CAPACITY DETERMINATION OF PUMPED STORAGE PROJECTS USING MARKET ELECTRICITY PRICES

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SEMİH ÇETİNKAYA

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submitted by **SEMİH ÇETİNKAYA** in partial fulfilment of the requirements for the degree of **Master 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. Şahnaz Tiğrek
Supervisor, **Civil Engineering Department, METU** __________________

Examining Committee Members:

Assoc. Prof. Dr. Nuri Merzi
Civil Engineering Department, METU __________________

Assoc. Prof. Dr. Şahnaz Tiğrek
Civil Engineering Department, METU __________________

Prof. Dr. A. Burcu Altan Sakarya
Civil Engineering Department, METU __________________

Assoc. Prof. Dr. Elçin Kentel
Civil Engineering Department, METU __________________

Kerim Orhon M.Sc.
Suiş Proje Eng. and Cons. Ltd. __________________

Date: 27.01.2014

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: Semih ÇETİNKAYA

Signature:

ABSTRACT

CAPACITY DETERMINATION OF PUMPED STORAGE PROJECTS USING MARKET ELECTRICITY PRICES

Çetinkaya, Semih
M.S., Department of Civil Engineering
Supervisor: Assoc. Prof. Dr. Şahnaz Tiğrek

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Renewable and clean energy is gaining more importance after the nuclear disasters with increasing awareness of depletion of fossil fuels, concerns about the global warming and increasing energy demand. However, intermittency of renewable resources is the biggest challenge in the restructuring world energy market. Energy has to be stored against sudden changes in the production and consumption. In order to keep the continuity of the energy supply, pumped storage can be a remedy. Therefore, pumped storage projects have became popular again since 2000s. There are several projects under construction or in planning stages all around the world. In Turkey, there is no pumped storage project under construction or in operation although it has considerably long history of using hydropower. Recently, both the government institutions and the private sector are seriously considering developing pumped storage projects. Therefore, in the present thesis, software which is called PXSC in Microsoft Excel with VBA is developed to assess pumped storage projects by the market electricity prices. The tool consists of both hydraulic and economic analysis.

Keywords: Pumped Hydroelectricity Storage, PHS, Electricity Prices, Electricity Market

ÖZ

POMPAJ DEPOLAMALI SANTRALLERİN KAPASİTESİNİN PİYASA ELEKTRİK FİYATLARIYLA BELİRLENMESİ

Çetinkaya, Semih
Yüksek Lisans, İnşaat Mühendisliği Bölümü
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Fosil yakıtların azıldığının farkına varılması, küresel ısınma ile ilgili kaygılar ve sürekli artan enerji talebiyle birlikte yenilenebilir ve temiz enerji, nükleer kazalardan sonra daha da önem kazanıyor. Fakat, yenilebilir kaynakların kesintili olması yeniden yapılanan dünya enerji piyasının önündeki en büyük engel olarak durmaktadır. Enerjinin, sürekliliğin korunması amacıyla üretimdeki ve tüketimdeki ani değişimlere karşı depolanması gerekir. Bu soruna pompaj depolamalı santraller çare olabilir. Bu nedenle, pompaj depolamalı projeler 2000'li yıllardan itibaren tekrar popüler olmuştur. Halen tüm Dünyada yapım veya planlama aşamasında çeşitli projeler bulunmaktadır. Ancak hidroelektrik kullanımı konusunda yeterince uzun bir tarihçeye sahip olmasına ragmen, Türkiye'de yapım aşamasında ve işletmede hiçbir pompaj depolamalı santral yoktur. Son zamanlarda kamunun ve özel sektörün pompaj depolamalı santraller geliştirmek için ciddi girişimleri bulunmaktadır. Bu nedenle, bu tezde, pompaj depolamalı projeleri piyasa elektrik fiyatlarıyla değerlendirmek amacıyla Microsoft Excel'de VBA kullanarak PXSC yazılımı geliştirilmiştir. Geliştirilen bu yazılım hem hidrolik hem de ekonomik analiz yapabilmektedir.

Anahtar Kelimeler: Pompaj Depolamalı Hidroelektrik Santraller, PHES, Elektrik Fiyatları, Elektrik Piyasası

To my beloved Family and
the Love of My Life

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For the last four years I have felt the constant support of Üründül Group. That's why I want to thank them one more time for their patience and support.

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LIST OF ABBREVIATIONS

ASM	: Ancillary Service Market
BCM	: Bilateral Contract Market
BCR	: Benefit Cost Ratio
BIST	: İstanbul Stock Exchange
BO	: Build-Operate
BOT	: Build-Operate-Transfer
BOTAŞ	: Petroleum Pipeline Corporation
BPM	: Balancing Power Market
BSR	: Balancing and Settlement Regulation
CAES	: Compressed Air Energy Storage
CBA	: Cost - Benefit Analysis
CBRT	: Central Bank of Republic of Turkey
CFRD	: Concrete Face Rock Fill Dam
DAM	: Day-Ahead Market
DAP	: Day-Ahead Price (TL/MWh)
DOE	: US Department of Energy
EAC	: The Electricity Advisory Committee
EAC	: Equivalent Annual Annuity
ECRD	: Earth Core Rock Fill Dam
EIA	: U.S. Energy Information Administration
EİE	: General Directorate of Electric Power Resources Survey and Development Administration
EMRA	: Energy Market Regulatory Authority
EPEX	: European Power Exchange
EPİAŞ	: Energy Markets Operations Company
EPRI	: Electric Power Research Institute
EU	: European Union
EÜAŞ	: Turkish Electricity Generation Company
EWEA	: European Wind Energy Association
F-BSR	: Final Balancing and Settlement Regulation
FERC	: The Federal Energy Regulatory Commission
FRR	: Financial Reconciliation Regulation
GW	: Gigawatt
GWh	: Gigawatt-hour
HEPP	: Hydroelectric Power Plant
IDM	: Intra-Day Market
IEA	: International Energy Agency
IRR	: Internal Rate of Return
JICA	: Japan International Cooperation Agency
kW	: kilowatt (1000 Watt)
kWh	: kilowatt-hour

LS	: Load Shedding
MENR	: Ministry of Energy and Natural Resources
MFRC	: Market Financial Reconciliation Center
MW	: megawatt (10^6 Watt)
MWh	: megawatt-hour
NGPP	: Natural Gas Power Plant
NLDC	: National Load Despatch Centre
NPP	: Nuclear Power Plant
NPV	: Net Present Value
OECD	: Organisation for Economic Co-operation and Development
ÖİB	: Privatization Administration
PHS	: Pumped Hydropower Storage
PPB	: Peak Power Benefit
PV	: Photovoltaic
RCC	: Roller Compacted Concrete
RES	: Renewable Energy Sources
SDAP	: System Day-Ahead Price
SIP	: System Imbalance Price
SMES	: Superconducting Magnetic Energy Storage
SMP	: System Marginal Price (TL/MWh)
SPK	: Capital Markets Board
T-BSR	: Temporary BSR
TEDAŞ	: Turkish Electricity Distribution Company
TEİAŞ	: Turkish Electricity Transmission Company
TEK	: Turkish Electricity Authority
TETAŞ	: Turkish Electricity Trading and Contracting Company
TOR	: Transfer of Operational Rights
TW	: Terawatt (10^{12}Watt)
TWh	: Terawatt-hour
USA	: United States of America
WPP	: Wind Power Plant
YEK	: Renewable Energy Law

LIST OF SYMBOLS

AMORF	: amortization factor
CC	: construction cost
D_t	: length of penstock
EC	: estimated cost
EP	: electricity price
E_P	: energy pumping
E_T	: energy turbining
H_g	: gross head
h_{net}	: net head
h_p	: head loss in penstock
h_t	: head loss in tunnel
IC	: investment cost
L_p	: length of penstock
L_t	: length of tunnel
L_{trans}	: length of transmission line
L_u	: tunnel length penalty (km)
n	: manning roughness coefficient
N	: number of tunnel or penstock
n_p	: number of penstock
n_t	: number of tunnel
OMF	: operation and maintenance factor
P	: installed generation capacity
PC	: project cost
P_p	: installed pumping capacity
Q	: generation discharge
Q_p	: pumping discharge
RF	: renewal factor
s	: slope
v_{max}	: maximum velocity
y	: investment period
η_g	: generation efficiency
η_p	: pumping efficiency

CHAPTER 1

INTRODUCTION

1.1. General

Energy continues to be a key element to the worldwide development. Due to the depletion of fossil fuel resources, rising fossil fuel costs, global warming and local pollution, and growth in energy demand; renewable energies have become much more important than at any time in history (Kousksou, et al., 2013) and (Brown, Lopes, & Matos, 2008). However, most importantly intermittency of resources will bring new challenges. Renewable energy resources cannot produce power steadily, since their power production rates change with seasons, months, days, hours, etc. Energy storage especially pumped hydroelectricity storage (PHS), which is the oldest kind of largescale energy storage technology, is the best known solution to the problem.

Pumped storage plants consist of two water reservoirs in different altitudes which are connected by a penstock. During off- peak periods, pumps are used to transfer water to the upper reservoir in order to release it to the lower reservoir during peak periods. Pumped storage is also attractive because it is the only renewable energy source (RES) that can be used to balance intermittent resources such as wind and solar. Thus, pumped storage can enable to meet the increasing demand and contribute to reduce greenhouse gas emissions at the same time (Ingram, 2009). Additionally, their operational flexibility and ability to provide rapid response to changes in system demand or spot price of electricity, make it possible to reduce the fuel cost in a vertically integrated market (Kanakasabapathy, 2013).

1.2. Scope of the Study

Pumped storage is popular in the World and becoming attractive in Turkey. However, first it has to be examined in detail according to the electricity market, administrative and infrastructure point of view. The main concern of present study is to evaluate the applicability of pumped storage projects in Turkey by including the prices of the current electricity market. In order to achieve this goal, a program based on Microsoft Excel and Visual Basic is developed to be used as a tool to carry out analysis. Assessments were performed on a case study namely Aslantaş PHS for various alternatives, to see the performance of the program.

In Chapter 2, history and development of pumped hydroelectricity storage are reviewed. Reasons behind the increasing popularity of pumped storage are discussed and current status of pumped storage in worldwide and Turkey is explained.

In Chapter 3, progresses of liberalizing Turkish Electricity Market is summarized from past to present. Current pricing mechanism in Turkey and further developments in electricity market are explained. Additionally, market electricity prices are examined. Effects of electricity production and consumption and response of the electricity market to them and changes in prices are expressed.

In Chapter 4, the program, PXSC which is developed within the concept of the present study for the evaluation of pumped storage projects using real time electricity prices is defined. Theory and procedures are explained in order to make correct usage of PXSC possible.

Chapter 5 is reserved for case studies for evaluation of pumped storage projects using the tool PXSC. Five different scenarios are introduced with different combinations of benefit and cost prices and one of the case results are explained in detailed in order to demonstrate usage of the tool. Discussions about the scenarios show the effect of electricity prices on pumped storage projects.

Finally in Chapter 6, conclusions of the performed study and recommendations for further studies are stated.

CHAPTER 2

PUMPED HYDROELECTRICITY STORAGE

2.1. General

Electricity generation can be summarized under three main titles; thermal power, nuclear power, renewable sources such as hydropower, wind, solar and geothermal. Although there is a strong debate on the classification of the hydropower as renewable, the electricity produced from small scale hydropower structures are widely accepted to be renewable energy (REN21, 2012). Design of pumped storage hydropower plants started after 50 years of hydropower application if the one counts the development of the first water turbine by a French engineer, Bernoit Fourmeyron in 1826 (Hay, 1991) as a milestone. Historical development of machinery can be seen in Appendıx A.

2.2. History of Pumped Storage Hydropower Plants

The first usage of pumped storage is very debatable, however many sources indicate that it was in the 1890s in Italy and Switzerland (IEC, 2011) and (EPRI, 2013). As early as 1890, the town of Zurich, Switzerland connected the local river to a nearby lake with a small pumped storage plant (Andritz Hydro, 2012). The first pumped storage station in Germany was installed in 1908 in the Voith research and development building, the Brunnenmühle in Heidenheim, Germany (Voith, 2011).

Switzerland was one of the first country where pumped storage system had been developed. In 1909 Schaffhausen pumped storage power plant was constructed with an installed capacity of 1500 kW and it is still in operation (Whittingham, 2012) and

(Torres, 2011). Rocky River was the first pumped storage project constructed in the United States. It is on the Housatonic River in Connecticut and was constructed by Connecticut Light and Power Company to provide seasonal storage for the existing 31 MW combined hydroelectric plant which contains one 24 MW conventional unit, two 3.5 MW motor generator units, and two pumps. Its initial operation was in 1929 (The U.S. Army Engineer Institute for Water Resources, 1981). Pumped hydroelectricity storage (PHS) was started to build with the commercial purposes in Europe in 1930s; however, after Second World War actual development was begun (Dursun & Alboyacı, 2010).

When the Rocky-River Pumped storage hydroelectric station was commissioned, the idea of the installed pumps could be operated as turbines to generate electricity at reduced efficiency is discussed but not applied. Meanwhile, in 1937 first reversible pump-turbine with and output of 5.3 MW was utilized in Brasil. In the same time period, development and design improvements of reversible Francis-turbines was going on, and from the 1950s, this has become the standard solution used for almost all new, large scale, pumped storage systems (Coleman, Brennan, Brown, & Cooper, 1976). Other breakthrough in the history of pumped storage was in 1964 which was world's first motor-generator unit (Voith, 2011).

Invention of reversible pump-turbine and motor-generator is very important after those milestones records all over the world. However the limit was reached for those ternary sets in 400 MW and 700 m head in 1990s. The need for bigger and efficient machines is never ended and those researches gave its fruit with the introduction of variable speed pump-turbines. Together with variable speed machines efficiencies and operating ranges are significantly changed. The main advantages of a variable speed pump-turbine are as follows (Alstom, 2010);

- It regulates the amount of energy absorbed in pumping mode. This facilitates energy storage during low power levels on the network thus reduces the number of starts and stops, and allows additional benefits from grid regulation services (network frequency and voltage) while in pumping mode.

- It operates close to the turbines optimal efficiency point, which results in a significant increase in global plant efficiency.
- It operates smoothly (for example at partial load), thus eliminate hydraulic instability and/or cavitations. This results improved reliability, reduced maintenance and increased lifetime.
- It operates over a wider head range therefore the availability of the plant increases.
- It adjusts instantaneous power output in order to help to rectify sudden voltage disruptions/variations caused by network problems.

Finally, the most extraordinary keystone in pumped-storage history was the Okinawa Yanburu Seawater Pumped Storage Power Plant. It has only 30 MW capacities however; the different than other plants it uses Philippines Ocean as its lower reservoir. This milestone power plant put into operation in 1999 and opens a new era in the history of hydroelectricity. Enlightenment of Okinawa a new saltwater pumped-storage plant, Glinsk, has been constructing in Ireland with an installed capacity of 960 MW (Organic Power Ltd, 2011).

2.3. Principles of PHS

Electricity cannot be stored directly, however indirectly it is possible to store it. The principle of pumped storage relays on utilizing gravitational potential to store energy. There are two bodies of water, one is highly elevated than the other, and a system of tunnels and pipes connects them. When demand is low and/or electricity is cheap the plant uses energy to pump water from the lower reservoir to the upper reservoir. When demand is high and/or electricity is more expensive water from the upper reservoir is released back into the lower reservoir through the same system of pipes to generate electricity (see Figure 2-1).

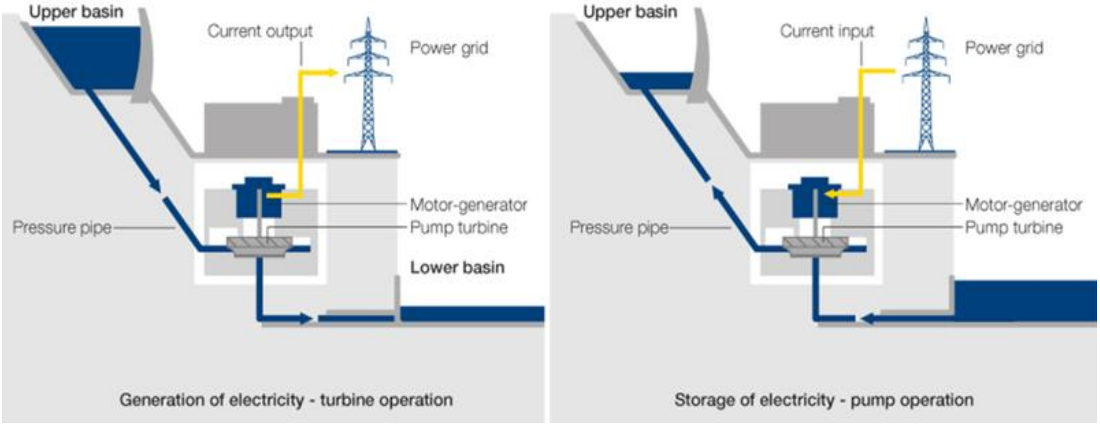


Figure 2-1: Operating Cycle of PHS
(HEA, 2012)

Pumped storage plants are generally used for balancing the electricity demands. Although more electricity is used to force the water uphill at night than production while flowing downhill during the day (Figure 2-2), shifting the availability of power from overnight generation to serve daytime load adds significant value (EIA, 2013). This value called load levelling which decreases the need for energy supply is shown in Figure 2-3. When electric demand is low, operators seek to increase the effective demand by moving power to storage. When demand is high, operators seek to decrease effective demand by using stored energy to generate electricity. Meanwhile they benefit from the high peak prices (EIA, 2013).

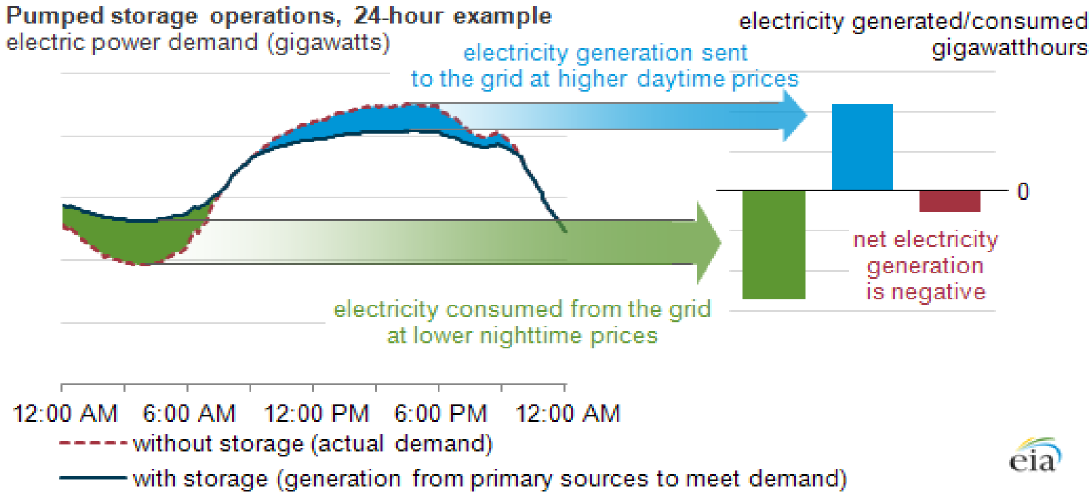


Figure 2-2: Role of PHS on Electricity Power Systems
(EIA, 2013)

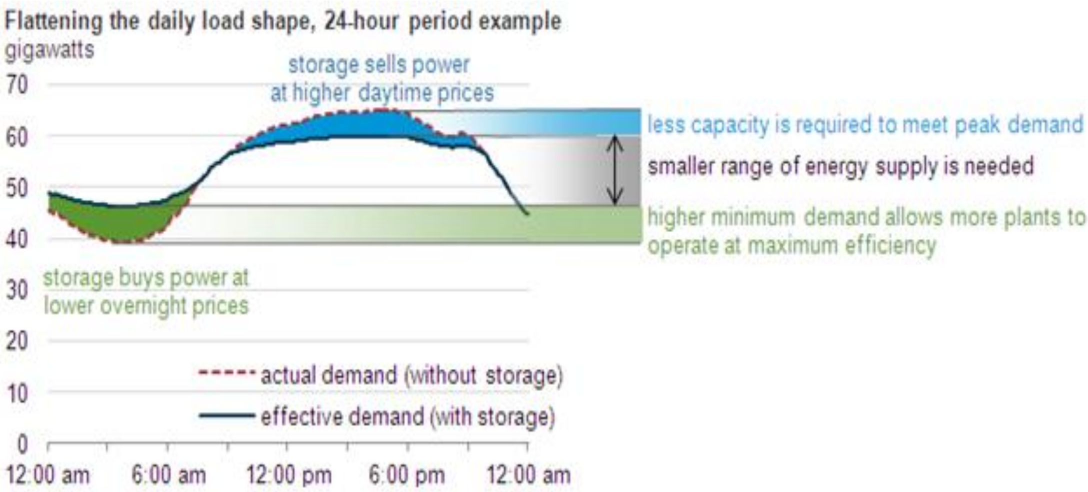


Figure 2-3: Flattening the Daily Load Shape
(EIA, 2013)

2.4. Main Elements of PHS

A hydroelectric pumped storage system consists of two reservoirs, pumps, turbines, motors, generators, penstocks, flow control valves, system controller and auxiliary equipments.

High and Low Reservoirs	Both reservoirs are open tanks that feature an inlet/outlet to a pipe, located on the bottom. The elevation difference between two reservoirs is called head.
Penstocks	There are large diameter steel pipes connecting the reservoirs to the pump and turbine.
Pump	When the system must store energy, pump shaft rotated with the force coming from a motor.
Turbine	The centrifugal turbine converts stored energy to mechanical energy and rotating the shaft, which is connected to the generators.
Generator	The generator converts mechanical energy from the turbine output shaft to electrical energy (nominally as DC, then converted to AC) for the grid.
Motor	The motor converts electrical energy (AC power from the grid) to mechanical energy in order to drive the pump when the system must store energy.
Flow Control Valve	The flow control valve modulates the water flow in turbine and pump mode. It serves as an emergency valve during operation. It is completely open during operation.
System Controller	The system controller decides the operating mode of the system, based on the power plant output and grid demand.
Auxiliary Equipments	Auxiliary equipments such as transformers, AC/DC panels are used for operation and protection of the system.

Nowadays; the numbers of elements are decreased in order to decrease capital cost. Pump, turbine, motor and generator can be arranged in different ways which increases the overall efficiency and make system more compact. The configurations are as follows (Tilahun, 2009):

- System which is composed of four units: motor, generator, pump and turbine which makes power house big in size
- Reversible motor/generator together with pump and turbine configuration has three units
- Reversible motor/generator and reversible pump/turbine systems have two compact components and this decrease the investment cost.

Developments in the machinery do not only decrease the number of units but also increase the round trip efficiencies of the system. Global efficiency of a pumped-storage system is between 75% and 80%. Table 2-1 shows the efficiency of every step in a usual PHS plant.

Table 2-1: Round Trip Efficiency

PHS Cycling Efficiency

	Low %	High %
Generating Components		
Water conductors	97.40	98.50
Pump turbine	91.50	92.00
Generator motor	98.50	99.00
Transformer	99.50	99.70
Subtotal	87.35	89.44
Pumping Components		
Water conductors	97.60	98.50
Pump turbine	91.60	92.50
Generator motor	98.70	99.00
Transformer	99.50	99.80
Subtotal	87.80	90.02
Operational	98.00	99.50
Total	**75.15**	**80.12**

(Compiled from (Zipparro & Hasen, 1993))

2.5. Types of PHS

In the literature pumped hydroelectricity storages is classified according to its structure and operation type (USA Army Corps of Engineers, 1985). Structurally, pumped-hydro storage systems are classified as three types; pure pumped-storage also named as off-stream PHS or closed-loop systems, pumped-back pumped storage and hybrid pumped storage plants. Pure pumped storage plants shift water between two reservoirs one of which is located off-stream and other is river, lake or sea ((USA Army Corps of Engineers, 1985) and (Tilahun, 2009)). The other type of PHS is the pump-back system approach (mixed pumped storage) which is a combination of pumped storage and conventional hydroelectric plants that use natural stream-flow (IEA, 2006).

Hybrid pumped storage systems seems like more conceptual when compared to the other two types. There are many examples of hybrid pumped storage power plant which are associated with wind power plant (WPP) or photovoltaic (PV) solar farms. PHS plants are very dependent on geology and topography like WPP and PV farms. Physically combining PHS and WPP units in the same location can be challenging due to their dependency on the natural conditions. More than often, installed capacity of the wind farm, which is the pump capacity of PHS is directly related with the energy need for pumping ((Büyükyıldız, 2012) and (Sezgin, 2010)). That's why combining those two plants in the same location restrict the total installed capacity. According to its reservoir capacity and operation policy PHS can be classified as daily, weekly and seasonally storage power plants.

At the daily operating plants, electricity is generated during peak hours and water is stored at out off peak hours (see Figure 2-4). In the weekly cycle of water, some portion of the water used in the generation of electricity during peak hours of weekdays, pumped back to the upper reservoir within that day (see Figure 2-5). Except peak hours of weekends water is stored in the upper reservoir, which become empty at the end of the weekdays. On the other hand, seasonally operating PHS' store water while the river flow and energy excess; and in order to increase its firm energy, use reserved water while the river flow is low (see Figure 2-6) (Yorgancılar & Kökçüoğlu, 2009).

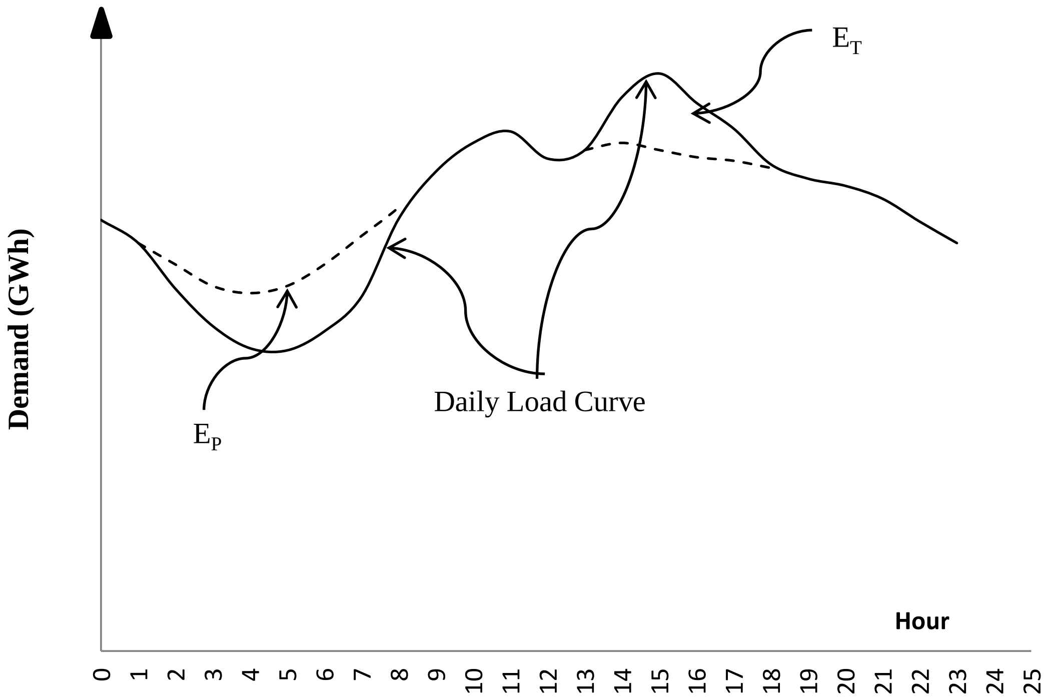


Figure 2-4: Daily Operation of PHS

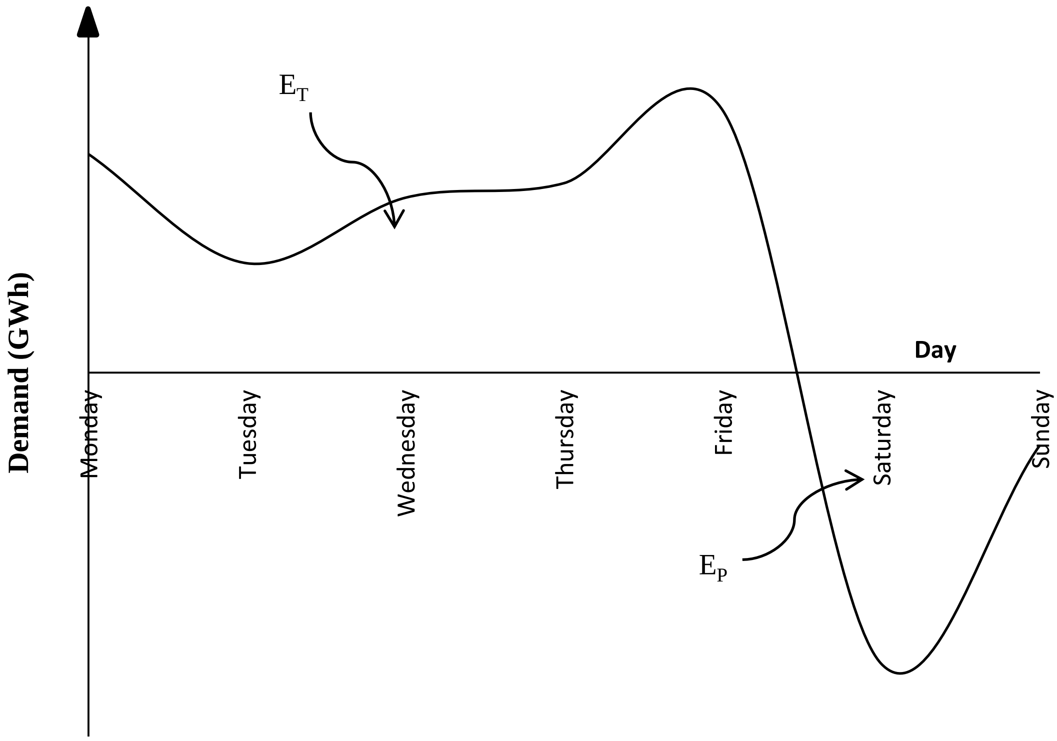


Figure 2-5: Weekly Operation of PHS

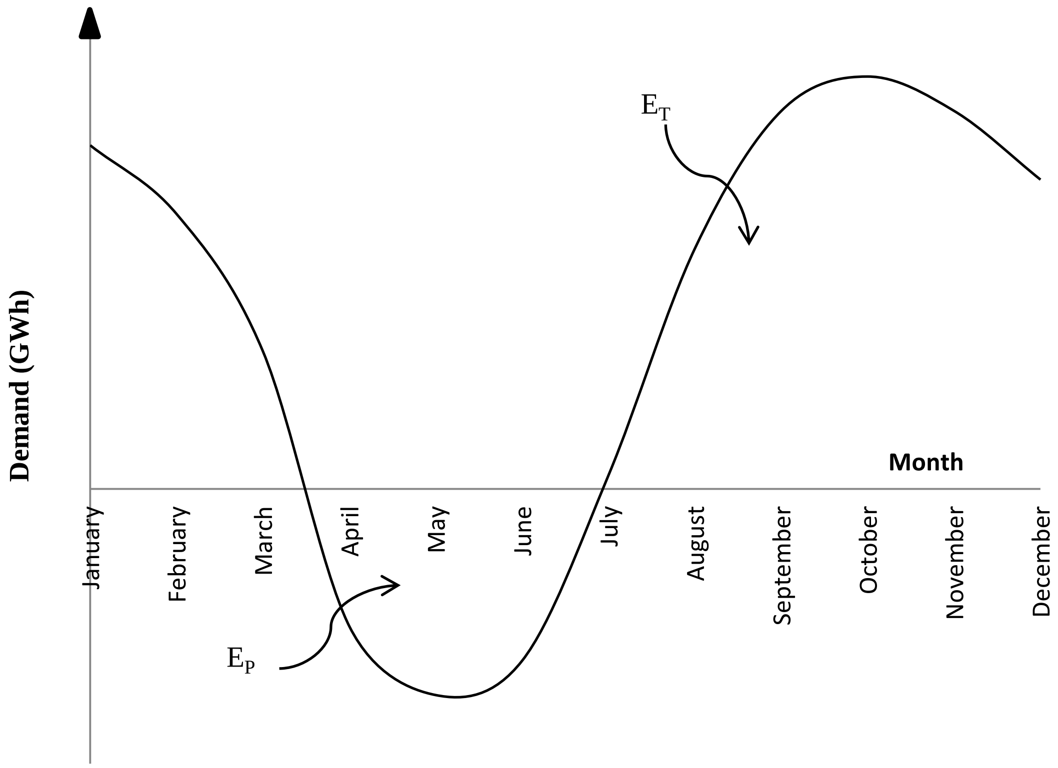


Figure 2-6: Seasonal Operation of PHS

2.6. Advantages and Disadvantages of PHS

2.6.1. Advantages of PHS

Pumped storage plants have the biggest share among other storage technologies so far. Main advantages of PHS are as follows:

Fast Response: Like other hydropower plants, PHS is faster in start up and it takes short time to reach its full generating capacity when compared to the other power plants. Thus, it is possible to balance the varying electricity demand due to consumers and some unplanned outages of other power plants in the grid system (Alstom, 2010).

Load Balancing: Voltage and frequency is very important. Sudden changes in these parameters damage the machines in houses and in the industry. Broken machines mean loss of values for consumer in the houses and loss of production in the industry (Büyükyıldız, 2012).

Black-Start Ability: Other power plants need an external power during start up the system. However, like hydropower plants PHS does not required an external energy to initiate the generation. Thus, network restoration is possible if a power blackout occurs (NHA, 2012).

Energy Storage: Grid energy storage balances electricity supply and demand which ensures stability and reliability in supply.

High global efficiency: Round trip efficiency can vary significantly for different energy storage technologies, depending on number of cycles, and duration of usage. Pumped-hydro storage systems have approximately 80% efficiency and PHS has the highest global cycle efficiency when compared to other storage technologies (Alstom, 2010).

Decrease in Peak Hour Electricity Prices: Pumped storage hydro plant provides the possibility of levelling the price of electricity in the market, by being used in connection with daily peak shaving, load levelling as well as weekly and seasonal variations (Huggins, 2010). PHS can lower electricity costs since it can store electricity bought at low off-peak prices and they can use it during peak periods in the place of expensive power (IEC, 2011).

Decrease Water Wastage: Pure pumped storage plants use the same water several times and prevent water consumption. Seasonally operating PHS facilities are storing excess water during overflow seasons of the river meanwhile prevent flood and store water before reaching to the sea.

Low operation and maintenance cost: PHS has low operation and maintenance cost and these costs are directly related with the electricity prices. Since PHS is used in peak hours, high prices are decreased significantly when pumped storages are in operation.

2.6.2. Disadvantages of PHS

There are several drawbacks of PHS facilities. The negative sides of pumped hydro storage are cost of the overall system and environmental issues which caused by the construction of the power plant, operation of pumps and turbines.

High capital cost: Although the operation and maintenance cost is very low, there is a high upfront capital investment, which can be recouped over long years. Construction of reservoirs, dams and in some cases underground structures are expensive and resource consuming.

Very dependent on location: The two basic requirements for a PHS facility are head and water. Pumped storage systems require not only large volumes of water and but also considerable amount of land with specific type of conditions. (Torres, 2011). Finding suitable place for a PHS is not an easy task that's why building the storage and generation facility may need some improvements in the geology, topography etc. which increase the costs.

Environmental Impacts: Environmental impacts are also serious concerns and have caused many cancellations of proposed PHS projects like other energy projects as well as hydropower. In general, hydropower receives critics due to flooding large areas, destroying terrestrial wildlife habitats and significantly changes the landscape. Blocking natural water flows or change the path of the water disrupt the aquatic ecosystem and effect sediment carrying capacity of the river resulting scouring at the downstream ((IHA, 2003) and (Rosenberg, Bodaly, & Usher, 1995)). Pumping may also increase the water temperature and stir up sediments at the bottom of the reservoirs and deteriorate water quality. PHS operation may also trap and kill fishes (Torres, 2011).

2.7. Status of PHS in the World

Pumped hydroelectric storage is a large, mature, and commercial utility-scale technology currently used at many locations around the world. Electric Power Research Institute (EPRI) announced that the pumped hydro systems are by far the most widely used, there are approximately 127,000 megawatts (MW) installed capacity and 1,500,000 megawatt-hours (MWh) production. Compressed air energy storage (CAES) installations are the next largest with a installed capacity of 440 MW and producing 3,730 MWh energy, followed by sodium-sulphur batteries with an installed capacity of 326 MW and production of 1900 MWh. The remaining are lead acid battery (35 MW and 70 MWh), nickel cadmium battery (27 MW and 6.75 MWh), flywheels (25 MW and 0.4 MWh) and redox flow battery (3 MW and 12 MWh) (EPRI, 2010).

According to U.S. Energy Information Administration (EIA) installed worldwide capacity of pumped storage power plants was reached 120 GW as of 2010. Table 2-2 shows the distribution and increase of the installed capacities in the last two decades on the basis of countries (EIA, 2013). According to the statistics of EIA, by addition of 43.5 GW, total installed capacity was increased 56% in the last 20 years. The biggest portion of that increase belongs to China which has more than 15 GW of PHS. However, enlightenment of 120 years of history in pumped storage European countries owns the many of the PHS plants and the installed capacity in total is more than 46 GW.

Table 2-2: Hydroelectric Pumped Storage Electricity Installed Capacity (MW)

Region	Country	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
North & South America	Canada	183	183	183	183	177	177	177	177	177	177	177	177	177	177	177	177	177	177	177	177
	United States	18,414	21,190	21,146	21,208	21,387	21,110	19,310	19,519	19,565	19,522	19,664	20,371	20,522	20,764	21,347	21,461	21,886	21,858	22,160	22,199
	Argentina	974	974	974	974	974	974	974	974	974	974	974	974	974	974	974	974	974	974	974	974
Europe	Austria	1,753	1,753	1,753	1,769	1,769	1,770	1,770	1,770	1,770	1,770	1,771	1,771	1,771	1,798	1,798	1,798	1,788	1,788	1,861	2,101
	Belgium	1,307	1,307	1,307	1,307	1,307	1,307	1,307	1,307	1,307	1,310	1,310	1,310	1,310	1,310	1,307	1,307	1,307	1,307	1,307	1,307
	Bulgaria	0	0	0	0	0	0	0	0	0	0	0	864	864	864	864	864	864	864	864	864
	Czech Republic	0	0	491	491	491	1,146	1,145	1,145	1,145	1,145	1,145	1,145	1,145	1,145	1,147	1,147	1,147	1,147	1,147	1,147
	France	7,087	7,090	7,088	7,089	7,089	7,074	7,071	7,071	7,168	7,167	7,167	7,182	7,182	7,125	7,125	7,125	7,125	6,985	6,985	6,985
	Germany	4,516	4,576	5,800	4,628	4,528	4,635	4,545	5,857	5,469	4,654	4,562	4,562	4,198	4,198	4,198	4,854	6,552	6,494	6,666	6,784
	Italy	6,386	6,633	6,881	6,881	6,880	6,877	6,886	7,000	7,027	6,957	6,978	6,957	6,957	6,955	7,103	7,544	7,544	7,544	7,544	7,544
	Luxembourg	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
	Norway	1,067	1,067	1,067	1,067	673	672	672	663	663	1,360	1,360	1,309	1,042	1,309	1,327	1,327	1,310	1,351	1,351	1,326
	Poland	1,241	1,366	1,366	1,366	1,366	1,366	1,366	1,366	1,366	1,366	1,366	1,366	1,406	1,406	1,406	1,406	1,406	1,406	1,406	1,406
	Portugal	561	561	561	561	561	561	561	561	597	597	597	597	597	537	537	1,048	1,029	1,029	1,029	1,029
	Spain	4,911	4,911	4,911	4,911	5,095	5,095	5,095	5,095	5,095	5,288	5,288	2,518	2,518	5,347	5,347	5,347	5,347	5,347	5,347	5,347
	Switzerland	1,455	1,455	1,455	1,455	1,455	1,629	1,629	1,629	1,625	1,655	1,655	1,655	1,655	1,655	1,655	1,655	1,636	1,776	1,816	1,817
	United Kingdom	2,787	2,787	2,787	2,788	2,788	2,788	2,788	2,788	2,788	2,788	2,788	2,788	2,788	2,788	2,788	2,726	2,744	2,744	2,744	2,744
Eurasia & Africa	Lithuania	0	0	0	0	0	0	0	0	0	0	0	760	760	760	760	760	760	760	760	760
	Russia	0	0	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
	Morocco	0	0	0	0	0	0	0	0	0	0	0	0	0	464	464	464	464	464	464	464
	South Africa	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
Asia & Oceania	Australia	940	940	940	940	940	940	940	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490
	China	0	0	600	1,200	1,400	1,600	2,000	2,300	3,500	5,000	5,000	5,000	5,000	5,000	5,600	6,200	8,945	10,200	13,700	15,250
	Japan	18,205	18,525	18,945	20,865	22,285	23,185	23,185	23,905	24,305	24,305	24,735	24,706	24,706	24,689	25,159	25,159	25,489	25,489	25,459	25,374
	Korea, South	0	0	0	1,000	1,600	1,600	1,600	1,600	1,600	1,600	2,300	2,300	2,300	2,300	2,300	3,900	3,900	3,900	3,900	3,900
	Taiwan	1,000	1,000	1,000	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602	2,602
	Other	1,323	1,323	2,058	2,058	2,058	2,058	1,724	2,024	1,952	2,036	2,243	2,246	2,248	2,243	2,206	2,813	2,859	2,899	2,886	3,390
	World	**77,224**	**80,755**	**85,627**	**89,657**	**91,739**	**93,480**	**91,661**	**95,157**	**96,499**	**98,077**	**99,486**	**98,964**	**98,526**	**102,214**	**103,995**	**107,848**	**113,045**	**114,295**	**118,339**	**120,681**

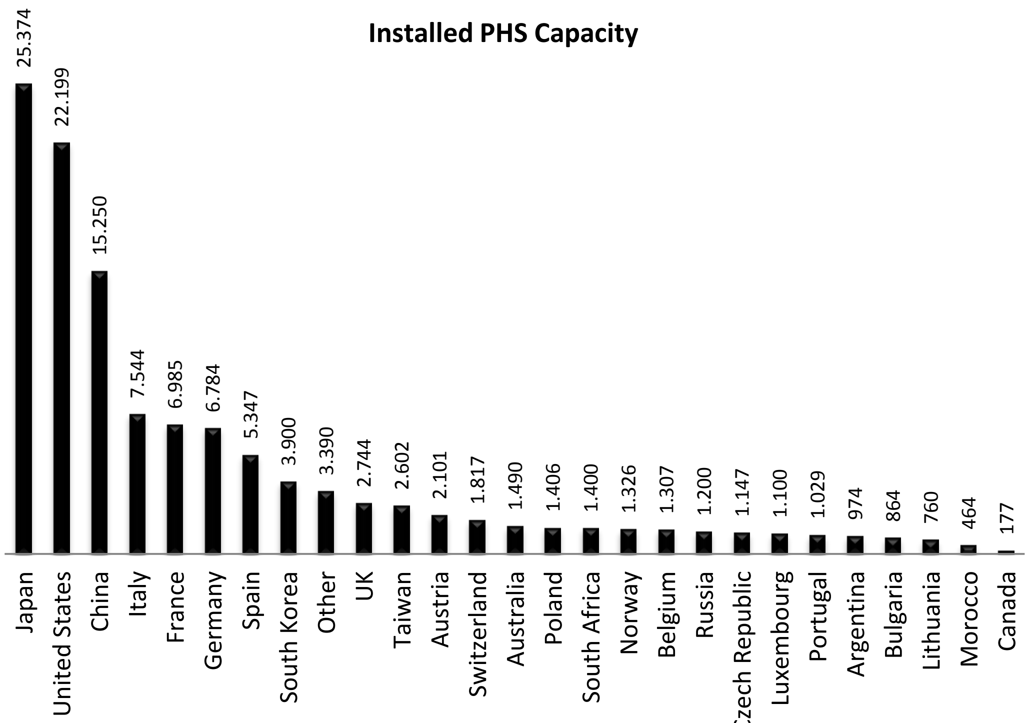


Figure 2-7: Installed PHS Capacity Worldwide

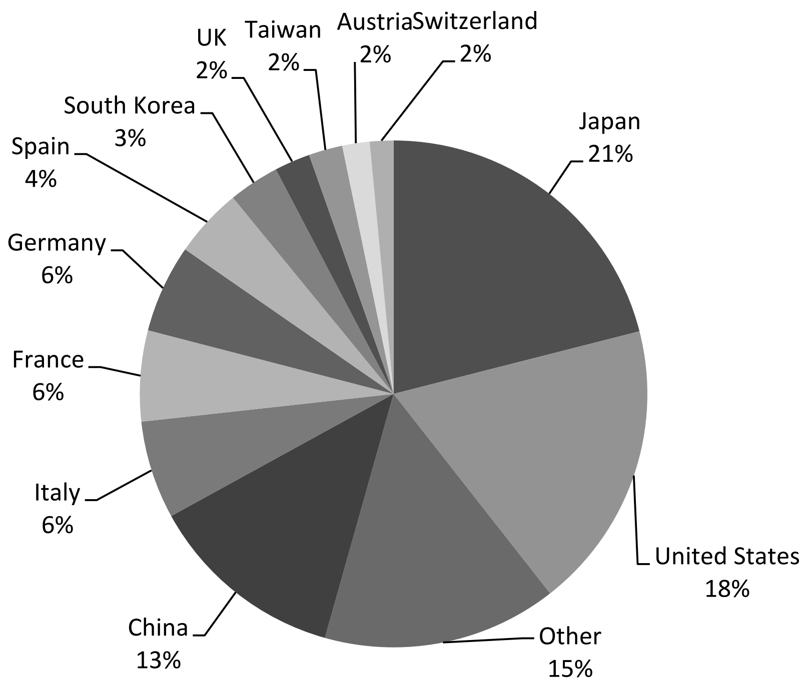


Figure 2-8: Installed PHS Capacity Worldwide

There are only two large-scale (>100 MW) technologies available commercially for grid-tied electricity storage, pumped hydro energy storage and compressed air energy storage. Of the two, PHS is far more widely adopted. Rocky River Station completed in 1929, is the oldest pumped storage plant in the United States (Yang & Jackson, 2011). Today there are 40 PHS stations with a total capacity of approximately 20 GW in USA (Jackson & Yang, 2011). Among those stations, Bath County PHS plant comes online with a capacity of 2100 MW in 1985, which has the biggest generation at that time. However, after revisions in 2004 and 2009 installed capacity increased to 3003 MW and Bath County Pumped Storage Station is the world's most powerful pumped storage generating station located in Virginia USA (Dominion, 2013).

