figure 3.1 Location of the Kaleköy reservoir system on map of Turkey (World Map, 2012)

Figure 3.2 illustrates the layout of the facilities aiming to utilize the hydroelectric potential between Alpaslan 1 Dam and Keban Dam. Note that, Keban and Alpaslan 1 Dams are in operation stage, Alpaslan 2 Dam in final design stage, and the others are in feasibility stage. In addition to this, a schematic diagram of a cascade system is shown in Figure 3.3.

The physical characteristics of the dams, minimum and maximum reservoir operation water levels have been obtained identically from the Feasibility Report (Temelsu International Engineering Services Inc., 2011).

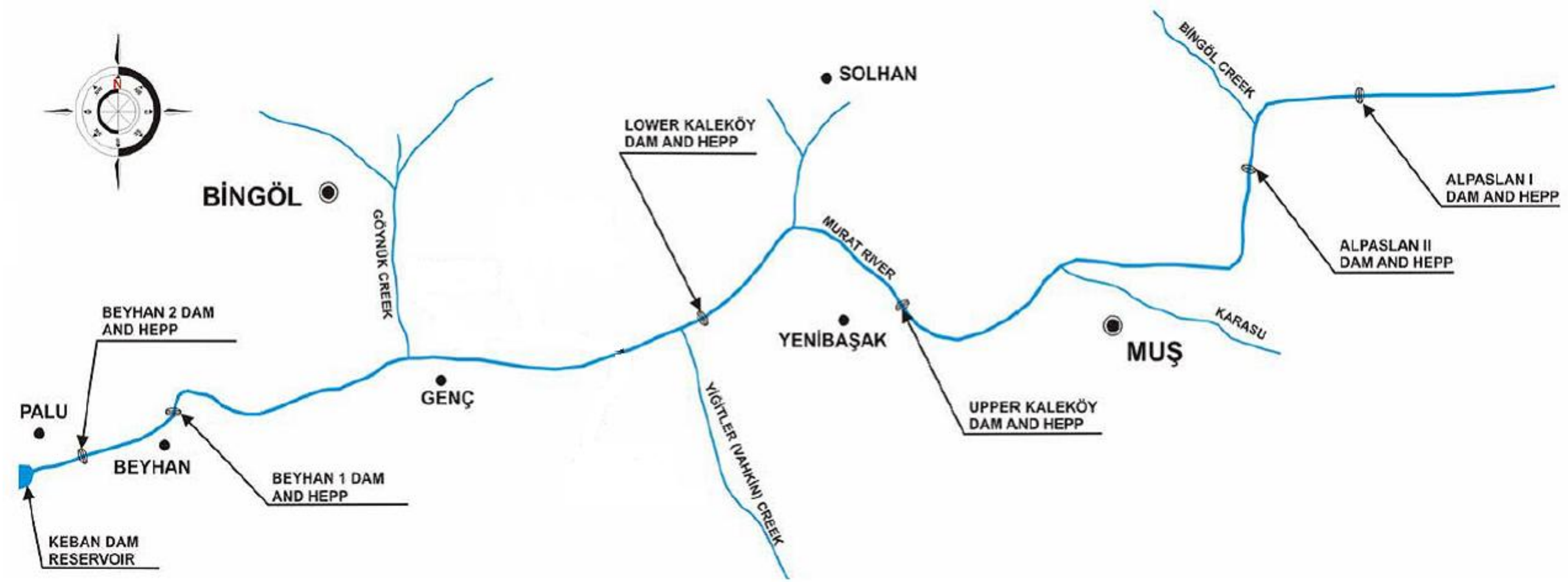


Figure 3.2 Hydropower plants' layout in the basin (Temelsu International Engineering Services Inc., 2011)

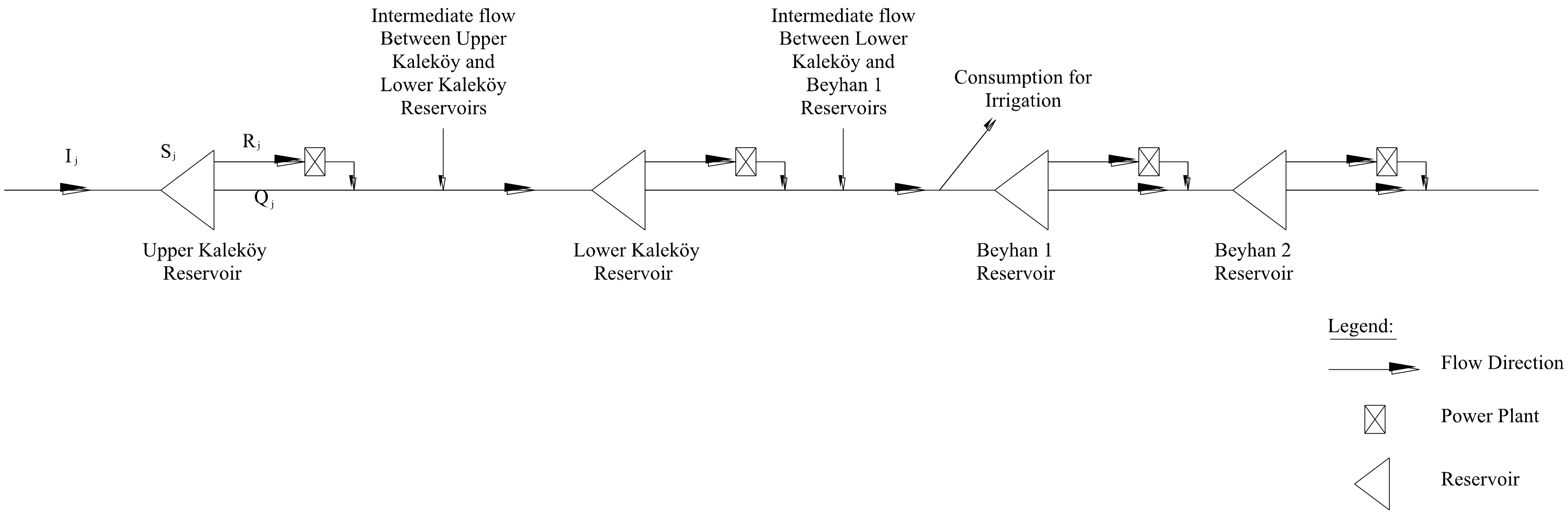


Figure 3.3 Schematic diagram of Kaleköy reservoir system

Limitation of the tailwater levels, as well as the topography of the region, geological conditions affect dam axes locations and operation water levels as mentioned in Feasibility Report (2011). Hydroelectric potential between the elevations of 1225 m and 870 m for Murat tributary was divided in two stages. These two stages compose the upstream part between the elevations of 1225 m and 1020 m and the downstream part between the elevations of 1020 m and 870 m. Settlement areas and irrigation areas specify the boundaries of the stages as shown in Figure 3.4. The maximum water elevation at the upstream part has been specified as 1225 m depending on the irrigation and drainage of Muş Plain, whereas the tailwater level has been specified as 1020 m depending on the elevation of Bingöl Plain. At the Kaleköy reservoir system downstream part, maximum water elevation has been specified as 982 m depending on the layout of Genç District. Tailwater elevation at the downstream part has been accepted as 870 m.

For the purpose of utilizing the means of energy offered by Murat River between the elevations of 870-1225 m, the main facilities from the upstream towards the downstream are a series of four dams listed as follows:

i) Upper Kaleköy Dam and HEPP
ii) Lower Kaleköy Dam and HEPP
iii) Beyhan 1 Dam and HEPP
iv) Beyhan 2 Dam and HEPP

It has been accepted that the Kaleköy reservoir system would have been completed and commissioned in 2015.

3.2 Installed Capacity

The first step in any system analysis study is to identify the hydrologic and physical features of the system.

The powerplant installed capacity establishes an upper limit on the amount of energy that can be generated in a period. The installed capacities of Upper Kaleköy HEPP, Lower Kaleköy HEPP, Beyhan 1 HEPP and Beyhan 2 HEPP have been determined as 600 MW, 450 MW, 550 MW, 255 MW, respectively by the owner based on the decision of General Directorate of Electrical Power Resources.

The upstream development facilities existing or planned to be constructed on Murat River and its tributaries are directly related with this project only in terms of water supply. The water requirements and water consumptions of the projects developed for the purposes of water supply and irrigation at the upstream of the proposed facilities have been analysed in two steps as for the existing and future cases. The effect of these water requirements on the inflows of the Kaleköy reservoir system has been taken into account and the inflows of the facilities have been calculated in Feasibility Report (Temelsu International Engineering Services Inc., 2011).

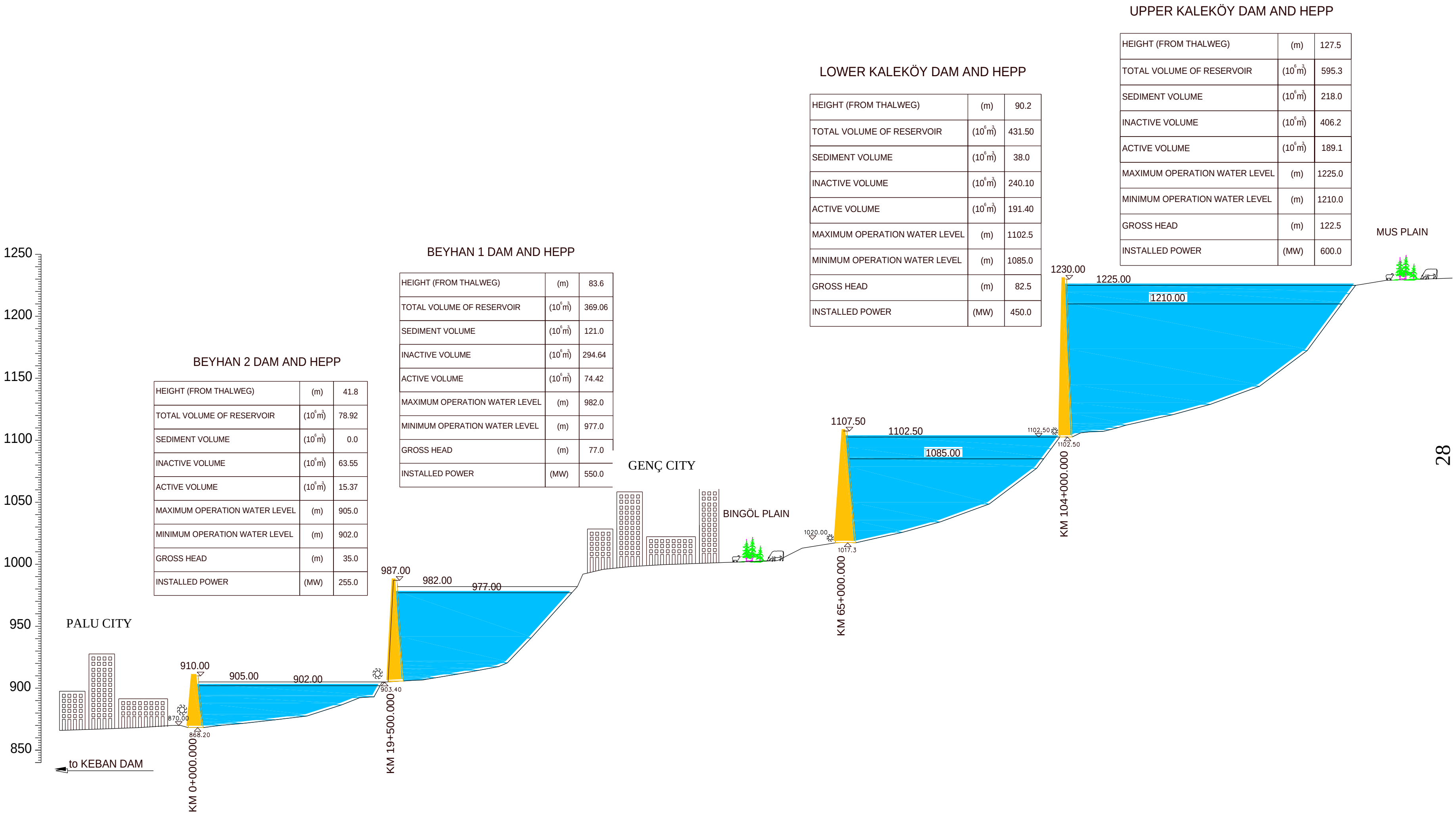


Figure 3.4 Profile of Kaleköy reservoir system

3.3 Hydrology

For a feasible decision on the size of the works, it is important to know the available river discharges at each dam site for a long period.

The flow through the Fırat basin varies from year to year. A summary of the hydrology of the Kaleköy reservoir system is given in this chapter. More detailed information is available in the Feasibility Report (Temelsu International Engineering Services Inc., 2011).

The greater part of the precipitation occurs between November and May and in the higher areas generally falls as snow from the beginning of December and sometimes as early as November. This snow accumulates during the winter and melts in April and May and, in conjunction with rainfall, produces the largest floods.

For the purpose of developing the water and land resources of the Murat River Basin, hydrometric stations were installed by the DSİ and EİE Administration on Murat River and its tributaries on various dates. Daily precipitation observations are carried out at all of the meteorological stations. In addition to this, other meteorological observations such as temperature, evaporation, relative humidity, wind, radiation are also recorded at some of the stations.

Murat River and its tributaries are the resource of water in the study area. The catchment areas of Murat River at the axis locations of Beyhan 2, Beyhan 1, Lower Kaleköy and Upper Kaleköy dams are, respectively; 25 426 km², 25 274 km², 22 243 km² and 21 337 km².

In this study, the operation studies have been performed in two stages on the basis of monthly flows obtained from Feasibility Report (Temelsu International Engineering Services Inc., 2011):

i) "Existing Case Inflows"

The case illustrating the full development of the irrigation projects existing at the upstream, or the irrigation projections of the projects put under operation, on the date of 2015.

ii) "Full Development Case Inflows"

The case illustrating the commissioning of all existing and future upstream projects with or without dams and aiming water supply, irrigation and energy production, and also illustrating the full development of their irrigation schemes.

The installed capacity and total energy production for Kaleköy reservoir system have been determined, taking the projects either existing or planned to be constructed at the upstream, into account. Accordingly, the flow series of the dams with big reservoirs (storage volumes) either existing or planned to be constructed at the upstream have been updated, operation studies have been carried out in Feasibility Report (Temelsu International Engineering Services Inc., 2011).

For a series of hydroelectric stations such as those envisaged on the Lower Murat, the useful discharges for each of the plants are composed of the following elements:

i) the inflows from the intermediate catchment area situated between the plant under consideration and that immediately upstream,

ii) the discharge of the plant situated directly upstream,

iii) the losses due to evaporation from the surface of the reservoir.

3.3.1 Climate

Continental climate is dominant within the catchment area of Murat River. The characteristics of this climate reveal that winters are cold and rainy, summers are hot and dry. Precipitation and temperature values are taken from Table 3.1.

Table 3.1 Annual Precipitation and Temperature (Temelsu International Engineering Services Inc., 2011)

Name of Facility	Annual mean precipitation	Annual mean temperature
Upper Kaleköy Dam	533 mm	11.8 ^{o}
Lower Kaleköy Dam	543 mm	11.8 ^{o}
Beyhan 1 Dam	576 mm	13.7 ^{o}
Beyhan 2 Dam	576 mm	13.7 ^{o}

3.3.2 Reservoir Inflows

Required input data of the model consist of inflow data, evaporation data and dam features. Thirty years of historical streamflow data is generally considered to be the minimum necessary to assure statistical reliability (EM 1110-2-1701, 1985). The model simulations cover the period Oct. 2015 to Sep. 2055 in daily time-steps. 40 years of monthly hydrological data are available for the simulation. The data were derived from observations of a 40-year period covering Oct. 1966 to Sep. 2006. Historic values are used for inflow and evaporation data. In other words, it is assumed that the pattern of runoff that occurred during the period of flow records will repeat itself in the future in the same chronological sequence; thus this represents the long-term water yield of the catchment areas. While such a method does not fully account for all the possible vagaries in runoff which may occur over long periods of time, it is nevertheless sufficiently reliable for the present purpose, and no data are available upon which better forecasts of the future behaviour of the river could be made. The operation studies performed in two stages on basis of monthly flows are “existing case” and “full development case”. The scenarios "existing case" and " full development case" differ in the flow data.

A flow duration curve gives the percentage of time a given flow has been equaled or exceeded for the period of record. The percentage of monthly flow data equal to or greater than a given flow measurement, termed the "percentage exceedance" is calculated.

Annual inflow graphs and flow duration curves are shown in Figures 3.5-3.12 respectively. In addition to this, comparison of monthly inflows at Upper Kaleköy reservoir in existing and full development cases are shown in Figure 3.13.

The mean runoff of the 40-year period of the “existing case” is computed to be 167 m^3/s at Upper Kaleköy, 191 m^3/s at Lower Kaleköy, and 240 m^3/s at Beyhan 1 and Beyhan 2.

The mean runoff of the 40-year period of the “full development case” is computed to be 131 m^3/s at Upper Kaleköy, 155 m^3/s at Lower Kaleköy, and 204 m^3/s at Beyhan 1 and Beyhan 2.

Murat river has relatively regular flow regime characterised by two months of high average flow in April and May, and with minimum flow usually occurring in August. The period of the eight consecutive driest months extends from July to February.

The river flows are influenced by the melting of snow which usually begins in mid-April and may last until the end of May. Except on some permanently snow-capped peaks snow falls in the upper areas of the basin normally during December and occasionally also during November.

The most severe and prolonged period of subnormal runoff that has been recorded to date was the three-year period between 1999 and 2001. This period included the year of lowest annual runoff (2000), and the average annual flow during the three-year period was only about 64 percent of the average runoff for the full period of records. Upper Kaleköy and Lower Kaleköy reservoirs being the largest reservoir in the system, will assume the dominant role of providing long-term holdover storage.

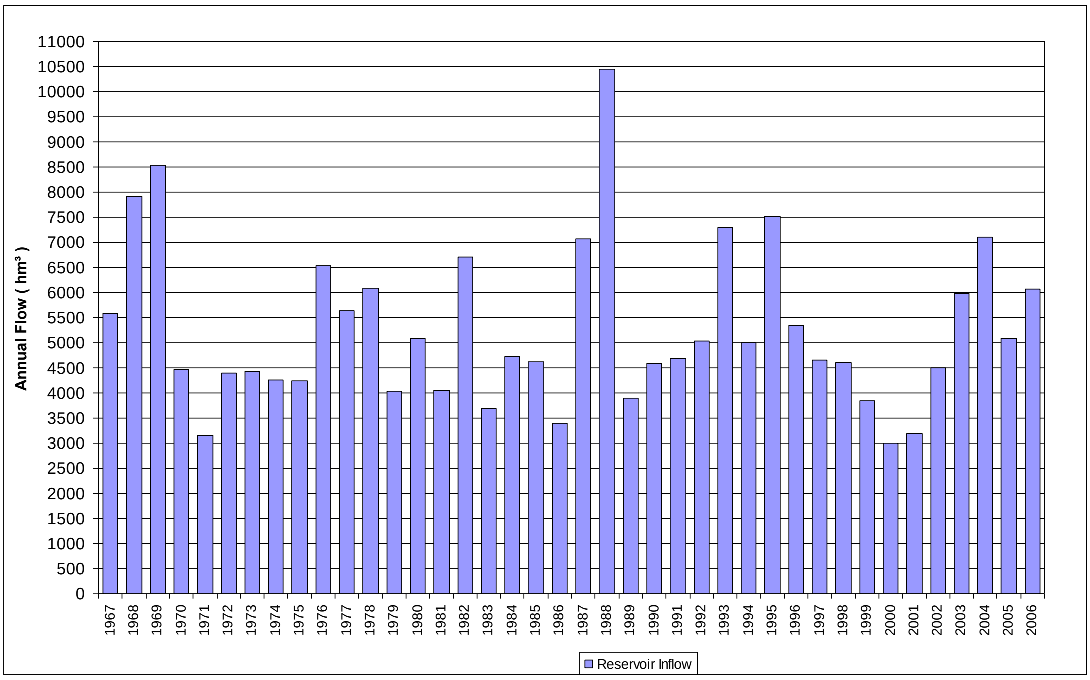


Figure 3.5 Annual inflow of Upper Kaleköy reservoir in existing case

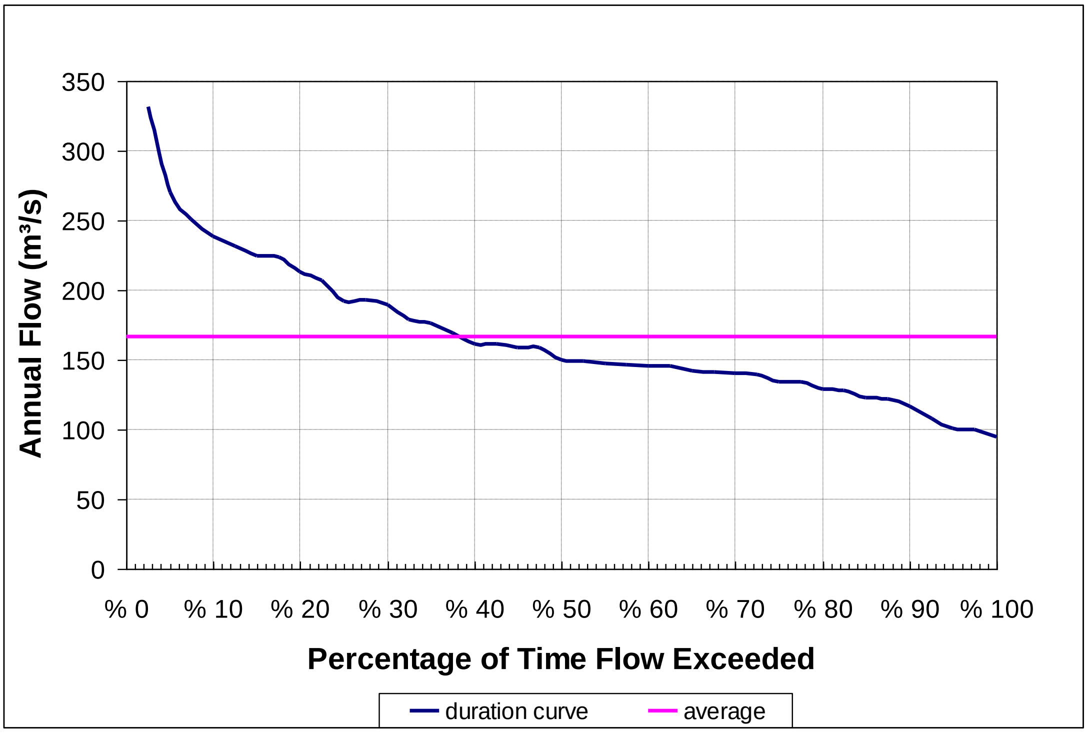


Figure 3.6 Annual flow duration curve of Upper Kaleköy reservoir in existing case

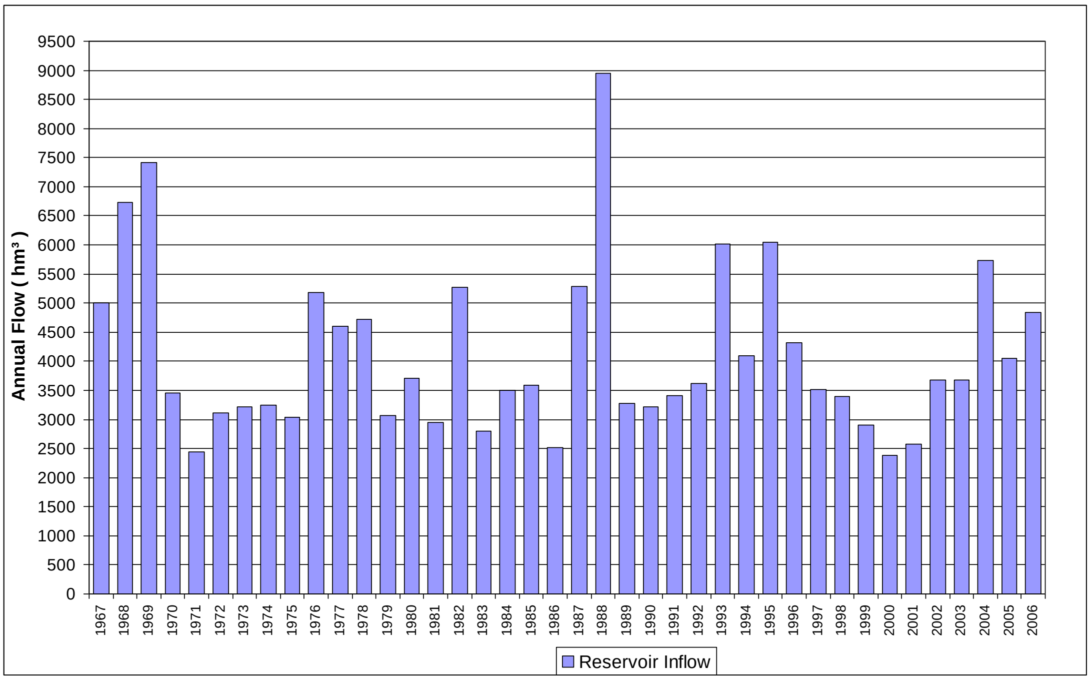


Figure 3.7 Annual inflow of Upper Kaleköy reservoir in full development case

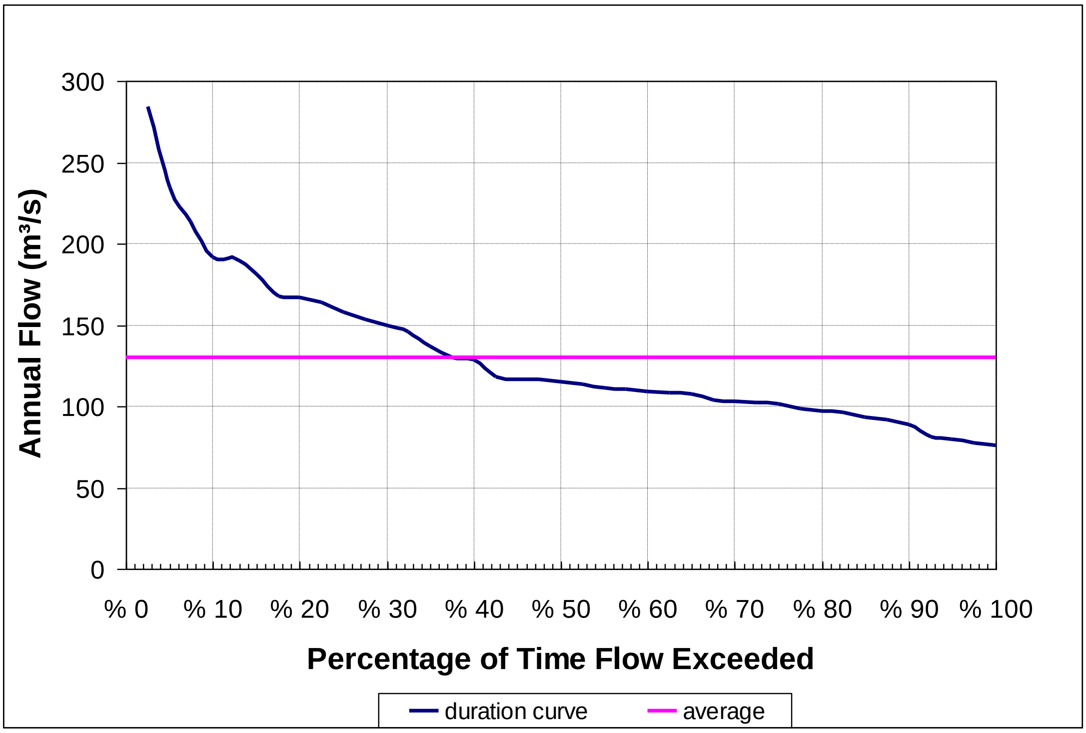


Figure 3.8 Annual flow duration curve of Upper Kaleköy reservoir in full development case

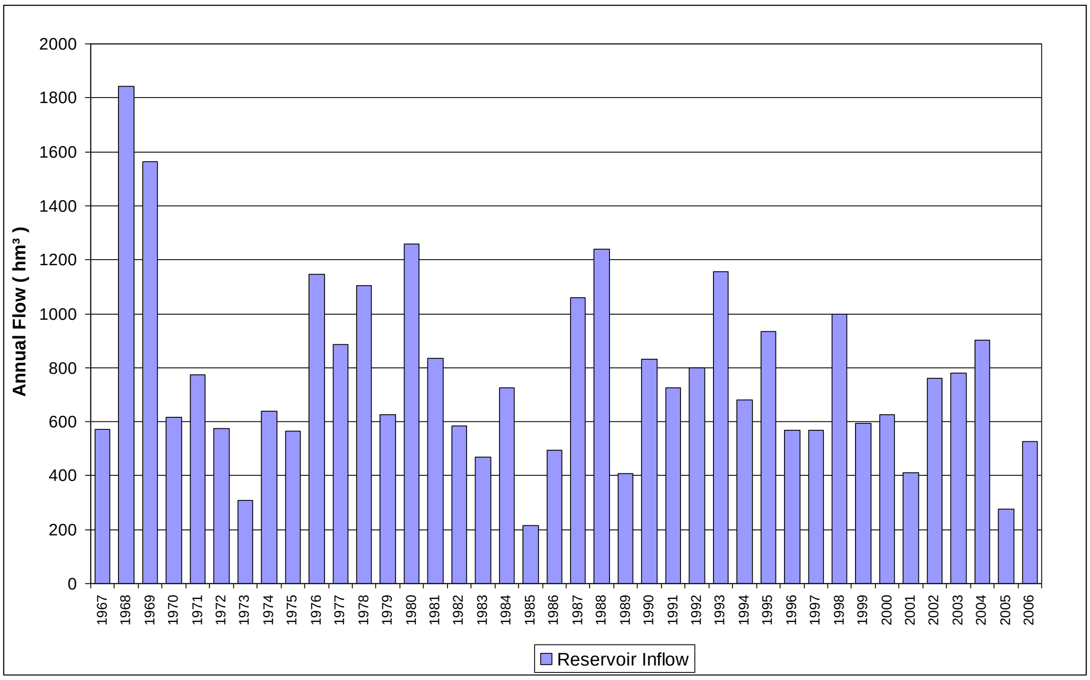


Figure 3.9 Annual intermediate inflow between Upper Kaleköy reservoir and Lower Kaleköy reservoir in existing and full development case

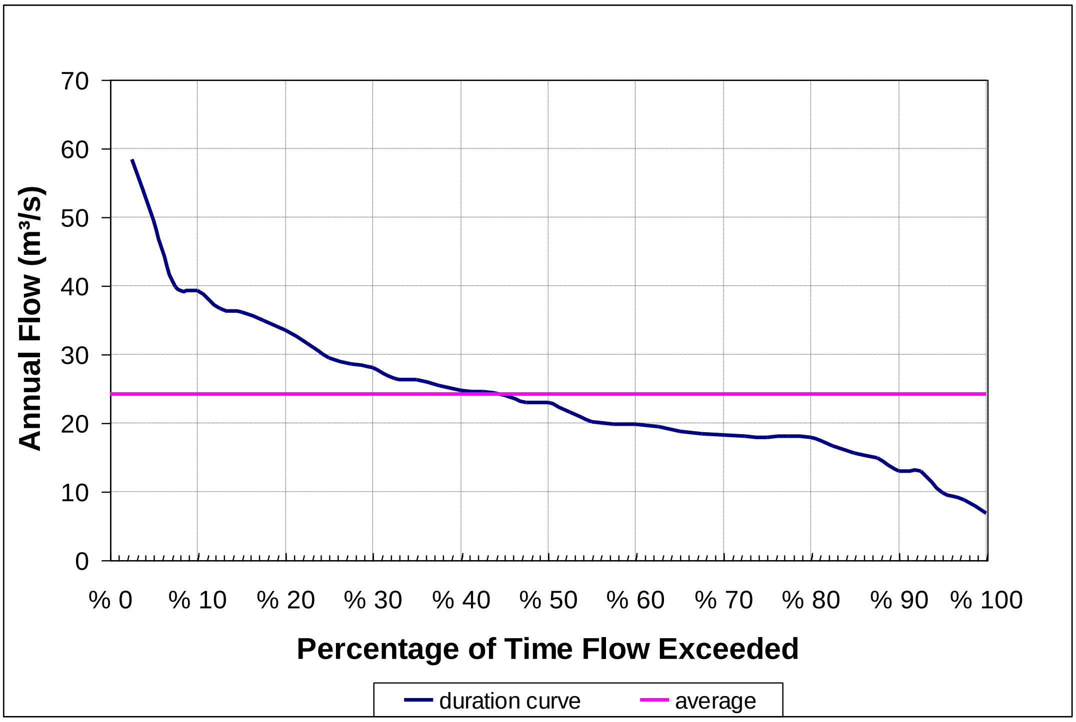


Figure 3.10 Annual flow duration curve of intermediate inflow between Upper Kaleköy and Lower Kaleköy reservoir in existing and full development case

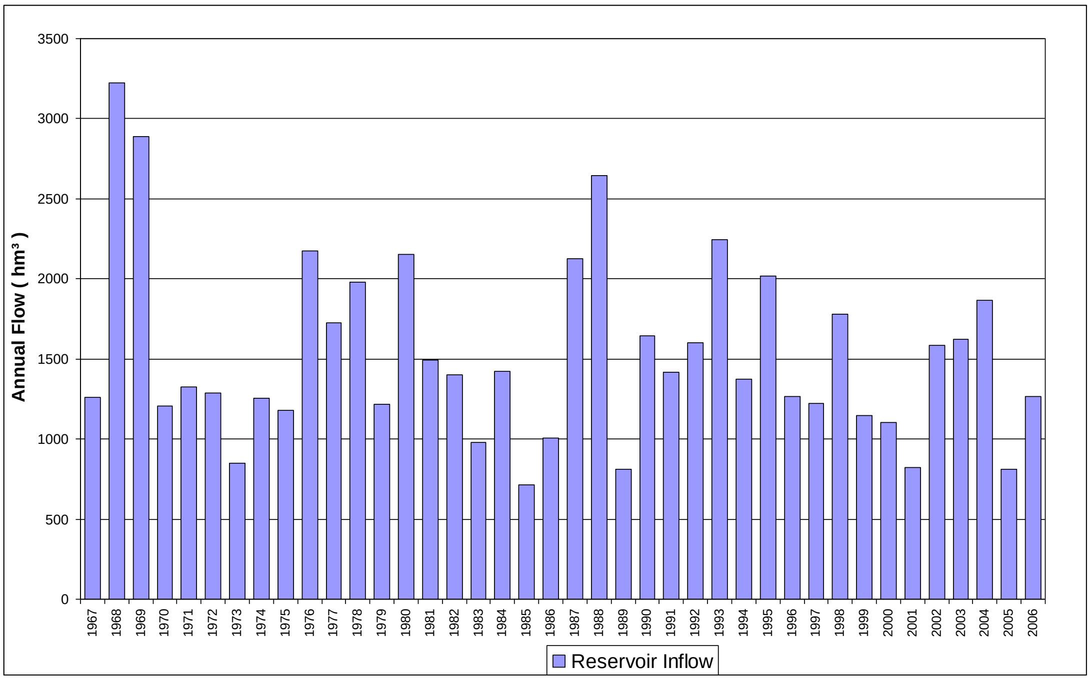


Figure 3.11 Annual intermediate inflow between Lower Kaleköy reservoir and Beyhan 1 reservoir in existing and full development case

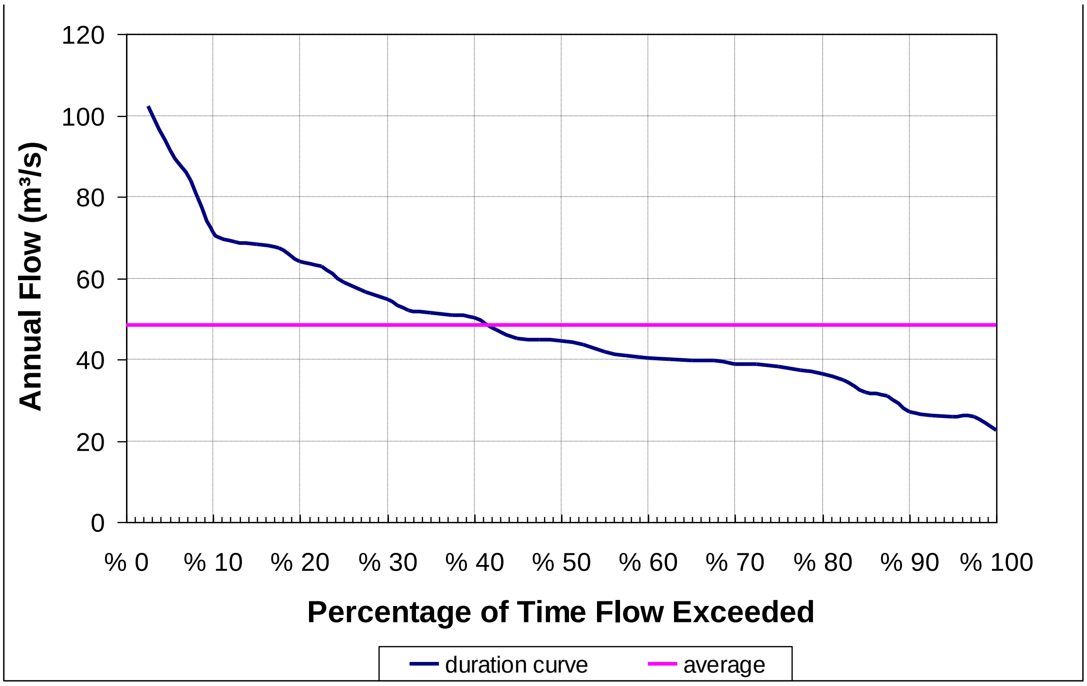


Figure 3.12 Annual flow duration curve of intermediate inflow between Lower Kaleköy reservoir and Beyhan 1 reservoir in existing and full development case

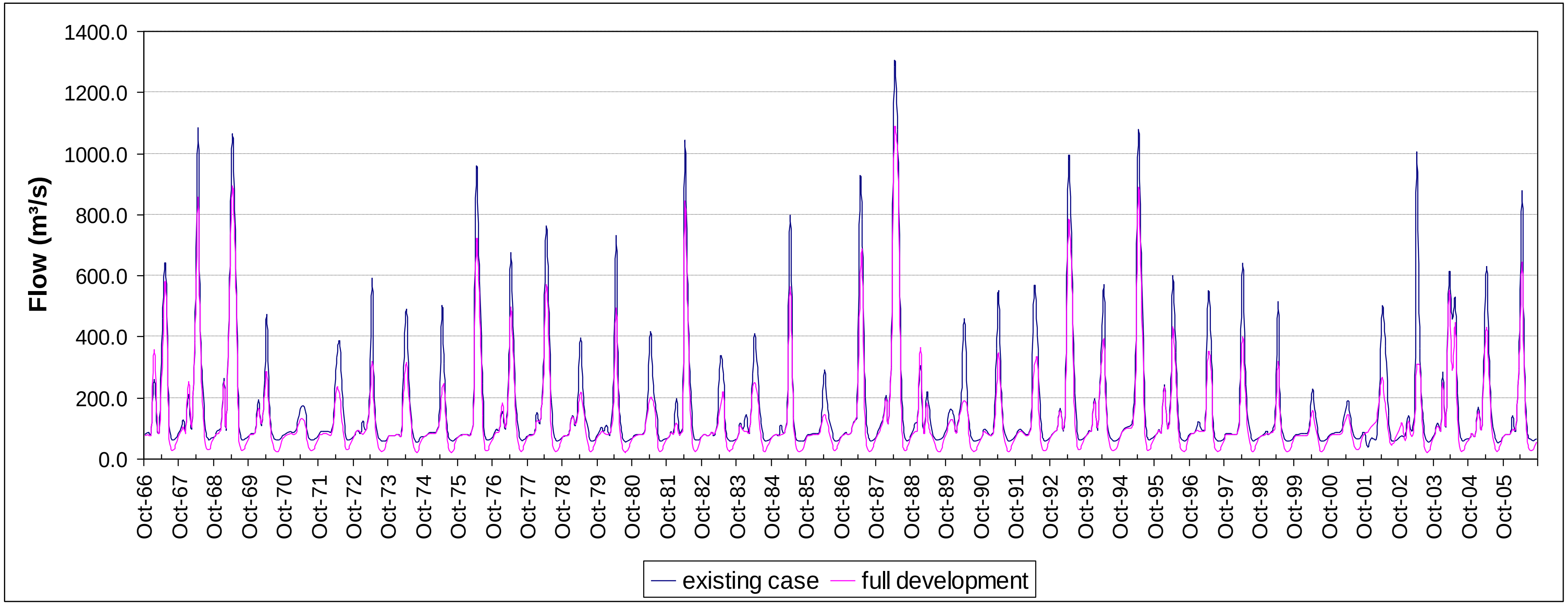


Figure 3.13 Comparison of monthly inflow at Upper Kaleköy reservoir in existing and full development case

3.3.3 Environmental Flows

When hydraulic structures are constructed on a river to regulate water, environmental flow is the minimum water regime to maintain ecosystems and their benefits (Dyson et al., 2003). Environmental flows based on the feasibility report prepared by Temelsu Inc., Turkey in 2011 are shown in Table 3.2.

Environmental flow in wet season (march, april, may, june) approximately equals to 20 percent of the annual average flow, in dry season it equals to 10 percent of the annual average flow. However, environmental flows should be set on the basis of the needs of the downstream reach and not simply from a formula whether related to average flow or the flow duration curve.

Table 3.2 Environmental Flows

Month	**Q_{env} (m^3/s)**			
	Upper Kaleköy	**Lower Kaleköy**	**Beyhan 1**	**Beyhan 2**
January	17.73	20.15	37.50	37.50
February	17.73	20.15	37.50	37.50
March	35.45	40.31	50.00	50.00
April	35.45	40.31	50.00	50.00
May	35.45	40.31	50.00	50.00
June	35.45	40.31	50.00	50.00
July	17.73	20.15	37.50	37.50
August	17.73	20.15	37.50	37.50
September	17.73	20.15	37.50	37.50
October	17.73	20.15	37.50	37.50
November	17.73	20.15	37.50	37.50
December	17.73	20.15	37.50	37.50

3.3.4 Trends in River Flow

The flow data shows that flows have been significantly below the long term average in recent years. The average flow over the past 10 years is about 91% of the long term average. It is not clear whether this is a result of natural variation or some long-term trend, but it would be prudent to consider the impact of lower flows on power generation.

The pattern of average monthly flows for the Murat at Upper Kaleköy is shown in Figure 3.13, from which the following hydrological conditions were deduced in the existing case:

Average flow in the driest month (November 2002)	39.8 m^3/s
Average flow in the driest year (2000)	95.1 m^3/s
Average flow in the driest 3-year period (1999 - 2001)	106.0 m^3/s
Average flow over the 40 years (1966 - 2006)	167 m^3/s
Average flow over the 10 years (1996 - 2006)	152.23 m^3/s

3.3.5 Evaporation

Net evaporation is normally expressed in terms of an average monthly value in millimeters applicable for all reservoirs. It can be converted to volume by multiplying with the reservoir surface area. Evaporation defined as 12 monthly values would be used repeatedly throughout a multi-year simulation. Given evaporation data, HEC-ResSim computes the net evaporation volume for each time period based on the average reservoir area during the time interval.

According to the Temelsu Feasibility Report, evaporation data for Upper Kaleköy and Beyhan 1 are given in Figure 3.14 and 3.15, respectively. The values of Upper Kaleköy are assumed to be valid also for Lower Kaleköy and the values of Beyhan 1 are assumed to be valid also for Beyhan 2.

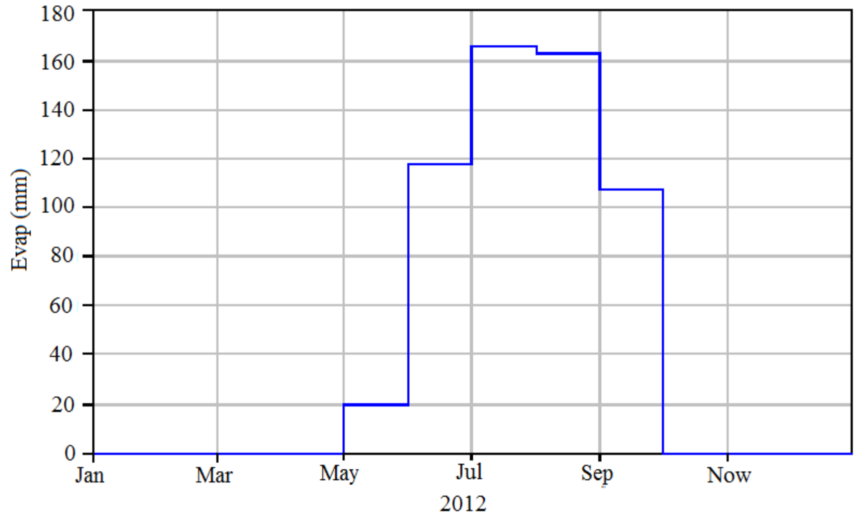


Figure 3.14 Monthly evaporation data for Upper and Lower Kaleköy Dams and HEPPs (Temelsu International Engineering Services Inc., 2011)

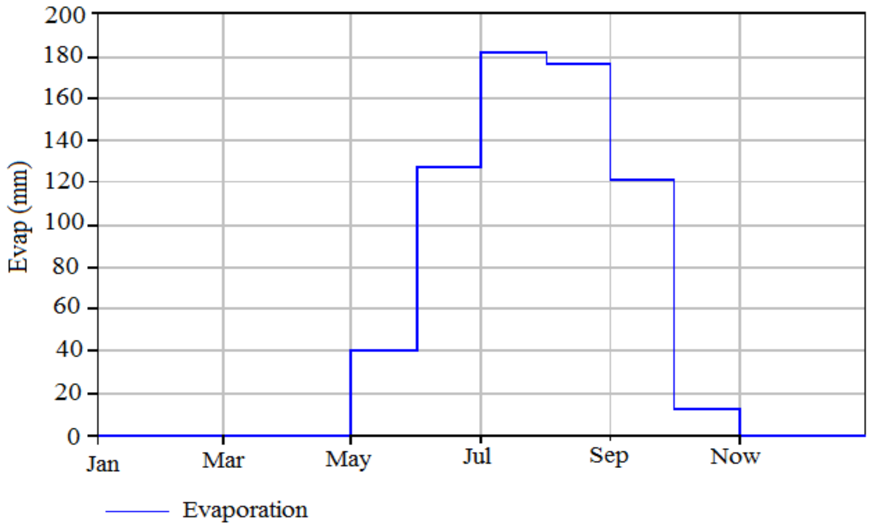


Figure 3.15 Monthly evaporation data for Beyhan 1 and Beyhan 2 Dams and HEPPs (Temelsu International Engineering Services Inc., 2011)

3.3.6 Sediment Yield

When Kaleköy reservoir system is under operation, Alpaslan I Dam will be under operation too. For this reason, Alpaslan I Dam will control the sediment volume expected from its own basin. Dead volume for each reservoir is calculated according to the 50 years operation period in Feasibility Report (Temelsu International Engineering Services Inc., 2011). Values in Table 3.3 are directly obtained from the same report.

Vortex effect limits operation water level as minimum. Whether the submergence provided at the minimum water level is sufficient or not is checked in order to avoid vortex formation in front of the intake structure. Several formulas have been developed that define the submergence required.

For a recommended method for computing submergence requirements at well operating prototypes, ASCE (1995) provided a graph as shown in Figure 3.16. The recommendations are valid for intakes with proper approach flow conditions. An example calculation for Beyhan 2 Dam's intake structure is presented below.

$$F_r = \frac{V}{\sqrt{g.D}} \quad (3.1)$$

Where

F_r = Froude number = 5.71/(9.81*7.80)0.5 = 0.653
Q = turbined flow = 272.90 m³/s
D = diameter of the penstock = 7.80 m = 25.584 ft
A = area of the penstock = 47.78 m²
V = velocity of the flow = 272.90/47.78 = 5.71 m/s = 18.73 ft/s

$$h = 2F_r + 1/2 \quad (3.2)$$

where

h = Submergence depth is defined as the distance between minimum water level and centerline of intake

h/D = 2*0.653 + 0.5
h = 1.806*7.8 = 14.1 m
Existing Submergence = 902.00 – 878.90 = 23.1 m > 14.1 m

Table 3.3 Sediment volumes of reservoirs

Name of Facility	Dead storage volume (hm³)	Dead storage height (m)	Invert elevation of intake structure (m)	Minimum operation water level (m)
Upper Kaleköy	218.0	1189.0	1190.0	1210.0
Lower Kaleköy	38.0	1048.0	1069.0	1085.0
Beyhan 1	121.0	962.0	962.0	977.0
Beyhan 2	0.0	868.2	875.0	902.0

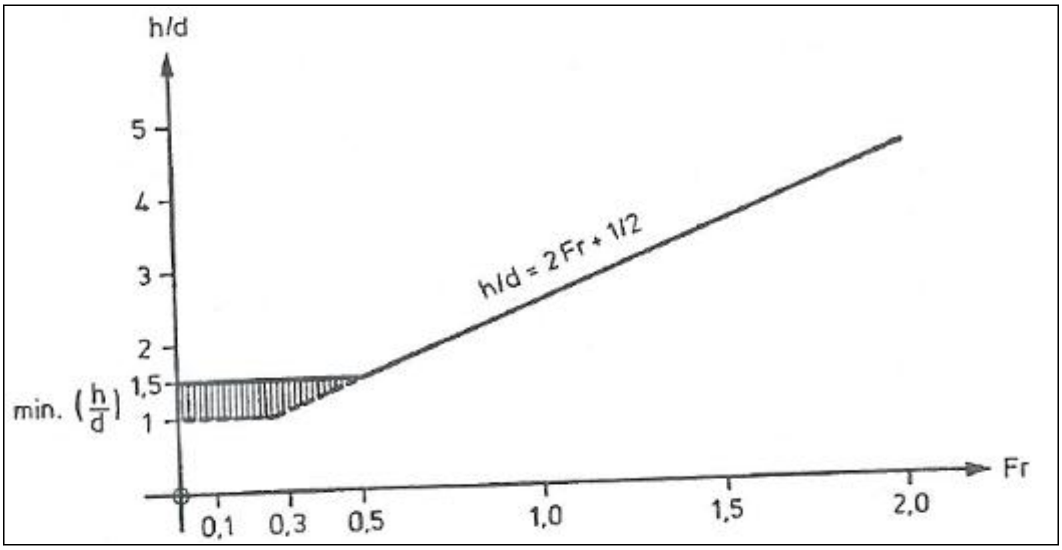


Figure 3.16 Recommended submergence for intakes (ASCE, 1995)

3.4 Reservoir Storage

Reservoirs are defined by a series of relationships based on storage. The storage against maximum outflow relationship is required. For conservation studies, reservoir areas are needed for evaporation computation and elevations are needed for hydropower computations. Both area and elevation are given as functions of storage.

The elevation-area curves for the dam in Kaleköy reservoir system is given in Figures 3.17 - 3.20.