One of the advantages of PHS plants is load balancing and it is key factor in the development of the pumped storage. Between 1970s and 2000s, PHS plants are the main complement of the nuclear power plants (NPP) in USA and Japan due to their fast response ability for peak demands. However, in the last decade, the interest for PHS is raised again because of the increasing capacity of wind power which is highly variable (Deane, Ó Gallachóir, & McKeogh, 2010).

The growth of the PHS in USA was drastically decreased starting from the late 1980s. The reason for the positive and the negative trend is basically market regulations. Growth in the 1970s and 1980s are the regulatory and financial statuses are very favourable for long-term and capital intensive projects such as pumped storage and nuclear power. However in the beginning of 1990s, market was deregulated and support mechanism is disappeared (Adamson, 2009) and (Miller & Winters, 2009). In 1982 US Army Corps of Engineers conducted an extensive research on PHS. According to that report United States is very rich in terms of constructing PHS plants bigger than 1000 MW (The U.S. Army Engineer Institute for Water Resources, 1981). Despite that, the deregulated market together with environmentalist movement wouldn't allow for further development of those huge capacities until last decade.

U.S. Department of Energy (DOE) revealed his goal as meeting 20% of the electricity demand from wind power by the year of 2030, which contributes to 300.000 MW of installed capacity. That huge wind penetration to the grid corresponds to a 50.000 MW of peak demand (Miller & Winters, 2009). This demand occurs when the wind is not blowing and it can only be overcome with pumped storage (Adamson, 2009). According to the data retrieved from U.S. Federal Energy Regulatory Commission (FERC) there are 62 issued preliminary permits which cumulative installed capacities are 46 GW and there are 10 pending preliminary permits which cumulative installed capacities are 8.5 GW (FERC, 2013). Full list of the preliminary and pending permits are listed in Appendıx B.

Currently around 50 GW of PHS’s are in operation throughout Europe, and the region increased investment by new developments. In April 2012, for example, Austria, Germany and Switzerland signed a declaration for the joint development of PHS. Construction of new pumped storage plants is underway across the continent. In 2012, the German state of Thuringia alone identified 13 pumped storage project sites with a total potential of 5.1 GW. In Switzerland, six projects with a total capacity of 4 GW are planned or under construction; for example, the 900 MW Nant de Drance. Austria is developing the 430 MW Reißeck and planning the 300 MW Pfaffenboden project. Portugal is developing 746 MW Venda Nova III. The biggest pumped hydroelectric storage plant construction in Europe is a 1,944 MW project in Ukraine (IHA, 2013).

Europe’s growth in pumped storage is similar to development in United States. There is a rapid growth between 1960 and 1990 (Deane, Ó Gallachóir, & McKeogh, 2010). The slowdown in the development of bulk energy storage was activated after increasing shares of renewable energy from the sources of wind and solar. In Germany importance of PHS facilities was increased, especially after Fukushima accident in 2011. The authorities decided to shut down all the nuclear power plants (NPP). The gap that will occur in the absence of NPP will be filled with renewable sources (Steffen, 2012).

General descriptions for pumped storage in European market are summarized below according to sources (Zuber, 2011) and (Ecoprog, 2011);

- By the year of 2011 there are about 170 PHS operating in Europe and 50 new projects are under construction or being planned.

- 75% of the installed pumped-storage capacity of Europe is concentrated in eight countries; more than 50% of it is in Germany, Italy, Spain and France.

- Oldest pumped-storage plants are in Germany and Switzerland and on average; plants are older than 30 years old.

- In the next 10 years, more pumped-storage plants will be constructed in Europe than in any other decade, both in terms of number and installed capacity. Altogether about 60 plants with an installed capacity of about 27 GW will be built. This represents about 50% of the existing plants.

- Austria and Switzerland both have nearly 5 GW of installed capacity in pumped-storage plants. The capacities of those countries will almost double by the end of 2020. The natural preconditions are perfect for the further expansion of PHS plants. And because the countries are located in the center of Europe, it is attractive for neighbouring countries to invest in PHS.

- In Spain Iberdrola, which is private electricity, generating company is the leader in development. Construction of 1200 MW PHS in Portugal undertaken by Iberdrola. This plant not only increases the capacity of Portugal but also provides peak generation by High Voltage Direct Current (HVDC) transmission lines.

- Scandinavian countries do not need PHS because they already meet their demands from conventional hydro. However, High Voltage Direct Current cables between Germany and Norway enable transfer of electricity from North to South. That’s why there will be some PHS projects on those countries.

- Eastern Europe is less developed compared to the rest of the continent in terms of electricity. However, the most important activity is expected in Romania, which has good hydropower conditions.

- In order to meet the increasing wind capacity of UK, new PHS projects are planning in Scotland. France is not planning to build new large capacity PHS plants.

China is the third biggest PHS capacity in the world with 15 GW of PHS generation capacities. However different then United States, Japan and European countries Chinese development was not completed at 1990s. China is working to expand its electricity generation capacity to sustain its rapid growth. China has the world's richest coal reserves and their generation was based on this. At present China's main electricity production is from coal (KPMG China, 2011) yet it is going to be changed in the near future by the strict policies of Chinese governments. China's goal is to have 20% of its total energy demand sourced from renewable energy by 2020. As a result of this policy, China increased its installed on-grid wind capacity to 68 GW and its solar capacity to 6.2 GW in 2012 and now produces more electricity from wind than from nuclear power. The aim for 2020 is 200 GW of installed wind, 50 GW of solar and 30 GW of biomass (IHA, 2013).

Such as coal reserve, Chinese water power potential is very important. In July 2012, the 22,500 MW Three Gorges complex entered full operation when the last of the 32 turbines were installed. In 2012, Three Gorges is estimated to have generated 14% of China's total hydropower generation. Other major construction is currently on-going at the 13,860 MW Xiluodu, the 6,400 MW Xiangjiaba, and the 5,850 MW Nuozhadu projects. Also Xiangjiaba station owns the world's largest hydropower generating turbines each of 800 MW. Like those mega conventional hydropower projects, China is currently planning a 3,600 MW pumped storage project in Hebei Province, which would be the world's largest (IHA, 2013).

In 2011, China announced its 12th Five Year Plan. After announcement they started construction of 120 GW conventional hydropower and 40 GW PHS plants. By 2015, the conventional hydropower, pumped storage power plant installed capacity will be reach 260 GW and 30 GW (China's State Council, 2013) and (National People's Congress, 2011).

Pumped storage type power plants have been a feature of Japanese electricity systems since 1930. In Japan, which has virtually no indigenous fossil-fuel resources, pumped-storage plants play an important role in stabilizing grids and in improving the efficiency and economics of hydropower generation (Peltier, 2006). Japan meets his demand's 10% from pumped storage with its 25 GW installed capacity. Pumped storage is very important for Japanese electricity system when compared to other countries. Japan has very limited sources in terms of energy that's why NPP correspond very huge portion of its demands. That scarcity in energy sources and huge variation between day and night electricity demands lead Japan to look for other alternatives and innovations in current technologies. Figure 2-9 shows the variation between day and night electricity demands of several countries including Japan (IEC, 2011).

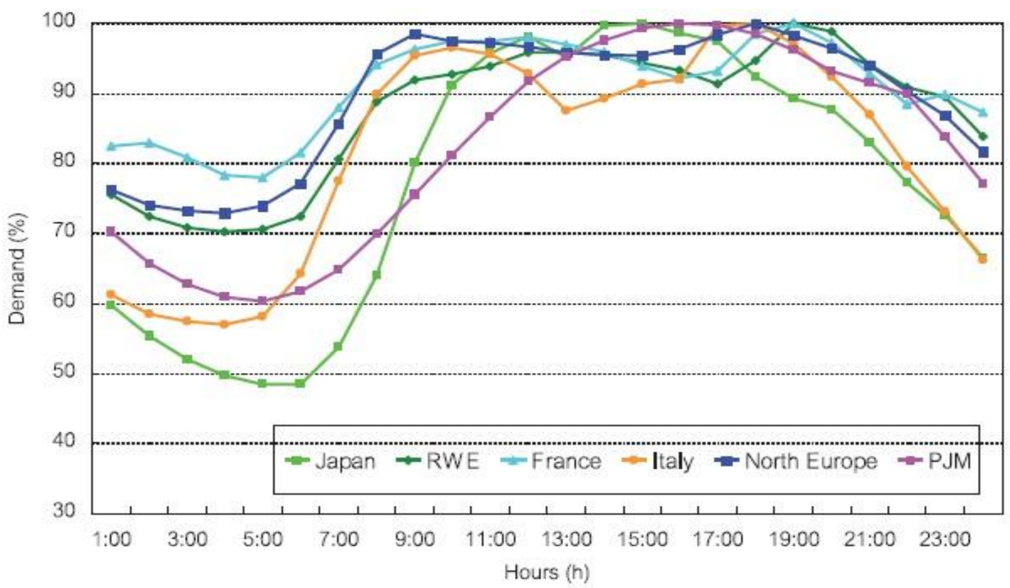


Figure 2-9: Comparison of daily load curves
(IEC, 2011)

The first underground hydraulic power generation facility in Japan was Hokkaido's Uryu power plant completed in 1943. The first underground pumped storage power plant was the Shiroyama power plant completed in 1965. A test pumped storage power plant using seawater has been completed in Okinawa and started to operate in 1998 (Aoki, 2004). Finally, they rewrite the limits of the pump-turbine with innovative design of runner called "high-efficiency/high-head pump-turbine" (Figure 2-10). A new technology, split runner was used in Kazunogawa and Kannagawa PHS plants which have installed capacities respectively 1600 MW and 2820 MW respectively (Peltier, 2006).

Okinawa Seawater Pumped Storage Power Plant (SPHS) is one of the first seawater PHS in the world. In 1981 Agency of Natural Resources and Energy of The Ministry of International Trade and Industry started the program called "Verification tests and investigation for seawater pumped-storage techniques" (Fujihara, Imano, & Oshima, 1998). After the investigations, construction was begun in 1991 and the program realized in March 1999. 30 MW plant went under a five-year period of testing after its first operation and it is inspiring others such as 960 MW Glinsk SPHS plant in Ireland.

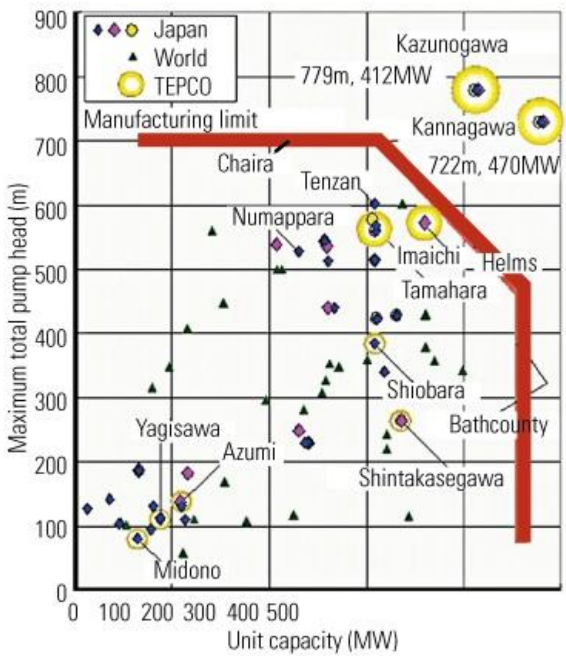


Figure 2-10: Unit Capacity vs. Maximum Pumping Head
(Peltier, 2006)

Penetration of renewable energy sources and increasing environmental suspicions on fossil fuels and nuclear power are key factors for PHS development. The pumped storage market is expected to grow 60% over the next five years, with an average of 7.5 GW of additional pumped storage capacity to be ordered each year. It is expected that 65% of the market to come from China. In Europe, which accounts for approximately 20% of the market, opportunities are mostly focused around the Alpine regions (Switzerland, Austria, Germany), Spain and Portugal (IWP, 2013).

2.8. Status of PHS in Turkey

Turkey has great hydroelectric potential when compared with the countries in Europe and its neighbourhoods. According to the reports prepared by State Hydraulics Works (DSİ) Turkey has 216.000 GWh hydroelectric potential technically and up to now she used approximately 33% of it (DSİ, 2013). However, contrary to that potential, there is no PHS plant in Turkey. Development of pumped storage is parallel to the development of nuclear power and other renewable energy sources (RES) such as solar and wind energy. Since, there is no NPP and the installed capacity of the RES in Turkey is very low absence of the PHS plants is understandable. However, Turkey is planning construction of two NPP projects in Akkuyu and Sinop regions until 2023 and aiming to increase its solar capacity to 3.000 MW and wind capacity to 20.000 MW (TEİAŞ, 2012). That is why importance of the PHS plants in Turkey is increasing every day.

In 2009, Turkish and Japan governments decided to conduct a work named Study on Optimal Power Generation for Peak Demand in Turkey which aims to decide the capacity, year to be ready for operation and conditions of the PHS plants. That study is between the Electric Power Resources Survey and Development Administration (EİE), Turkish Electricity Transmission Company (TEİAŞ) and Tokyo Electric Power Company (TEPCO) in the name of Japan International Cooperation Agency (JICA). The results of the study published to the public in April 2011. According to the results a detailed investigation was conducted on Gökçekaya PHS plant (1400 MW) and Altınkaya PHS plant (1800 MW) (YEGM, 2012).

Other projects which were developed by EİE are listed as below (Yorgancılar & Kökçüoğlu, 2009) and (EİE, 2008).

Table 2-3: List of proposed PHS in Turkey (EİE, 2008)

Project Name	Location	Installed Capacity (MW)	Discharge (m^3/s)	Head (m)
Kargı PHES	Ankara	1000	238	496
Sarıyar PHES	Ankara	1000	270	434
Gökçekaya PHES	Eskişehir	1600	193	962
İznik-I PHES	Bursa	1500	687	255
İznik-ll PHES	Bursa	500	221	263
Yalova PHES	Yalova	500	147	400
Demirköprü PHES	Manisa	300	166	213
Adıgüzel PHES	Denizli	1000	484	242
Burdur Gölü PHES	Burdur	1000	316	370
Eğridir Gölü PHES	Isparta	1000	175	672
Karacaören-ll	Burdur	1000	190	615
Oymapınar PHES	Antalya	500	156	372
Aslantaş PHES	Osmaniye	500	379	154
Bayramhacılı	Kayseri	1000	720	161
Yamula PHES	Kayseri	500	228	260
Hasan Uğurlu	Samsun	1000	204	570

General Directorate of Renewable Energy (YEGM) prepared pre-feasibility studies of the pumped-storage projects listed above. According to those studies some basic information for some of the projects is stated in below (Saraç, 2009).

Sarıyar PHS Plant is located in Ankara. Its capacity is 1000 MW and it uses Sarıyar Dam as its lower reservoir. Upper reservoir of Sarıyar PHS plant concrete covered. Project head is 435 m, penstock length is 982 m and it has an 815 tailrace tunnel.

Bayramhacılı PHS Plant is located in Kayseri. Its capacity is 1000 MW and it uses Bayramhacılı Dam as its lower reservoir. Upper reservoir of Bayramhacılı PHS plant concrete covered. Project head is 161 m, penstock length is 305 m and it has a 160 tailrace tunnel.

Hasan Uğurlu PHS Plant is located in Samsun. Its capacity is 1000 MW and it uses Hasan Uğurlu Dam as its lower reservoir. Upper reservoir of Hasan Uğurlu PHS plant concrete covered. Project head is 570 m, penstock length is 635 m and it has a 965 tailrace tunnel.

Adıgüzel PHS Plant is located in Denizli. Its capacity is 1000 MW and it uses Adıgüzel Dam as its lower reservoir. Upper reservoir of Adıgüzel PHS plant concrete covered. Project head is 242 m, penstock length is 519 m and it has a 447 tailrace tunnel.

Kargı PHS Plant is located in Ankara. Its capacity is 1000 MW and it uses Kargı Dam as its lower reservoir. Upper reservoir of Kargı PHS plant is made from clay. Project head is 513 m, penstock length is 2182 m and it has a 580 tailrace tunnel.

Yalova PHS Plant is located in Yalova. Its capacity is 500 MW and it uses Yalova Diversion Weir as its lower reservoir. Upper reservoir of Yalova PHS plant concrete covered. Project head is 400 m, penstock length is 800 m and it has a 300 tailrace tunnel.

Yamula PHS Plant is located in Kayseri. Its capacity is 500 MW and it uses Yamula Dam as its lower reservoir. Upper reservoir of Yamula PHS plant concrete covered. Project head is 260 m, penstock length is 1620 m and it has a 300 tailrace tunnel.

Oymapınar PHS Plant is located in Antalya. Its capacity is 500 MW and it uses Oymapınar Dam as its lower reservoir. Upper reservoir of Oymapınar PHS plant concrete covered. Project head is 372 m, penstock length is 419 m and it has a 500 tailrace tunnel.

Aslantaş PHS Plant is located in Osmaniye. Its capacity is 500 MW and it uses Aslantaş Dam as its lower reservoir. Upper reservoir of Aslantaş PHS plant concrete covered. Project head is 154 m, penstock length is 875 m and it has a 225 tailrace tunnel.

Demirköprü PHS Plant is located in Manisa. Its capacity is 300 MW and it uses Demirköprü Dam as its lower reservoir. Upper reservoir of Demirköprü PHS plant concrete covered. Project head is 215 m, penstock length is 630 m and it has an 832 tailrace tunnel.

CHAPTER 3

DEVELOPMENT AND ANALYSIS OF TURKISH ELECTRICITY MARKET

3.1. General

Energy and development is inseparably correlated with each other moreover, they find meanings together while benefiting from each other's improvement iteratively. Therefore, today energy and its security is one of the priority policies of a country in terms of continuity. In order to maintain development a safe and stable market has to be established and audited by laws and regulations.

During the War of Currents era in 1880s a liberal electricity market in US was started to develop. The growth in the market was so rapid that 24 companies were established between 1883 and 1887 just in Chicago. Most of these companies were vertically integrated (services including; generating, transmission, distribution and sale) and competition in the market was so fierce on the other hand electricity prices were high due to high costs and overlapping lines (Sevaioğlu, 2011).

Monopolistic electricity market created by Samuel Insull, who was the president of National Electric Light Association, solved the problem in 1898 (McDermott, 2012). After that time, electricity supply was a natural monopoly, which was owned by the governments until 1980s. Energy was a public service during those monopolistic years. However, melting in capital during 1960s and petroleum crisis in 1973 were aroused a global financial crisis. In order to overcome that crisis a new economic model called liberalization is developed in 1980s (Türkoğlu, 2005). That new model was applied first in petroleum and gas and their markets are created. After that, petroleum and its by-products like oil and gas became a commercial commodity that can be traded in competitive market. Thus, electrical energy obtained by using these commodities must also be regarded as a commodity.

In the area of hydropower generation Turkey has a short history. A small hydroelectric power plant of 60 kW installed capacity for lighting up established in 1902 in Tarsus. In 1914, the production and distribution of electricity in Istanbul was started by companies which were founded by special permission of Ottoman Sultan. After the foundation of the Republic of Turkey, electricity was produced by the state entities ((Altınbilek, Bayram, & Hazar, 1999) and (Tiğrek & Kibaroğlu, 2011)). However, the monopolistic market structure in Turkey was started after 1970s. Turkish electricity sector can be examined in three different eras. TEK era between 1970 and 1994, unbundling era between 1994 and 2001 and market structuring era started after 2001 (Deloitte, 2010).

This chapter includes an overview about development and analysis of Turkish Electricity Market especially after the year of 2001. Analysis of Turkish electricity market includes investigation of market structure and its development throughout time.

3.2. Liberalization in Turkish Electricity Sector

Electricity market, which was vertically and horizontally integrated monopolistic structure, is unbundled in both directions. That is called liberalization of electricity market. The aim is to introduce competition and transparency into the electricity sector that would lead to improvements in competitive offers, better services and cheaper prices (EMRA, 2012). History of Turkish electricity market starts with the establishment of Turkish Electricity Authority (TEK) in 1970 and from that day till 1984 that market was ruled with a state owned monopoly. Figure 3-1 shows the liberalization process in Turkish Electricity Market.

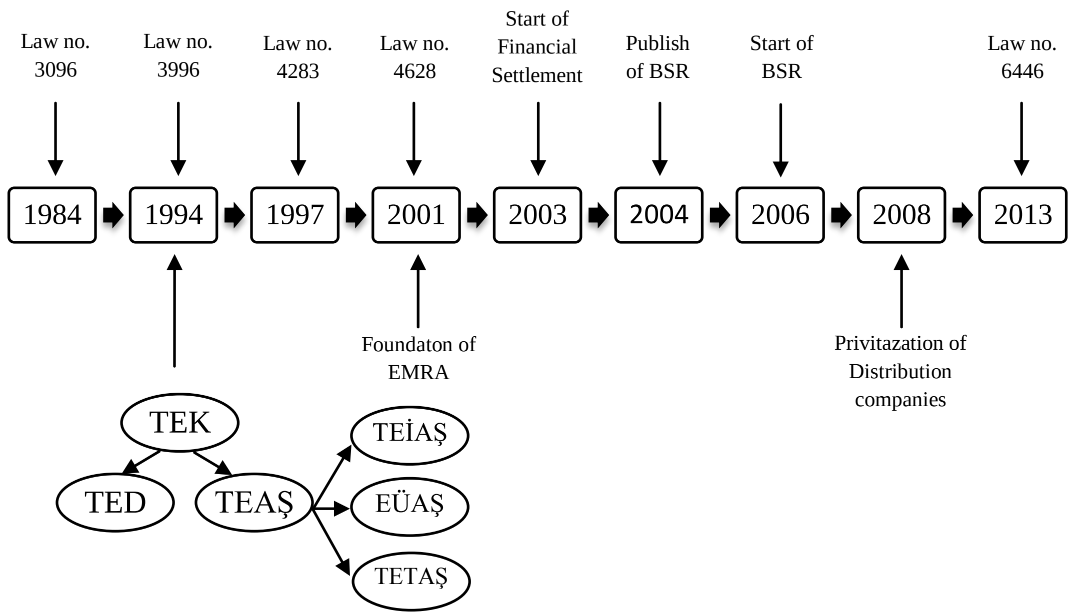


Figure 3-1: Liberalization Process of Electricity Sector in Turkey

TEK was responsible from electricity generation, transmission, distribution and trade in Turkey. Law no. 3096 and dated 04.12.1984 on the assignment the entities for generation, transmission, distribution and trade of electricity other than TEK was the first step for liberalization of Electricity Market in Turkey. Decision No: 93/4789 dated on 12.08.1993 of the Council of Ministers split TEK into two separate state economic enterprises namely, Turkish Electricity Generation Transmission Co. (TEAS) and Turkish Electricity Distribution Co. (TEDAŞ). However, until Law no. 3974 and dated 22.02.1994 on privatization of TEK, physical division of TEK does not realized. Constitutional Court annulled basic provisions of the Law no. 3974 on 10.12.1994 and privatization of state electric via asset sale was blocked. In this context, Law no. 4046 on regulating the privatization applications and amending certain Decree-in-Laws came in to force in 24.11.1994 and opened gates for privatization by transferring operational rights (TOR). TEAŞ and TEDAŞ were finally established with the Law no. 3996 and dated 08.06.1994. In 1994 on performance of certain investment services within Build-Operate-Transfer (BOT) scheme came into force and smoothens the way for legal entities for investment rather than public corporations, then autoproducer application was started. Since, Constitutional Court annulled the law of privatization, the state found a way to transfer of operational rights to private through BOT mechanism. Finally, Law no. 4283 and dated 10.07.1997 on regulating the construction of power generation facilities and energy sales under Build-Operate (BO) scheme was enforced for addition of new generation facilities ((TETAŞ, 2009) and (TEİAŞ, 2013)).

In order to align the laws accordingly with the European Union's (EU) legal acquis, electricity sector in Turkey had to be restructured. Liberalization idea for Turkish Electricity Market was started in 1984 with Law no. 3096; however the real step was Law no. 4628 in 2001. The Electricity Market Law no. 4628 and dated 20.02.2001 was the keystone of the current market in Turkey. After the law, Electiricity Market Regulatory Authority (EMRA) was founded and liberalism of market was started from vertical unbundling of TEAŞ. TEAŞ split into three separate state economic enterprises in the status of joint-stock companies under the titles of Turkish Electricity Transmission Co. (TEİAŞ), Electricity Generation Co. (EÜAŞ) and Turkish Electricity Contracting and Trading Co. (TETAŞ). They are responsible from transmission, generation and wholesale business respectively. On the other hand, electricity distribution remained under the responsibility of TEDAŞ.

This progress ended up the unbundling period and started the market-structuring period. Deregulation of electricity market was continued with the horizontal unbundling. Investment of private companies in generation part, privatization of distribution companies, introduction of private companies in wholesale and retail electricity market are the three major items in that process. After those regulations in the market there are two types of producers and consumers and it is possible customer to choose its own producer. A regulatory authority was needed concerning balance supply-demand and calculates the debts and owings due to unrestricted market in order to prevent any kind of misuse, abuse etc.

In order to perform those tasks, Market Financial Reconciliation Center (MFRC) and National Load Dispatch Center (NLDC) was established accordance with the regulations of Financial Reconciliation Regulation (FRR) and Balancing and Settlement Regulation (BSR) respectively. Recent process in market structuring period is the new Electricity Market Law no. 6446 which has enacted on 14.03.2013 by the Turkish Parliament (Official Gazette, 2013).

3.2.1. Balancing and Settlement

Turkish High Planning Council published Electricity Energy Market and Supply Security Strategy Paper in March 2004 with the purpose of sectorial reform. Main idea of the strategy paper was to create competitive and secure market which includes; supply security, sustainable electricity market, minimization of losses and increase in efficiency, decrease in electricity prices, diversity of resources using maximum of domestic renewable sources and increase share of private investment in the sector. Designed new market was based on bilateral contracting between buyers and sellers, which was integrated through a balancing and settlement mechanism. Balancing is maintaining the supply and demand equilibrium in the grid and settlement is calculating debts and owings among the market participants. For controlling his mechanism NLDC and MFRC were created.

3.2.2. National Load Dispatch Center

National Load Dispatch Center (NLDC) is a system operator responsible from real-time balancing of electricity grid by performing technical manipulation under the organizational framework of TEİAŞ. Since each market player has to report its supply and/or demand quantities either by bilateral agreements or day-ahead planning, there is need of a balancing authority which oversees imbalances between supply and demand due to several reason such as failure of plants, transmission or distribution lines, wrong prediction or overloading which causes oscillation in frequency. NLDC can track every movement in the grid by means of the technical infrastructure and in order to level the frequency, it uses up and down regulation instructions.

3.2.3. Market Financial Reconciliation Center

Another system operator in the Turkish Electricity Market is Market Financial Reconciliation Center (MFRC), which also works under TEİAŞ. MFRC is created for financial settlement of market. Currently there are two active markets, which are Day-Ahead Market (DAM) and Balancing Power Market (BPM). DAM mechanism is created one day before the real time and according to the production and consumption predictions, system balance and price settlement is achieved. BPM is a real-time market benefitting from up and down regulation instructions of NLDC.

3.3. Turkish Electricity Markets

Liberalization process of market has been released step by step over in the last decade. After establishing the Bilateral Contracts Market (BCM); other three markets was established as a complimentary to BCM. Those market developments can be explained in four phases.

There are four phases of that development which is illustrated in Figure 3-2. Phase 1 is between August 2006 and November 2009, which was started with publishing Temporary Balancing and Settlement Regulation (T-BSR). That phase was training for most of the market player. In 14 April 2009 Final Balancing and Settlement Regulation (F-BSR) was published in Official Gazette and it was the footsteps of phase 2 (Official Gazette, 2009).

Phase 2 was covering the period of 2 year starting from December 2009 to 2011. Day Ahead Market (DAM), Balancing Power Market (BPM) and Ancillary Service Market (ASM) were established during that period and operating by MFRC under TEİAŞ (TEİAŞ, 2012).

In Phase 3 Hourly settlement and Guaranty Mechanism was introduced. Final period of liberalization of Turkish Electricity Market is going to start in 2014. In March 2013 the New Electricity Law No: 6446 was published and according to that law Intra-Day

Market (IDM) and Derivative Markets was defined. Activation of those two new markets will probably be in early 2014.

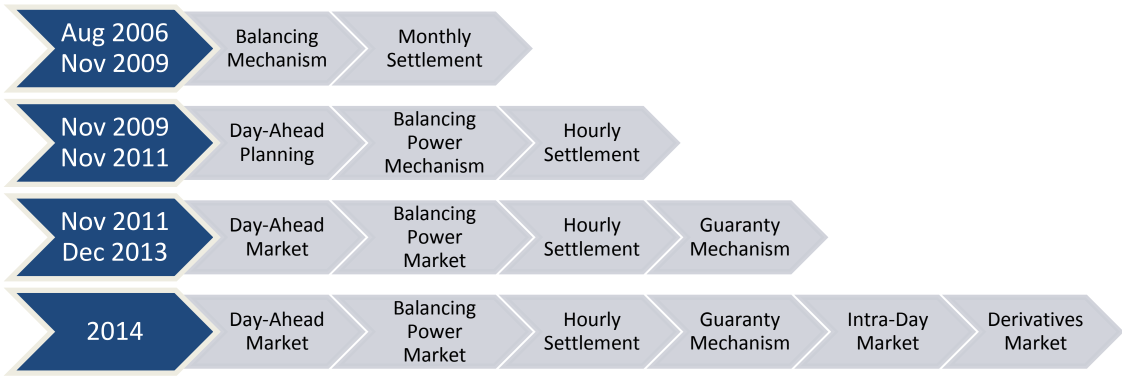


Figure 3-2: Development of Turkish Electricity Market

Every producer or consumer in electricity market has to declare its generation and consumption capacity to MFRC for the following day in hourly basis from the web interface of MFRC whether producer operates in Bilateral Contract Market (BCM) or not. BCM players have to indicate they are in the market. After completion of declaration, MFRC intersects supply and demand for each hour and electricity price is settled for the recpective hour and for each trade zone. This price is called Day-Ahead Price (DAP). Contrary to DAP, electricity prices in bilateral contracts are decided between the sides of contract and do not affect the electricity prices in other markets. Priced occurred in DAM is the bases for the reconciliation method. If the predicted (declared) generation is achieved electricity is sold from Market Clearing Price of DAP otherwise imbalance occurs. If imbalance is the case, payment is calculated in different ways and System Marginal Price (SMP) in Balancing Power Market becomes part of this process. This procedure also states that Day Ahead Market (DAM) and Balancing Power Market (BPM) are strongly related with each other. BPM utilized in the case of imbalances in the grid. SMP is the maximum of hourly offers when up-regulation is ordered for energy deficit or the minimum of hourly offers when the down-regulation is ordered for energy surplus. Figure 3-3 shows the energy flow and pricing mechanism in Turkish Electricity Markets.

Addition to DAM and BPM, third market is called Ancillary Service Market (ASM). Electricity Market Ancillary Service Regulation defines Ancillary Services duties as follows;

- Load-Frequency Control
  - Primary Frequency Control, governor action
  - Secondary Frequency Control
  - Stand-by Reserves
- Volts/VAR control
  - Reactive Power Support and Voltage Control
- Emergency Control
  - System Restoration and Black-start
  - Demand Side Management

The main aim of the Ancillary Services is to maintain operation security and demand security and quality which are defined by the regulations under the control of system operator.

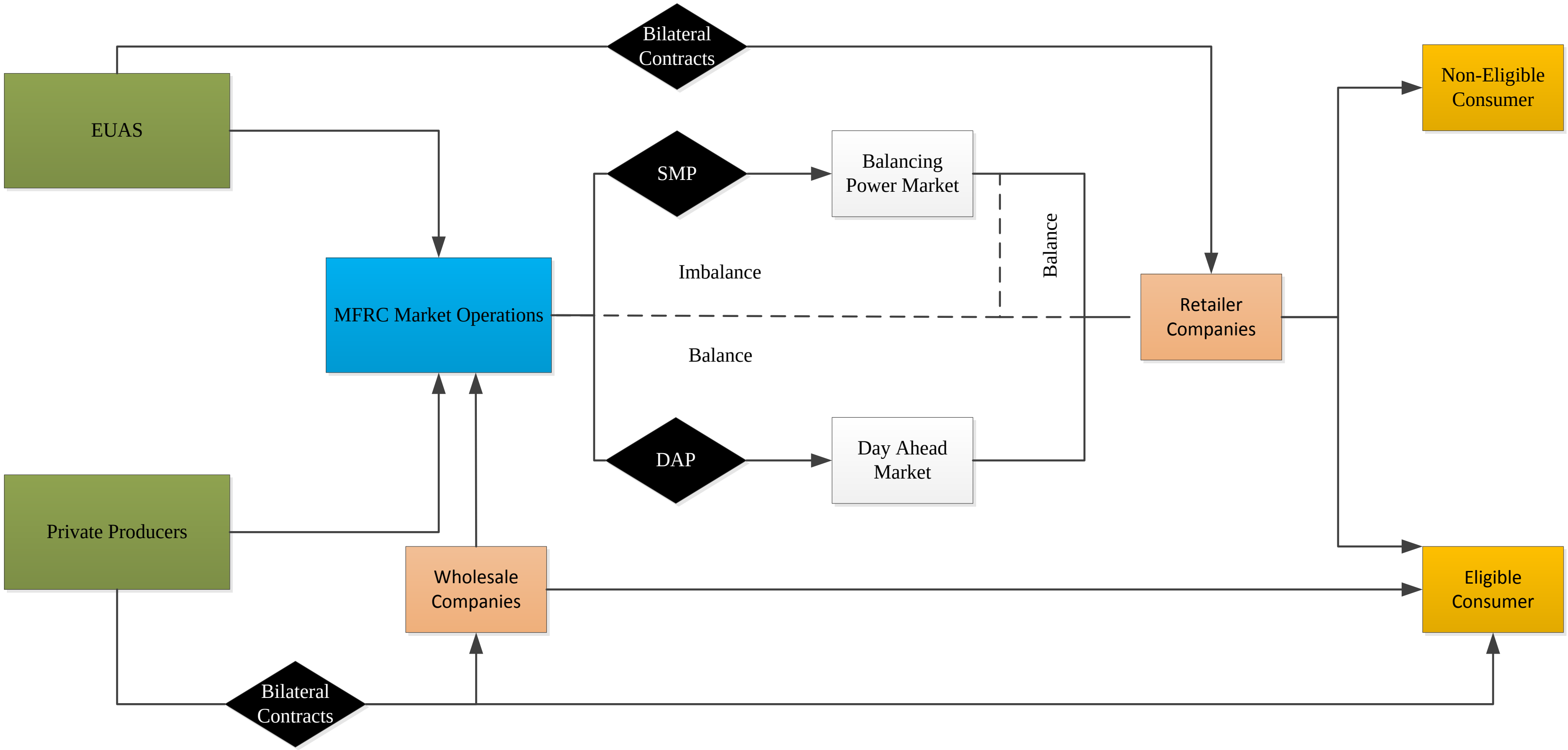


Figure 3-3: Electricity Markets and Pricing Mechanism

The new Electricity Law no. 6446, published in the Official Gazette on 30.03.2013, has brought a new regulatory framework (Official Gazette, 2013). The new law gives definition of two new markets that are Intra Day Market (IDM) and Derivatives Market. IDM will allow more flexibility to the operators by giving opportunity to make contracts two hours before the real-time. Due to large share of state-owned utilities in power generation and regulated prices of natural gas, prices in DAM do not reflect the real supply-demand balance (Bademli, 2013). However, IDM will work two hours difference than the real-time and balancing in grid will be more effective.

According to the new law Energy Markets Operation Company (EPİAŞ) will be established and EMRA will publish a regulation to lay out the working principles of EPİAŞ, taking into consideration the opinion of the Capital Markets Board (Turkish acronym SPK). EPİAŞ will also be entered in the Istanbul Stock Exchange Market (BIST). After physical establishment of EPİAŞ operation of DAM and IDM will be executed by it. Operation of BPM and ASM will remain in TEİAŞ. EPİAŞ will take over the duties and MFRC with the addition of IDM and derivatives market such as emission trading.

3.4. Analysis of Electricity Prices in DAM and BPM

Day Ahead Market (DAM) and Balancing Power Market (BPM) started operating in 1 July 2009. In order to understand the variation, electricity prices starting from the time period of 1 July 2009 – 1 November 2013 are analysed hourly, monthly and yearly bases in the present study. In the following sections the important outcomes of this analysis will be summarized, complementary information and data are given in the Appendices.

Daily averages of DAP and SMP are shown in Appendix C. Shortage of data and unstable price variation brought questions in 2009. The two peaks in Figure 3-5 for 2009 and daily averages of prices in 2009 represent that market instability very well. During those peaking hours SMP reaches to 15000 TL/MWh, which is the ceiling price due to supply deficit. The ceiling price was rearranged in 1 December 2009 and determined to be 2000 TL/MWh with the starting application of Final Balancing and Settlement Regulation (F-BSR) (Official Gazette, 2009).

3.4.1. Hourly Analysis of Electricity Prices

In Figure 3-4 and Figure 3-5 hourly electricity prices of DAP and SMP for the period of 2009 - 2013, was given by taking average of 365 days of each hour. Figures show the prices in 2012 are higher than other years and 2010 prices are the lowest.

The differences between the night hours and day time shows electricity usage trend in Turkey. In the usual trend it is expected that the prices are low after midnight and high at night hours. However, in Turkey the expensive electricity prices are recorded in between 10.00 – 11.00 and highest at 11.00 o'clock (171 TL/MWh on average, 2009 to 2013) for every year. Second expensive period is between 14.00 - 17.00 whom peak is observed at around 14.00 o'clock (163 TL/MWh on average, 2009 to 2013).

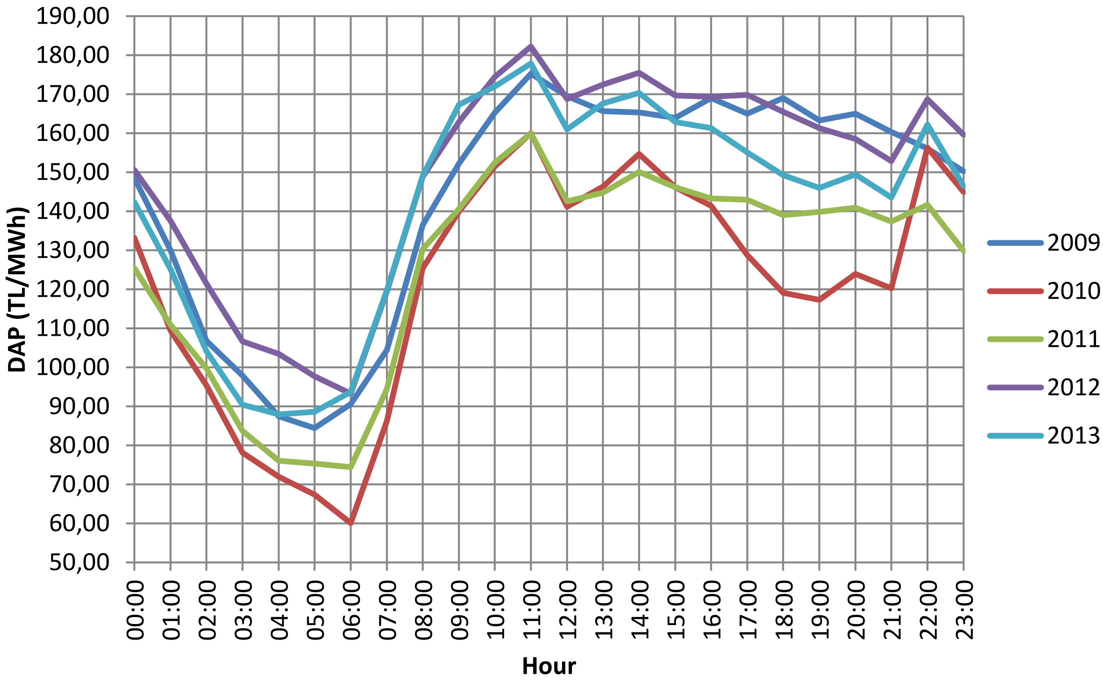


Figure 3-4: Average Hourly Day-Ahead Prices

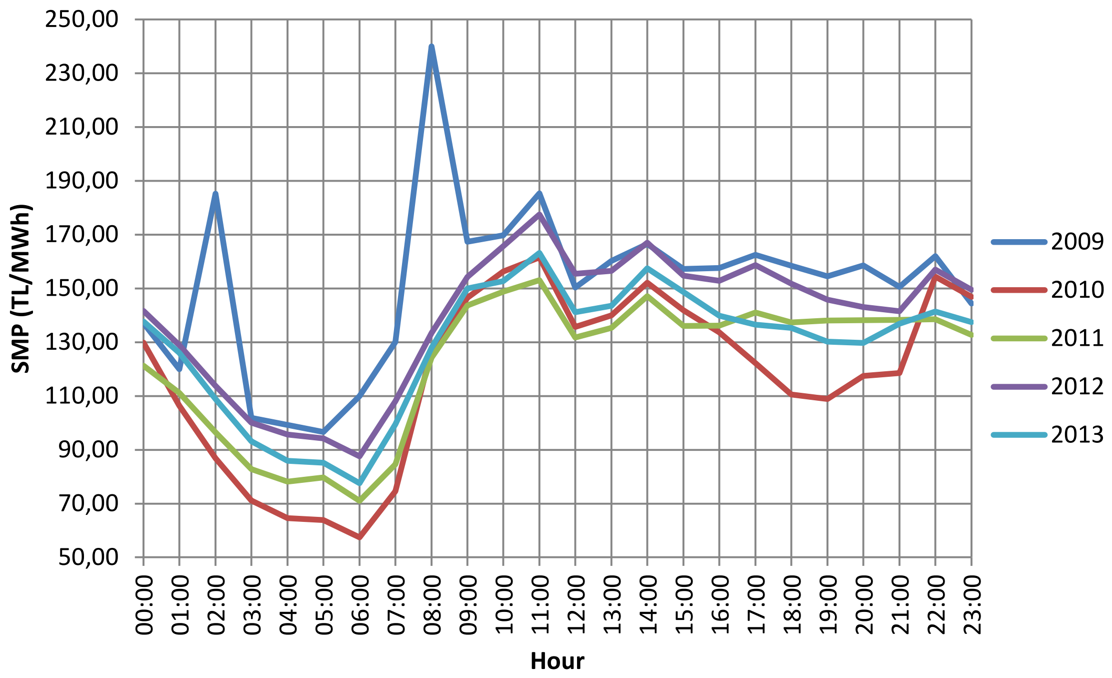


Figure 3-5: Average Hourly System Marginal Prices

3.4.2. Monthly Analysis of Electricity Prices

Electricity prices in Turkey are directly related with electricity generation from hydroelectricity and natural gas. Both winter and flood season's prices are cheaper than summer season and Table 3-1, Figure 3-6 and Figure 3-7 illustrates that clearly. Increasing electricity consumption and low hydroelectricity generation in summer months causes inflate in electricity prices. During flood season, the behavior of electricity prices are directly depends on flow, when the flow is high; electricity prices are low; on the contrary, vice versa. Figure 3-8 is the representative of comparison between the hydroelectricity generation and electricity prices in March, April, May and June for 2010 – 2013 years which are inversely proportional. Data are retrieved from TEİAŞ sources ((TEİAŞ, 2012,2011,2010,2009), (TEİAŞ, 2013) and (TEİAŞ, 2013)).

Table 3-1: Average Monthly of DAP (TL/MWh) and SMP (TL/MWh)

	2009		2010		2011		2012		2013		Ave.	
	DAP	**SMP**	**DAP**	**SMP**	**DAP**	**SMP**	**DAP**	**SMP**	**DAP**	**SMP**	**DAP**	**SMP**
January	0,00	0,00	119,83	115,09	130,03	130,48	148,23	150,45	155,41	142,55	138,38	134,65
February	0,00	0,00	109,43	109,43	113,75	109,27	195,81	198,01	135,15	125,13	138,54	135,46
March	0,00	0,00	96,89	99,84	102,41	93,80	121,98	121,64	127,55	108,41	112,21	105,92
April	0,00	0,00	109,26	114,87	85,56	81,42	112,51	83,65	144,47	137,88	112,95	104,45
May	0,00	0,00	114,35	104,18	92,75	84,05	141,13	130,62	137,88	117,74	121,53	109,15
June	0,00	0,00	108,05	96,14	95,32	84,40	144,17	141,72	147,41	140,11	123,74	115,59
July	161,53	161,36	147,69	148,39	155,47	161,42	168,42	170,36	157,29	145,89	158,08	157,48
August	153,73	155,36	169,55	170,47	145,48	143,27	160,57	143,52	151,73	151,82	156,21	191,11
September	124,20	146,07	140,16	129,28	149,16	147,86	153,93	153,19	156,40	148,35	144,77	181,19
October	155,61	186,40	128,39	123,13	137,87	133,60	151,77	116,68	143,69	147,54	143,47	176,84
November	140,01	135,54	96,29	83,18	150,84	157,52	145,14	126,07	0,00	0,00	133,07	125,58
December	124,40	120,83	116,96	117,75	149,77	143,61	153,46	137,44	0,00	0,00	136,15	129,91

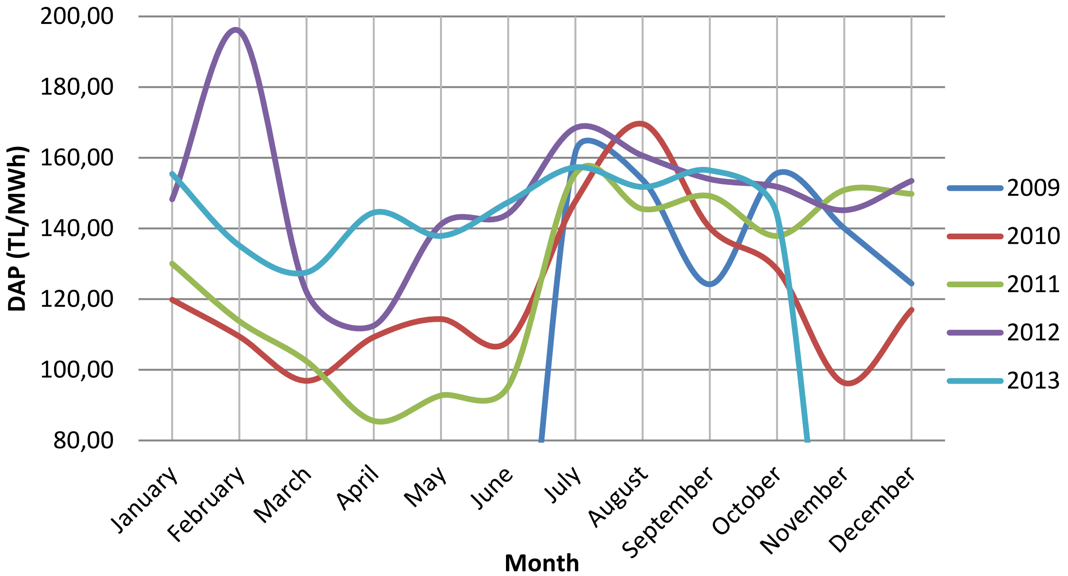


Figure 3-6: Average Monthly Day-Ahead Prices

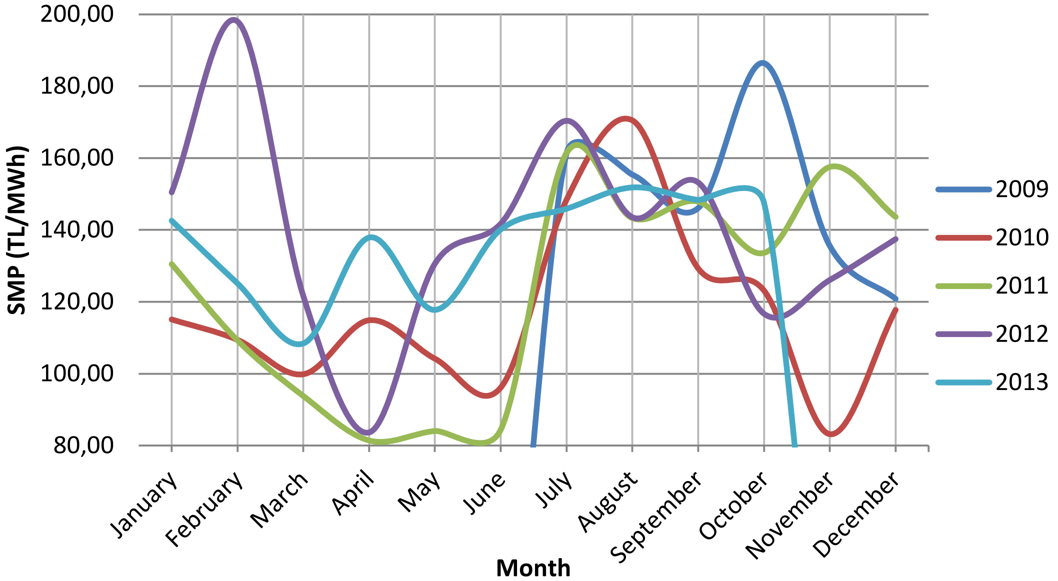


Figure 3-7: Average Monthly System Marginal Prices

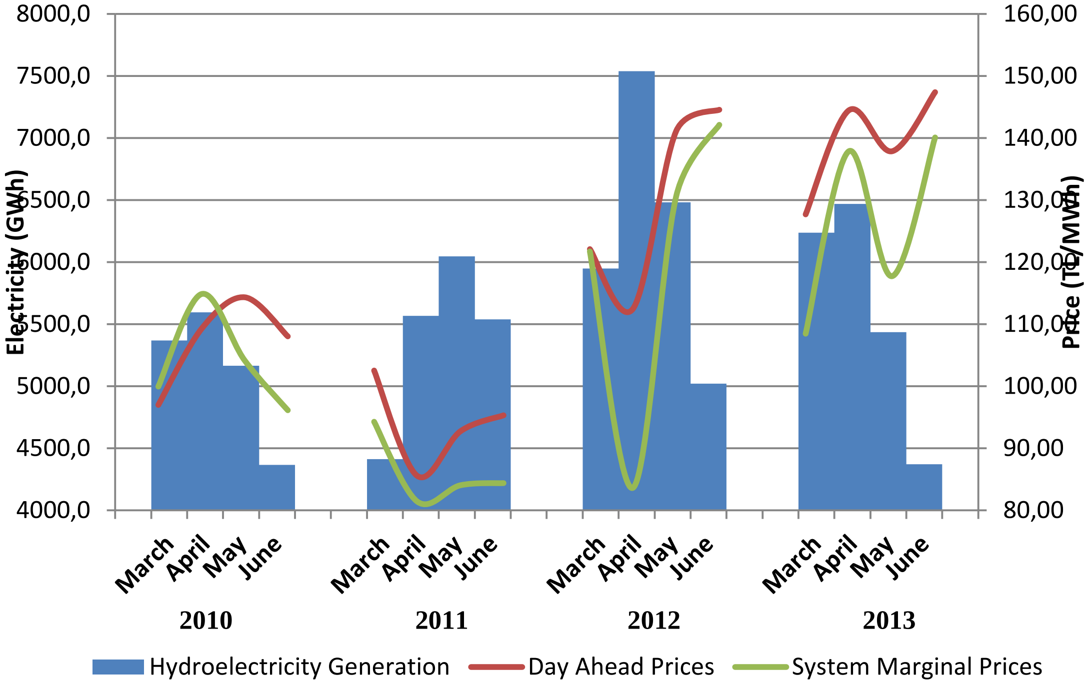


Figure 3-8: Comparison of Hydroelectricity Generation in Flood Season vs. Electricity Prices

Natural Gas Power Plants (NGPP) has the biggest pie in total electricity generation; even though Turkey owns a very small amount of natural gas resources. Thus, natural gas import is significantly important for determination the electricity prices. Natural gas crisis in February 2012 explains this relationship very well. BOTAŞ cutback gas for electricity generation companies arise from interruption in gas import from Azerbaijan and Iran and gave priority for heating in residences because of extensive cold weathers. Throughout the cutback, compulsory decrease was occurred in electricity supply in total of 11.320 MW and more than 70% of it 7792 MW is directly related with NGPP. That forced decrease in generation capacity increase the prices up to 2000 TL/MWh and beat the record of all times (Turkish Competition Authority, 2012). Daily average price in 13^{th} February was 678 TL/MWh and 21 million kWh electricity was sold from 2000 TL/MWh (Altunsoy, 2012). Details can be found in Appendıx D.

3.4.3. Yearly Analysis of Electricity Prices

Daily averages of DAP and SMP are sorted in Figure 3-9 and Figure 3-10 respectively. According to the graphs majority of the prices are changing between 100 TL and 175 TL. More than 75% of the prices in DAM are more than 100 TL and less than 175 TL. Likewise, at least 57% of the SMP are more than 100 TL and less than 175 TL. Details of the analysis are in Appendıx E.

Unsorted daily averages of prices are in zero. Peaks and bottoms of the prices are clearly stated in those graphics. The graphs show that there are four peaks and four bottoms within a 30 day or in a month. Those fluctuations in the prices are the representatives of the change in weekday and weekends. Increasing electricity consumption in weekdays is the cause of price rise. Another important parameter is public or religious holidays. During holidays prices show decline trend even if it is a weekday. The reason for those fluctuations in weekends and holidays is related with the electricity demand. Electricity consumption in industry is more than consumption in residential buildings official buildings and offices (Figure 3-11 & Table 3-2). Thus, during weekdays increasing demand also increase the prices.

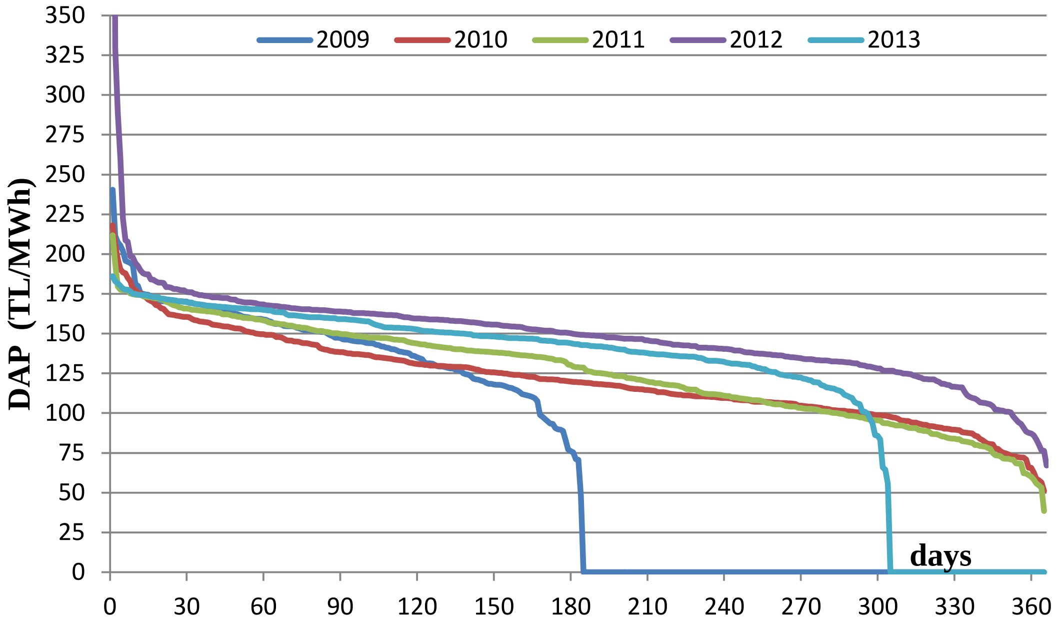


Figure 3-9: Sorted Daily Averages of DAP over years
(Peak was 687.00 TL/MWh in year 2012. For better illustration graphic is limited to 350 TL/MWh)

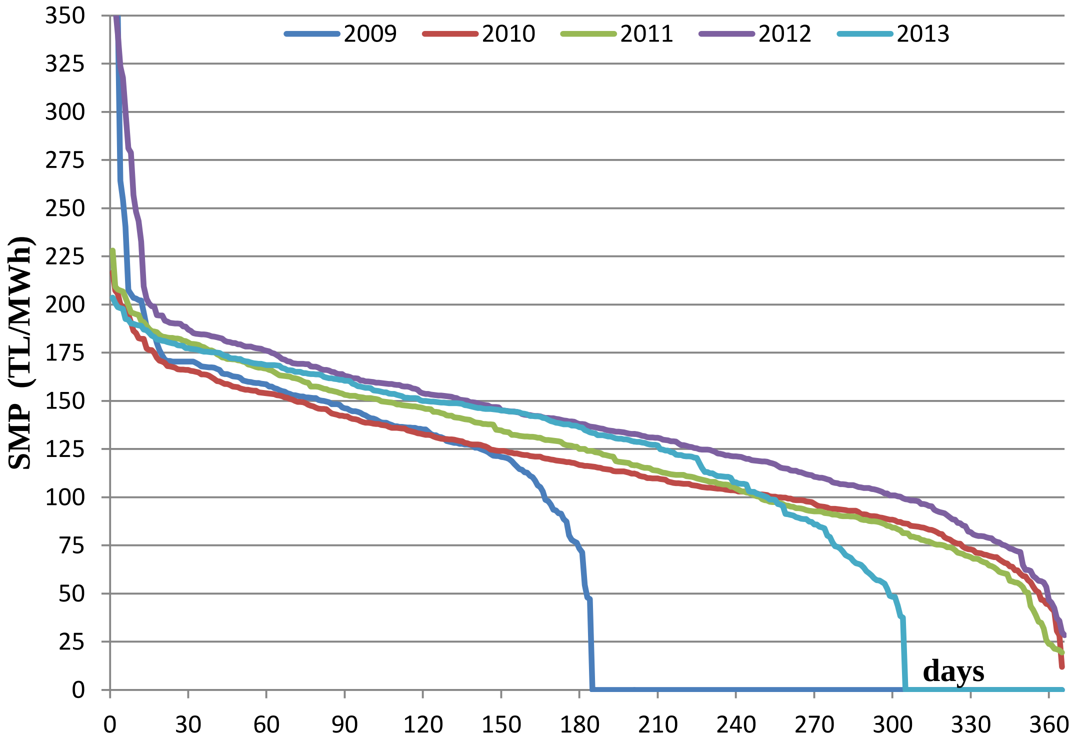


Figure 3-10: Sorted Daily Averages of SMP over years
(Peak was 687.00 TL/MWh in year 2012 and 778 TL/MW in year 2009. For better illustration graphic is limited to 350 TL/MWh)

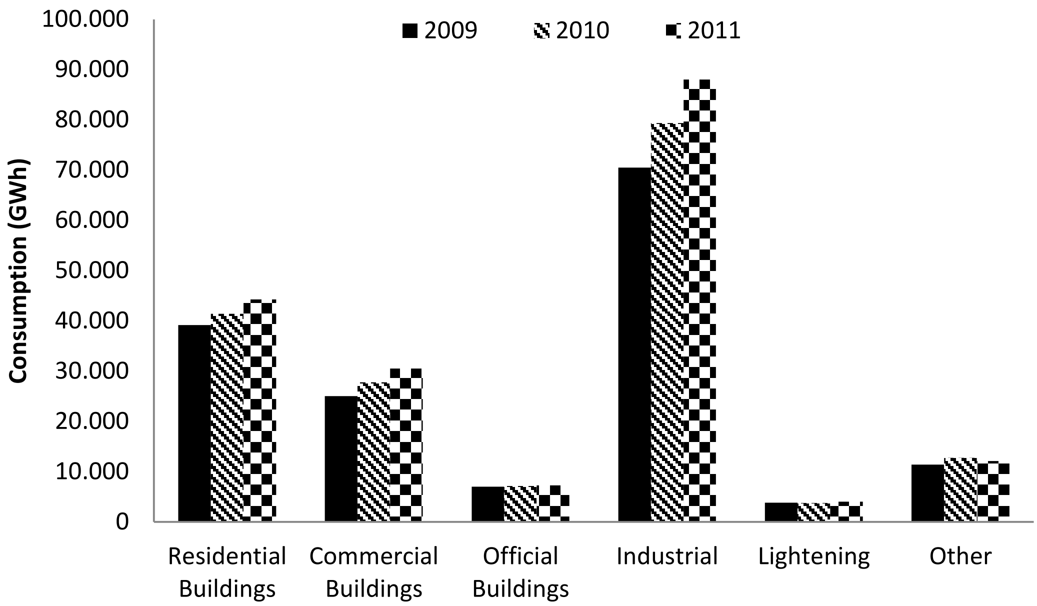


Figure 3-11: Net Electricity Consumption According to Sectors (Data are compiled from TUIK (TUIK, 2013))

Table 3-2: Net Electricity Consumption According to Sectors (Data are compiled from TUIK (TUIK, 2013))

	2009 (GWh)	**2010 (GWh)**	**2011 (GWh)**
Residential Buildings	39,148	41,411	44,271
Commercial Buildings	25,019	27,732	30,525
Official Buildings	6,990	7,102	7,272
Industrial	70,470	79,331	87,980
Lightening	3,845	3,768	3,986
Other	11,423	12,707	12,064
Total	**156,894**	**172,050**	**186,099**

CHAPTER 4

EVALUATION OF PUMPED STORAGE PROJECT USING PXSC

4.1. General

Development of hydropower projects requires an extensive work and collaborations of workforces of different disciplines such as ecologists, engineers, lawyers and economists, etc. Thus, there is not a single tool, which completely covers all those branches and performs evaluation of projects. There are a few available package programs to estimate energy production capacity, dimensioning of main structures, project estimated cost and economical indicators for small hydropower (ASCE Small Hydro, HES, Hydra, IMP, PEACH, PROPHETE, Remote Small Hydro, RETScreen) (IEA, 2007). However each reserve its own specific conditions.

In the present study, a tool was developed which is called PXSC for evaluation of pumped hydroelectric storage plants using real time electricity prices. The tool aims to provide quick and reliable results in terms of hydraulics and economy. Working principle behind the tool, formulas used in the analysis, economical evaluation procedure of the projects are explained in detailed in following chapters.

4.2. Methodology and Procedure of PXSC

Costs and benefits of a power plant depends on its installed capacity. Obviously, increasing installed capacity results in increase in energy generation and consequently increase in energy income. However, increasing installed capacity also affects the project investment cost in upward direction. Based on this starting point, Cost – Benefit Analysis (CBA) can be performed for a project. Annual incomes and annual costs are calculated for corresponding installed capacity, then net annual incomes vs. installed capacity of the project plotted on chart and the peak point of that curve (benefits subtracted from costs) corresponds to the optimum installed capacity (Figure 4-1). This approach is valid for every type of the power plant. Thus it will be a reasonable way to use the same for PHS projects. By using the optimum installed capacity, the penstock diameter and tunnel diameter are calculated by following the same procedure. Then the final value of the installed capacity is corrected according to hydraulic variables.

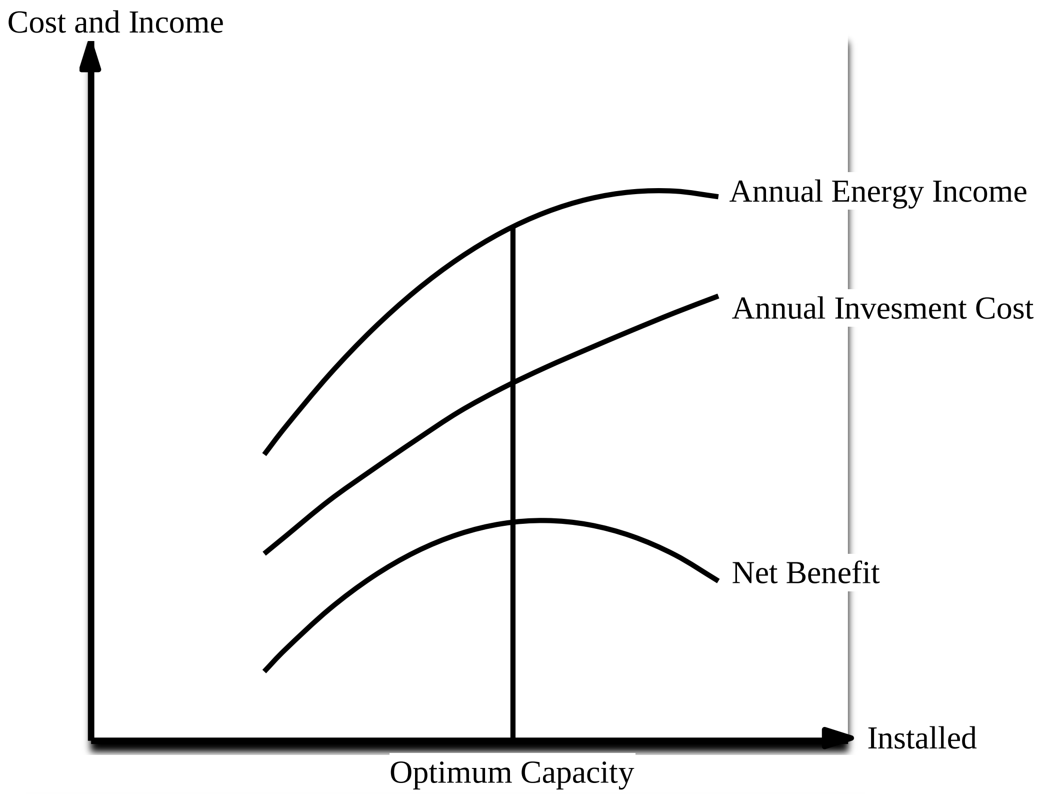


Figure 4-1: Cost-Benefit vs. Installed Capacity Chart for a Hydropower Plant (Ak, 2011) and (Aydın, 2010)

Assumptions used in the PXSC are as follows;

- There is an already built or natural reservoir for lower reservoir of pumped storage project.
- Pumped storage project has daily operations. Electricity generation and pumping water to upper reservoir is completed in the same day.
- Pumping water from lower reservoir to upper reservoir does not affect lower reservoirs water level if the conditions of lower reservoir if available for operation.
- During selection of optimum discharge, penstock and tunnel speed initially are assumed 5 m/s and 3 m/s consecutively (Unite States Department of Interior - Bureau of Reclemation, 1987) and (Coleman, Wei, & Lindell, 2004).
- Manning roughness coefficient for tunnel is assumed 0.014 for smooth concrete surface and for penstock is 0.010 for stainless steel (CE 372 Hydromechanics Lectures Notes, 2006) and (Potter & Wiggert, 2002).
- Tunnel is pressurized tunnel.
- For penstock cost calculations, penstocks layout is assumed to be on ground.
- Vertical axis reversible pump/turbine and reversible motor/generator are considered for electromechanical equipment.
- All costs are in terms of USD.

PXSC is created in Microsoft Excel using Visual Basic Analysis (VBA). There are 9 sheets in PXSC and they are categorized by the color codes according to their functions. Yellow colored sheets, **“Electricity Prices”** and **“Project Information”**, are used for data entrance. Black colored sheet named **“Average Electricity Prices”** is used for analysis of electricity prices. Three green colored sheets which are **“Discharge Selection”**, **“Penstock Diameter Selection”** and **“Tunnel Diameter Selection”** are used for selection of optimum project net benefit. Finally, **“Economy Summary”, “Revenue/Expenditure Ratio”** and **“Internal Rate of Return”** sheets are created for economic analysis of the project. Figure 4-2 shows the flowchart of the PXSC.

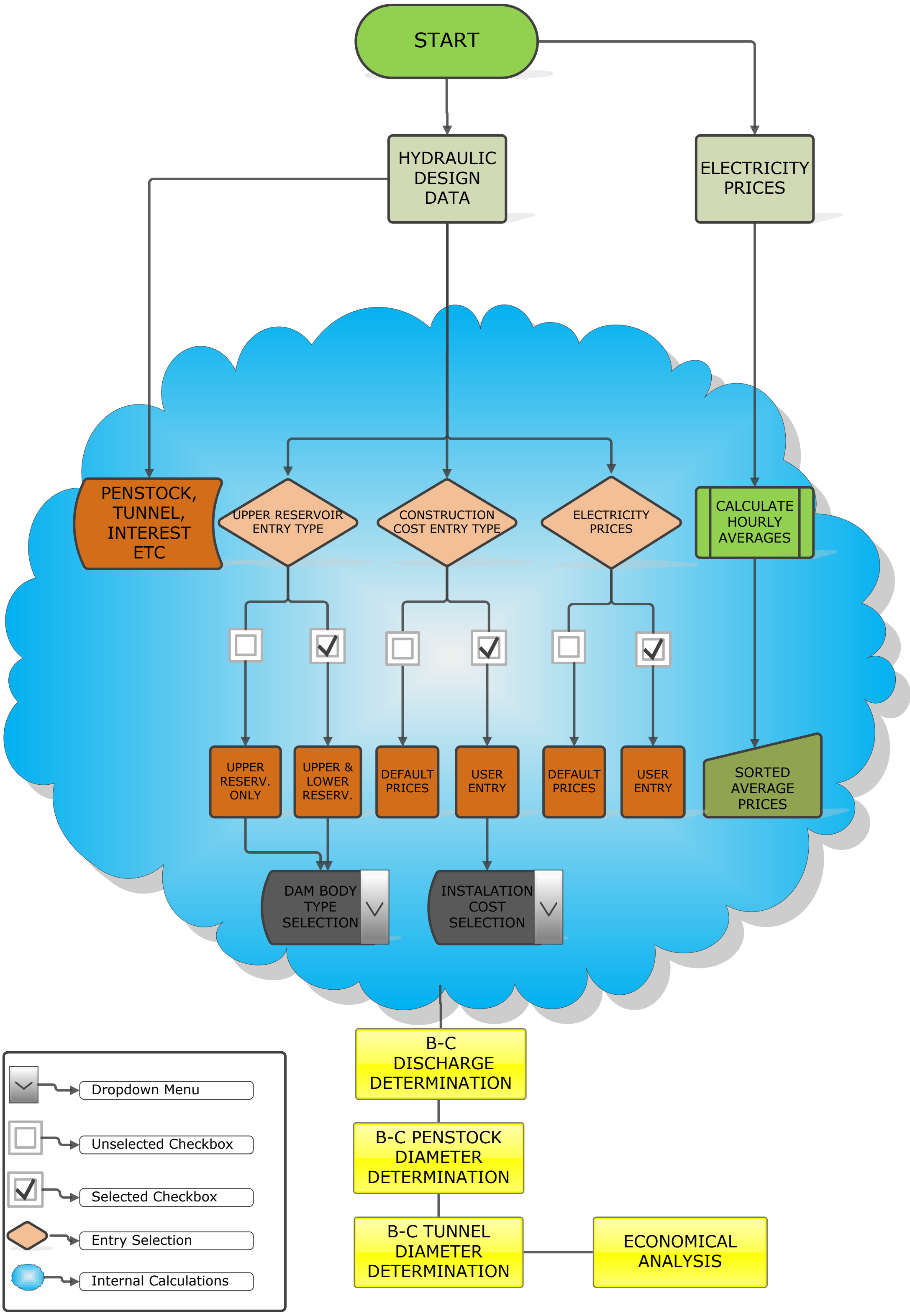


Figure 4-2: PXSC Flowchart

User enters data into the PXSC interface and made selections (using default prices or entering own prices) for cost calculation from either via checkboxes or dropdown menus. At the same time PXSC makes internal computations with the codes written in VBA. The results are shown in the yellow color sheets.

4.3. PXSC Manual and Theory

Electricity prices are the main inputs for the tool during the calculation of the revenues and expenditures. User can enter any electricity prices in **"Electricity Prices"** sheet accordance with the Figure 4-3. Each year has 8760 hours and there are 8760 rows reserved for this entry except full years like year 2012 which have 8784 rows. Electricity prices with its corresponding hour are entered. After the data are introduced to the tool, automatically calculates the monthly and hourly averages of the prices and sort from maximum to minimum for electricity generation and minimum to maximum for pumping action. Averaged and sorted prices are stored in **"Average Electricity Prices"** sheet. The user will decide the number of operation hours according to the sorted prices.

Other important input needed for the tool is the project informations. For nice and tidy appearance, project information is entered into another page which is only composed of text boxes and userforms. Figure 4-4 and Figure 4-5 are the screen shots taken from the PXSC **"Project Information"** page and **"Tailrace Water Level"** userform.

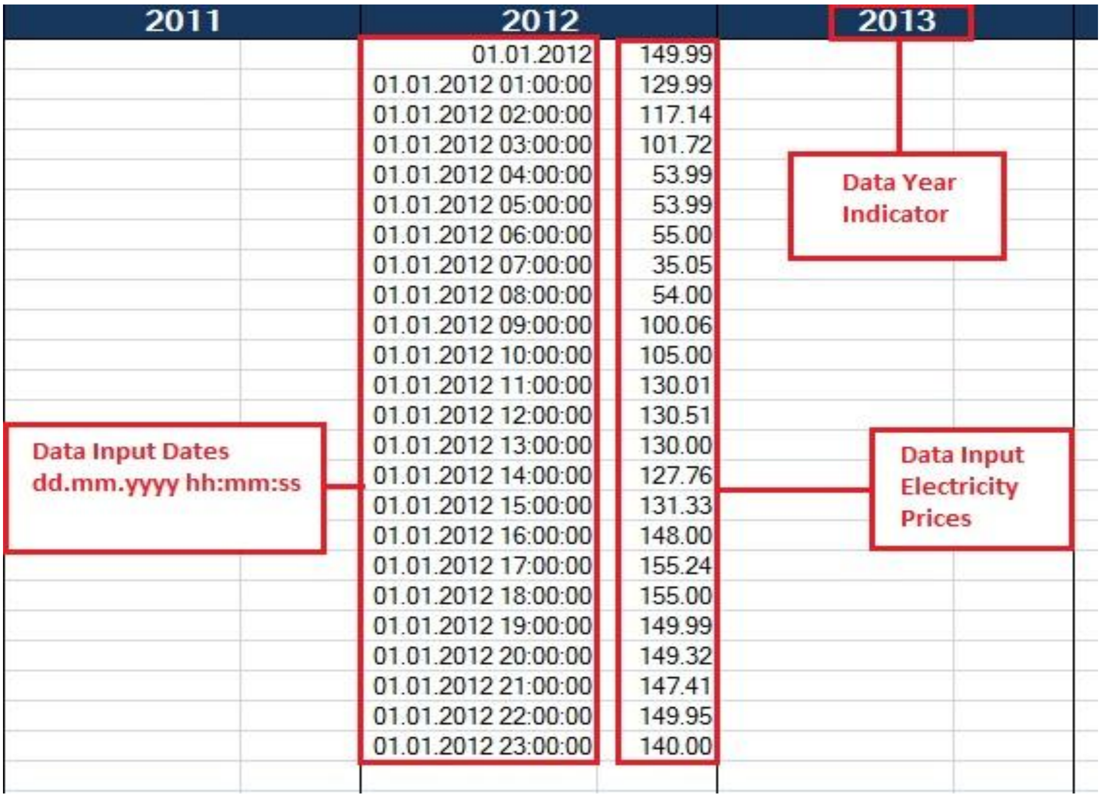


Figure 4-3: Electricity Price Entry User Interface Page

Head Informations: User can choose the entry type by clicking the checkbox button in order to activate the **"Tailrace Water Level"** userform shown in Figure 4-5. If the checkbox is unchecked, **"Upper Reservoir Minimum Water Level"** , **"Upper Reservoir Maximum Water Level"** , **"Thalweg Elevation"** and **"Tailrace Water Level"** informations has to be entered for calculation of gross head. Otherwise, **"Tailrace Water Level Userform"** will open and user has to enter the tailrace water level for each month. If the lower reservoir detail information is known, it is preferred to use that form. By activating the userform, user can specify the number of working days in a year. The userform is created for the representation of rule curve of the lower reservoir.

if	$water\ level\ in\ month - tailwater\ level < 0$	No operation
	$water\ level\ in\ month - tailwater\ level > 0$	Operating

After data entry is completed pressing the command button **"Close"** will calculates the gross head and number of working days in a year.

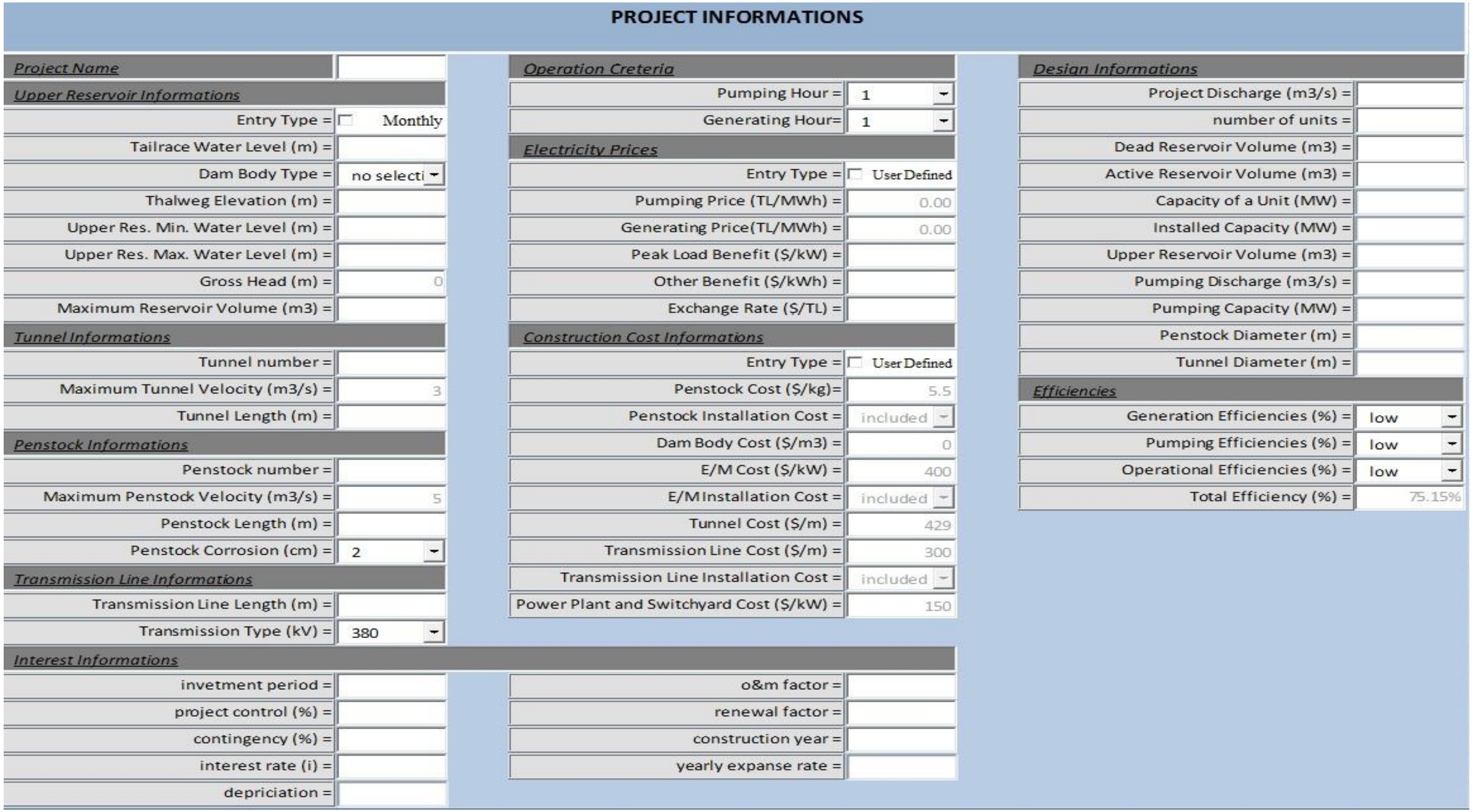


Figure 4-4: User Data Interface

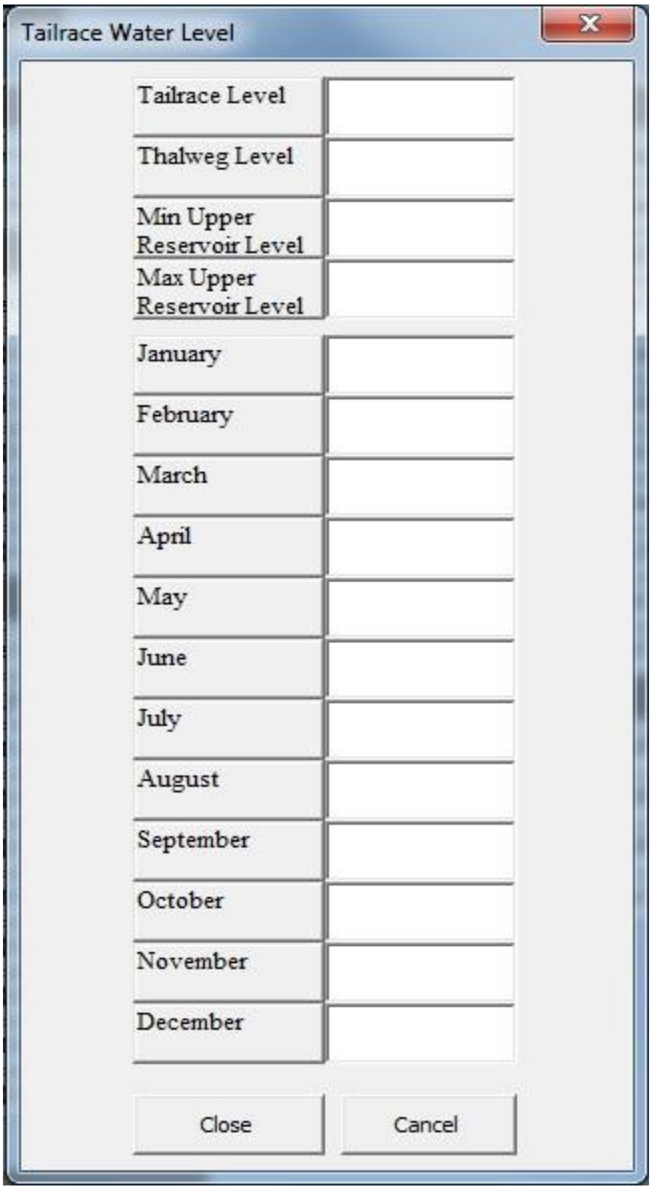


Figure 4-5: Upper and Lower Reservoir Water Level Entry User Form

Upper Reservoir Information: User chooses the upper reservoir dam body type from the dropdown menu and enters the dam body information for calculation of the volume. User enters the basic dimensions into there and approximate dam body volume is calculated within the tool There are four types of dam body type is chosen for the menu which are **"Roller Compacted Concrete (RCC)"** (see Figure 4-6), **"Earth Core Rock Fill Dam (ECRD)"** (see Figure 4-7), **"Concrete Face Rock Fill Dam (CFRD)"** (see Figure 4-7) and there is an option for other types of structures like embankment or etc. For ECRD and CFRD types the same formulas and user forms are used.

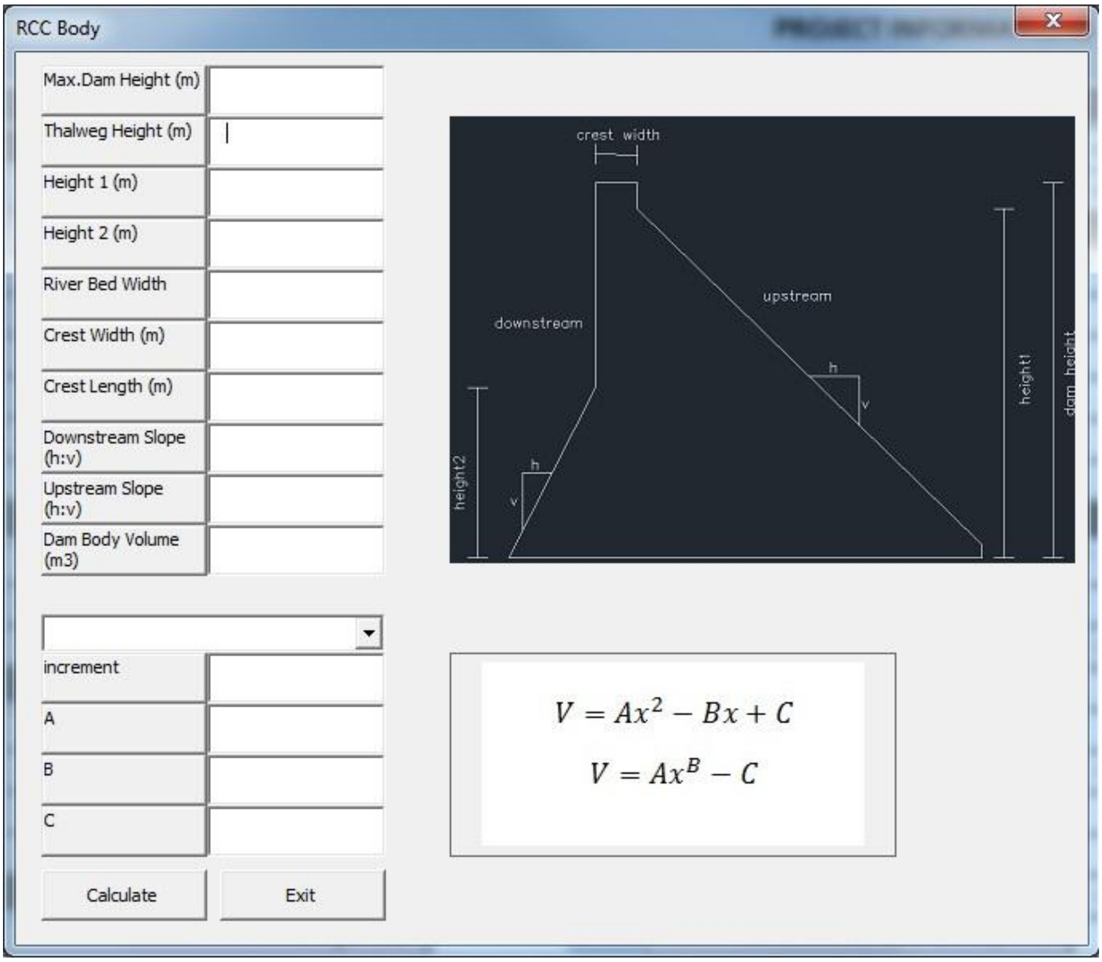


Figure 4-6: RCC Dam Body Data Input Interface

User enters the **"Maximum Dam Height", "Thalweg Elevation", "Rive Bed Width", "Crest Width", "Crest Length"** and **"Downstream and Upstream Slopes"** for ECRD and CFRD types, addition to that inputs two height inputs have to be entered in user forms.