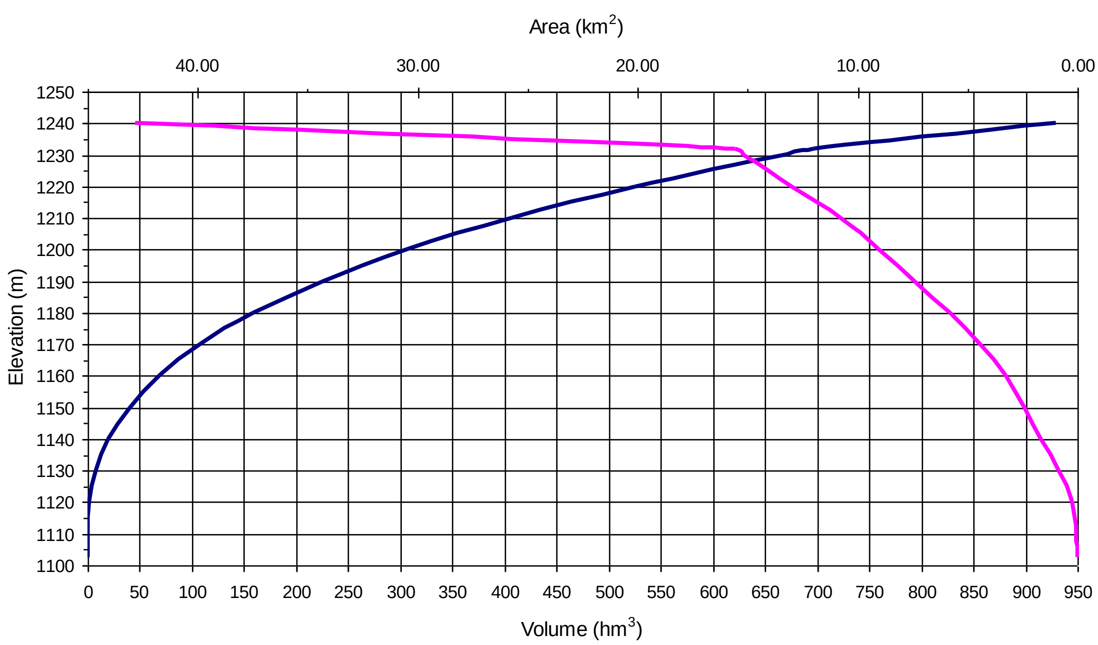


Figure 3.17 Elevation-area curve for Upper Kaleköy Dam (Temelsu International Engineering Services Inc., 2011)

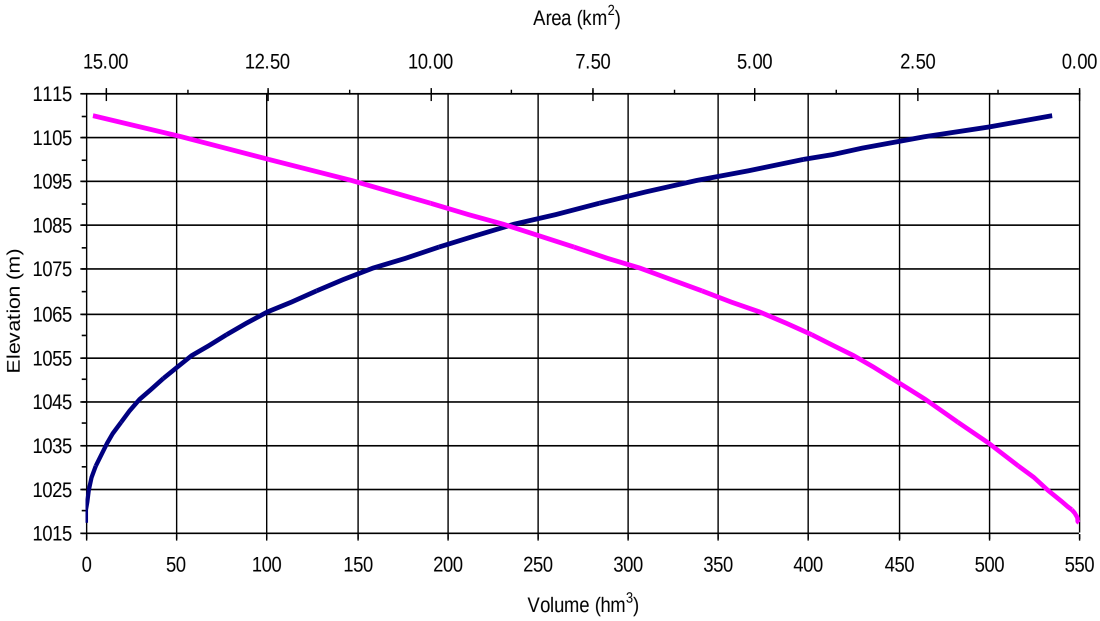


Figure 3.18 Elevation-area curve for Lower Kaleköy Dam (Temelsu International Engineering Services Inc., 2011)

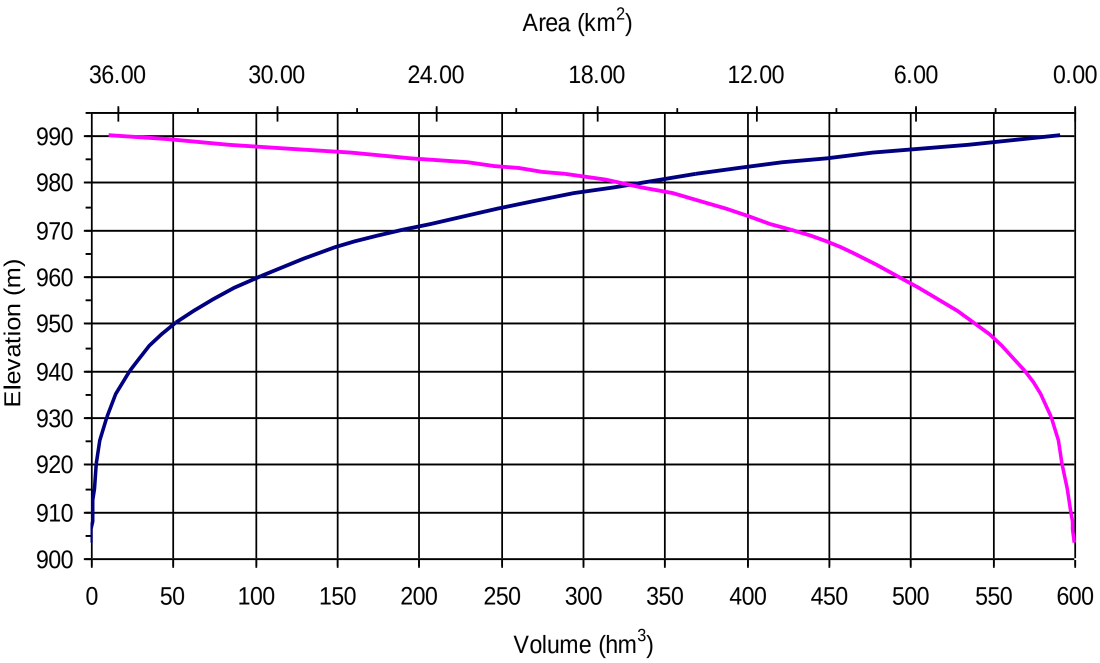


Figure 3.19 Elevation-area curve for Beyhan 1 Dam (Temelsu International Engineering Services Inc., 2011)

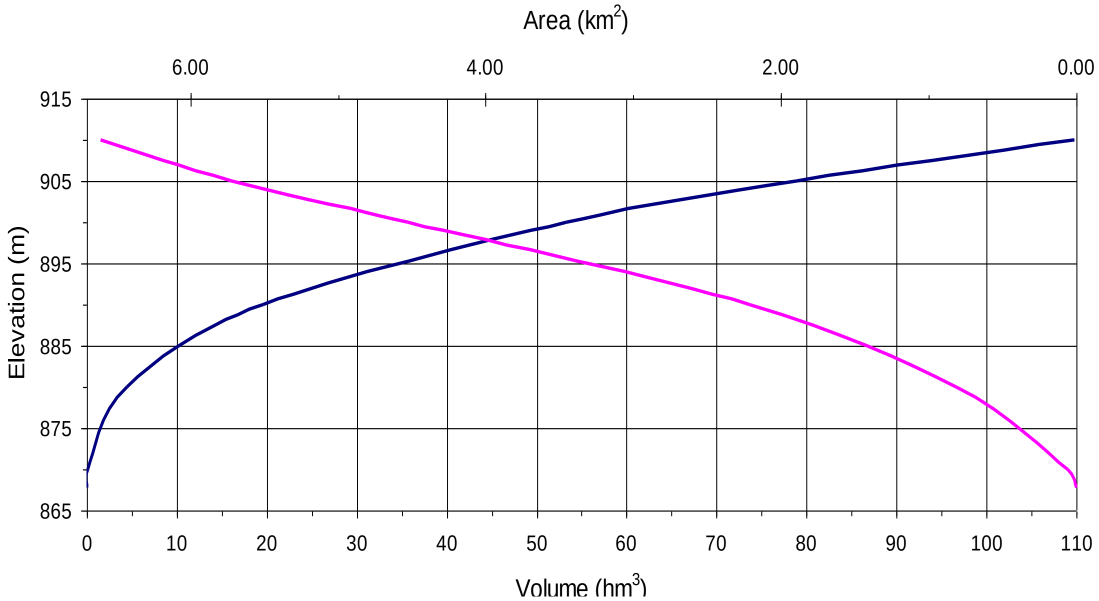


Figure 3.20 Elevation-area curve for Beyhan 2 Dam (Temelsu International Engineering Services Inc., 2011)

3.5 Tailwater Rating Curves

The tailwater may be specified as a constant value or with a rating curve. If a downstream lake elevation could affect the tailwater elevation, the program can check that elevation to see if it is higher than the block loading tailwater elevation or the tailwater rating curve. If it is, then the downstream lake elevation would be used. When two or more ways are used to describe the tailwater, the higher tailwater is used.

Tailwater elevation is a function of the total project discharge, the outlet channel geometry, and backwater effects and is represented by a tailwater rating curve.

Developing a curve for tailwater elevation versus river discharge can be the source of a great deal of field work. A way of developing a tailwater curve for a given site; is to develop the curve from the computed backwater curve, i.e., HECRAS 4.1, developed by the Hydraulic Engineering Center (HEC), U.S. Army Corps of Engineers, Davis, California.

The tailwater rating curves for all the dam sites are given in Figures 3.21-3.23 respectively.

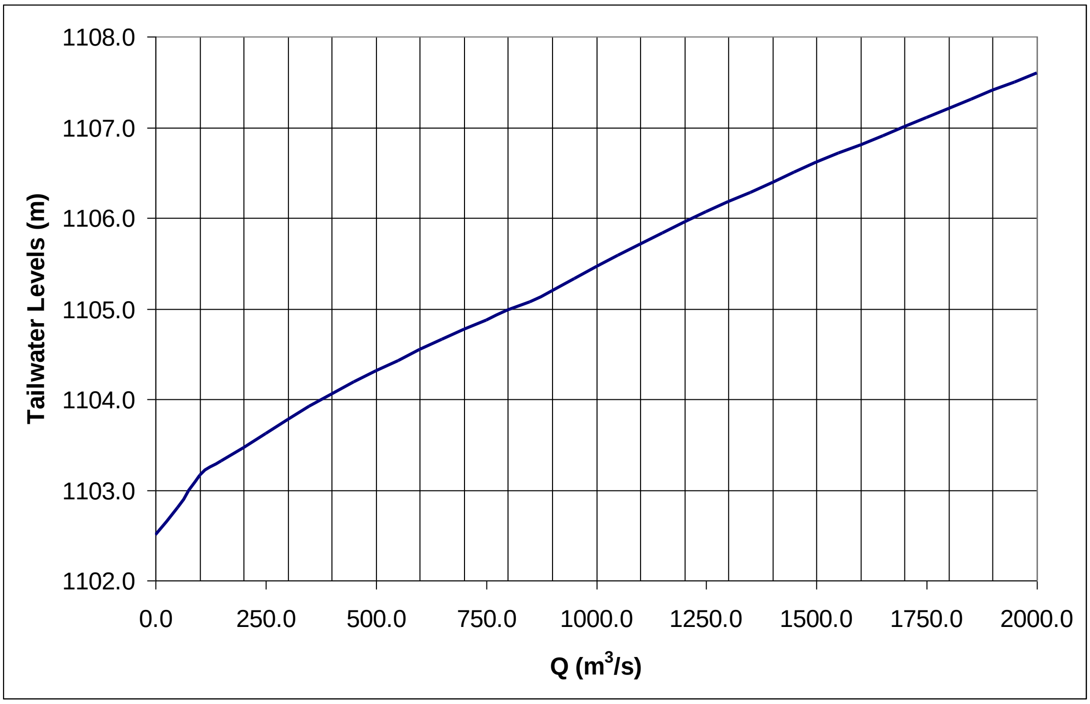


Figure 3.21 Tailwater rating curve for the dam site of Upper Kaleköy

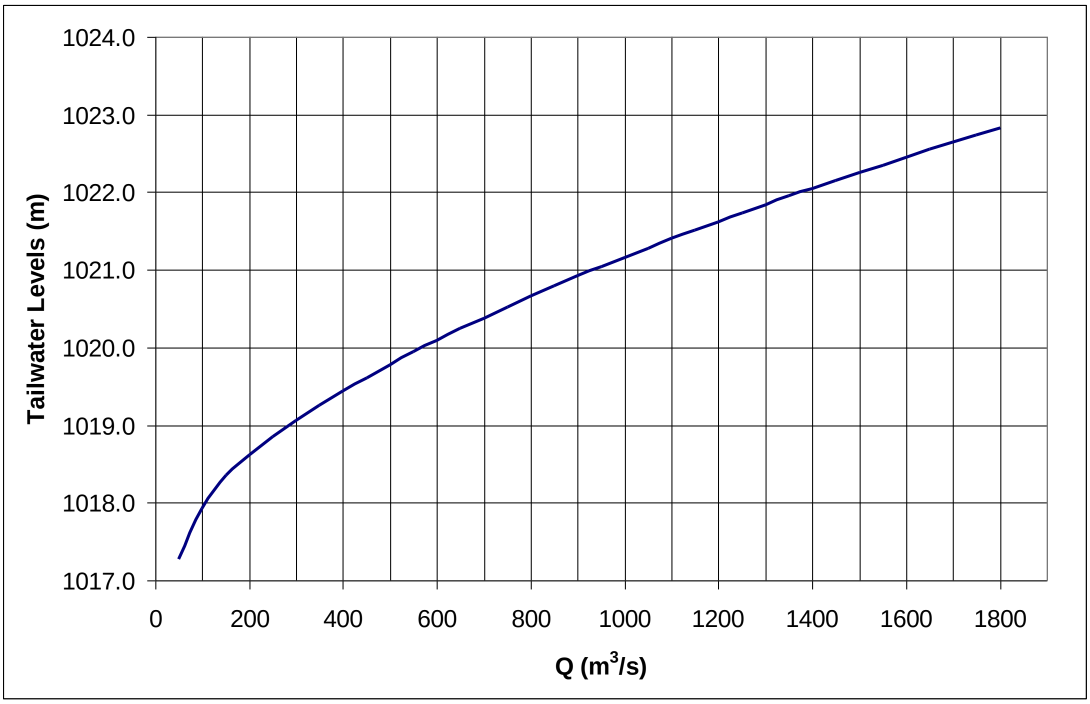


Figure 3.22 Tailwater rating curve for the dam site of Lower Kaleköy

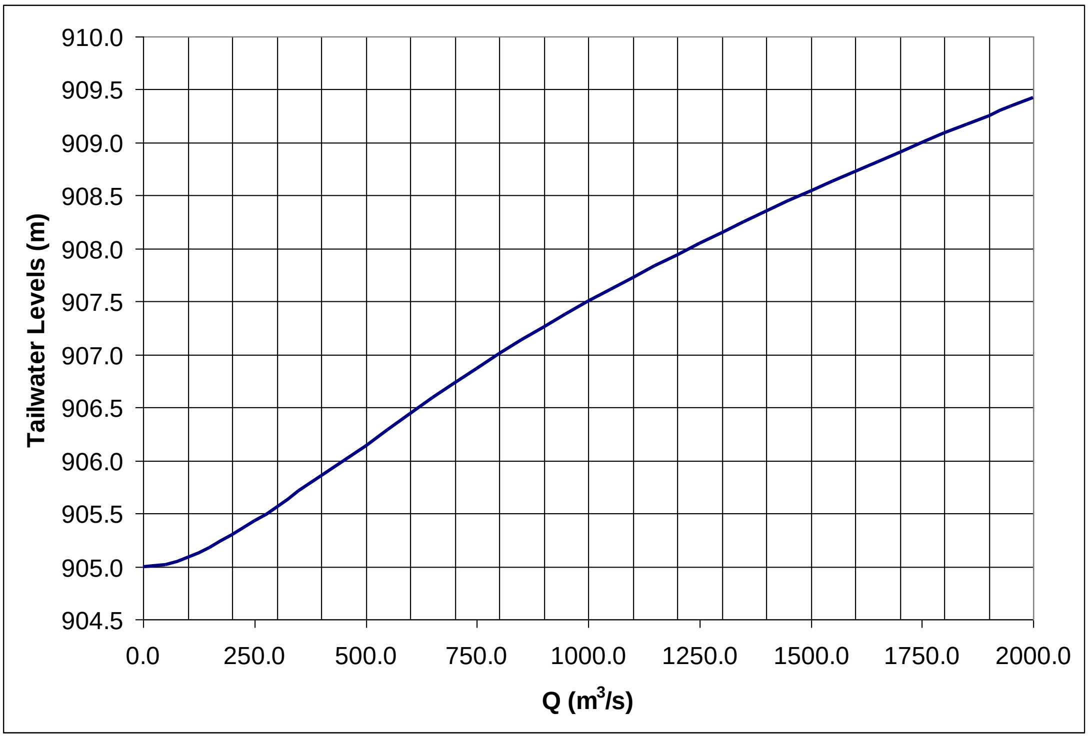


Figure 3.23 Tailwater rating curve for the dam site of Beyhan 1

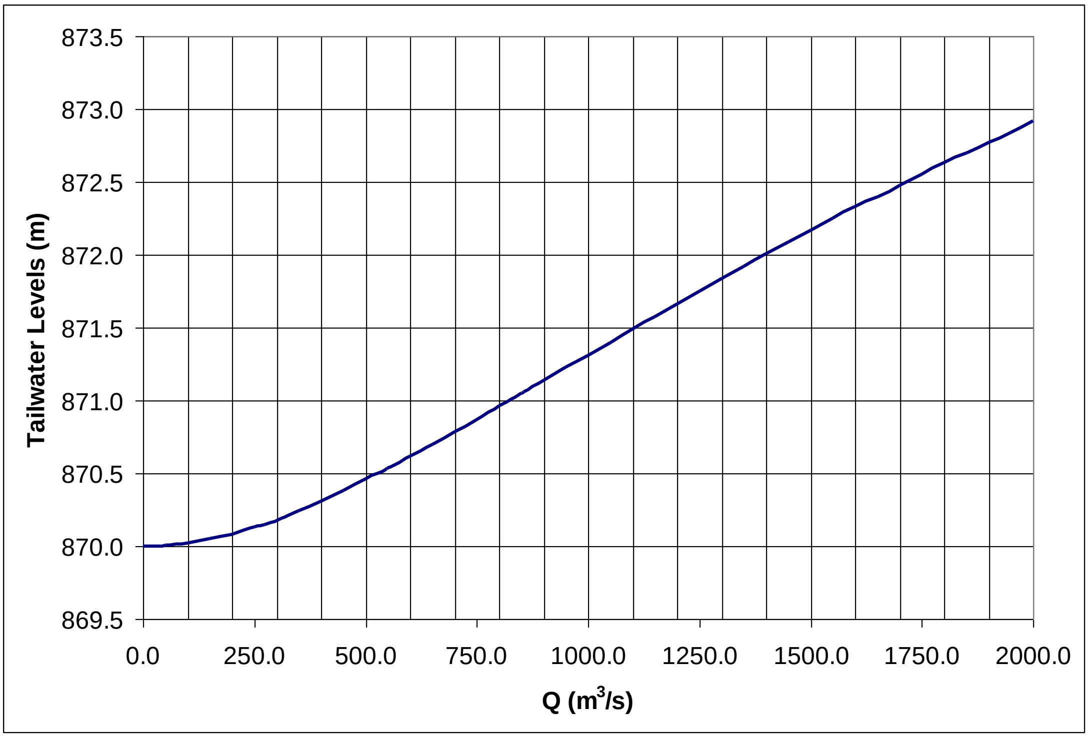


Figure 3.24 Tailwater rating curve for the dam site of Beyhan 2

3.6 Head Losses

In determining the net head available for power generation, it is necessary to account for head loss in the water passages. These losses include primarily friction losses in the trashrack, intake structure, and penstock. Hydraulic losses between the entrance to the turbine and the draft tube exit are accounted for in the turbine efficiency. Head losses for Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 dams are 2.5 m, 1.0 m, 2.0 m and 1.0 m respectively (Temelsu International Engineering Services Inc., 2011). Friction, entrance, trashrack, gate, transition and curvature losses are the main hydraulic losses taken into account.

3.7 Efficiency

When calculating the power and energy output of each plant, the gross head was determined day by day as the difference between reservoir and tailwater level. Efficiencies in the hydraulic system, estimated for average conditions and the same for each plant, are deducted, by assuming the following efficiencies for operation under average conditions:

$$e = \text{overall plant efficiency} = e_{\text{turbine}} \times e_{\text{generator}} \times e_{\text{transformer}} \quad (3.3)$$

e = 0.92 x 0.98 x 0.99 = 0.893 (Temelsu International Engineering Services Inc., 2011)

3.8 Dams' Features

The characteristics of the reservoir system are defined by a number of parameters that are described below in brief.

3.8.1 Upper Kaleköy Dam and HEPP

Upper Kaleköy dam is located just at the downstream of the confluence of Murat River and Karasu and its catchment area is 21 337 km². The annual mean flow at Upper Kaleköy dam site for this period is 5590 hm³.

A hydroelectric power plant with an installed capacity of 600 MW will be constructed by the roller compacted concrete at the location shown in Figure 3.4 with a height of 127.5 m from the thalweg and 150.0 m from the foundation. The power plant has three main and one small Francis type of turbines.

The maximum operation water level of Upper Kaleköy Dam has been selected as 1225.0 m by taking the irrigation and drainage system elevation of Muş-Arıncık Irrigation Project into account. Crest elevation of the dam is 1230.0 m. The minimum operation water elevation is 1210.0 m. The characteristics of Upper Kaleköy Dam and HEPP is given in Appendix B.

The general plan and typical cross section of Upper Kaleköy Dam and HEPP are shown in Appendix B.

3.8.2 Lower Kaleköy Dam and HEPP

Lower Kaleköy dam is located at the downstream of Upper Kaleköy dam site and its catchment area is 22 243 km². The annual mean flow at Lower Kaleköy dam site for this period is 6356 hm³.

A hydroelectric power plant with a capacity of 450 MW is installed by the roller compacted concrete type at the location shown in Figure 3.4 with a height of 90.2 m from the thalweg and 102.5 m from the foundation.

The maximum operation water level of Lower Kaleköy Dam is defined by the tailwater level of Upper Kaleköy Dam and HEPP. For this reason, the maximum water elevation has been specified as 1102.5 m. Crest elevation of the dam is 1107.5 m. The minimum operation water elevation is 1085.0 m.

The spillway has been located at right bank as overflow type with gates. The spillway crest elevation, whose dimensions have been computed according to the probable maximum flood peak discharge, is

1087.0 m. The characteristics of Lower Kaleköy Dam and HEPP is given in Appendix B. The general lan and typical cross section of Lower Kaleköy Dam and HEPP are shown in Appendix B.

3.8.3 Beyhan 1 Dam and HEPP

A hydroelectric power plant with a capacity of 400 MW is installed at the location shown in Figure 3.3 with a height of 83.6 m from the thalweg and 97.0 m from the foundation.

The settlement area of Genç District defines the maximum operation water level of Beyhan 1 Dam. The maximum water level elevation is 982.0 m so that the settlement areas in Genç District are not inundated. Crest elevation of the dam is 987.0 m. The minimum operation water elevation is 977.0 m as a result of the sediment estimation.

The spillway has been located at left bank apart from the dam body as overflow type with gates. The spillway crest elevation, whose dimensions have been computed according to the probable maximum flood peak discharge, is 967.0 m.

Beyhan 2 and Beyhan 1 dams are the two successive dams located on Murat River. Their catchment areas are 25 426 km2 and 25 274 km2, respectively. The annual mean flows of Beyhan 2 and Beyhan 1 dams for this period is 7884 hm^3. The characteristics of Beyhan 1 Dam and HEPP is given in Appendix B. The general plan and typical cross section of Beyhan 1 Dam and HEPP are shown in Appendix B.

3.8.4 Beyhan 2 Dam and HEPP

Beyhan 2 dam site is located on Murat River at the thalweg elevation of 868.2 m. The dam site is located at an air distance of 5.5 km in the east of Palu district center and at the 8th km of the 22 km long provincial road between Palu-Beyhan. The annual mean flow of Murat River at Beyhan 2 dam site is 7884 hm^3.

A hydroelectric power plant with a capacity of 255 MW is installed by the concrete gravity at the location shown in Figure 3.3 with a height of 41.8 m from the thalweg and 62,0 m from the foundation. The power plant has three main and one small Francis type of turbines.

The maximum operation water level of Beyhan 2 Dam is defined by the tailwater level of Beyhan 1 Dam and HEPP. For this reason, the maximum water elevation has been specified as 905.0 m. Crest elevation of the dam is 910,0 m. The characteristics of Beyhan 2 Dam and HEPP is given in Appendix B. The general plan and typical cross section of Beyhan 2 Dam and HEPP are shown in Appendix B.

An overview over the most relevant modelling components used for simulation in the Lower Murat Basin are presented below.

3.9 Model Components in HEC-ResSim

A large number of different modelling components are available in HEC-ResSim. This enables the modeller to build an adequate representation of the system to be studied. For different studies, different modelling components will become important. For instance, in the flood study river routing and detailed spillway characteristics are important, whereas in the reservoir simulation study diversions, water requirements and evaporation are important. The current study focuses on the general simulation of the reservoirs as well as the impact of the reservoirs on energy generation.

The scenarios also have different modelling time-steps. Daily time intervals are the maximum possible length of modelling time-steps in HEC-ResSim. Therefore, the available monthly inflow data in the Lower Murat basin are treated as daily values that do not vary within a month. The simulation period covers 40 years in daily time-steps. Due to the discrete computational time-steps, numerical artefacts may occur, which can cause jumps in the simulated values between months. However, these numerical artefacts are in general negligible.

An important feature of HEC-ResSim is that the model is divided into three separate sets of functions called modules:

i) Watershed Setup Module

ii) Reservoir Network Module

iii) Simulation Module

Figure 3.25 provides a graphical illustration of the three modules that constitute HEC-ResSim.

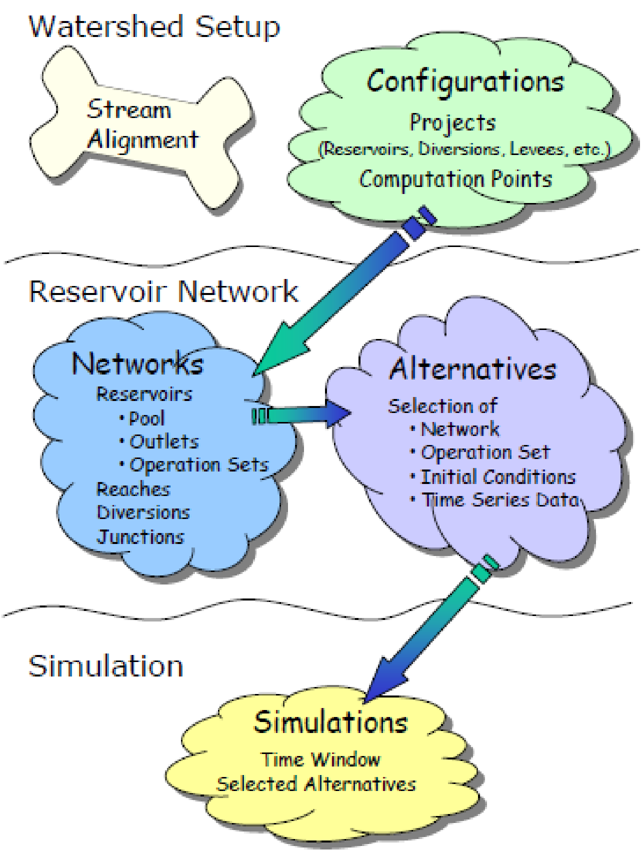


Figure 3.25 HEC-ResSim Module concepts (Klipsch, 2007)

The river network, based on the stream alignment, is represented by computation points that are connected by reaches. This structure defines the topology, such that the model knows in which direction the water flows as well as where the confluences of separate rivers are located. Intermediate basin inflows can be specified for each computation point. Similarly, upstream net water consumptions can be accounted for by subtracting water from river runoff at computation points.

Several different methods for routing of runoff through the reaches between computation points are available. However, this is generally used in the flood studies, runoff routing is not important for the reservoir simulation study, which is based on monthly data.

Reservoirs are added upon the stream alignment. In HEC-ResSim model, a large number of properties for the reservoir can be specified. Some of these include:

i) elevation-area-storage curves
ii) evaporation
iii) outlets
iv) operation rules

The elevation-area-storage curve defines the basic properties of the reservoir for the mass balance accounting between inflows and outflows. This curve is also used for determining the evaporation from the surface area of the water body. The water level affects the energy generation as well as the spillway losses. Further, the operation rules are based upon the water level.

Outlets can represent power plants, diverted outlet, controlled or uncontrolled spillways, outlets for environmental flow, etc. Power plant specifications include design discharge, tailwater levels, efficiencies, hydraulic losses. Spillway properties are usually defined by a curve giving the relationship between water level in the reservoir and spillway discharge. As there may be several outlets at each reservoir, it is important to specify rules for prioritizing the allocation of water. There would not be a conflicting demand between diversion of water and environmental flow releases by specifying rules.

Operation rules are defined for different storage zones in the reservoir. Such operation rules can represent rules for diversion of water, environmental flow release, or downstream water requirements. The storage of a reservoir is typically split into three parts: inactive zone (dead zone), conservation zone, and flood control zone. A guide curve for the operation of the reservoir is implemented by specifying a seasonal variation in the elevation of the conservation zone. In the simulation, the model will preferentially try to keep the reservoir water level at the top of the conservation zone, while obeying all rules like downstream water requirements. If the water level reaches a different zone, then a different set of rules comes into effect.

3.10 Model Set-up of HEC-ResSim

The HEC-ResSim model is set-up to simulate the operation of the reservoirs in the Lower Murat basin.

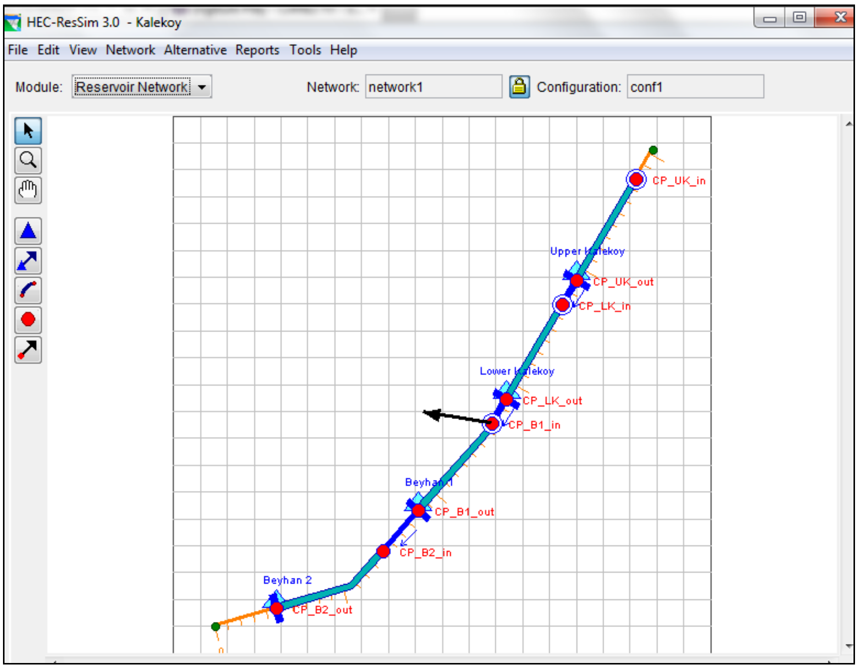


Figure 3.26 Reservoir Network Module, Kaleköy cascade reservoir system

Figure 3.26 shows the river network module and the location of reservoirs. In all scenarios, it has been accepted that four dams are under operation. Figure 3.27 illustrates that from the reservoir editor tab physical properties such as spillway, power plant and pump can be modeled for each reservoir.

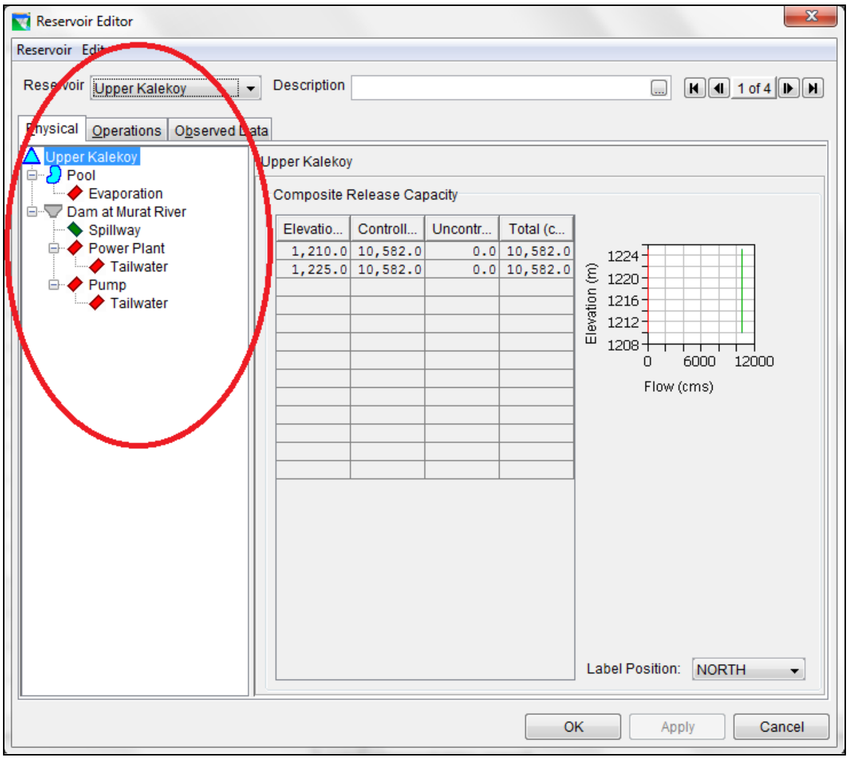


Figure 3.27 Reservoir editor tab, physical properties of hydraulic structures

Different types of rules are available for specifying the operation of the reservoir depending on the storage zone. Basic rules representing environmental flows and firm energy requirements are implemented as shown in Figure 3.28.

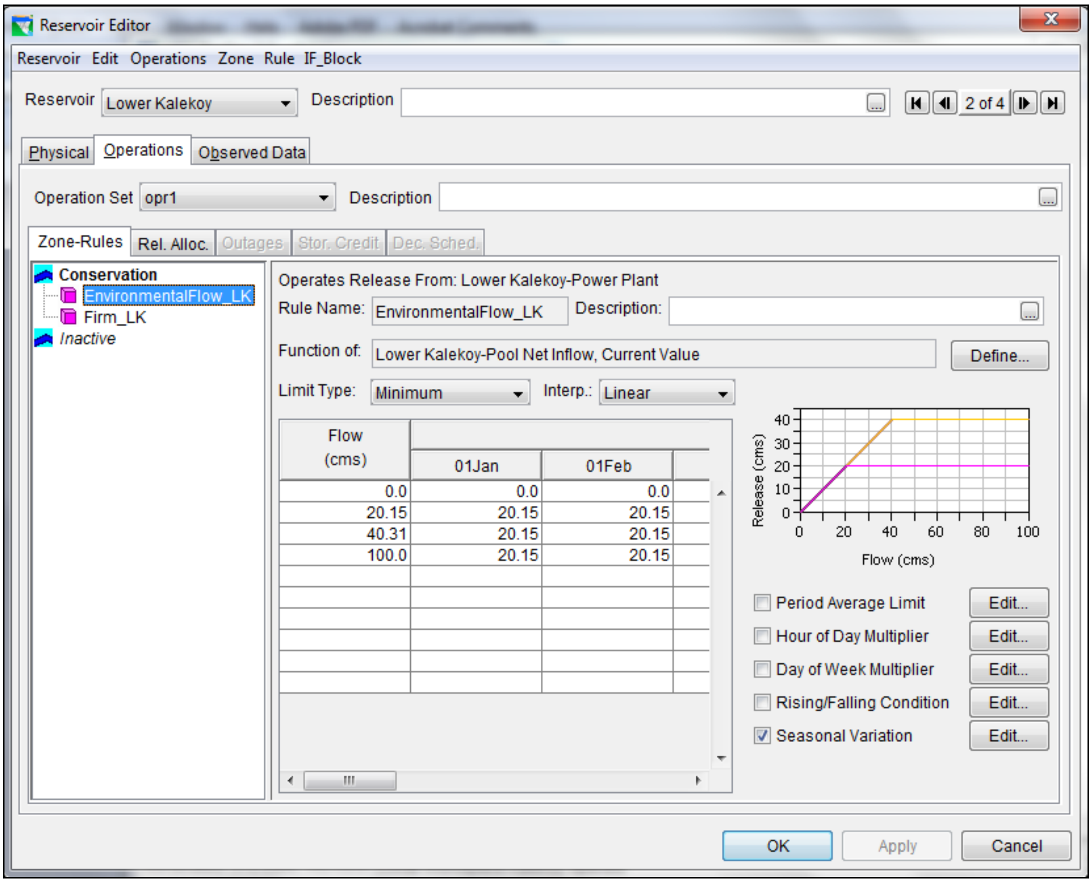


Figure 3.28 Reservoir Editor, operating rules

Environmental flow releases due to downstream requirements are simulated in the model as turbined flows. For environmental flows a rule is applied which considers that the amount of water that has to be released must not be greater than the inflow to the reservoir.

Figure 3.29 shows prioritization of the allocation of water to different outlets is specified separately. The following decreasing priorities were used:

i) environmental flows (highest priority)
ii) hydro-power plant
iii) spillway (lowest priority)

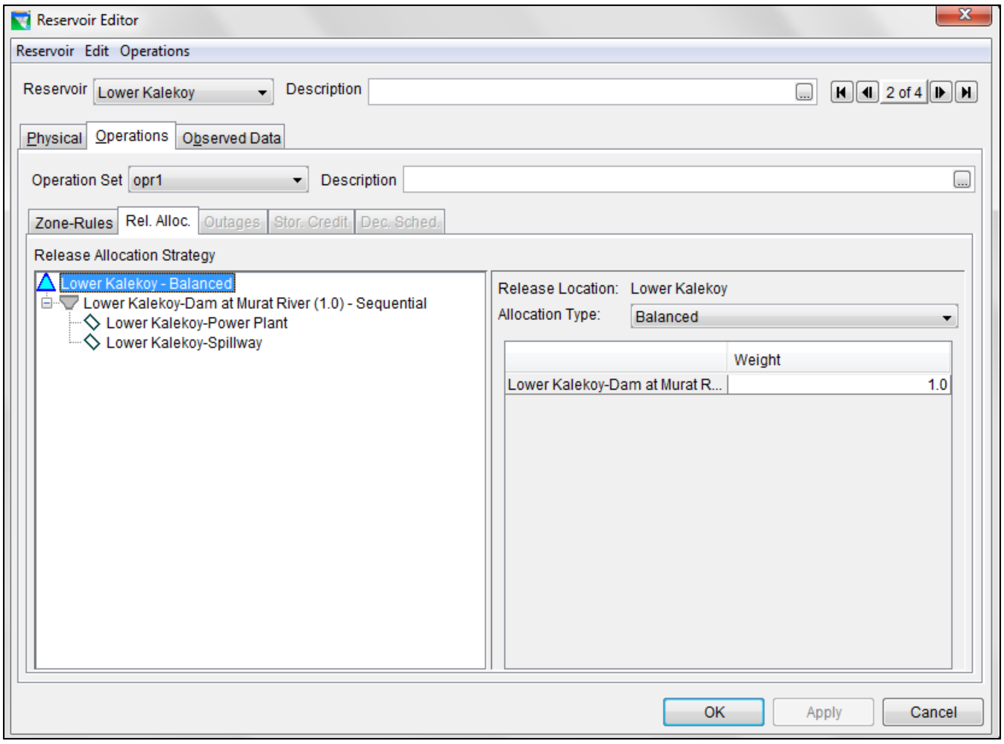


Figure 3.29 Specification of release allocation strategy with the HEC-ResSim Reservoir Editor

Pump schedule rule is an operation rule that provides the capability of pumping water from one reservoir to another. Pump schedule rule is selected from a pump component in the reservoir which will receive the pumped water as shown in Figure 3.30. A constant value or zone may be chosen for the target fill elevation from section A. Section B reflects the available time range for operation. In Figure 3.30, pumping is to occur 25% of a day and begins at 24:00. Pumping strategy may be chosen from section C either to minimize the time spent pumping or to run the pumps at a rate which is less than full capacity in order to just reach the target at the end of the pumping period. If the pumping strategy is "use full pump capacity", one can select one of the following from section D:

i) Beginning of period,

ii) Middle of period,

iii) End of period.

By using the button in section E, one can give the ability to force reservoir to pump as even if it doesn't need to.

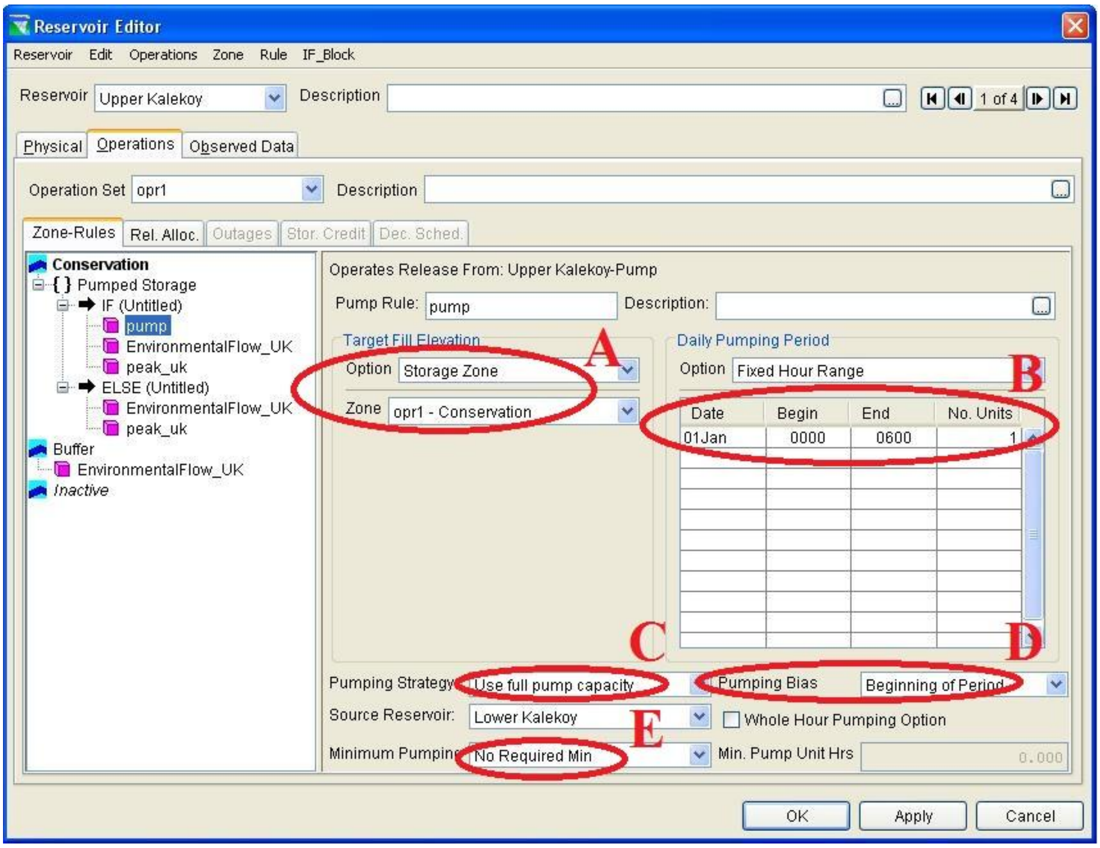


Figure 3.30 Pump Rule Editor

HEC-ResSim offers several different ways of analyzing results. These include graphical plots of time-series variables, tables listing time-series of variables, and summary reports listing statistical measures such as mean, maximum, minimum flow or water level. A number of pre-defined plots, tables and reports are available. These pre-defined sets can be edited or new sets can be created. This offers the possibility to produce outputs specifically focused on the problem to be analyzed. In addition, the results can also be exported for post-processing in other software, such as for example MS Excel.

The real value of HEC-ResSim is to view a graphical display of the results on screen, as the zoom and pan tools of HEC-ResSim offer an efficient, interactive way of analyzing time-series plots.

The following presentation of the results is intended to give an illustrative overview of the simulation with HEC-ResSim. It is not a detailed presentation of all the results at each dam for each scenario. Instead, the focus is on reporting results for any reservoir. Results for all dams and all scenarios and a large number of variables are available in tabular forms in Chapter 4.

Examples for pre-defined plots include:

“Default plot” showing basic operation of the reservoir is shown in Figure 3.31.

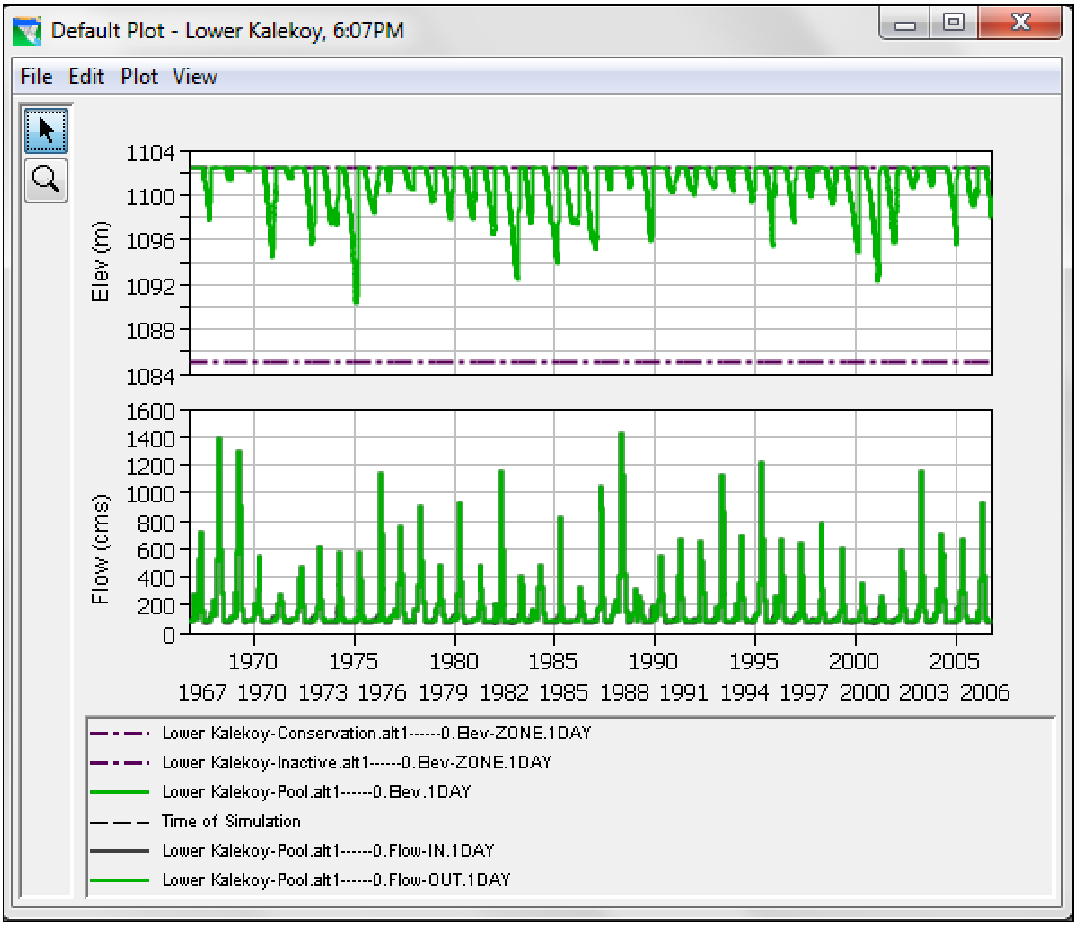


Figure 3.31 Graphical display of "Default plot" function

“Power plot” showing energy generation is presented in Figure 3.32. This includes also a variable showing the power capability, i.e. the power generation when all of the water is allocated to the turbine. In the actual operation of the reservoir this power capability will not be reached due to restrictions related to e.g. the guide curve, diversions and water requirements.

Figure 3.32 Graphical display of “Power plot” function

“Releases plot” showing all individual releases from the reservoir as shown in Figure 3.33. The number of variables displayed here depends on the elements added to the specific reservoir.

Figure 3.33 Graphical display of “Releases plot” function

CHAPTER 4

SIMULATION ANALYSIS

4.1 Introduction

Upper Kaleköy Dam, the first facility at the upstream of Kaleköy reservoir system, is operated with the inflows as shown in Figure 3.13. However, the downstream facilities are operated by adding the intermediate flows to the power plant and spillway outflows of the upstream facility, from the resulting flows. Usually upstream reservoirs are more important since they provide inflow for downstream hydroplants.

The operation of four cascade reservoirs is simulated by considering ten different scenarios. The model considers operation of the reservoirs with guide curves. In the operation scenarios for the dams, power plant located at the toe of the dam has been simulated. Releases from the reservoirs include turbined discharge, environmental flows, spillway losses, and evaporation losses. Diversion is included to reflect water consumptions for irrigation.

Reservoir operation simulation primarily depends on the state of the reservoir at each time interval. The general goal is to keep the reservoir at the top of the conservation pool. As the pool level moves into flood, conservation, and inactive storage zones, the operation goals may change. The model was performed on time-step from 6 hours to a day and simulates the coupled system of the four hydropower plants. Main inputs of the simulation include:

i) Reservoir storage characteristics, as defined by the relationship volume-area-elevation.

ii) Evaporation from reservoir storage.

iii) Operation guide curve to determine release from reservoir storage.

iv) Tailwater rating-curve, which affects the hydraulic head as a function of runoff.

v) Environmental flow requirements.

vi) Broad consideration of hydraulic losses and turbine efficiency.

ix) Intra-daily turbine operation to allocate energy generation preferentially to peak hours as opposed to off-peak hours.

x) Links between reservoirs, i.e. outflow from Upper Kaleköy is inflow to Lower Kaleköy, outflow from Lower Kaleköy is inflow to Beyhan 1, and outflow from Beyhan 1 is inflow to Beyhan 2.

xi) Intermediate inflow between reservoirs.

xii) Pump and turbine characteristics.

Reservoir system with many units may have various operational rules. An operational rule applied at one reservoir will have consequences for other plants in the system. In this chapter, the various types of operation rules and guide curves were investigated and the results of the scenarios are given in the following sections.

Operating rules for water resource system must be established to specify how water is managed throughout the system. System demands may be expressed as minimum required flows to be met at selected locations in the system. Some or all of the operation policies may be designed to vary seasonally in response to the seasonal demands for water and the stochastic nature of supplies.

Storage capacities for the Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 reservoirs are shown in Table 4.1.

Table 4.1 Storage capacities for the Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 reservoirs

Reservoir	Operation levels	Total capacity	Inactive capacity	Active capacity
	(m above sea level)	hm³	hm³	hm³
Upper Kaleköy	1225.0 - 1210.0	595.3	406.2	189.1
Lower Kaleköy	1102.5 - 1085.0	431.5	240.1	191.4
Beyhan 1	982.0 - 977.0	369.06	294.64	74.42
Beyhan 2	905.0 - 902.0	78.92	63.55	15.37

Relationships between required reservoir storage and reservoir height for full capacity operation of each reservoir in varying time durations are shown in Figures 4.1-4.4. Required storage is inversely proportional to head.

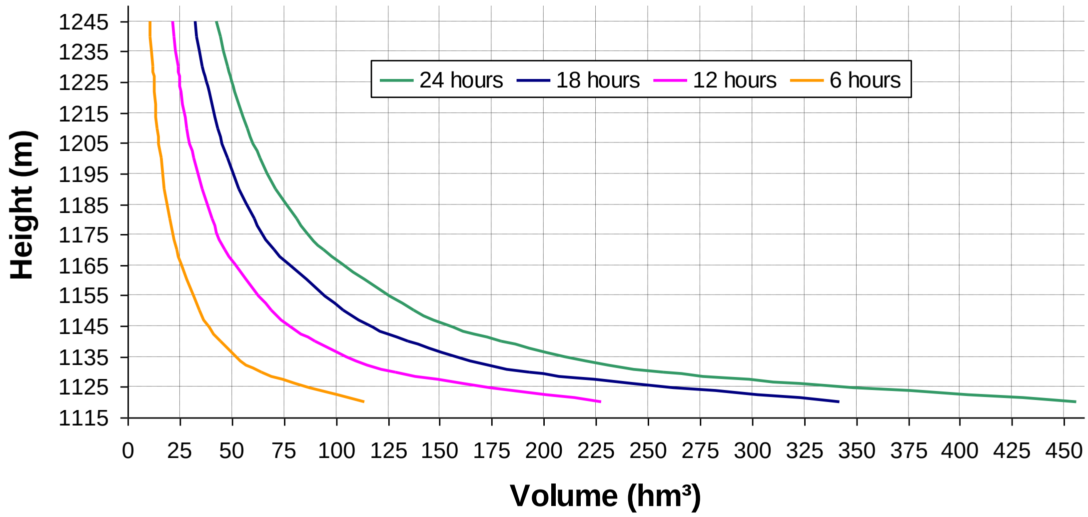


Figure 4.1 Upper Kaleköy reservoir storage required vs. height for 600 MW plant with 6, 12, 18 and 24 hours of operation

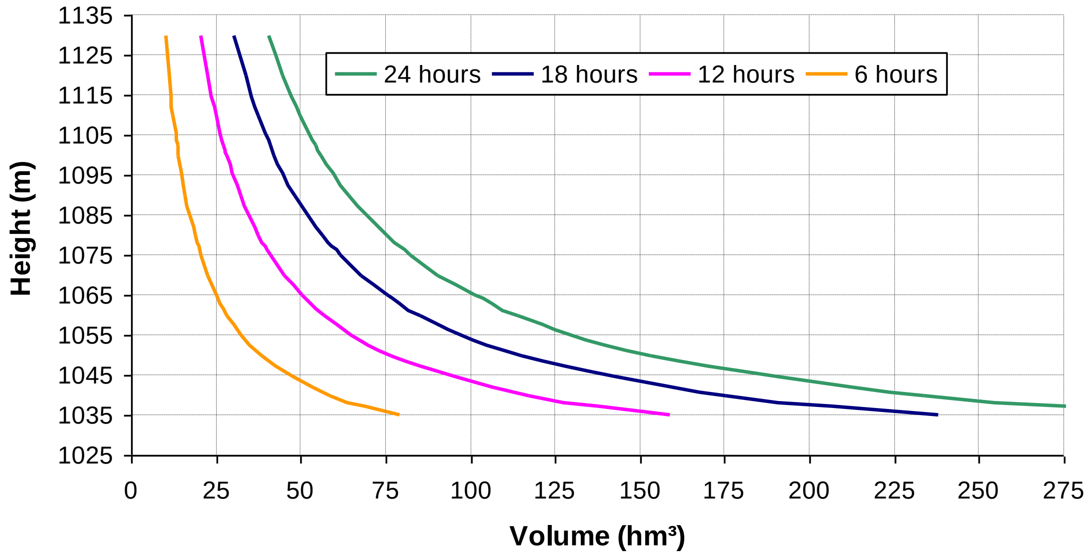


Figure 4.2 Lower Kaleköy reservoir storage required vs. height for 450 MW plant with 6, 12, 18 and 24 hours of operation

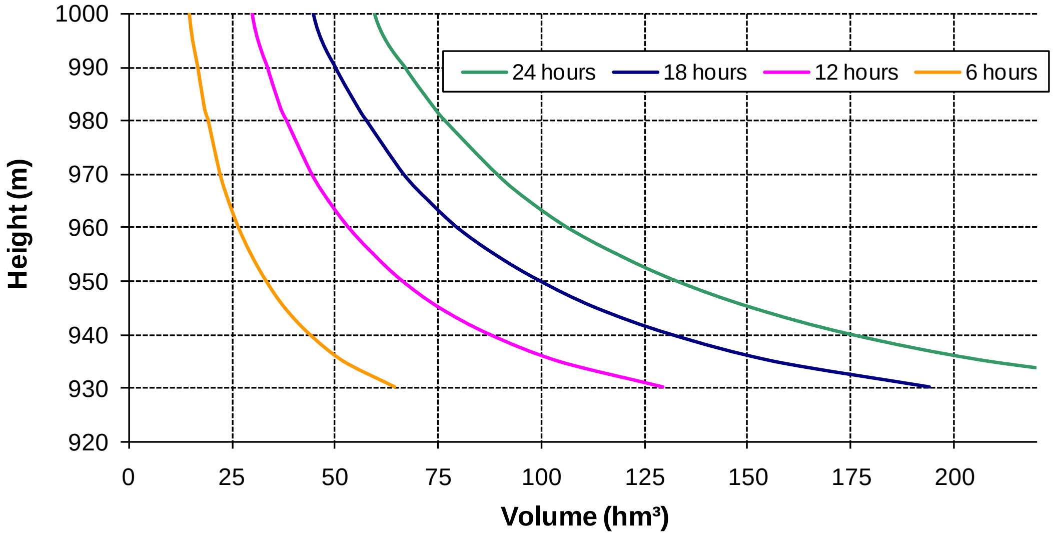


Figure 4.3 Beyhan 1 reservoir storage required vs. height for 550 MW plant with 6, 12, 18 and 24 hours of operation

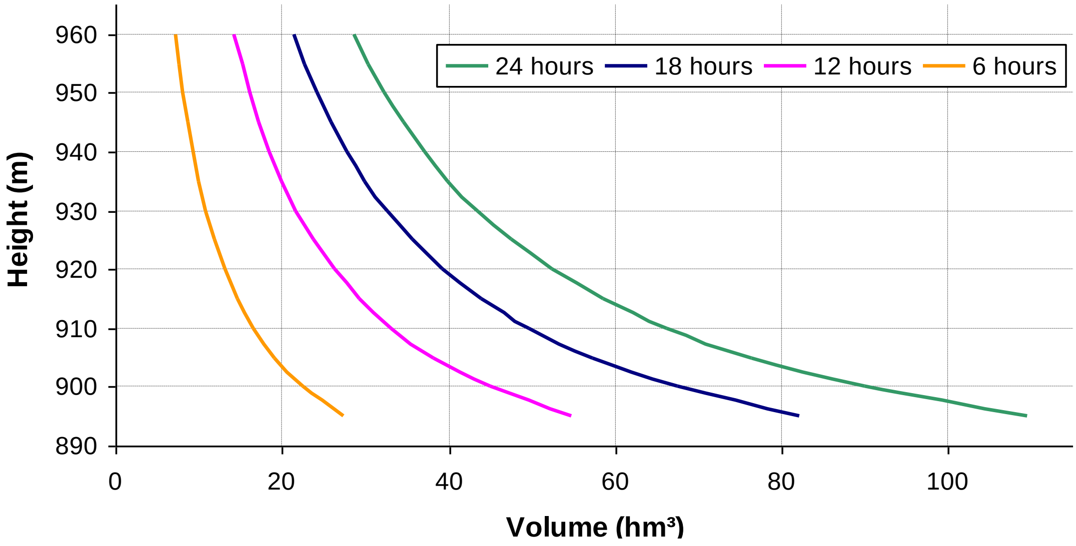


Figure 4.4 Beyhan 2 reservoir storage required vs. height for 255 MW plant with 6, 12, 18 and 24 hours of operation

Unless otherwise mentioned, all scenarios have the same following definitions:

- Hydrological scenario: Existing case.
- Environmental scenario: Environmental flow requirements.
- Four dams are under operation.
- Simulation period: 40 years 1.10.2015 to 30.9.2055, daily time-steps.
- Physical characteristics of the reservoirs mentioned in Chapter 3 were used.
- Overload ratio is used by the program to determine the maximum energy where power plant can produce in a time interval. The maximum production would then be a limit how much excess energy could be generated during periods of surplus water. No overload ratio is considered so it is taken as 1.

In Table 3.2, it was understood that environmental flow requirements are changing between wet and dry seasons for all reservoirs. In all scenarios seasonal variation editor is used to specify releases.

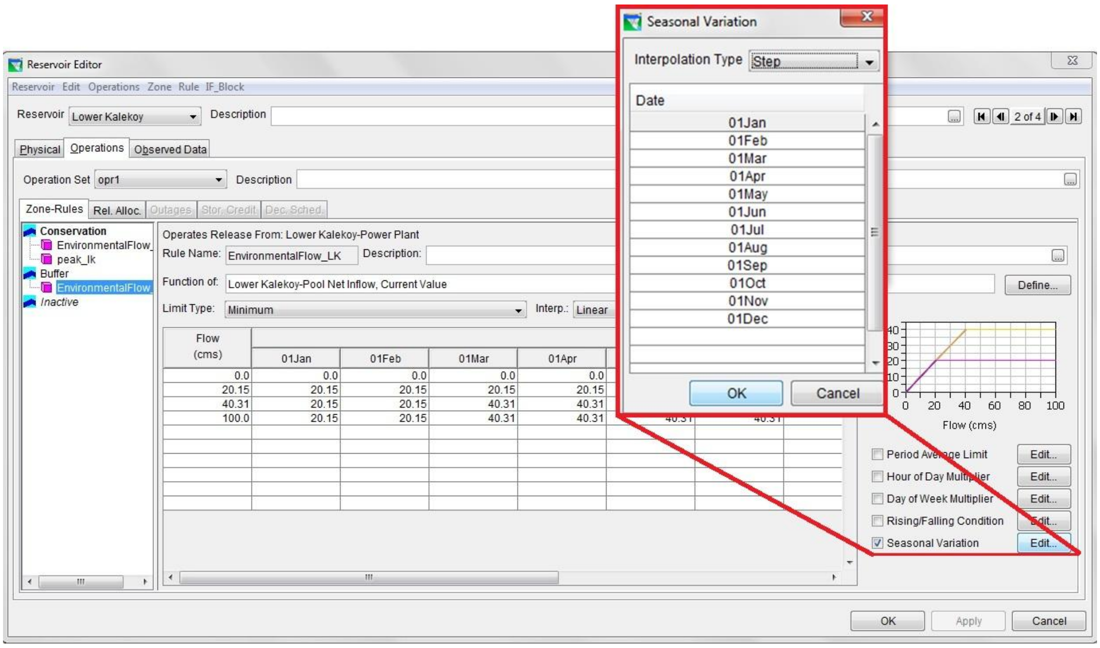


Figure 4.5 Seasonal variation editor

For example, the minimum required release allowed at a downstream location is described as a function of inflow at upstream location which is a function of internal variable. By using the seasonal variation option the simulations will obey the specified graph as shown in Figure 4.6 for Lower Kaleköy reservoir. In this graph; it is seen that if the net inflows are higher than environmental flows, the minimum release in dry seasons and wet seasons should be 20.15 m³/s and 40.31 m³/s respectively.

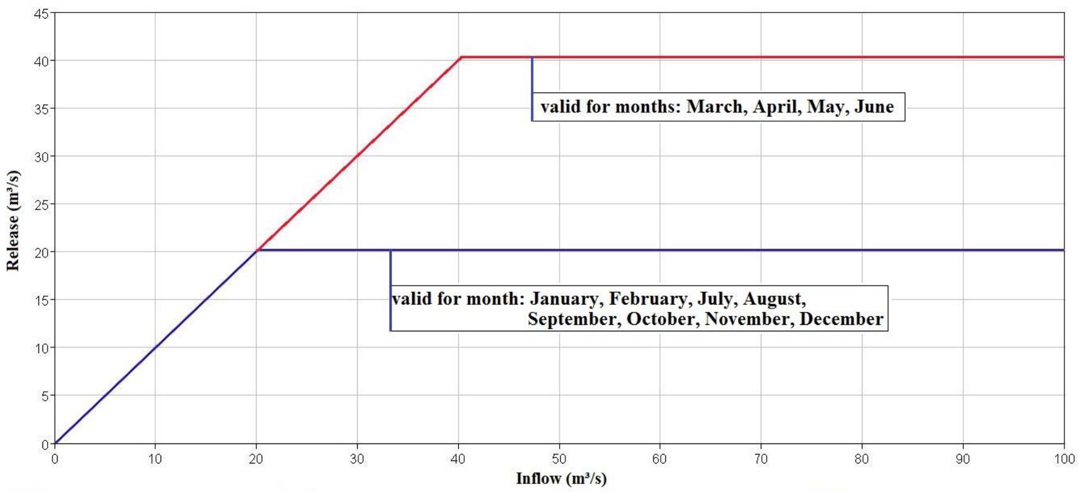


Figure 4.6 Seasonal variation editor graph of Lower Kaleköy

In the scope of this study, ten scenarios have been investigated to utilize the hydraulic potential of Murat River between the elevations of 870 m – 1225 m.

4.2 Scenario 1

Dam is operated continuously at maximum operation water level at all reservoirs. Operation studies were performed by using daily inflows in existing case.

Conservation zone comprises only environmental flow rule. HEC-ResSim tries to maintain the reservoir water level specified in the conservation zone's top elevation. As an example, when the Upper Kaleköy's reservoir water level exceeds 1225.0, the spillway is activated. In the inactive pool, no releases are made. The only loss of water would come from evaporation.

Figure 4.7 shows a part of daily operating cycle. In this scenario, the plant is required to operate at maximum operation level for 24 hours a day, seven days a week through all years. Not specifying firm energy requirements provides an alternative strategy that will maximize the average annual energy output.

The power duration curves shown in Figure 4.8-4.11 are based on all the time period of record. In other words, it can be treated as an annual generation curve, describing the average annual output over the period of record.

The average annual energy can be obtained by computing the area under the power output curve and multiplying by the number of 8760 hrs.

$$\text{Annual energy (kWh)} = \frac{8760\ \text{hours}}{100\ \text{percent}} \int_0^{100} P\,dp \qquad (4.1)$$

where

P = generator output in kW

p = percent of time

As an example, the average annual energy for the Upper Kaleköy would be 1,398,955 kWh.

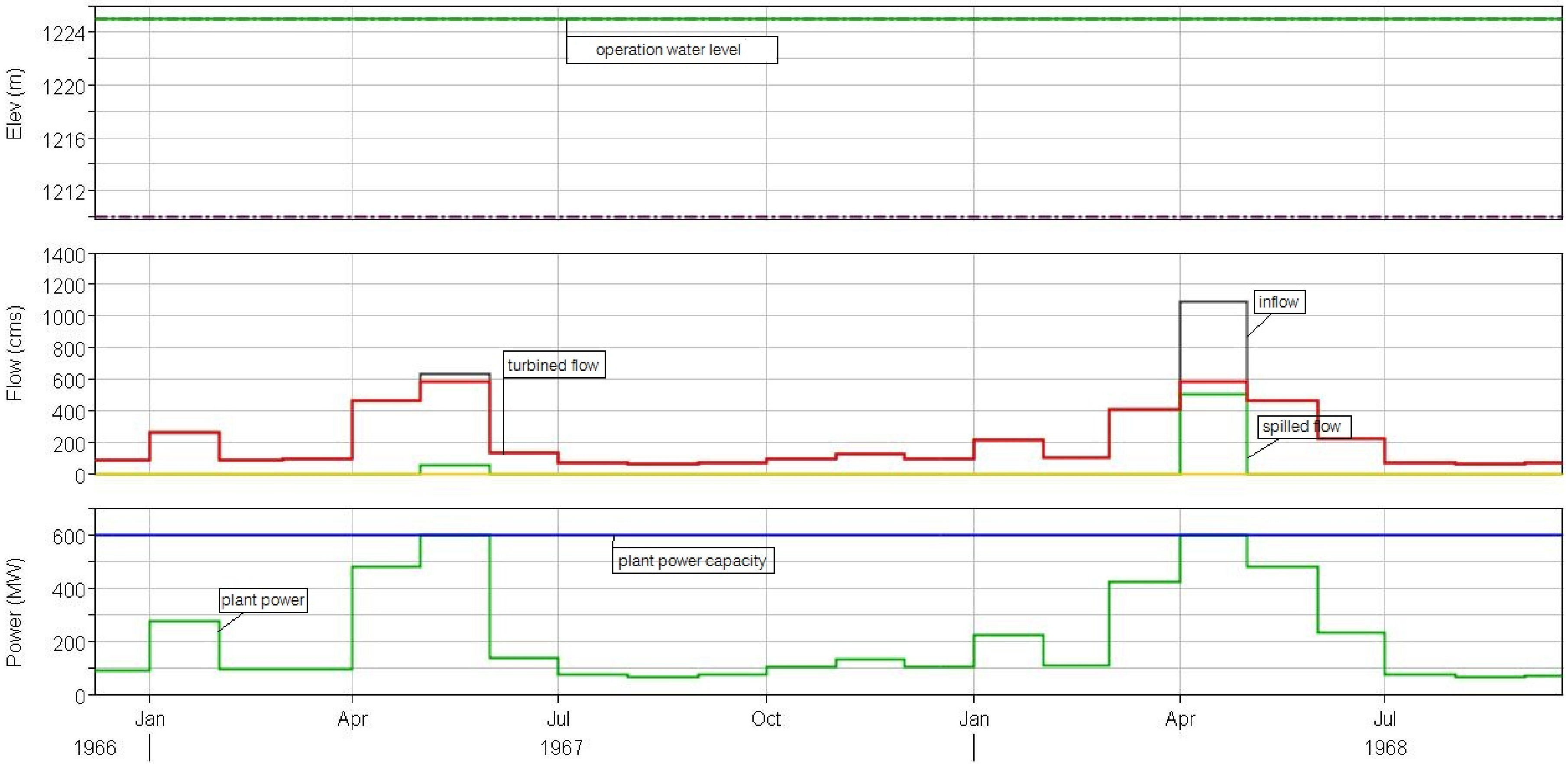


Figure 4.7 A part of daily operating cycle for Upper Kaleköy reservoir storage

Plant Factors are ratios indicating the portion of time that the plant is generating.

$$\text{Annual plant factor} = \frac{\text{Average yearly energy}}{365 \text{ x } 24 \text{ x Installed capacity}} \quad (4.2)$$

In Scenario 1 plant factors of Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 HEPPs are 0.27, 0.28, 0.26 and 0.25 respectively as shown in Table 4.2. In addition to this, the results of the Scenario 1 are given in Table 4.2.

Table 4.2 Summary of results for Scenario 1

Name of Facility	Annual net inflow (hm³)	Annual flow spill (m³/s)	Annual turbined flow (m³/s)	Annual total energy (GWh)	Plant factors
Upper K.	5 254.3	407.0	4 846.3	1 399.0	0.27
Lower K.	6 012.6	530.6	5 481.7	1 099.3	0.28
Beyhan 1	7 468.7	566.4	6 901.6	1 240.5	0.26
Beyhan 2	7 464.9	531.7	6 932.7	564.9	0.25
Total	**26 200.5**	**2 035.7**	**24 162.3**	**4 303.7**	

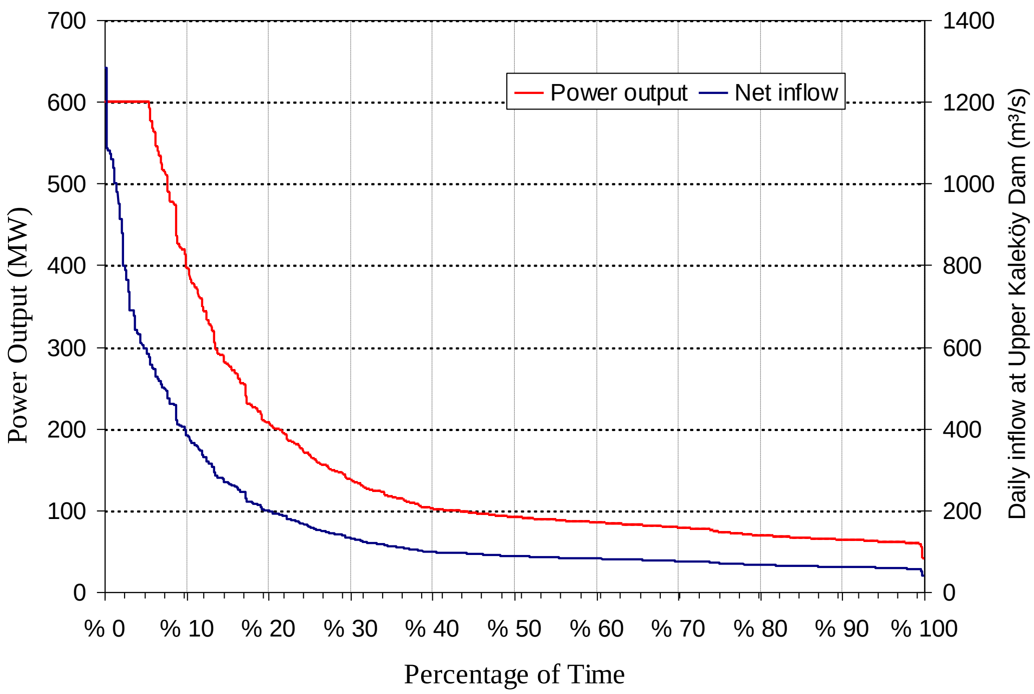


Figure 4.8 Power and net-inflow duration curve at Upper Kaleköy reservoir in Scenario 1

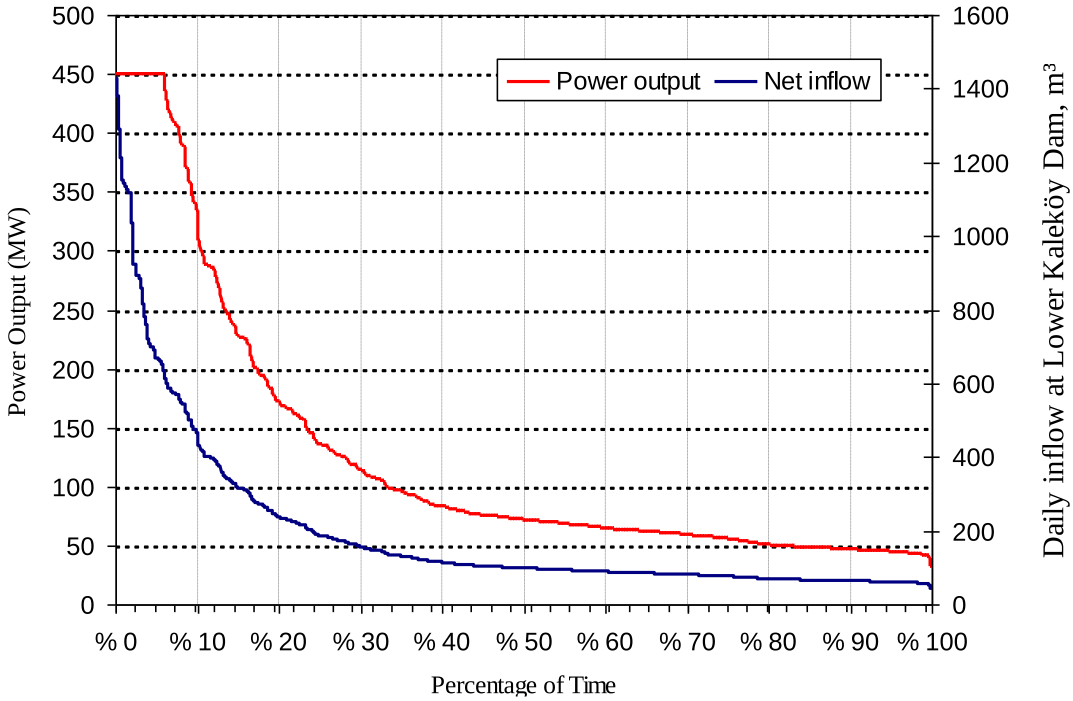


Figure 4.9 Power and net-inflow duration curve at Lower Kaleköy reservoir in Scenario 1

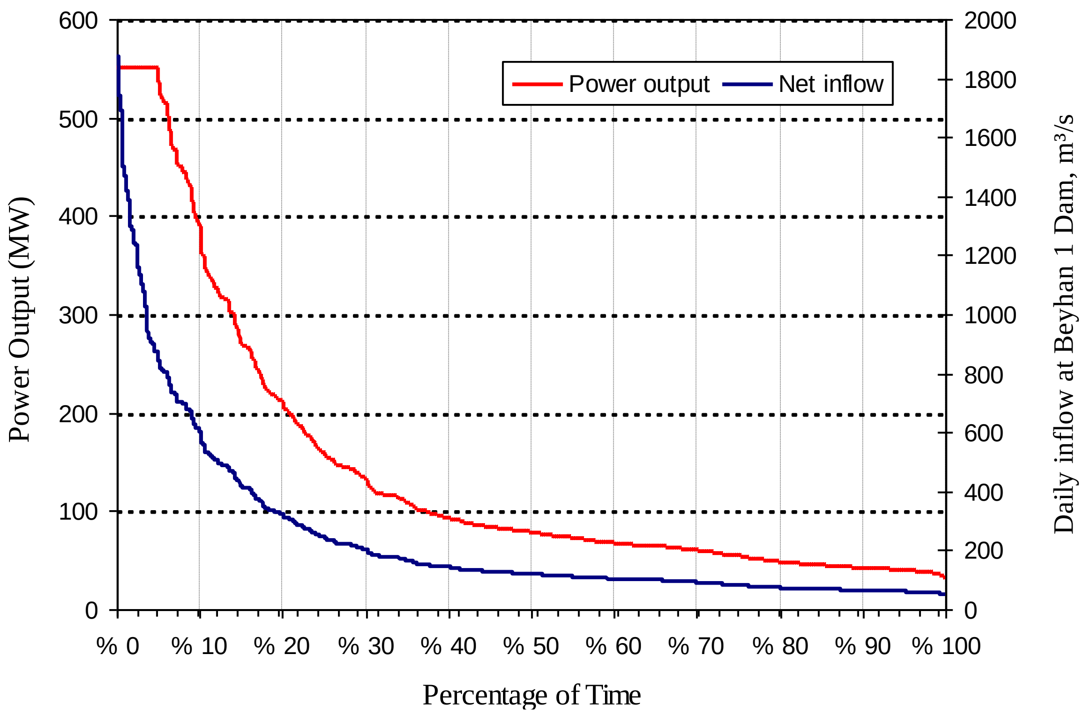


Figure 4.10 Power and net-inflow duration curve at Beyhan 1 reservoir in Scenario 1

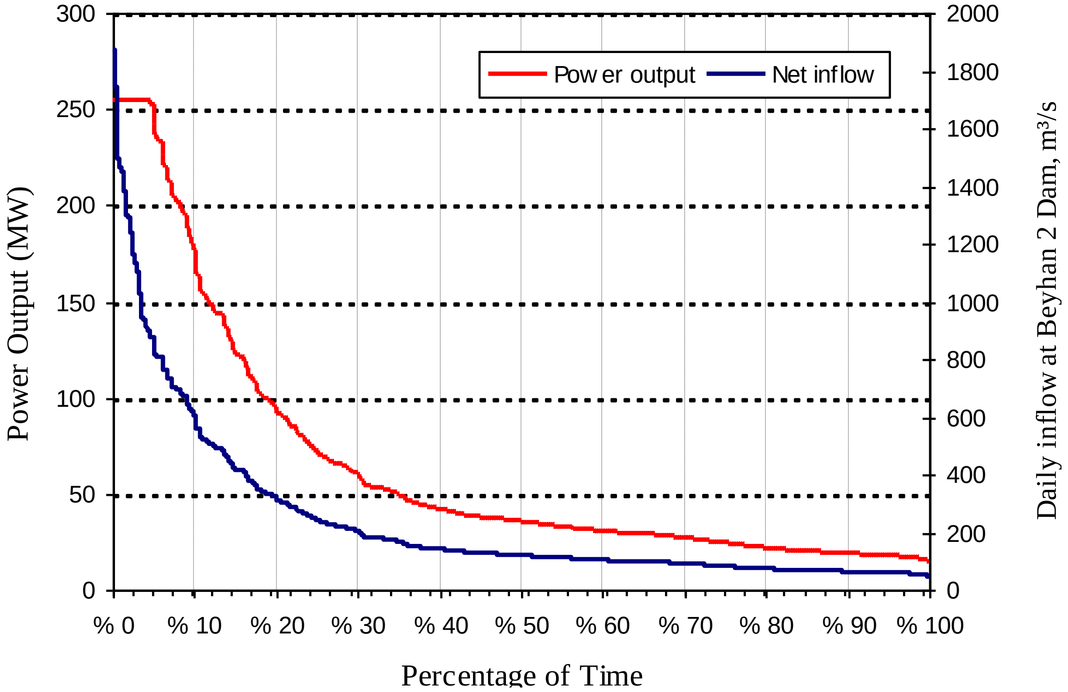


Figure 4.11 Power and net-inflow duration curve at Beyhan 2 reservoir in Scenario 1

4.3 Scenario 2

The aim of this scenario is to evaluate the change in power generation of Kaleköy reservoir system for a 10% percent increase in the inflows. Inflows at all computation points were increased from the Scenario 1 by 10 % for the Scenario 2.

On the local flow tab (Figure 4.12) of the junction editor, inflows were increased by a factor of 1.1 for each external flow entering the junction.

Higher inflow results in a increase in power generation of more than 7.8% at Kaleköy reservoir system as shown in Table 4.3.

Table 4.3 Summary of results for Scenario 2

Name of Facility	Annual net inflow (hm^3)	Annual flow spill (m^3/s)	Annual turbined flow (m^3/s)	Annual total energy (GWh)
Upper K.	5 780.5	554.6	5 224.8	1 507.7
Lower K.	6 615.4	709.8	5 905.1	1 183.4
Beyhan 1	8 224.3	770.0	7 453.4	1 338.9
Beyhan 2	8 220.5	726.3	7 493.6	610.1
Total	**28 840.7**	**2 760.7**	**26 076.9**	**4 640.1**

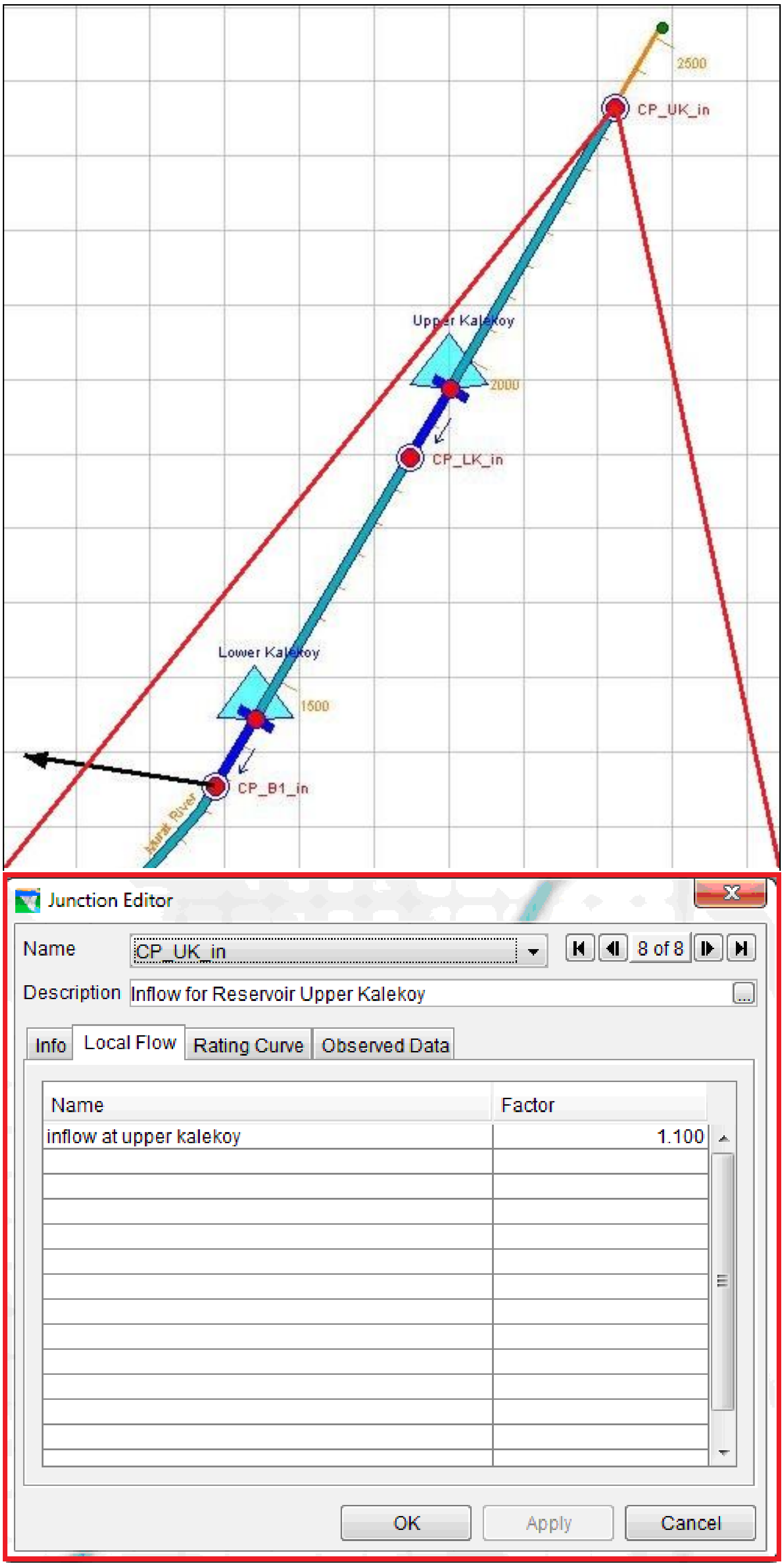


Figure 4.12 %10 percent increase in local inflow at computation points

4.4 Scenario 3

Inflow is distributed by the model between storage, power generation and spillage according to the reservoir level and operating rules. Energy generated is calculated for each time interval and aggregated to find the firm, secondary and annual average energy. For the purpose of this project firm energy has been assessed as the energy which will be available for 100% of any given year. Hydroelectic firm energy is usually based on energy output over the most adverse sequence of flows in the existing streamflow data. This adverse sequence of flows is called the critical period.

This scenario results in full use of power storage in critical water years, but in good water years, it generally maintains the reservoir as close to the top of the power pool as possible.

Since daily time step simulation has been performed daily energy requirement was specified. Data entry for this rule is described in Figure 4.13. As an example, for Upper Kaleköy reservoir firm energy was found 1788 MWh/day with a few iterations, this value equals to 74.5 MW power per hour in a day.

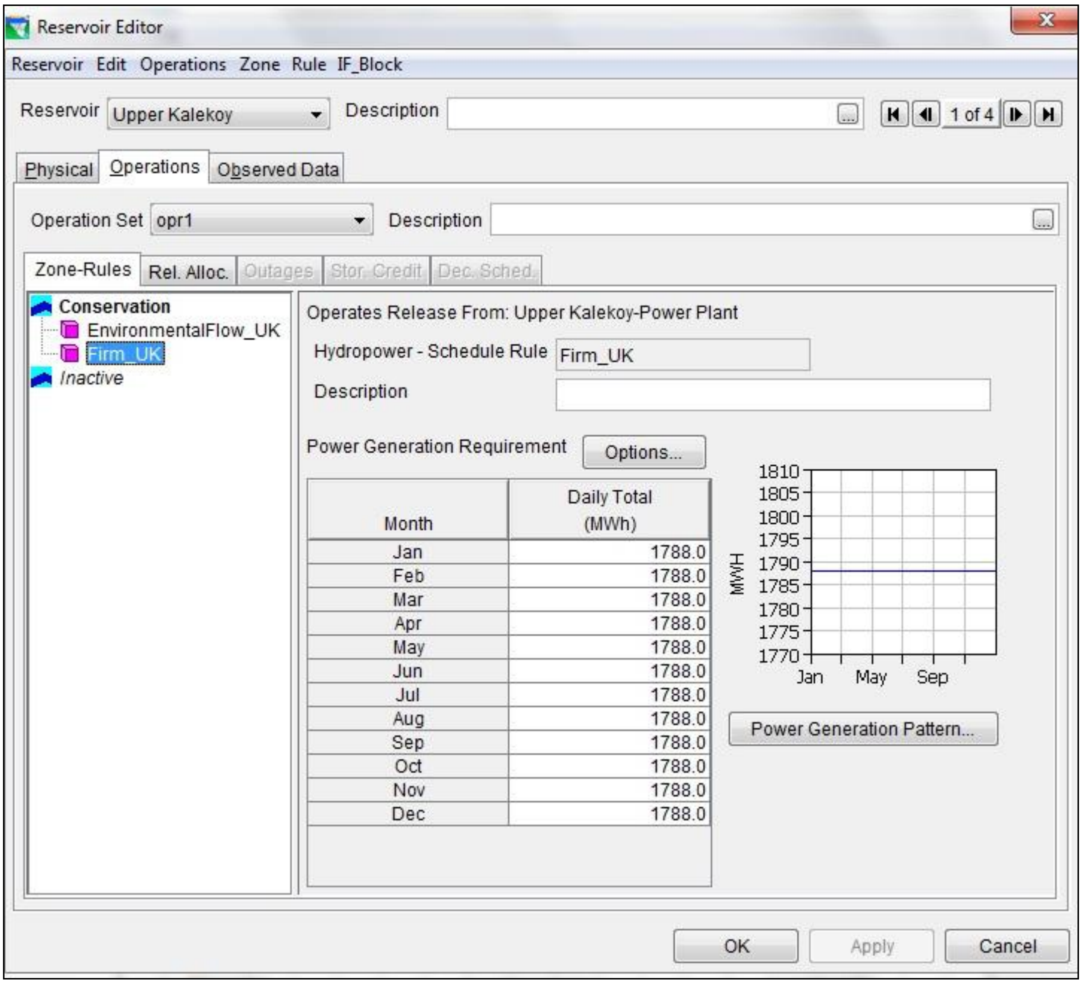


Figure 4.13 Application of firm power generation requirement rule

Environmental flow and firm energy requirement rules limits the allowable release range of power plants. In Figure 4.14, it is shown that because of the operation rules of Upper Kaleköy reservoir, allowable range is limited between 71.25 - 582.00 m³/s.

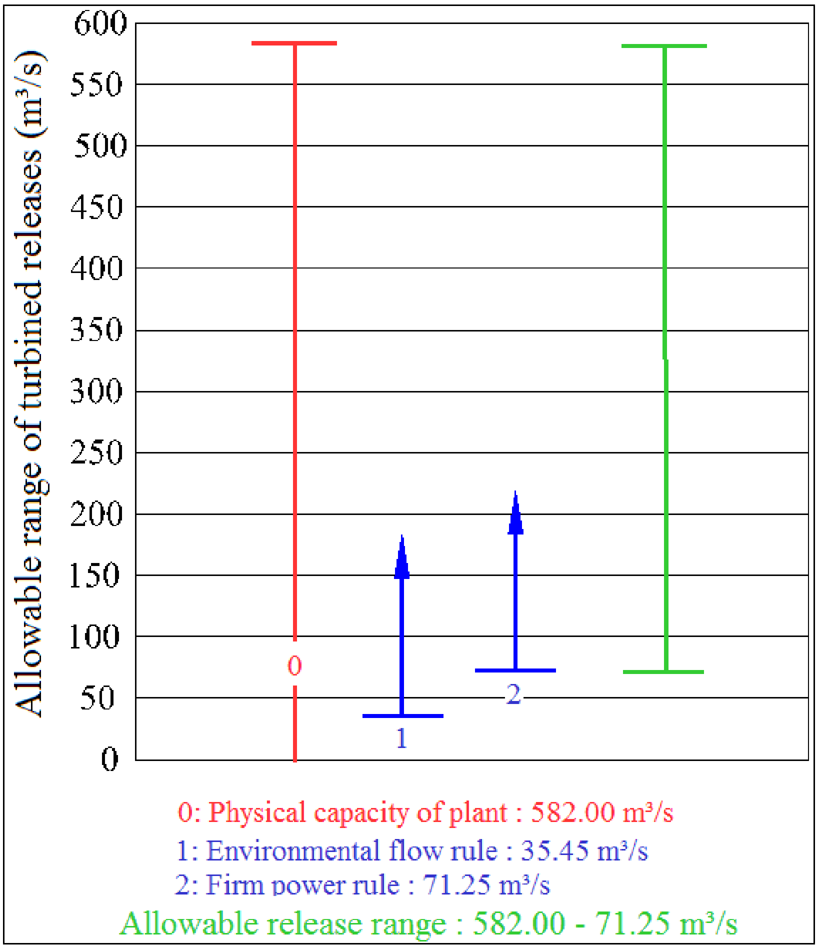


Figure 4.14 Allowable turbined release range of Upper Kaleköy in Scenario 3

Note that the reservoir water levels are not identical to the conservation storage in the reservoir during operation as shown in Figures 4.15-19, because of limitations imposed by inflows, environmental flow and firm power requirements.

A review of the long-term flow records shows a period of markedly reduced flows in 2000 and 2001, followed by high floods in the spring of 2002. These dry season years corresponds to 2050 and 2051 in simulation model. Therefore, the flow records from 2050 to 2051 are basis to determine the firm power of the Upper Kaleköy plants during critical period as shown in Figure 4.16.

In Figures 4.16, the use of the term ‘critical period' begins at a point in time when the reservoir is full. The end of the ‘critical period’ is defined as the point when the reservoir has refilled following the drought period. The larger the amount of reservoir storage, the higher the firm yield or firm energy output that can be sustained. Increasing the amount of reservoir storage also increases the length of the critical period, sometimes even changing the critical period to a completely different sequence of historical streamflows. Critical period may be a portion of a year, an entire year, or a period longer than a year.

Same procedure is applied to all other three reservoirs. Since reservoirs have different volumes and operation rules the time of critical period of each reservoir are not similar. In Figure 4.17, critical period of Lower Kaleköy reservoir is summer of year 2024. In addition to this, critical period of Beyhan 1 reservoir is summer of year 2034 as shown in Figure 4.18.

The procedure to find out the firm power capacity of each reservoir is simple. If the project fails to use all of the storage, the preliminary energy estimate understates the project’s firm capability. The monthly energy requirements were increased and the sequential routing was performed again in an effort to fully use the storage.

If the project is drafted below the bottom of the power pool, the preliminary power requirement estimate was too high. An adjustment was made similar to that described for the previous situation.

In either case, one or more additional iterations were made before the regulation exactly utilizes the power storage and the reservoir fully refills. Once a satisfactory regulation obtained, the projects firm energy output has been determined.

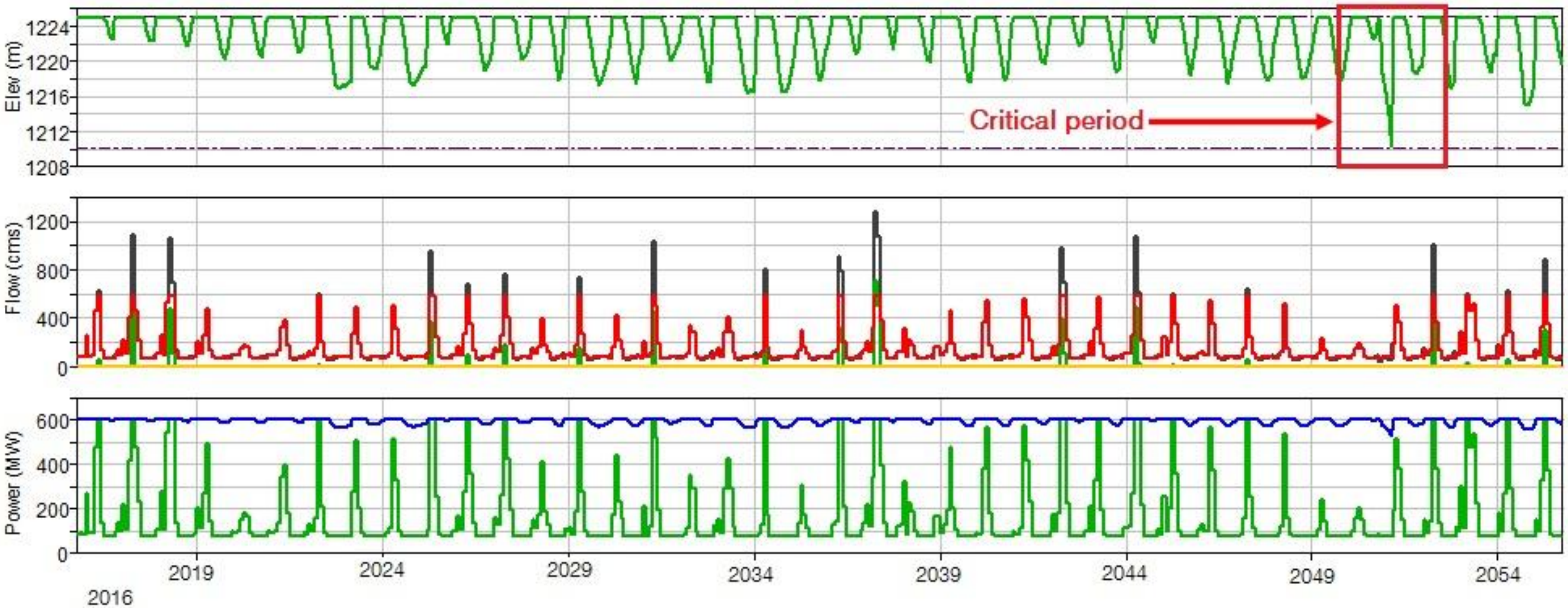


Figure 4.15 40 years time series simulation period operating cycle for Upper Kaleköy Dam and HEPP in Scenario 3

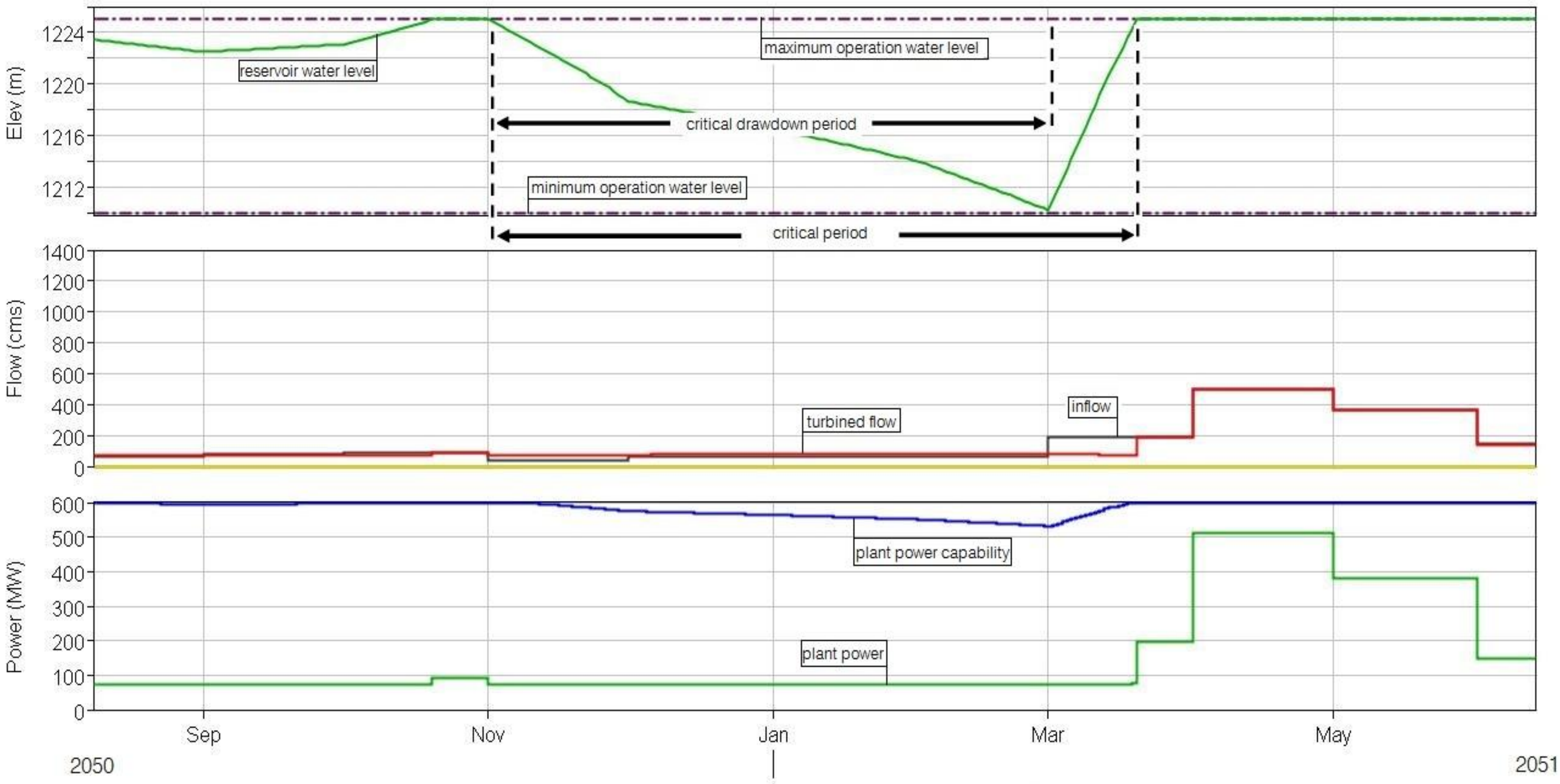


Figure 4.16 Critical period and critical drawdown period for Upper Kaleköy Dam and HEPP in Scenario 3

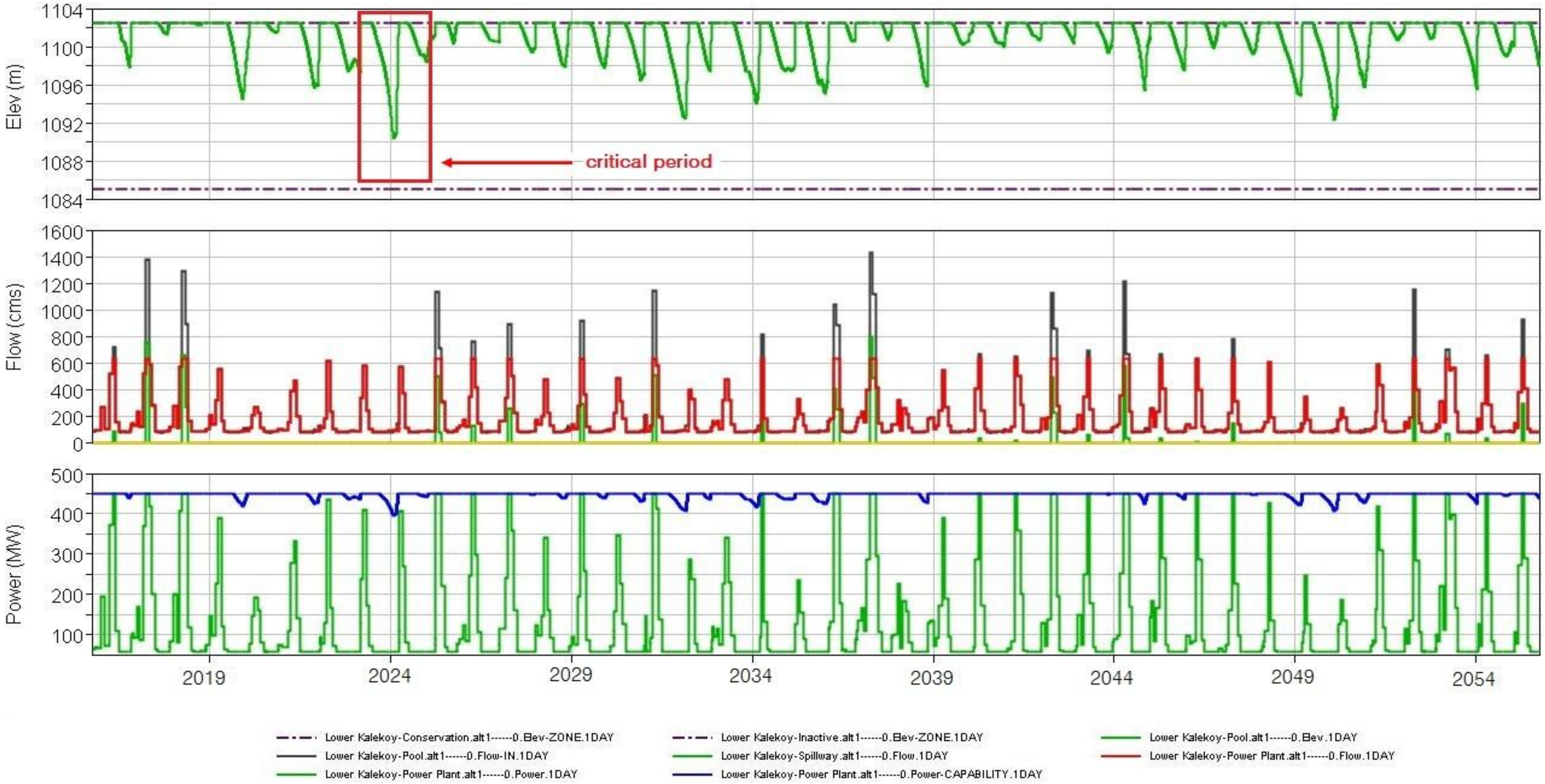


Figure 4.17 40 years time series simulation period operating cycle for Lower Kaleköy Dam and HEPP in Scenario 3