Last information related with the dam body is the selection of elevation vs. reservoir volume function and entering its inputs. User examines its own reservoir volume elevation graph and fit the best curve either polynomial or exponential. Then she/he chooses the function either as **"Polynomial"** or **"Power"** and enters the function coefficients into the textbox. This is information is needed since the dam height of the upper reservoir will increase when the volume of the pumped water increases, thus the cost of the dam will increase.

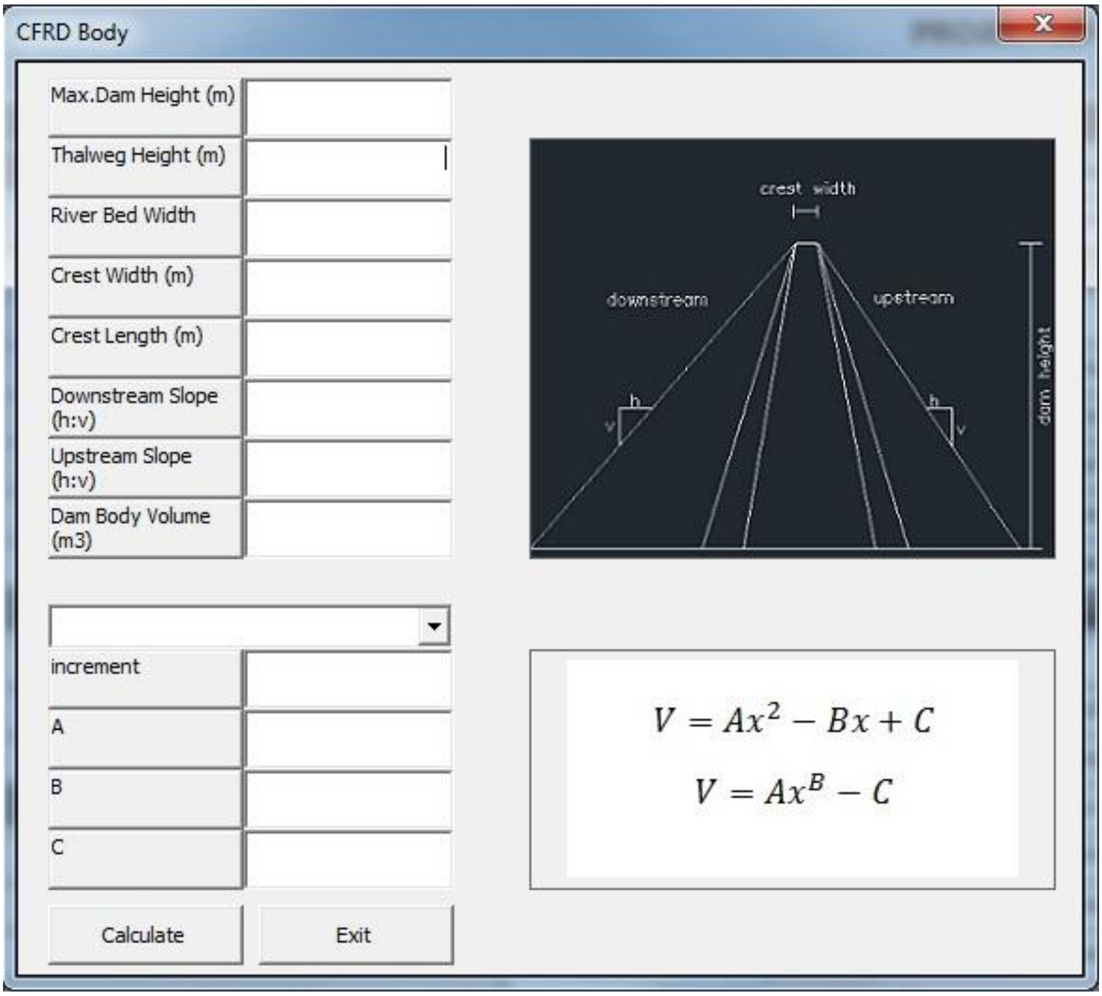


Figure 4-7: CFRD and ECRD Dam Body Data Input Interface

Tunnel Information: User enters the tunnel length and number of tunnels into the textboxes. Maximum tunnel speed is in default mode set as 3 m/s. User can have the option to change the maximum velocity which changes the tunnel diameter and tunnel cost as well.

Penstock Information: User enters the penstock length and number of penstocks into the textboxes. Maximum penstock speed is in default mode set as 5 m/s. User can have the option to change the maximum velocity which changes the diameter and cost. Addition to that, user can choose the penstock corrosion thickness from the dropdown menu.

Transmission Line Information: User enters the transmission line length and chooses the transmission line voltage in order to estimate the cost of the transmission line.

Interest Information: From the information entered into the textboxes depreciation and yearly expense rate is calculated to determine the yearly expenses of structures. Details of the calculations are expressed in the Section 4.4.4.1.

Electricity Prices: After electricity prices are entered into the prices sheet, there is an option to choose to use the entered prices or user's own prices. This is enabled by checking the box near the entry type. User enters fixed the electricity prices, USD/TL exchange rate and feed-in tariffs if supplied.

Operation Criteria: User chooses the number of pumping and generating hours within a day by examining the sorted prices which is used in calculations yearly electricity generation and yearly electricity needed for pumping.

Construction Cost Information: User enters the unit costs penstock, tunnel, transmission line, electromechanical equipment and power plant if the checkbox is clicked. Addition to that, if the prices are not include the installation costs or workforce cost of the penstock, electromechanical equipment and transmission line user can add predefined costs to them by adding 20% the prices that they have entered. If user have no opinion about the unit costs of the structures uncheck the box and predefined unit costs are shown in the boxes. Details of the construction cost are examined under the Section 4.4.4.

Efficiencies: User chooses the efficiencies for generation, pumping and operation from the dropdown menu. Overall cycling efficiency is calculated from multiplication of those. The efficiencies can selected as **"low"** or **"high"** from the menu. The values of those selections are stated in the Table 2-1 (Levine & Barnes, 2011) .

Project Design Information: User can enter the project discharge in order to see the capacities of the project. That information is not used in the determination of optimum project discharge, penstock and tunnel diameters.

4.4. Optimum Discharge Selection

After completion of data entry user switches to the next sheet which is **"Discharge Selection"**. Within the page there is a table shown in Figure 4-9. By clicking the command button **"Get Installed Capacity"**, **"Discharge"** form pop-ups as shown in the Figure 4-8. User enters the **"Initial Discharge"** and **"Increment"** values into the user form and presses **"Continue"** button to start to calculations. Calculations will finish within a second and User can select the optimum discharge value corresponds to the maximum of Benefit – Cost value. After determination of the optimum discharge User proceeds to the next step which is penstock & tunnel diameter selection sheets explained in the Section 4.5, otherwise by changing the values in **"Discharge"** form calculations are repeated until the determination of optimum discharge for pumped storage. Details of the optimum discharge calculations are explained in below sections.

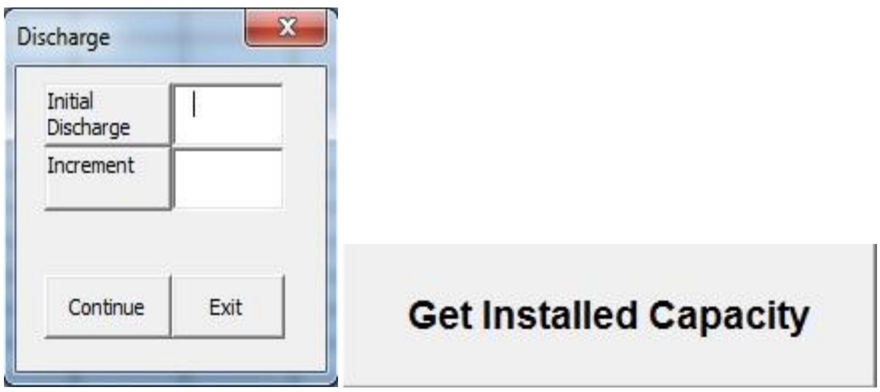


Figure 4-8: Command Button and User Form for Discharge Selection

PROJECT DISCHARGE OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION											Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diameter m	Penstock Diameter m	Tunnel Loss m	Penstock Loss m	Net Head m	Generating Discharge m^3/s	Pumping Discharge m^3/s	Installed Capacity MW	Pumping Capacity MW	Total G Energy GWh	Total P Energy GWh	Power Plant & Switchyard	E/M	Transmission Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	

Figure 4-9: Discharge Selection Page

4.4.1. Diameter Calculations

Diameters of tunnel and penstock are calculated using the same formula expect one difference which is the initial speeds. Diameter, D (m), of the tunnel and penstocks are directly related with the estimated costs of the structures. Increase in diameter also increases the costs. Equation 1 is derived from the basic formula. $speed = Discharge\ /\ Area$

$$D = \sqrt{\frac{4Q}{N\pi v}} \qquad [1]$$

where, $v\ (m/s)$ is the average velocity of the section, Q (m^3/s) is the discharge and N is the number of the penstock or tunnel number.

4.4.2. Head Loss Calculations

There is an inverse proportion between head losses in tunnel and penstock and the diameters of them. Head loss in energy tunnel is calculated from the slope of the tunnel which can also be considered as energy stream line.

$$v_{max} = \frac{Q}{0.785D^2} = \frac{1}{n}\left(\frac{D_t}{4}\right)^{2/3} s^{1/2} \qquad [2]$$

$$s = 2.018\ x10^{-3}\,\frac{Q^2}{{D_t}^{16/3}} \qquad [3]$$

where; $n = 0.014$, s is the slope, $D_t(m)$ is the diameter of the tunnel and Q (m^3/s) is the discharge. The constant is calculated from the division of Manning roughness coefficient. Total head loss in the tunnel is calculated from Equation 4 and Equation 5.

$$h_t = s \; x \; L_t \qquad [4]$$

$$h_t = 2.018 \; x 10^{-3} \frac{Q^2}{{D_t}^{16/3}} \; x \; L_t \qquad [5]$$

where; L_t (m) is the length of the tunnel. Equation 2 and 3 can be modified for the penstock losses. Where; $n = 0.010$ and total head loss for penstock, $h_p(m)$ can be calculated as follows;

$$h_p = 1.482 \; x 10^{-3} \frac{Q^2}{{D_p}^{16/3}} \; x \; L_p \qquad [6]$$

In which $L_p(m)$ and $D_p(m)$ is the length and diameter of the penstock, respectively. After calculation of head losses for penstock and tunnel, net head, $h_{net}(m)$, has to be found in order to calculate the installed capacity of the pumped storage plant. Net head is the difference between the gross head, H_g (m), and the total head losses, (h_t+h_p) (m)

$$h_{net} = H_g - (h_t + h_p) \qquad [7]$$

4.4.3. Installed and Pumping Capacities

There is no difference between conventional hydropower plant and pumped storage plant in terms of calculation of installed capacity. From Equation 8 installed capacities is determined. Efficiency is taken from Table 2-1 and $h_{net}(m)$ is calculated according to Equation 7. Where, η_g is the total efficiency for generation and 9.81 is the unit weight of water in KN/m^3.

$$P = 9.81 * \eta_g * Q * h_{net} \qquad [8]$$

After finding the installed capacity,P (MW), pumping capacity has to be determined. PXSC calculates the pumping capacity according to the operation criteria and efficiencies selected. First volume of water,V(m^3), is calculated during electricity generation from equation 9.

$$V = Q * generation\ hour * 3600 \quad [9]$$

Using calculated volume, maximum pumping discharge, Q_p(m^3/s) , is calculated from equation 10.

$$Q_p = \frac{V}{pumping\ hour * 3600} \quad [10]$$

From the calculated pumping discharge, pumping capacity, P_p (MW), is found from equation 11. In which η_p is the total efficiency of pumping.

$$P_p = 9.81 * Q_p * h_{net} / \eta_p \quad [11]$$

Yearly electricity generation(MWh) and electricity needed for pumping(MWh) within a year is calculated from equation 12 and 13 respectively. Number of working days is calculated from the tailrace water level menu which is examined detailed in section 4.3.

$$Yearly\ Electricity\ Generation = P * generation\ hour * number\ of\ working\ days \quad [12]$$

$$Yearly\ Electricity\ Consumption = P_p * pumping\ hour * number\ of\ working\ days \quad [13]$$

4.4.4. Cost Calculations

Cost of the pumped storage plant basically is assumed to be composed of six components which are;

i. Upper reservoir
ii. Tunnel
iii. Penstock
iv. Power plant and switchyard
v. Electromechanical equipments
vi. Transmission line

Those six components can be considered to be the main elements of pumped storage systems. However, tunnel can be an optional structure and can be determined according to the location of the projects. Other than those structures, other small components can be considered in the contingencies in project cost calculations. For cost calculations PXSC uses unit costs which are defined in the following sections. However, if the unit cost is different than the defined value, user can enter its own unit cost for every facility.

4.4.4.1. Equivalent Annual Annuity Approach

Equivalent Annual Annuity (EAA) Approach can be performed for the determination of yearly expense costs. First the annual investment cost of the project is calculated then the other expenses such as operation and maintenance cost and renewal cost added in order to give the yearly expense cost.

Estimated cost of the project is calculated from the input data related with the project information. After finding the estimated cost of the project, construction cost (CC), project cost (PC) and investment cost (IC) are calculated to find the total cost. Equation 14, 15 and 16 are used for determination of those. Construction cost is the determined by the addition of contingencies to the estimated cost (EC). Project cost is defined as addition of the project control percentage to the construction cost. Finally, addition of interest rate during the construction gives the investment cost (Korkmaz, 2009) and (Yalçın, 2010).

$$\mathrm{CC} = \mathrm{EC} \times (1 + \mathrm{contingency}) \quad [14]$$

$$\mathrm{PC} = \mathrm{CC} + \mathrm{EC} \times \mathrm{project\ control} \quad [15]$$

$$\mathrm{IC} = \mathrm{PC} \times (1 + \mathrm{i})^{y} \quad [16]$$

where, *i*(%) is the interest rate and *y* is the number of years. The investment cost Net Present Value (NPV) of the structure is also called the structure. The annual investment cost is obtained by multiplying investment cost by the amortization factor. Amortization factor,*Amorf*, is calculated as follows;

$$Amorf = \frac{i * (1 + i)^{y}}{(1 + i)^{y} - 1} \quad [17]$$

Finally, adding the operation and maintenance (OMF) and renewal cost (RF) gives the yearly expense of the facility which is calculated as in the Equation 18 (Yalçın, 2010);

$$\mathrm{Yearly\ Expense\ of\ facility} = \mathrm{IC} \times \mathrm{Amorf} + \mathrm{CC} \ (\mathrm{OMF} + \mathrm{RF}) \quad [18]$$

4.4.4.2. Power Plant and Switchyard, Electromechanical Equipments and Transmission Line Cost Calculation

Estimated cost calculation of power plant and switchyard, electromechanical equipments and transmission line are straight forward procedure after one determines the installed capacity providing that the unit cost is known.

Unit cost of the power plant building and switchyard multiplied by the installed capacity gives the cost of the building. Unit cost of the power house is taken 62.5 $/kW in the study of Yalçın (25% of the electromechanical equipments cost), however in the study of Ak it is taken 450 $/kW including the power house, switchyard and electromechanical equipments (If we take the value of electromechanical equipments as 250$/kW same as Yalçın, the remaining 200 $/kW for power plant as switchyard unit cost) (Yalçın, 2010) and (Ak, 2011). Since there are two different figures for the same facility, we assumed the unit cost of power house and switchyard as 150 $/kW which is the average of two studies.

$$\text{Power Plant Cost} = 150 \times \text{P} \quad [19]$$

Unit cost of electromechanical equipment cost multiplied by the installed capacity gives the estimated cost of the equipment. In his study, Küçükbeycan clearly states that the electromechanical equipment cost is significantly varying between producers after the involvement of Chinese manufacturers in conventional hydropower market (Küçükbeycan, 2008). However, in pump storage equipment manufacturing China has not threaten European and Japanese manufacturers yet. High know-how level and continuous improvement of those two manufacturers in pumped storage technology, prevents market involvement of Chinese manufacturers. That’s why electromechanical equipment cost for pumped storage system is higher than conventional hydropower plants. In this study we assumed a default value 400 $/kW for the unit electromechanical equipment cost for pumped storage system. This value is taken from very recent contracts amounts all around the world. Addition to that, we add installation cost option to the tool. User can add the installation cost or not from the drop-down menu. After enabling the installation cost there is an addition of %20 to the estimated cost or by any other means estimated cost is multiplied by 1.2. In default, the installation cost is added to the electromechanical equipment cost.

$$\text{Electromechanical Equipment Cost} = 400 \times \text{P} \quad [20]$$

Estimation of the cost of the energy transmission line is similar to the calculation of the power plant and turbine-generation costs. The estimated cost for energy transmission line is calculated from the Equation 20. Küçükbeycan estimated the unit cost of the 154 kV transmission line 156,200 TL/km which is the average of the minimum and the maximum unit costs defined in the TEİAŞ 2006 unit prices (Küçükbeycan, 2008).

However, TEİAŞ stopped publishing the unit prices booklet after 2010.Therefore, we created a selective menu for 34 kV, 154 kV and 380 kV (mostly used transmission line voltages in Turkey) transmission lines with unit cost 100 $/m, 200 $/m and 300 $/m respectively. Where, L_{trans} (m) is length of transmission line

$$\text{Transmission Line Cost} = \text{unit cost} \times L_{trans} \qquad [21]$$

4.4.4.3. Tunnel Cost Calculation

In the studies of Cofcof (1992) the estimated cost of tunnel is calculated according to the Equation 22. However, each study has different equation constant because of the unit price of the construction components. In his recent study the equation constants calculated 511 from the unit prices of DSİ and tunnel cost is calculated in Turkish Lira. Tunnel is intended to be opened in soil classified as 3 and 4 on a Terzaghi scale consisting of cracked filled with quartz and calcite, fractured and fragmented magmatic rocks, metamorphite and sediments in the medium strength rock. (Cofcof, 2008), (Cofcof, 1996) and (Cofcof, 1992).

$$Tunnel\ Cost_1 = 511 * D^{1.676} * {L_u}^{0.168} * L_t \qquad [22]$$

$$\text{if} \quad L_u \leq 1\ km \qquad L_u = 1$$
$$\text{if} \quad L_u > 1\ km \qquad L_u = L_u$$

where, D(m) is the diameter of the tunnel, $L_t(m)$ is the length of the tunnel, L_u is used for penalizing the tunnel length.

Equation 23 is based on the 2007 unit prices of DSİ. In order to achieve better results we need to escalate the formula using the inflation rate since the date when the formula was derived. Using the inflation rate shown in Table 4-1 Equation 23 is achieved. However PXSC uses equation 24 which is in terms of USD. Exchange rate is assumed 2 TL/USD (CBRT, 2013).

Table 4-1: Inflation Rate 2007 and 2013
(CBRT, 2013)

year	month	value
2007	January	100.00 TL
2013	November	167.82 TL

$$Tunnel\ Cost_2 = 857 * D^{1.676} * {L_u}^{0.168} * L_t \qquad [23]$$

$$Tunnel\ Cost_3 = 429 * D^{1.676} * {L_u}^{0.168} * L_t \qquad [24]$$

4.4.4.4. Penstock Cost Calculation

The estimated cost of penstock is found from multiplication of unit price of the steel and its total weight. Different than other structural components, penstock estimated cost is more accurate because overall cost is mainly composed of steel structures and calculation of penstock weight is well formulated in general. Cofcof uses Equation 25 in his work for determining the estimated cost (Cofcof, 2008). In this formula they used 2007 DSİ unit prices which is 7.01 TL/kg and for representation of additional weights such as supports. 10% of the overall weight is added. Where, *W* (kg) is the weight of penstock, n_p is the number of penstock.

$$Penstock\ Cost_1 = 7.01 * W * 1.1 * n_p \qquad [25]$$

Total weight, *W* (kg), calculated from multiplication of specific weight of the steel with volume. Cofcof used Equation 27 for calculation of thickness which gives the maximum thickness at the turbine end. However for more accurate results, PXSC uses average thickness, t_{ave} (mm), which is calculated from Equation 26 and 27 (Hydraulic Gate and Penstock Association, 1986, p. 57) and 27 (Cofcof, 2008).

$$t_{min} = Max\left(6, \frac{D+800}{400}\right) + cor \qquad [26]$$

$$t_{max} = 0.05 * H * D + cor \qquad [27]$$

$$t_{ave} = \frac{t_{min} + t_{max}}{2} \qquad [28]$$

Modified weight formula according to the average thickness is given below in equation 29. Unit cost of the penstock steel is updated from the 2013 unit cost booklet of DSİ from the article number **B-23.D/4-a as** 10.95 TL/kg. Converting the currency from TL to USD, we obtain the Equation 30 for our calculations (Exchange rate is assumed 2 TL/USD (CBRT, 2013)). Likewise transmission line and electromechanical equipment estimated costs there is an option to add the installation cost of penstock which is 20% of overall cost.

$$W = \pi * D * 7.85 * t_{ave} * L_p \qquad [29]$$

$$Penstock\ Cost_2 = 5.5 * W * 1.1 * n_p \qquad [30]$$

4.4.4.5. Upper Reservoir Cost Calculation

For estimated cost of upper reservoir EİE uses 7.5 $/m^3 for the unit cost of reservoir which they retrieved from the average of the unit cost per meter cube of the stored water from realized projects in Turkey (EİE, 2008). However, every project has different topography conditions which may vary the cost significantly. Because of that fact, in the tool we created a user form for the calculation of the dam body volume.

Estimated cost of the upper reservoir is found by Equation 31. Unit cost for the upper reservoir is changing when the dam type chances. Korkmaz (2009), in her study analyzed and found the estimated costs of the CFRD, ECRD and RCC bodies for Gökçeler Dam. Korkmaz used the 2008 DSİ unit prices and found the estimated costs of three dam types (Korkmaz, 2009). The analysis of Korkmaz is updated by using the unit price of 2013. Then the costs of three dams are obtained. After that the unit cost of each dam type is obtained by dividing the estimated total cost to the dam body volume. Table 4-2 shows unit costs of 2008 and 2013 for three dam types. Details of the unit prices are explained in the Appendıx A.

$$Dam\ Cost = unit\ cost\ \times dam\ body\ volume \qquad [31]$$

Table 4-2: Comparison of Unit Costs for Dam Types
(Korkmaz, 2009), (DSİ, 2013) and (DSİ, 2008)

	Dam Body Volume (m³)	2008		2013		
		Estimated Cost (TL)	Unit Cost (TL/m³)	Estimated Cost (TL)	Unit Cost (TL/m³)	Unit Cost (USD/m³)
CFRD	2,119,250	35,646,507	16.82	50,172,490	23.67	11.84
ECRD	2,943,500	35,640,184	12.11	51,698,199	17.56	8.93
RCC	840,000	40,354,316	48.04	54,707,769	65.13	32.56

4.4.4.6. Cost of Electricity Consumed During Pumping

Cost of electricity consumed during pumping is calculated from the Equation 32. Sum of the multiplication of electricity price, EP (TL/MWh), (sorted from minimum to maximum, also explained in the section 4.3) with pumping capacity, P_P (MW), for each hour gives the total cost of pumping for a day. Multiplying the daily cost with number of working days gives the yearly expense of pumping task.

$$Electricity\ Consumption\ Cost = \sum_{i=1}^{pumping\ hour} (EP_i \times P_P) \times working\ days \qquad [32]$$

4.4.5. Benefit Calculations

Benefits of the PHS are divided in three categories which are electricity generation, peak power benefit and other benefits. Electricity generation benefit is common for all types of power plants. Peak power benefit is only used for hydropower projects in Turkey. Finally, we reserved space for other benefits for feed-in tariffs of PHS support mechanisms.

4.4.5.1. Electricity Generation Benefit

Main revenue of the pumped storage plant is result from electricity generation. Benefit of this task is calculated from Equation 33. Sum of the multiplication of electricity price, EP (TL/MWh), (sorted from maximum to minimum, also explained in the section 4.3) with installed capacity, P (MW), gives the total cost of pumping for a day. Multiplying the daily cost with number of working days gives the yearly expense of pumping task.

$$Electricity\ Generation\ Benefit = \sum_{i=1}^{\substack{generating \\ hour}} (EP_i \times P) \times working\ days \qquad [33]$$

4.4.5.2. Peak Power Benefit

In order to evaluate economic analysis of hydropower projects State Hydraulic Works (DSİ) and General Directorate of Electric Power Resources Survey and Development Administration (EİE) developed their own methodology.

According to the DSİ criteria, first annual investment cost of combined natural gas power plant and thermal power plant is summed with the operation and maintenance costs and then half of the calculated price is defined as Peak Power Benefit. The peak power can be expressed by the following formula (Ak, 2011);

$$Peak\ Power = P\ \ kW\ - \frac{Annual\ Firm\ Energy\ (kWh)}{8760\ \times 0.72\ (hours)} \qquad [34]$$

EİE defines the peak power benefit as the annual investment cost required to generate 1 kW power from a thermal power plant. Peak power is calculated by the following formula;

$$Peak\ Power(kW) = \frac{Annual\ firm\ Energy\ (kWh)}{8760\ \times 0.33\ (hours)} \quad [35]$$

In Table 4-3, benefits related to firm energy, secondary energy and peak power are given for both DSİ and EİE approaches. However, in this study we use electricity market prices rather than firm energy and secondary energy prices. Peak Power Benefit (PPB) is not the real income of the project it is a conseptual price. However, it can be important if one examines, overall production options of the country and if one consider environmental effect of the different energy options.

Table 4-3: Benefits for DSİ and EİE Methods
(Ak, 2011)

Type of Energy Benefit	Prices	
	DSİ	EİE
Firm Energy	6.0 cent/kWh	4.5 cent/kWh
Secondary Energy	3.3 cent/kWh	3.5 cent/kWh
Peak Power Benefit	85.0 $/kW	240.0 $/kW

$$Peak\ Benefit = PPB \times installed\ capacity \quad [36]$$

4.4.5.3. Other Benefit

Other benefits are calculated from the Equation 37. It is found from the multiplication of yearly electricity generation and feed-in tariffs (FIT). However, in Turkish regulations there is no feed-in tariff of support mechanisms for pumped storage projects. Other benefit calculations are created in case of future support mechanisms.

$$Other\ Benefits = FIT \times yearly\ electricity\ generation \quad [37]$$

4.5. Penstock and Tunnel Diameter Selection

After calculation of the optimum discharge, penstock and tunnel diameter determination are the next stages. An **"Initial Penstock Diameter"** and **"Diameter**

Increment" value is entered into the form and calculations are repeated with fixed **"Optimum Discharge"** after pressing the **"Continue"** command button (see Figure 4-10). Optimum penstock diameter is selected for the condition satisfies the maximum net benefit and maximum allowable penstock speed which is 7.5 m/s at the same time (Unite States Department of Interior - Bureau of Reclemation, 1987).

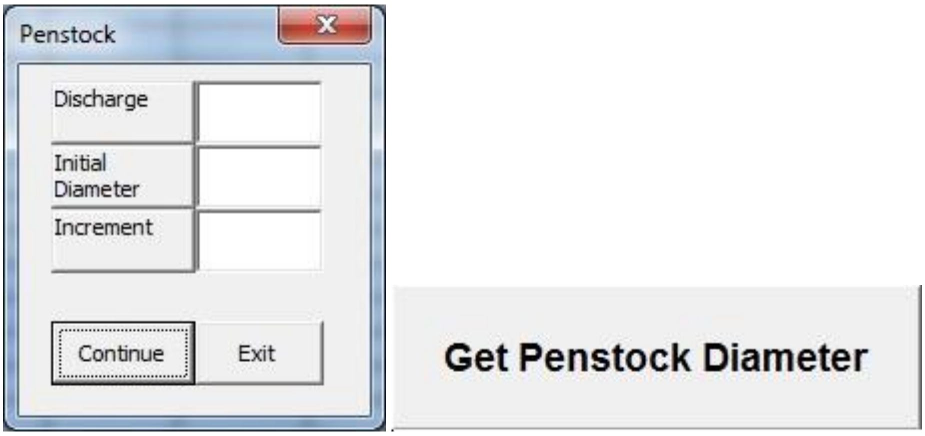


Figure 4-10: Command Button and User Form for Penstock Selection

Next, **"Initial Tunnel Diameter"** and **"Diameter Increment"** is entered into the form and calculations are repeated with fixed **"Optimum Discharge"** and **"Penstock Diameter"** after pressing the **"Continue"** command button (see Figure 4-11). Optimum tunnel diameter is selected for the conditions simultaneously satisfies the maximum net benefit and allowed tunnel speed of being between 3.0 m/s and 5.0 m/s (Coleman, Wei, & Lindell, 2004).

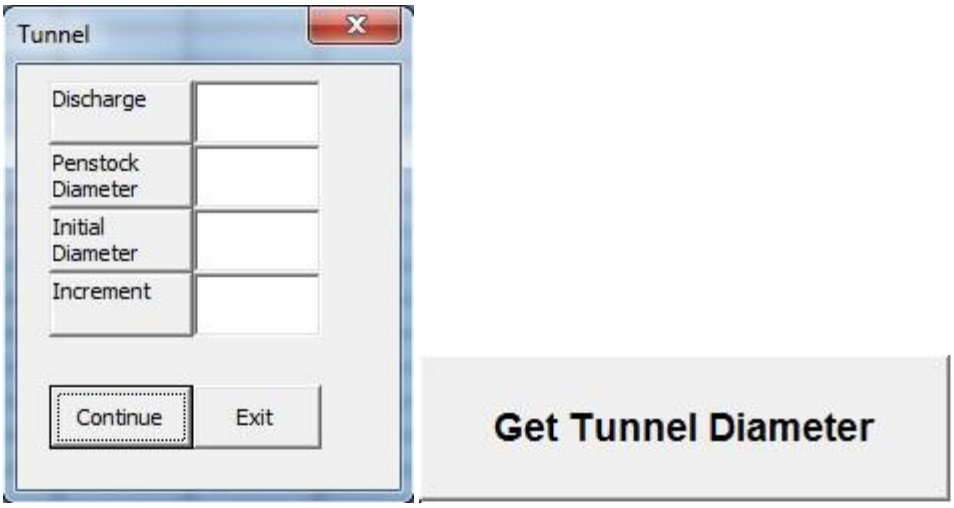


Figure 4-11: Command Button and User Form for Tunnel Selection

4.6. Economical Analysis

There are two main project rantability indicators which are **"Revenue/Expenditure Ratio"** and **"Internal Rate of Return (IRR)"**. These two indexes are calculated in their own sheets. After, determination of the maximum B–C for tunnel diameter in **"Tunnel Diameter Selection"** sheet, user selects any cell in corresponding row and pressing the **"Go to Economy"** command button in the sheet all the economical data in that row are transferred to the **"Economy Summary"** sheet (see Figure 4-12).

Figure 4-12: Command Button for Data Transfer to Economical Analysis

In the **"Economy Summary"** sheet there are four tables named **"Estimated Cost Table"** (see Table 4-4), **"Investment Cost and Annual Expense Table"** (see Table 4-5), **"Replacement Cost Table"** (see Table 4-6) and **"Investment over Years"** (see Table 4-7) and numbered as 1.1, 1.2, 1.3 and 1.4 respectively. Estimated costs of the facilities are transferred to the **"Table 1.1"**of PXSC after the execution of command button **"Go to Economy"** and cumulative estimated cost of the pumped storage is calculated.

Table 4-4: Estimated Cost Table in PXSC
(Table 1.1 in PXSC)

NAME	ESTIMATED COST($)
Upper Reservoir	0
Tunnel	0
Penstock	0
Power Plant and Tailrace	0
Electromechanical Equipments	0
Transmission Line	0
TOTAL ESTIMATED COST	

Table 4-5: Investment Cost and Annual Expense Table in PXSC
(Table 1.2 in PXSC)

contingency = 0%

project control = 0%

NAME	Estimated Cost	Construction Cost	Project Control	Project Cost	Interest During Construction	Investment Cost	Depriciation Factor	Depriciation Expenditure	O&M Factor	O&M Expenditure	Renewal Factor	Renewal Expenditure	Total Expenditure
Upper Reservoir	0	0	0	0	0	0	0.00000	0	0.000	0	0.000000	0.00	0
Tunnel	0	0	0	0	0	0	0.00000	0	0.000	0	0.000000	0.00	0
Penstock	0	0	0	0	0	0	0.00000	0	0.000	0	0.000000	0.00	0
Power Plant and Tailrace	0	0	0	0	0	0	0.00000	0	0.000	0	0.000000	0.00	0
Electromechanical Equipments	0	0	0	0	0	0	0.00000	0	0.000	0	0.000000	0.00	0
Transmission Line	0	0	0	0	0	0	0.00000	0	0.000	0	0.000000	0.00	0
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**		**0**		**0**		**0**	**0**

Expenditure= 0

Revenue=

Net Benefit=

Benefit / Cost Ratio =

Table 4-6: Replacement Cost Table in PXSC
(Table 1.3 in PXSC)

NAME	CONSTRUCTION COST	RENEWAL TIME(year)	RENEWAL RATIO	YEARS			
				20 YEAR	35 YEAR	40 YEAR	45 YEAR
Upper Reservoir	0	45	0.02				0
Tunnel	0	45	0.02				0
Penstock	0	45	0.50				0
Power Plant and Tailrace	0	20	0.10	0		0	
Electromechanical Equipments	0	35	0.80		0		
Transmission Line	0	45	0.80				0
TOTAL				**0**	**0**	**0**	**0**

Table 4-7: Investment over Years Table in PXSC
(Table 1.4 in PXSC)

	PROJECT COST				**PROJECT COST**	**INVESTMENT COST**
NAME	**1st YEAR**	**2nd YEAR**	**3rd YEAR**	**4th YEAR**		
Upper Reservoir	0	0	0		0	0
Tunnel	0	0	0		0	0
Penstock	0	0	0		0	0
Power Plant and Tailrace	0	0	0		0	0
Electromechanical Equipments	0	0	0	0	0	0
Transmission Line	0	0	0	0	0	0
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**

In **"Table 1.2"** of PXSC construction costs, project costs and investment costs are calculated with equation 14, 15 and 16 respectively, using the **"project control"** and **"contingency"** percentage data entered in the **"Project Information"** sheet. Additionally, depreciation cost, operation and maintenance cost and renewal (replacement) cost is calculated for a year with the equation 38, 39 and 40 respectively, using the **"depreciation factor"**, DF, **" operation and maintenance factor"** and **"replacement factor"** values from the **"Project Information"** sheet. Finally all the cost variables for each facility are summed and a total expenditure value is found.

$$\text{Depriciation Cost} = \text{IC} \times \text{DF} \quad [38]$$

$$\text{O\&}M\ Cost = CC \times OMF \quad [39]$$

$$\text{Renewal Cost} = \text{CC} \times \text{RF} \quad [40]$$

In **"Table 1.3"** of PXSC replacement costs are tabulated for the corresponding years which are the standard renewal periods of the DSİ.

$$\text{Replacement Cost} = \text{CC} \times \text{renewal ratio} \quad [41]$$

In **"Table 1.4"** of PXSC cash flow of the project is tabulated for the construction schedule given in Table 4-8. Project cost of the facility for corresponding year is calculated by Equation 42.

$$\text{Project cost per year} = \frac{\text{PC}}{\text{construction year of facility}} \quad [42]$$

Table 4-8: Assumed Construction Schedule in PXSC

Name of the Facility	1st year						2nd year						3rd year						4th year					
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
Upper Reservoir	■	■	■	■	■	■	■	■	■	■	■	■												
Tunnel													■	■	■	■	■	■						
Penstock							■	■	■	■	■	■	■	■	■	■	■	■						
Power Plant and Tailrace				■	■	■	■	■	■	■	■	■	■	■	■									
Electromechanical Equipments										■	■	■	■	■	■	■	■	■	■	■	■			
Transmission Line																			■	■	■	■	■	■

4.6.1. Revenue/Expenditure Ratio

Using the calculated values in **"Table 1.2"**, **"Table 1.3"** and **"Table 1.4"** Revenue/Expenditure ratio is calculated in **"Table 1.5"** of PXSC by dividing sum of all revenues to sum of all expenditures. All the present values of the yearly revenues and expenditures are calculated with the interest rate entered to the interest information part. Then dividing sum of all revenues to sum of all expenditures gives the ratio.

4.6.2. Internal Rate of Return

Internal rate of return (IRR) is another indicator of project rantability. **"Table 1.6"** in PXSC is created for determination of IRR of projects. In order to calculate IRR, the first, project expenses are determined. Yearly operation and maintenance cost summed with the replacement cost of the facilities for each year operation. Investment cost over years of construction is calculated secondly. After that, net cash flow is calculated including the revenues is determined in terms of present values. From the Goal Seek function of the Excel internal rate of return value is calculated which makes the sum of the cash flow is zero.

CHAPTER 5

ANALYSES OF ASLANTAŞ PHS WITH PXSC AND DISCUSSIONS OF THE RESULTS

5.1. General

Every investment has its own cost and income criteria specified for. Economical return of an investment may not always be a primary priority, other benefits such as social benefits, political benefits, and environmental benefits may be more important. However, it is the first step to analyze the economical benefits providing that other concerns will follow it. In present study our aim is to make economical evaluation of pumped storage projects according to market situations of Turkey. In order to achieve this goal we made a tool named PXSC and in the present chapter evaluation of feasibility of the pumped storage projects using PXSC is examined.

Demirdizen (2013) showed in his work feed-in tariff mechanism and RES support mechanism in Turkey are not in a satisfactory level for renewable energy investments and day-ahead market prices are more profitable. Addition to that, unsustainable market structure creates a risk for energy companies. Increasing share of renewable energies in total energy production has possibility of creating imbalances in the system therefore, force instability in system marginal prices (Demirdizen, 2013). Pumped storage projects may be the solution for that problem addition to their peak power subsidization.

This chapter focuses on whether PHS in Turkey is profitable or not, on various cases. After the analysis with PXSC role of real time electricity prices and rantability of cases can be seen clearly.

5.2. Case Studies on Aslantaş PHS

In order to test the PXSC and investigate the pumped storage project feasibility in Turkey we choose the Aslantaş PHS which was developed by EİE. Detail information about the Aslantaş PHS is stated in section 5.2.1. Analyses of Aslantaş PHS are made for five different scenarios. Aslantaş HEPP was commissioned in 1984 and located on the river Ceyhan in Osmaniye. Dam body of Aslantaş HEPP is 8,493,000 m^3 and it has a height of 95 m from foundation. Aslantaş has a reservoir area of 49 km^2 and 1150 hm^3 water storage volume. Aslantaş Dam, irrigates water to the area of approximately 150,000 hectares, Aslantaş HEPP which has an installed capacity 138 MW generates 569 GWh electricity annually. EIE was selected the Aslantaş Dam to be lower reservoir and developed a pure PHS (EİE, 2008).

Further Büyükyıldız (2012) in her study investigate the hybrid pumped storage case for Aslantaş PHS, which uses Wind Power Plant (WPP) for pumping. In her study she faced capacity problems in WPP because of landing and unavailable wind. Therefore, she optimized a 30 MW WPP for pumping purpose, which has an electricity generation capacity of 162.8 GWh annually. EİE study, which needs 722 GWh electricity for pumping, is not analyzed. Instead, she worked a smaller scale of Aslantaş pumped storage project. According to Büyükyıldız, Aslantaş hybrid PHS has 14.5 MW installed capacity of pumped storage power plant and 30 MW of WPP (Büyükyıldız, 2012).

5.2.1. PXSC Inputs for Analyses of Cases

Since Aslantaş Pumped Hydroelectricity Storage Power Plant was developed by EİE, input values for PXSC is taken from the pre-feasibility study of EİE which is tabulated in Table 5-1 (EİE, 2008). Day Ahead Market Electricity prices are taken from the MFRC. Electricity prices are between **01.07.2009 00:00** and **31.10.2013 23:00** (MFRC, 2013). Between those dates there are 1784 days and 38016 hours and for every contributing hour, real time electricity price values are entered.

Table 5-1: Inputs Needed for PXSC Analyses
(Data are compiled from EİE (EİE, 2008))

Tailrace Level	130.00 m
Min. Upper Reservoir Level	285.00 m
Max.Upper Reservoir Level	300.00 m
Reservoir Volume	4,100,000 m^3
Penstock Length	875.00 m
Penstock Number	2
Tunnel Length	225.00 m
Tunnel Number	2
Transmission Line Voltage	380 kV
Transmission Line Length	30.00 km
Number of Working Days	365
Generating Hour in a Day	3
Pumping Hour in a Day	5

5.2.2. Scenarios and Results

Analyses of five cases are performed by using price and cost alternatives Basic information for analyses in all cases are the same, however electricity prices and unit costs for calculations are changed. Results of the Scenario 4 is given in below, other cases are given in Appendıx H. The description of the cases as follows:

Scenario 1: Real time electricity prices and default unit costs are used.

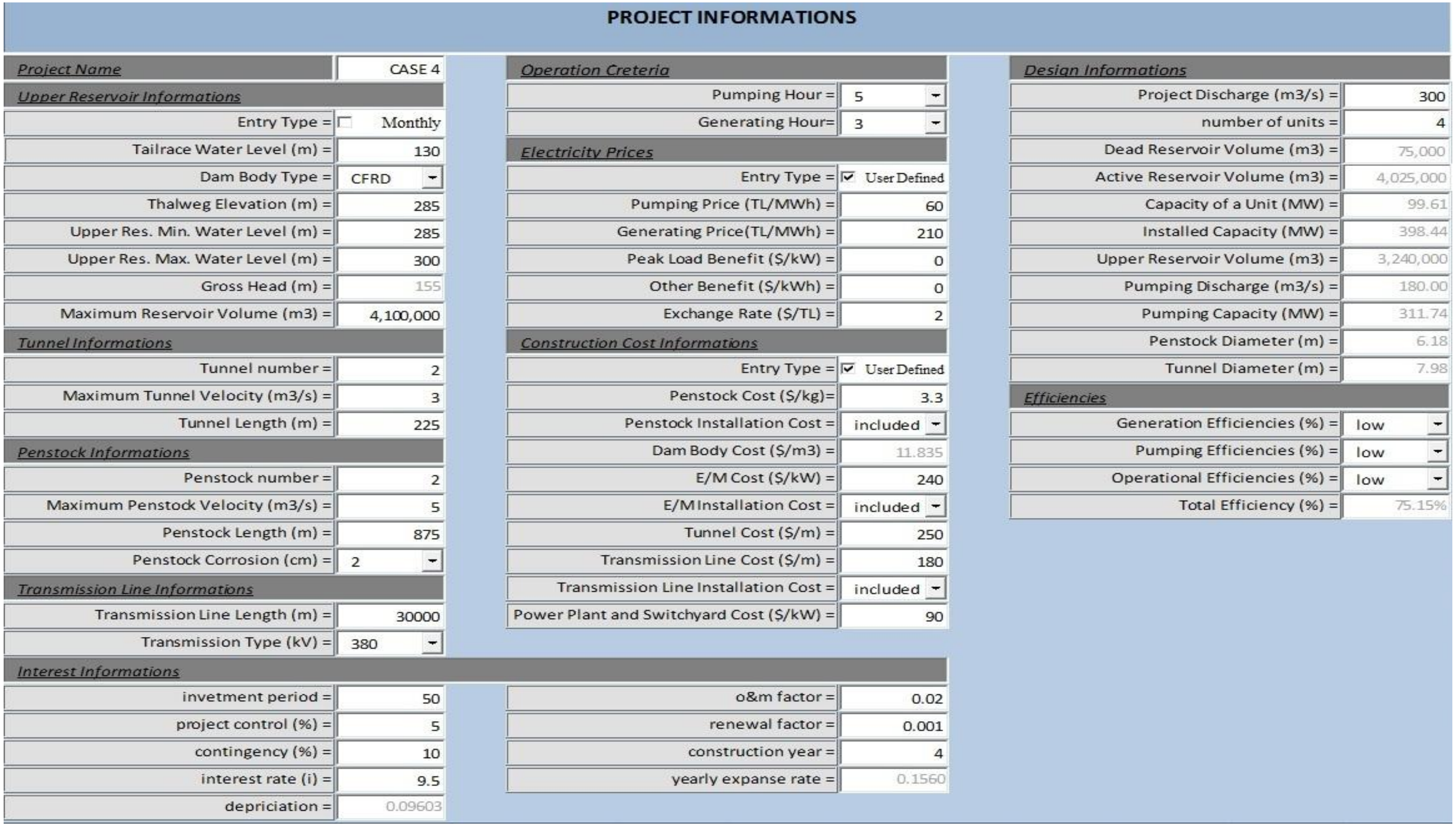
Scenario 2: Additionally to the Scenario 1 we use peak power benefit which is assumed 240$/kW.