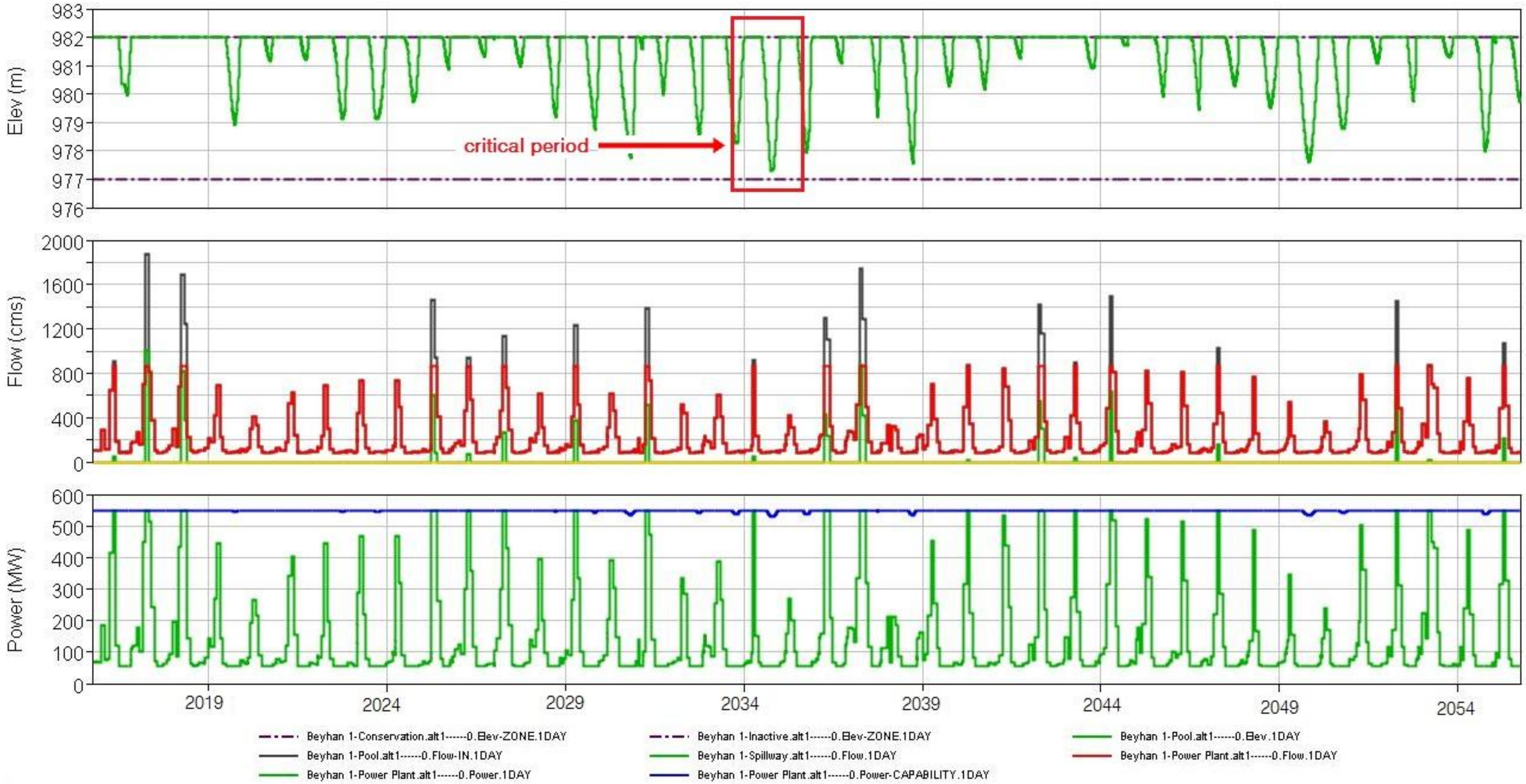


Figure 4.18 40 years time series simulation period operating cycle for Beyhan 1 Dam and HEPP in Scenario 3

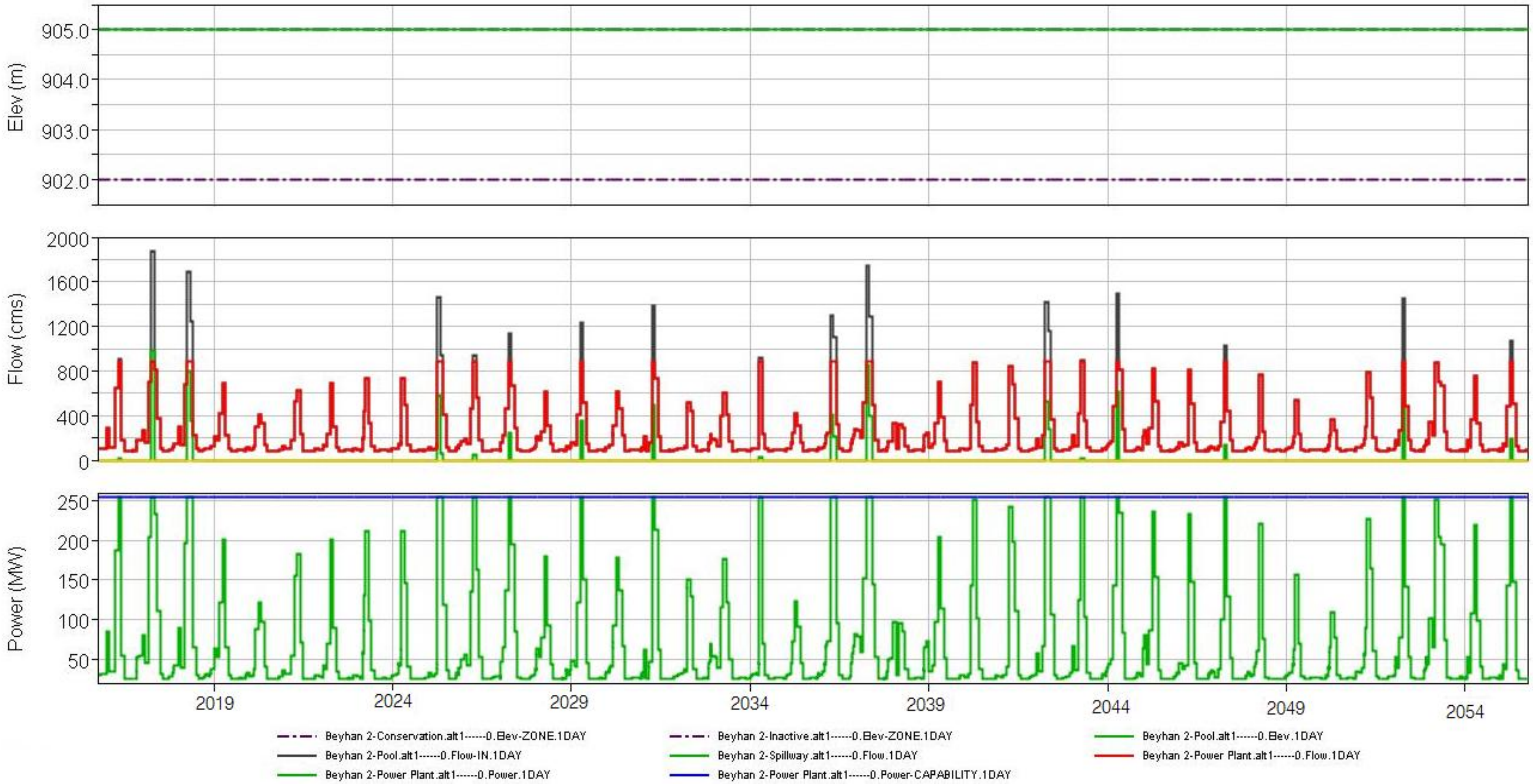


Figure 4.19 40 years time series simulation period operating cycle for Beyhan 2 Dam and HEPP in Scenario 3

Energy generated in excess of a project or system's firm energy output is defined as secondary energy. Thus, it is produced in years outside of the critical period and is often concentrated primarily in the high runoff season of those years. Secondary and firm energy generated at each power plant is shown in Figure 4.20-23. Yellow region presents secondary energy and green region presents the firm energy.

Secondary energy produced in years of higher inflow has to be maximised. This is achieved by keeping the heads as high as possible and reducing energy losses by keeping spillway operation to a minimum. The firm and secondary energy production values obtained for Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 dams on the basis of Scenario 3 are shown in Table 4.4.

Table 4.4 Summary of results for Scenario 3

Name of Facility	Annual net - inflow (hm^3)	Annual flow spill (m^3/s)	Annual turbined flow (m^3/s)	Firm power (MW)	Annual firm energy (GWh)	Annual secondary energy (GWh)	Annual total energy (GWh)
Upper Kal.	5254.5	407.0	4848.4	**74.5**	653.1	735.8	1388.9
Lower Kal.	6014.8	530.6	5485.3	**58.0**	508.4	583.0	1091.4
Beyhan 1	7472.6	566.4	6906.4	**55.5**	486.5	751.8	1238.3
Beyhan 2	7469.7	531.7	6937.6	**25.0**	219.6	345.7	565.3
Total	**26211.6**	**2035.7**	**24177.7**	**213.0**	**1867.6**	**2416.3**	**4283.9**

In Scenario 3 plant factors of Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 HEPPs are 0.26, 0.28, 0.26 and 0.25 respectively.

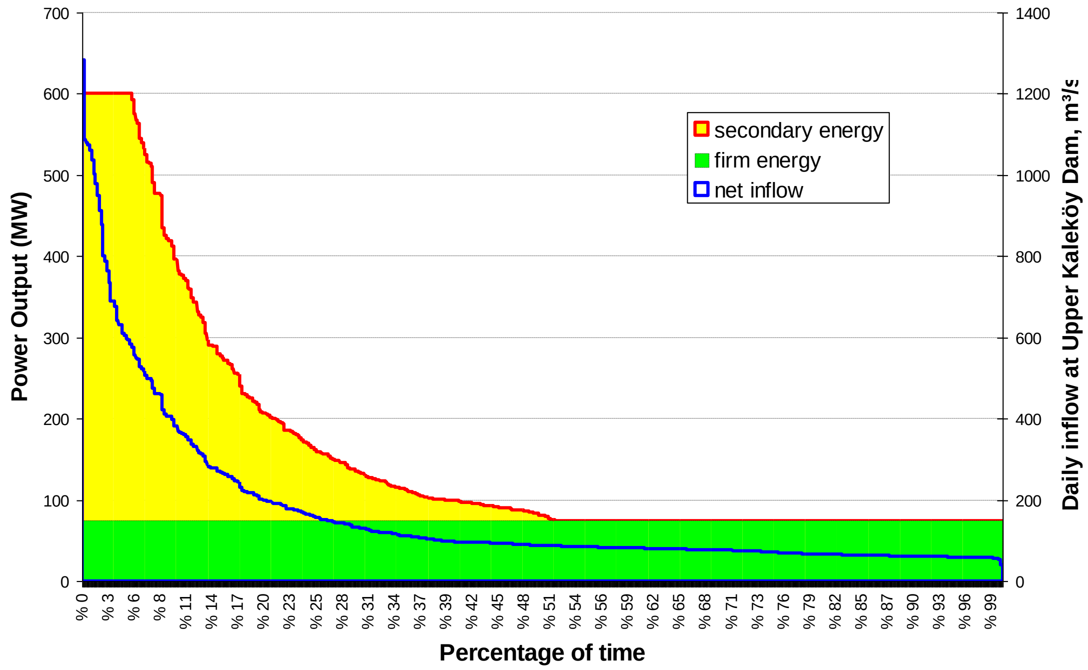


Figure 4.20 Power and net-inflow duration curve at Upper Kaleköy reservoir in Scenario 3

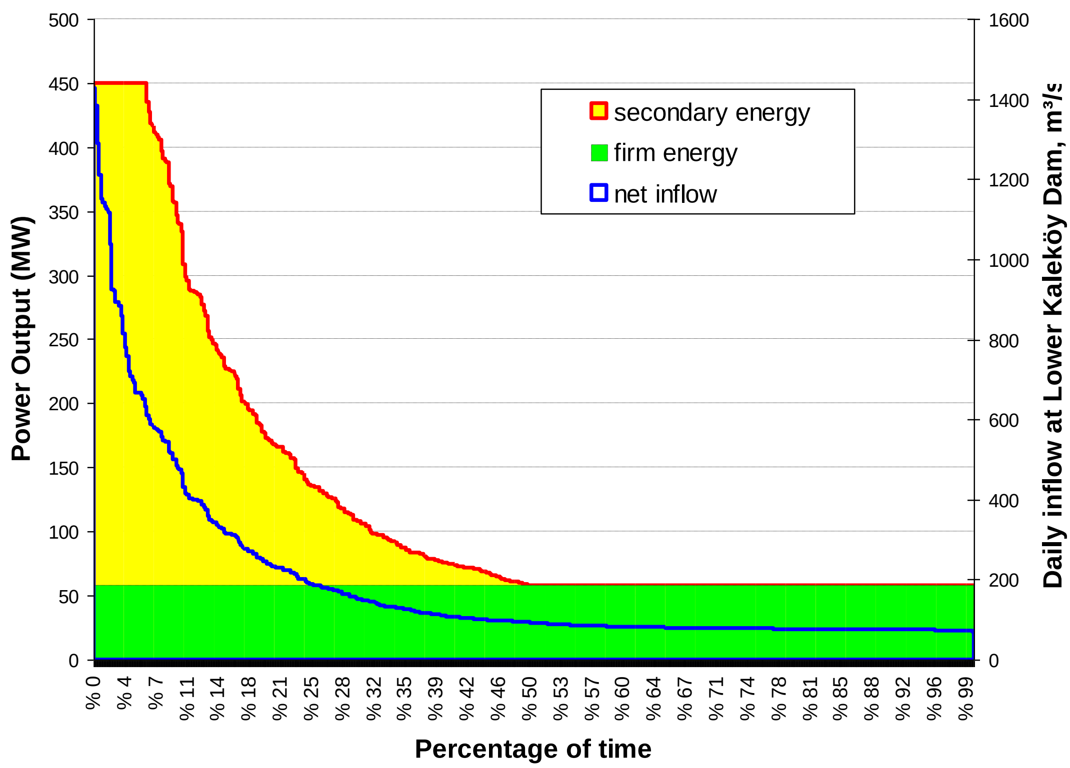


Figure 4.21 Power and net-inflow duration curve at Lower Kaleköy reservoir in Scenario 3

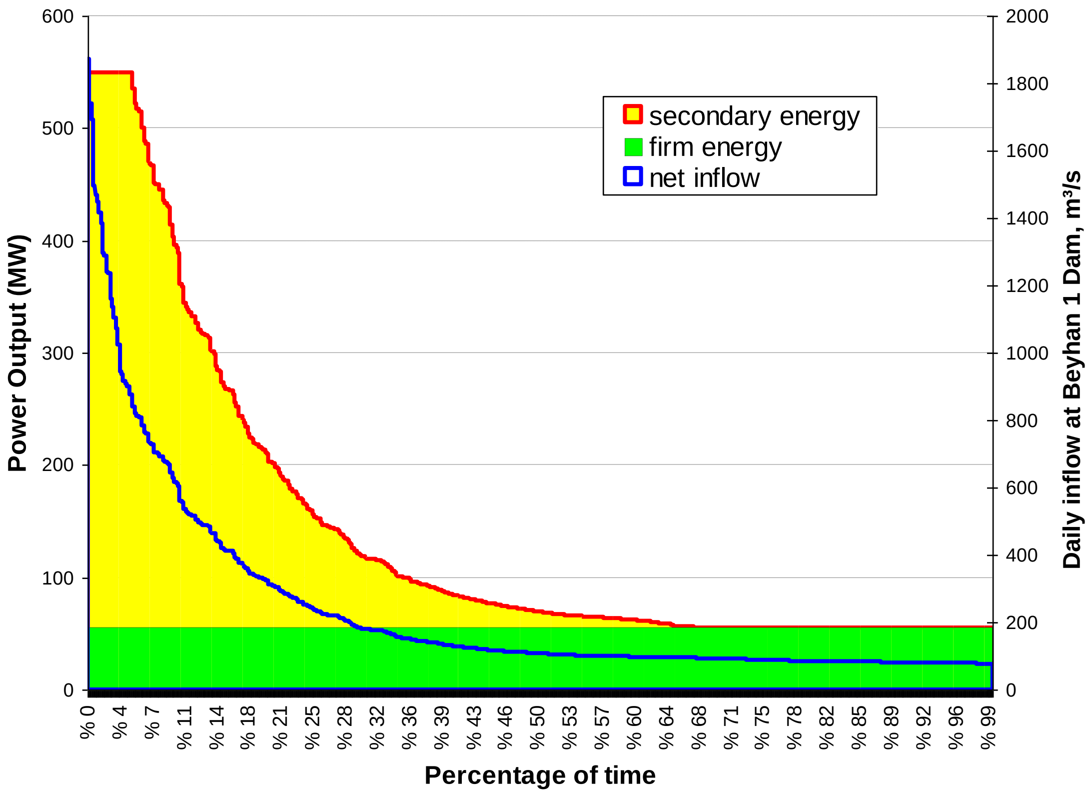


Figure 4.22 Power and net-inflow duration curve at Beyhan 1 reservoir in Scenario 3

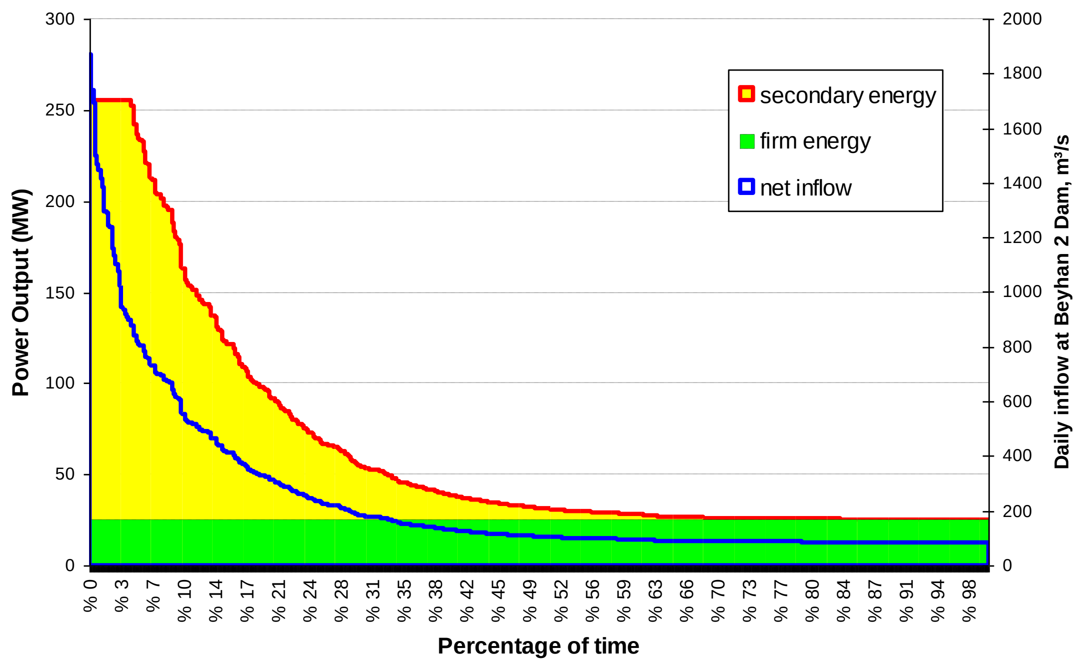


Figure 4.23 Power and net-inflow duration curve at Beyhan 2 reservoir in Scenario 3

4.5 Scenario 4

The model is designed to compare power releases to meet firm energy requirements between existing case (Scenario 3) and full development case. Since the inflow decreases in full development case, the firm energy generation decreases. The impacts of low inflow, result in considerable deviation on the energy generation and operation water level.

The useful storage volume of the Upper, Lower Kaleköy and Beyhan 1 has provided considerable hold-over storage capacity for inter-annual regulation, in other words a part of the flow in wet years were stored in order to permit additional releases in subsequent dry years.

Table 4.5 lists the firm and secondary energy generation for the design scenario 4. It is shown that there is a 20% decreases in total firm power and 16% decrease in total generated energy.

Table 4.5 Summary of results for Scenario 4

Name of Facility	Annual net - inflow (hm^3)	Annual flow spill (m^3/s)	Annual turbined flow (m^3/s)	Firm power (MW)	Annual firm energy (GWh)	Annual secondary energy (GWh)	Annual total energy (GWh)
Upper Kal.	4106.2	170.7	3939.0	**56.0**	490.9	632.2	1123.1
Lower Kal.	4868.7	261.4	4608.7	**47.0**	412.0	506.2	918.2
Beyhan 1	6326.6	318.8	6008.4	**46.0**	403.2	675.6	1078.8
Beyhan 2	6323.8	297.4	6026.2	**20.8**	182.3	309.7	492.0
Total	**21 625.3**	**1 048.3**	**20 582.3**	**169.8**	**1 488.4**	**2 123.7**	**3 612.1**

In Scenario 4 plant factors of Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 HEPPs decreases to 0.21, 0.23, 0.22 and 0.22 respectively.

4.6 Scenario 5

Full development case time series were used in Scenario 5. In addition to this, all inputs and variables are the same with Scenario 4 except that Lower Kaleköy's minimum operation level has been lowered from 1085.0 to 1065.0 as shown in Figure 4.24. The reason is that in Feasibility Report (Temelsu International Engineering Services Inc., 2011) sediment volume is at 1048.0 m however the intake level was chosen as 1069.0 m. Now it is considered to evaluate the effect of the increase in conservation volume on power generation.

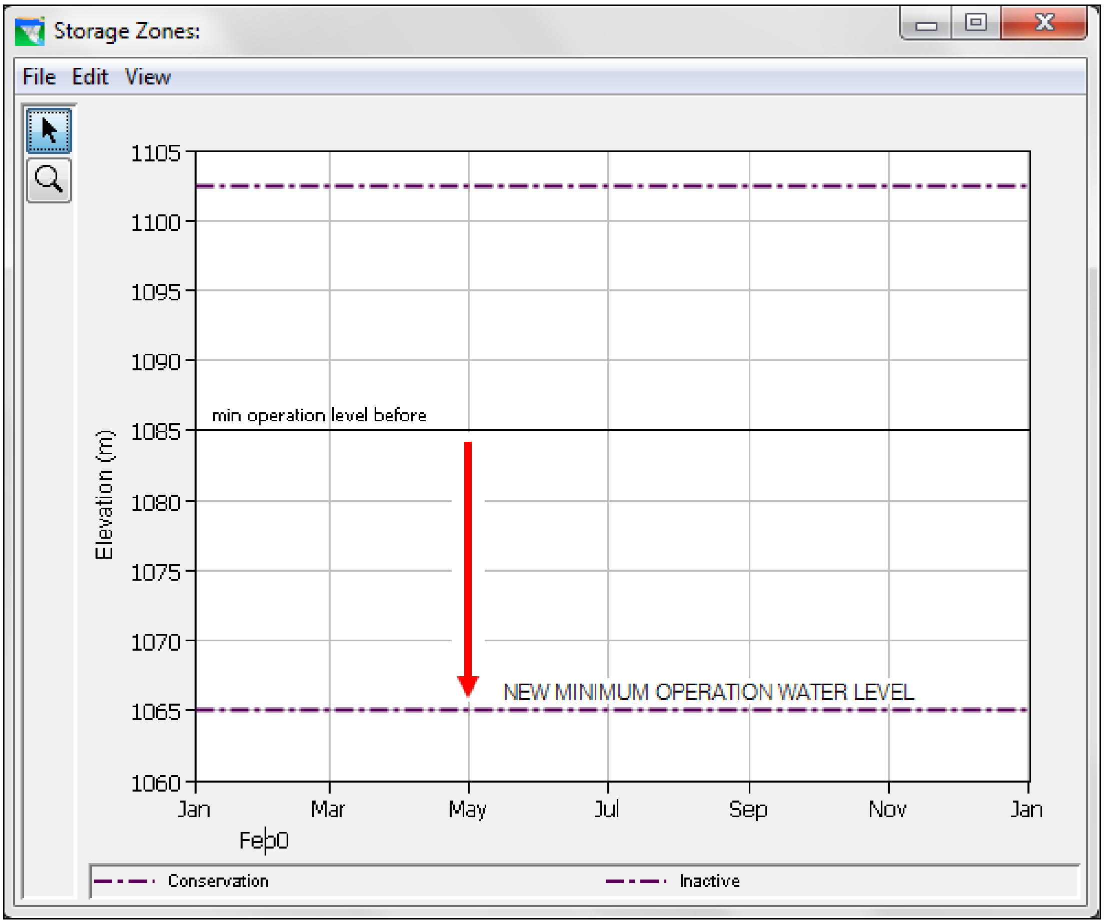


Figure 4.24 Revised storage zone at Lower Kaleköy reservoir in Scenario 5

With this assumption Table 4.6 lists the firm and secondary energy generation for the design Scenario 5.

Table 4.6 Summary of results for Scenario 5

Name of Facility	Annual net - inflow (hm³)	Annual flow spill (m³/s)	Annual turbined flow (m³/s)	Firm power (MW)	Annual firm energy (GWh)	Annual secondary energy (GWh)	Annual total energy (GWh)
Upper Kal.	4106.2	170.7	3939.0	56.0	490.9	632.2	1123.1
Lower Kal.	4868.7	261.4	4609.1	48.1	421.6	489.3	910.9
Beyhan 1	6327.1	318.8	6009.0	47.4	415.5	663.5	1079.0
Beyhan 2	6324.4	297.4	6026.8	21.4	187.6	304.5	492.1
Total	**21 626.4**	**1 048.3**	**20 583.9**	**172.9**	**1 515.6**	**2 089.5**	**3 605.1**

In Scenario 5, plant factors of Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 HEPPs are 0.21, 0.23, 0.22 and 0.22 respectively.

4.7 Scenario 6

The model is designed to compare firm energy and total energy generation between Scenario 4 and Scenario 6 at full development case. In Scenario 6, to determine the release from the reservoir in order to increase firm energy, some adjustments are made by iterations on the guide curve. Without any other operational constraints, the decision logic will attempt to get to and keep the reservoir at the guide curve, within maximum outlet capacity and physical rate of change constraints.

The coordinates of the points of the operation guide curves are specified by parameters, which are subject to iterations. It is obvious that it is not required to iterate all coordinates of the points. For example, it is obvious that the reservoir should be full after the snowmelt period. Similarly, to reduce spillway losses the reservoir should be at a lower operation level before the onset of the snowmelt runoff peak in spring.

Figure 4.25 shows a common operation guide curve for Kaleköy reservoir system. Usage of more points on the operation guide curve is not desirable because of only insignificant increase in revenue generation and the problem becomes considerably more complex.

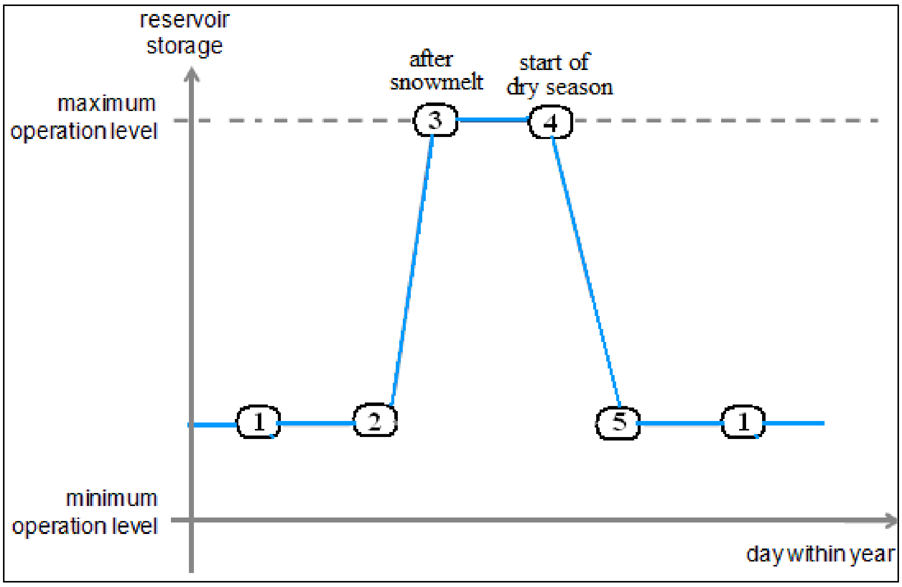


Figure 4.25 A general example of guide curve for Kaleköy reservoir system

In Scenario 6, many iterations were made to increase the firm energy capacity of Kaleköy reservoir system. In Figure 4.26, guide curves for related reservoirs are shown. In Figures 4.27-28 all simulation period is illustrated as an example for Lower Kaleköy reservoir.

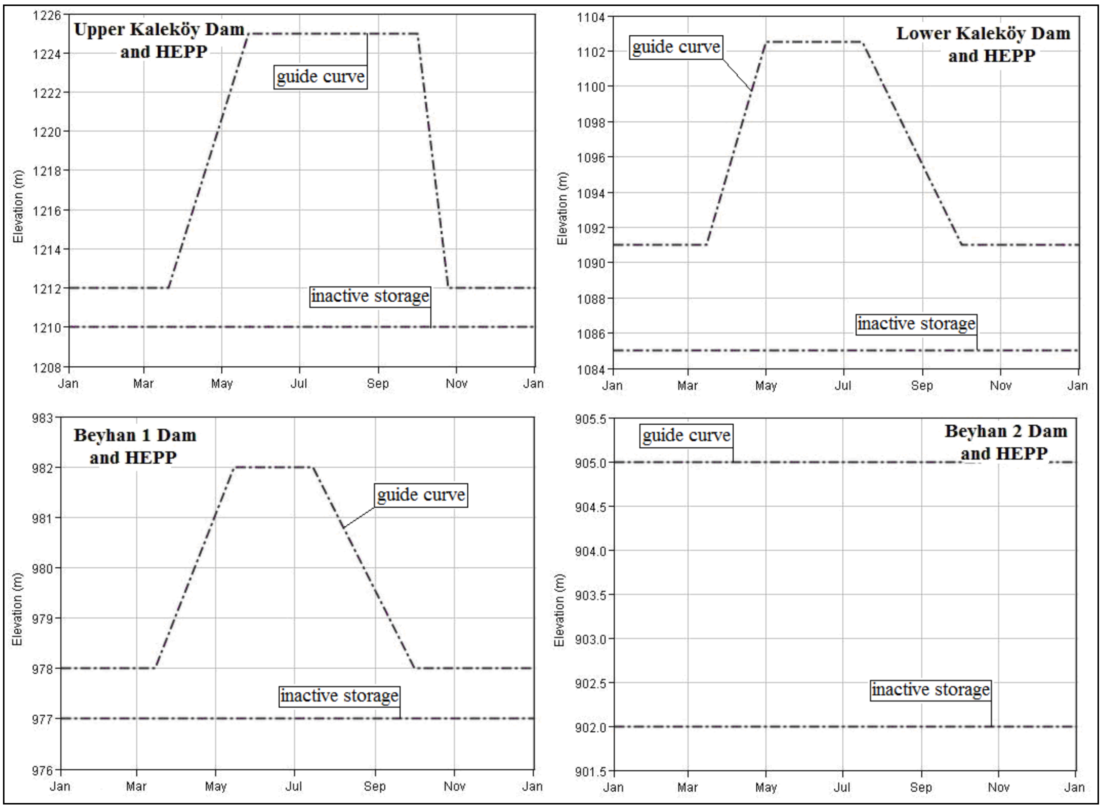


Figure 4.26 Operation guide curves for Kaleköy reservoir system

Increase in firm energy does not mean increase in total annual energy or increase in benefit this subject is discussed in Chapter 5. The results of Scenario 6 is summarized in Table 4.7.

Table 4.7 Summary of results for Scenario 6

Name of Facility	Annual net - inflow (hm³)	Annual flow spill (m³/s)	Annual turbined flow (m³/s)	Firm power (MW)	Annual firm energy (GWh)	Annual secondary energy (GWh)	Annual total energy (GWh)
Upper Kal.	4106.2	149.7	3960.2	56.0	490.9	573.6	1064.5
Lower Kal.	4868.9	209.9	4658.8	49.8	436.6	429.8	866.4
Beyhan 1	6325.6	262.2	6063.2	50.3	440.9	618.9	1059.8
Beyhan 2	6321.8	243.6	6077.8	22.8	199.9	297.0	496.9
Total	**21 622.5**	**865.4**	**20 760**	**178.9**	**1 568.3**	**1 919.3**	**3 487.6**

In Scenario 6, plant factors of Upper Kaleköy, Lower Kaleköy, Beyhan 1 and Beyhan 2 HEPPs are 0.20, 0.22, 0.22 and 0.22 respectively.

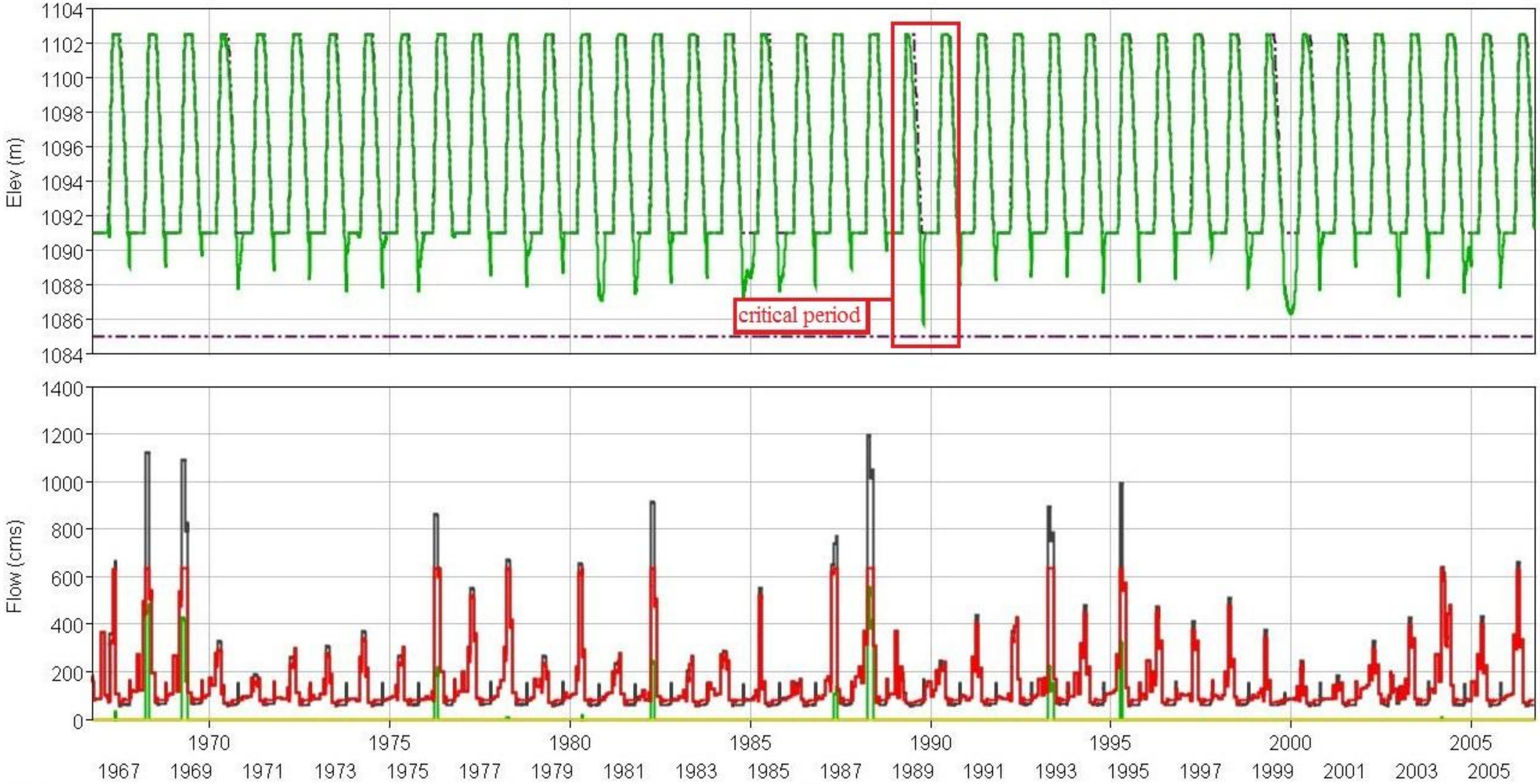


Figure 4.27 40 years time series simulation period operating cycle for Lower Kaleköy Dam and HEPP in Scenario 6

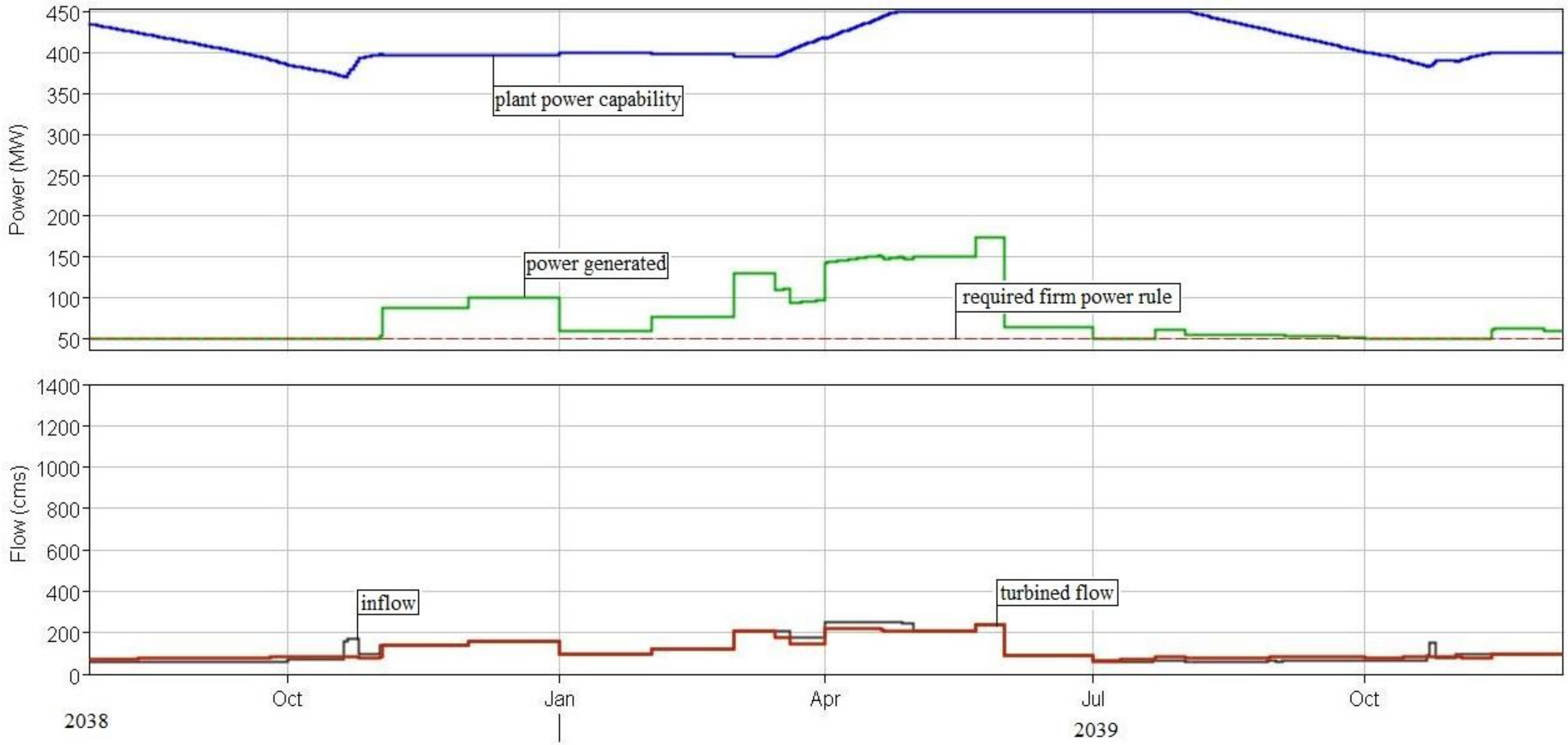


Figure 4.28 A closer look to the power plot for the critical period operating cycle for Lower Kaleköy Dam and HEPP in Scenario 6

4.8 Scenario 7

The hydrology of Turkey makes the hydro plants predominantly peaking plants, so that the demand for additional peak energy is supplied by the installation of further hydro plant. The additional base energy needed is obtained from fossil-fuelled (lignite and coal) plant as mentioned in Chapter 2.

Hydroelectric plants will operate with a relatively simple daily peaking operation, with a fixed number of on-peak and off-peak hours each day. The goal of hydroelectric plant operation is to have as much flow available for generation as possible during on-peak hours, in order to increase income. In all months of the year peak energy has been produced. The peak operation period is assumed to be 6 hrs/day as shown in Figure 4.29.

Load or demand for electric power varies from hour to hour, from day to day, and from season to season in response to the needs and living patterns of the power users. Demand for power is at a low point in the early morning hours, when most of the population is at rest. Demand increases markedly at 6 am, as people get up and begin going to work, and reaches a peak in the late morning hours.

As the long term average natural flow rate of the Kaleköy reservoir system is about 167.0 m^3/s, the maximum turbine discharge capacities of turbines are more than three times as much as the long term average stream flow, and hence, Kaleköy reservoir system is suitable for discontinuous running and producing large energies during peaking demand hours.

The electric distribution companies have been applying the so-called 'wise -hours-schedule' system of pricing on voluntary basis. Hourly operation studies are short-term sequential streamflow routing studies, performed primarily to evaluate the performance of hydro peaking projects. The term “hourly studies” has been applied to this scenario as a matter of convenience; the simulation presented here was applied to six-hour intervals.

Table 4.8 Wise -hours-schedule for Scenario 7

Peak	18:00 - 24:00	(25% day)
Day	06:00 - 18:00	(50% day)
Off-Peak	24:00 - 06:00	(25% day)

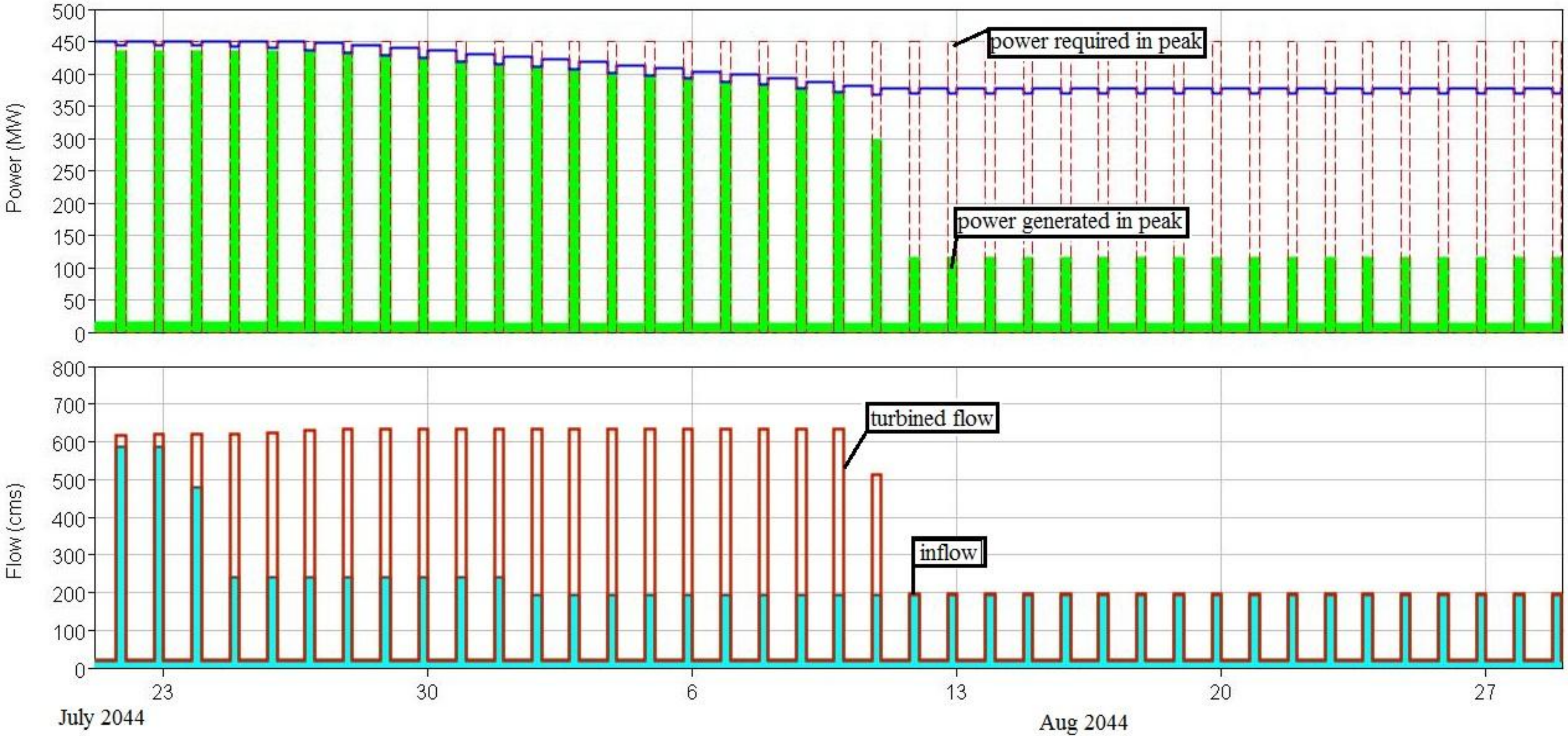


Figure 4.29 Peak power generation operation cycle for Lower Kaleköy Dam and HEPP in Scenario 7

A number of factors influence the amount of peaking capacity of Kaleköy reservoir system at given installed capacities and storage volumes:

i) average reservoir's inflows,
ii) time distribution of reservoir inflow,
iii) required generating pattern,
iv) required minimum discharge,
v) reservoir elevation at start of weekly operating cycle,
vi) downstream discharge.

Table 4.9 Summary of results for Scenario 7

Name of Facility	Production (GWh/year)			
	18-24 (T2)	**06-18 (T1)**	**24-06 (T3)**	**Total**
Upper Kaleköy	798.76	379.30	150.95	**1 329.01**
Lower Kaleköy	608.25	283.72	118.93	**1 010.90**
Beyhan 1	712.72	355.98	144.10	**1 212.80**
Beyhan 2	323.46	160.82	64.29	**548.57**

The power duration curves shown in Figures 4.30-4.33 illustrate what percentage of the time peak power operation occurs in Kaleköy reservoir system.