Scenario 3: Real time electricity prices are used. Unit costs of the facilities are reduced by %40 in order to represent the market prices for construction. Thus, the costs of the pumped storage will decrease besides the benefits will be same as Scenario 1. This will lead to an increase in the feasibility of the project.

Scenario 4: The unit costs of Scenario 3 are used. However, different than Scenario 3 this time we use fixed electricity prices which are increased and decreased by 30% for generating and pumping price respectively.

Scenario 5: The same unit costs are used as in Scenario 3 and Scenario 4. But, Electricity prices are retrieved from the European Power Exchange SPOT (EPEX Spot, 2013). EPEX Spot is an exchange for power spot trading in Germany, France, Austria and Switzerland for day ahead market and intraday markets. In European Power Exchange Market there are three price zones. Germany and Austria are cover one of the zones together market named PHELIX. France is another zone market named FRANCE and finally Switzerland is market named SWISSIX. Electricity Price Index (ELIX)(generated from other 3 markets) and PHELIX prices are taken from the web site of EPEX Spot and in analysis of scenario 5 ELIX prices are used. Details of the ELIX and PHELIX prices are in Appendıx G.

Figure 5-1 is the data entry page of PXSC and Figure 5-2 is the discharge selection of table of Scenario 4. Optimum discharge is found as 379 m^3/s which is the highest net benefit value. Figure 5-3 shows the variation of net benefit against discharge and the peak point corresponds to the optimum project discharge. Assigned discharge value is entered as an input for penstock and diameter selection pages and the calculations are carried out.



PROJECT INFORMATIONS

Project Name	CASE 4
Upper Reservoir Informations	
Entry Type =	☐ Monthly
Tailrace Water Level (m) =	130
Dam Body Type =	CFRD
Thalweg Elevation (m) =	285
Upper Res. Min. Water Level (m) =	285
Upper Res. Max. Water Level (m) =	300
Gross Head (m) =	155
Maximum Reservoir Volume (m3) =	4,100,000
Tunnel Informations	
Tunnel number =	2
Maximum Tunnel Velocity (m3/s) =	3
Tunnel Length (m) =	225
Penstock Informations	
Penstock number =	2
Maximum Penstock Velocity (m3/s) =	5
Penstock Length (m) =	875
Penstock Corrosion (cm) =	2
Transmission Line Informations	
Transmission Line Length (m) =	30000
Transmission Type (kV) =	380

Operation Creteria	
Pumping Hour =	5
Generating Hour=	3
Electricity Prices	
Entry Type =	☑ User Defined
Pumping Price (TL/MWh) =	60
Generating Price(TL/MWh) =	210
Peak Load Benefit ($/kW) =	0
Other Benefit ($/kWh) =	0
Exchange Rate ($/TL) =	2
Construction Cost Informations	
Entry Type =	☑ User Defined
Penstock Cost ($/kg)=	3.3
Penstock Installation Cost =	included
Dam Body Cost ($/m3) =	11.835
E/M Cost ($/kW) =	240
E/M Installation Cost =	included
Tunnel Cost ($/m) =	250
Transmission Line Cost ($/m) =	180
Transmission Line Installation Cost =	included
Power Plant and Switchyard Cost ($/kW) =	90

Design Informations	
Project Discharge (m3/s) =	300
number of units =	4
Dead Reservoir Volume (m3) =	75,000
Active Reservoir Volume (m3) =	4,025,000
Capacity of a Unit (MW) =	99.61
Installed Capacity (MW) =	398.44
Upper Reservoir Volume (m3) =	3,240,000
Pumping Discharge (m3/s) =	180.00
Pumping Capacity (MW) =	311.74
Penstock Diameter (m) =	6.18
Tunnel Diameter (m) =	7.98
Efficiencies	
Generation Efficiencies (%) =	low
Pumping Efficiencies (%) =	low
Operational Efficiencies (%) =	low
Total Efficiency (%) =	75.15%

Interest Informations

invetment period =	50	o&m factor =	0.02
project control (%) =	5	renewal factor =	0.001
contingency (%) =	10	construction year =	4
interest rate (i) =	9.5	yearly expanse rate =	0.1560
depriciation =	0.09603		

Figure 5-1: Data Entry Page for Scenario 4

CASE 4

PROJECT DISCHARGE OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION											Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diameter m	Penstock Diameter m	Tunnel Loss m	Penstock Loss m	Net Head m	Generating Discharge m^3/s	Pumping Discharge m^3/s	Installed Capacity MW	Pumping Capacity MW	Total G Energy GWh	Total P Energy GWh	Power Plant & Switchyard	E/M	Transmission Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
8.74	6.77	0.14	1.56	167.30	360.00	216.00	**516.07**	**403.77**	565.10	736.88	7,245,143	19,320,381	842,343	667,300	685,347	6,236,937	22,106,487	**57,103,937**	59,335,235	0	0	59,335,235	2,231,298
8.75	6.78	0.14	1.56	167.30	361.00	216.60	**517.51**	**404.90**	566.68	738.94	7,265,405	19,374,412	842,343	668,855	685,347	6,253,572	22,168,310	**57,258,243**	59,501,172	0	0	59,501,172	2,242,929
8.77	6.79	0.14	1.55	167.31	362.00	217.20	**518.96**	**406.03**	568.26	741.00	7,285,666	19,428,444	842,343	670,409	685,347	6,270,206	22,230,133	**57,412,548**	59,667,109	0	0	59,667,109	2,254,561
8.78	6.80	0.14	1.55	167.31	363.00	217.80	**520.40**	**407.16**	569.84	743.07	7,305,928	19,482,476	842,343	671,962	685,347	6,286,839	22,291,957	**57,566,852**	59,833,048	0	0	59,833,048	2,266,196
8.79	6.81	0.14	1.55	167.31	364.00	218.40	**521.84**	**408.29**	571.42	745.13	7,326,190	19,536,508	842,343	673,515	685,347	6,303,472	22,353,781	**57,721,155**	59,998,987	0	0	59,998,987	2,277,832
8.80	6.82	0.14	1.54	167.32	365.00	219.00	**523.29**	**409.42**	573.00	747.19	7,346,453	19,590,540	842,343	675,067	685,347	6,320,103	22,415,605	**57,875,458**	60,164,928	0	0	60,164,928	2,289,470
8.82	6.83	0.14	1.54	167.32	366.00	219.60	**524.73**	**410.55**	574.58	749.25	7,366,715	19,644,573	842,343	676,618	685,347	6,336,733	22,477,430	**58,029,760**	60,330,870	0	0	60,330,870	2,301,110
8.83	6.84	0.14	1.54	168.32	367.00	220.20	**529.32**	**414.14**	579.60	755.80	7,431,126	19,816,335	842,343	678,169	768,454	6,353,363	22,673,960	**58,563,750**	60,858,370	0	0	60,858,370	2,294,620
8.84	6.85	0.14	1.54	168.33	368.00	220.80	**530.77**	**415.27**	581.19	757.87	7,451,508	19,870,689	842,343	679,719	768,454	6,369,991	22,736,153	**58,718,858**	61,025,299	0	0	61,025,299	2,306,441
8.85	6.86	0.14	1.53	168.33	369.00	221.40	**532.22**	**416.41**	582.78	759.94	7,471,891	19,925,044	842,343	681,268	768,454	6,386,619	22,798,346	**58,873,965**	61,192,229	0	0	61,192,229	2,318,263
8.86	6.87	0.14	1.53	168.33	370.00	222.00	**533.67**	**417.54**	584.37	762.02	7,492,275	19,979,399	842,343	682,817	768,454	6,403,246	22,860,539	**59,029,072**	61,359,159	0	0	61,359,159	2,330,087
8.88	6.87	0.14	1.53	168.33	371.00	222.60	**535.13**	**418.68**	585.96	764.09	7,512,658	20,033,754	842,343	684,365	768,454	6,419,871	22,922,733	**59,184,178**	61,526,091	0	0	61,526,091	2,341,913
8.89	6.88	0.14	1.53	168.34	372.00	223.20	**536.58**	**419.82**	587.55	766.16	7,533,041	20,088,110	842,343	685,912	768,454	6,436,496	22,984,927	**59,339,283**	61,693,024	0	0	61,693,024	2,353,740
8.90	6.89	0.14	1.52	168.34	373.00	223.80	**538.03**	**420.95**	589.14	768.24	7,553,425	20,142,466	842,343	687,459	768,454	6,453,120	23,047,121	**59,494,388**	61,859,958	0	0	61,859,958	2,365,570
8.91	6.90	0.14	1.52	168.34	374.00	224.40	**539.48**	**422.09**	590.73	770.31	7,573,808	20,196,822	842,343	689,005	768,454	6,469,743	23,109,316	**59,649,492**	62,026,892	0	0	62,026,892	2,377,401
8.92	6.91	0.14	1.52	168.35	375.00	225.00	**540.93**	**423.22**	592.32	772.38	7,594,192	20,251,179	842,343	690,550	768,454	6,486,366	23,171,511	**59,804,594**	62,193,828	0	0	62,193,828	2,389,234
8.93	6.92	0.14	1.51	168.35	376.00	225.60	**542.39**	**424.36**	593.91	774.46	7,614,576	20,305,536	842,343	692,095	768,454	6,502,987	23,233,707	**59,959,697**	62,360,765	0	0	62,360,765	2,401,068
8.95	6.93	0.14	1.51	168.35	377.00	226.20	**543.84**	**425.50**	595.50	776.53	7,634,960	20,359,893	842,343	693,639	768,454	6,519,607	23,295,902	**60,114,798**	62,527,702	0	0	62,527,702	2,412,904
8.96	6.94	0.14	1.51	168.36	378.00	226.80	**545.29**	**426.63**	597.09	778.60	7,655,344	20,414,250	842,343	695,182	768,454	6,536,227	23,358,099	**60,269,899**	62,694,641	0	0	62,694,641	2,424,742
8.97	6.95	0.14	1.51	168.36	379.00	227.40	**546.74**	**427.77**	598.68	780.68	7,675,728	20,468,608	842,343	696,725	768,454	6,552,845	23,420,295	**60,424,998**	62,861,580	0	0	62,861,580	2,436,582
8.98	6.96	0.13	1.50	168.36	380.00	228.00	**548.19**	**428.90**	598.68	780.68	7,696,112	20,522,966	842,343	698,267	768,454	6,569,463	23,420,295	**60,517,900**	62,861,580	0	0	62,861,580	2,343,680
8.99	6.97	0.13	1.50	168.36	381.00	228.60	**549.65**	**430.04**	598.68	780.68	7,716,497	20,577,325	842,343	699,809	768,454	6,586,080	23,420,295	**60,610,802**	62,861,580	0	0	62,861,580	2,250,779
9.01	6.98	0.13	1.50	168.37	382.00	229.20	**551.10**	**431.18**	598.68	780.68	7,736,881	20,631,684	842,343	701,349	768,454	6,602,696	23,420,295	**60,703,701**	62,861,580	0	0	62,861,580	2,157,879
9.02	6.98	0.13	1.50	168.37	383.00	229.80	**552.55**	**432.31**	598.68	780.68	7,757,266	20,686,043	842,343	702,889	768,454	6,619,311	23,420,295	**60,796,600**	62,861,580	0	0	62,861,580	2,064,980
9.03	6.99	0.13	1.49	168.37	384.00	230.40	**554.00**	**433.45**	598.68	780.68	7,777,651	20,740,402	842,343	704,429	768,454	6,635,925	23,420,295	**60,889,498**	62,861,580	0	0	62,861,580	1,972,082
9.04	7.00	0.13	1.49	168.38	385.00	231.00	**555.45**	**434.58**	598.68	780.68	7,798,036	20,794,762	842,343	705,968	768,454	6,652,538	23,420,295	**60,982,395**	62,861,580	0	0	62,861,580	1,879,186
9.05	7.01	0.13	1.49	168.38	386.00	231.60	**556.91**	**435.72**	598.68	780.68	7,818,421	20,849,122	842,343	707,506	768,454	6,669,151	23,420,295	**61,075,290**	62,861,580	0	0	62,861,580	1,786,290
9.06	7.02	0.13	1.49	168.38	387.00	232.20	**558.36**	**436.86**	598.68	780.68	7,838,806	20,903,482	842,343	709,043	768,454	6,685,762	23,420,295	**61,168,185**	62,861,580	0	0	62,861,580	1,693,396
9.08	7.03	0.13	1.48	168.38	388.00	232.80	**559.81**	**437.99**	598.68	780.68	7,859,191	20,957,842	842,343	710,580	768,454	6,702,373	23,420,295	**61,261,078**	62,861,580	0	0	62,861,580	1,600,502
9.09	7.04	0.13	1.48	168.39	389.00	233.40	**561.26**	**439.13**	598.68	780.68	7,879,576	21,012,203	842,343	712,116	768,454	6,718,983	23,420,295	**61,353,970**	62,861,580	0	0	62,861,580	1,507,610

Figure 5-2: Optimum Discharge Selection for Scenario 4

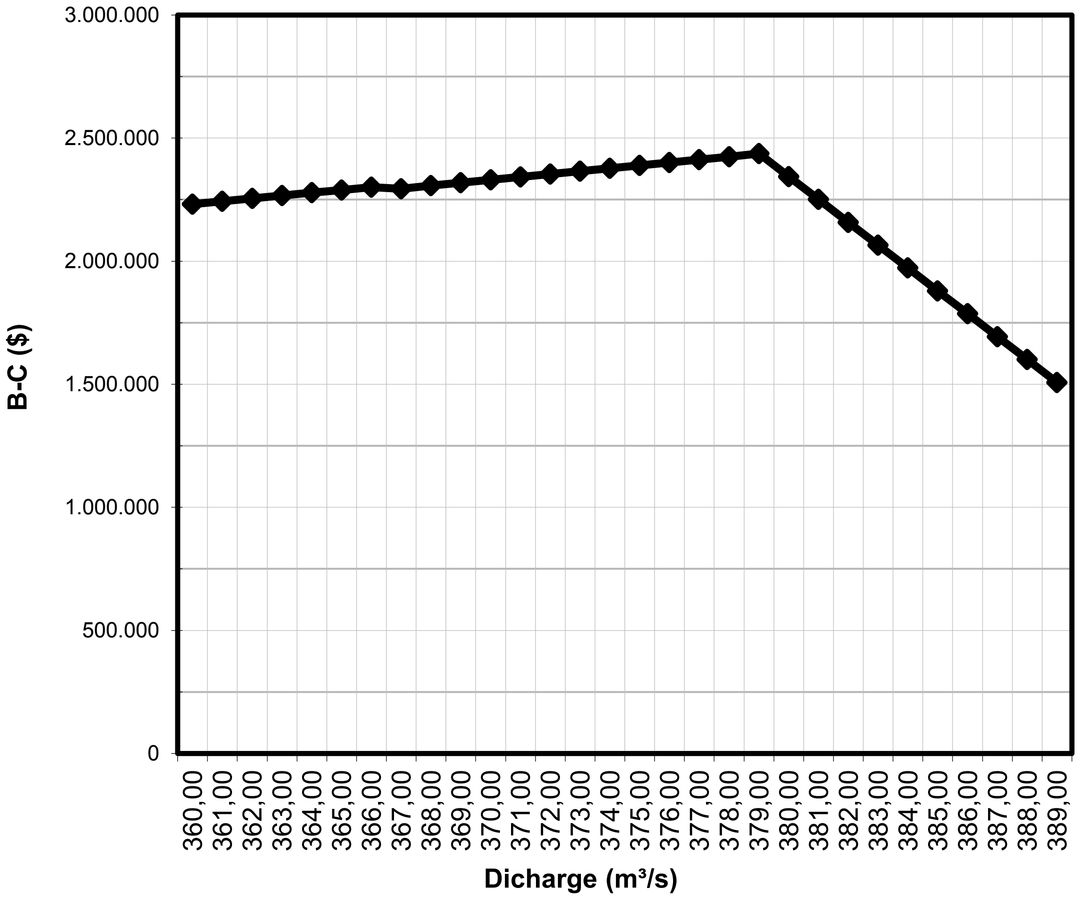


Figure 5-3: Discharge vs. B-C Curve for Scenario 4

CASE 4

PENSTOCK DIAMETER OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION												Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diameter m	Penstock Diameter m	Penstock Speed m^3/s	Tunnel Loss m	Penstock Loss m	Net Head m	Generating Discharge m^3/s	Pumping Discharge m^3/s	Installed Capacity MW	Pumping Capacity MW	Total G Energy GWh	Total P Energy GWh	Power Plant & Switchyard	E/M	Transmission Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
8.97	4.00	15.09	0.14	28.65	141.22	379.00	227.40	**458.60**	**358.81**	502.17	654.82	6,438,330	17,168,879	842,343	696,725	768,454	2,295,974	19,644,727	**47,855,431**	52,727,711	0	0	52,727,711	4,872,280
8.97	4.10	14.36	0.14	25.11	144.75	379.00	227.40	**470.08**	**367.79**	514.74	671.22	6,599,489	17,598,637	842,343	696,725	768,454	2,404,697	20,136,458	**49,046,804**	54,047,551	0	0	54,047,551	5,000,748
8.97	4.20	13.68	0.14	22.08	147.78	379.00	227.40	**479.92**	**375.48**	525.51	685.26	6,737,572	17,966,860	842,343	696,725	768,454	2,515,924	20,557,781	**50,085,659**	55,178,408	0	0	55,178,408	5,092,749
8.97	4.30	13.06	0.14	19.48	150.39	379.00	227.40	**488.37**	**382.10**	534.77	697.34	6,856,321	18,283,522	842,343	696,725	768,454	2,629,654	20,920,107	**50,997,125**	56,150,915	0	0	56,150,915	5,153,790
8.97	4.40	12.47	0.14	17.23	152.63	379.00	227.40	**495.67**	**387.81**	542.76	707.76	6,958,800	18,556,801	842,343	696,725	768,454	2,745,887	21,232,794	**51,801,804**	56,990,188	0	0	56,990,188	5,188,383
8.97	4.50	11.92	0.14	15.29	154.58	379.00	227.40	**502.00**	**392.76**	549.68	716.78	7,047,537	18,793,432	842,343	696,725	768,454	2,864,624	21,503,549	**52,516,664**	57,716,910	0	0	57,716,910	5,200,246
8.97	4.60	11.41	0.14	13.59	156.27	379.00	227.40	**507.49**	**397.05**	555.70	724.62	7,124,620	18,998,987	842,343	696,725	768,454	2,985,865	21,738,746	**53,155,739**	58,348,194	0	0	58,348,194	5,192,455
8.97	4.70	10.93	0.14	12.12	157.74	379.00	227.40	**512.27**	**400.80**	560.94	731.46	7,191,785	19,178,094	842,343	696,725	768,454	3,109,609	21,943,682	**53,730,693**	58,898,255	0	0	58,898,255	5,167,563
8.97	4.80	10.48	0.14	10.83	159.03	379.00	227.40	**516.45**	**404.07**	565.51	737.43	7,250,481	19,334,616	842,343	696,725	768,454	3,235,857	22,122,775	**54,251,250**	59,378,952	0	0	59,378,952	5,127,701
8.97	4.90	10.05	0.14	9.71	160.16	379.00	227.40	**520.11**	**406.94**	569.53	742.66	7,301,919	19,471,784	842,343	696,725	768,454	3,364,609	22,279,723	**54,725,557**	59,800,212	0	0	59,800,212	5,074,655
8.97	5.00	9.66	0.14	8.71	161.15	379.00	227.40	**523.33**	**409.45**	573.05	747.25	7,347,119	19,592,316	842,343	696,725	768,454	3,495,864	22,417,637	**55,160,458**	60,170,382	0	0	60,170,382	5,009,924
8.97	5.10	9.28	0.14	7.84	162.02	379.00	227.40	**526.17**	**411.67**	576.16	751.30	7,386,939	19,698,505	842,343	696,725	768,454	3,629,623	22,539,139	**55,561,728**	60,496,501	0	0	60,496,501	4,934,773
8.97	5.20	8.93	0.14	7.07	162.80	379.00	227.40	**528.68**	**413.63**	578.90	754.88	7,422,109	19,792,290	842,343	696,725	768,454	3,765,885	22,646,448	**55,934,253**	60,784,525	0	0	60,784,525	4,850,272
8.97	5.30	8.59	0.14	6.39	163.48	379.00	227.40	**530.89**	**415.37**	581.33	758.05	7,453,244	19,875,318	842,343	696,725	768,454	3,904,651	22,741,449	**56,282,183**	61,039,513	0	0	61,039,513	4,757,330
8.97	5.40	8.28	0.14	5.78	164.08	379.00	227.40	**532.86**	**416.91**	583.48	760.86	7,480,872	19,948,992	842,343	696,725	768,454	4,045,920	22,825,747	**56,609,052**	61,265,775	0	0	61,265,775	4,656,723
8.97	5.50	7.98	0.14	5.24	164.62	379.00	227.40	**534.61**	**418.28**	585.40	763.36	7,505,441	20,014,510	842,343	696,725	768,454	4,189,693	22,900,714	**56,917,881**	61,466,991	0	0	61,466,991	4,549,110
8.97	5.60	7.70	0.14	4.76	165.10	379.00	227.40	**536.17**	**419.50**	587.11	765.58	7,527,338	20,072,901	842,343	696,725	768,454	4,335,970	22,967,525	**57,211,256**	61,646,317	0	0	61,646,317	4,435,061
8.97	5.70	7.43	0.14	4.33	165.53	379.00	227.40	**537.56**	**420.59**	588.63	767.57	7,546,893	20,125,047	842,343	696,725	768,454	4,484,750	23,027,190	**57,491,402**	61,806,462	0	0	61,806,462	4,315,060
8.97	5.80	7.18	0.14	3.95	165.92	379.00	227.40	**538.81**	**421.56**	590.00	769.35	7,564,390	20,171,708	842,343	696,725	768,454	4,636,034	23,080,580	**57,760,234**	61,949,763	0	0	61,949,763	4,189,529
8.97	5.90	6.93	0.14	3.60	166.26	379.00	227.40	**539.93**	**422.44**	591.22	770.95	7,580,078	20,213,541	842,343	696,725	768,454	4,789,821	23,128,446	**58,019,407**	62,078,238	0	0	62,078,238	4,058,830
8.97	6.00	6.71	0.14	3.30	166.57	379.00	227.40	**540.93**	**423.22**	592.32	772.38	7,594,168	20,251,115	842,343	696,725	768,454	4,946,112	23,171,438	**58,270,355**	62,193,633	0	0	62,193,633	3,923,277
8.97	6.10	6.49	0.14	3.02	166.85	379.00	227.40	**541.83**	**423.93**	593.31	773.67	7,606,847	20,284,925	842,343	696,725	768,454	5,104,906	23,210,124	**58,514,323**	62,297,466	0	0	62,297,466	3,783,143
8.97	6.20	6.28	0.14	2.77	167.10	379.00	227.40	**542.65**	**424.57**	594.20	774.83	7,618,275	20,315,400	842,343	696,725	768,454	5,266,204	23,244,993	**58,752,394**	62,391,058	0	0	62,391,058	3,638,664
8.97	6.30	6.08	0.14	2.54	167.32	379.00	227.40	**543.38**	**425.14**	595.01	775.88	7,628,593	20,342,915	842,343	696,725	768,454	5,430,006	23,276,476	**58,985,511**	62,475,560	0	0	62,475,560	3,490,049
8.97	6.40	5.89	0.14	2.34	167.53	379.00	227.40	**544.05**	**425.66**	595.73	776.83	7,637,924	20,367,798	842,343	696,725	768,454	5,596,311	23,304,947	**59,214,502**	62,551,979	0	0	62,551,979	3,337,477
8.97	6.50	5.71	0.14	2.15	167.71	379.00	227.40	**544.65**	**426.13**	596.39	777.69	7,646,376	20,390,336	842,343	696,725	768,454	5,765,120	23,330,735	**59,440,089**	62,621,196	0	0	62,621,196	3,181,107
8.97	6.60	5.54	0.14	1.98	167.88	379.00	227.40	**545.20**	**426.56**	596.99	778.47	7,654,043	20,410,781	842,343	696,725	768,454	5,936,433	23,354,129	**59,662,908**	62,683,987	0	0	62,683,987	3,021,079
8.97	6.70	5.38	0.14	1.83	168.04	379.00	227.40	**545.69**	**426.95**	597.53	779.18	7,661,008	20,429,356	842,343	696,725	768,454	6,110,249	23,375,382	**59,883,516**	62,741,031	0	0	62,741,031	2,857,514
8.97	6.80	5.22	0.14	1.69	168.17	379.00	227.40	**546.14**	**427.30**	598.03	779.82	7,667,345	20,446,254	842,343	696,725	768,454	6,286,568	23,394,718	**60,102,407**	62,792,929	0	0	62,792,929	2,690,521
8.97	6.90	5.07	0.14	1.56	168.30	379.00	227.40	**546.56**	**427.62**	598.48	780.41	7,673,119	20,461,650	842,343	696,725	768,454	6,465,391	23,412,334	**60,320,016**	62,840,211	0	0	62,840,211	2,520,195

Figure 5-4: Penstock Diameter Selection for Scenario 4

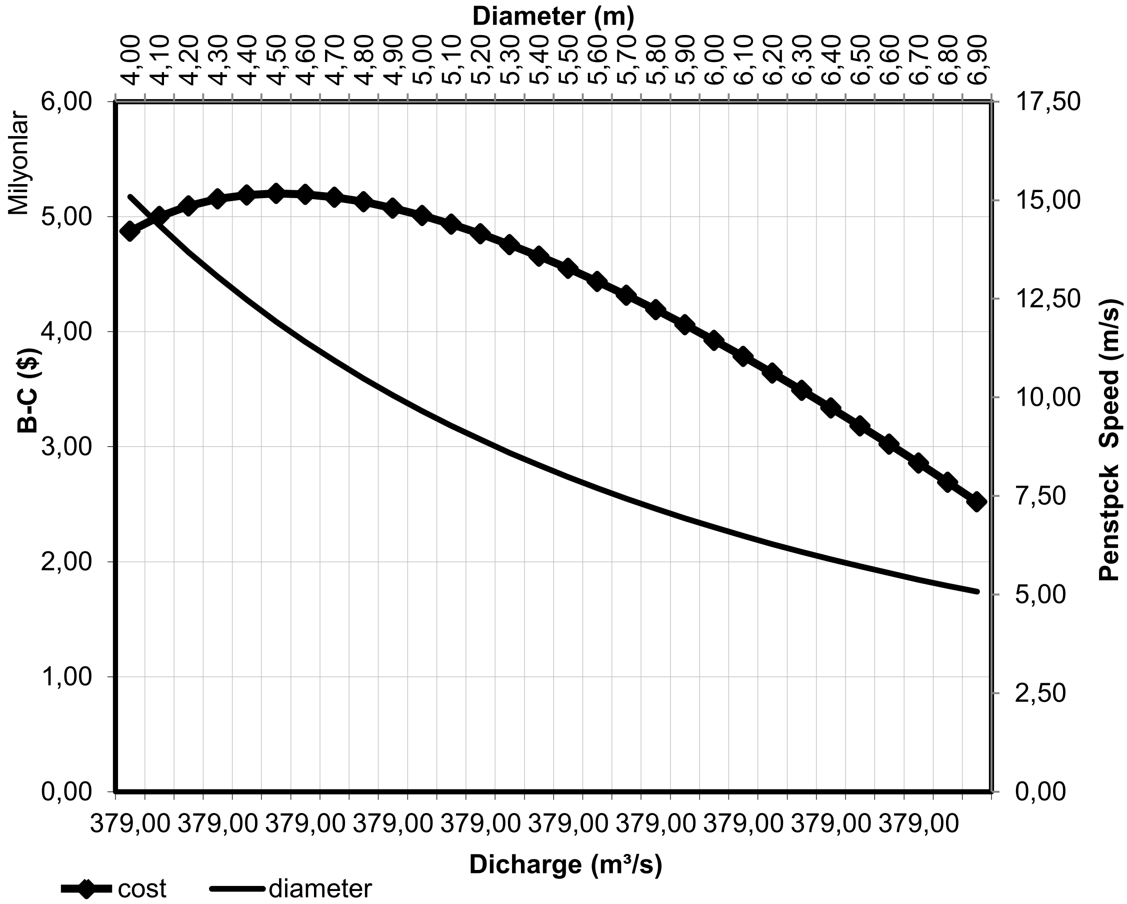


Figure 5-5: Discharge vs. B-C Curve against Penstock Diameter for Scenario 4

Penstock diameter and tunnel diameter selection have two criteria; maximum net benefit and maximum allowable speed. Figure 5-5 and Figure 5-7 show the graphs of those curves together with the variation in net benefit and diameters. In Case 4 penstock diameter is selected as 5.70 m and tunnel diameter is selected as 7.0 m. Figure 5-4 and Figure 5-6 is screen shots from the PXSC shows the tabular form the tunnel and penstock selections. After the selection of diameters economical calculations can be done. Table 5-2, Table 5-3,

Table 5-4, Table 5-5, Table 5-6 and Table 5-7 are the tables shows the economical evaluation of the project. Table 5-3 shows the investment cost of the project to be 302,312,564 USD, Table 5-6 shows the Revenue/Expenditure Ratio as 1.16 and finally Table 5-7 that shows the internal rate of return (IRR) as 1.08.

CASE 4

TUNNEL DIAMETER OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION												Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diameter m	Penstock Diameter m	Tunnel Speed m³/s	Tunnel Loss m	Penstock Loss m	Net Head m	Generating Discharge m³/s	Pumping Discharge m³/s	Installed Capacity MW	Pumping Capacity MW	Total G Energy GWh	Total P Energy GWh	Power Plant & Switchyard	E/M	Transmission Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
5.00	5.70	9.66	3.05	4.33	162.62	379.00	227.40	**528.09**	**413.18**	578.26	754.05	7,413,940	19,770,506	842,343	261,288	768,454	4,484,752	22,621,523	**56,162,805**	60,717,623	0	0	60,717,623	**4,554,818**
5.10	5.70	9.28	2.75	4.33	162.92	379.00	227.40	**529.09**	**413.96**	579.35	755.47	7,427,883	19,807,687	842,343	270,116	768,454	4,484,752	22,664,066	**56,265,301**	60,831,812	0	0	60,831,812	**4,566,511**
5.20	5.70	8.93	2.48	4.33	163.19	379.00	227.40	**529.96**	**414.64**	580.31	756.72	7,440,197	19,840,525	842,343	279,062	768,454	4,484,752	22,701,639	**56,356,973**	60,932,662	0	0	60,932,662	**4,575,689**
5.30	5.70	8.59	2.24	4.33	163.43	379.00	227.40	**530.74**	**415.25**	581.16	757.83	7,451,099	19,869,597	842,343	288,126	768,454	4,484,752	22,734,903	**56,439,274**	61,021,945	0	0	61,021,945	**4,582,670**
5.40	5.70	8.28	2.02	4.33	163.64	379.00	227.40	**531.43**	**415.79**	581.92	758.81	7,460,773	19,895,394	842,343	297,306	768,454	4,484,752	22,764,420	**56,513,442**	61,101,169	0	0	61,101,169	**4,587,727**
5.50	5.70	7.98	1.84	4.33	163.83	379.00	227.40	**532.04**	**416.27**	582.59	759.69	7,469,375	19,918,335	842,343	306,603	768,454	4,484,752	22,790,669	**56,580,531**	61,171,624	0	0	61,171,624	**4,591,092**
5.60	5.70	7.70	1.67	4.33	164.00	379.00	227.40	**532.59**	**416.70**	583.18	760.47	7,477,042	19,938,780	842,343	316,015	768,454	4,484,752	22,814,063	**56,641,449**	61,234,413	0	0	61,234,413	**4,592,965**
5.70	5.70	7.43	1.52	4.33	164.15	379.00	227.40	**533.08**	**417.08**	583.72	761.17	7,483,889	19,957,038	842,343	325,541	768,454	4,484,752	22,834,954	**56,696,972**	61,290,487	0	0	61,290,487	**4,593,516**
5.80	5.70	7.18	1.38	4.33	164.28	379.00	227.40	**533.51**	**417.42**	584.20	761.79	7,490,016	19,973,376	842,343	335,181	768,454	4,484,752	22,853,648	**56,747,771**	61,340,663	0	0	61,340,663	**4,592,892**
5.90	5.70	6.93	1.26	4.33	164.41	379.00	227.40	**533.90**	**417.72**	584.63	762.35	7,495,509	19,988,024	842,343	344,935	768,454	4,484,752	22,870,408	**56,794,425**	61,385,648	0	0	61,385,648	**4,591,223**
6.00	5.70	6.71	1.15	4.33	164.51	379.00	227.40	**534.26**	**418.00**	585.01	762.85	7,500,443	20,001,180	842,343	354,801	768,454	4,484,752	22,885,462	**56,837,435**	61,426,053	0	0	61,426,053	**4,588,618**
6.10	5.70	6.49	1.06	4.33	164.61	379.00	227.40	**534.57**	**418.25**	585.36	763.30	7,504,882	20,013,019	842,343	364,780	768,454	4,484,752	22,899,007	**56,877,237**	61,462,410	0	0	61,462,410	**4,585,173**
6.20	5.70	6.28	0.97	4.33	164.70	379.00	227.40	**534.86**	**418.47**	585.67	763.71	7,508,883	20,023,689	842,343	374,870	768,454	4,484,752	22,911,216	**56,914,208**	61,495,180	0	0	61,495,180	**4,580,972**
6.30	5.70	6.08	0.89	4.33	164.78	379.00	227.40	**535.11**	**418.67**	585.95	764.07	7,512,496	20,033,323	842,343	385,071	768,454	4,484,752	22,922,240	**56,948,680**	61,524,768	0	0	61,524,768	**4,576,088**
6.40	5.70	5.89	0.82	4.33	164.85	379.00	227.40	**535.35**	**418.85**	586.21	764.41	7,515,764	20,042,036	842,343	395,383	768,454	4,484,752	22,932,209	**56,980,940**	61,551,526	0	0	61,551,526	**4,570,586**
6.50	5.70	5.71	0.75	4.33	164.91	379.00	227.40	**535.56**	**419.02**	586.44	764.71	7,518,723	20,049,928	842,343	405,804	768,454	4,484,752	22,941,239	**57,011,242**	61,575,762	0	0	61,575,762	**4,564,520**
6.60	5.70	5.54	0.69	4.33	164.97	379.00	227.40	**535.75**	**419.17**	586.65	764.98	7,521,407	20,057,087	842,343	416,334	768,454	4,484,752	22,949,430	**57,039,807**	61,597,748	0	0	61,597,748	**4,557,940**
6.70	5.70	5.38	0.64	4.33	165.03	379.00	227.40	**535.92**	**419.30**	586.84	765.23	7,523,846	20,063,590	842,343	426,974	768,454	4,484,752	22,956,871	**57,066,831**	61,617,721	0	0	61,617,721	**4,550,891**
6.80	5.70	5.22	0.59	4.33	165.08	379.00	227.40	**536.08**	**419.43**	587.01	765.45	7,526,065	20,069,507	842,343	437,721	768,454	4,484,752	22,963,642	**57,092,484**	61,635,893	0	0	61,635,893	**4,543,409**
6.90	5.70	5.07	0.55	4.33	165.12	379.00	227.40	**536.22**	**419.54**	587.17	765.66	7,528,087	20,074,898	842,343	448,576	768,454	4,484,752	22,969,810	**57,116,920**	61,652,449	0	0	61,652,449	**4,535,529**
7.00	5.70	4.93	0.51	4.33	165.16	379.00	227.40	**536.36**	**419.64**	587.31	765.85	7,529,931	20,079,816	842,343	459,539	768,454	4,484,752	22,975,437	**57,140,271**	61,667,552	0	0	61,667,552	**4,527,281**
7.10	5.70	4.79	0.47	4.33	165.20	379.00	227.40	**536.48**	**419.74**	587.44	766.02	7,531,616	20,084,308	842,343	470,608	768,454	4,484,752	22,980,577	**57,162,658**	61,681,349	0	0	61,681,349	**4,518,691**
7.20	5.70	4.66	0.44	4.33	165.23	379.00	227.40	**536.59**	**419.82**	587.56	766.18	7,533,156	20,088,417	842,343	481,783	768,454	4,484,752	22,985,279	**57,184,184**	61,693,968	0	0	61,693,968	**4,509,784**
7.30	5.70	4.53	0.41	4.33	165.26	379.00	227.40	**536.69**	**419.90**	587.67	766.32	7,534,568	20,092,180	842,343	493,064	768,454	4,484,752	22,989,584	**57,204,945**	61,705,524	0	0	61,705,524	**4,500,580**
7.40	5.70	4.41	0.38	4.33	165.29	379.00	227.40	**536.78**	**419.97**	587.77	766.45	7,535,861	20,095,630	842,343	504,450	768,454	4,484,752	22,993,532	**57,225,023**	61,716,120	0	0	61,716,120	**4,491,097**
7.50	5.70	4.29	0.35	4.33	165.32	379.00	227.40	**536.86**	**420.04**	587.87	766.57	7,537,049	20,098,798	842,343	515,941	768,454	4,484,752	22,997,156	**57,244,493**	61,725,847	0	0	61,725,847	**4,481,354**
7.60	5.70	4.18	0.33	4.33	165.34	379.00	227.40	**536.94**	**420.10**	587.95	766.68	7,538,141	20,101,708	842,343	527,537	768,454	4,484,752	23,000,486	**57,263,421**	61,734,786	0	0	61,734,786	**4,471,365**
7.70	5.70	4.07	0.31	4.33	165.36	379.00	227.40	**537.01**	**420.16**	588.03	766.79	7,539,145	20,104,386	842,343	539,236	768,454	4,484,752	23,003,550	**57,281,866**	61,743,010	0	0	61,743,010	**4,461,144**
7.80	5.70	3.97	0.28	4.33	165.38	379.00	227.40	**537.08**	**420.21**	588.10	766.88	7,540,070	20,106,853	842,343	551,039	768,454	4,484,752	23,006,372	**57,299,883**	61,750,585	0	0	61,750,585	**4,450,703**
7.90	5.70	3.87	0.27	4.33	165.40	379.00	227.40	**537.14**	**420.26**	588.17	766.97	7,540,923	20,109,127	842,343	562,945	768,454	4,484,752	23,008,974	**57,317,517**	61,757,569	0	0	61,757,569	**4,440,052**

Figure 5-6: Tunnel Diameter Selection for Scenario 4

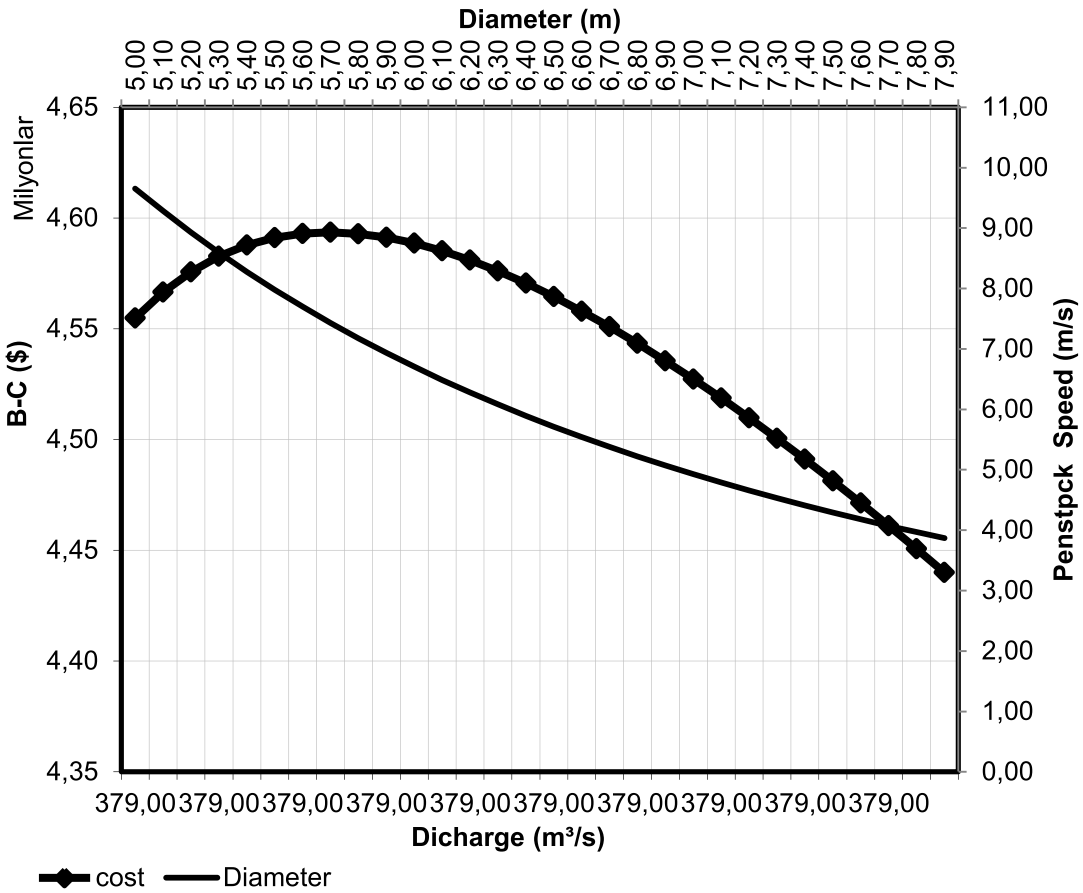


Figure 5-7: Discharge vs. B-C Curve against Tunnel Diameter for Scenario 4

Table 5-2: Estimated Cost for Scenario 4

NAME	ESTIMATED COST($)
Upper Reservoir	4,926,319
Tunnel	2,945,960
Penstock	28,750,359
Power Plant and Tailrace	48,272,056
Electromechanical Equipments	128,725,484
Transmission Line	5,400,000
TOTAL ESTIMATED COST	**219,020,177**

Table 5-3: Investment Cost and Annual Expense Table for Scenario 2

contingency = 10%

project control = 5%

NAME	Estimated Cost	Construction Cost	Project Control	Project Cost	Interest During Construction	Investment Cost	Depriciation Factor	Depriciation Expenditure	O&M Factor	O&M Expenditure	Renewal Factor	Renewal Expenditure	Total Expenditure
Upper Reservoir	4,926,319	5,418,951	270,948	5,689,898	1,132,432	6,822,330	0.09603	655,148	0.020	108,379	0.00100	5,418.95	768,946
Tunnel	2,945,960	3,240,556	162,028	3,402,584	323,245	3,725,829	0.09603	357,791	0.020	64,811	0.00100	3,240.56	425,843
Penstock	28,750,359	31,625,394	1,581,270	33,206,664	6,608,956	39,815,621	0.09603	3,823,494	0.020	632,508	0.00100	31,625.39	4,487,627
Power Plant and Tailrace	48,272,056	53,099,262	2,654,963	55,754,225	11,096,485	66,850,710	0.09603	6,419,674	0.020	1,061,985	0.00100	53,099.26	7,534,758
Electromechanical Equipments	128,725,484	141,598,032	7,079,902	148,677,934	29,590,626	178,268,559	0.09603	17,119,130	0.020	2,831,961	0.00100	141,598.03	20,092,688
Transmission Line	5,400,000	5,940,000	297,000	6,237,000	592,515	6,829,515	0.09603	655,838	0.020	118,800	0.00100	5,940.00	780,578
TOTAL	**219,020,177**	**240,922,195**	**12,046,110**	**252,968,305**	**49,344,259**	**302,312,564**		**29,031,076**		**4,818,444**		**240,922**	**34,090,442**

Pumping Cost=	22,975,437
Cost=	57,065,878
Benefit=	61,667,552
Net Benefit=	4,601,674
Benefit / Cost Ratio =	1,08

Table 5-4: Replacement Cost Table for Scenario 4

NAME	CONSTRUCTION COST($)	RENEWAL TIME(year)	RENEWAL RATIO	YEARS			
				20 YEAR	35 YEAR	40 YEAR	45 YEAR
Upper Reservoir	5,418,951	45	0.02				108,379
Tunnel	3,240,556	45	0.02				64,811
Penstock	31,625,394	45	0.50				15,812,697
Power Plant and Tailrace	53,099,262	20	0.10	5,309,926		5,309,926	
Electromechanical Equipments	141,598,032	35	0.80		113,278,426		
Transmission Line	5,940,000	45	0.80				4,752,000
TOTAL				**5,309,926**	**113,278,426**	**5,309,926**	**20,737,887**

Table 5-5: Investment over Years for Scenario 4

	PROJECT COST($)				PROJECT COST($)	INVESTMENT COST($)
NAME	**1st YEAR**	**2nd YEAR**	**3rd YEAR**	**4th YEAR**		
Upper Reservoir	2,844,949	2,844,949	0		5,689,898	6,822,330
Tunnel	0	0	3,402,584		3,402,584	3,725,829
Penstock	0	16,603,332	16,603,332		33,206,664	39,815,621
Power Plant and Tailrace	13,938,556	27,877,113	13,938,556		55,754,225	66,850,710
Electromechanical Equipments	0	37,169,483	74,338,967	37,169,483	148,677,934	178,268,559
Transmission Line	0	0	0	6,237,000	6,237,000	6,829,515
TOTAL	**16,783,505**	**84,494,877**	**108,283,439**	**43,406,483**	**252,968,305**	**302,312,564**

Table 5-6: Revenue/Expenditure Ratio for Scenario 4

	Expenditure			Revenue	Present Value	9.50%
	Project Cost	Oper. & Main.	Total		Expenditure	Revenue
1	16,783,505	0	16,783,505	0	15,327,402	0
2	84,494,877	0	84,494,877	0	70,469,654	0
3	108,283,439	0	108,283,439	0	82,474,498	0
4	43,406,483	0	43,406,483	0	30,192,434	0
4	0	27,793,881	27,793,881	61,667,552	19,332,709	42,894,364
5	0	27,793,881	27,793,881	61,667,552	17,655,442	39,172,935
6	0	27,793,881	27,793,881	61,667,552	16,123,691	35,774,370
7	0	27,793,881	27,793,881	61,667,552	14,724,832	32,670,658
8	0	27,793,881	27,793,881	61,667,552	13,447,335	29,836,217
9	0	27,793,881	27,793,881	61,667,552	12,280,672	27,247,687
10	0	27,793,881	27,793,881	61,667,552	11,215,225	24,883,732
11	0	27,793,881	27,793,881	61,667,552	10,242,215	22,724,870
12	0	27,793,881	27,793,881	61,667,552	9,353,621	20,753,305
13	0	27,793,881	27,793,881	61,667,552	8,542,119	18,952,790
14	0	27,793,881	27,793,881	61,667,552	7,801,022	17,308,484
15	0	27,793,881	27,793,881	61,667,552	7,124,221	15,806,835
16	0	27,793,881	27,793,881	61,667,552	6,506,138	14,435,466
17	0	27,793,881	27,793,881	61,667,552	5,941,679	13,183,074
18	0	27,793,881	27,793,881	61,667,552	5,426,191	12,039,337
19	0	27,793,881	27,793,881	61,667,552	4,955,425	10,994,828
20	0	27,793,881	27,793,881	61,667,552	4,525,502	10,040,939
21	0	27,793,881	27,793,881	61,667,552	4,132,879	9,169,807
22	0	27,793,881	27,793,881	61,667,552	3,774,319	8,374,253
23	0	27,793,881	27,793,881	61,667,552	3,446,866	7,647,720
24	5,309,926	27,793,881	33,103,807	61,667,552	3,749,204	6,984,219
25	0	27,793,881	27,793,881	61,667,552	2,874,724	6,378,282
26	0	27,793,881	27,793,881	61,667,552	2,625,319	5,824,915
27	0	27,793,881	27,793,881	61,667,552	2,397,552	5,319,557
28	0	27,793,881	27,793,881	61,667,552	2,189,545	4,858,043
29	0	27,793,881	27,793,881	61,667,552	1,999,584	4,436,569
30	0	27,793,881	27,793,881	61,667,552	1,826,104	4,051,661
31	0	27,793,881	27,793,881	61,667,552	1,667,675	3,700,147
32	0	27,793,881	27,793,881	61,667,552	1,522,991	3,379,130
33	0	27,793,881	27,793,881	61,667,552	1,390,859	3,085,963
34	0	27,793,881	27,793,881	61,667,552	1,270,191	2,818,231
35	0	27,793,881	27,793,881	61,667,552	1,159,992	2,573,727
36	0	27,793,881	27,793,881	61,667,552	1,059,353	2,350,436
37	0	27,793,881	27,793,881	61,667,552	967,446	2,146,517
38	0	27,793,881	27,793,881	61,667,552	883,512	1,960,289
39	113,278,426	27,793,881	141,072,306	61,667,552	4,095,351	1,790,219
40	0	27,793,881	27,793,881	61,667,552	736,859	1,634,903
41	0	27,793,881	27,793,881	61,667,552	672,931	1,493,062
42	0	27,793,881	27,793,881	61,667,552	614,549	1,363,527
43	0	27,793,881	27,793,881	61,667,552	561,232	1,245,230
44	5,309,926	27,793,881	33,103,807	61,667,552	610,459	1,137,196
45	0	27,793,881	27,793,881	61,667,552	468,073	1,038,535
46	0	27,793,881	27,793,881	61,667,552	427,464	948,434
47	0	27,793,881	27,793,881	61,667,552	390,378	866,150
48	0	27,793,881	27,793,881	61,667,552	356,510	791,005
49	20,737,887	27,793,881	48,531,768	61,667,552	568,505	722,379
50	0	27,793,881	27,793,881	61,667,552	297,333	659,706
51	0	27,793,881	27,793,881	61,667,552	271,537	602,472
52	0	27,793,881	27,793,881	61,667,552	247,979	550,202
53	0	27,793,881	27,793,881	61,667,552	226,465	502,468
54	0	27,793,881	27,793,881	61,667,552	206,817	458,875
				TOTAL	**423,352,589**	**489,583,723**
				Revenue / Expenditure	**1.16**	

Table 5-7: Internal Rate of Return for Scenario 4

N	REVENUE	EXPENDITURE		EXPENDITURE FLOW	CASH FLOW	PRESENT VALUE	
	BENEFIT	PROJECT COST	O&M			0.095	0.1273
1	2	3	4	(3+4) = 5	(2-5) = 6	7	7
1	0	16,783,505	0	16,783,505	-16,783,505	-15,327,402	-14,887,806
2	0	84,494,877	0	84,494,877	-84,494,877	-70,469,654	-66,485,424
3	0	108,283,439	0	108,283,439	-108,283,439	-82,474,498	-75,579,869
4	0	43,406,483	0	43,406,483	-43,406,483	-30,192,434	-26,874,892
4	61,667,552	0	27,793,881	4,818,444	56,849,108	23,561,655	20,972,703
5	61,667,552	0	27,793,881	4,818,444	56,849,108	21,517,493	18,603,833
6	61,667,552	0	27,793,881	4,818,444	56,849,108	19,650,679	16,502,527
7	61,667,552	0	27,793,881	4,818,444	56,849,108	17,945,825	14,638,565
8	61,667,552	0	27,793,881	4,818,444	56,849,108	16,388,882	12,985,137
9	61,667,552	0	27,793,881	4,818,444	56,849,108	14,967,015	11,518,464
10	61,667,552	0	27,793,881	4,818,444	56,849,108	13,668,507	10,217,452
11	61,667,552	0	27,793,881	4,818,444	56,849,108	12,482,655	9,063,389
12	61,667,552	0	27,793,881	4,818,444	56,849,108	11,399,685	8,039,678
13	61,667,552	0	27,793,881	4,818,444	56,849,108	10,410,671	7,131,595
14	61,667,552	0	27,793,881	4,818,444	56,849,108	9,507,462	6,326,081
15	61,667,552	0	27,793,881	4,818,444	56,849,108	8,682,614	5,611,549
16	61,667,552	0	27,793,881	4,818,444	56,849,108	7,929,328	4,977,724
17	61,667,552	0	27,793,881	4,818,444	56,849,108	7,241,395	4,415,489
18	61,667,552	0	27,793,881	4,818,444	56,849,108	6,613,146	3,916,759
19	61,667,552	0	27,793,881	4,818,444	56,849,108	6,039,403	3,474,360
20	61,667,552	0	27,793,881	4,818,444	56,849,108	5,515,436	3,081,931
21	61,667,552	0	27,793,881	4,818,444	56,849,108	5,036,928	2,733,826
22	61,667,552	0	27,793,881	4,818,444	56,849,108	4,599,934	2,425,040
23	61,667,552	0	27,793,881	4,818,444	56,849,108	4,200,853	2,151,132
24	61,667,552	5,309,926	27,793,881	10,128,370	51,539,182	3,235,015	1,609,044
25	61,667,552	0	27,793,881	4,818,444	56,849,108	3,503,558	1,692,634
26	61,667,552	0	27,793,881	4,818,444	56,849,108	3,199,596	1,501,451
27	61,667,552	0	27,793,881	4,818,444	56,849,108	2,922,006	1,331,862
28	61,667,552	0	27,793,881	4,818,444	56,849,108	2,668,498	1,181,428
29	61,667,552	0	27,793,881	4,818,444	56,849,108	2,436,985	1,047,985
30	61,667,552	0	27,793,881	4,818,444	56,849,108	2,225,557	929,615
31	61,667,552	0	27,793,881	4,818,444	56,849,108	2,032,472	824,615
32	61,667,552	0	27,793,881	4,818,444	56,849,108	1,856,139	731,475
33	61,667,552	0	27,793,881	4,818,444	56,849,108	1,695,104	648,855
34	61,667,552	0	27,793,881	4,818,444	56,849,108	1,548,040	575,566
35	61,667,552	0	27,793,881	4,818,444	56,849,108	1,413,735	510,556
36	61,667,552	0	27,793,881	4,818,444	56,849,108	1,291,082	452,889
37	61,667,552	0	27,793,881	4,818,444	56,849,108	1,179,071	401,735
38	61,667,552	0	27,793,881	4,818,444	56,849,108	1,076,777	356,359
39	61,667,552	113,278,426	27,793,881	118,096,870	-56,429,318	-2,305,132	-741,003
40	61,667,552	0	27,793,881	4,818,444	56,849,108	898,044	280,404
41	61,667,552	0	27,793,881	4,818,444	56,849,108	820,131	248,732
42	61,667,552	0	27,793,881	4,818,444	56,849,108	748,978	220,638
43	61,667,552	0	27,793,881	4,818,444	56,849,108	683,998	195,717
44	61,667,552	5,309,926	27,793,881	10,128,370	51,539,182	526,737	146,396
45	61,667,552	0	27,793,881	4,818,444	56,849,108	570,462	154,001
46	61,667,552	0	27,793,881	4,818,444	56,849,108	520,970	136,607
47	61,667,552	0	27,793,881	4,818,444	56,849,108	475,772	121,177
48	61,667,552	0	27,793,881	4,818,444	56,849,108	434,495	107,490
49	61,667,552	20,737,887	27,793,881	25,556,331	36,111,221	153,874	36,975
50	61,667,552	0	27,793,881	4,818,444	56,849,108	362,373	84,579
51	61,667,552	0	27,793,881	4,818,444	56,849,108	330,935	75,026
52	61,667,552	0	27,793,881	4,818,444	56,849,108	302,223	66,552
53	61,667,552	0	27,793,881	4,818,444	56,849,108	276,003	59,035
54	61,667,552	0	27,793,881	4,818,444	56,849,108	252,058	52,367
					TOTAL	66,231,134	0
					INTERNAL RATE OF RETURN (IRR) %		12.73%

5.3. Discussion of Scenarios

The results of five scenarios of the case study Aslantaş PHS is given in Table 5-8. Selection of project discharge, penstock diameter and tunnel diameter are all based on the idea that intersecting the marginal benefit and marginal costs curves. Intersection of those two curves gives the optimum result for project. There are three different situations that may appear during computations according to Ramos and Arrojo (Ramos & Arrojo, 1991);

i. Charging: It implies that there is no extra profit can be obtained from pumping more energy.
ii. Discharging: The second situation is reached when no extra profit can be obtained from energy production
iii. Reservoir limit constraining: Intersection is not achieved before reservoir limit.

For Scenario 1, Scenario 3 and Scenario 5 no intersection point is reach and discharging situation governs. Negative B – C value is obtained for minimum discharge during the analyses. For Scenario 1 we used default unit costs for calculations and for Scenario 3 and Scenario 5 we used lowered unit costs for representation of market prices. However, for all three cases net benefit is found negative which means there is no optimum result for that project although there is a trend towards positive direction. This situation represents that market electricity prices are not reasonable for pumped storage projects at present.

In Scenario 2 in order to see the effect of Peak Power Benefit additional input was entered as 240$/kW for corresponding area. The change in project feasibility is drastic. Among all those five scenarios, Scenario 2 has the best Revenue/Expenditure Ratio and IRR. However, the Peak Power Benefit which is explained in section 4.4.5.2 is not an input for a direct economical measurement.

Table 5-8: Comparison of Results of Scenarios

		1	2	3	4	5
Tailrace Level	m	130.00	130.00	130.00	130.00	130.00
Min. Upper Reservoir Level	m	285.00	285.00	285.00	285.00	285.00
Max.Upper Reservoir Level	m	300.00	300.00	300.00	300.00	300.00
Reservoir Volume		4,100,000	4,100,000	4,100,000	4,100,000	4,100,000
Penstock Length	m	875.00	875.00	875.00	875.00	875.00
Penstock Number		2	2	2	2	2
Tunnel Length	m	225.00	225.00	225.00	225.00	225.00
Tunnel Number		2	2	2	2	2
Transmission Line Voltage	kV	380	380	380	380	380
Transmission Line Length	km	30.00	30.00	30.00	30.00	30.00
Generation Price	TL/MWh	166.48	166.48	166.48	210.00	177.49
Pumping Price	TL/MWh	90.43	90.43	90.43	60.00	68.95
Peak Power Benefit	TL/kW	0.00	240.00	0.00	0.00	0.00
Other Benefits	TL/kWh	0.00	0.00	0.00	0.00	0.00
Number of Working Days		365	365	365	365	365
Generating Hour in a Year		1095	1095	1095	1095	1095
Pumping Hour in a Year		1825	1825	1825	1825	1825
Efficiencies		low	low	low	low	low
Costs		default	default	%40 low	% 40 low	%40 low
Project Discharge	m^3	----	375.00	----	379.00	----
Pumping Discharge	m^3	----	225.00	----	227.40	----
Penstock Diameter	m	----	5.70	----	5.70	----
Penstock Speed	m/s	----	7.35	----	7.43	----
Tunnel Diameter	m	----	7.20	----	7.00	----
Tunnel Speed	m/s	----	4.61	----	4.93	----
Rated Head	m	----	165.33	----	165.53	----
Installed Capacity	MW	----	531.24	----	536.36	----
Yearly Electricity Generation	GWh	----	581.71	----	587.31	----
Pumping Capacity	MW	----	415.64	----	419.64	----
Yearly Electricity Consumption	GWh	----	758.55	----	768.85	----
B-C	$	negative	85,570,386	negative	4,527,281	negative
Total Estimated Cost	$	----	359,328,035	----	219,020,177	----
Total Construction Cost	$	----	395,260,838	----	240,922,195	----
Total Project Cost	$	----	415,023,880	----	252,968,305	----
Total Investment Cost	$	----	495,905,882	----	302,312,564	----
Yearly Revenue	$	----	175,920,069	----	61,667,552	----
Yearly Cost	$	----	90,220,625	----	57,065,878	----
Benefit/Cost Ratio		----	1.95	----	1.08	----
Revenue/Expenditure Ratio		----	2.09	----	1.16	----
IRR		----	29.29%	----	12.73%	----

Finally, in Scenario 4 the electricity prices are increased for generation and decreased for pumping operations. The results taken from PXSC show positive attitude for the Aslantaş PHS. This also shows that the fluctuations in real time electricity prices are not significant to obtain economical benefit from the pumped projects. In analyses of Scenario 2 and Scenario 4 upper reservoir limited the further increase in installed capacity and third situation is binding according to the work of Ramos and Arrojo (Ramos & Arrojo, 1991).

Table 5-9 compares the results of PXSC against EİE results. Project discharge and pumping discharge in both analyses are found similar to each other, however installed capacities calculated in PXSC is larger than EİE results. Main reason for that is the net head difference. PXSC adds the active reservoir water level to the net head; on the other hand EİE formulation uses only the minimum water level in upper reservoir. Secondly, head losses are different in each formulation. EİE formulation assumes smaller velocities in tunnel and penstock diameter calculations which increase the diameters and decrease head losses. That differences in head calculations cause changes in installed capacities, yearly electricity generation and yearly electricity consumption of the project. Second difference between two approaches is the benefit and cost calculations. EİE uses generalized costs for facilities (EİE, 2008) however PXSC changes the cost formulas dynamically according to the project characteristics.

Table 5-9: Comparison of PXSC against EİE Results
(Data in the last column are compiled from EİE (EİE, 2008))

		SCENARIO 2	SCENARIO 4	EİE
Project Discharge	m^3	375.00	379.00	379.00
Pumping Discharge	m^3	225.00	227.40	227.40
Penstock Diameter	m	5.70	5.70	7.00
Penstock Speed	m/s	7.35	7.43	5.00
Tunnel Diameter	m	7.20	7.00	7.80
Tunnel Speed	m/s	4.61	4.93	4.00
Rated Head	m	165.33	165.53	151.40
Installed Capacity	MW	531.24	536.36	500.00
Yearly Electricity Generation	GWh	581.71	587.31	547.50
Pumping Capacity	MW	415.64	419.64	395.60
Yearly Electricity Consumption	GWh	758.55	768.85	722.00
Total Investment Cost	$	495,905,882	302,312,564	409,680,563
Yearly Revenue	$	175,920,069	61,667,552	144,637,500
Yearly Cost	$	90,220,625	57,065,878	93,962,856
Benefit/Cost Ratio		1.95	1.08	1.54

Currently, developers tend to repower or enhance existing facilities or build pump-back storage (mixed PHS) facilities rather than building new pure pumped storage (off-stream) facilities to decrease capital cost. In some cases, there is a lack of economically attractive new sites for pure PHS plants (Deane, Ó Gallachóir, & McKeogh, 2010).

Capital cost of a PHS varies from 500 to 3600 €/kW according to European Commission (European Commission, 2011) and 500 to 1500 €/kW according to study of Kaldellis and Zafirakis (Kaldellis & Zafirakis, 2007). This variation results from site conditions and project characteristics. The capital cost of Aslantaş PHS which is a pure PHS 930 $/kW, 560$/kW and 820$/kW for Scenario 2, Scenario 4 and EİE study respectively.

Finally, peak price to off-peak price ratio for generation and pumping respectively is 1.85:1 in DAM of Turkey (166.68 peak price average and 90.48 off peak price average) and 2.6:1 in EPEX spot for November 2013(177.49 peak price average and 68.95 off-peak price average). This ratio is around 2:1 for projects developed in European countries. However, in Scenario 4 we assumed the peak electricity prices 210 TL/MWh and off-peak electricity price 60 TL/MWh (corresponds to 3.5:1 peak/off-peak spread ratio) and found a corresponding project discharge and the installed capacity. This confirms the experience gained through the operation of existing large-scale developments demanding a peak/off-peak price ratio of approximately 3:1 to ensure a profitable project (Beisler, 2013).

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

Turkey, taking steps in the road of fully liberalized electricity market and assessment of pumped storage projects with the electricity market prices is the aim of this study. Therefore, we developed a software tool named PXSC in Microsoft Excel 2007 with VBA for evaluation of the projects in general. A project developed by EİE, Aslantaş PHS, is selected for testing the tool and examining the effects of the electricity market prices in Turkey. PXSC is capable of selection of design discharge, penstock diameter and tunnel diameter additionally, it carries out economical evaluation; calculation of estimated cost, construction cost, project cost, investment cost, operation and maintenance cost, project income, most importantly determination of revenue/expenditure ratio and internal rate return. The results of the case studies may lead to important outcomes:

First, daily fluctuations of the electricity market prices is not sufficient to develop a profitable pumped project in the time being.

Secondly, calculation of project cost using the PXSC in default mode gives higher results than the prices of the construction market. However, in case of construction market costs daily fluctuations of the electricity market prices still is not sufficient to design a profitable project.

Thirdly, for making way for pumped storage project in Turkey electricity prices spread ratio between peak and off-peak has to be 3:1 or greater. However, in liberalized electricity market manipulation of electricity prices cannot be done so feed-in tariffs (FIT) for pumped storage in Turkey is necessary. However, this confirms the conclusions of some other study state that the Feed-in Tariffs and Renewable Energy

Support mechanism is poor than the market electricity prices from economical point of view.

Finally, pumped-back storage(mixed pumped storage) can be more feasible than the pure-pumped storage(off-stream) facilities if a suitable site can be located for the reservoirs, since using existing facilities decreases the overall cost of projects, since the river basins in Turkey are heavily developed.

Further, the rule of liberal market or deregulated market should not limit our effort to develop a storage projects, since they have added values in terms of increasing in storage thus maintaining the supply of electricity at peak demands. If the total capacity of PHS is increase than high prices at peak demands will decrease.

Therefore the present study can be further developed by;

i. Addition of lower reservoir information menu (rule curve of lower reservoir, reservoir operation of PHS and existing dam if any etc.) improve the PXSC and increases the capability of software.
ii. Improvements in VBA codes can enable weekly or seasonally analyses with PXSC
iii. Addition of hydrology menu into the software can enables the analysis of mixed pumped storage projects.

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APPENDIX A

HISTORICAL DEVELOPMENT OF HYDROPOWER

The history of the hydroelectricity is summarized by the International Energy Agency (IEA) from the book of Hydroelectric Development in the United States 1880-1940 which is written by Duncan Hay, as follows (Hay, 1991).

1826 French engineer, Benoit Fourneyron, developed a high efficiency (80%) outward flow water turbine in which water was directed tangentially through the turbine runner causing it to spin. Another French engineer, Jean V. Poncelet, designed an inward-flow turbine in 1826 that used the same principles. It was not built until 1838 when S. B. Howd obtained a U.S. patent for a similar design.1848 James B. Francis improved on these designs to create a turbine with 90% efficiency.

1870 the world's earliest hydroelectric project at Cragside, Rothbury, England supplied electric light.1880 the first industrial use of hydropower to generate electricity occurred in Grand Rapids Michigan when 16 brush-arc lamps were powered using a water turbine at the Wolverine Chair Factory in Grand Rapids, Michigan1881 in Niagara Falls, New York a brush dynamo was connected to a turbine in Quigley's flour mill to light city street lamps.1882 in Appleton, Wisconsin the first hydroelectric station to use the Edison system was the Vulcan Street Plant.

1887 the San Bernadino, California, High Grove Station was the first hydroelectric plant in the West of the U.S.1889 at Oregon City, Oregon, the Willamette Falls station was the first AC hydroelectric plant. It transmitted single phase power 13 miles to Portland at 4,000 volts, stepped down to 50 volts for distribution.

1891 at Frankfort on Main, Germany, and the first three phase hydroelectric system was used for a 175 km, 25,000 volt demonstration line from plant at Lauffen.

1895 the first publicly-owned hydro-electric plant in the Southern Hemisphere was completed at Duck Reach, Tasmania and supplied power to the city of Launceston for street lighting.

1898 Decew Falls 1, St. Catherines, Ontario, Canada was completed. Owned by Ontario Power Generation, four units are still operational. On 25 August 1898 this station transmitted power at 22,500 Volts, 66 2/3 Hz, two-phase, a distance of 56 km to Hamilton, Ontario. Using the higher voltage permitted efficient transmission over that distance. (Recognized as an IEEE Milestone in Electrical Engineering & Computing by the IEEE Executive Committee in 2002)

1901 at Trenton Falls, New York, saw the first installation of high head reaction turbines designed and built in the U. S.1905 at Sault Ste. Marie, Michigan, the first low head plant with direct connected vertical shaft turbines and generators was built.

1906 at Ilchester, Maryland, a fully submerged hydroelectric plant was built inside Ambursen Dam.1911 R. D. Johnson invented the differential surge tank and Johnson hydrostatic penstock valve.

1912 at Holtwood, Pennsylvania, there was the first commercial installation of a Kingsbury vertical thrust bearing in hydroelectric plant.

1914 S.J. Zowski developed the high specific speed reaction (Francis) turbine runner for low head applications.

1916 there was the first commercial installation of fixed blade propeller turbine designed by Forrest Nagler.

1917 the hydracone draft tube was patented by W. M. White.

1919 Viktor Kaplan demonstrated an adjustable blade propeller turbine runner at Podebrady, Czechoslovakia.

1922 was the first time a hydroelectric plant was built specifically for peaking power.

1929 the Rocky River Plant at New Milford, Connecticut, was the first major pumped storage hydroelectric plant.

APPENDIX B

FERC ISSUED PRELIMINARY AND PENDING PERMITS

Table B-1 is retrieved from U.S. Federal Energy Regulatory Commission (FERC) and shows the information of 62 issued preliminary permits of pumped storage projects. Table B-2 shows the information of 10 pending preliminary permits of pumped storage projects in USA (FERC, 2013).

Table B-1: Issued Preliminary Permits of FERC for Pumped Storage

#	Docket Number	Project Name	Expiration Date	Issue Date	Authorized Capacity (MW)	Licensee	Waterway	ST
1	P-13793	Pajuela Peak Pumped Storage	10/31/13	11/05/10	250	Pajuela Peak Hydro, LLC	Closed-Loop	CA
2	P-13760	Music Mountains	10/31/13	11/05/10	350	Music Mountain Hydro, LLC	Closed-Loop	AZ
3	P-13836	Medicine Bow Pumped Storage	11/30/13	12/03/10	400	Medicine Bow Hydro, LLC	Closed-Loop	WY
4	P-13835	Coffin Butte Pumped Storage	11/30/13	12/03/10	250	Coffin Butte Energy Park, LLC	Closed-Loop	MT
5	P-12807	Mulqueeney Ranch Pumped Storage	12/31/13	01/13/11	280	Bpus Generation Development LLC	Closed-Loop	CA
6	P-13841	Elmhurst Quarry Pumped Storage	02/28/14	03/04/11	250	County Of Dupage	Closed-Loop	IL
7	P-13862	Deer Creek Pumped Storage	02/28/14	03/28/11	500	Deer Creek Hydro, LLC	Deer Creek	WY
8	P-13860	Oregon Winds Pumped Storage	02/28/14	03/28/11	400	Jones Canyon Hydro, LLC.	Closed-Loop	OR
9	P-13876	South Run Pumped Storage	03/31/14	04/14/11	1500	South Run Pumped Storage, LLC	South Run, Hudson Run	OH
10	P-13863	Mount Storm Pumped Storage	04/30/14	05/02/11	350	Mount Storm Hydro, LLC	Closed-Loop	WV
11	P-12966	Lake Powell Pipeline (PS&Con)	04/30/14	05/20/11	345.4	Utah Board Of Water Resources	Closed-Loop	UT
12	P-14087	Black Canyon Pumped Storage	06/30/14	07/15/11	700	Black Canyon Hydro, LLC	Closed-Loop	WY
13	P-14147	Camp Pendleton Pumped Storage	06/30/14	07/27/11	1271.185	Storage Development Partners, LLC	Pacific Ocean	CA
14	P-14144	Vandenberg #5 Pumped Storage	06/30/14	07/27/11	1196.41	Storage Development Partners, LLC	Pacific Ocean	CA
15	P-14146	Vandenberg #3 Pumped Storage	06/30/14	07/27/11	1136.592	Storage Development Partners, LLC	Pacific Ocean	CA
16	P-14114	Rockaway Pumped Storage	07/31/14	08/01/11	1000	Reliable Storage 2, LLC.	Closed-Loop	NJ
17	P-14061	Verde Pumped Storage	07/31/14	08/15/11	801	Arizona Independent Power, Inc.	Closed-Loop	AZ
18	P-14060	Owyhee Pumped Storage	08/31/14	09/02/11	500	Owyhee Hydro, LLC	Owyhee River, Lake Owyhee	OR
19	P-13842	Wild Flower Pumped Storage	08/31/14	09/15/11	1100	Wild Flower Water, LLC	Closed-Loop	OK
20	P-13851	Indian Blanket Pumped Storage	08/31/14	09/15/11	750	Indian Blanket Water, LLC	Closed-Loop	OK
21	P-13853	Magnolia Pumped Storage	08/31/14	09/15/11	750	Magnolia Water, LLC	Closed-Loop	OK
22	P-13852	Hawthorn Pumped Storage	08/31/14	09/15/11	750	Hawthorn Water, LLC	Closed-Loop	OK

Issued Preliminary Permits of FERC for Pumped Storage (Cont'd)

#	Docket Number	Project Name	Expiration Date	Issue Date	Authorized Capacity (MW)	Licensee	Waterway	ST
23	P-13854	Oklahoma Rose Pumped Storage	08/31/14	09/15/11	840	Oklahoma Rose Water, LLC.	Closed-Loop	OK
24	P-13221	Mokelumne Pumped Storage	11/30/14	12/02/11	1200	Pacific Gas And Electric Co	Bear River, Lower Bear River	CA
25	P-14201	Bison Peak Pumped Storage	12/31/14	01/27/12	1000	Bison Peak Pumped Storage, LLC.	Closed-Loop	CA
26	P-14124	Horseshoe Mountain Pumped Storage	01/31/15	02/10/12	331	Reliable Storage 1, LLC.	Spruce Lick Branch	TN
27	P-14151	Ravebscroft Pumped Storage	01/31/15	02/10/12	600	Reliable Storage 1, LLC.	Doe Creek	TN
28	P-14150	Bon Air Pumped Storage	01/31/15	02/10/12	700	Reliable Storage 1, LLC.	Wildcat Creek	TN
29	P-13798	Lanai Pumped Storage	01/31/15	02/10/12	300	Lanai Hydro, LLC	Pacific Ocean	HI
30	P-14120	Keaton Creek Pumped Storage	01/31/15	02/10/12	309	Reliable Storage 1, LLC.	Unnamed Tributary To Swan Creek	TN
31	P-14125	Cross Mountain Pumped Storage	01/31/15	02/10/12	1062	Reliable Storage 1, LLC.	Closed-Loop	TN
32	P-14122	Leech Mountain Pumped Storage	01/31/15	02/10/12	390	Reliable Storage 1, LLC.	Closed-Loop	TN
33	P-13861	Eldorado Pumped Storage	01/31/15	02/13/12	400	El Dorado Pumped Storage, LLC.	Closed-Loop	NV
34	P-14239	Mona North Pumped Storage	01/31/15	02/24/12	1000	Mona North Pumped Storage, LLC	Closed-Loop	UT
35	P-14240	Mona South Pumped Storage	01/31/15	02/24/12	1000	Mona South Pumped Storage, LLC	Closed-Loop	UT
36	P-14287	Table Mountain Pumped Storage	02/28/15	03/13/12	400	Table Mountain Irrigation Dist	Closed- Loop	AZ
37	P-14286	Haiwee Ridge Pumped Storage	02/28/15	03/23/12	500	Haiwee Ridge Hydro, LLC.	Closed- Loop	CA
38	P-13220	Kings River Pumped Storage	02/28/15	03/27/12	1200	Pacific Gas And Electric Co	Short Hair Creek	CA
39	P-14341	Longview Pumped Storage	03/31/15	04/26/12	2000	Longview Energy Exchange, LLC.	Closed- Loop	AZ
40	P-14152	Stamps Hollow Pumped Storage	03/31/15	04/30/12	600	Reliable Storage 1, LLC.	Unnamed Tributary	TN
41	P-14304	Don Pedro Pumped Storage	03/31/15	04/30/12	1000	Don Pedro Hydro, LLC	Tuolumne River	CA
42	P-14336	Silver Creek Pumped Storage	04/30/15	05/17/12	250	Peak Hour Power, LLC.	Silver Creek	PA
43	P-14382	Black Mountain Pumped Storage	06/30/15	07/11/12	1000	Black Mountain Hydro, LLC	Closed-Loop	NV
44	P-14344	Blue Diamond Pumped Storage	06/30/15	07/11/12	450	Inter Consortium Of Energy Managers	Closed-Loop	NV

Issued Preliminary Permits of FERC for Pumped Storage (Cont'd)

#	Docket Number	Project Name	Expiration Date	Issue Date	Authorized Capacity (MW)	Licensee	Waterway	ST
45	P-14337	Maysville Pumped Storage	06/30/15	07/13/12	1000	Maysville Pumped Storage, LLC	Closed-Loop	KY
46	P-13316	Mesa De Los Carros Pumped Storage	08/31/15	09/07/12	1154	Mesa De Los Carros Hydro ,LLC	Closed-Loop	NM
47	P-13324	Cedar Creek Pumped Storage	08/31/15	09/21/12	660	Cedar Creek Hydro, LLC.	Closed-Loop	TX
48	P-14354	Long Canyon Pumped Storage	08/31/15	09/24/12	800	Utah Independent Power	Closed-Loop	UT
49	P-13315	Yegua Mesa Pumped Storage	08/31/15	09/28/12	1100	Yegua Mesa Hydro, LLC.	Closed-Loop	NM
50	P-14426	Plateau Creek Pumped Storage	09/30/15	10/01/12	500	Dolores Water Conservancy Dist.	Plateau Creek	CO
51	P-14227	Lake Elsinore Advanced Pumped Storage	09/30/15	10/24/12	600	Nevada Hydro Company, Inc.	Lake Elsinore & San Juan Creek	CA
52	P-13333	JD Pool Pumped Storage	10/31/15	11/16/12	1500	Pud No.1 Of Klickitat County, Wa	Closed-Loop	WA
53	P-13318	Swan Lake North Pumped Storage	10/31/15	11/16/12	1000	Swan Lake North Hydro, LLC	Closed-Loop	OR
54	P-14422	Winnemucca Farms East Pumped Storage	10/31/15	11/29/12	400	Water Asset Management, Inc	Humboldt River	NV
55	P-14414	Winnemucca Farms West Pumped Storage	10/31/15	11/29/12	400	Water Asset Management, Inc	Humboldt River	NV
56	P-14416	Lorella Pumped Storage	11/30/15	12/21/12	250	FFP Project 111, LLC	Closed-Loop	OR
57	P-13314	Corral Creek South Pumped Storage	12/31/15	01/09/13	1100	Corral Creek South Hydro ,LLC.	Closed-Loop	ID
58	P-14464	Cascade Pumped Storage	01/31/16	02/07/13	600	Cascade Energy Storage, LLC	Cub Creek	WA
59	P-14418	Cold Creek Valley	05/31/16	06/12/13	2000	S. Martinez Livestock, Inc.	Columbia River	WA
60	P-14453	Princeville Pumped Storage	06/30/16	07/19/13	150	Prineville Energy Storage, LLC	Crooked River	OR
61	P-14329	Banks Lake Pumped Storage	07/31/16	08/22/13	1000	Grand Coulee Hydro Authority	Columbia River	WA
62	P-13642	Gordon Butte Pumped Storage	07/31/16	08/26/13	4000	GB Energy Park, LLC	Closed-Loop	MT

Table B-2: Pending Preliminary Permits of FERC for Pumped Storage

#	Docket No.	Permit Name	Waterway	ST	Applicant Name	Proposed Capacity (MW)	Filing Date
1	P-12714	Phantom Canyon/South Slope PS	Closed-Loop	CO	H2O Holdings, LLC	440	08/14/13
2	P-12747	San Vicente Pumped-Storage Water Power	Closed-Loop	CA	San Diego County Water Authority	500	06/28/13
3	P-13705	White Pine Pumped Storage	Closed Loop	NV	White Pine Waterpower, LLC	750	09/04/13
4	P-14472	River Mountain Advanced Pumped Storage	Arkansas River	AR	Control Technologies Inc.	600	12/18/12
5	P-14541	Gregory County Pump Storage Project	Missouri River	SD	Western Minnesota Municipal Power Company	800	07/30/13
6	P-14543	Fort Ross	Pacific Ocean	CA	HGE Energy Storage 1, LLC	1270	08/05/13
7	P-14544	Vandenburg West	Pacific Ocean	CA	HGE Energy Storage 1, LLC	1351	08/05/13
8	P-14545	Vandenburg East	Pacific Ocean	CA	HGE Energy Storage 1, LLC	1338	08/07/13
9	P-14548	Pendleton South	Pacific Ocean	CA	HE Energy Storage 1, LLC	1232	08/15/13
10	P-14556	Rose Creek Pumped Storage	Walker River	NV	Rose Creek Hydro, LLC	250	09/12/13

APPENDIX C

DAILY AVERAGES OF DAP AND SMP

Data compiled from the TEİAŞ and plotted into the graphs for each year separately for Day Ahead Prices (DAP) and System Marginal Prices (SMP) (TEİAŞ, 2012,2011,2010,2009). All prices are in terms of TL/MWh. Prices are between 01.July.2009 and 31.October.2013.