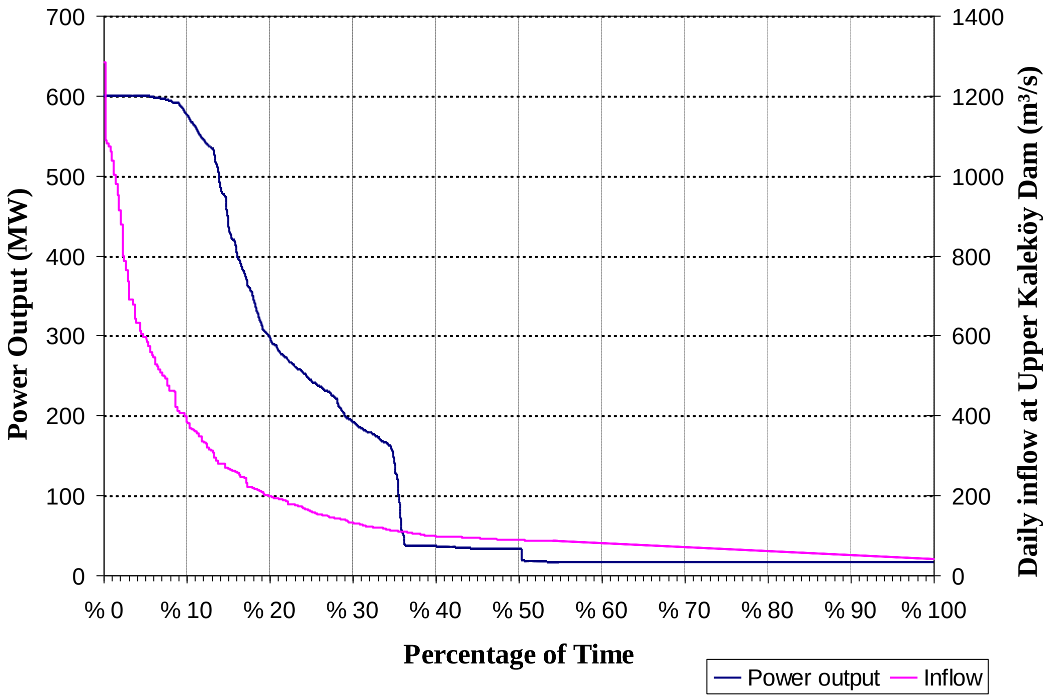


Figure 4.30 Power and net-inflow duration curve at Upper Kaleköy reservoir in Scenario 7

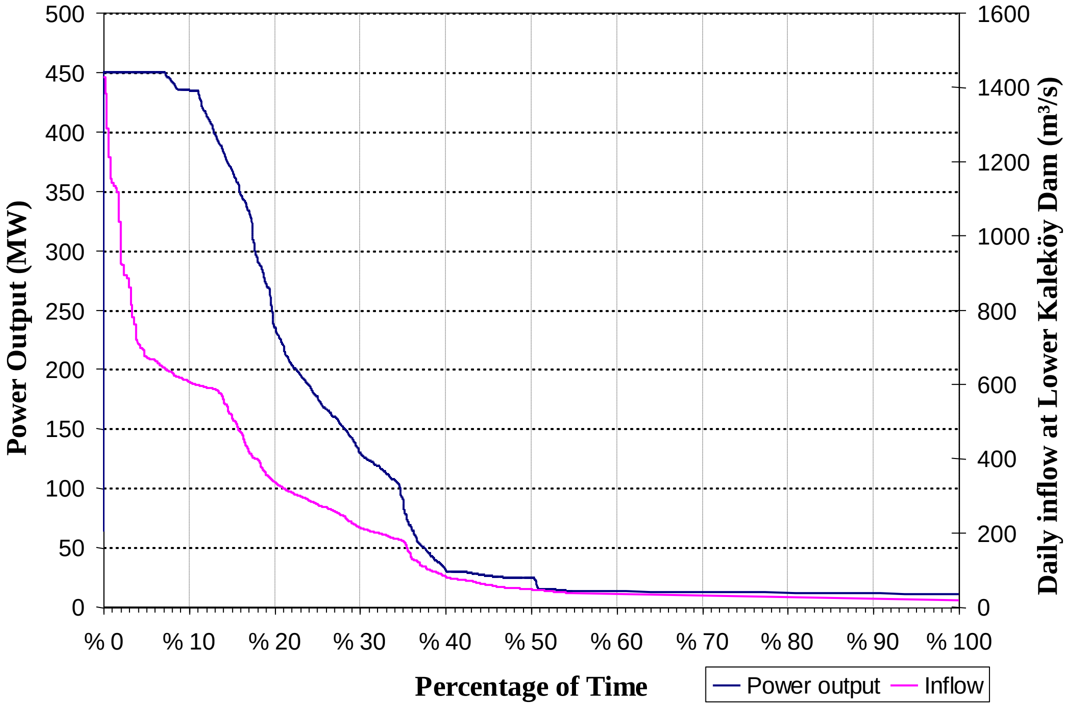


Figure 4.31 Power and net-inflow duration curve at Lower Kaleköy reservoir in Scenario 7

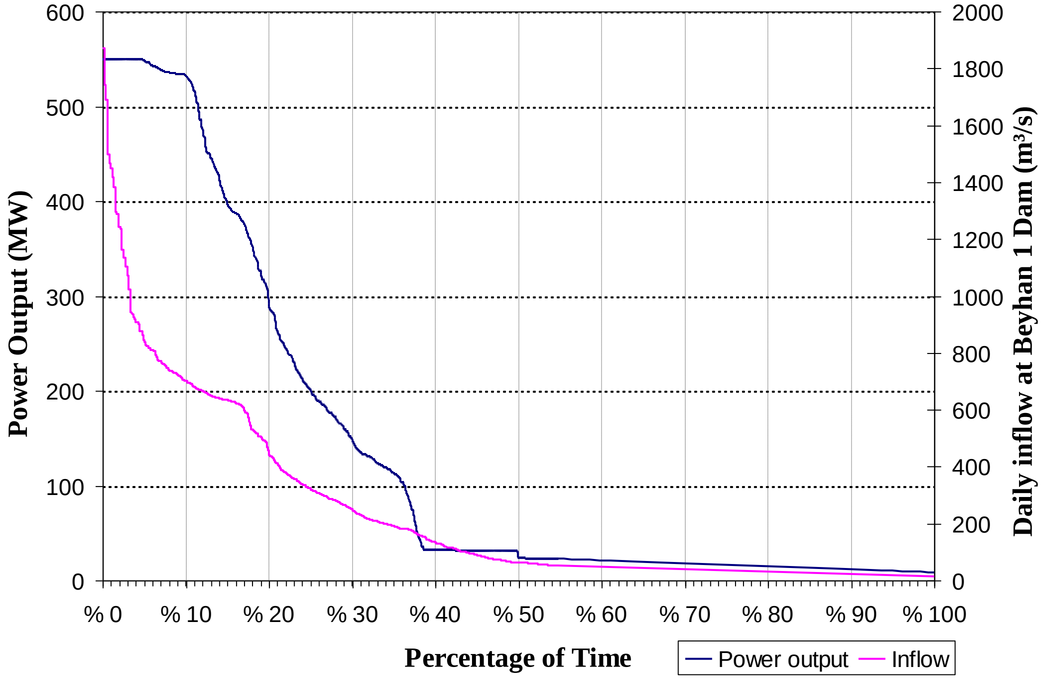


Figure 4.32 Power and net-inflow duration curve at Beyhan 1 reservoir in Scenario 7

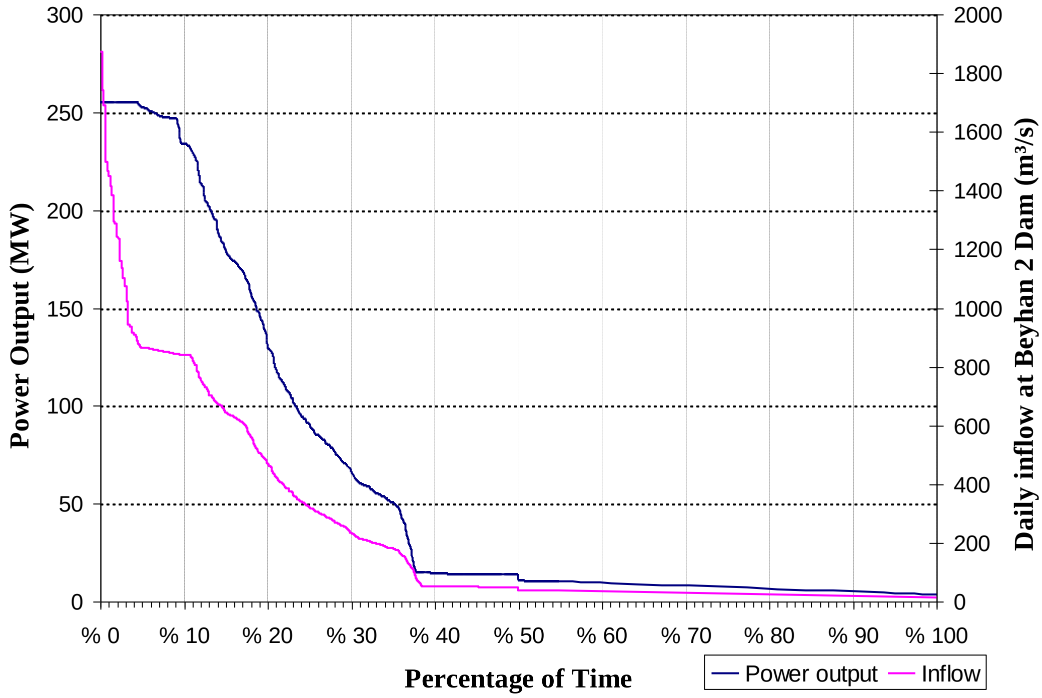


Figure 4.33 Power and net-inflow duration curve at Beyhan 2 reservoir in Scenario 7

4.9 Pumped Storage Scenarios

Zhang (2012) states that pumped storage has many advantages like stored water can be used for hydroelectric power generation to cover temporary peaks in demand. Although, it is not an easy task to generate energy, planning needs a detailed examination of future system operation.

In this chapter, pump storage alternatives have been analyzed. Three pump storage scenarios have been investigated to utilize the hydraulic potential.

Pump storage scenarios have been studied for Scenario 8, Scenario 9 and Scenario 10. Scenario 8 and Scenario 9 have four cascade dams which includes one reversible pump turbines and three conventional turbines each. Scenario 10 has two reversible pump turbines as Upper Kaleköy and Beyhan 1 reservoirs and two conventional turbines as Lower Kaleköy and Beyhan 2 reservoirs. Different installed pump capacities have been analyzed for these scenarios.

It has been accepted that units will operate in pump mode during off-peak period whereas they will operate in turbine mode during peak period.

The general assumptions made in the analyses are given below.

i) The installed capacity in turbine and pump modes are assumed to be different. Accordingly, turbined and pumped discharge values have been calculated.

ii) In all months of the year peak energy has been produced.

iii) The peak operation period is assumed to be 6 hrs/day.

iv) Target fill elevation in the reservoir receiving the pumped water is selected as highest elevation of the conservation zone as shown in Figure 4.34.

v) Full pump capacity strategy is selected. It will minimize the time spent for pumping. As a result of this, sometimes there are more time available in the pumping period than is needed to get the reservoir pool back to its target elevation.

vi) Minimum pumping option is not selected, since there is no need to force the reservoir to pump, even if it doesn't need to.

vii) A fixed hour range is specified for daily pumping period as shown in Figure 4.34. The maximum duration of pumping is taken as 6 hrs/day.

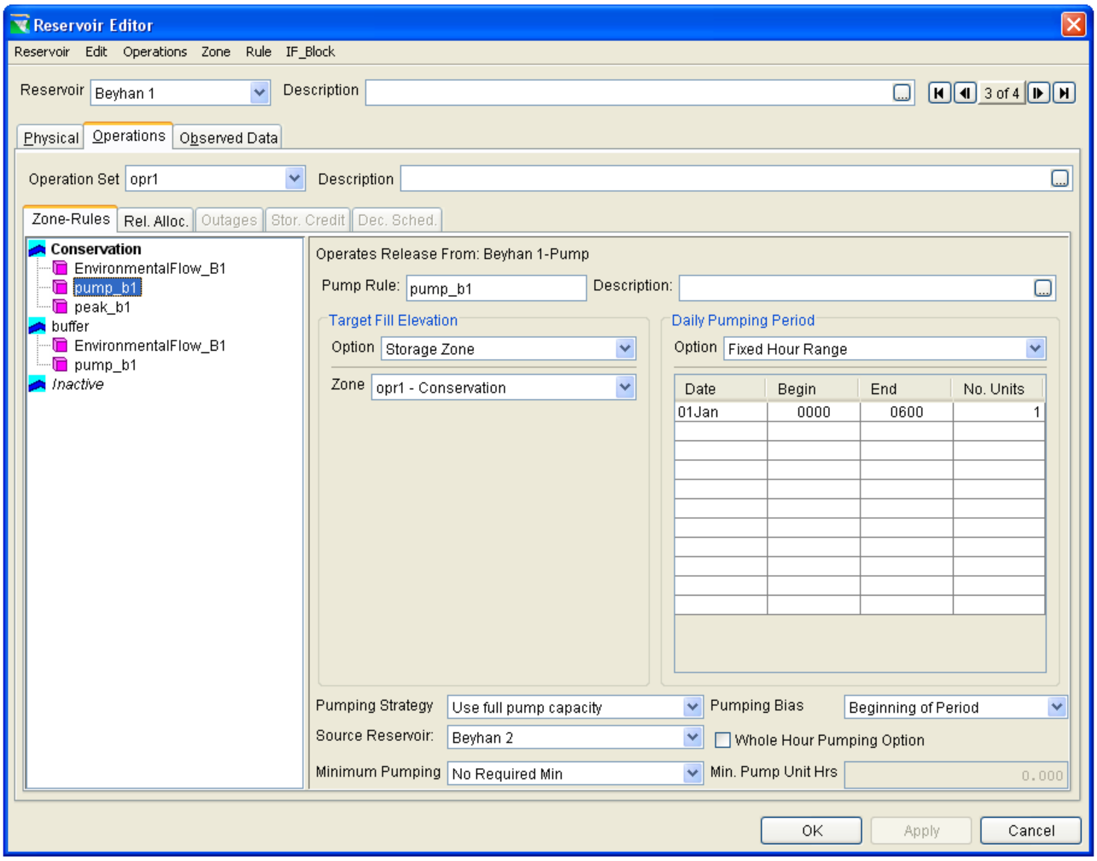


Figure 4.34 Reservoir editor tab to define the physical characteristics of pump

Daily pumping period is selected from midnight to 6:00 am. In additon to this, since water is pumped back to the upper reservoir there is no need to turbine environmental flow between off-peak hours (24:00-06:00). Hour of day multiplier operation allows us to specify a factor that will be applied to the release specified by environmental flow rule as shown in Figure 4.35. Since environmental release rule is not required during pumping period, it is set the multiplier for off-peak hours to 0.0 and all other to 1.0.

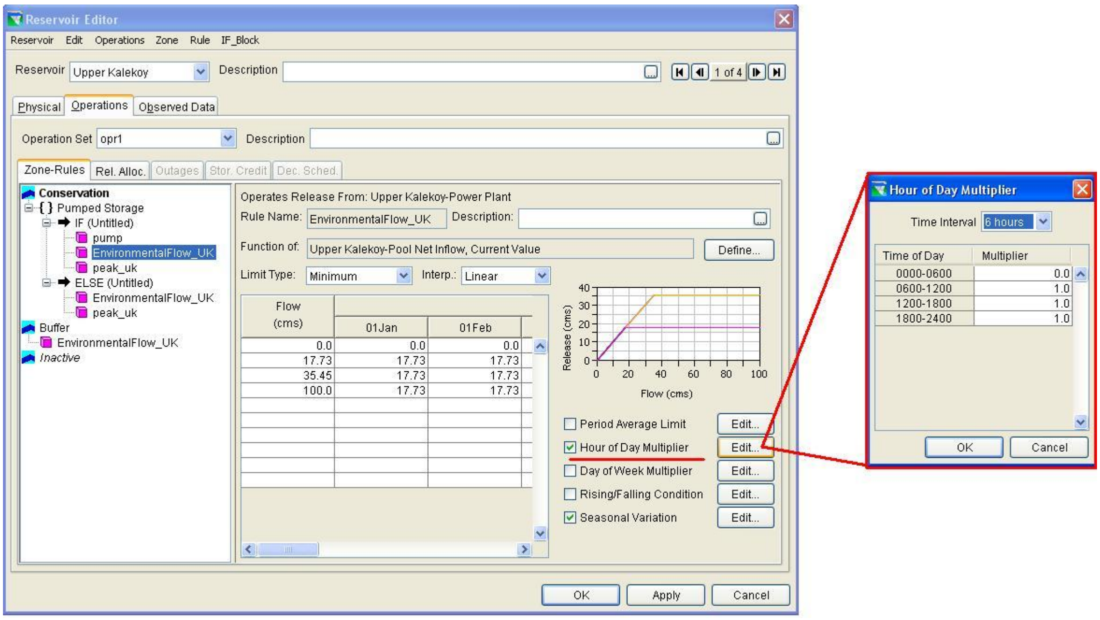


Figure 4.35 Hour of day multiplier with values of 0.0 and 1.0 specified for a portion of day

Since there are many types of machines appropriate for pumped-storage applications, the type is selected by the available head. Single-stage reversible Francis turbines are best choice between 50 to 800 m range. If the head is above 800 m, multi stage units or seperate pump and turbines should be considered (Voith, 2009). In addition to this, in near future with improvement in technology single-stage Francis units may be used for greater than 800 m. Figure 4.36 illustrates the performance range for pump-turbines.

In pumped storage Scenario 8 and Scenario 10, Upper Kaleköy reservoir has a reversible turbine which has a 550 MW installed capacity in pump mode 600 MW installed capacity in turbine mode. In addition to this, Beyhan 1 reservoir has a reversible turbine which has a 500 MW installed capacity in pump mode 550 MW installed capacity in turbine mode in Scenario 9 and Scenario 10. Lower Kaleköy and Beyhan 1 reservoirs have the same installed capacities in all scenarios as 450 MW and 255 MW respectively.

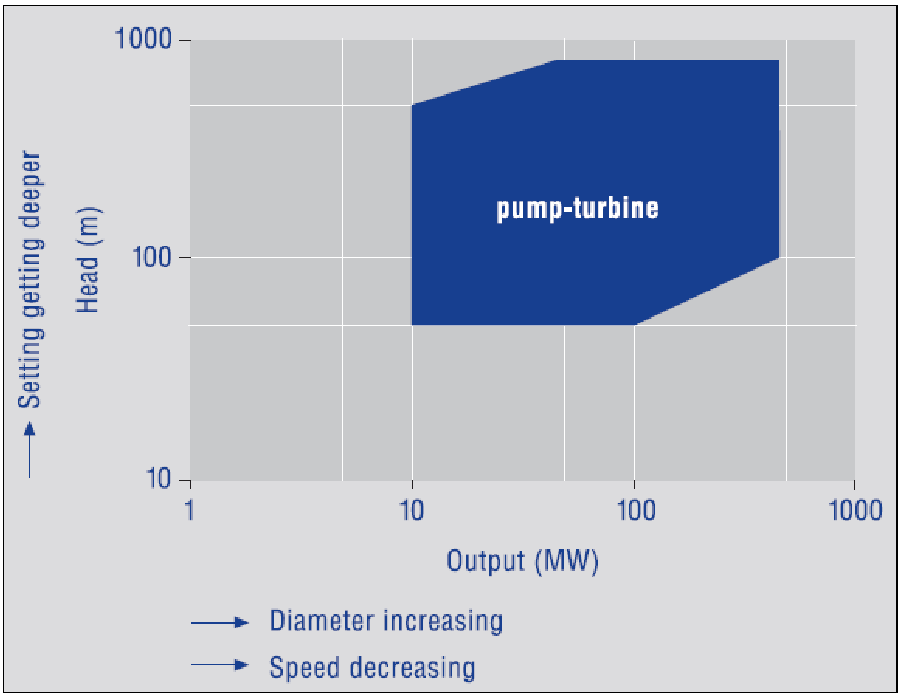


Figure 4.36 Performance range for pump-turbines (Voith, 2009)

Regardless of pumping strategy selection, if the target cannot be reached in the pumping period, the pumps will be operated at full capacity over the entire pumping period in order to get as close to the target as possible.

Same head losses presented in Chapter 3.5 in turbine mode are used in pump mode too. Hydraulic losses for Upper Kaleköy and Beyhan 1 pump-turbines are 2.5 and 2.0 m, respectively.

4.9.1 Scenario 8

In this scenario, Upper Kaleköy Dam at the upstream will be upper reservoir whereas Lower Kaleköy Dam at the downstream will be the lower reservoir in the system as shown in Figure 4.37. The power plant of the upper reservoir will be equipped with reversible pump-turbines. In pump mode the water from Lower Kaleköy reservoir will flow to Upper Kaleköy reservoir during off-peak hours between 24:00-06:00. In turbine mode the water from Upper Kaleköy reservoir will flow to Lower Kaleköy reservoir between 06:00-24:00 hours. Operation cycle is shown in Figure 4.38 for 40 years long time series.

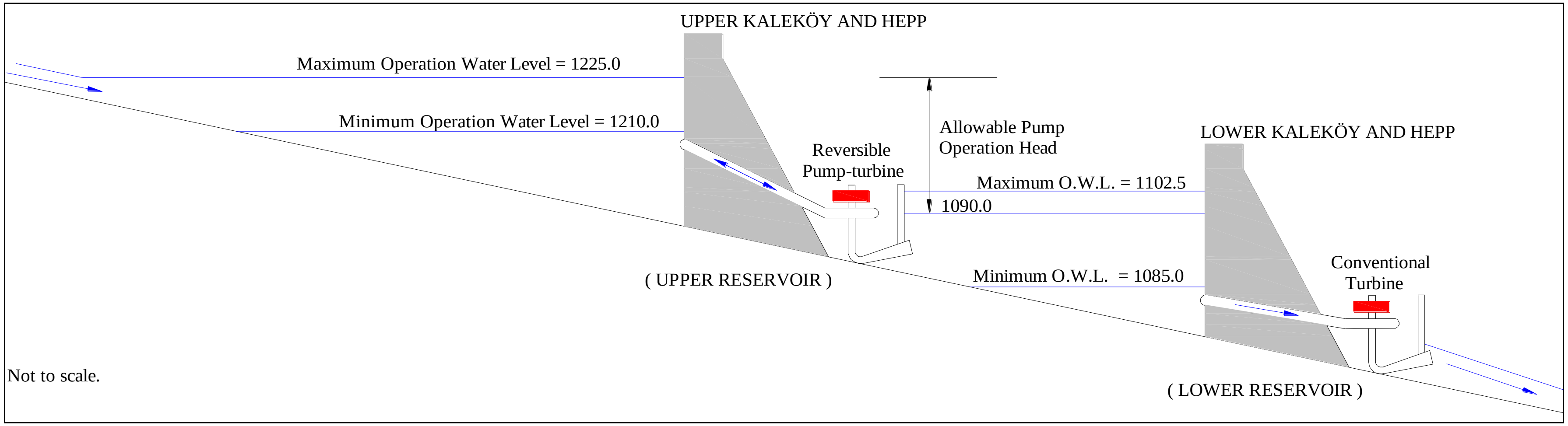


Figure 4.37 Visual presentation of Scenario 8

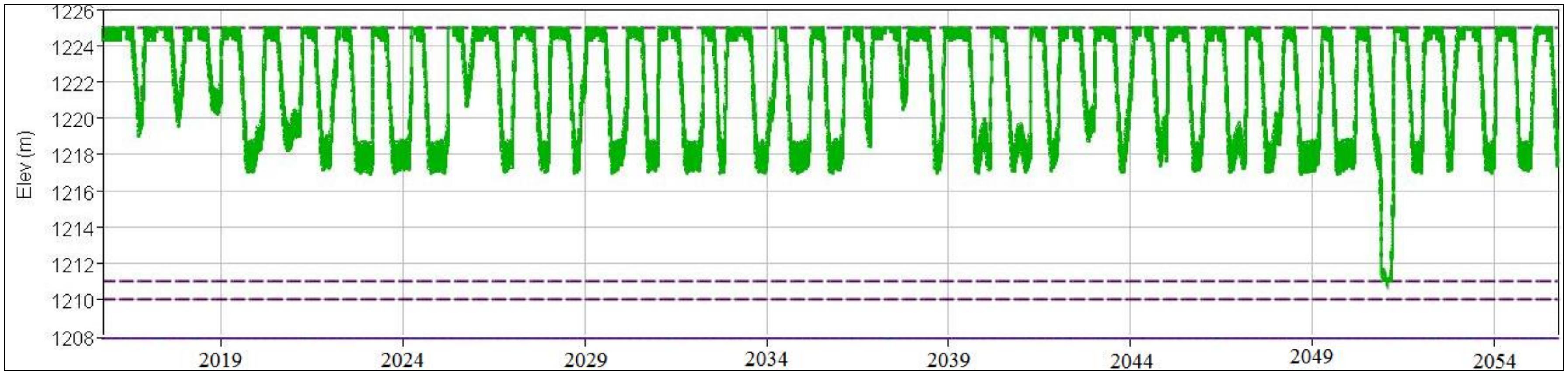


Figure 4.38 40 years long time series simulation period operating cycle for Upper Kaleköy Dam and HEPP in Scenario 8

In Hec-ResSim it is not possible to get directly the consumed energy during pump mode. By simple calculations it is easy to find out pumped energy at each time step. For example, on the first day of February in 2016 at Upper Kaleköy, net head (124.67 m) is assumed as hydraulic loss (2.5 m) plus gross head (122.17 m) in Table 4.10. Then energy for pumping is calculated (3226.77 MWh) by multiplying net head (124.67) with maximum pump discharge (395.75 m³/s) for six hours and finally divide by pump efficiency (0.9).

Table 4.10 Calculation methodology of consumed pump energy

Time	**simulation results**			**calculated**		
	Upper Kaleköy Pool Elevation (m)	**Lower Kaleköy Pool Elevation (m)**	**Pumping Duration (hr)**	**Gross Pump Head (m)**	**Net Pump Head (m)**	**Consumed Pump Energy MWh**
29Jan2016 24:00	1224.51	1102.5	0.00	122.26	124.76	**435.91**
30Jan2016 06:00	1225.00	1102.5	0.81			
30Jan2016 24:00	1224.51	1102.5	0.00	122.26	124.76	**435.91**
31Jan2016 06:00	1225.00	1102.5	0.81			
31Jan2016 24:00	1224.51	1102.5	0.00	122.26	124.76	**1862.04**
01Feb2016 06:00	1225.00	1102.5	3.46			
01Feb2016 24:00	1224.25	1102.4	0.00	122.17	124.67	**3226.77**
02Feb2016 06:00	1224.99	1102.5	6.00			
02Feb2016 24:00	1224.25	1102.13	0.00	122.31	124.81	**3230.26**

The results of the analyses performed considering the given assumptions are summarized in Table 4.11.

Table 4.11 Summary of results for Scenario 8

Name of Facility	Production (GWh/year)				
	Pumping 24-06	18-24 (T2)	06-18 (T1)	24-06 (T3)	Total
Upper Kaleköy	- 781.0	1276.0	531.0	117.8	**1143.8**
Lower Kaleköy		612.3	350.1	96.2	**1058.6**
Beyhan 1		681.2	397.8	132.0	**1211.0**
Beyhan 2		313.8	180.4	59.4	**553.6**

Sometimes, natural flows in combination with available pondage may be sufficient to support the plants peaking capacity. On the contrary, pumping water to upstream reservoir may not be possible due to the insufficient pump operation head as shown in Figure 4.39. During low flow periods, however, a portion of the peaking discharge would be pumped back at night, to insure that sufficient water is available to meet peaking requirements on subsequent days.

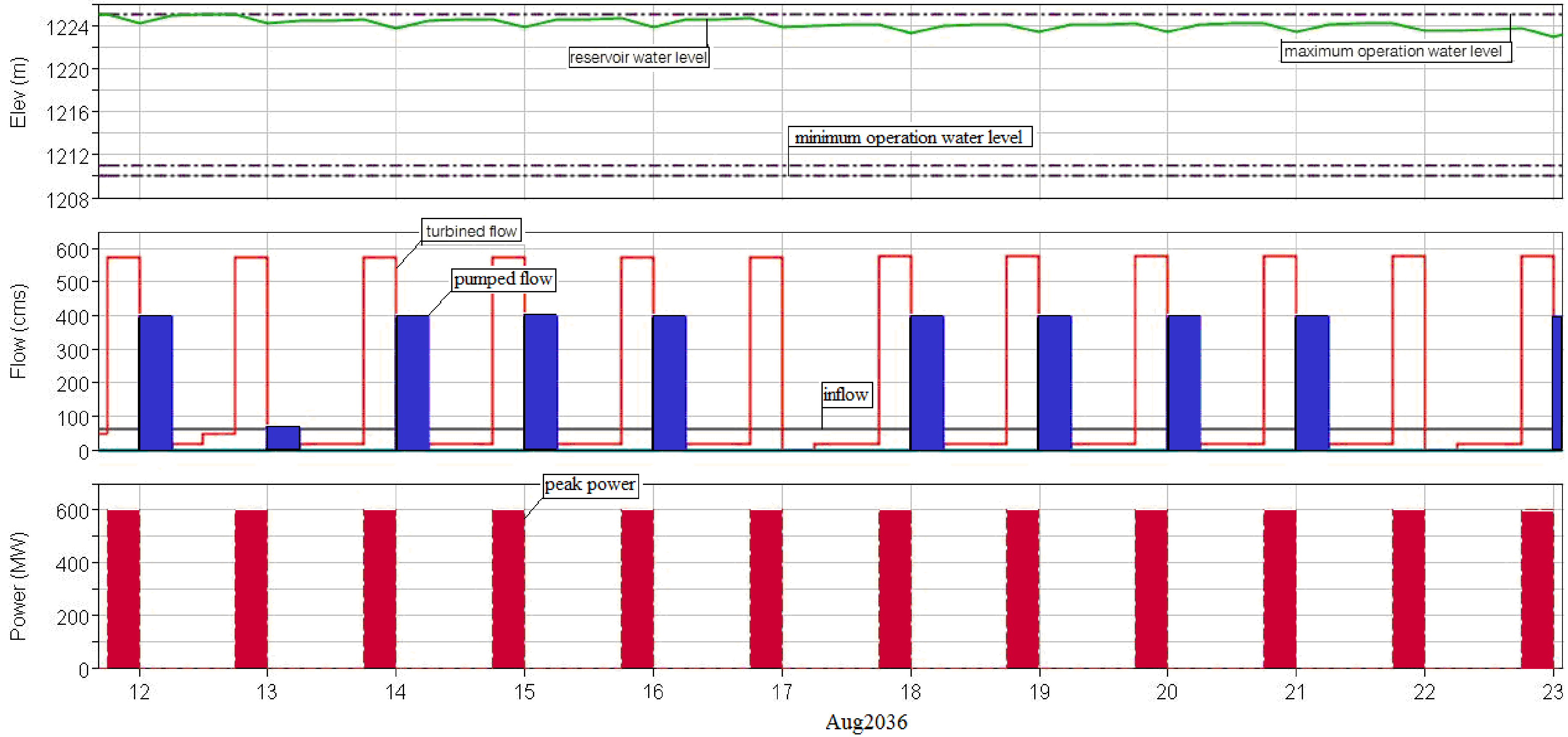


Figure 4.39 Peak operation of Scenario 8

4.9.2 Scenario 9

In this scenario Beyhan 2 Dam has been used as lower reservoir of pump storage scheme and an upper reservoir has been designed as Beyhan 1 Dam as shown in Figure 4.40. The maximum operation water level of the upper reservoir has been assumed as 982.0 m. Tailwater elevation of the power plant will be the reservoir water level of Beyhan 2 Dam.

The results of the simulation performed are summarized in Table 4.12.

Table 4.12 Summary of results for Scenario 9

Name of Facility	Production (GWh/year)				
	Pumping 24-06	18-24 (T2)	06-18 (T1)	24-06 (T3)	Total
Upper Kaleköy		799.0	379.0	151.0	**1329.0**
Lower Kaleköy		608.0	284.0	119.0	**1011.0**
Beyhan 1	- 581.3	1159.0	389.0	108.0	**1074.7**
Beyhan 2		336.0	169.0	50.0	**555.0**

4.9.3 Scenario 10

In this scenario Beyhan 2 Dam and Lower Kaleköy Dam have been used as lower reservoirs of pump storage schemes and an upper reservoirs have been designed as Beyhan 1 Dam and Upper Kaleköy Dam. The results of the simulation performed considering the above given assumptions are summarized in Table 4.13.

Table 4.13 summarizes the annual energy generation which is obtained from the four individual Kaleköy plants in peak, day and off-peak hours, if the plants and their reservoirs are operated according to scenario 10.

Table 4.13 Summary of results for Scenario 10

Name of Facility	Production (GWh/year)				
	Pumping 24-06	18-24 (T2)	06-18 (T1)	24-06 (T3)	Total
Upper Kaleköy	- 781.0	1276.0	531.0	118.0	**1144.0**
Lower Kaleköy		612.0	350.0	96.0	**1058.0**
Beyhan 1	- 683.8	1176.0	444.0	110.0	**1046.2**
Beyhan 2		312.0	188.0	51.0	**551.0**

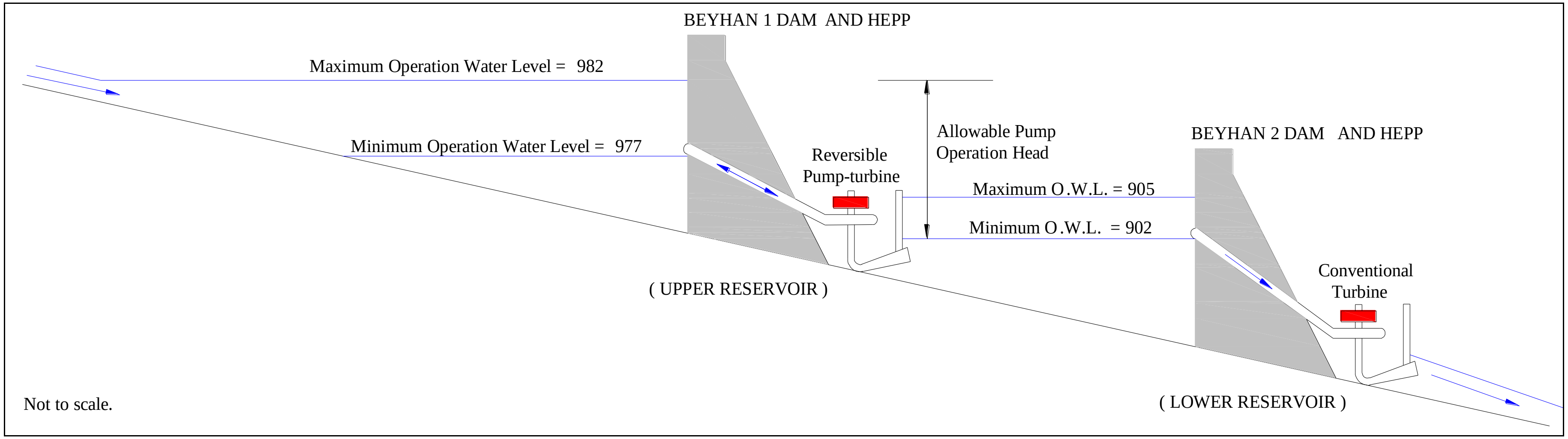


Figure 4.40 Visual presentation of Scenario 9

CHAPTER 5

FINANCIAL ANALYSIS

5.1 Introduction

The purpose of this chapter is highlighting the effectiveness of the analyzed scenarios for the operation period of 50 years. Based on the following economic scenario ratios, there will be necessary information for future investments.

In addition to the reservoir model, also financial analyses are presented for the comparison of the scenarios. In Figure 5.1 general structure of the financial model is shown.

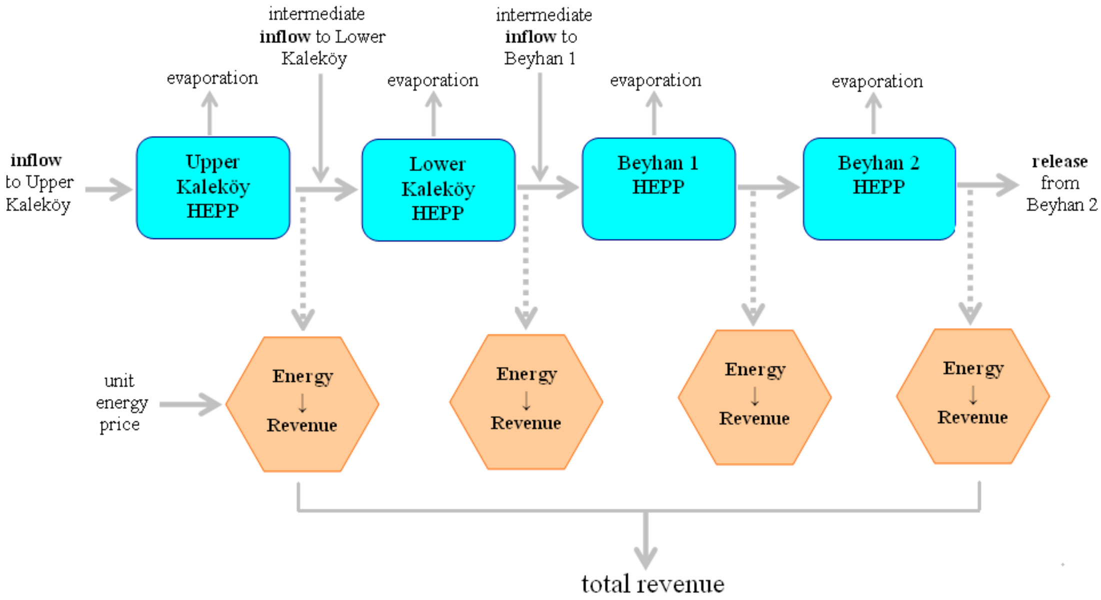


Figure 5.1 General structure of the financial model

5.2 Cost of Facilities

Costs of facilities proposed for Kaleköy reservoir system have been based on quantity estimation obtained from Feasibility Report (Temelsu International Engineering Services Inc., 2011). Construction costs have been calculated for Scenarios 1 to 7 in Table 5.3, for Scenario 8 in Table 5.6, for Scenario 9 in Table 5.9, and for Scenario 10 in Table 5.12. In pumped storage scenarios (Scenario 8, 9, 10), the difference between unit price of electromechanical equipment for conventional turbine and pump-turbine has been taken as 100 USD/kW.

5.3 Direct and Investment Costs

5.3.1 Direct Costs

In Feasibility Report, construction costs are made up from detailed estimates of quantities of the various categories of work required to build each feature of the project (Temelsu International Engineering Services Inc., 2011). Construction costs given in Tables 5.3, 5.6, 5.9 and 5.12 have been increased by 15% due to the contingencies for the estimation of direct cost of Kaleköy reservoir system. Direct costs are shown for Scenarios 1 to 7 in Table 5.4, for Scenario 8 in Table 5.7, for Scenario 9 in Table 5.10, and for Scenario 10 in Table 5.13.

5.3.2 Project Costs

Project cost has been found out by the summation of direct cost, investigation-design-supervision cost and expropriation cost. The required expenses for investigation-design-supervision during the period starting from the first stage of the project until the commissioning of operation have been accepted to be 15% of the direct cost.

5.3.3 Investment Program and Investment Cost

It is assumed that the construction of Kaleköy reservoir system will be completed in a period of 4 years. Yearly distribution of investment for the proposed facilities are obtained from Feasibility Report (Temelsu International Engineering Services Inc., 2011) as shown in Table 5.1.

Table 5.1 Yearly distribution of investment for Kaleköy reservoir system (%) (Temelsu International Engineering Services Inc., 2011)

Facility	Year 1	Year 2	Year 3	Year 4
Diversion Structures	85	15	0	0
Dam Body	40	60	0	0
Spillway	10	75	15	0
Intake Structure and Penstocks	0	40	60	0
Turbine-Generator	15	25	30	30
Switchyard	0	0	50	50
Powerhouse	0	25	65	10
Access and Service Roads	60	0	0	40
Permanent Site Facilities	30	0	0	70
Energy Transmission Line	0	0	30	70
Expropriation	15	0	0	85
Tailrace Channel	0	0	65	35
Grouting Works	0	50	50	0

Investment cost has been calculated by adding interest during the construction period to the project cost. The amount of interest during the construction period has been determined by the compound interest method and the interest rate has been accepted to be 9.5% (Temelsu International Engineering Services Inc., 2011).

Interest amount estimated according to the distributions and the investment costs are given in Tables 5.4, 5.7, 5.10 and 5.13. As an example, investment cost of Kaleköy reservoir system has been found out to be 6 107 767 203 TL for Scenarios 1 to 7.

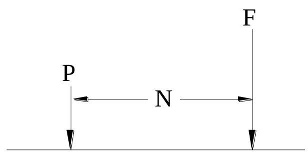
5.4 Annual Costs

Annual costs of the facility consist of the following components:

i. Capital costs (interest-depreciation and renewal costs)

ii. Operation and maintenance costs

Although interest-depreciation part of capital costs comprises all investment cost, renewal costs do not include the costs of design-supervision, expropriation and interest during construction period. Interest-depreciation cost is found by multiplication of investment cost by the coefficient determined as 9,603% accepting 50 years economic life and 9,5% interest-discount rate. Considering the assumption that renewals made during operation will be evenly distributed during the operation period, factors used for computing the annual renewal cost are given in Table 5.2.



$$F = P(1+i)^N \tag{5.1}$$

where

P = present value (TL),

N = 50 years of operation,

i = annual investment rate (TL/year),

F = final value (TL).

In Table 5.5, operation and maintenance costs have been estimated as 46 888 770 TL for Scenario 1 to 7 using the operation-maintenance factors given in Table 5.2.

Table 5.2 Renewal and operation-maintenance factors(Temelsu International Engineering Services Inc., 2011)

Facility Name	Renewal Factor	Operation - Maintenance Factor
Diversion Structures	0.0000326	0.005
Dam Body	0.0000326	0.005
Spillway	0.0000326	0.010
Intake Structure and Penstocks	0.0000326	0.010
Turbine-Generator	0.0041376	0.015
Switchyard	0.0041376	0.015
Powerhouse	0.0018480	0.010
Access and Service Roads	0.0000326	0.040
Permanent Site Facilities	0.0018480	0.010
Energy Transmission Line	0.0000326	0.015
Tailrace Channel	0.0000326	0.005
Grouting Works	0.0000326	0.005

Annual cost estimation of the scenarios are given in Tables 5.5, 5.8, 5.11 and 5.14. It can be seen from the Table 5.5 that annual total cost of the project is 640 285 903 TL for Scenario 1 to 7.

Table 5.3 Construction costs for Scenario 1, 2, 3, 4, 5, 6 and 7

Name of the Facility	Upper Kaleköy	Lower Kaleköy	Beyhan 1	Beyhan 2	Construction Cost
	Dam and HEPP	Dam and HEPP	Dam and HEPP	Dam and HEPP	(TL)
Diversion Structures	92 454 419	83 266 051	114 261 054	9 740 832	299 722 356
Dam Body	309 582 813	170 828 892	198 578 522	95 312 716	774 302 943
Spillway	87 574 319	82 995 205	95 272 977	190 229 564	456 072 065
Intake Structure and Penstocks	113 769 817	89 150 970	59 673 664	96 589 571	359 184 022
Turbine-Generator	387 000 000	338 625 000	378 400 000	191 887 500	1295 912 500
Switchyard	12 900 000	9 675 000	11 825 000	5 482 500	39 882 500
Powerhouse	64 500 000	48 375 000	59 125 000	27 412 500	199 412 500
Access and Service Roads	20 850 000	13 850 000	14 462 429	16 000 000	65 162 429
Permanent Site Facilities	778 750	778 750	772 880	772 880	3 103 260
Energy Transmission Line	32 775 000	40 470 000	44 000 000	26 790 000	144 035 000
Tailrace Channel	14 173 744	15 837 750	2 184 985	12 447 677	44 644 156
Grouting Works	7 999 713	6 893 745	7 668 432	17 004 254	39 566 144
Expropriation	27 300 000	19 900 000	31 500 000	3 300 000	
					3 720 999 875

Table 5.4 Calculation of investment costs for Scenario 1, 2, 3, 4, 5, 6 and 7

INVESTMENT	Construction Cost	Direct Cost	Investigation-Design	Project Cost (TL)					Interest During Construction (TL)					Investment Cost
Name of the Facility	**(TL)**	**(TL)**	**Supervision (TL)**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Total**	**(TL)**
Diversion Structures	299 722 356	344 680 709	51 702 106	336 925 393	59 457 422	0	0	396 382 816	125 970 322	15 143 015	0	0	141 113 338	537 496 153
Dam Body	774 302 943	890 448 384	133 567 258	409 606 257	614 409 385	0	0	1024 015 642	153 144 385	156 481 905	0	0	309 626 290	1333 641 932
Spillway	456 072 065	524 482 875	78 672 431	60 315 531	452 366 479	90 473 296	0	603 155 306	22 550 888	115 211 730	13 193 957	0	150 956 576	754 111 882
Intake Structure	359 184 022	413 061 625	61 959 244	0	190 008 348	285 012 521	0	475 020 869	0	48 392 601	41 564 120	0	89 956 721	564 977 591
Turbine-Generator	1295 912 500	1490 299 375	223 544 906	257 076 642	428 461 070	514 153 284	514 153 284	1713 844 281	96 116 316	109 123 340	74 980 316	23 868 269	304 088 242	2017 932 523
Switchyard	39 882 500	45 864 875	6 879 731	0	0	26 372 303	26 372 303	52 744 606	0	0	3 845 942	1 224 268	5 070 209	57 814 816
Powerhouse	199 412 500	229 324 375	34 398 656	0	65 930 758	171 419 970	26 372 303	263 723 031	0	16 791 688	24 998 622	1 224 268	43 014 577	306 737 609
Access and Service Roads	65 162 429	74 936 793	11 240 519	51 706 387	0	0	34 470 925	86 177 312	19 332 085	0	0	1 600 226	20 932 311	107 109 623
Permanent Site Facilities	3 103 260	3 568 749	535 312	1 231 218	0	0	2 872 843	4 104 061	460 330	0	0	133 364	593 695	4 697 756
Energy Transmission Line	144 035 000	165 640 250	24 846 038	0	0	57 145 886	133 340 401	190 486 288	0	0	8 333 734	6 189 992	14 523 726	205 010 013
Tailrace Channel	44 644 156	51 340 779	7 701 117	0	0	38 377 233	20 664 664	59 041 896	0	0	5 596 652	959 305	6 555 957	65 597 853
Grouting Works	39 566 144	45 501 066	6 825 160	0	26 163 113	26 163 113	0	52 326 225	0	6 663 397	3 815 435	0	10 478 832	62 805 058
Expropriation		0	0	12 300 000	0	0	69 700 000	*82 000 000*	4 598 748	0	0	3 235 647	7 834 395	89 834 395
	3 720 999 875	**4 279 149 856**	**641 872 478**	**1 129 161 429**	**1 836 796 576**	**1 209 117 607**	**827 946 723**	**5 003 022 335**	**422 173 074**	**467 807 677**	**176 328 779**	**38 435 338**	**1 104 744 868**	**6 107 767 203**

Table 5.5 Calculation of annual costs for Scenario 1, 2, 3, 4, 5, 6 and 7

COST	Construction Cost	Direct Cost	Project Cost	Interest	Investment	Annual Costs (TL)			
Name of the Facility	**(TL)**	**(TL)**	**(TL)**	**During Construction**	**Cost (TL)**	**Interest-Depreciation**	**Renewal**	**Operation-Maintenance**	**Total**
Diversion Structures	299 722 356	344 680 709	396 382 816	141 113 338	537 496 153	51 615 756	11 237	1 723 404	53 350 396
Dam Body	774 302 943	890 448 384	1024 015 642	309 626 290	1333 641 932	128 069 635	29 029	4 452 242	132 550 905
Spillway	456 072 065	524 482 875	603 155 306	150 956 576	754 111 882	72 417 364	17 098	5 244 829	77 679 291
Intake Structure and Penstocks	359 184 022	413 061 625	475 020 869	89 956 721	564 977 591	54 254 798	13 466	4 130 616	58 398 880
Turbine-Generator	1295 912 500	1490 299 375	1713 844 281	304 088 242	2017 932 523	193 782 060	6 166 263	22 354 491	222 302 813
Switchyard	39 882 500	45 864 875	52 744 606	5 070 209	57 814 816	5 551 957	189 771	687 973	6 429 700
Powerhouse	199 412 500	229 324 375	263 723 031	43 014 577	306 737 609	29 456 013	423 791	2 293 244	32 173 048
Access and Service Roads	65 162 429	74 936 793	86 177 312	20 932 311	107 109 623	10 285 737	2 443	2 997 472	13 285 652
Permanent Site Facilities	3 103 260	3 568 749	4 104 061	593 695	4 697 756	451 126	6 595	35 687	493 408
Energy Transmission Line	144 035 000	165 640 250	190 486 288	14 523 726	205 010 013	19 687 112	5 400	2 484 604	22 177 115
Tailrace Channel	44 644 156	51 340 779	59 041 896	6 555 957	65 597 853	6 299 362	1 674	256 704	6 557 739
Grouting Works	39 566 144	45 501 066	52 326 225	10 478 832	62 805 058	6 031 170	1 483	227 505	6 260 158
Expropriation			82 000 000	7 834 395	89 834 395	8 626 797			8 626 797
Total	**3 720 999 875**	**4 279 149 856**	**5 003 022 335**	**1 104 744 868**	**6 107 767 203**	**586 528 884**	**6 868 249**	**46 888 770**	**640 285 903**

Table 5.6 Construction costs for Scenario 8

Name of the Facility	Upper Kalekoy Dam and HEPP	Lower Kalekoy Dam and HEPP	Beyhan 1 Dam and HEPP	Beyhan 2 Dam and HEPP	Construction Cost (TL)
Diversion Structures	92 454 419	83 266 051	114 261 054	9 740 832	299 722 356
Dam Body	309 582 813	170 828 892	198 578 522	95 312 716	774 302 943
Spillway	87 574 319	82 995 205	95 272 977	190 229 564	456 072 065
Intake Structure and Penstocks	113 769 817	89 150 970	59 673 664	96 589 571	359 184 022
Reversible-turbine and Generator	**475 000 000**	338 625 000	378 400 000	191 887 500	1383 912 500
Switchyard	12 900 000	9 675 000	11 825 000	5 482 500	39 882 500
Powerhouse	64 500 000	48 375 000	59 125 000	27 412 500	199 412 500
Access and Service Roads	20 850 000	13 850 000	14 462 429	16 000 000	65 162 429
Permanent Site Facilities	778 750	778 750	772 880	772 880	3 103 260
Energy Transmission Line	32 775 000	40 470 000	44 000 000	26 790 000	144 035 000
Tailrace Channel	14 173 744	15 837 750	2 184 985	12 447 677	44 644 156
Grouting Works	7 999 713	6 893 745	7 668 432	17 004 254	39 566 144
Expropriation	27 300 000	19 900 000	31 500 000	3 300 000	
					3 808 999 875

Additional Reversible Pump-Turbine			
Installed Capacity to Upper Kalekoy	550.0 MW	x 100.0 USD/kW	= 55 000 000 USD
		1 USD =	1.60 TL
			= 88 000 000TL

Table 5.7 Calculation of investment costs for Scenario 8

INVESTMENT	Construction Cost	Direct Cost	Investigation-Design	Project Cost (TL)					Interest During Construction (TL)					Investment Cost
Name of the Facility	**(TL)**	**(TL)**	**Supervision (TL)**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Total**	**(TL)**
Diversion Structures	299 722 356	344 680 709	51 702 106	336 925 393	59 457 422	0	0	396 382 816	125 970 322	15 143 015	0	0	141 113 338	537 496 153
Dam Body	774 302 943	890 448 384	133 567 258	409 606 257	614 409 385	0	0	1024 015 642	153 144 385	156 481 905	0	0	309 626 290	1333 641 932
Spillway	456 072 065	524 482 875	78 672 431	60 315 531	452 366 479	90 473 296	0	603 155 306	22 550 888	115 211 730	13 193 957	0	150 956 576	754 111 882
Intake Structure and Penstocks	359 184 022	413 061 625	61 959 244	0	190 008 348	285 012 521	0	475 020 869	0	48 392 601	41 564 120	0	89 956 721	564 977 591
Reversible-turbine-Generator	1383 912 500	1591 499 375	238 724 906	274 533 642	457 556 070	549 067 284	549 067 284	1830 224 281	102 643 173	116 533 450	80 071 916	25 489 063	324 737 603	2154 961 884
Switchyard	39 882 500	45 864 875	6 879 731	0	0	26 372 303	26 372 303	52 744 606	0	0	3 845 942	1 224 268	5 070 209	57 814 816
Powerhouse	199 412 500	229 324 375	34 398 656	0	65 930 758	171 419 970	26 372 303	263 723 031	0	16 791 688	24 998 622	1 224 268	43 014 577	306 737 609
Access and Service Roads	65 162 429	74 936 793	11 240 519	51 706 387	0	0	34 470 925	86 177 312	19 332 085	0	0	1 600 226	20 932 311	107 109 623
Permanent Site Facilities	3 103 260	3 568 749	535 312	1 231 218	0	0	2 872 843	4 104 061	460 330	0	0	133 364	593 695	4 697 756
Energy Transmission Line	144 035 000	165 640 250	24 846 038	0	0	57 145 886	133 340 401	190 486 288	0	0	8 333 734	6 189 992	14 523 726	205 010 013
Tailrace Channel	44 644 156	51 340 779	7 701 117	0	0	38 377 233	20 664 664	59 041 896	0	0	5 596 652	959 305	6 555 957	65 597 853
Grouting Works	39 566 144	45 501 066	6 825 160	0	26 163 113	26 163 113	0	52 326 225	0	6 663 397	3 815 435	0	10 478 832	62 805 058
Expropriation		0	0	12 300 000	0	0	69 700 000	*82 000 000*	4 598 748	0	0	3 235 647	7 834 395	89 834 395
Total	**3 808 999 875**	**4 380 349 856**	**657 052 478**	**1 146 618 429**	**1 865 891 576**	**1 244 031 607**	**862 860 723**	**5 119 402 335**	**428 699 932**	**475 217 787**	**181 420 379**	**40 056 132**	**1 125 394 229**	**6 244 796 564**

Table 5.8 Calculation of annual costs for Scenario 8

COST	Construction Cost	Direct Cost	Project Cost	Interest	Investment	Annual Costs (TL)			
Name of the Facility	**(TL)**	**(TL)**	**(TL)**	**During Construction**	**Cost (TL)**	**Interest-Depreciation**	**Renewal**	**Operation-Maintenance**	**Total**
Diversion Structures	299 722 356	344 680 709	396 382 816	141 113 338	537 496 153	51 615 756	11 237	1 723 404	53 350 396
Dam Body	774 302 943	890 448 384	1024 015 642	309 626 290	1333 641 932	128 069 635	29 029	4 452 242	132 550 905
Spillway	456 072 065	524 482 875	603 155 306	150 956 576	754 111 882	72 417 364	17 098	5 244 829	77 679 291
Intake Structure and Penstocks	359 184 022	413 061 625	475 020 869	89 956 721	564 977 591	54 254 798	13 466	4 130 616	58 398 880
Reversible-turbine-Generator	1383 912 500	1591 499 375	1830 224 281	324 737 603	2154 961 884	206 940 990	6 584 988	23 872 491	237 398 468
Switchyard	39 882 500	45 864 875	52 744 606	5 070 209	57 814 816	5 551 957	189 771	687 973	6 429 700
Powerhouse	199 412 500	229 324 375	263 723 031	43 014 577	306 737 609	29 456 013	423 791	2 293 244	32 173 048
Access and Service Roads	65 162 429	74 936 793	86 177 312	20 932 311	107 109 623	10 285 737	2 443	2 997 472	13 285 652
Permanent Site Facilities	3 103 260	3 568 749	4 104 061	593 695	4 697 756	451 126	6 595	35 687	493 408
Energy Transmission Line	144 035 000	165 640 250	190 486 288	14 523 726	205 010 013	19 687 112	5 400	2 484 604	22 177 115
Tailrace Channel	44 644 156	51 340 779	59 041 896	6 555 957	65 597 853	6 299 362	1 674	256 704	6 557 739
Grouting Works	39 566 144	45 501 066	52 326 225	10 478 832	62 805 058	6 031 170	1 483	227 505	6 260 158
Expropriation			82 000 000	7 834 395	89 834 395	8 626 797			8 626 797
Total	**3 808 999 875**	**4 380 349 856**	**5 119 402 335**	**1 125 394 229**	**6 244 796 564**	**599 687 814**	**7 286 974**	**48 406 770**	**655 381 558**

Table 5.9 Construction costs for Scenario 9

Name of the Facility	Upper Kaleköy Dam and HEPP	Lower Kaleköy Dam and HEPP	Beyhan 1 Dam and HEPP	Beyhan 2 Dam and HEPP	Construction Cost (TL)
Diversion Structures	92 454 419	83 266 051	114 261 054	9 740 832	299 722 356
Dam Body	309 582 813	170 828 892	198 578 522	95 312 716	774 302 943
Spillway	87 574 319	82 995 205	95 272 977	190 229 564	456 072 065
Intake Structure and Penstocks	113 769 817	89 150 970	59 673 664	96 589 571	359 184 022
Reversible-turbine-Generator	387 000 000	338 625 000	**458 400 000**	191 887 500	1375 912 500
Switchyard	12 900 000	9 675 000	11 825 000	5 482 500	39 882 500
Powerhouse	64 500 000	48 375 000	59 125 000	27 412 500	199 412 500
Access and Service Roads	20 850 000	13 850 000	14 462 429	16 000 000	65 162 429
Permanent Site Facilities	778 750	778 750	772 880	772 880	3 103 260
Energy Transmission Line	32 775 000	40 470 000	44 000 000	26 790 000	144 035 000
Tailrace Channel	14 173 744	15 837 750	2 184 985	12 447 677	44 644 156
Grouting Works	7 999 713	6 893 745	7 668 432	17 004 254	39 566 144
Expropriation	27 300 000	19 900 000	31 500 000	3 300 000	
					3 800 999 875

Additional Reversible Pump-Turbine				
Installed Capacity to Beyhan 1	500.0 MW	x 100.0 USD/kW	= 50 000 000 USD	
		1 USD =	1.60 TL	
			= 80 000 000TL	

Table 5.10 Calculation of investment costs for Scenario 9

INVESTMENT	Construction Cost	Direct Cost	Investigation-Design	Project Cost (TL)					Interest During Construction (TL)					Investment Cost
Name of the Facility	(TL)	(TL)	Supervision (TL)	Year 1	Year 2	Year 3	Year 4	Total	Year 1	Year 2	Year 3	Year 4	Total	(TL)
Diversion Structures	299 722 356	344 680 709	51 702 106	336 925 393	59 457 422	0	0	396 382 816	125 970 322	15 143 015	0	0	141 113 338	537 496 153
Dam Body	774 302 943	890 448 384	133 567 258	409 606 257	614 409 385	0	0	1024 015 642	153 144 385	156 481 905	0	0	309 626 290	1333 641 932
Spillway	456 072 065	524 482 875	78 672 431	60 315 531	452 366 479	90 473 296	0	603 155 306	22 550 888	115 211 730	13 193 957	0	150 956 576	754 111 882
Intake Structure and Penstocks	359 184 022	413 061 625	61 959 244	0	190 008 348	285 012 521	0	475 020 869	0	48 392 601	41 564 120	0	89 956 721	564 977 591
Reversible-turbine-Generator	1375 912 500	1582 299 375	237 344 906	272 946 642	454 911 070	545 893 284	545 893 284	1819 644 281	102 049 822	115 859 804	79 609 044	25 341 718	322 860 388	2142 504 669
Switchyard	39 882 500	45 864 875	6 879 731	0	0	26 372 303	26 372 303	52 744 606	0	0	3 845 942	1 224 268	5 070 209	57 814 816
Powerhouse	199 412 500	229 324 375	34 398 656	0	65 930 758	171 419 970	26 372 303	263 723 031	0	16 791 688	24 998 622	1 224 268	43 014 577	306 737 609
Access and Service Roads	65 162 429	74 936 793	11 240 519	51 706 387	0	0	34 470 925	86 177 312	19 332 085	0	0	1 600 226	20 932 311	107 109 623
Permanent Site Facilities	3 103 260	3 568 749	535 312	1 231 218	0	0	2 872 843	4 104 061	460 330	0	0	133 364	593 695	4 697 756
Energy Transmission Line	144 035 000	165 640 250	24 846 038	0	0	57 145 886	133 340 401	190 486 288	0	0	8 333 734	6 189 992	14 523 726	205 010 013
Tailrace Channel	44 644 156	51 340 779	7 701 117	0	0	38 377 233	20 664 664	59 041 896	0	0	5 596 652	959 305	6 555 957	65 597 853
Grouting Works	39 566 144	45 501 066	6 825 160	0	26 163 113	26 163 113	0	52 326 225	0	6 663 397	3 815 435	0	10 478 832	62 805 058
Expropriation		0	0	12 300 000	0	0	69 700 000	*82 000 000*	4 598 748	0	0	3 235 647	7 834 395	89 834 395
	3 800 999 875	**4 371 149 856**	**655 672 478**	**1 145 031 429**	**1 863 246 576**	**1 240 857 607**	**859 686 723**	**5 108 822 335**	**428 106 581**	**474 544 141**	**180 957 506**	**39 908 787**	**1 123 517 015**	**6 232 339 349**

Table 5.11 Calculation of annual costs for Scenario 9

COST	Construction Cost	Direct Cost	Project Cost	Interest	Investment	Annual Costs (TL)			
Name of the Facility	(TL)	(TL)	(TL)	During Construction	Cost (TL)	Interest-Depreciation	Renewal	Operation-Maintenance	Total
Diversion Structures	299 722 356	344 680 709	396 382 816	141 113 338	537 496 153	51 615 756	11 237	1 723 404	53 350 396
Dam Body	774 302 943	890 448 384	1024 015 642	309 626 290	1333 641 932	128 069 635	29 029	4 452 242	132 550 905
Spillway	456 072 065	524 482 875	603 155 306	150 956 576	754 111 882	72 417 364	17 098	5 244 829	77 679 291
Intake Structure and Penstocks	359 184 022	413 061 625	475 020 869	89 956 721	564 977 591	54 254 798	13 466	4 130 616	58 398 880
Reversible-turbine-Generator	1375 912 500	1582 299 375	1819 644 281	322 860 388	2142 504 669	205 744 723	6 546 922	23 734 491	236 026 136
Switchyard	39 882 500	45 864 875	52 744 606	5 070 209	57 814 816	5 551 957	189 771	687 973	6 429 700
Powerhouse	199 412 500	229 324 375	263 723 031	43 014 577	306 737 609	29 456 013	423 791	2 293 244	32 173 048
Access and Service Roads	65 162 429	74 936 793	86 177 312	20 932 311	107 109 623	10 285 737	2 443	2 997 472	13 285 652
Permanent Site Facilities	3 103 260	3 568 749	4 104 061	593 695	4 697 756	451 126	6 595	35 687	493 408
Energy Transmission Line	144 035 000	165 640 250	190 486 288	14 523 726	205 010 013	19 687 112	5 400	2 484 604	22 177 115
Tailrace Channel	44 644 156	51 340 779	59 041 896	6 555 957	65 597 853	6 299 362	1 674	256 704	6 557 739
Grouting Works	39 566 144	45 501 066	52 326 225	10 478 832	62 805 058	6 031 170	1 483	227 505	6 260 158
Expropriation			82 000 000	7 834 395	89 834 395	8 626 797			8 626 797
Total	**3 800 999 875**	**4 371 149 856**	**5 108 822 335**	**1 123 517 015**	**6 232 339 349**	**598 491 548**	**7 248 908**	**48 268 770**	**654 009 226**

Table 5.12 Construction costs for Scenario 10

Name of the Facility	**Upper Kaleköy Dam and HEPP**	**Lower Kaleköy Dam and HEPP**	**Beyhan 1 Dam and HEPP**	**Beyhan 2 Dam and HEPP**	**Construction Cost (TL)**
Diversion Structures	92 454 419	83 266 051	114 261 054	9 740 832	299 722 356
Dam Body	309 582 813	170 828 892	198 578 522	95 312 716	774 302 943
Spillway	87 574 319	82 995 205	95 272 977	190 229 564	456 072 065
Intake Structure and Penstocks	113 769 817	89 150 970	59 673 664	96 589 571	359 184 022
Reversible-turbine-Generator	**475 000 000**	338 625 000	**458 400 000**	191 887 500	1463 912 500
Switchyard	12 900 000	9 675 000	11 825 000	5 482 500	39 882 500
Powerhouse	64 500 000	48 375 000	59 125 000	27 412 500	199 412 500
Access and Service Roads	20 850 000	13 850 000	14 462 429	16 000 000	65 162 429
Permanent Site Facilities	778 750	778 750	772 880	772 880	3 103 260
Energy Transmission Line	32 775 000	40 470 000	44 000 000	26 790 000	144 035 000
Tailrace Channel	14 173 744	15 837 750	2 184 985	12 447 677	44 644 156
Grouting Works	7 999 713	6 893 745	7 668 432	17 004 254	39 566 144
Expropriation	27 300 000	19 900 000	31 500 000	3 300 000	
					3 888 999 875

Additional Reversible Pump-Turbine

Installed Capacity to Upper Kaleköy	550.0 MW	x 100.0 USD/kW	= 55 000 000 USD
		1 USD =	1.60 TL
			= 88 000 000TL
Installed Capacity to Beyhan 1	500.0 MW	x 100.0 USD/kW	= 50 000 000 USD
			= 80 000 000TL

Table 5.13 Calculation of investment costs for Scenario 10

INVESTMENT	Construction Cost	Direct Cost	Investigation-Design	Project Cost (TL)					Interest During Construction (TL)					Investment Cost
Name of the Facility	(TL)	(TL)	Supervision (TL)	Year 1	Year 2	Year 3	Year 4	Total	Year 1	Year 2	Year 3	Year 4	Total	(TL)
Diversion Structures	299 722 356	344 680 709	51 702 106	336 925 393	59 457 422	0	0	396 382 816	125 970 322	15 143 015	0	0	141 113 338	537 496 153
Dam Body	774 302 943	890 448 384	133 567 258	409 606 257	614 409 385	0	0	1024 015 642	153 144 385	156 481 905	0	0	309 626 290	1333 641 932
Spillway	456 072 065	524 482 875	78 672 431	60 315 531	452 366 479	90 473 296	0	603 155 306	22 550 888	115 211 730	13 193 957	0	150 956 576	754 111 882
Intake Structure and Penstocks	359 184 022	413 061 625	61 959 244	0	190 008 348	285 012 521	0	475 020 869	0	48 392 601	41 564 120	0	89 956 721	564 977 591
Reversible-turbine-Generator	1463 912 500	1683 499 375	252 524 906	290 403 642	484 006 070	580 807 284	580 807 284	1936 024 281	108 576 679	123 269 914	84 700 643	26 962 513	343 509 749	2279 534 031
Switchyard	39 882 500	45 864 875	6 879 731	0	0	26 372 303	26 372 303	52 744 606	0	0	3 845 942	1 224 268	5 070 209	57 814 816
Powerhouse	199 412 500	229 324 375	34 398 656	0	65 930 758	171 419 970	26 372 303	263 723 031	0	16 791 688	24 998 622	1 224 268	43 014 577	306 737 609
Access and Service Roads	65 162 429	74 936 793	11 240 519	51 706 387	0	0	34 470 925	86 177 312	19 332 085	0	0	1 600 226	20 932 311	107 109 623
Permanent Site Facilities	3 103 260	3 568 749	535 312	1 231 218	0	0	2 872 843	4 104 061	460 330	0	0	133 364	593 695	4 697 756
Energy Transmission Line	144 035 000	165 640 250	24 846 038	0	0	57 145 886	133 340 401	190 486 288	0	0	8 333 734	6 189 992	14 523 726	205 010 013
Tailrace Channel	44 644 156	51 340 779	7 701 117	0	0	38 377 233	20 664 664	59 041 896	0	0	5 596 652	959 305	6 555 957	65 597 853
Grouting Works	39 566 144	45 501 066	6 825 160	0	26 163 113	26 163 113	0	52 326 225	0	6 663 397	3 815 435	0	10 478 832	62 805 058
Expropriation		0	0	12 300 000	0	0	69 700 000	*82 000 000*	4 598 748	0	0	3 235 647	7 834 395	89 834 395
	3 888 999 875	**4 472 349 856**	**670 852 478**	**1 162 488 429**	**1 892 341 576**	**1 275 771 607**	**894 600 723**	**5 225 202 335**	**434 633 438**	**481 954 251**	**186 049 106**	**41 529 581**	**1 144 166 376**	**6 369 368 711**

Table 5.14 Calculation of annual costs for Scenario 10

COST	Construction Cost	Direct Cost	Project Cost	Interest	Investment	Annual Costs (TL)			
Name of the Facility	(TL)	(TL)	(TL)	During Construction	Cost (TL)	Interest-Depreciation	Renewal	Operation-Maintenance	Total
Diversion Structures	299 722 356	344 680 709	396 382 816	141 113 338	537 496 153	51 615 756	11 237	1 723 404	53 350 396
Dam Body	774 302 943	890 448 384	1024 015 642	309 626 290	1333 641 932	128 069 635	29 029	4 452 242	132 550 905
Spillway	456 072 065	524 482 875	603 155 306	150 956 576	754 111 882	72 417 364	17 098	5 244 829	77 679 291
Intake Structure and Penstocks	359 184 022	413 061 625	475 020 869	89 956 721	564 977 591	54 254 798	13 466	4 130 616	58 398 880
Reversible-turbine-Generator	1463 912 500	1683 499 375	1936 024 281	343 509 749	2279 534 031	218 903 653	6 965 647	25 252 491	251 121 791
Switchyard	39 882 500	45 864 875	52 744 606	5 070 209	57 814 816	5 551 957	189 771	687 973	6 429 700
Powerhouse	199 412 500	229 324 375	263 723 031	43 014 577	306 737 609	29 456 013	423 791	2 293 244	32 173 048
Access and Service Roads	65 162 429	74 936 793	86 177 312	20 932 311	107 109 623	10 285 737	2 443	2 997 472	13 285 652
Permanent Site Facilities	3 103 260	3 568 749	4 104 061	593 695	4 697 756	451 126	6 595	35 687	493 408
Energy Transmission Line	144 035 000	165 640 250	190 486 288	14 523 726	205 010 013	19 687 112	5 400	2 484 604	22 177 115
Tailrace Channel	44 644 156	51 340 779	59 041 896	6 555 957	65 597 853	6 299 362	1 674	256 704	6 557 739
Grouting Works	39 566 144	45 501 066	52 326 225	10 478 832	62 805 058	6 031 170	1 483	227 505	6 260 158
Expropriation			82 000 000	7 834 395	89 834 395	8 626 797			8 626 797
Total	**3 888 999 875**	**4 472 349 856**	**5 225 202 335**	**1 144 166 376**	**6 369 368 711**	**611 650 477**	**7 667 633**	**49 786 770**	**669 104 880**

5.5 Annual Benefits

Kaleköy reservoir system aims only energy generation. Therefore, these facilities do not have any irrigation or flood control benefit.

In the financial analysis of Scenarios 3 to 6, unit energy benefit values accepted by the General Directorate of State Hydraulic Works have been used. These are 6 cent/kWh (0.096 TL/kWh) for firm energy and 3.3 cent/kWh (0.0528 TL/kWh) for secondary energy. Peak power benefit has been specified as 85 USD/kW (136 TL/kW). In addition to this 1 USD = 1.6 TL has been accepted. Production characteristics of the power plants as a result of operation studies performed for Scenarios 3 to 6 are given in Chapter 4. According to these energy generation results, annual energy benefits are given in Tables 5.18, 5.19, 5.20 and 5.21.

On the other hand, researches for Scenarios 1, 2, 7, 8, 9 and 10 have been performed accepting the unit energy benefits to be used for benefit **-** cost analyses close to the tariff specified by Turkish Electricity Distribution Co. from the date of July 1, 2012 in Table 5.15.

Table 5.15 Unit energy benefits

T1 → between 06:00 - 18:00 →	8.00 Euro cent/kWh = 0.17192 TL/kWh
T2 → between 18:00 - 24:00 →	14.28 Euro cent/kWh = 0.30696 TL/kWh
T3 → between 24:00 - 06:00 →	3.47 Euro cent/kWh = 0.07455 TL/kWh

As a result of the operation studies performed in Chapter 4, benefits of Scenarios 1, 2, 7, 8, 9 and 10 are given in Tables 5.16, 5.17, 5.22, 5.23, 5.24 and 5.25.

Table 5.16 Calculation of annual benefits for Scenario 1

Name of facility	T2 18:00 - 24:00	T1 06:00 - 18:00	T3 24:00 - 06:00	Total Energy	T2 17:00 - 22:00 Benefit	T1 06:00 - 17:00 Benefit	T3 22:00 - 06:00 Benefit	Total Energy Benefit
	GWh/year	**GWh/year**	**GWh/year**	**GWh/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**
Upper kaleköy	466.32	466.32	466.32	1398.96	143 141 105	80 169 464	34 764 039	**258 074 607**
Lower kaleköy	366.44	366.44	366.44	1099.33	112 482 966	62 998 669	27 318 234	**202 799 870**
Beyhan 1	413.51	413.51	413.51	1240.54	126 932 334	71 091 370	30 827 487	**228 851 190**
Beyhan 2	188.29	188.29	188.29	564.87	57 797 385	32 370 753	14 036 992	**104 205 130**
Total	1 435	1 435	1 435	**4303.69**	440 353 789	246 630 256	106 946 752	**793 930 798 TL**

Table 5.17 Calculation of annual benefits for Scenario 2

Name of facility	T2 18:00 - 24:00	T1 06:00 - 18:00	T3 24:00 - 06:00	Total Energy	T2 17:00 - 22:00 Benefit	T1 06:00 - 17:00 Benefit	T3 22:00 - 06:00 Benefit	Total Energy Benefit
	GWh/year	**GWh/year**	**GWh/year**	**GWh/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**
Upper kaleköy	502.58	502.58	502.58	1 507.7	154 271 071	86 403 057	37 467 124	**278 141 252**
Lower kaleköy	394.45	394.45	394.45	1 183.3	121 080 051	67 813 664	29 406 170	**218 299 885**
Beyhan 1	446.29	446.29	446.29	1 338.9	136 993 552	76 726 386	33 271 010	**246 990 949**
Beyhan 2	203.36	203.36	203.36	610.1	62 424 145	34 962 077	15 160 672	**112 546 894**
Total	1 547	1 547	1 547	**4640.04**	474 768 819	265 905 184	115 304 976	**855 978 979 TL**

Table 5.18 Calculation of annual benefits for Scenario 3

Name of facility	Firm Power	Peak* Power	Firm Energy	Secondary Energy	Total Energy	Firm Energy Benefit	Secondary Energy Benefit	Peak* Power Benefit	Total Energy Benefit
	MW	MW	GWh/year	GWh/year	GWh/year	TL/year	TL/year	TL/year	TL/year
Upper kaleköy	74.5	499.32	653.07	735.86	1 388.93	62 694 432	38 853 572	67 908 108	**169 456 112**
Lower kaleköy	58.0	371.62	508.43	582.93	1 091.36	48 809 088	30 778 756	50 540 541	**130 128 385**
Beyhan 1	55.5	475.00	486.51	751.76	1 238.28	46 705 248	39 693 053	64 600 000	**150 998 301**
Beyhan 2	25.0	221.22	219.15	346.15	565.30	21 038 400	18 276 956	30 085 405	**69 400 762**
Total			1 867	2 417	**4283.87**	179 247 168	127 602 337	213 134 054	**519 983 560 TL**

Table 5.19 Calculation of annual benefits for Scenario 4

Name of facility	Firm Power	Peak* Power	Firm Energy	Secondary Energy	Total Energy	Firm Energy Benefit	Secondary Energy Benefit	Peak* Power Benefit	Total Energy Benefit
	MW	MW	GWh/year	GWh/year	GWh/year	TL/year	TL/year	TL/year	TL/year
Upper kaleköy	56.0	524.32	490.90	632.17	1 123.07	47 126 016	33 378 831	71 308 108	**151 812 955**
Lower kaleköy	47.0	386.49	412.00	506.23	918.24	39 552 192	26 729 207	52 562 162	**118 843 561**
Beyhan 1	46.0	487.84	403.24	675.60	1 078.83	38 710 656	35 671 466	66 345 946	**140 728 068**
Beyhan 2	20.8	226.89	182.33	309.64	491.97	17 503 949	16 348 994	30 857 297	**64 710 240**
Total			1 488	2 124	**3612.11**	142 892 813	112 128 498	221 073 514	**476 094 825 TL**

Table 5.20 Calculation of annual benefits for Scenario 5

Name of facility	Firm Power	Peak* Power	Firm Energy	Secondary Energy	Total Energy	Firm Energy Benefit	Secondary Energy Benefit	Peak* Power Benefit	Total Energy Benefit
	MW	MW	GWh/year	GWh/year	GWh/year	TL/year	TL/year	TL/year	TL/year
Upper kaleköy	56.0	524.32	490.90	632.17	1 123.07	47 126 016	33 378 831	71 308 108	**151 812 955**
Lower kaleköy	48.1	385.00	421.64	489.27	910.92	40 477 882	25 833 543	52 360 000	**118 671 424**
Beyhan 1	47.4	485.95	415.51	663.43	1 078.94	39 888 806	35 029 024	66 088 649	**141 006 479**
Beyhan 2	21.4	226.08	187.59	304.47	492.07	18 008 870	16 076 269	30 747 027	**64 832 166**
Total			1 516	2 089	**3604.99**	145 501 574	110 317 667	220 503 784	**476 323 025 TL**

Table 5.21 Calculation of annual benefits for Scenario 6

Name of facility	Firm Power	Peak* Power	Firm Energy	Secondary Energy	Total Energy	Firm Energy Benefit	Secondary Energy Benefit	Peak* Power Benefit	Total Energy Benefit
	MW	MW	GWh/year	GWh/year	GWh/year	TL/year	TL/year	TL/year	TL/year
Upper kaleköy	56.0	524.32	490.90	573.63	1 064.53	47 126 016	30 287 882	71 308 108	**148 722 006**
Lower kaleköy	49.8	382.70	436.55	429.84	866.39	41 908 493	22 695 632	52 047 568	**116 651 693**
Beyhan 1	50.3	482.03	440.93	618.89	1 059.82	42 329 261	32 677 170	65 555 676	**140 562 106**
Beyhan 2	22.8	224.19	199.86	297.04	496.91	19 187 021	15 683 918	30 489 730	**65 360 668**
Total	178.9		1568.24	1919.41	**3487.64**	150 550 790	101 344 602	219 401 081	**471 296 473 TL**

Table 5.22 Calculation of annual benefits for Scenario 7

Name of facility	T2 18:00 - 24:00	T1 06:00 - 18:00	T3 24:00 - 06:00	Total Energy	T2 17:00 - 22:00 Benefit	T1 06:00 - 17:00 Benefit	T3 22:00 - 06:00 Benefit	Total Energy Benefit
	GWh/year	**GWh/year**	**GWh/year**	**GWh/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**
Upper kalekoy	798.76	379.30	150.95	1329.01	183 411 190	50 561 017	9 638 702	**243 610 909**
Lower kalekoy	608.25	283.72	118.93	1010.90	139 666 478	37 820 053	7 594 048	**185 080 579**
Beyhan 1	712.72	355.98	144.10	1212.80	163 653 869	47 452 201	9 201 585	**220 307 655**
Beyhan 2	323.46	160.82	64.29	548.56	74 272 112	21 437 290	4 104 979	**99 814 380**
Total	2 443	1 180	478	**4101.27**	561 003 649	157 270 561	30 539 314	**748 813 523 TL**

Table 5.23 Calculation of annual benefits for Scenario 8

Name of facility	Pumping 24:00 - 06:00	T2 18:00 - 24:00	T1 06:00 - 18:00	T3 24:00 - 06:00	Total Energy Generated	Pumping 24:00 - 06:00 Cost	T2 17:00 - 22:00 Benefit	T1 06:00 - 17:00 Benefit	T3 22:00 - 06:00 Benefit	Total Energy Benefit
	GWh/year	**GWh/year**	**GWh/year**	**GWh/year**	**GWh/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**
Upper kaleköy	-781.02	1 276	531	118	1924.79	- 49 871 794	292 997 132	70 776 146	7 524 078	**321 425 562**
Lower kaleköy		612	350	96	1058.64		140 604 916	46 671 141	6 141 474	**193 417 532**
Beyhan 1		681	398	132	1211.02		156 418 893	53 026 993	8 429 756	**217 875 642**
Beyhan 2		314	180	59	553.60		72 061 098	24 049 384	3 790 195	**99 900 677**
Total		2 883	1 459	405	**4748.05**	- 49 871 794	662 082 040	194 523 664	25 885 502	**832 619 413 TL**

Table 5.24 Calculation of annual benefits for Scenario 9

Name of facility	Pumping 24:00 - 06:00	T2 18:00 - 24:00	T1 06:00 - 18:00	T3 24:00 - 06:00	Total Energy Generated	Pumping 24:00 - 06:00 Cost	T2 17:00 - 22:00 Benefit	T1 06:00 - 17:00 Benefit	T3 22:00 - 06:00 Benefit	Total Energy Benefit
	GWh/year	**GWh/year**	**GWh/year**	**GWh/year**	**GWh/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**
Upper kaleköy		799	379	151	1329.01		183 411 190	50 561 017	9 638 702	**243 610 909**
Lower kaleköy		608	284	119	1010.90		139 666 478	37 820 053	7 594 048	**185 080 579**
Beyhan 1	- 581.3	1 159	389	108	1074.93	- 37 118 273	266 172 165	51 844 340	6 903 282	**287 801 514**
Beyhan 2		336	169	50	554.38		77 156 790	22 497 487	3 166 343	**102 820 620**
Total		2 902	1 221	428	**3969.22**	- 37 118 273	666 406 622	162 722 897	27 302 375	**819 313 622 TL**

Table 5.25 Calculation of annual benefits for Scenario 10

Name of facility	Pumping 24:00 - 06:00	T2 18:00 - 24:00	T1 06:00 - 18:00	T3 24:00 - 06:00	Total Energy Generated	Pumping 24:00 - 06:00 Cost	T2 17:00 - 22:00 Benefit	T1 06:00 - 17:00 Benefit	T3 22:00 - 06:00 Benefit	Total Energy Benefit
	GWh/year	**GWh/year**	**GWh/year**	**GWh/year**	**GWh/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**	**TL/year**
Upper kalekoy	- 781.0	1 276	531	118	1143.78	- 49 871 794	292 997 132	70 776 146	7 524 078	**321 425 562**
Lower kalekoy		612	350	96	1058.64		140 604 916	46 671 141	6 141 474	**193 417 532**
Beyhan 1	- 683.8	1 176	444	110	1047.01	- 43 664 109	270 028 540	59 238 775	7 051 391	**292 654 597**
Beyhan 2		312	188	51	550.71		71 644 238	25 064 513	3 235 392	**99 944 144**
Total		3 376	1 514	375	**3800.13**	- 93 535 903	775 274 826	201 750 576	23 952 335	**907 441 834 TL**

5.6 Benefit – Cost Analyses

The benefit-cost ratio is expressed by the ratio of:

$$\frac{\text{Present Worth of Gross Benefits - Present Worth of Recurring Project Costs}}{\text{Present Worth of Capital Costs}}$$

Recurring project costs comprise the annual costs of operation and maintenance of the project works, costs of replacement of depreciable equipment at the end of its useful life.

Computations of benefits and costs to be used in benefit-cost analyses are given in Chapter 5.4 and Chapter 5.5, respectively. Benefit-cost analyses performed using these values are given in the following pages.

Annual total energy benefit of Kaleköy reservoir system according to unit energy benefits are shown below for each scenario.

Annual total benefit and cost ratios are also computed below for each scenario, too.

Scenario 1

Annual total energy generated :	**4303.69**	(GWh/year)
T2 :	440 353 789	(TL/year)
T1 :	246 630 256	(TL/year)
T3 :	106 946 752	(TL/year)
Annual total energy benefit :	**793 930 798**	(TL/year)
Annual total cost :	640 285 903	(TL/year)
Annual Net Benefit :	153 644 894	(TL/year)
Benefit /Cost ratio :	1.24	

Scenario 2

Annual total energy generated :	**4640.04**	(GWh/year)
T2 :	474 768 819	(TL/year)
T1 :	265 905 184	(TL/year)
T3 :	115 304 976	(TL/year)
Annual total energy benefit :	**855 978 979**	(TL/year)
Annual total cost :	640 285 903	(TL/year)
Annual Net Benefit :	215 693 076	(TL/year)
Benefit /Cost ratio :	1.34	

Scenario 3

Annual total energy generated:	**4283.87**	(GWh/year)
Annual firm energy benefit:	179 247 168	(TL/year)
Annual secondary energy benefit:	127 602 337	(TL/year)
Annual peak energy benefit:	213 134 054	(TL/year)
Annual total energy benefit:	**519 983 560**	(TL/year)
Annual total cost:	640 285 903	(TL/year)
Annual Net Benefit :	-120 302 344	(TL/year)
Benefit/Cost ratio :	0.81	

Scenario 4

Annual total energy generated:	**3612.11**	(GWh/year)
Annual firm energy benefit:	142 892 813	(TL/year)
Annual secondary energy benefit:	112 128 498	(TL/year)
Annual peak energy benefit:	221 073 514	(TL/year)
Annual total energy benefit:	**476 094 825**	(TL/year)
Annual total cost:	640 285 903	(TL/year)
Annual Net Benefit :	-164 191 079	(TL/year)
Benefit/Cost ratio :	0.74	

Scenario 5

Annual total energy generated:	**3604.99**	(GWh/year)
Annual firm energy benefit:	145 501 574	(TL/year)
Annual secondary energy benefit:	110 317 667	(TL/year)
Annual peak energy benefit:	220 503 784	(TL/year)
Annual total energy benefit:	**476 323 025**	(TL/year)
Annual total cost:	640 285 903	(TL/year)
Annual Net Benefit :	-163 962 879	(TL/year)
Benefit/Cost ratio :	0.74	

Scenario 6

Annual total energy generated:	**3487.64**	(GWh/year)
Annual firm energy benefit:	150 550 790	(TL/year)
Annual secondary energy benefit:	101 344 602	(TL/year)
Annual peak energy benefit:	219 401 081	(TL/year)
Annual total energy benefit:	**471 296 473**	(TL/year)
Annual total cost:	640 285 903	(TL/year)
Annual Net Benefit :	-168 989 430	(TL/year)
Benefit/Cost ratio :	0.74	

Scenario 7

Annual total energy generated :	**4101.27**	(GWh/year)
T2 :	749 959 411	(TL/year)
T1 :	202 835 370	(TL/year)
T3 :	35 654 308	(TL/year)
Annual total energy benefit :	**988 449 089**	(TL/year)
Annual total cost :	640 285 903	(TL/year)
Annual Net Benefit :	348 163 186	(TL/year)
Benefit /Cost ratio :	1.54	

Scenario 8

Annual pumping cost :	- 58 224 763	(TL/year)
T2 :	885 082 759	(TL/year)
T1 :	250 881 533	(TL/year)
T3 :	30 221 035	(TL/year)
Annual total energy benefit :	**1107 960 564**	(TL/year)
Annual total cost :	655 381 558	(TL/year)
Annual Net Benefit :	452 579 006	(TL/year)
Benefit /Cost ratio :	1.69	

Scenario 9

Annual pumping cost :	- 43 335 170	(TL/year)
T2 :	890 863 935	(TL/year)
T1 :	209 867 370	(TL/year)
T3 :	31 875 219	(TL/year)
Annual total energy benefit :	**1089 271 354**	(TL/year)
Annual total cost:	654 009 226	(TL/year)
Annual Net Benefit :	435 262 129	(TL/year)
Benefit/Cost ratio :	1.67	

Scenario 10

Annual pumping cost :	- 109 202 123	(TL/year)
T2 :	1036 400 839	(TL/year)
T1 :	260 202 243	(TL/year)
T3 :	27 964 083	(TL/year)
Annual total energy benefit :	**1215 365 043**	(TL/year)
Annual total cost:	669 104 880	(TL/year)
Annual Net Benefit :	546 260 162	(TL/year)
Benefit/Cost ratio :	1.82	

5.7 Internal Rate of Return

The Internal Rate of Return (IRR) refers to the discount rate, for which, considered the given study period, the Net Present Value is zero (NPV = 0). In other words, internal rate of return is the interest-discount rate that equates the present worth values of all annual costs and benefits throughout the economic life of the project. IRR describes to what extent the investment delivers a higher discount rate than the selected discount rate i representing capital cost. The necessary requirement for the investment to be accepted is that IRR > i.

$$\sum_{t=1}^{n} \frac{R_t - (I_t + C_t)}{(1+IRR)^t} = 0 \qquad (5.2)$$

where,

R_t = annual revenues resulted from the sale of electricity (TL/year),

I_t = annual investment (TL/year),

C_t = annual operating related costs (TL/year),

n = 4 years of project development and 50 years of operation.

Graphs of cash flow and the computations of internal rate of return of the scenarios are given in Appendix A.

In the computations, net income loss due to expropriation has been added to annual costs. This value has been obtained from Feasibility Report as 4 240 000 TL (Temelsu International Engineering Services Inc., 2011).

Internal rate of return values for Kaleköy reservoir system are summarized from Tables A1-A10 and illustrated in Table 5.26.

Table 5.26 Internal rate of return values for Scenarios

	Internal rate of return (%)
Scenario 1	12.21
Scenario 2	13.08
Scenario 3	8.05
Scenario 4	7.31
Scenario 5	7.31
Scenario 6	7.23
Scenario 7	14.85
Scenario 8	16.06
Scenario 9	15.85
Scenario 10	17.07

CHAPTER 6

DISCUSSION OF RESULTS

6.1 Discussion of Results

The economic feasibility of the Kaleköy reservoir system is evaluated on the basis of its internal rate of return and also, for a selected discount rate, on the basis of the present worth of net benefits and the benefit-cost ratio.

Various scenarios provide different insight into the economics of the project. The internal rate of return gives the average annual return on the investment. It is the only parameter which is independent of the selection of a discount rate at which fully accounts for the phasing of costs and benefits. The internal rate of return is the discount rate at which the project shows a benefit-cost ratio of unity. In Figure 6.1, internal rate of return values of the scenarios are presented. Scenario 10 with two pumped power plants has the highest internal rate of return value.

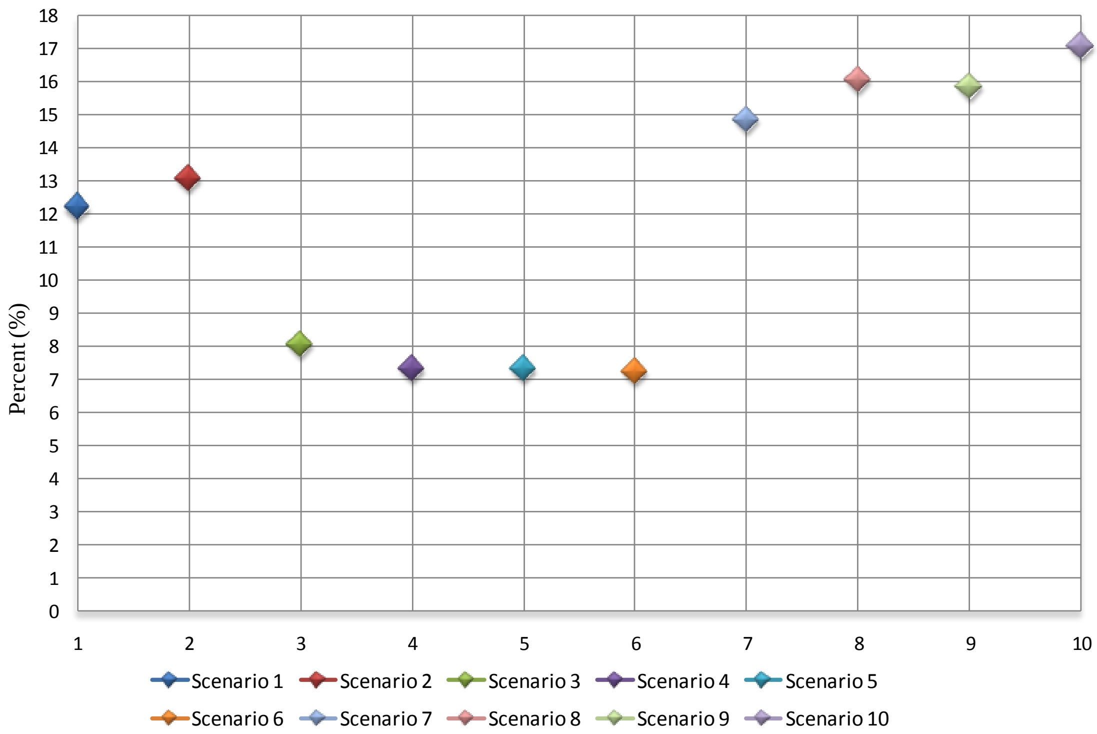


Figure 6.1 Internal rate of return values (%) for Scenarios

The reservoirs are operated at the full operation level (i.e. no usage of operation guide curves) in the Scenario 1. The results for the energy generation for the Scenario 1 is that mean power generation is computed to be 490.9 MW, which is equivalent to an annual energy generation of 4303.7 GWh. For the other design scenarios the annual energy generation ranges from 3488 GWh to 4640 GWh as shown in Figure 6.2.

In Scenario 2, 10% percent increase in the inflows of Kaleköy reservoir system is applied to the simulation model. The results for the energy and revenue generation of the Scenario 2 is less than 10% percent compared to Scenario 1 as shown in Figure 6.1 and 6.2.

Firm energy is the minimum output which can be guaranteed if no worse hydrological conditions occur than those represented by the flow data of the critical period. The critical period has also been investigated for the case that "firm" energy is produced according to a given non-uniform pattern, as was explained in sections 3.4 and 3.5. In Scenario 3 and 4, if we consider firm energy requirement it results decrease in annual energy generation and benefits since operation head is not usually at maximum level. However, there is a 22% decrease in inflow in Scenario 4 due to full development case inflows, reduction in energy generation is 16%.

In this thesis, the official unit prices of firm and secondary energies and the discount ratio advocated by the General Directorate of State Water Works is used as 6 and 3.3 US Cents/kWh, respectively which are unrealistically too low. In Chapter 5 the present worth of benefits of the Kaleköy reservoir system is computed using these values. In Scenario 3, the sensitivity of the present worth of benefits on the unit prices is quantitatively analyzed by making the unit prices 10 and 5 US Cents/kWh than it is observed that the benefit/cost ratio increases to 1.1.

Besides, for a given discount rate the benefit-costs ratio indicates the profitability of the project and the present worth of net benefits reflects the size of the profits. In order for these economic parameters to provide a valid basis for scenario evaluation, the selected discount rate (9.5%) must reflect the true value of capital in the Turkish economy. Sensitivity analyses may be performed for different discount rates as well.

The effect of the increase in conservation volume on power generation is investigated in Scenario 5. The minimum storage level indicated on the designs has been selected in a way that is above dead storage and vortex limitations. In the case of Lower Kaleköy Reservoir, this design minimum is lowered in Scenario 5. When we compare Scenario 4 and Scenario 5, results show that there is almost no difference in energy generation at Upper Kaleköy since no change made on upstream network. In addition to this, only 2% increase in total firm energy generation, is achieved.

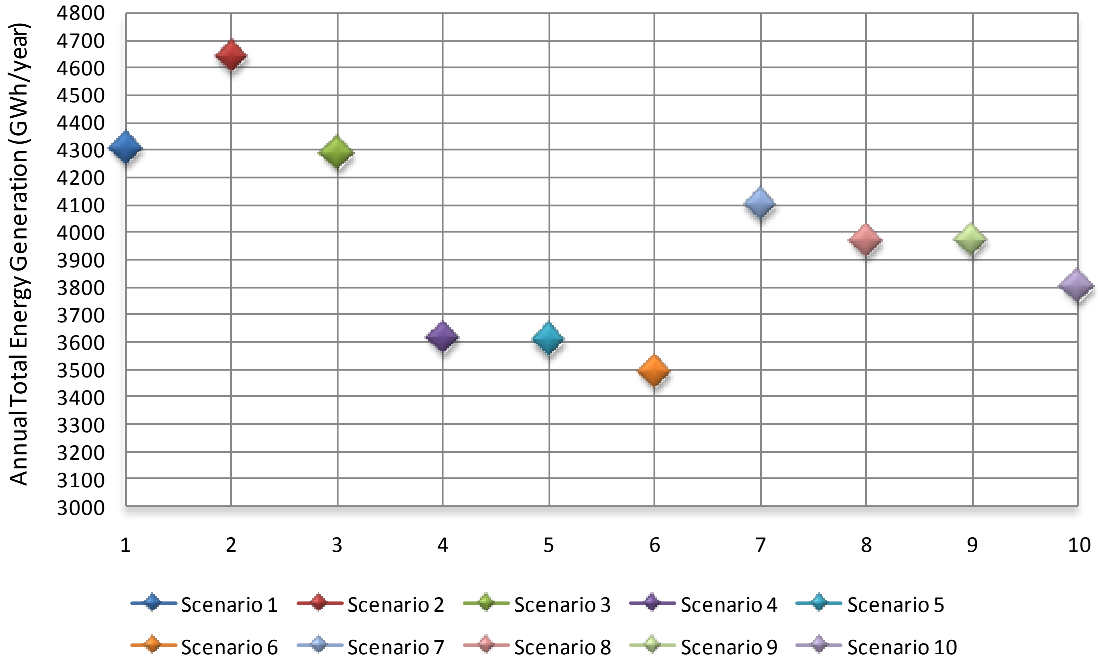


Figure 6.2 Annual Total Energy Generation (GWh/year) for Scenarios

In Scenario 6, the model is designed to compare firm energy and total energy generation compared to Scenario 4. Guide curve is adjusted to have an increment of 5 % firm energy. However, decrease in spilled water is 18% in Scenario 6 there is a decrease in annual energy. The reason for that is withdrawal of stored water in July cannot be compensated for several months due to low runoff in summer and autumn, resulting in a longer period of smaller hydraulic head. As a result of this, keeping guide curve at maximum level increases annual energy generation.

Nowadays, the cost charged from households for electricity used during early morning and evening rush hours is much greater than that during low-consumption hours, daily. For the Scenario 7 investigated in this thesis, if the turbines are operated in accordance with the so-called "wise-hours-schedule", which means any turbines are completely shut off during the off-peak period, and the peak hours have the priority for energy generation. In this case, the revenue of Scenario 7 is the maximum in all scenarios which have conventional turbines as shown in Figure 6.3.

This increase in revenue generation is primarily due to the timing of energy production (i.e. when prices are high), whereas overall energy generation is not increased in Scenario 7 as shown in Figure 6.2.

The contract eventually signed for the sale of power and energy (or the schedule used) may be more complex than our simple on and off-peak energy values. The marginal cost of electricity for a utility can vary greatly through any given day. If the purchase price of energy produced by the hydroelectric plant is tied to a marginal cost, for example, a more detailed operational analysis with daily flow routing and a past history of energy values may be more accurate.

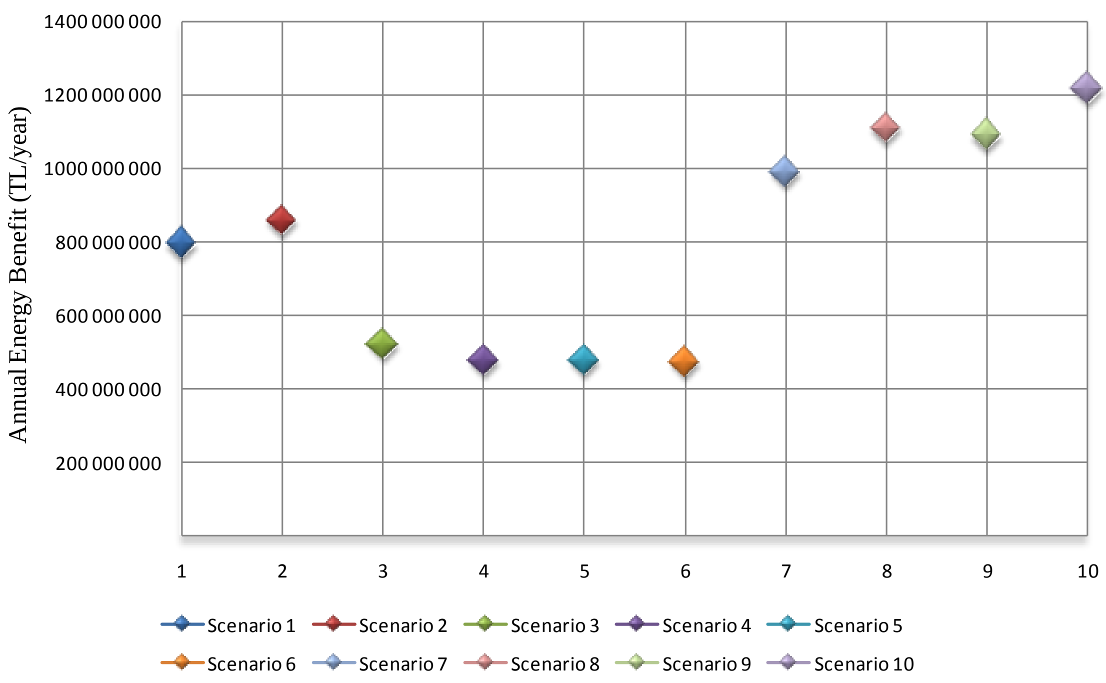


Figure 6.3 Annual Energy Benefit (TL/year) for Scenarios

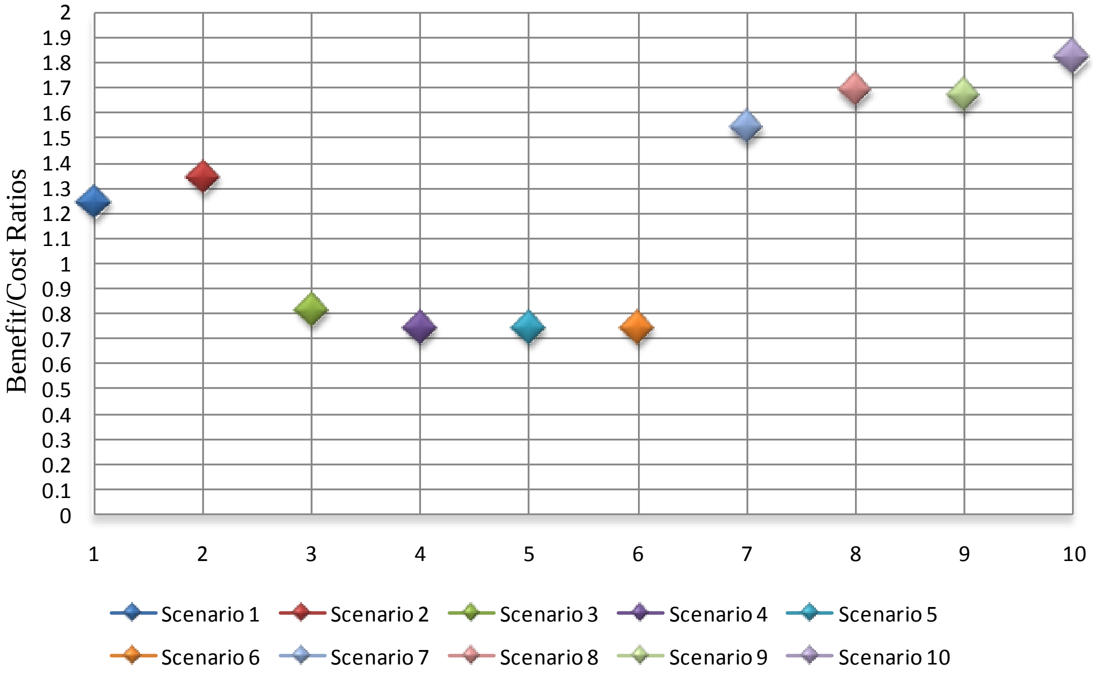


Figure 6.4 Benefit/Cost Ratios for Scenarios

The rising demand for peaking power is creating a completely new market value, which is also increasing the attractiveness of pumped storage power stations. In Scenario 8, 9 and 10 pumped storage scenarios have been analyzed.

The costs and benefits of power and energy production have been evaluated over a period of fifty years and the benefit/cost ratios are determined in Chapter 5. In Figure 6.4, pumped storage scenarios have the maximum benefit/cost ratio over all scenarios.

According to the above given benefit/cost ratios in Figure 6.4 and unit energy prices, pump storage alternative seems feasible. Scenario 10 has the maximum benefit/cost ratio over all scenarios with two reversible turbines. These results demonstrate the increasing attractiveness of the Kaleköy reservoir system with pump turbines. In addition to this, it is quite sensitive to the energy unit prices and working hours in pump and turbine modes. The analyses have been performed according to the accepted current unit prices which are subject to change either in short term or long term. Therefore it will be beneficial to re-evaluate pump storage alternative after carrying out a projection study in energy prices to decide if it is feasible or not.

Annual total energy generation in pumped storage scenarios is below the average values respect to Scenario 1, 3 and 7 in existing case inflows. Therefore, it is plausible that such an operation of the reservoirs increases revenue generation, but not energy generation.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

In production of electrical energy, compared to fossil and nuclear thermal plants, natural gas-fired power plants; hydroelectric power plants have two important properties such as renewable source and peak operation. Consumption of electrical energy is one of the most important indicators of economic development and social well-being. Electricity production or consumption per capita of any country is one of the indicators of the living standart.

The growing demand for electricity in Turkey will require the addition of large increments of generating capacity to supply the interconnected system. Hydro-electric power plants on the Murat River are logical and economical sources of power and their development through the construction of dams on the Murat forms an integral part of the national long range power development plan.

Hydropower can be used in a power system in several ways: for peaking, for meeting intermediate loads, for base load operation, or for meeting a combination of these loads. These alternative operations is illustrated in the previous chapters.

Instead of energy production using foreign dependent fuel as natural gas and imported coal, Turkey has to give priority to and realize energy production using local resources as hydropower in order to lessen the foreign dependency.

Feasibility report for Lower Fırat basin was carried out in 2011 by Pöyry and Temelsu International Engineering Services Inc. in order to investigate the potential for exploiting the hydro-electric potential of the river system. Maximization of firm energy and operation of reservoirs in peak mode were studied in the feasibility study.

In this thesis the feasibility report is improved by considering different operation scenarios and pumped storage alternatives. Scenarios and the financial analysis are described regarding the hydropower potential in the previous chapters.

Kaleköy reservoir system, located upstream of the Keban Dam, will utilise the hydro potential of the Murat river between the elevations of 870 m and 1225 m in four powerplants totalling 1705 MW of installed capacity.

HEC-ResSim simulation program is used to model the cascade reservoir system. Analysis of the complex system is easy to model by using the HEC-ResSim. In order to minimize spillage during high flow season and to benefit from a higher head various operation rules have been defined.

Pumped storage applications are investigated as well. Pumped storage hydroelectricity is the only economic and flexible means of storing grid scale amounts of excess energy, allowing power plants dispatchers to successfully manage that balancing act. This is becoming even more important as more and more countries are building up their power generation from intermittent renewables such as wind and solar.