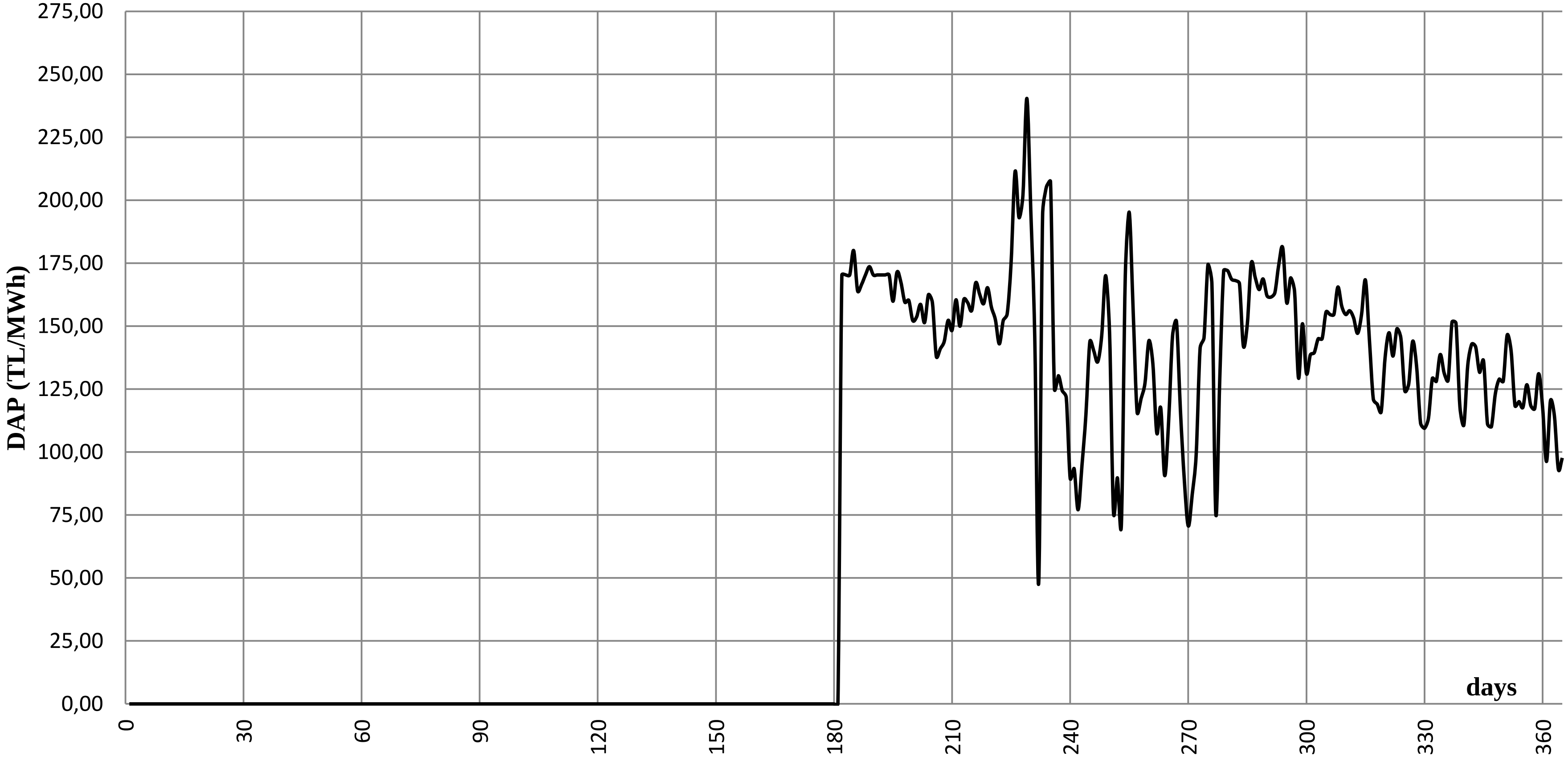


Figure C-1: Daily Averages of DAP in 2009

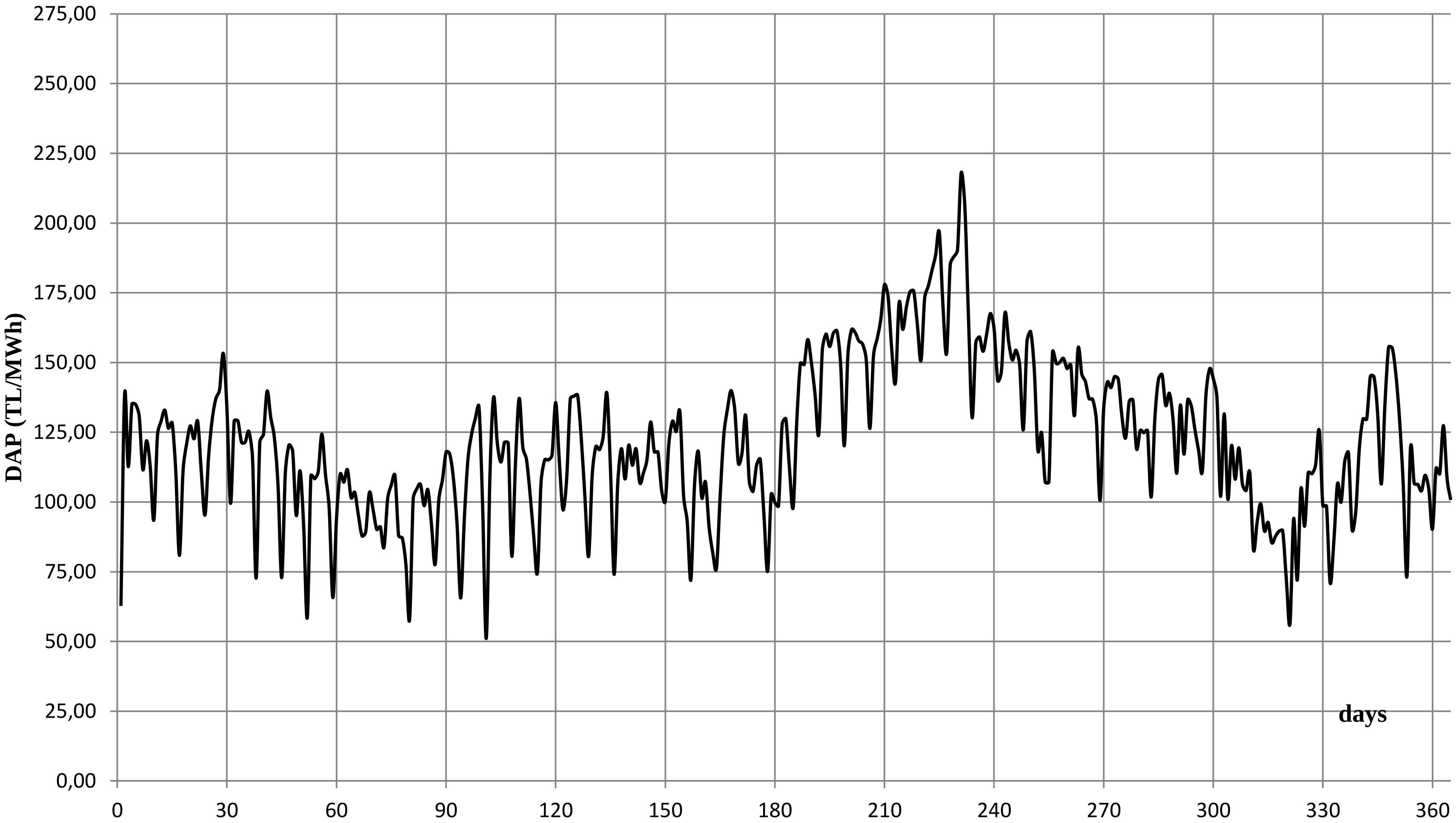


Figure C-2: Daily Averages of DAP in 2010

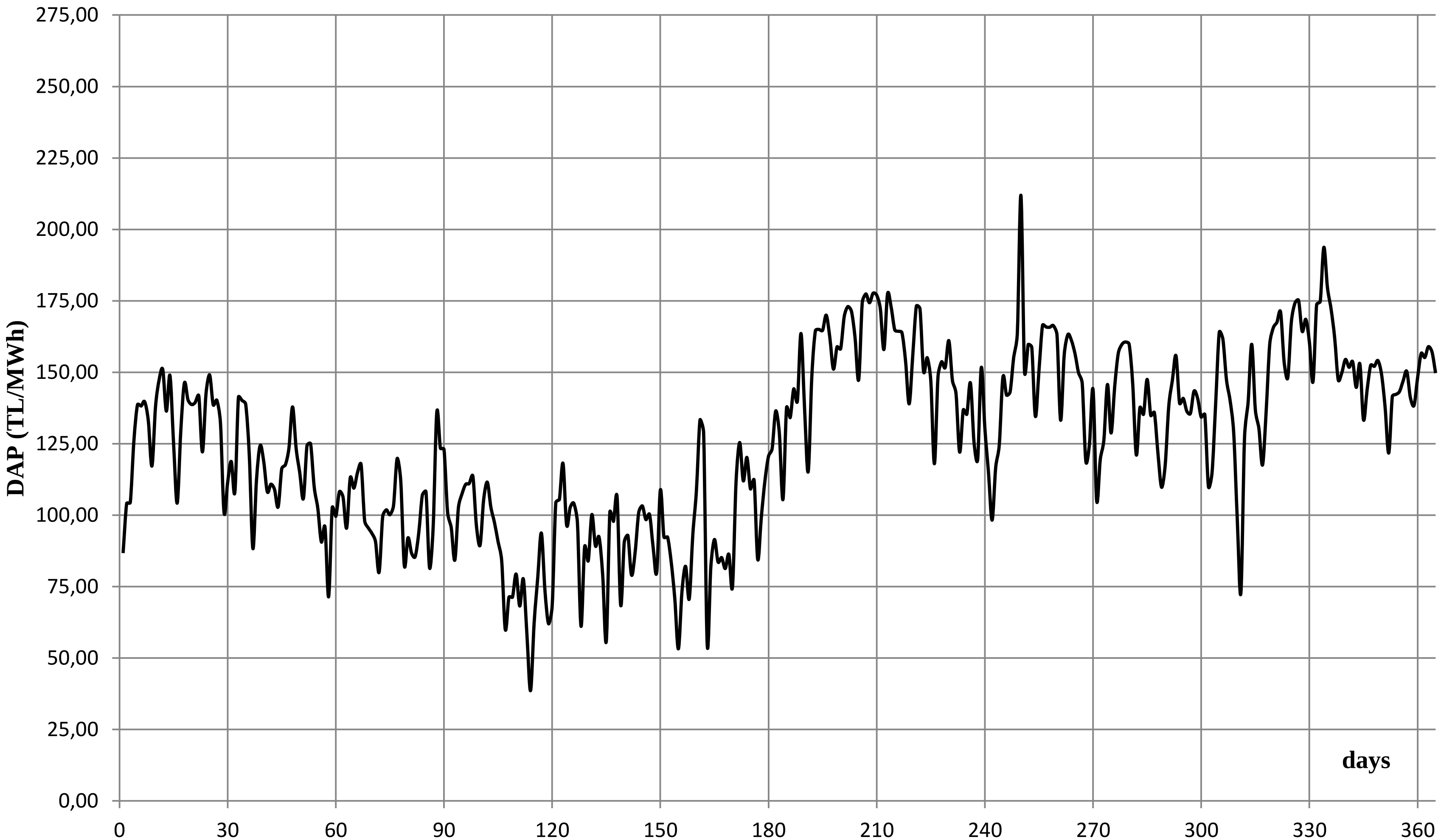


Figure C-3: Daily Averages of DAP in 2011

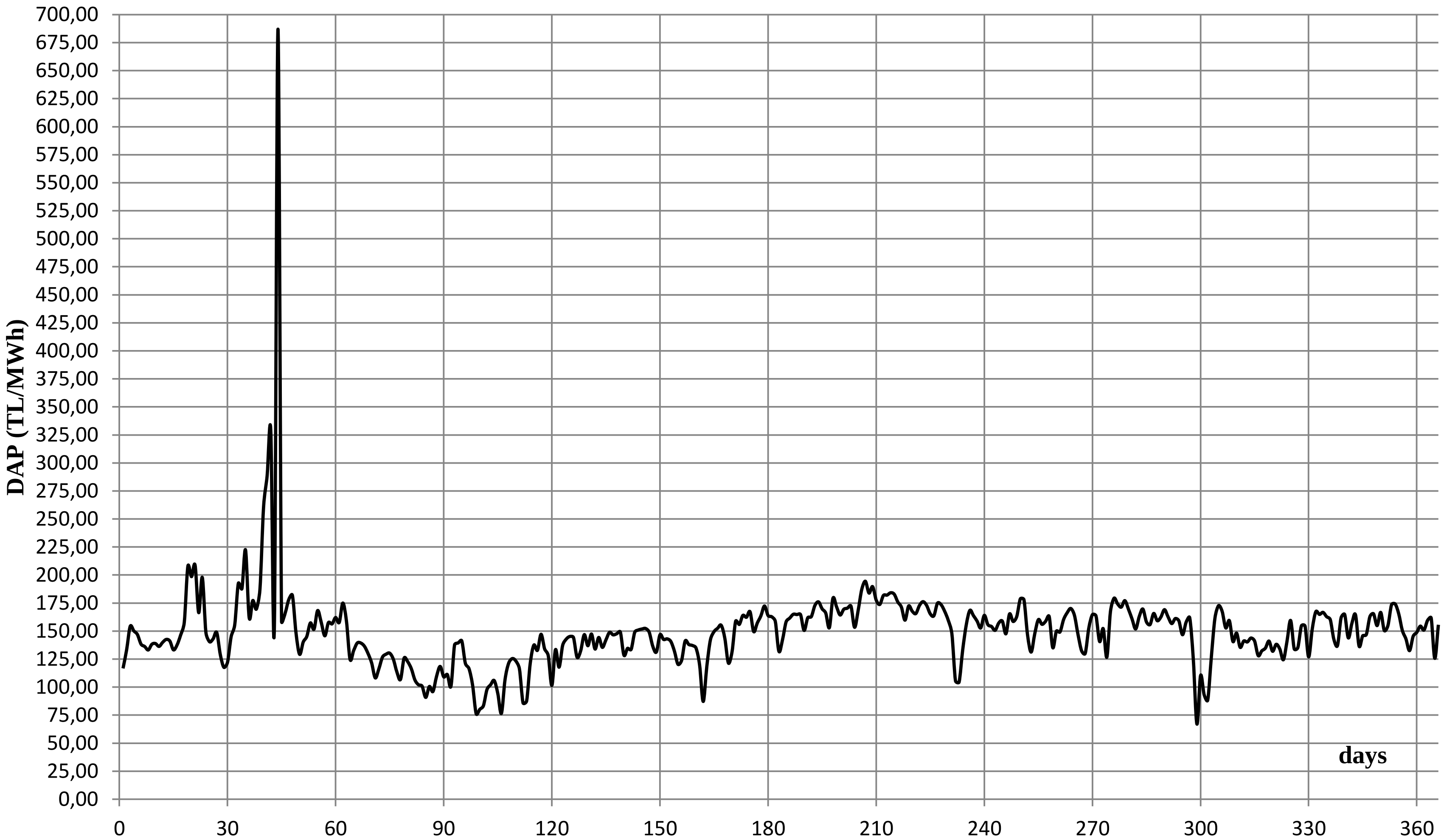


Figure C-4: Daily Averages of DAP in 2012

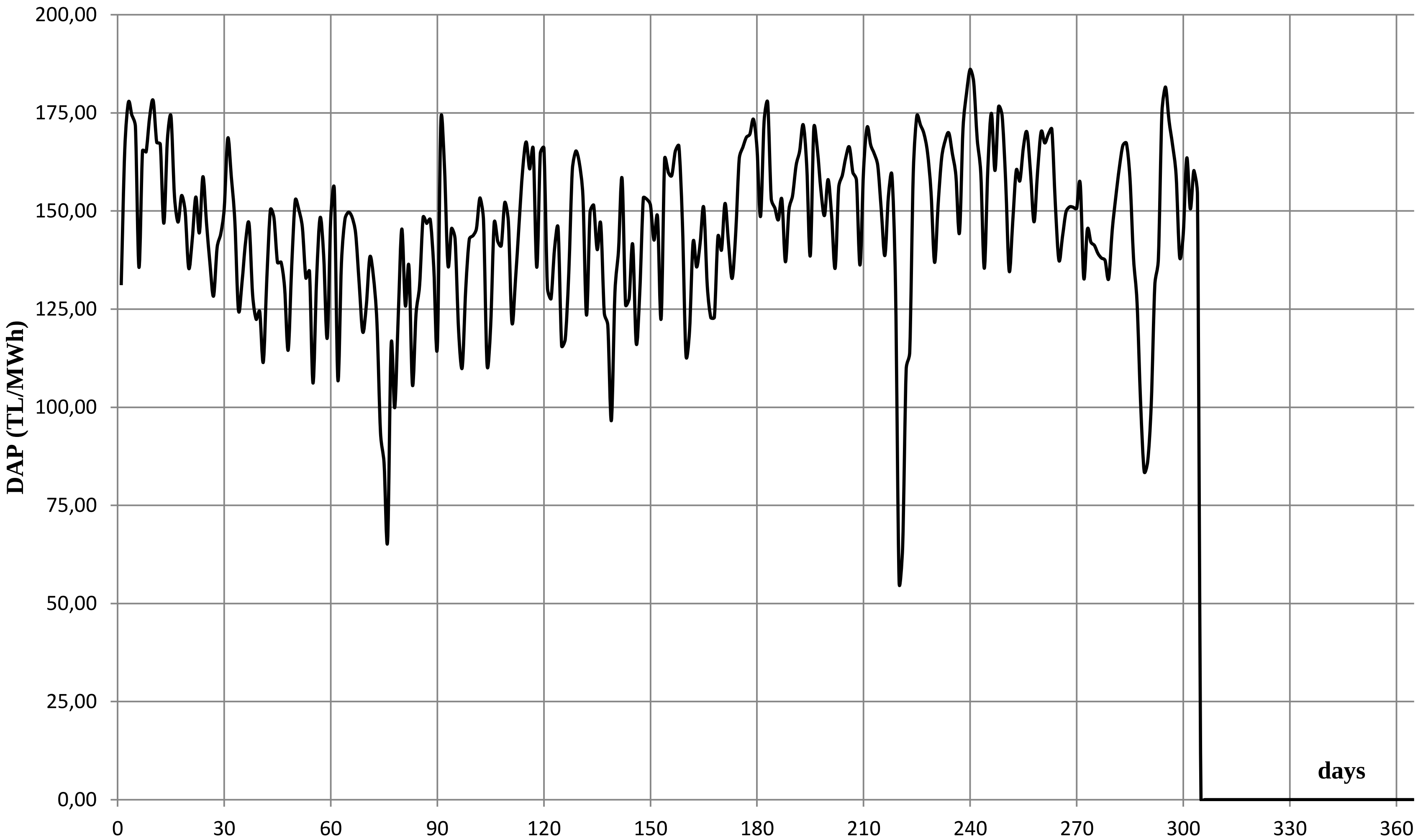


Figure C-5: Daily Averages of DAP in 2013

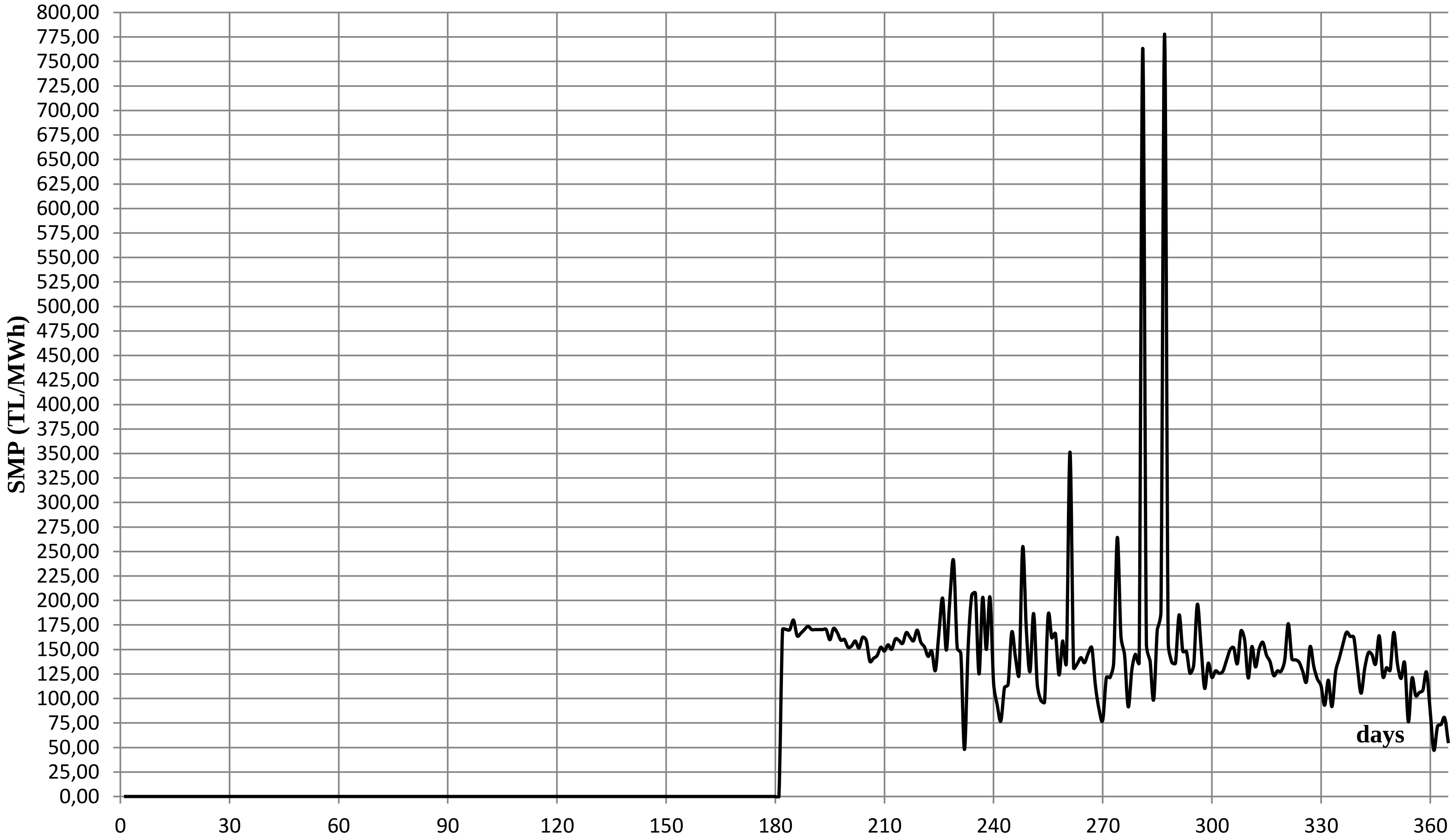


Figure C-6: Daily Averages of SMP in 2009

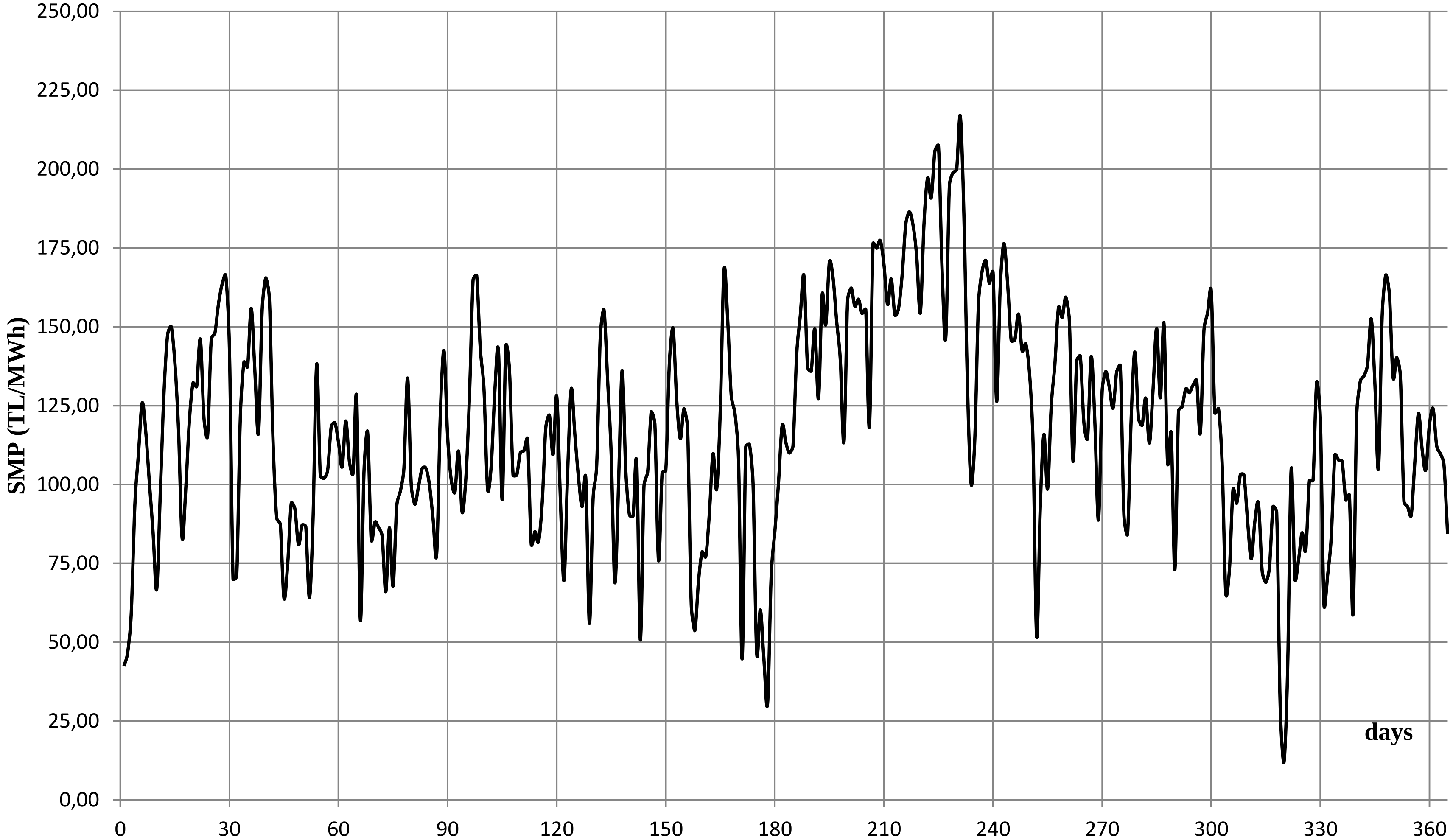


Figure C-7: Daily Averages of SMP in 2010

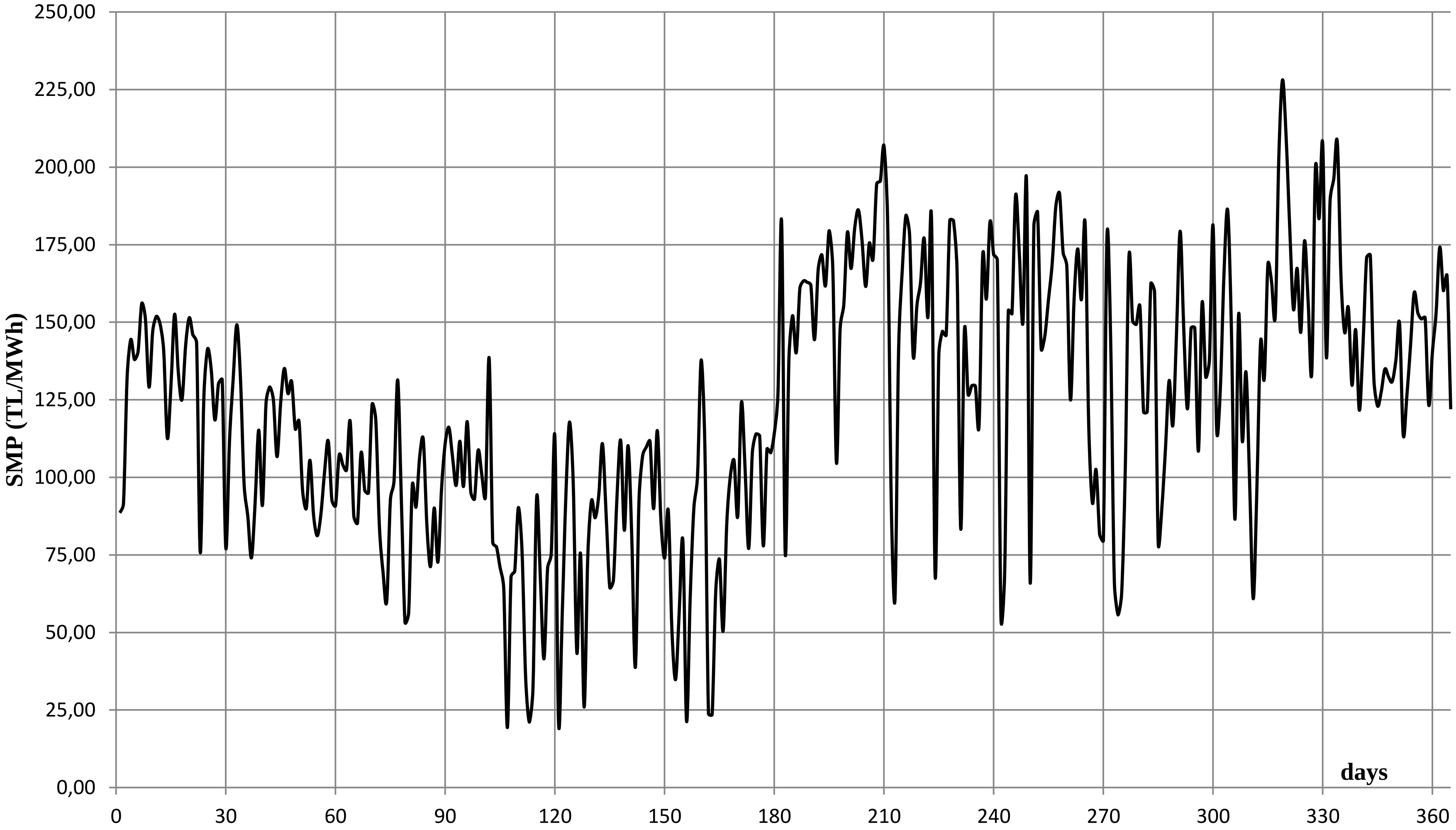


Figure C-8: Daily Averages of SMP in 2011

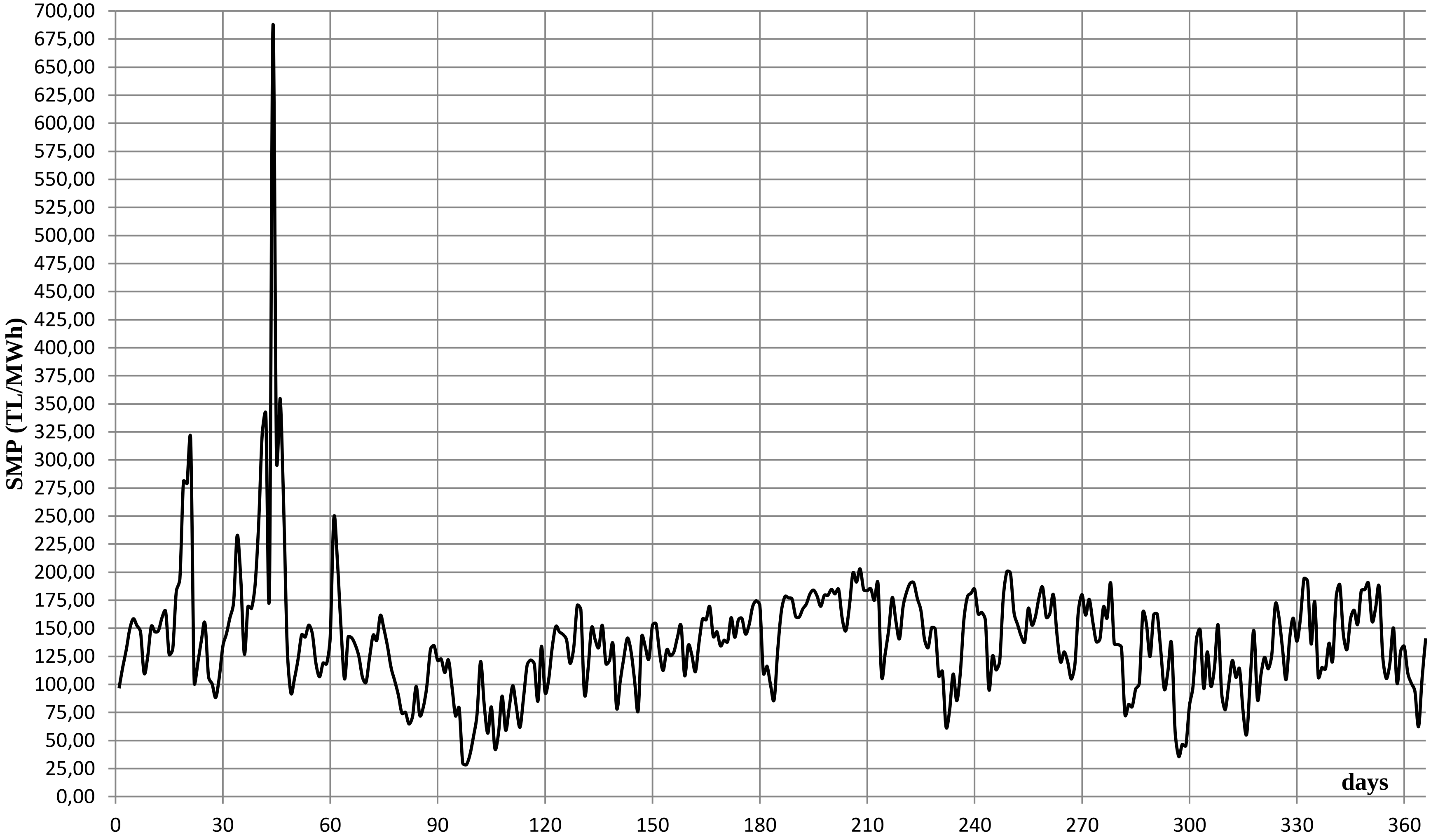


Figure C-9: Daily Averages of SMP in 2012

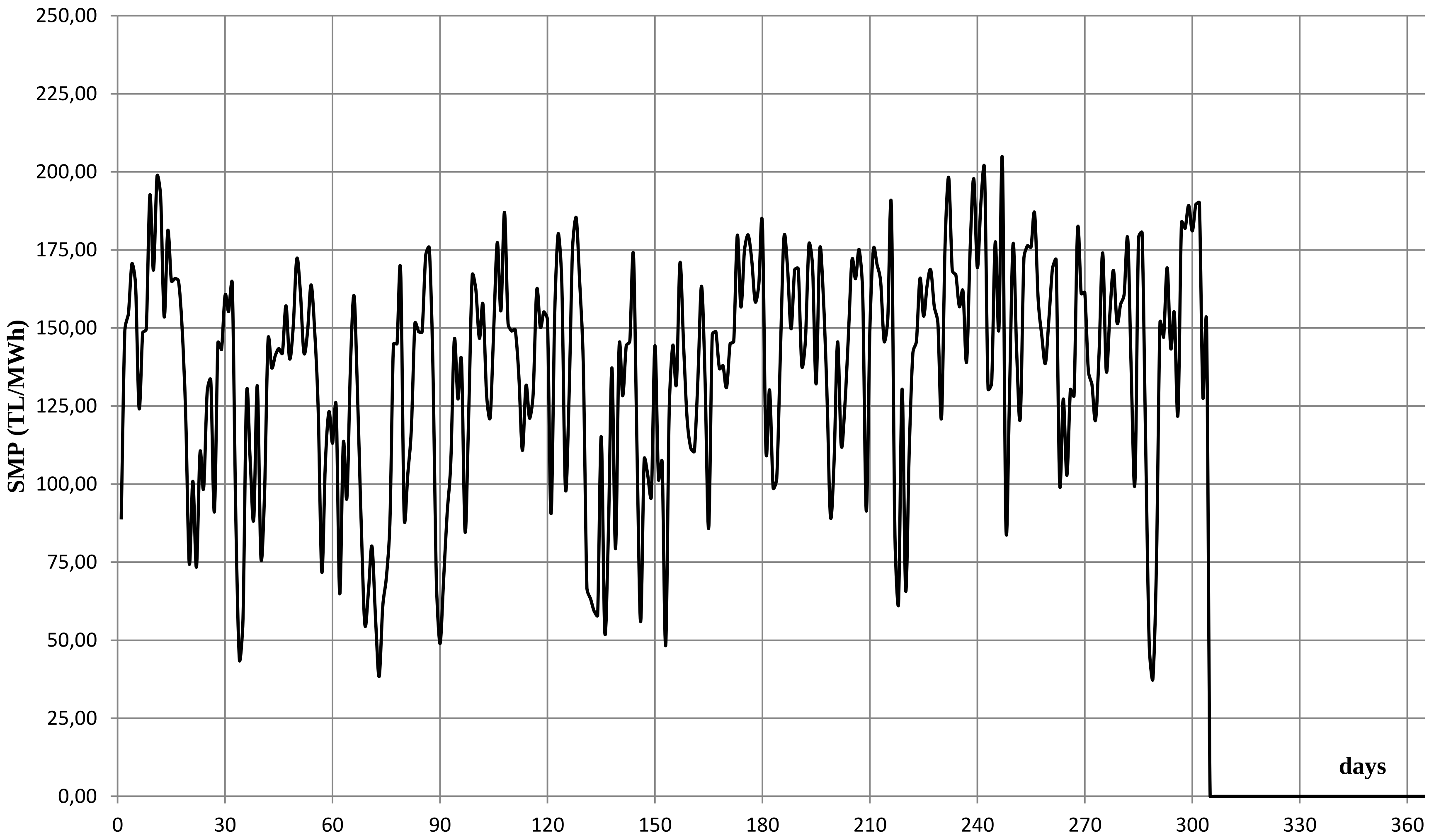


Figure C-10: Daily Averages of SMP in 2013

APPENDIX D

13.02.2012 ELECTIRICTY MARKET CRISIS IN TURKEY

İsmail Altunsoy investigates and writes the details of that crisis in his 2 two article in Zaman Gazette in 13 February 2012 and 21 February 2012. Summary of those articles are written in below (Altunsoy, Yüksek Fiyattan 80 Milyon Liralık Elektrik Satıldı, 2012) (Altunsoy, Cold Weather Spells Hike in Electricity Prices, 2012).

Natural gas accounts for 47 percent of Turkey's electricity generation, according to Energy Ministry data, a larger share than other major resources. A steep rise in natural gas consumption across the country due to cold weather for the past two weeks has prompted the Energy Ministry to increase supply to households. Things became even worse when supply from Iran and Azerbaijan also declined during the same period. Most electricity plants had to switch to the use of oil following the “crisis.”

The price per kilowatt hour (kWh) for wholesale electricity sold by the Turkish Electricity Production Company (TEİAŞ) to electricity distributors (normally around Kr 20-25) last week surged to Kr 97.8 at the Market Financial Settlement Center (MFRC). Fueled for the most part by natural gas, this price was expected to hit 2 TL on Monday (a record) raising concerns of a possible hike in electricity prices.

Turkey's current natural gas consumption is 192 million cubic meters per day, which is above the seasonal average due to the particularly cold weather over the past few weeks. Last year, Turkey's natural gas consumption was 171 million cubic meters per day during the winter.

Table D-1: DAP vs. Demand in 13.02.2012

Hour	Price (TL/MWh)	Demand (MWh)	TL
00:00	159.99	6,778	1,084,412.22 TL
01:00	149.99	5,961	894,090.39 TL
02:00	139.99	5,796	811,382.04 TL
03:00	125.00	5,674	709,250.00 TL
04:00	125.00	5,731	716,375.00 TL
05:00	134.74	5,818	783,917.32 TL
06:00	149.23	5,950	887,918.50 TL
07:00	159.99	6,713	1,074,012.87 TL
08:00	200.00	8,192	1,638,400.00 TL
09:00	756.10	7,361	5,565,652.10 TL
10:00	2000.00	7,072	14,144,000.00 TL
11:00	2000.00	6,686	13,372,000.00 TL
12:00	1162.77	7,595	8,831,238.15 TL
13:00	1600.04	7,674	12,278,706.96 TL
14:00	2000.00	7,576	15,152,000.00 TL
15:00	999.01	7,725	7,717,352.25 TL
16:00	999.00	7,715	7,707,285.00 TL
17:00	925.87	7,533	6,974,578.71 TL
18:00	952.13	7,514	7,154,304.82 TL
19:00	599.17	7,699	4,613,009.83 TL
20:00	450.05	7,885	3,548,644.25 TL
21:00	250.01	8,302	2,075,583.02 TL
22:00	250.01	8,924	2,231,089.24 TL
23:00	199.99	9,133	1,826,508.67 TL
TOTAL		**173,007**	**121,791,711.34 TL**

APPENDIX E

PRICE DISTRIBUTION OF DAP AND SMP

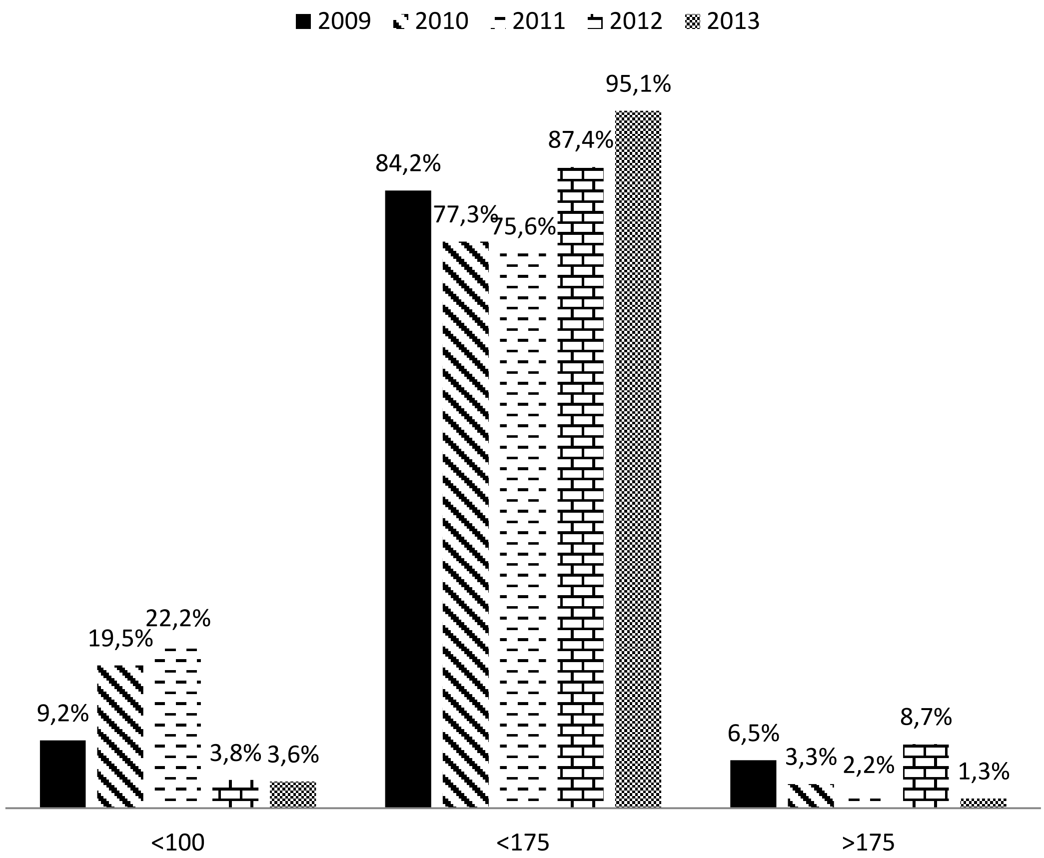


Figure E-1: DAP Distribution over years

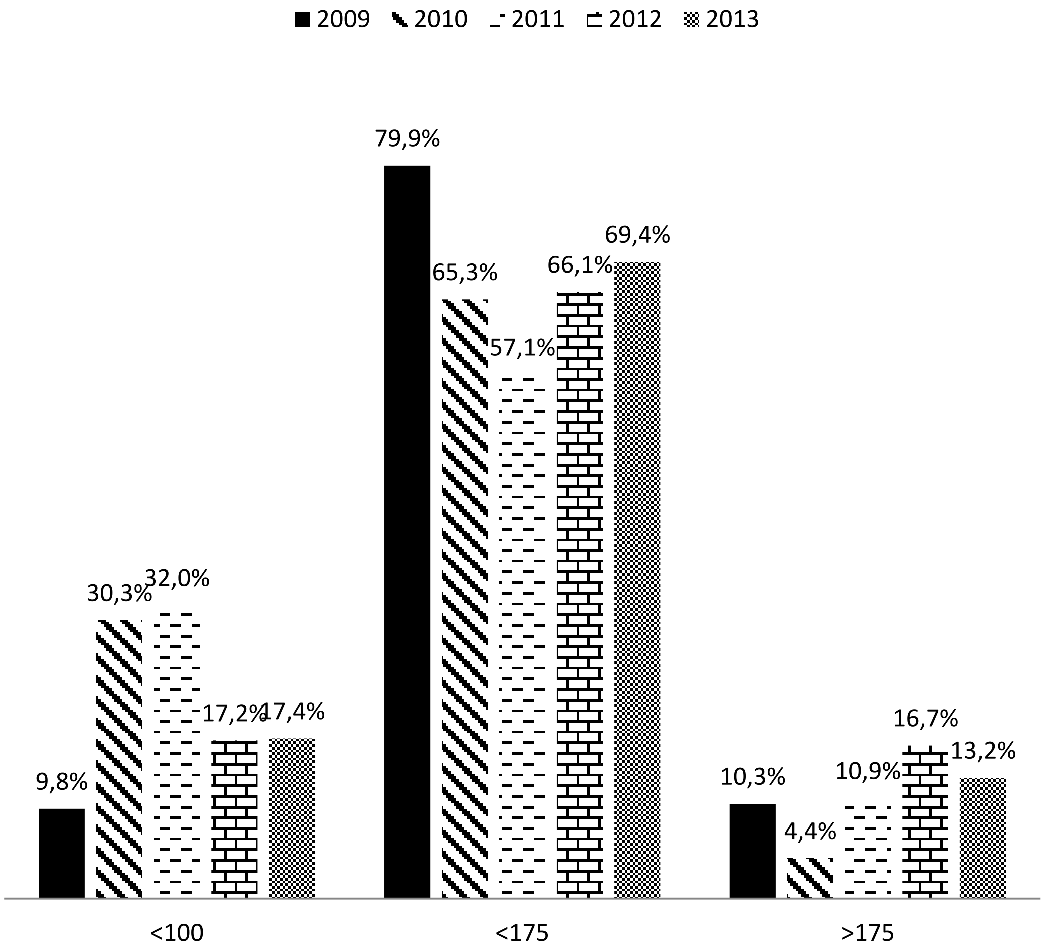


Figure E-2: SMP Distribution over years

APPENDIX F

UNIT COST CALCULATION FOR DAM TYPES

Korkmaz in her study worked the estimated costs of the Concrete Face Rock Fill Dam (CFRD), Earth Core Rock Fill Dam (ECRD) and Roller Compacted Concrete (RCC). In the study 2008 DSİ unit prices are used for calculations of estimated cost of Gökçeler Dam. For 3 dam types, she created own unit prices from GKL-01 to GKL-19 which are composed of DSİ unit prices (Korkmaz, 2009) . In this project we used the present unit prices of the DSİ and recalculate the estimated costs of the three dam type. Dividing the dam body volumes with the estimated costs gives the unit cost for each dam type that we used in the PXSC.