The advantage of this technology is that it can come online very quickly, making it a useful tool to balance the varying electricity demand from consumers or unplanned outages of other power plants.

In recent years, the profitability of pumped storage plants has increased as a consequence of increased price volatility on electricity spot markets.

A financial assessment was carried out for the full range of ten scenarios, in order to assess the cost effective operation regime and the economic feasibility of the scenarios. Ten scenarios are made of the type of operation required in order to reduce spillage and maintain high water levels in the reservoir. The results of the scenarios show that the Kaleköy Reservoir System is profitable. However, choosing an appropriate operation is more delicate, particularly as measuring future demand for peak energy or fluctuations in the electricity price is uncertain.

The scenarios related to evaluation indicators are the internal rate of return and the benefit-cost ratio, which provide information on the degree of profitability of the scenarios. From the current analysis, Scenario 7 and scenarios with reversible pump turbines seem to give the best internal rate of return and benefit-cost ratios.

7.2 Recommendations

In developing an operational procedure, one may also want to consider the stochastic nature of the flow; i.e., it is useful to remember that the future is not an exact replica of the past. Uncertainty must be taken into account in the forecasts. Once means of achieving this would be to generate a number of flow forecasts, each with a given probability of occurrence, and in an operation routine one should consider all the forecasts and their probabilities. For this reason the rules for the operation of the reservoirs derived from present conditions must be considered flexible and subject to minor changes as future events and operating experience may dictate.

Sensitivity scenarios should be considered for capital cost over runs and increased operation costs, and a reduction on generation over the life of the plant. The necessity for sensitivity scenarios for electricity prices should be simulated.

During the winter season, the watershed is covered by snow. Snowmelt is significant part of the river flow in the spring season. A snow hydrology model of the basin using available ground and remotely sensed data should be developed to better understand the water resources in the Upper Fırat Basin. The snow model may accurately model snow accumulation and melt and can provide useful information about the snow hydrology of the region. Reservoir managers can use this information in operating decisions, to maximize water supply.

The revenues are all related to the sales of electricity only. The sales price rates are expected to be the prices at the moment of the commissioning of the power plant. Projections in energy prices and peak hours should be considered in other scenarios. An increase of the energy price may be expected to occur during the lifetime of the Kaleköy Reservoir System. The financial viability of the project should be assessed more precisely in a specific economic model. An economic model for future unit energy prices will be essential for more accurate results.

It is essential to formulate the operation rules with information that will be available at the time when operation decisions are made. If forecasts are used in operation, the degree of reliability must be taken into account in deriving operating rules. In assessing the benefits that would be associated with a particular set of operating rules, forecast errors must be simulated in such a manner as to represent average anticipated accomplishment under those rules.

Watershed development plans prepared at different times may become inconsistent because of the economic point of view at later dates. However, some preliminary studies have been abandoned, within the time according to the changes occurring in the energy benefits and economic costs of facilities of the same projects may be feasible. For this reason, at certain intervals watershed development plans should be revised.

BIBLIOGRAPHY

Alantor, D.D., Malkoç, F., Bektaşoğlu, B. and Eminoğlu, E., *Efficiency in Reservoir Operation,* With International Participation Third National Symposium on Dam Safety, Eskişehir, 2012, pp 359-366 (in Turkish).

ASCE, *Guidelines for Design of Intakes for Hydroelectric Plants*, New York, 1995.

Bakır, N., *http://www.ere.com.tr/EMO_21Aralik2005.pdf,* last visited on January 2013.

Deloitte Financial Advisory Services LLP, *Turkish Electricity Market: Developments and Expectations 2010-2011,* 2010.

Doland, J.J., *Hydro Power Engineering*, The Roland Press Company, New York, 1954.

Dyson, M., Bergkamp, G. and Scanlon, J., *The essentials of environmental flows*, The World Conversation Union, UK, 2003.

EM 1110-2-1701, *Engineering and Design Hydropower*, Engineering Manual, Washington, 1985.

Energy Market Regulatory Authority, *Electricity Market Report 2010,* Ankara, 2011.

Energy Market Regulatory Authority, *Electricity Market Report 2011,* Ankara, 2012.

General Directorate of Renewable Energy, *http://www.eie.gov.tr/yenilenebilir/ h_turkiye_potansiyel.aspx*, last visited on December 2012.

Gulliver, J.S. and Arndt, R.E.A., *Hydropower Engineering Handbook*, McGraw-Hill Inc., 1991.

International Energy Agency, *World Energy Outlook 2012,* 2012.

Investment Support and Promotion Agency, *Turkey's Energy Sector Report*, Deloitte, 2010.

İnci, K.O., *Hydroelectric Power Plant Investments and Technologies*, International Energy Congress and Fair, Ankara, 2012.

Jefferies, D.G., *Institution of Civil Engineers, Pumped Storage*, Thomas Telford, London, 1990.

Kansal, M.L., *System Analysis Techniques in Water Resources Management*, Turkish Water Foundation, Istanbul, 2005.

Klipsch, J.D., *HEC-ResSim Reservoir System Simulation – User's Manual Version 3.0*, U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, 2007.

Lempérière, F., *Global overview of pumped storage potential and cost,* Hydro Conference Papers, 2011, pp 18.01.

Miller, R., *Opportunities in Pumped Storage Hydropower*, Power Engineering Magazine, 2010, pp 50-52.

Mitteregger, A., *Austrian pumped storage power stations supply peak demands*, World Pump Magazine, 2008.

Nandalal, K.D.W. and Bogardi, J.J., *Dynamic Programming Based Operation of Reservoirs: Applicability and Limits,* Cambridge University Press, 2007.

Oliveira, M.A., *Venda Nova III repowering project*, Hydro Conference Papers, 2011, pp 15.03.

Özbakır, B., *Modelling of Seyhan and Ceyhan River Basin with Using HEC-ResSim Program*, M.Sc.Thesis, Department of Civil Engineering, Gazi University, 2009.

Rukuni, S., *Modeling the response of small multi-purpose reservoirs to hydrology for improved rural livelihoods in the Mzingwane catchment: Limpopo Basin*, M.Sc.Thesis, Department of Civil Engineering, Zimbabwe University, 2006.

Saraç, M., *The First Hydroelectric Power Plant Projects in Turkey*, With International Participation Third National Symposium on Dam Safety, Eskişehir, 2012, pp 161-168 (in Turkish).

Saraç, M., *Pumped Storage Hydroelectric Power Plants*, With International Participation Third National Symposium on Dam Safety, Eskişehir, 2012, pp 459-470.

Temelsu International Engineering Services Inc., *Lower Murat Basin Final Feasibility Report*, 2011.

Turkish Electricity Distribution Company, *http://www.tedas.gov.tr/274,2012_ Tarifeler.html*, last visited on December 2012.

Turkish Electricity Transmission Company, *Turkish Electrical Energy 10-Year Generation Capacity Projection (2011-2020),* Ankara, 2011.

University of Texas, *http://www.crwr.utexas.edu/gis/gishyd98/dhi/mikebas/ Mbasmain.htm*, last visited on December 2012.

Voith, *Pumped Storage Machines*, Turbine Catalogs and Manuals, Germany, 2009.

Yanmaz, A.M., *Applied Water Resources Engineering*, METU Press Publishing Co., Ankara, 2006.

Zhang, H., Xia, Xiaohua., Zhang, Jiangfeng., *Optimal sizing and operation of pumping systems to achieve energy efficiency and load shifting*, Electric Power Systems Research 86, Elsevier, 2012, pp 41-50.

World Map, *http://mapas.owje.com/maps/8725_eastern-turkey-and-vicinity-shaded-relief-map.htm*, last visited on December 2012.

APPENDIX A

INTERNAL RATE OF RETURN CALCULATIONS

Table A.1 Internal rate of return for Scenario 1

Internal Rate of Return				
Year	**Costs**	**Benefits**	**Net Benefit**	**Net Present Value**
1	1 116 861 429		-1 116 861 429	-1054 325 472
2	1 836 796 576		-1 836 796 576	-1545 209 181
3	1 209 117 607		-1 209 117 607	-906 453 597
4	758 246 723		- 758 246 723	-506 568 740
5	57 997 019	793 930 798	735 933 779	438 144 530
6	57 997 019	793 930 798	735 933 779	390 452 499
7	57 997 019	793 930 798	735 933 779	347 951 745
8	57 997 019	793 930 798	735 933 779	310 077 198
9	57 997 019	793 930 798	735 933 779	276 325 296
10	57 997 019	793 930 798	735 933 779	246 247 288
11	57 997 019	793 930 798	735 933 779	219 443 272
12	57 997 019	793 930 798	735 933 779	195 556 872
13	57 997 019	793 930 798	735 933 779	174 270 507
14	57 997 019	793 930 798	735 933 779	155 301 163
15	57 997 019	793 930 798	735 933 779	138 396 631
16	57 997 019	793 930 798	735 933 779	123 332 158
17	57 997 019	793 930 798	735 933 779	109 907 453
18	57 997 019	793 930 798	735 933 779	97 944 027
19	57 997 019	793 930 798	735 933 779	87 282 820
20	57 997 019	793 930 798	735 933 779	77 782 085
21	57 997 019	793 930 798	735 933 779	69 315 506
22	57 997 019	793 930 798	735 933 779	61 770 513
23	57 997 019	793 930 798	735 933 779	55 046 793
24	57 997 019	793 930 798	735 933 779	49 054 949
25	57 997 019	793 930 798	735 933 779	43 715 318
26	57 997 019	793 930 798	735 933 779	38 956 906
27	57 997 019	793 930 798	735 933 779	34 716 447
28	57 997 019	793 930 798	735 933 779	30 937 562
29	57 997 019	793 930 798	735 933 779	27 570 008
30	57 997 019	793 930 798	735 933 779	24 569 013
31	57 997 019	793 930 798	735 933 779	21 894 676
32	57 997 019	793 930 798	735 933 779	19 511 440
33	57 997 019	793 930 798	735 933 779	17 387 620
34	57 997 019	793 930 798	735 933 779	15 494 978
35	57 997 019	793 930 798	735 933 779	13 808 350
36	57 997 019	793 930 798	735 933 779	12 305 311
37	57 997 019	793 930 798	735 933 779	10 965 878
38	57 997 019	793 930 798	735 933 779	9 772 242
39	57 997 019	793 930 798	735 933 779	8 708 533
40	57 997 019	793 930 798	735 933 779	7 760 610
41	57 997 019	793 930 798	735 933 779	6 915 867
42	57 997 019	793 930 798	735 933 779	6 163 075
43	57 997 019	793 930 798	735 933 779	5 492 224
44	57 997 019	793 930 798	735 933 779	4 894 396
45	57 997 019	793 930 798	735 933 779	4 361 641
46	57 997 019	793 930 798	735 933 779	3 886 876
47	57 997 019	793 930 798	735 933 779	3 463 790
48	57 997 019	793 930 798	735 933 779	3 086 756
49	57 997 019	793 930 798	735 933 779	2 750 763
50	57 997 019	793 930 798	735 933 779	2 451 342
51	57 997 019	793 930 798	735 933 779	2 184 514
52	57 997 019	793 930 798	735 933 779	1 946 729
53	57 997 019	793 930 798	735 933 779	1 734 828
54	57 997 019	793 930 798	735 933 779	1 545 992
	7 820 873 279	39 696 539 887	31 875 666 608	0

Internal Rate of Return : 12.21%

Figure A.1 Cash flow graph for Scenario 1

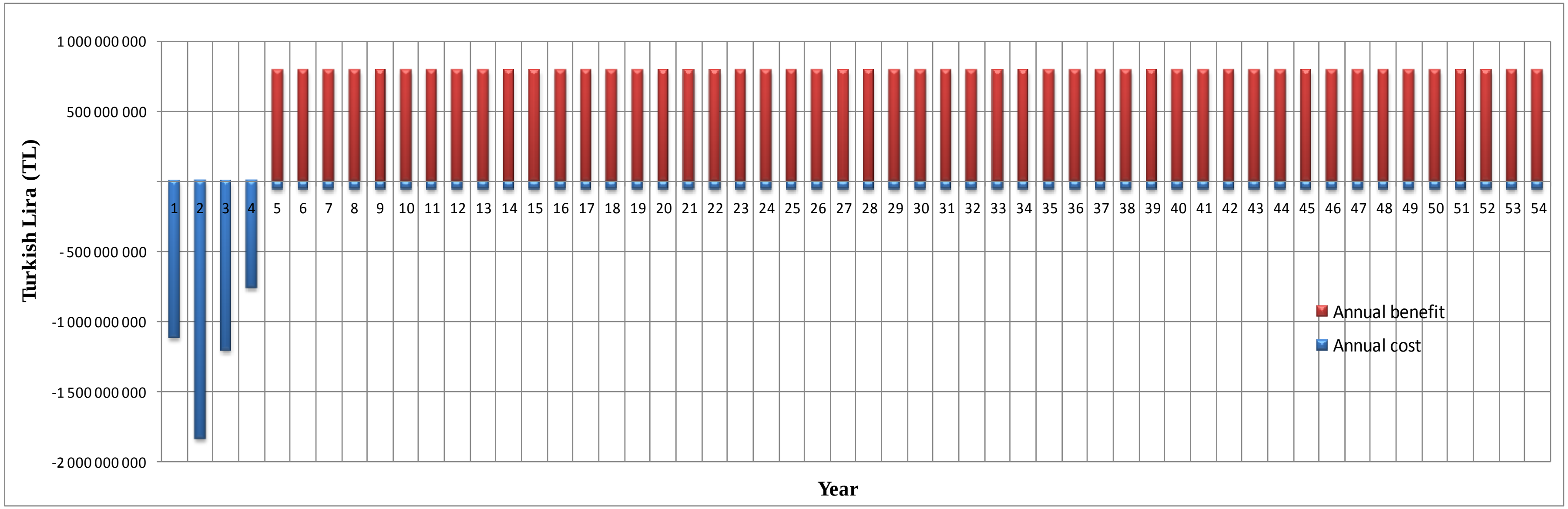


Table A.2 Internal rate of return for Scenario 2

Internal Rate of Return				
Year	**Costs**	**Benefits**	**Net Benefit**	**Net Present Value**
1	1 116 861 429		-1 116 861 429	-1050 295 417
2	1 836 796 576		-1 836 796 576	-1527 557 598
3	1 209 117 607		-1 209 117 607	-889 261 386
4	758 246 723		- 758 246 723	-493 169 020
5	57 997 019	855 978 979	797 981 960	458 989 419
6	57 997 019	855 978 979	797 981 960	405 907 457
7	57 997 019	855 978 979	797 981 960	358 964 405
8	57 997 019	855 978 979	797 981 960	317 450 300
9	57 997 019	855 978 979	797 981 960	280 737 286
10	57 997 019	855 978 979	797 981 960	248 270 119
11	57 997 019	855 978 979	797 981 960	219 557 769
12	57 997 019	855 978 979	797 981 960	194 165 991
13	57 997 019	855 978 979	797 981 960	171 710 764
14	57 997 019	855 978 979	797 981 960	151 852 475
15	57 997 019	855 978 979	797 981 960	134 290 791
16	57 997 019	855 978 979	797 981 960	118 760 109
17	57 997 019	855 978 979	797 981 960	105 025 545
18	57 997 019	855 978 979	797 981 960	92 879 378
19	57 997 019	855 978 979	797 981 960	82 137 911
20	57 997 019	855 978 979	797 981 960	72 638 691
21	57 997 019	855 978 979	797 981 960	64 238 052
22	57 997 019	855 978 979	797 981 960	56 808 945
23	57 997 019	855 978 979	797 981 960	50 239 011
24	57 997 019	855 978 979	797 981 960	44 428 887
25	57 997 019	855 978 979	797 981 960	39 290 702
26	57 997 019	855 978 979	797 981 960	34 746 746
27	57 997 019	855 978 979	797 981 960	30 728 298
28	57 997 019	855 978 979	797 981 960	27 174 581
29	57 997 019	855 978 979	797 981 960	24 031 850
30	57 997 019	855 978 979	797 981 960	21 252 575
31	57 997 019	855 978 979	797 981 960	18 794 723
32	57 997 019	855 978 979	797 981 960	16 621 120
33	57 997 019	855 978 979	797 981 960	14 698 893
34	57 997 019	855 978 979	797 981 960	12 998 971
35	57 997 019	855 978 979	797 981 960	11 495 645
36	57 997 019	855 978 979	797 981 960	10 166 178
37	57 997 019	855 978 979	797 981 960	8 990 463
38	57 997 019	855 978 979	797 981 960	7 950 719
39	57 997 019	855 978 979	797 981 960	7 031 221
40	57 997 019	855 978 979	797 981 960	6 218 063
41	57 997 019	855 978 979	797 981 960	5 498 946
42	57 997 019	855 978 979	797 981 960	4 862 995
43	57 997 019	855 978 979	797 981 960	4 300 591
44	57 997 019	855 978 979	797 981 960	3 803 230
45	57 997 019	855 978 979	797 981 960	3 363 387
46	57 997 019	855 978 979	797 981 960	2 974 413
47	57 997 019	855 978 979	797 981 960	2 630 423
48	57 997 019	855 978 979	797 981 960	2 326 216
49	57 997 019	855 978 979	797 981 960	2 057 190
50	57 997 019	855 978 979	797 981 960	1 819 276
51	57 997 019	855 978 979	797 981 960	1 608 878
52	57 997 019	855 978 979	797 981 960	1 422 812
53	57 997 019	855 978 979	797 981 960	1 258 264
54	57 997 019	855 978 979	797 981 960	1 112 746
	7 820 873 279	42 798 948 964	34 978 075 685	0

Internal Rate of Return : 13.08%

Figure A.2 Cash flow graph for Scenario 2

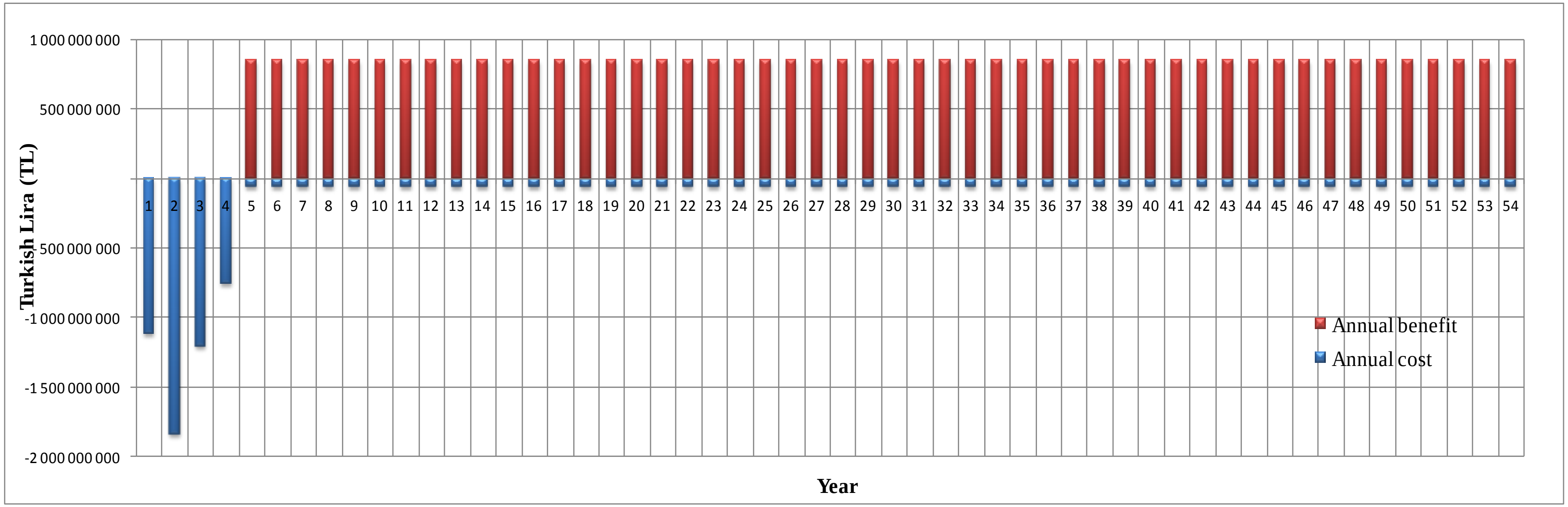


Table A.3 Internal rate of return for Scenario 3

Internal Rate of Return				
Year	**Costs**	**Benefits**	**Net Benefit**	**Net Present Value**
1	1 116 861 429		-1 116 861 429	-1 074 442 234
2	1 836 796 576		-1 836 796 576	-1 635 356 332
3	1 209 117 607		-1 209 117 607	- 996 293 824
4	758 246 723		- 758 246 723	- 578 225 170
5	57 997 019	519 983 560	461 986 541	326 049 344
6	57 997 019	519 983 560	461 986 541	301 752 507
7	57 997 019	519 983 560	461 986 541	279 266 244
8	57 997 019	519 983 560	461 986 541	258 455 633
9	57 997 019	519 983 560	461 986 541	239 195 805
10	57 997 019	519 983 560	461 986 541	221 371 198
11	57 997 019	519 983 560	461 986 541	204 874 862
12	57 997 019	519 983 560	461 986 541	189 607 814
13	57 997 019	519 983 560	461 986 541	175 478 449
14	57 997 019	519 983 560	461 986 541	162 401 989
15	57 997 019	519 983 560	461 986 541	150 299 973
16	57 997 019	519 983 560	461 986 541	139 099 785
17	57 997 019	519 983 560	461 986 541	128 734 223
18	57 997 019	519 983 560	461 986 541	119 141 091
19	57 997 019	519 983 560	461 986 541	110 262 829
20	57 997 019	519 983 560	461 986 541	102 046 165
21	57 997 019	519 983 560	461 986 541	94 441 798
22	57 997 019	519 983 560	461 986 541	87 404 099
23	57 997 019	519 983 560	461 986 541	80 890 843
24	57 997 019	519 983 560	461 986 541	74 862 946
25	57 997 019	519 983 560	461 986 541	69 284 243
26	57 997 019	519 983 560	461 986 541	64 121 257
27	57 997 019	519 983 560	461 986 541	59 343 012
28	57 997 019	519 983 560	461 986 541	54 920 837
29	57 997 019	519 983 560	461 986 541	50 828 197
30	57 997 019	519 983 560	461 986 541	47 040 536
31	57 997 019	519 983 560	461 986 541	43 535 127
32	57 997 019	519 983 560	461 986 541	40 290 938
33	57 997 019	519 983 560	461 986 541	37 288 501
34	57 997 019	519 983 560	461 986 541	34 509 804
35	57 997 019	519 983 560	461 986 541	31 938 171
36	57 997 019	519 983 560	461 986 541	29 558 174
37	57 997 019	519 983 560	461 986 541	27 355 532
38	57 997 019	519 983 560	461 986 541	25 317 028
39	57 997 019	519 983 560	461 986 541	23 430 431
40	57 997 019	519 983 560	461 986 541	21 684 421
41	57 997 019	519 983 560	461 986 541	20 068 522
42	57 997 019	519 983 560	461 986 541	18 573 038
43	57 997 019	519 983 560	461 986 541	17 188 996
44	57 997 019	519 983 560	461 986 541	15 908 091
45	57 997 019	519 983 560	461 986 541	14 722 637
46	57 997 019	519 983 560	461 986 541	13 625 523
47	57 997 019	519 983 560	461 986 541	12 610 164
48	57 997 019	519 983 560	461 986 541	11 670 468
49	57 997 019	519 983 560	461 986 541	10 800 798
50	57 997 019	519 983 560	461 986 541	9 995 934
51	57 997 019	519 983 560	461 986 541	9 251 049
52	57 997 019	519 983 560	461 986 541	8 561 671
53	57 997 019	519 983 560	461 986 541	7 923 664
54	57 997 019	519 983 560	461 986 541	7 333 202
	7 820 873 279	25 999 177 977	18 178 304 699	0

Internal Rate of Return : 8.05%

Figure A.3 Cash flow graph for Scenario 3

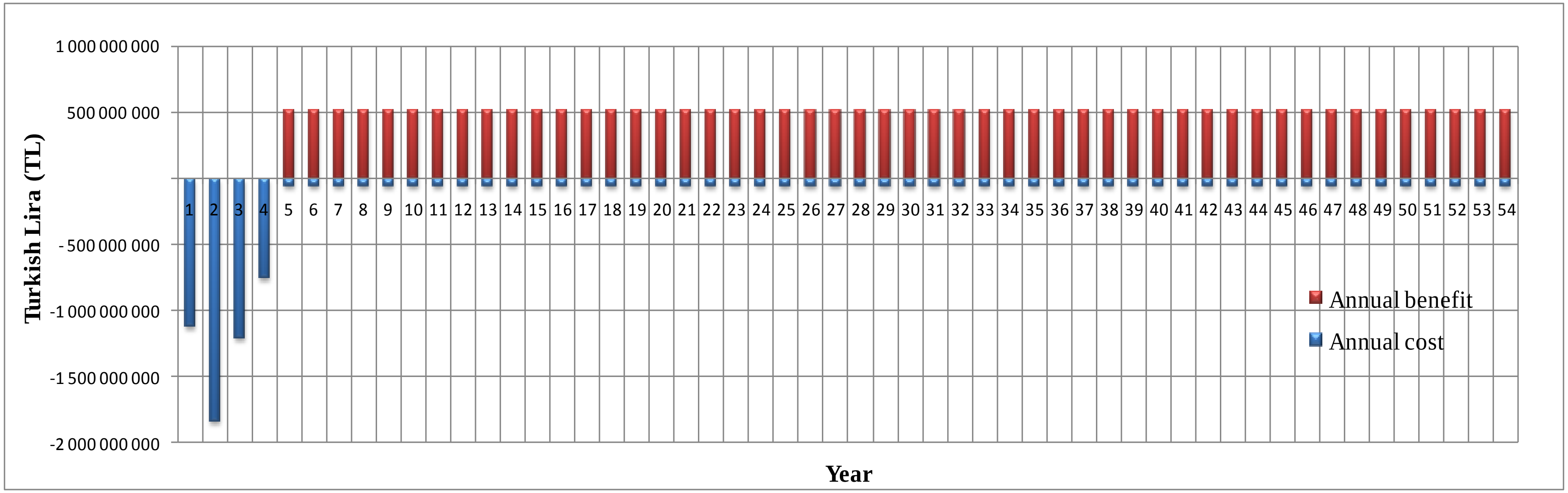


Table A.4 Internal rate of return for Scenario 4

Internal Rate of Return				
Year	**Costs**	**Benefits**	**Net Benefit**	**Net Present Value**
1	1 116 861 429		-1 116 861 429	-1 078 146 865
2	1 836 796 576		-1 836 796 576	-1 652 330 639
3	1 209 117 607		-1 209 117 607	-1 013 588 568
4	758 246 723		- 758 246 723	- 592 326 228
5	57 997 019	476 094 825	418 097 806	304 358 597
6	57 997 019	476 094 825	418 097 806	283 623 908
7	57 997 019	476 094 825	418 097 806	264 301 787
8	57 997 019	476 094 825	418 097 806	246 296 002
9	57 997 019	476 094 825	418 097 806	229 516 877
10	57 997 019	476 094 825	418 097 806	213 880 844
11	57 997 019	476 094 825	418 097 806	199 310 029
12	57 997 019	476 094 825	418 097 806	185 731 863
13	57 997 019	476 094 825	418 097 806	173 078 722
14	57 997 019	476 094 825	418 097 806	161 287 586
15	57 997 019	476 094 825	418 097 806	150 299 732
16	57 997 019	476 094 825	418 097 806	140 060 434
17	57 997 019	476 094 825	418 097 806	130 518 698
18	57 997 019	476 094 825	418 097 806	121 627 000
19	57 997 019	476 094 825	418 097 806	113 341 057
20	57 997 019	476 094 825	418 097 806	105 619 601
21	57 997 019	476 094 825	418 097 806	98 424 176
22	57 997 019	476 094 825	418 097 806	91 718 945
23	57 997 019	476 094 825	418 097 806	85 470 513
24	57 997 019	476 094 825	418 097 806	79 647 762
25	57 997 019	476 094 825	418 097 806	74 221 690
26	57 997 019	476 094 825	418 097 806	69 165 274
27	57 997 019	476 094 825	418 097 806	64 453 331
28	57 997 019	476 094 825	418 097 806	60 062 393
29	57 997 019	476 094 825	418 097 806	55 970 591
30	57 997 019	476 094 825	418 097 806	52 157 547
31	57 997 019	476 094 825	418 097 806	48 604 269
32	57 997 019	476 094 825	418 097 806	45 293 062
33	57 997 019	476 094 825	418 097 806	42 207 434
34	57 997 019	476 094 825	418 097 806	39 332 016
35	57 997 019	476 094 825	418 097 806	36 652 489
36	57 997 019	476 094 825	418 097 806	34 155 507
37	57 997 019	476 094 825	418 097 806	31 828 634
38	57 997 019	476 094 825	418 097 806	29 660 281
39	57 997 019	476 094 825	418 097 806	27 639 649
40	57 997 019	476 094 825	418 097 806	25 756 674
41	57 997 019	476 094 825	418 097 806	24 001 979
42	57 997 019	476 094 825	418 097 806	22 366 824
43	57 997 019	476 094 825	418 097 806	20 843 065
44	57 997 019	476 094 825	418 097 806	19 423 113
45	57 997 019	476 094 825	418 097 806	18 099 897
46	57 997 019	476 094 825	418 097 806	16 866 826
47	57 997 019	476 094 825	418 097 806	15 717 759
48	57 997 019	476 094 825	418 097 806	14 646 973
49	57 997 019	476 094 825	418 097 806	13 649 136
50	57 997 019	476 094 825	418 097 806	12 719 277
51	57 997 019	476 094 825	418 097 806	11 852 765
52	57 997 019	476 094 825	418 097 806	11 045 286
53	57 997 019	476 094 825	418 097 806	10 292 816
54	57 997 019	476 094 825	418 097 806	9 591 609
	7 820 873 279	23 804 741 237	15 983 867 958	0

Internal Rate of Return : 7.31%

Figure A.4 Cash flow graph for Scenario 4

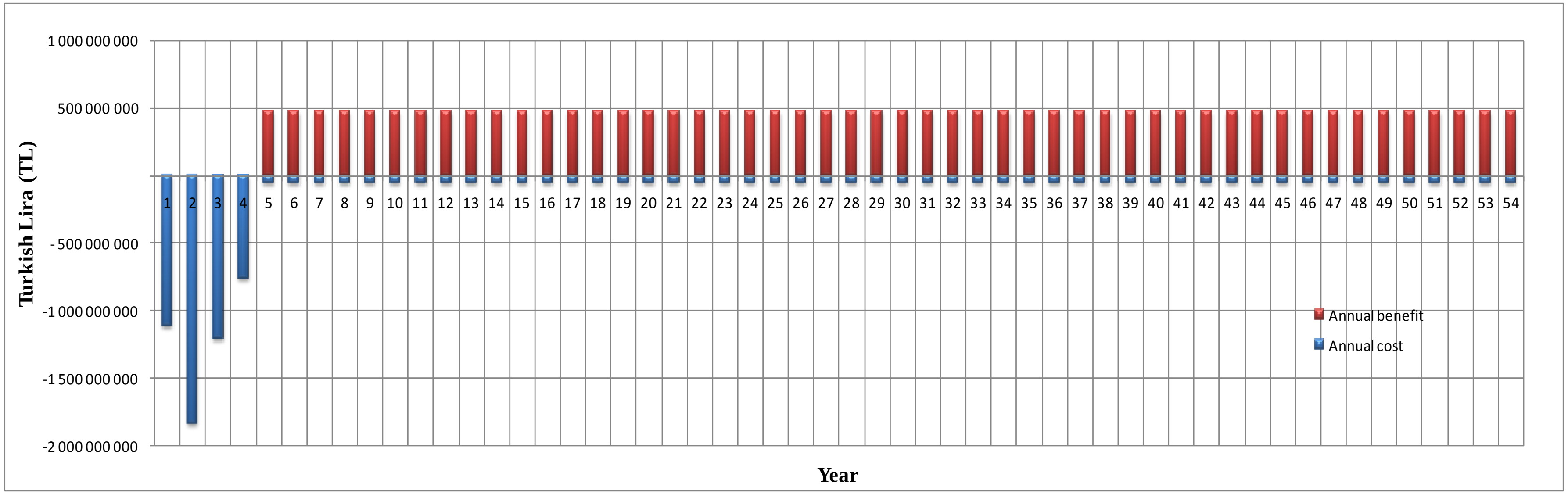


Table A.5 Internal rate of return for Scenario 5

Internal Rate of Return				
Year	Costs	Benefits	Net Benefit	Net Present Value
1	1 116 861 429		-1 116 861 429	-1 078 127 131
2	1 836 796 576		-1 836 796 576	-1 652 239 909
3	1 209 117 607		-1 209 117 607	-1 013 495 808
4	758 246 723		- 758 246 723	- 592 250 340
5	57 997 019	476 323 025	418 326 006	304 474 555
6	57 997 019	476 323 025	418 326 006	283 721 580
7	57 997 019	476 323 025	418 326 006	264 383 127
8	57 997 019	476 323 025	418 326 006	246 362 782
9	57 997 019	476 323 025	418 326 006	229 570 703
10	57 997 019	476 323 025	418 326 006	213 923 171
11	57 997 019	476 323 025	418 326 006	199 342 175
12	57 997 019	476 323 025	418 326 006	185 755 019
13	57 997 019	476 323 025	418 326 006	173 093 963
14	57 997 019	476 323 025	418 326 006	161 295 885
15	57 997 019	476 323 025	418 326 006	150 301 962
16	57 997 019	476 323 025	418 326 006	140 057 386
17	57 997 019	476 323 025	418 326 006	130 511 079
18	57 997 019	476 323 025	418 326 006	121 615 448
19	57 997 019	476 323 025	418 326 006	113 326 143
20	57 997 019	476 323 025	418 326 006	105 601 837
21	57 997 019	476 323 025	418 326 006	98 404 020
22	57 997 019	476 323 025	418 326 006	91 696 805
23	57 997 019	476 323 025	418 326 006	85 446 754
24	57 997 019	476 323 025	418 326 006	79 622 706
25	57 997 019	476 323 025	418 326 006	74 195 625
26	57 997 019	476 323 025	418 326 006	69 138 454
27	57 997 019	476 323 025	418 326 006	64 425 979
28	57 997 019	476 323 025	418 326 006	60 034 706
29	57 997 019	476 323 025	418 326 006	55 942 743
30	57 997 019	476 323 025	418 326 006	52 129 687
31	57 997 019	476 323 025	418 326 006	48 576 530
32	57 997 019	476 323 025	418 326 006	45 265 555
33	57 997 019	476 323 025	418 326 006	42 180 256
34	57 997 019	476 323 025	418 326 006	39 305 251
35	57 997 019	476 323 025	418 326 006	36 626 207
36	57 997 019	476 323 025	418 326 006	34 129 766
37	57 997 019	476 323 025	418 326 006	31 803 482
38	57 997 019	476 323 025	418 326 006	29 635 758
39	57 997 019	476 323 025	418 326 006	27 615 786
40	57 997 019	476 323 025	418 326 006	25 733 495
41	57 997 019	476 323 025	418 326 006	23 979 500
42	57 997 019	476 323 025	418 326 006	22 345 059
43	57 997 019	476 323 025	418 326 006	20 822 020
44	57 997 019	476 323 025	418 326 006	19 402 792
45	57 997 019	476 323 025	418 326 006	18 080 298
46	57 997 019	476 323 025	418 326 006	16 847 946
47	57 997 019	476 323 025	418 326 006	15 699 590
48	57 997 019	476 323 025	418 326 006	14 629 507
49	57 997 019	476 323 025	418 326 006	13 632 360
50	57 997 019	476 323 025	418 326 006	12 703 179
51	57 997 019	476 323 025	418 326 006	11 837 331
52	57 997 019	476 323 025	418 326 006	11 030 499
53	57 997 019	476 323 025	418 326 006	10 278 660
54	57 997 019	476 323 025	418 326 006	9 578 067
	7 820 873 279	23 816 151 236	15 995 277 957	0

Internal Rate of Return : 7.31%

Figure A.5 Cash flow graph for Scenario 5

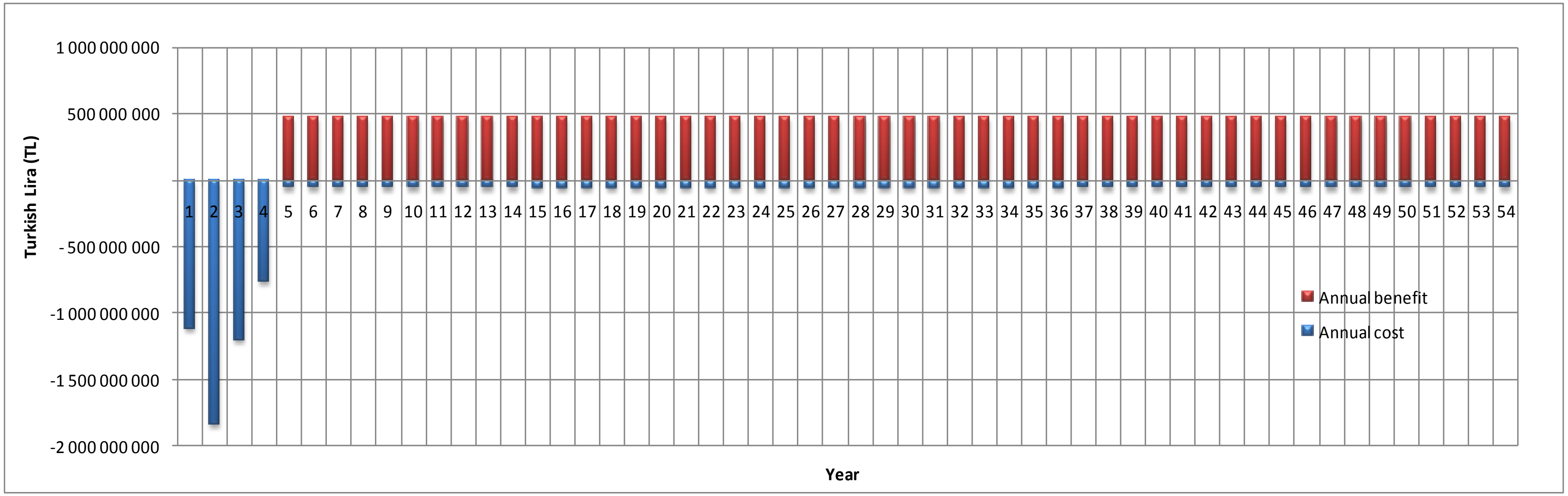


Table A.6 Internal rate of return for Scenario 6

Internal Rate of Return				
Year	**Costs**	**Benefits**	**Net Benefit**	**Net Present Value**
1	1 116 861 429		-1 116 861 429	-1 078 563 033
2	1 836 796 576		-1 836 796 576	-1 654 244 792
3	1 209 117 607		-1 209 117 607	-1 015 546 320
4	758 246 723		- 758 246 723	- 593 928 561
5	57 997 019	471 296 473	413 299 454	301 912 418
6	57 997 019	471 296 473	413 299 454	281 561 619
7	57 997 019	471 296 473	413 299 454	262 582 591
8	57 997 019	471 296 473	413 299 454	244 882 870
9	57 997 019	471 296 473	413 299 454	228 376 221
10	57 997 019	471 296 473	413 299 454	212 982 225
11	57 997 019	471 296 473	413 299 454	198 625 881
12	57 997 019	471 296 473	413 299 454	185 237 245
13	57 997 019	471 296 473	413 299 454	172 751 087
14	57 997 019	471 296 473	413 299 454	161 106 575
15	57 997 019	471 296 473	413 299 454	150 246 977
16	57 997 019	471 296 473	413 299 454	140 119 384
17	57 997 019	471 296 473	413 299 454	130 674 455
18	57 997 019	471 296 473	413 299 454	121 866 173
19	57 997 019	471 296 473	413 299 454	113 651 625
20	57 997 019	471 296 473	413 299 454	105 990 789
21	57 997 019	471 296 473	413 299 454	98 846 342
22	57 997 019	471 296 473	413 299 454	92 183 476
23	57 997 019	471 296 473	413 299 454	85 969 729
24	57 997 019	471 296 473	413 299 454	80 174 827
25	57 997 019	471 296 473	413 299 454	74 770 539
26	57 997 019	471 296 473	413 299 454	69 730 533
27	57 997 019	471 296 473	413 299 454	65 030 256
28	57 997 019	471 296 473	413 299 454	60 646 807
29	57 997 019	471 296 473	413 299 454	56 558 830
30	57 997 019	471 296 473	413 299 454	52 746 408
31	57 997 019	471 296 473	413 299 454	49 190 968
32	57 997 019	471 296 473	413 299 454	45 875 187
33	57 997 019	471 296 473	413 299 454	42 782 910
34	57 997 019	471 296 473	413 299 454	39 899 072
35	57 997 019	471 296 473	413 299 454	37 209 623
36	57 997 019	471 296 473	413 299 454	34 701 460
37	57 997 019	471 296 473	413 299 454	32 362 363
38	57 997 019	471 296 473	413 299 454	30 180 936
39	57 997 019	471 296 473	413 299 454	28 146 551
40	57 997 019	471 296 473	413 299 454	26 249 296
41	57 997 019	471 296 473	413 299 454	24 479 928
42	57 997 019	471 296 473	413 299 454	22 829 827
43	57 997 019	471 296 473	413 299 454	21 290 952
44	57 997 019	471 296 473	413 299 454	19 855 808
45	57 997 019	471 296 473	413 299 454	18 517 401
46	57 997 019	471 296 473	413 299 454	17 269 212
47	57 997 019	471 296 473	413 299 454	16 105 158
48	57 997 019	471 296 473	413 299 454	15 019 569
49	57 997 019	471 296 473	413 299 454	14 007 155
50	57 997 019	471 296 473	413 299 454	13 062 985
51	57 997 019	471 296 473	413 299 454	12 182 457
52	57 997 019	471 296 473	413 299 454	11 361 283
53	57 997 019	471 296 473	413 299 454	10 595 461
54	57 997 019	471 296 473	413 299 454	9 881 260
	7 820 873 279	23 564 823 654	15 743 950 376	0

Internal Rate of Return : 7.23%

Figure A.6 Cash flow graph for Scenario 6

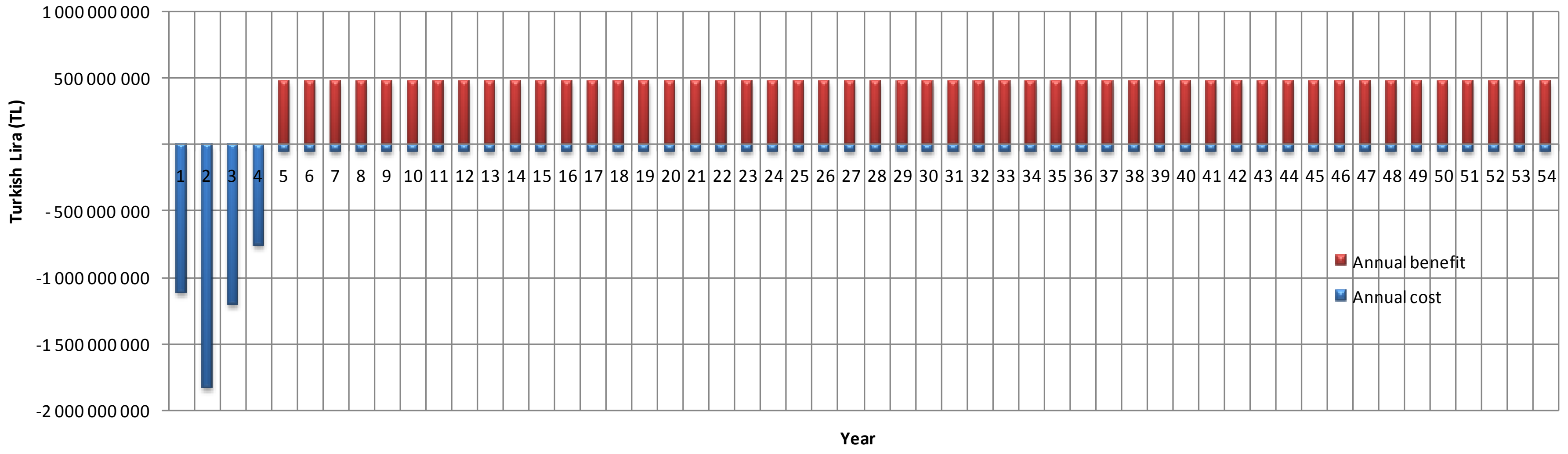


Table A.7 Internal rate of return for Scenario 7

Internal Rate of Return				
Year	**Costs**	**Benefits**	**Net Benefit**	**Net Present Value**
1	1 116 861 429		-1 116 861 429	-1042 178 000
2	1 836 796 576		-1 836 796 576	-1492 412 529
3	1 209 117 607		-1 209 117 607	-855 424 308
4	758 246 723		- 758 246 723	-467 098 853
5	57 997 019	988 449 089	930 452 070	499 088 407
6	57 997 019	988 449 089	930 452 070	434 572 959
7	57 997 019	988 449 089	930 452 070	378 397 201
8	57 997 019	988 449 089	930 452 070	329 483 092
9	57 997 019	988 449 089	930 452 070	286 891 941
10	57 997 019	988 449 089	930 452 070	249 806 403
11	57 997 019	988 449 089	930 452 070	217 514 785
12	57 997 019	988 449 089	930 452 070	189 397 394
13	57 997 019	988 449 089	930 452 070	164 914 642
14	57 997 019	988 449 089	930 452 070	143 596 691
15	57 997 019	988 449 089	930 452 070	125 034 439
16	57 997 019	988 449 089	930 452 070	108 871 666
17	57 997 019	988 449 089	930 452 070	94 798 198
18	57 997 019	988 449 089	930 452 070	82 543 960
19	57 997 019	988 449 089	930 452 070	71 873 785
20	57 997 019	988 449 089	930 452 070	62 582 907
21	57 997 019	988 449 089	930 452 070	54 493 029
22	57 997 019	988 449 089	930 452 070	47 448 902
23	57 997 019	988 449 089	930 452 070	41 315 345
24	57 997 019	988 449 089	930 452 070	35 974 652
25	57 997 019	988 449 089	930 452 070	31 324 332
26	57 997 019	988 449 089	930 452 070	27 275 143
27	57 997 019	988 449 089	930 452 070	23 749 379
28	57 997 019	988 449 089	930 452 070	20 679 378
29	57 997 019	988 449 089	930 452 070	18 006 226
30	57 997 019	988 449 089	930 452 070	15 678 622
31	57 997 019	988 449 089	930 452 070	13 651 901
32	57 997 019	988 449 089	930 452 070	11 887 166
33	57 997 019	988 449 089	930 452 070	10 350 553
34	57 997 019	988 449 089	930 452 070	9 012 572
35	57 997 019	988 449 089	930 452 070	7 847 548
36	57 997 019	988 449 089	930 452 070	6 833 122
37	57 997 019	988 449 089	930 452 070	5 949 828
38	57 997 019	988 449 089	930 452 070	5 180 714
39	57 997 019	988 449 089	930 452 070	4 511 021
40	57 997 019	988 449 089	930 452 070	3 927 897
41	57 997 019	988 449 089	930 452 070	3 420 151
42	57 997 019	988 449 089	930 452 070	2 978 040
43	57 997 019	988 449 089	930 452 070	2 593 079
44	57 997 019	988 449 089	930 452 070	2 257 880
45	57 997 019	988 449 089	930 452 070	1 966 012
46	57 997 019	988 449 089	930 452 070	1 711 872
47	57 997 019	988 449 089	930 452 070	1 490 584
48	57 997 019	988 449 089	930 452 070	1 297 902
49	57 997 019	988 449 089	930 452 070	1 130 126
50	57 997 019	988 449 089	930 452 070	984 039
51	57 997 019	988 449 089	930 452 070	856 836
52	57 997 019	988 449 089	930 452 070	746 075
53	57 997 019	988 449 089	930 452 070	649 633
54	57 997 019	988 449 089	930 452 070	565 657
	7 820 873 279	49 422 454 451	41 601 581 172	0

Internal Rate of Return : 14.85%

Figure A.7 Cash flow graph for Scenario 7

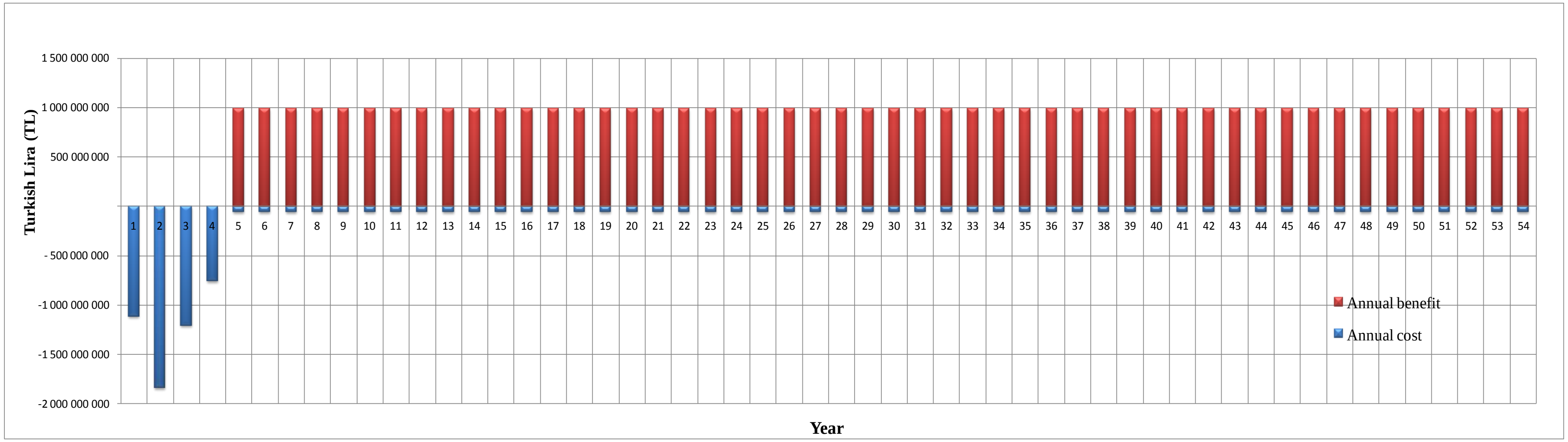


Table A.8 Internal rate of return for Scenario 8

Internal Rate of Return				
Year	**Costs**	**Benefits**	**Net Benefit**	**Net Present Value**
1	1 134 318 429		-1 134 318 429	-1052 931 522
2	1 865 891 576		-1 865 891 576	-1492 388 257
3	1 244 031 607		-1 244 031 607	-857 347 949
4	793 160 723		- 793 160 723	-470 995 956
5	59 933 744	1107 960 564	1048 026 820	536 239 318
6	59 933 744	1107 960 564	1048 026 820	462 049 956
7	59 933 744	1107 960 564	1048 026 820	398 124 783
8	59 933 744	1107 960 564	1048 026 820	343 043 735
9	59 933 744	1107 960 564	1048 026 820	295 583 217
10	59 933 744	1107 960 564	1048 026 820	254 688 920
11	59 933 744	1107 960 564	1048 026 820	219 452 398
12	59 933 744	1107 960 564	1048 026 820	189 090 892
13	59 933 744	1107 960 564	1048 026 820	162 929 937
14	59 933 744	1107 960 564	1048 026 820	140 388 382
15	59 933 744	1107 960 564	1048 026 820	120 965 479
16	59 933 744	1107 960 564	1048 026 820	104 229 758
17	59 933 744	1107 960 564	1048 026 820	89 809 444
18	59 933 744	1107 960 564	1048 026 820	77 384 198
19	59 933 744	1107 960 564	1048 026 820	66 678 000
20	59 933 744	1107 960 564	1048 026 820	57 453 018
21	59 933 744	1107 960 564	1048 026 820	49 504 323
22	59 933 744	1107 960 564	1048 026 820	42 655 340
23	59 933 744	1107 960 564	1048 026 820	36 753 921
24	59 933 744	1107 960 564	1048 026 820	31 668 972
25	59 933 744	1107 960 564	1048 026 820	27 287 531
26	59 933 744	1107 960 564	1048 026 820	23 512 268
27	59 933 744	1107 960 564	1048 026 820	20 259 317
28	59 933 744	1107 960 564	1048 026 820	17 456 416
29	59 933 744	1107 960 564	1048 026 820	15 041 300
30	59 933 744	1107 960 564	1048 026 820	12 960 317
31	59 933 744	1107 960 564	1048 026 820	11 167 242
32	59 933 744	1107 960 564	1048 026 820	9 622 240
33	59 933 744	1107 960 564	1048 026 820	8 290 992
34	59 933 744	1107 960 564	1048 026 820	7 143 923
35	59 933 744	1107 960 564	1048 026 820	6 155 552
36	59 933 744	1107 960 564	1048 026 820	5 303 924
37	59 933 744	1107 960 564	1048 026 820	4 570 120
38	59 933 744	1107 960 564	1048 026 820	3 937 838
39	59 933 744	1107 960 564	1048 026 820	3 393 034
40	59 933 744	1107 960 564	1048 026 820	2 923 603
41	59 933 744	1107 960 564	1048 026 820	2 519 119
42	59 933 744	1107 960 564	1048 026 820	2 170 596
43	59 933 744	1107 960 564	1048 026 820	1 870 291
44	59 933 744	1107 960 564	1048 026 820	1 611 534
45	59 933 744	1107 960 564	1048 026 820	1 388 577
46	59 933 744	1107 960 564	1048 026 820	1 196 465
47	59 933 744	1107 960 564	1048 026 820	1 030 933
48	59 933 744	1107 960 564	1048 026 820	888 302
49	59 933 744	1107 960 564	1048 026 820	765 404
50	59 933 744	1107 960 564	1048 026 820	659 510
51	59 933 744	1107 960 564	1048 026 820	568 266
52	59 933 744	1107 960 564	1048 026 820	489 646
53	59 933 744	1107 960 564	1048 026 820	421 902
54	59 933 744	1107 960 564	1048 026 820	363 532
	8 034 089 535	55 398 028 194	47 363 938 659	0

Internal Rate of Return : 16.06%

Figure A.8 Cash flow graph for Scenario 8

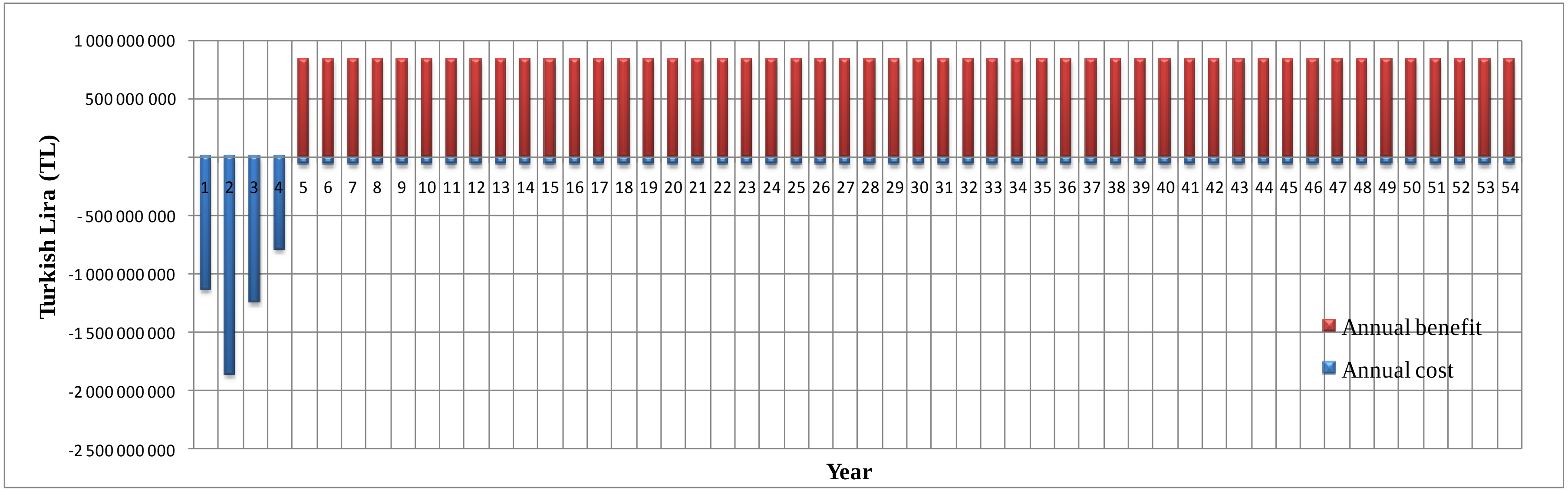


Table A.9 Internal rate of return for Scenario 9

Internal Rate of Return				
Year	Costs	Benefits	Net Benefit	Net Present Value
1	1 132 731 429		-1 132 731 429	-1052 379 704
2	1 863 246 576		-1 863 246 576	-1494 193 596
3	1 240 857 607		-1 240 857 607	-858 913 665
4	789 986 723		- 789 986 723	-471 996 071
5	59 757 678	1089 271 354	1029 513 676	530 935 466
6	59 757 678	1089 271 354	1029 513 676	458 281 961
7	59 757 678	1089 271 354	1029 513 676	395 570 402
8	59 757 678	1089 271 354	1029 513 676	341 440 328
9	59 757 678	1089 271 354	1029 513 676	294 717 443
10	59 757 678	1089 271 354	1029 513 676	254 388 144
11	59 757 678	1089 271 354	1029 513 676	219 577 529
12	59 757 678	1089 271 354	1029 513 676	189 530 417
13	59 757 678	1089 271 354	1029 513 676	163 594 969
14	59 757 678	1089 271 354	1029 513 676	141 208 543
15	59 757 678	1089 271 354	1029 513 676	121 885 487
16	59 757 678	1089 271 354	1029 513 676	105 206 609
17	59 757 678	1089 271 354	1029 513 676	90 810 078
18	59 757 678	1089 271 354	1029 513 676	78 383 576
19	59 757 678	1089 271 354	1029 513 676	67 657 524
20	59 757 678	1089 271 354	1029 513 676	58 399 231
21	59 757 678	1089 271 354	1029 513 676	50 407 847
22	59 757 678	1089 271 354	1029 513 676	43 510 009
23	59 757 678	1089 271 354	1029 513 676	37 556 076
24	59 757 678	1089 271 354	1029 513 676	32 416 881
25	59 757 678	1089 271 354	1029 513 676	27 980 937
26	59 757 678	1089 271 354	1029 513 676	24 152 010
27	59 757 678	1089 271 354	1029 513 676	20 847 036
28	59 757 678	1089 271 354	1029 513 676	17 994 316
29	59 757 678	1089 271 354	1029 513 676	15 531 963
30	59 757 678	1089 271 354	1029 513 676	13 406 561
31	59 757 678	1089 271 354	1029 513 676	11 572 000
32	59 757 678	1089 271 354	1029 513 676	9 988 481
33	59 757 678	1089 271 354	1029 513 676	8 621 651
34	59 757 678	1089 271 354	1029 513 676	7 441 860
35	59 757 678	1089 271 354	1029 513 676	6 423 512
36	59 757 678	1089 271 354	1029 513 676	5 544 515
37	59 757 678	1089 271 354	1029 513 676	4 785 800
38	59 757 678	1089 271 354	1029 513 676	4 130 909
39	59 757 678	1089 271 354	1029 513 676	3 565 633
40	59 757 678	1089 271 354	1029 513 676	3 077 710
41	59 757 678	1089 271 354	1029 513 676	2 656 554
42	59 757 678	1089 271 354	1029 513 676	2 293 030
43	59 757 678	1089 271 354	1029 513 676	1 979 250
44	59 757 678	1089 271 354	1029 513 676	1 708 409
45	59 757 678	1089 271 354	1029 513 676	1 474 629
46	59 757 678	1089 271 354	1029 513 676	1 272 840
47	59 757 678	1089 271 354	1029 513 676	1 098 664
48	59 757 678	1089 271 354	1029 513 676	948 322
49	59 757 678	1089 271 354	1029 513 676	818 553
50	59 757 678	1089 271 354	1029 513 676	706 542
51	59 757 678	1089 271 354	1029 513 676	609 858
52	59 757 678	1089 271 354	1029 513 676	526 405
53	59 757 678	1089 271 354	1029 513 676	454 371
54	59 757 678	1089 271 354	1029 513 676	392 195
	8 014 706 239	54 463 567 715	46 448 861 477	0

Internal Rate of Return : 15.85%

Figure A.9 Cash flow graph for Scenario 9

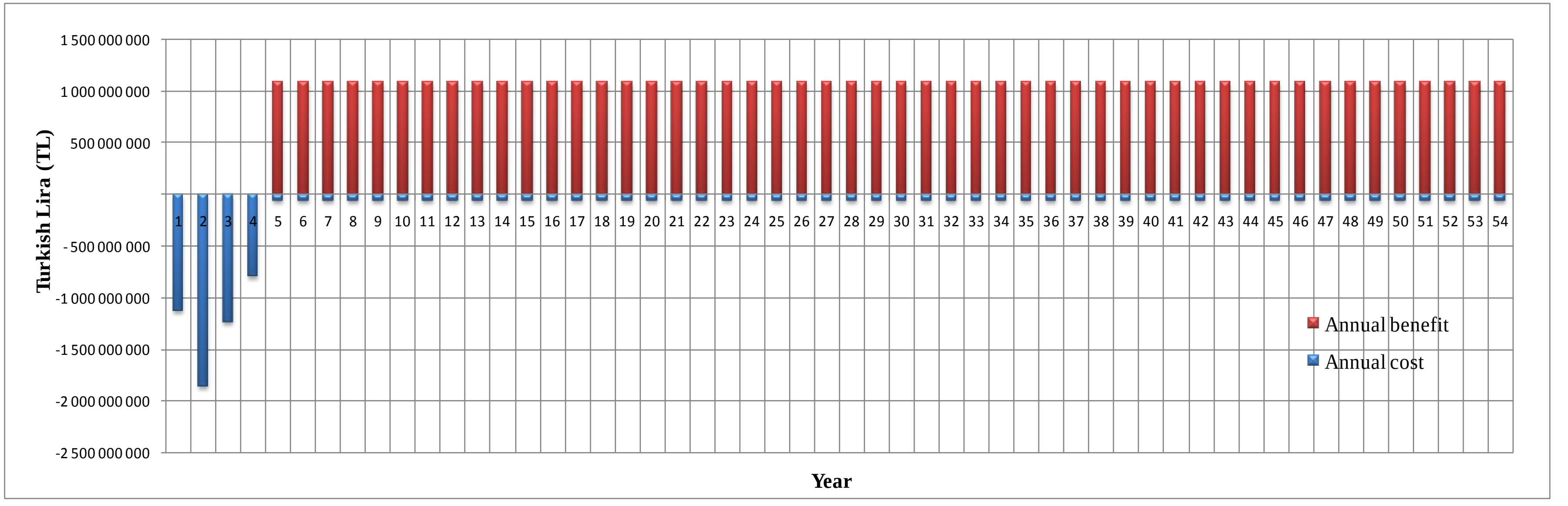
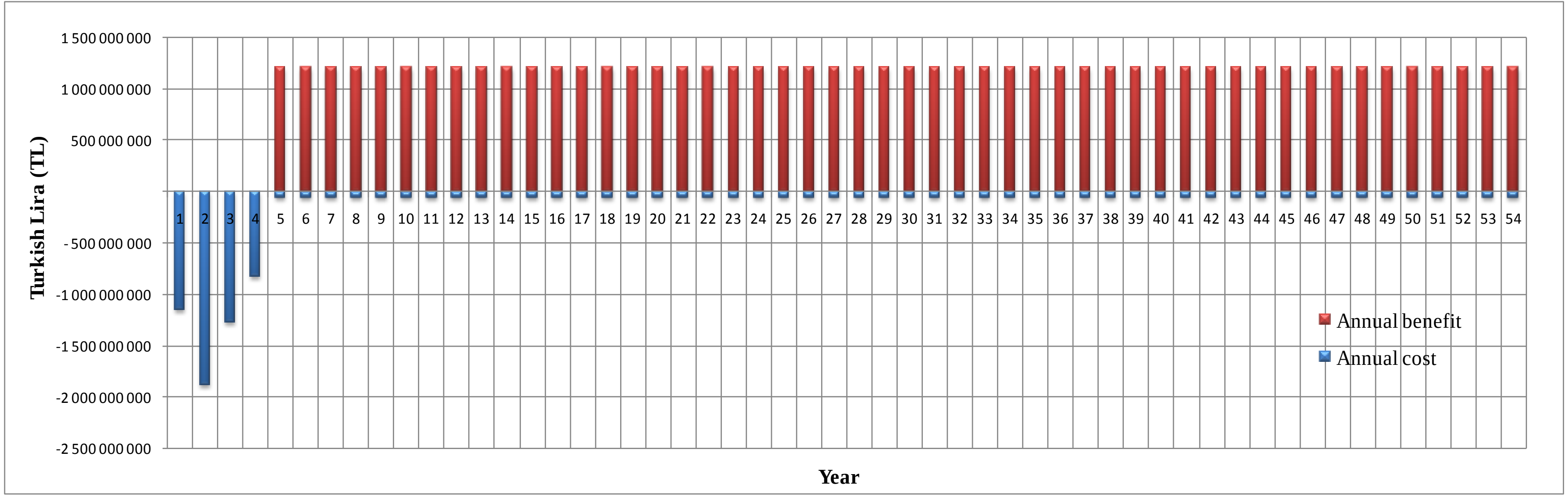


Table A.10 Internal rate of return for Scenario 10

Internal Rate of Return				
Year	**Costs**	**Benefits**	**Net Benefit**	**Net Present Value**
1	1 150 188 429		-1 150 188 429	-1063 045 505
2	1 892 341 576		-1 892 341 576	-1493 991 460
3	1 275 771 607		-1 275 771 607	-860 373 923
4	824 900 723		- 824 900 723	-475 205 779
5	61 694 403	1215 365 043	1153 670 639	567 711 369
6	61 694 403	1215 365 043	1153 670 639	484 945 925
7	61 694 403	1215 365 043	1153 670 639	414 246 681
8	61 694 403	1215 365 043	1153 670 639	353 854 530
9	61 694 403	1215 365 043	1153 670 639	302 266 824
10	61 694 403	1215 365 043	1153 670 639	258 199 980
11	61 694 403	1215 365 043	1153 670 639	220 557 549
12	61 694 403	1215 365 043	1153 670 639	188 402 929
13	61 694 403	1215 365 043	1153 670 639	160 936 063
14	61 694 403	1215 365 043	1153 670 639	137 473 533
15	61 694 403	1215 365 043	1153 670 639	117 431 557
16	61 694 403	1215 365 043	1153 670 639	100 311 457
17	61 694 403	1215 365 043	1153 670 639	85 687 261
18	61 694 403	1215 365 043	1153 670 639	73 195 096
19	61 694 403	1215 365 043	1153 670 639	62 524 137
20	61 694 403	1215 365 043	1153 670 639	53 408 875
21	61 694 403	1215 365 043	1153 670 639	45 622 508
22	61 694 403	1215 365 043	1153 670 639	38 971 298
23	61 694 403	1215 365 043	1153 670 639	33 289 755
24	61 694 403	1215 365 043	1153 670 639	28 436 512
25	61 694 403	1215 365 043	1153 670 639	24 290 813
26	61 694 403	1215 365 043	1153 670 639	20 749 506
27	61 694 403	1215 365 043	1153 670 639	17 724 479
28	61 694 403	1215 365 043	1153 670 639	15 140 465
29	61 694 403	1215 365 043	1153 670 639	12 933 168
30	61 694 403	1215 365 043	1153 670 639	11 047 669
31	61 694 403	1215 365 043	1153 670 639	9 437 053
32	61 694 403	1215 365 043	1153 670 639	8 061 245
33	61 694 403	1215 365 043	1153 670 639	6 886 013
34	61 694 403	1215 365 043	1153 670 639	5 882 115
35	61 694 403	1215 365 043	1153 670 639	5 024 574
36	61 694 403	1215 365 043	1153 670 639	4 292 052
37	61 694 403	1215 365 043	1153 670 639	3 666 323
38	61 694 403	1215 365 043	1153 670 639	3 131 817
39	61 694 403	1215 365 043	1153 670 639	2 675 236
40	61 694 403	1215 365 043	1153 670 639	2 285 219
41	61 694 403	1215 365 043	1153 670 639	1 952 062
42	61 694 403	1215 365 043	1153 670 639	1 667 475
43	61 694 403	1215 365 043	1153 670 639	1 424 377
44	61 694 403	1215 365 043	1153 670 639	1 216 720
45	61 694 403	1215 365 043	1153 670 639	1 039 337
46	61 694 403	1215 365 043	1153 670 639	887 814
47	61 694 403	1215 365 043	1153 670 639	758 382
48	61 694 403	1215 365 043	1153 670 639	647 819
49	61 694 403	1215 365 043	1153 670 639	553 375
50	61 694 403	1215 365 043	1153 670 639	472 699
51	61 694 403	1215 365 043	1153 670 639	403 786
52	61 694 403	1215 365 043	1153 670 639	344 919
53	61 694 403	1215 365 043	1153 670 639	294 634
54	61 694 403	1215 365 043	1153 670 639	251 680
	8 227 922 495	60 768 252 133	52 540 329 638	0

Internal Rate of Return : 17.07%

Figure A.10 Cash flow graph for Scenario 10



APPENDIX B

THE CHARACTERISTICS OF RESERVOIRS

Table B.1 The characteristics of Upper Kaleköy Dam

Dam Body	
	Type: roller compacted concrete (RCC)
	Thalweg elevation: 1102.5 m
	Foundation elevation: 1080.0 m
	Crest elevation: 1230.0 m
	Maximum operation water elevation: 1225.0 m
	Minimum operation water elevation: 1210.0 m
	Total volume of the reservoir: 595.3 hm^3
	Minimum volume of the reservoir: 406.2 hm^3
	Active volume: 189.1 hm^3
	Height from thalweg: 127.5 m
	Height from foundation: 150.0 m
Spillway	
	Location: left bank
	Design discharge: 8777 m^3/s
	Type: radial gated
	Number of gates: 4
	Crest elevation of spillway: 1209.5 m
Intake Structure and Penstocks	
	Invert elevation of intake structure: 1190.0 m
	Number of penstocks: 3 + 1
	Diameter of penstocks: 3 x 6.4 m + 1 x 2.2 m
	Length of penstocks: 3 x 165.0 m + 1 x 169.0 m
Power Plant	
	Installed capacity: 600 MW (3 x 193.8 + 1 x18.6)
	Tailwater level: 1102.5 m
	Gross head: 122.5 m
	Net head: 120.1 m

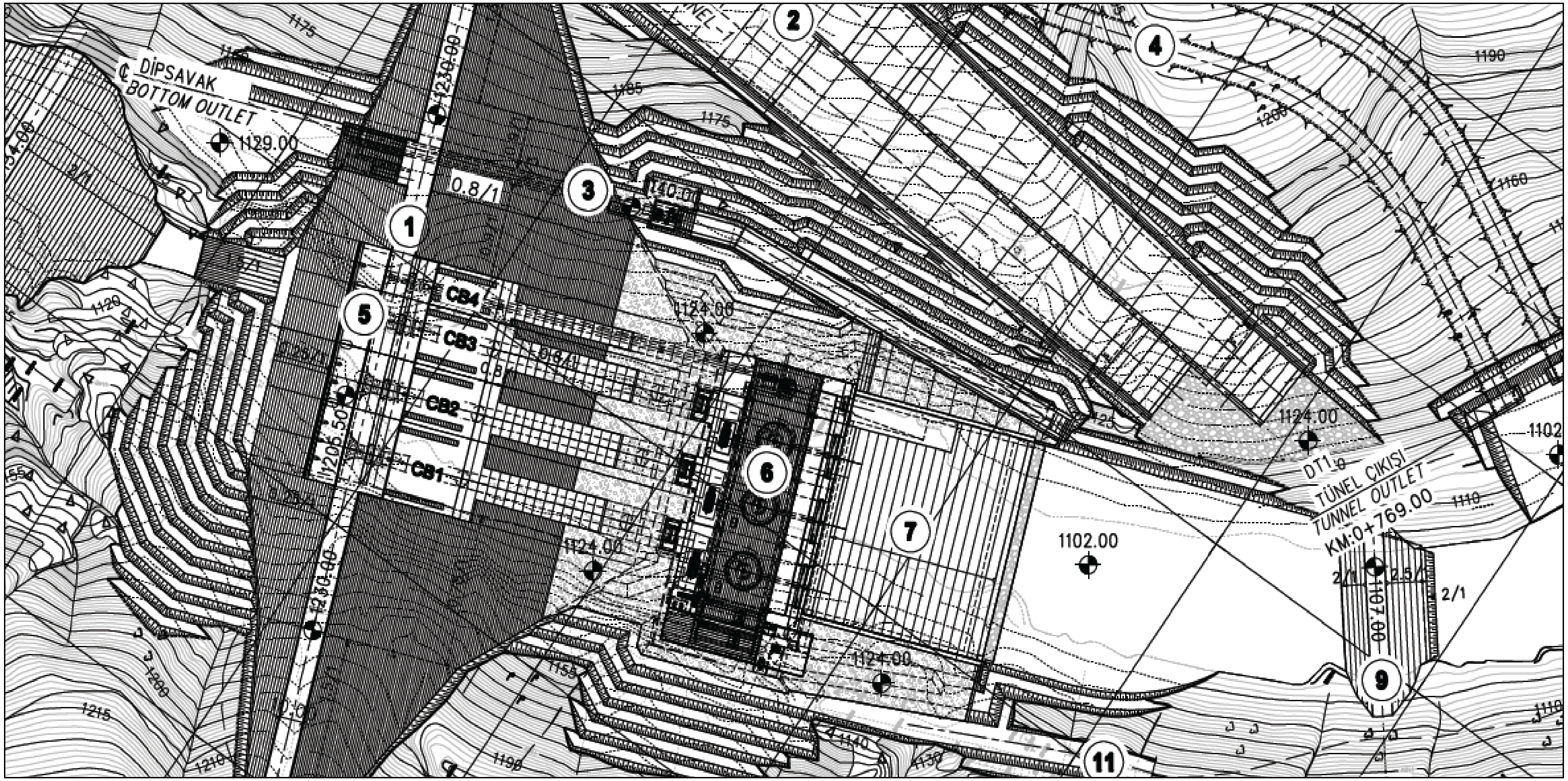


Figure B.1 General plan of Upper Kaleköy Dam and HEPP (Temelsu International Engineering Services Inc., 2011)

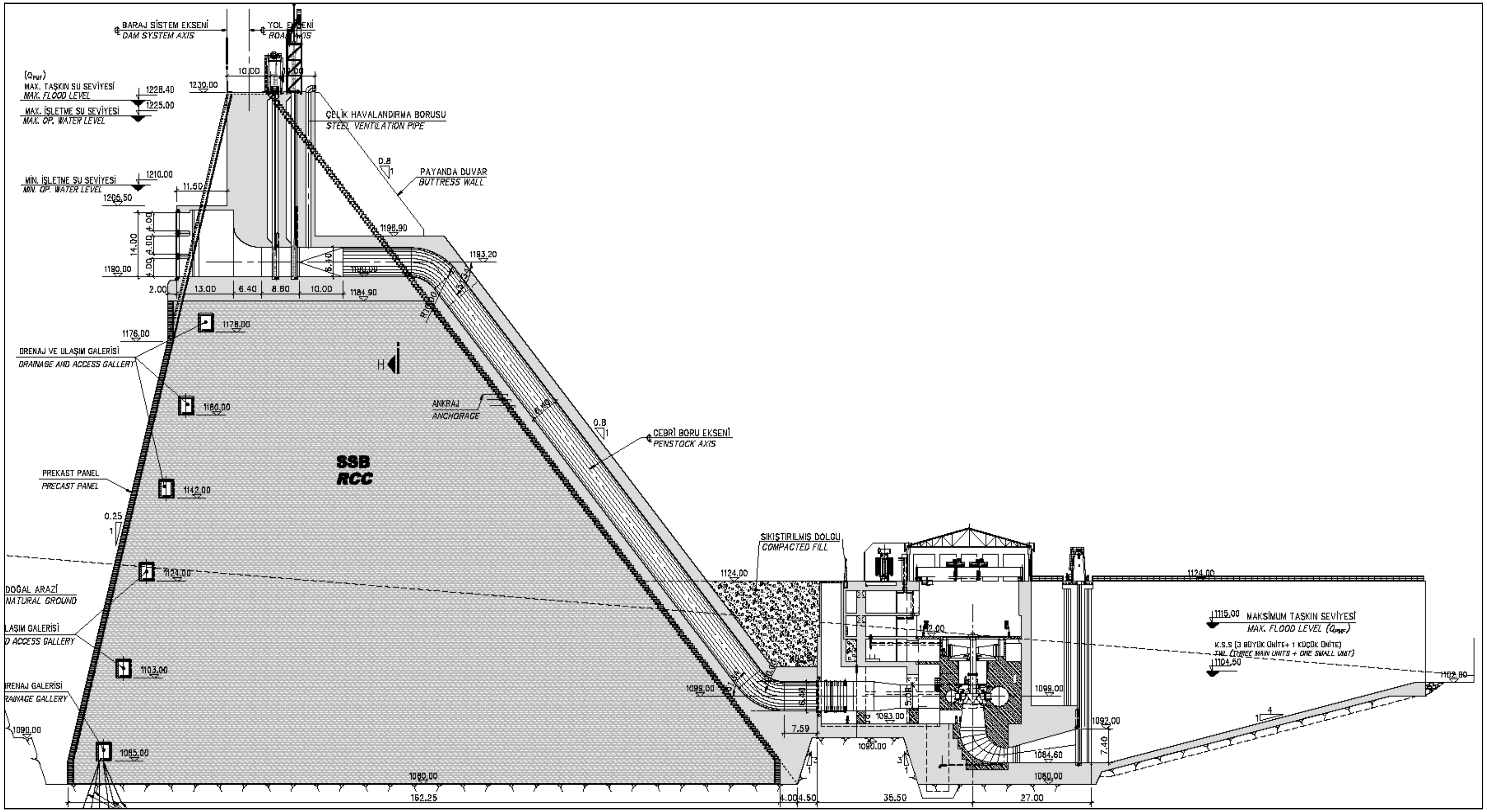


Figure B.2 Typical cross section of Upper Kaleköy Dam and HEPP (Temelsu International Engineering Services Inc., 2011)

Table B.2 The characteristics of Lower Kaleköy Dam

Dam Body
Type: roller compacted concrete (RCC)
Thalweg elevation: 1017.3 m
Foundation elevation: 1005.0 m
Crest elevation: 1107.5 m
Maximum operation water elevation: 1102.5 m
Minimum operation water elevation: 1085.0 m
Total volume of the reservoir: 431.5 hm^3
Minimum volume of the reservoir: 240.1 hm^3
Active volume: 191.4 hm^3
Height from thalweg: 90.2 m
Height from foundation: 102.5 m
Spillway
Location: right bank
Design discharge: 9162 m^3/s
Type: radial gated
Number of gates: 4
Crest elevation of spillway: 1087.0 m
Intake Structure and Penstocks
Invert elevation of intake structure: 1069.0 m
Number of penstocks: 3 + 1
Diameter of penstocks: 3 x 7.0 m + 1 x 2.4 m
Length of penstocks: 3 x 113.0 m + 1 x 117.0 m
Power Plant
Installed capacity: 450 MW
Tailwater level: 1020.0 m
Gross head: 82.5 m
Net head: 81.7 m

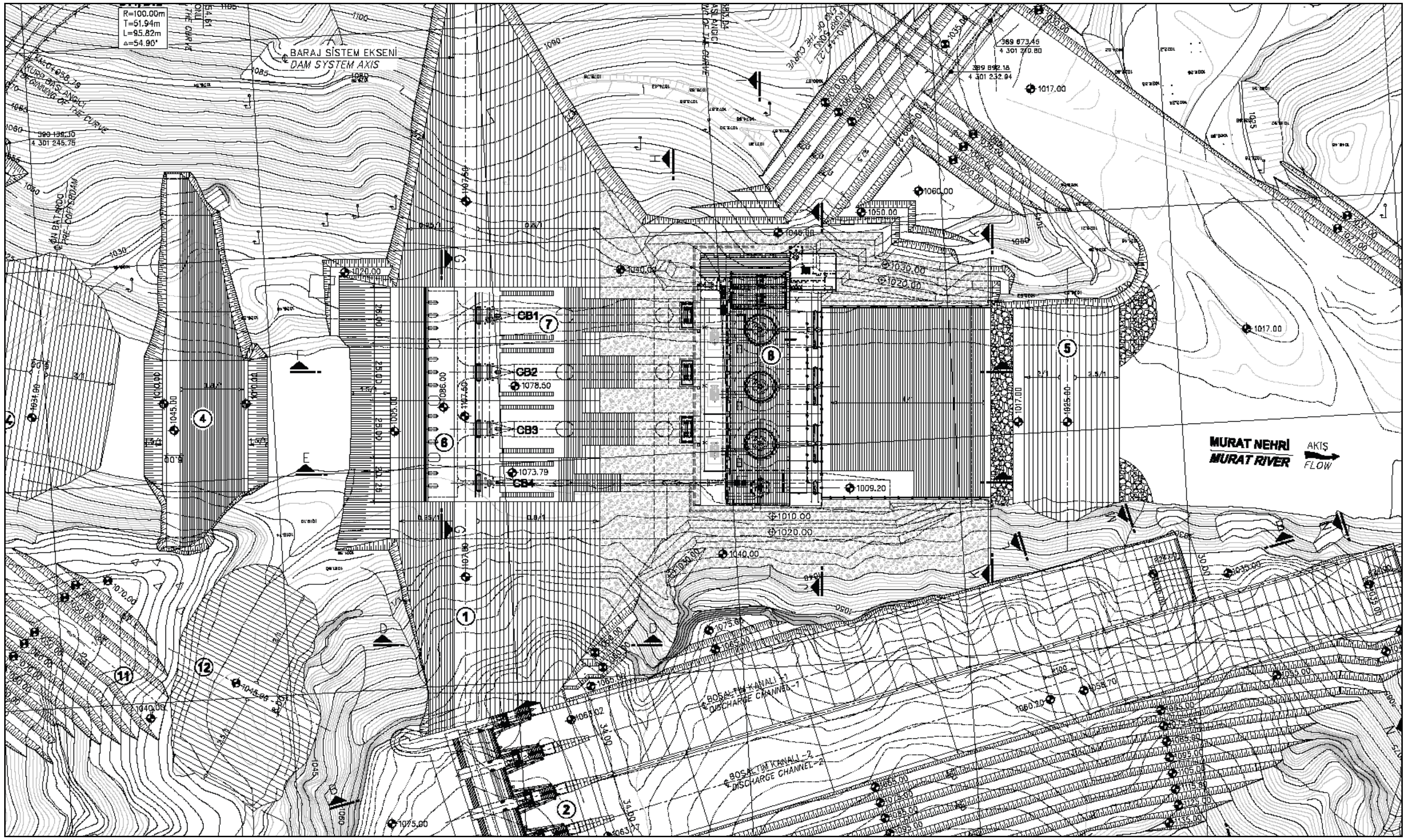


Figure B.3 General plan of Lower Kaleköy Dam and HEPP (Temelsu International Engineering Services Inc., 2011)

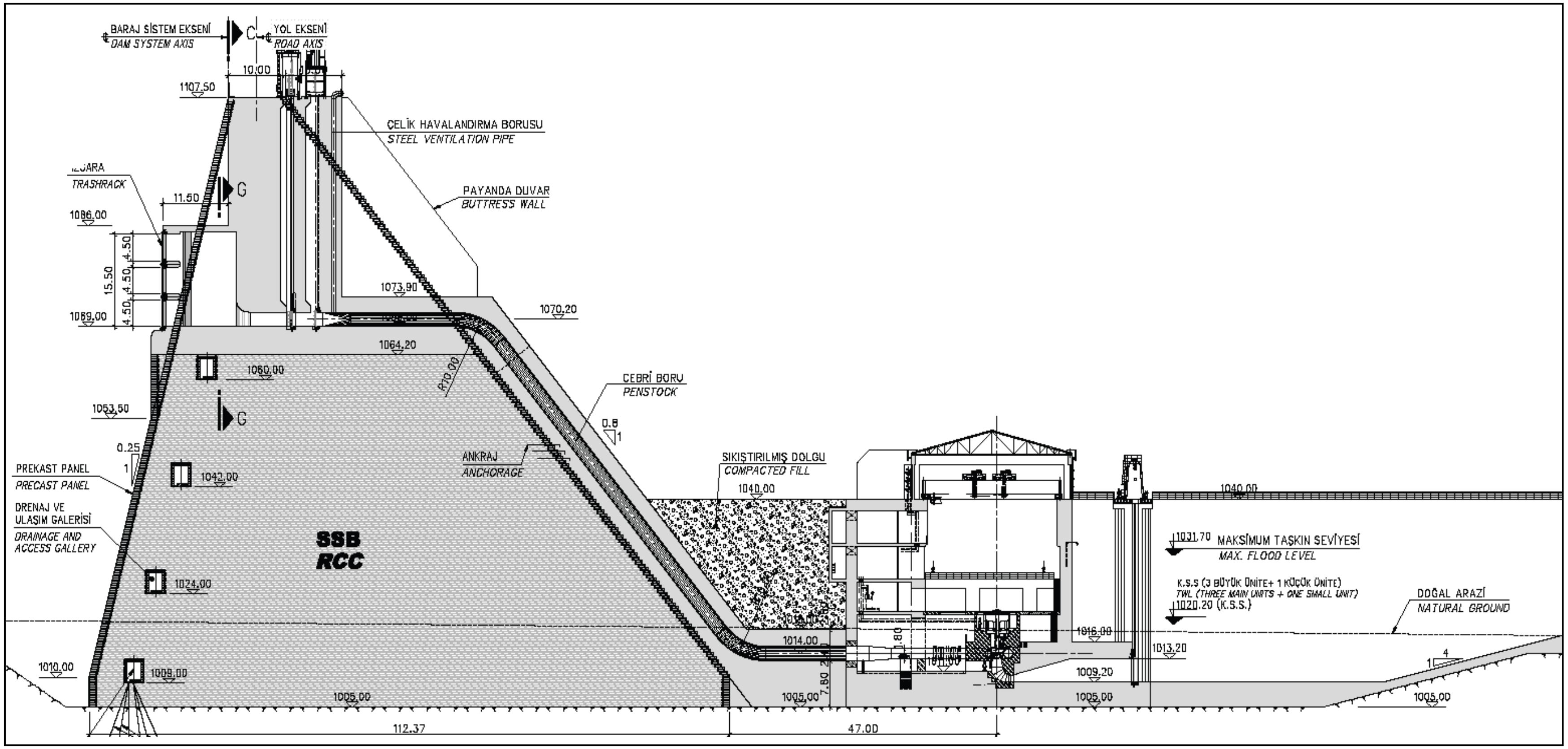


Figure B.4 Typical cross section of Lower Kaleköy Dam and HEPP (Temelsu International Engineering Services Inc., 2011)

Table B.3 The characteristics of Beyhan 1 Dam

Dam Body	
	Type: roller compacted concrete (RCC)
	Thalweg elevation: 903.4 m
	Foundation elevation: 890.0 m
	Crest elevation: 987.0 m
	Maximum operation water elevation: 982.0 m
	Minimum operation water elevation: 977.0 m
	Total volume of the reservoir: 369.06 hm^3
	Minimum volume of the reservoir: 294.64 hm^3
	Active volume: 74.42 hm^3
	Height from thalweg: 83.6 m
	Height from foundation: 97.0 m
Spillway	
	Location: left bank
	Design discharge : 10 528 m^3/s
	Type: radial gated
	Number of gates : 6
	Crest elevation of spillway: 967.0 m
Intake Structure and Penstocks	
	Invert elevation of intake structure at inlet: 962.0 m
	Number of penstocks: 4
	Diameter of penstock: 6.70 m / 4.80 m
	Length of penstock: 4 x 106 m
Power Plant	
	Installed capacity: 400 MW
	Tailwater level: 905.0 m
	Gross head: 77.0 m
	Net head: 76.0 m

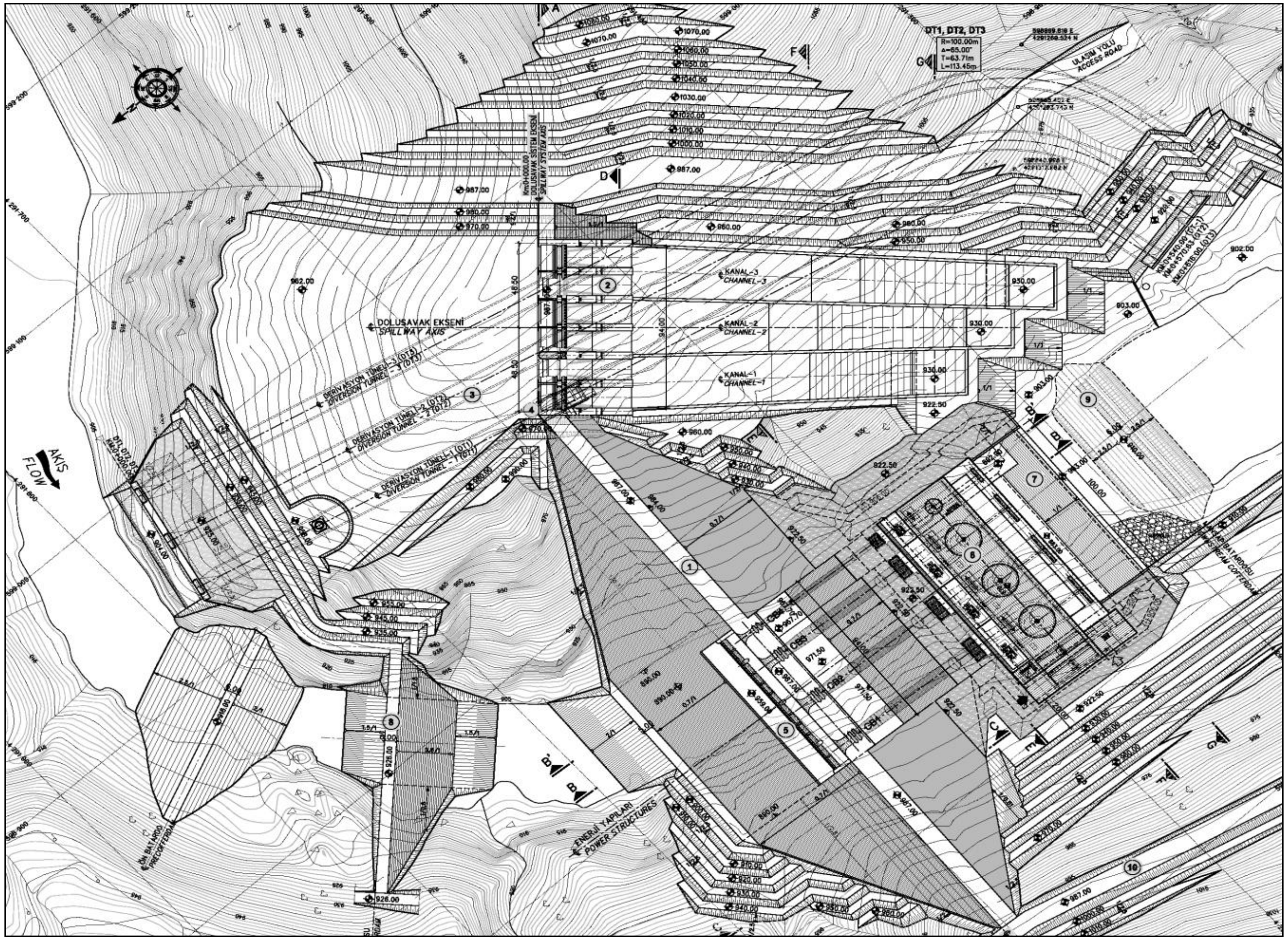


Figure B.5 General plan of Beyhan 1 Dam and HEPP (Temelsu International Engineering Services Inc., 2011)

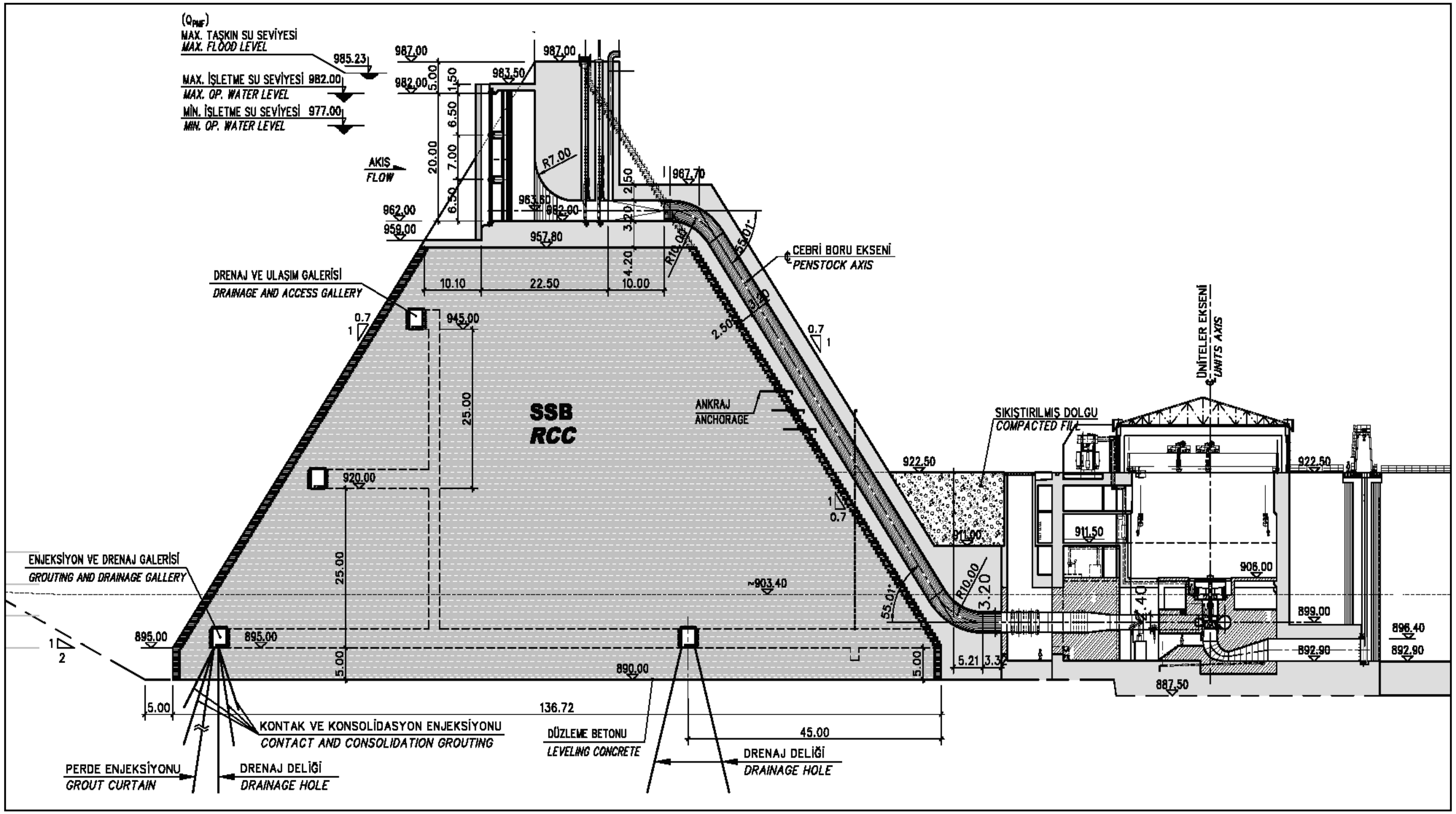


Figure B.6 Typical cross section of Beyhan 1 Dam and HEPP (Temelsu International Engineering Services Inc., 2011)

Table B.4 The characteristics of Beyhan 2 Dam

Dam Body	
	Type : concrete gravity
	Thalweg elevation : 868.2 m
	Foundation elevation : 848.0 m
	Crest elevation : 910.0 m
	Maximum operation water elevation : 905.0 m
	Minimum operation water elevation : 902.0 m
	Total volume of the reservoir : 78.92 hm^3
	Minimum volume of the reservoir : 63.55 hm^3
	Active volume : 15.37 hm^3
	Height from thalweg : 41.8 m
	Height from foundation : 62.0 m
Spillway	
	Location : on dam body
	Design discharge : 10 528 m^3/s
	Type : radial gated
	Number of gates : 6
	Crest elevation of spillway : 890.0 m
Intake Structure and Penstocks	
	Invert elevation of intake structure at inlet : 875.0 m
	Number of penstocks : 3 + 1
	Diameter of penstocks : 3 x 7.8 m + 1 x 3.4 m
	Length of penstocks : 3 x 76.0 m + 1 x 76.0 m
Power Plant	
	Installed capacity : 255 MW
	Tailwater level : 870.0 m
	Gross head : 35.0 m
	Net head : 34.0 m

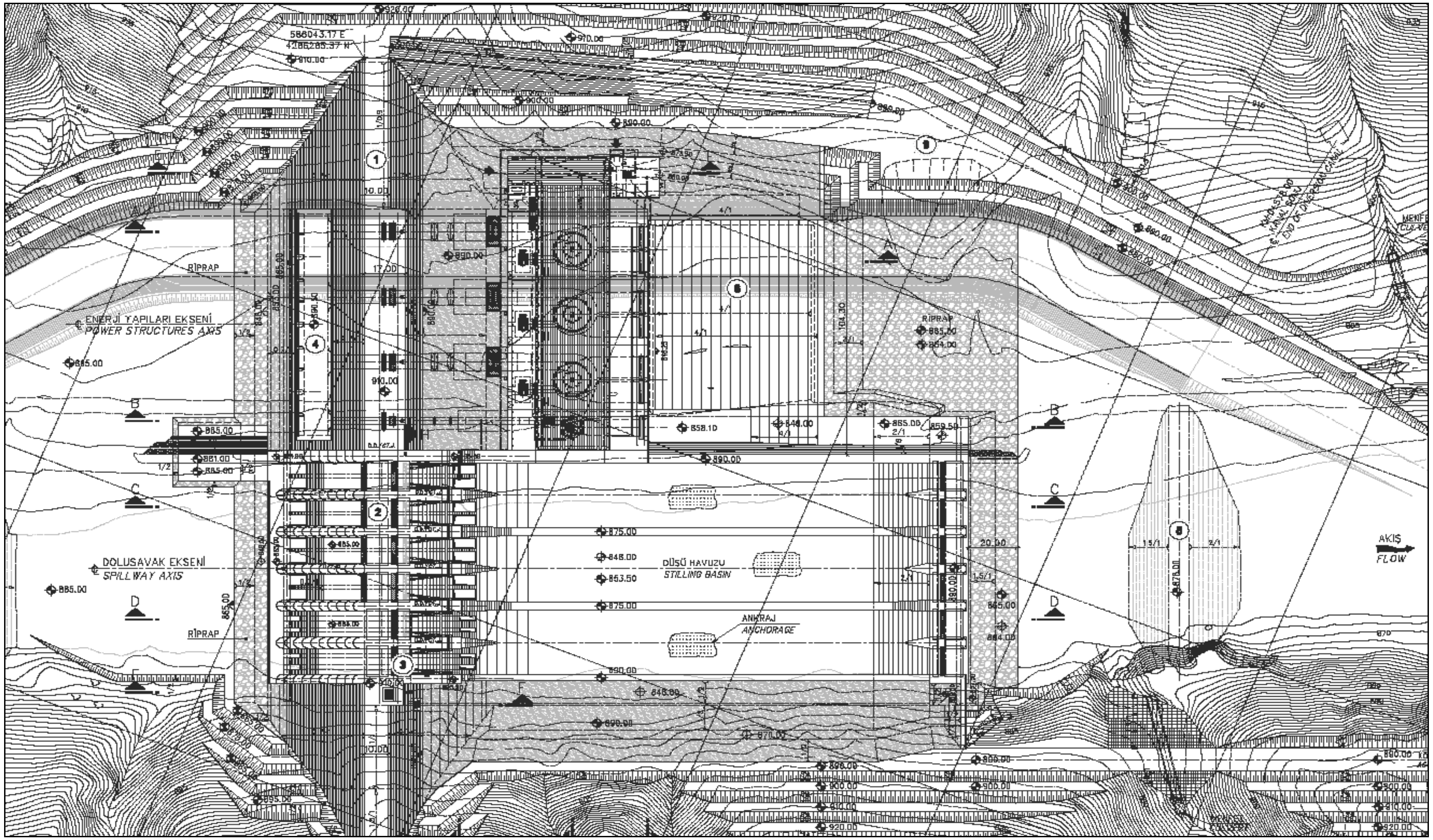


Figure B.7 General plan of Beyhan 2 Dam and HEPP (Temelsu International Engineering Services Inc., 2011)

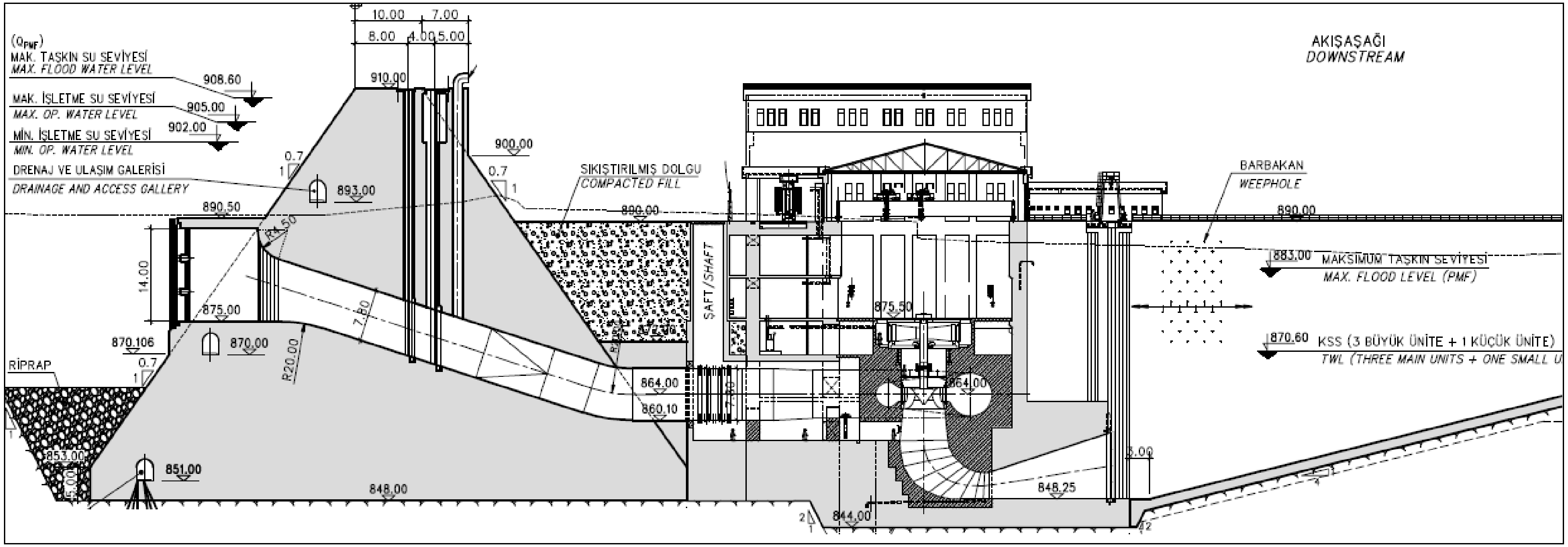


Figure B.8 Typical cross section of Beyhan 2 Dam and HEPP (Temelsu International Engineering Services Inc., 2011)