Table F-1: Unit Price Analysis (2008 DUC)

GKL-01	**EXCAVATION OF PERVIOUS AND IMPERVIOUS FOUNDATION**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.301	Excavation of all kinds and classes of foundation except rock and placement in deposit site	1	m^3	1.38	1.38
	B-07.D/4	Hauling of excavated material to dumping site (1 km)	1	m^3	1.86	1.86
				SUB TOTAL =		3.24
				UNIT PRICE FOR GKL-01 (DUC / m^3) =	3.24	
GKL-02	**EXCAVATION OF ROCKY FOUNDATION**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.310	Excavation of all kinds and classes of rock foundations and placement in deposit site	1	m^3	8.56	8.56
	B-07.D/5	Hauling of excavated rock material to dumping site (1 km)	1	m^3	2.69	2.69
				SUB TOTAL =		11.25
				UNIT PRICE FOR GKL-02 (DUC / m^3) =	11.25	
GKL-03	**PREPARATION OF FOUNDATION FOR FILL PLACEMENT**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.301	Excavation of all kinds and classes of foundation except rock and placement in deposit site	0.45	m^3	1.38	0.62
	B-15.310	Excavation of all kinds and classes of rock foundations and placement in deposit site	0.3	m^3	8.56	2.57
	B-15.306/A	Excavation of marshy foundation and placement in deposit site	0.25	m^3	2.8	0.70
	B-15.040	Treatment and cleaning of excavation surface	1	m^2	1.35	1.35
	B-07.D/5	Hauling of foundation excavation material to the placement site (1 km)	1	m^3	2.69	2.69
				SUB TOTAL =		7.93
				UNIT PRICE FOR GKL-03 (DUC / m^3) =	7.93	

Unit Price Analysis (2008 DUC) (Cont’d)

GKL-04	**PLACEMENT OF IMPERVIOUS FILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.302	Excavation of impervious fill material from barrow area and placement with in the embankment	1	m^3	2.78	2.78
	B-07.D/5	Hauling of excavated impervious material to the placement site (3 km)	1	m^3	3.59	3.59
				SUB TOTAL =		6.37
				UNIT PRICE FOR GKL-04 (DUC / m^3) =	6.37	
GKL-05	**PLACEMENT OF PERVIOUS FILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.302	Excavation of pervious fill material from barrow area and placement with in the embankment	1	m^3	2.18	2.18
	B-07.D/5	Hauling of excavated impervious material to the placement site (23 km)	1	m^3	10.33	10.33
				SUB TOTAL =		12.51
				UNIT PRICE FOR GKL-05 (DUC / m^3) =	12.51	
GKL-06	**PLACEMENT OF ROCK FILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.310	Excavation of rock fill material from quarries and placement with in the rockfill	1	m^3	8.51	8.51
	B-07.D/5	Hauling of excavated pervious material to the placement site (2.5 km)	1	m^3	4.26	4.26
				SUB TOTAL =		12.77
				UNIT PRICE FOR GKL-06 (DUC / m^3) =	12.77	
GKL-07	**PLACEMENT OF EXCAVATED IMPERVIOUS OR PERVIOUS MATERIAL WITHIN EMBANKMENT**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.307	Excavation of all kinds and classes of foundation except rock and placement within the embankment	1	m^3	0.79	0.79
	B-07.D/4	Hauling of excavated material to placement location (0.5 km)	1	m^3	1.46	1.46
				SUB TOTAL =		2.25
				UNIT PRICE FOR GKL-07 (DUC / m^3) =	2.25	

Unit Price Analysis (2008 DUC) (Cont'd)

GKL-08	**PLACEMENT OF EXCAVATED ROCK MATERIAL WITHIN EMBANKMENT**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.311	Excavation of all kinds and classes of rock foundations and placement within embankment	1	m^3	1.2	1.20
	B-07.D/4	Hauling of excavated rock material to placement location (0.5 km)	1	m^3	1.46	1.46
				SUB TOTAL =		2.66
				UNIT PRICE FOR GKL-08 (DUC / m^3) =	2.66	
GKL-09	**PREPARATION AND PLACEMENT OF FILTER MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.343	Extraction of filter material from barrow area, preparation and placing within the embankment	1	m^3	8.86	8.86
	B-15.344	Washing of filter material	1	m^3	0.64	0.64
	B-07.D/4	Hauling of filter material to placement location (23 km)	1	m^3	9.3	9.30
				SUB TOTAL =		18.80
				UNIT PRICE FOR GKL-09 (DUC / m3) =	18.80	
GKL-10	**COMPACTION OF PERVIOUS FILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.052/B	Compaction of pervious embankment material by vibratory roller compactors	1	hour	98.79	98.79
	B-15.344	Sluicing and washing of pervious fill material	7.5	m^3	0.64	4.80
				SUB TOTAL (for 150 m^3)=		103.59
				UNIT PRICE FOR GKL-10 (DUC / m^3) =	0.69	
GKL-11	**COMPACTION OF IMPERVIOUS FILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.054	Compaction of impervious embankment material by vibratory sheep-foot compactors	1	hour	62.45	62.45
	B-15.322	Sluicing and washing of impervious fill material	10	m^3	2.28	22.80
				SUB TOTAL (for 100 m^3)=		85.25
				UNIT PRICE FOR GKL-11 (DUC / m^3) =	0.85	

Unit Price Analysis (2008 DUC) (Cont'd)

GKL-12	**COMPACTION OF ROCKFILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.052/B	Compaction of rockfill material by vibratory roller compactors	1	hour	98.79	98.79
	B-15.323	Washing of rockfill material with high pressurized water	29.25	m^3	1.09	31.88
				SUB TOTAL (for 225 m^3)=		130.67
				UNIT PRICE FOR GKL-12 (DUC / m^3) =	0.58	
GKL-13	**PLACEMENT OF SURFACE PROTECTION**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.348	Preparation of qualified rock boulders extracted from quarries	1	m^3	12.91	12.91
	B-07.D/3	Hauling of extracted protection material to the placement site (2.5 km)	1	m^3	3.28	3.28
				SUB TOTAL=		16.19
				UNIT PRICE FOR GKL-13 (DUC / m^3) =	16.19	
GKL-14	**PREPARATION OF CONCRETE AGGREGATE**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.344	Preparation of conrete aggregate by washing	1	m^3	0.64	0.64
	B-07.D/4	Hauling of aggregate to the concrete plant (23 km)	1	m^3	9.3	9.30
				SUB TOTAL=		9.94
				UNIT PRICE FOR GKL-14 (DUC / m^3) =	9.94	
GKL-15	**SUPPLY OF CEMENT FOR CONCRETE**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-16.501/B	Cost of cement	1	ton	156.38	156.38
	B-07.D/4	Hauling of cement to the concrete plant (199 km)	1	ton	26.32	26.32
				SUB TOTAL=		182.70
				UNIT PRICE FOR GKL-15 (DUC / ton) =	182.70	

Unit Price Analysis (2008 DUC) (Cont'd)

GKL-16	**SUPPLY OF CONSTRUCTIONAL STEEL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-23.002	Cost of steel bars	1	ton	1437.4	1437.40
	B-07.D/4	Hauling of steel bars to the site workshop (499 km)	1	ton	70.09	70.09
				SUB TOTAL=		1507.49
				UNIT PRICE FOR GKL-16 (DUC / ton) =	1507.49	
GKL-17	**PREPARATION AND PLACEMENT OF CONCRETE**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-16.507	Preparation of concrete with required compressive strength	1	m^3	86.99	86.99
	B-21.024/2	Formwork for curved surfaces which expose water directly	2	m^2	64.99	129.98
	D.18.503/B	Supply and placement of PVC waterstops	7.6	kg	10.15	77.14
				SUB TOTAL=		294.11
				UNIT PRICE FOR GKL-17 (DUC / m^3) =	294.11	
GKL-18	**FOUNDATION GROUTING**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	31-13-7829	Drilling of bore holes without sampling	1	m	119.14	119.14
	31-7842/A	Grout mix injection from boreholes	0.0565	m^3	676.87	38.24
	YAS-07.D/1	Supply of required cement for grout mix	0.02	ton	156.38	3.13
	YAS-07.005	Hauling of grout mix cement	0.02	ton	26.32	0.53
				SUB TOTAL=		161.04
				UNIT PRICE FOR GKL-18 (DUC / m) =	161.04	

Unit Price Analysis (2008 DUC) (Cont'd)

	PREPARATION AND PLACEMENT OF ROLLER COMPACTED CONCRETE					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.344	Preparation of concrete aggregate by washing	1.25	m^3	0.64	0.8
	B-07.D/4	Hauling of aggregate to the concrete plant (23 km)	1.25	m^3	9.3	11.62
GKL-19	B-16.501/B	Cost of cement	0.08	ton	156.38	12.51
	B-07.D/4	Hauling of cement to the concrete plant (199 km)	0.08	ton	26.32	2.11
	B-15.052/B	Compaction of roller compacted concrete by vibratory roller compactors	0.01	hour	98.79	0.99
	1.502	Laboring	5	hour	3.7	18.5
				SUB TOTAL=		46.53
				UNIT PRICE FOR GKL-19 (DUC / m^3) =	46.53	

Table F-2: Estimated Cost Analysis Table for CFRD Dam Body (2008 DUC)

UNIT PRICE CODE	DEFINITION OF THE WORK	QUANTITY	UNIT	UNIT PRICE (DUC)	TOTAL (DUC)
GKL-03	Preparation of embankment foundation for placement of fill material.	184,500	m^3	7.929	1,462,901
GKL-06	Extraction of rockfill material from quarries, placement within the fill and haulage for 2.5 km. (For remaining portion of 3B Zone and 3A Zone)	1,710,250	m^3	12.77	21,839,893
GKL-07	Placement of excavated pervious or impervious foundation material within embankment and haulage for 1 km. (1A and 1B Zones)	105,000	m^3	3.46	363,300
GKL-08	Placement of excavated rock foundation within the rockfill and haulage for 1 km . (From tunnel and spillway excavation for 3C Zone and some portion	34,750	m^3	2.66	92,435
GKL-09	Preparation of filter material and haulage for 23 km (For 2A and 2B Zones)	50,000	m^3	18.80	940,000
GKL-10	Sluicing and compaction of pervious material fPYrpnt rnrkl	50,000	m^3	0.69	34,530
GKL-11	Sluicing and compaction of impervious material.	105,000	m^3	0.85	89,513
GKL-12	Sluicing and compaction of rockfill material.	1,745,000	m^3	0.58	1,013,438
GKL-13	Placement of surface protection from rockfill and haulage for 2.5 km.	25,000	m^3	16.19	404,750
GKL-14	Preparation of aggregate mixed in concrete mortar and haulage for 23 km .	31,875	m^3	9.94	316,838
GKL-15	Supply of cement mixed in concrete mortar and haulage for 199 km.	7,650	ton	182.70	1,397,655
GKL-16	Supply of construction steel and haulage for 499 km.	127	ton	1,507.49	191,451
GKL-17	Preparation and placement of concrete (For handrail poles on the crest)	25,500	m^3	294.11	7,499,805
			SUB TOTAL =		35,646,507
			TOTAL COST OF DAM BODY(DUC) =		**35,646,507**

Table F-3: Estimated Cost Analysis Table for ECRD Dam Body (2008 DUC)

UNIT PRICE CODE	**DEFINITION OF THE WORK**	**QUANTITY**	**UNIT**	**UNIT PRICE (DUC)**	**TOTAL (DUC)**
GKL-03	Preparation of embankment foundation for placement of fill material.	273,000	m^3	7.929	2,164,617
GKL-04	Extraction of impervious fill material from barrow areas, placement within the fill and haulage for 3 km.	547,000	m^3	6.37	3,484,390
GKL-06	Extraction of rockfill material from quarries, placement within the fill and haulage for 2.5 km.	1,905,000	m^3	12.77	24,326,850
GKL-09	Preparation of filter material and haulage for 23 km.	161,500	m^3	18.80	3,036,200
GKL-10	Sluicing and compaction of pervious material (except rock)	161,500	m^3	0.69	111,532
GKL-11	Sluicing and compaction of impervious material.	547,000	m^3	0.85	466,318
GKL-12	Sluicing and compaction of rockfill material.	1,905,000	m^3	0.58	1,106,361
GKL-13	Placement of surface protection from rockfill and haulage for 2.5 km.	57,000	m^3	16.19	922,830
GKL-14	Preparation of aggregate mixed in concrete mortar and haulage for 23 km .	63	m^3	9.94	626
GKL-15	Supply of cement for concrete mortar and haulage for 199 km.	15	ton	182.70	2,741
GKL-16	Supply of construction steel and haulage for 499 km.	2	ton	1,507.49	3,015
GKL-17	Preparation and placement of concrete (For handrail poles on the crest)	50	m^3	294.11	14,706
		SUB TOTAL =			35,640,184
		TOTAL COST OF DAM BODY(DUC) =			**35,640,184**

Table F-4: Estimated Cost Analysis Table for RCC Dam Body (2008 DUC)

UNIT PRICE CODE	DEFINITION OF THE WORK	QUANTITY	UNIT	UNIT PRICE (DUC)	TOTAL (DUC)
GKL-03	Preparation of embankment foundation for placement of fill material.	81,750	m^3	7.929	648,196
GKL-14	Preparation of aggregate mixed in concrete mortar and haulage for 23 km. (For upstream covering and handrail')	2,138	m^3	9.94	21,252
GKL-15	Supply of cement mixed in concrete mortar and haulage for 199 km.	513	ton	182.70	93,725
GKL-16	Supply of construction steel and haulage for 499 km. (For handrail on the crest)	2	ton	1,507.49	3,015
GKL-17	Preparation and placement of concrete for upstream covering. (For upstream covering and handrail)	1,710	m^3	294.11	502,928
GKL-19	Preparation and placement of roller compacted concrete	840,000	m3	46.53	39,085,200
			SUB TOTAL =		40,354,316
			TOTAL COST OF DAM BODY(DUC) =		**40,354,316**

Table F-5: Unit Price Analysis (2013 DUC)

GKL-01	**EXCAVATION OF PERVIOUS AND IMPERVIOUS FOUNDATION**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.301	Excavation of all kinds and classes of foundation except rock and placement in deposit site	1	m^3	2.11	2.11
	B-07.D/4	Hauling of excavated material to dumping site (1 km)	1	m^3	2.84	2.84
				SUB TOTAL =		4.95
				UNIT PRICE FOR GKL-01 (DUC / m^3) =	4.95	
GKL-02	**EXCAVATION OF ROCKY FOUNDATION**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.310	Excavation of all kinds and classes of rock foundations and placement in deposit site	1	m^3	11.91	11.91
	B-07.D/5	Hauling of excavated rock material to dumping site (1 km)	1	m^3	4.11	4.11
				SUB TOTAL =		16.02
				UNIT PRICE FOR GKL-02 (DUC / m^3) =	16.02	
GKL-03	**PREPARATION OF FOUNDATION FOR FILL PLACEMENT**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.301	Excavation of all kinds and classes of foundation except rock and placement in deposit site	0.45	m^3	2.11	0.95
	B-15.310	Excavation of all kinds and classes of rock foundations and placement in deposit site	0.3	m^3	11.91	3.57
	B-15.306/A	Excavation of marshy foundation and placement in deposit site	0.25	m^3	4.31	1.08
	B-15.040	Treatment and cleaning of excavation surface	1	m^2	1.9	1.90
	B-07.D/5	Hauling of foundation excavation material to the placement site (1 km)	1	m^3	4.11	4.11
				SUB TOTAL =		11.61
				UNIT PRICE FOR GKL-03 (DUC / m^3) =	11.61	

Unit Price Analysis (2013 DUC) (Cont'd)

	PLACEMENT OF IMPERVIOUS FILL MATERIAL					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
GKL-04	B-15.302	Excavation of impervious fill material from barrow area and placement with in the embankment	1	m^3	3.38	3.38
	B-07.D/5	Hauling of excavated impervious material to the placement site (3 km)	1	m^3	5.45	5.45
				SUB TOTAL =		8.83
				UNIT PRICE FOR GKL-04 (DUC / m^3) =	8.83	
	PLACEMENT OF PERVIOUS FILL MATERIAL					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
GKL-05	B-15.302	Excavation of pervious fill material from barrow area and placement with in the embankment	1	m^3	3.38	3.38
	B-07.D/5	Hauling of excavated impervious material to the placement site (23 km)	1	m^3	15.7	15.70
				SUB TOTAL =		19.08
				UNIT PRICE FOR GKL-05 (DUC / m^3) =	19.08	
	PLACEMENT OF ROCK FILL MATERIAL					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
GKL-06	B-15.310	Excavation of rock fill material from quarries and placement with in the rockfill	1	m^3	11.91	11.91
	B-07.D/5	Hauling of excavated pervious material to the placement site (2.5 km)	1	m^3	6.47	6.47
				SUB TOTAL =		18.38
				UNIT PRICE FOR GKL-06 (DUC / m^3) =	18.38	
	PLACEMENT OF EXCAVATED IMPERVIOUS OR PERVIOUS MATERIAL WITHIN EMBANKMENT					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
GKL-07	B-15.307	Excavation of all kinds and classes of foundation except rock and placement within the embankment	1	m^3	1.25	1.25
	B-07.D/4	Hauling of excavated material to placement location (0.5 km)	1	m^3	2.21	2.21
				SUB TOTAL =		3.46
				UNIT PRICE FOR GKL-07 (DUC / m^3) =	3.46	

Unit Price Analysis (2013 DUC) (Cont'd)

GKL-08	**PLACEMENT OF EXCAVATED ROCK MATERIAL WITHIN EMBANKMENT**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.311	Excavation of all kinds and classes of rock foundations and placement within embankment	1	m^3	1.9	1.90
	B-07.D/4	Hauling of excavated rock material to placement location (0.5 km)	1	m^3	2.21	2.21
				SUB TOTAL =		4.11
				UNIT PRICE FOR GKL-08 (DUC / m^3) =	4.11	
GKL-09	**PREPARATION AND PLACEMENT OF FILTER MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.343	Extraction of filter material from barrow area, preparation and placing within the embankment	1	m^3	13.49	13.49
	B-15.344	Washing of filter material	1	m^3	0.94	0.94
	B-07.D/4	Hauling of filter material to placement location (23 km)	1	m^3	14.13	14.13
				SUB TOTAL =		28.56
				UNIT PRICE FOR GKL-09 (DUC / m3) =	28.56	
GKL-10	**COMPACTION OF PERVIOUS FILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.052/B	Compaction of pervious embankment material by vibratory roller compactors	1	hour	161.59	161.59
	B-15.344	Sluicing and washing of pervious fill material	7.5	m^3	0.94	7.05
				SUB TOTAL (for 150 m^3)=		168.64
				UNIT PRICE FOR GKL-10 (DUC / m^3) =	1.12	
GKL-11	**COMPACTION OF IMPERVIOUS FILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.054	Compaction of impervious embankment material by vibratory sheep-foot compactors	1	hour	98.21	98.21
	B-15.322	Sluicing and washing of impervious fill material	10	m^3	3.47	34.70
				SUB TOTAL (for 100 m^3)=		132.91
				UNIT PRICE FOR GKL-11 (DUC / m^3) =	1.33	

Unit Price Analysis (2013 DUC) (Cont’d)

GKL-12	**COMPACTION OF ROCKFILL MATERIAL**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.052/B	Compaction of rockfill material by vibratory roller compactors	1	hour	161.59	161.59
	B-15.323	Washing of rockfill material with high pressurized water	29.25	m^3	1.64	47.97
				SUB TOTAL (for 225 m^3)=		209.56
				UNIT PRICE FOR GKL-12 (DUC / m^3) =	0.93	
GKL-13	**PLACEMENT OF SURFACE PROTECTION**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.348	Preparation of qualified rock boulders extracted from quarries	1	m^3	18.91	18.91
	B-07.D/3	Hauling of extracted protection material to the placement site (2.5 km)	1	m^3	4.98	4.98
				SUB TOTAL=		23.89
				UNIT PRICE FOR GKL-13 (DUC / m^3) =	23.89	
GKL-14	**PREPARATION OF CONCRETE AGGREGATE**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.344	Preparation of conrete aggregate by washing	1	m^3	0.94	0.94
	B-07.D/4	Hauling of aggregate to the concrete plant (23 km)	1	m^3	14.13	14.13
				SUB TOTAL=		15.07
				UNIT PRICE FOR GKL-14 (DUC / m^3) =	15.07	
GKL-15	**SUPPLY OF CEMENT FOR CONCRETE**					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-16.501/B	Cost of cement	1	ton	147.29	147.29
	B-07.D/4	Hauling of cement to the concrete plant (199 km)	1	ton	40.01	40.01
				SUB TOTAL=		187.30
				UNIT PRICE FOR GKL-15 (DUC / ton) =	187.30	

Unit Price Analysis (2013 DUC) (Cont’d)

GKL-16		**SUPPLY OF CONSTRUCTIONAL STEEL**				
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-23.002	Cost of steel bars	1	ton	2013.75	2013.75
	B-07.D/4	Hauling of steel bars to the site workshop (499 km)	1	ton	106.53	106.53
				SUB TOTAL=		2120.28
				UNIT PRICE FOR GKL-16 (DUC / ton) =	2120.28	
GKL-17		**PREPARATION AND PLACEMENT OF CONCRETE**				
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-16.507	Preparation of concrete with required compressive strength	1	m^3	132.04	132.04
	B-21.024/2	Formwork for curved surfaces which expose water directly	2	m^2	88.85	177.70
	D.18.503/B	Supply and placement of PVC waterstops	7.6	kg	11.16	84.82
				SUB TOTAL=		394.56
				UNIT PRICE FOR GKL-17 (DUC / m^3) =	394.56	
GKL-18		**FOUNDATION GROUTING**				
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	31-13-7829	Drilling of bore holes without sampling	1	m	182.88	182.88
	31-7842/A	Grout mix injection from boreholes	0.0565	m^3	1023.85	57.85
	YAS-07.D/1	Supply of required cement for grout mix	0.02	ton	237.7	4.75
	YAS-07.005	Hauling of grout mix cement	0.02	ton	40.01	0.80
				SUB TOTAL=		246.28
				UNIT PRICE FOR GKL-18 (DUC / m) =	246.28	

Unit Price Analysis (2013 DUC) (Cont'd)

	PREPARATION AND PLACEMENT OF ROLLER COMPACTED CONCRETE					
	CODE	DEFINITON OF THE WORK	QUANTITY	Unit	Unit Price (DUC)	Total (DUC)
	B-15.344	Preparation of concrete aggregate by washing	1.25	m^3	0.94	1.18
	B-07.D/4	Hauling of aggregate to the concrete plant (23 km)	1.25	m^3	14.13	17.66
GKL-19	B-16.501/B	Cost of cement	0.08	ton	147.29	11.78
	B-07.D/4	Hauling of cement to the concrete plant (199 km)	0.08	ton	40.01	3.20
	B-15.052/B	Compaction of roller compacted concrete by vibratory roller compactors	0.01	hour	161.59	1.62
	1.502	Laboring	5	hour	5.52	27.60
	SUB TOTAL=					63.04
	UNIT PRICE FOR GKL-19 (DUC / m^3) =				63.04	

Table F-6: Estimated Cost Analysis Table for CFRD Dam Body (2013 DUC)

UNIT PRICE CODE	DEFINITION OF THE WORK	QUANTITY	UNIT	UNIT PRICE (DUC)	TOTAL (DUC)
GKL-03	Preparation of embankment foundation for placement of fill material.	184,500	m^3	11.61	2,142,045
GKL-06	Extraction of rockfill material from quarries, placement within the fill and haulage for 2.5 km. (For remaining portion of 3B Zone and 3A Zone)	1,710,250	m^3	18.38	31,434,395
GKL-07	Placement of excavated pervious or impervious foundation material within embankment and haulage for 1 km. (1A and 1B Zones)	105,000	m^3	3.46	363,300
GKL-08	Placement of excavated rock foundation within the rockfill and haulage for 1 km . (From tunnel and spillway excavation for 3C Zone and some portion	34,750	m^3	4.11	142,823
GKL-09	Preparation of filter material and haulage for 23 km (For 2A and 2B Zones)	50,000	m^3	28.56	1,428,000
GKL-10	Sluicing and compaction of pervious material fPYrpnt rnrkl	50,000	m^3	1.12	56,213
GKL-11	Sluicing and compaction of impervious material.	105,000	m^3	1.33	139,556
GKL-12	Sluicing and compaction of rockfill material.	1,745,000	m^3	0.93	1,625,254
GKL-13	Placement of surface protection from rockfill and haulage for 2.5 km.	25,000	m^3	23.89	597,250
GKL-14	Preparation of aggregate mixed in concrete mortar and haulage for 23 km .	31,875	m^3	15.07	480,356
GKL-15	Supply of cement mixed in concrete mortar and haulage for 199 km.	7,650	ton	187.30	1,432,845
GKL-16	Supply of construction steel and haulage for 499 km.	127	ton	2,120.28	269,276
GKL-17	Preparation and placement of concrete (For handrail poles on the crest)	25,500	m^3	394.56	10,061,178
			SUB TOTAL =		50,172,490
			TOTAL COST OF DAM BODY(DUC) =		**50,172,490**

Table F-7: Estimated Cost Analysis Table for ECRD Dam Body (2013 DUC)

UNIT PRICE CODE	DEFINITION OF THE WORK	QUANTITY	UNIT	UNIT PRICE (DUC)	TOTAL (DUC)
GKL-03	Preparation of embankment foundation for placement of fill material.	273,000	m^3	11.61	3,169,530
GKL-04	Extraction of impervious fill material from barrow areas, placement within the fill and haulage for 3 km.	547,000	m^3	8.83	4,830,010
GKL-06	Extraction of rockfill material from quarries, placement within the fill and haulage for 2.5 km.	1,905,000	m^3	18.38	35,013,900
GKL-09	Preparation of filter material and haulage for 23 km.	161,500	m^3	28.56	4,612,440
GKL-10	Sluicing and compaction of pervious material (except rock)	161,500	m^3	1.12	181,569
GKL-11	Sluicing and compaction of impervious material.	547,000	m^3	1.33	727,018
GKL-12	Sluicing and compaction of rockfill material.	1,905,000	m^3	0.93	1,774,275
GKL-13	Placement of surface protection from rockfill and haulage for 2.5 km.	57,000	m^3	23.89	1,361,730
GKL-14	Preparation of aggregate mixed in concrete mortar and haulage for 23 km .	63	m^3	15.07	949
GKL-15	Supply of cement for concrete mortar and haulage for 199 km.	15	ton	187.30	2,810
GKL-16	Supply of construction steel and haulage for 499 km.	2	ton	2120.28	4,241
GKL-17	Preparation and placement of concrete (For handrail poles on the crest)	50	m^3	394.56	19,728
		SUB TOTAL =			51,698,199
		TOTAL COST OF DAM BODY(DUC) =			**51,698,199**

Table F-8: Estimated Cost Analysis Table for RCC Dam Body (2013 DUC)

UNIT PRICE CODE	DEFINITION OF THE WORK	QUANTITY	UNIT	UNIT PRICE (DUC)	TOTAL (DUC)
GKL-03	Preparation of embankment foundation for placement of fill material.	81,750	m^3	11.61	949,118
GKL-14	Preparation of aggregate mixed in concrete mortar and haulage for 23 km. (For upstream covering and handrail')	2,138	m^3	15.07	32,220
GKL-15	Supply of cement mixed in concrete mortar and haulage for 199 km.	513	ton	187.30	96,085
GKL-16	Supply of construction steel and haulage for 499 km. (For handrail on the crest)	2	ton	2,120.28	4,241
GKL-17	Preparation and placement of concrete for upstream covering. (For upstream covering and handrail)	1,710	m^3	394.56	674,691
GKL-19	Preparation and placement of roller compacted concrete	840,000	m3	63.04	52,951,416
			SUB TOTAL =		54,707,769
			TOTAL COST OF DAM BODY(DUC) =		**54,707,769**

APPENDIX G

EPEX SPOT DAM PRICES

Data compiled from EPEX SPOT web page (EPEX Spot, 2013)). ELIX and PHELIX prices within the 01.November.2013 and 30.November.2013 and in terms of €/MWh. European Electricity Index (ELIX) are generated from the combination of PHELIX, SWISSIX and FRANCE markets which are the markets for Germany and Austria, Switzerland and France respectively operating in the EPEX SPOT.

Table G-1: PHELIX Prices for November 2013
(Data compiled from EPEX SPOT **(EPEX Spot, 2013)**)

	01/11	02/11	03/11	04/11	05/11	06/11	07/11	08/11	09/11	10/11	11/11	12/11	13/11	14/11	15/11	16/11	17/11	18/11	19/11	20/11	21/11	22/11	23/11	24/11	25/11	26/11	27/11	28/11	29/11	30/11	Average (€/MWh)	Average ($/MWh)
1	29.7	27.8	13.1	7.1	21.7	20.0	27.2	31.2	29.6	16.1	20.9	25.9	31.1	30.8	32.6	32.0	29.0	32.1	30.8	31.7	31.4	32.0	33.5	31.5	29.6	29.8	32.0	27.8	26.0	15.0	**27.0**	**37.7**
2	28.0	19.9	11.0	9.1	20.1	19.6	17.5	29.5	25.8	11.3	23.1	21.2	30.1	29.4	32.0	30.7	27.3	31.3	30.4	30.5	30.7	31.2	32.0	29.4	28.1	30.3	31.1	23.0	24.1	14.4	**25.1**	**35.1**
3	25.0	13.1	8.9	8.2	19.6	13.2	14.1	27.5	19.7	8.6	20.9	18.0	29.1	29.1	31.3	30.6	28.1	31.2	30.0	29.2	30.0	29.8	30.9	25.5	25.0	29.8	30.6	14.8	22.4	11.9	**22.9**	**32.0**
4	25.1	12.1	5.5	6.6	18.3	9.0	11.0	25.4	14.5	2.1	15.1	18.1	27.6	29.2	31.3	30.4	28.0	29.1	30.7	29.5	30.7	29.8	29.8	24.0	24.7	30.2	30.2	14.8	26.4	14.1	**21.8**	**30.5**
5	22.4	11.6	2.3	9.1	19.6	7.0	10.6	25.5	12.9	2.0	14.9	22.0	28.8	29.3	31.6	30.7	28.5	29.2	32.0	30.6	31.6	31.1	31.3	25.6	25.2	30.6	30.4	21.5	29.0	12.7	**22.3**	**31.3**
6	25.0	12.2	2.5	10.6	27.0	17.4	16.6	30.1	17.1	3.3	20.8	27.5	30.5	30.8	33.5	30.9	29.0	32.1	32.6	32.1	33.6	32.3	29.9	23.0	29.1	32.1	30.0	29.5	29.1	14.4	**24.8**	**34.7**
7	29.9	12.5	3.8	31.8	38.8	32.9	30.2	39.6	15.6	8.2	37.9	35.7	39.2	39.4	42.8	30.6	28.3	41.3	41.0	39.7	43.9	40.8	31.0	14.4	38.0	48.8	38.1	39.7	39.1	20.3	**32.4**	**45.4**
8	28.6	14.2	1.4	42.5	43.7	35.9	31.6	55.9	22.9	11.1	43.7	64.3	54.9	53.7	62.5	31.3	31.0	55.9	60.0	54.9	66.0	51.9	32.2	14.8	62.5	61.1	62.9	55.6	65.0	30.4	**43.4**	**60.8**
9	33.0	25.1	4.9	38.7	42.9	39.6	33.9	55.1	29.0	13.8	47.3	60.0	55.9	55.9	65.8	33.1	32.6	55.0	67.2	58.9	65.0	60.9	37.8	28.8	60.7	65.5	64.0	51.0	69.3	34.7	**46.2**	**64.7**
10	32.7	32.4	12.2	34.9	38.4	31.7	32.5	54.4	20.0	19.2	51.3	49.6	54.5	54.2	66.7	35.1	35.0	52.4	63.1	59.5	64.5	61.9	52.4	34.0	45.5	65.4	50.9	50.2	60.0	36.0	**45.0**	**63.0**
11	32.5	35.6	12.2	34.1	35.0	30.2	31.9	56.0	16.7	27.4	46.3	43.9	54.0	50.0	60.4	35.3	34.5	50.1	56.8	64.2	61.2	61.0	59.1	35.4	39.2	53.8	41.9	50.1	53.3	37.5	**43.3**	**60.6**
12	35.9	37.4	15.1	33.8	36.1	30.5	32.5	57.3	16.7	35.2	47.8	40.6	53.9	52.0	54.0	35.1	43.4	47.5	58.0	64.2	64.0	67.5	61.9	36.0	39.4	51.9	38.3	50.9	48.0	37.2	**44.1**	**61.7**
13	39.3	37.1	13.9	30.5	36.6	30.0	32.4	56.2	14.2	36.1	51.6	40.6	49.1	52.9	51.9	33.6	35.8	44.0	56.9	58.5	63.9	65.0	60.0	34.1	39.6	49.1	38.9	46.2	39.4	36.9	**42.5**	**59.5**
14	37.0	35.9	11.9	31.6	40.0	31.1	32.5	57.0	13.1	30.3	49.0	50.3	50.0	57.9	50.9	33.0	35.7	47.7	59.9	58.5	64.5	60.0	47.7	29.9	43.4	52.9	45.0	44.3	35.6	37.9	**42.5**	**59.5**
15	35.1	34.2	8.8	32.3	39.9	36.1	35.3	54.0	14.2	25.9	46.6	52.4	50.0	57.4	49.4	33.2	36.2	51.3	61.1	57.9	65.0	52.0	40.0	29.5	53.5	57.0	50.3	38.8	33.3	38.4	**42.3**	**59.2**
16	34.5	34.6	8.1	33.3	45.6	38.9	40.0	52.6	20.9	22.8	51.4	56.6	50.6	56.5	51.0	34.1	41.1	55.1	60.1	59.0	64.5	54.3	44.5	29.2	62.5	63.8	60.5	37.5	31.9	42.9	**44.6**	**62.5**
17	35.9	35.9	11.0	37.9	48.6	42.3	49.0	51.9	32.7	26.7	51.9	59.0	52.8	55.9	55.1	45.1	45.0	58.0	63.0	63.9	64.1	64.8	51.9	33.9	59.6	70.7	61.6	47.9	34.6	49.8	**48.7**	**68.2**
18	39.7	41.0	20.7	46.0	64.0	51.1	65.4	69.3	38.8	36.1	56.5	90.0	80.0	75.6	64.9	53.0	53.7	80.1	89.8	85.0	94.3	73.4	67.0	34.4	79.3	114.3	82.5	59.7	35.3	63.1	**63.5**	**88.8**
19	41.6	48.4	23.7	45.0	62.4	65.4	79.9	73.7	40.1	39.6	63.5	105.3	99.9	90.5	65.0	53.0	58.0	58.9	95.0	69.5	93.1	61.9	62.0	35.0	84.2	110.2	59.9	50.0	35.6	65.0	**64.5**	**90.3**
20	38.0	41.4	21.9	41.4	42.6	51.7	64.7	54.0	38.1	38.1	58.0	70.0	57.2	61.1	54.6	42.1	50.9	52.9	68.4	53.0	65.7	52.0	52.9	37.0	59.0	74.9	52.0	45.5	36.3	48.9	**50.8**	**71.1**
21	35.3	37.4	18.9	35.3	37.9	40.1	51.7	45.9	34.9	35.1	50.5	60.0	52.6	54.6	48.8	32.5	37.9	41.2	58.4	52.0	55.7	52.9	38.0	34.6	52.0	59.9	38.2	38.4	33.4	37.5	**43.4**	**60.7**
22	31.6	30.7	13.9	29.2	32.9	32.6	38.0	36.2	32.9	34.2	40.3	50.1	39.5	52.0	34.2	32.1	34.2	35.8	44.8	38.7	40.1	38.5	36.2	34.0	40.9	52.8	32.4	36.5	30.9	34.0	**36.3**	**50.9**
23	35.0	33.3	16.2	28.4	29.5	32.5	35.9	34.9	31.9	35.4	35.8	37.3	36.0	40.2	33.4	32.4	34.3	34.0	36.5	37.0	37.7	36.8	37.0	35.5	38.5	38.7	32.1	34.1	30.7	34.3	**34.2**	**47.8**
24	32.5	28.7	9.9	23.1	21.6	29.9	32.5	31.2	22.9	24.1	30.8	33.2	32.2	34.1	32.1	31.0	32.8	31.0	32.0	30.8	32.9	32.8	32.0	31.1	34.9	31.7	29.1	31.0	28.5	30.8	**29.7**	**41.6**

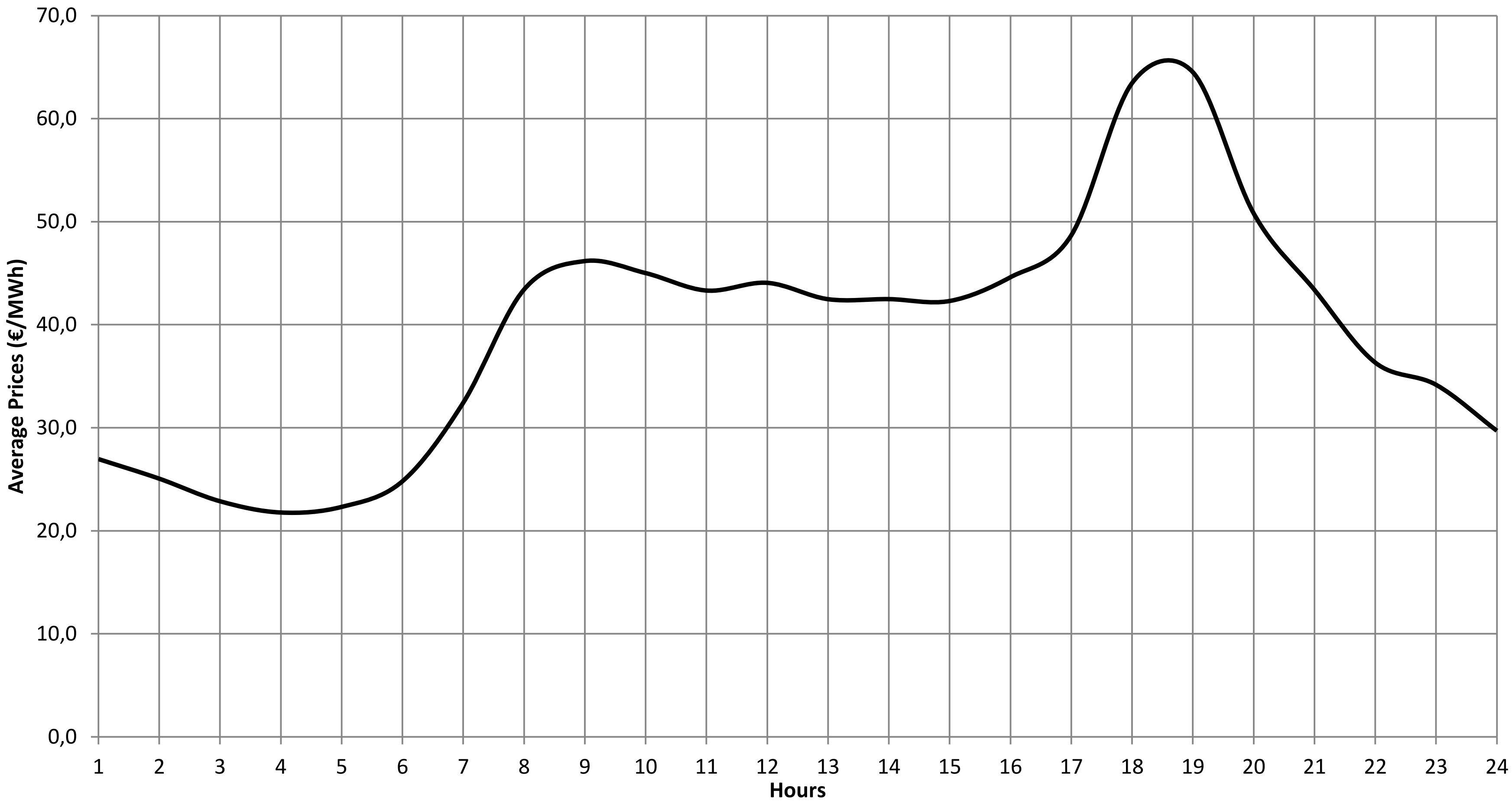


Figure G-1: Hourly Average of PHELIX Prices

Table G-2: ELIX Prices for November 2013
(Data compiled from EPEX SPOT **(EPEX Spot, 2013)**)

	01/11	02/11	03/11	04/11	05/11	06/11	07/11	08/11	09/11	10/11	11/11	12/11	13/11	14/11	15/11	16/11	17/11	18/11	19/11	20/11	21/11	22/11	23/11	24/11	25/11	26/11	27/11	28/11	29/11	30/11	Average (€/MWh)	Average ($/MWh)
1	26.1	29.3	12.4	8.3	28.7	25.4	23.5	30.2	28.4	16.6	23.0	31.1	33.9	32.3	38.3	41.3	32.0	33.1	32.1	34.7	36.1	39.5	46.4	39.5	33.1	44.4	38.2	38.0	37.6	34.8	**31.6**	**44.3**
2	25.0	23.4	10.0	7.7	21.7	19.7	17.4	27.7	23.1	11.0	19.1	28.1	31.2	30.7	34.5	35.7	30.0	31.4	31.1	31.9	33.9	36.1	41.2	34.1	30.0	39.7	40.0	36.0	36.2	32.1	**28.3**	**39.6**
3	20.6	18.2	7.9	5.3	18.9	13.4	13.9	24.0	16.7	7.2	16.0	22.0	28.8	29.3	31.2	34.0	29.3	28.4	30.7	30.6	31.0	32.1	37.9	29.3	25.6	38.0	37.4	32.0	33.8	28.1	**25.0**	**35.1**
4	19.7	14.0	4.2	1.1	15.8	9.6	10.2	21.3	14.2	0.9	11.8	18.9	24.1	28.0	30.2	31.1	24.4	25.6	29.7	29.6	30.0	30.5	33.2	21.8	20.1	34.4	32.3	31.1	32.0	26.8	**21.9**	**30.6**
5	19.0	11.4	1.6	2.9	17.1	10.0	8.8	21.5	12.8	0.9	11.0	20.6	25.5	27.6	29.9	29.9	22.1	25.4	30.2	30.5	30.7	31.4	31.6	20.9	20.5	33.5	32.0	31.7	33.6	19.5	**21.5**	**30.1**
6	20.1	16.1	1.7	8.0	24.5	17.4	16.6	29.1	13.9	1.8	16.0	29.7	31.6	30.7	34.2	32.1	23.0	31.6	34.6	32.7	37.7	37.4	32.1	20.8	31.3	42.1	38.3	38.3	45.5	24.0	**26.4**	**37.0**
7	24.4	17.1	2.4	27.8	34.8	33.1	31.2	39.8	14.4	6.5	31.9	45.1	42.3	38.9	45.4	34.1	24.1	47.6	47.6	44.9	51.5	51.6	38.8	22.5	46.6	54.4	53.9	58.0	59.3	30.3	**36.7**	**51.4**
8	25.8	16.6	1.4	37.9	45.0	39.1	36.2	52.6	20.6	8.9	40.3	60.6	57.1	52.9	60.5	36.5	29.3	57.0	59.1	58.6	63.1	60.9	44.0	25.0	61.9	68.5	67.2	70.0	71.9	42.0	**45.7**	**64.0**
9	30.0	27.0	4.0	39.2	44.9	42.0	39.8	54.1	29.4	11.4	44.1	59.7	60.6	56.0	63.9	41.2	32.0	62.5	65.4	64.5	66.0	65.6	47.9	31.5	62.8	70.2	63.7	65.0	76.7	48.9	**49.0**	**68.6**
10	33.6	33.1	10.8	37.9	40.9	38.4	36.0	53.3	29.5	16.8	44.0	55.9	57.6	52.4	62.1	44.2	35.3	60.6	63.9	64.0	66.8	67.4	56.4	39.0	59.0	69.9	59.7	64.0	73.4	50.5	**49.2**	**68.9**
11	33.5	35.2	11.9	37.9	39.2	35.0	34.3	53.0	27.1	24.1	41.0	53.6	55.4	50.0	59.2	42.4	36.5	57.3	61.1	64.9	63.3	65.1	57.3	39.8	55.6	62.8	56.1	62.5	69.9	51.6	**47.9**	**67.0**
12	34.1	35.2	12.9	40.0	40.0	33.9	36.0	53.0	22.3	31.0	42.0	54.1	55.1	51.4	57.2	41.7	38.7	57.6	62.7	65.4	64.9	66.1	57.6	40.4	56.2	61.4	55.1	62.5	65.1	51.9	**48.2**	**67.5**
13	35.9	34.0	13.5	38.1	39.9	33.0	36.0	52.0	19.0	31.5	44.5	51.2	51.9	50.0	53.9	42.7	39.3	55.4	59.0	60.1	63.5	65.4	58.1	42.8	53.0	58.9	55.1	59.0	62.2	53.7	**47.1**	**65.9**
14	31.3	32.4	11.2	38.5	39.9	37.1	37.3	52.5	16.6	28.0	42.2	54.3	51.7	51.8	52.6	40.6	37.7	55.9	61.3	61.2	64.5	63.0	52.0	35.0	53.4	61.4	55.9	58.0	59.9	52.6	**46.3**	**64.9**
15	30.0	31.2	8.7	38.7	40.5	38.5	39.8	51.0	18.4	23.0	40.7	55.2	51.3	51.9	52.0	39.2	37.5	57.2	63.0	63.4	65.7	61.7	48.6	32.4	57.9	63.0	59.9	54.5	55.1	51.3	**46.0**	**64.5**
16	30.6	31.4	6.6	38.4	40.7	38.8	41.3	50.4	26.0	21.2	43.1	55.1	52.6	52.3	51.9	38.2	35.3	57.1	61.2	64.0	66.0	60.7	48.2	29.9	62.0	67.1	62.6	52.7	50.9	50.1	**46.2**	**64.7**
17	34.7	33.0	10.9	38.1	43.0	43.3	46.0	52.0	30.9	25.3	45.0	58.4	54.8	54.0	53.5	42.4	40.0	59.0	65.0	66.3	66.5	65.0	54.6	34.5	64.1	72.5	62.0	59.9	53.5	52.4	**49.3**	**69.1**
18	38.9	39.9	20.7	47.5	52.0	54.9	59.6	64.5	38.6	35.0	55.1	82.6	75.1	79.1	66.1	52.5	48.1	76.0	88.3	87.8	94.1	73.2	61.5	42.5	84.9	113.9	89.6	71.0	61.9	60.4	**63.8**	**89.4**
19	42.2	45.1	25.2	58.4	57.4	62.6	70.1	72.1	44.2	39.0	60.0	100.3	100.0	98.0	71.3	57.8	57.2	81.1	92.9	88.5	93.5	71.3	61.9	47.9	90.5	114.6	98.9	71.2	64.0	63.1	**70.0**	**98.0**
20	38.9	40.0	23.0	50.6	47.0	51.1	58.9	58.1	40.0	37.9	54.0	71.9	65.0	62.1	57.5	51.4	54.5	59.2	67.0	63.7	70.2	63.6	58.0	47.8	70.0	79.5	68.8	61.4	61.1	58.0	**56.3**	**78.9**
21	32.1	32.2	18.0	41.4	40.8	40.9	48.1	46.0	32.9	35.2	45.7	59.0	54.4	53.1	50.4	41.9	49.2	51.3	58.0	55.1	59.9	58.8	50.0	44.0	61.0	65.0	60.0	61.3	55.0	53.4	**48.5**	**67.8**
22	29.8	28.6	13.6	32.4	35.0	34.1	35.2	35.8	30.0	31.4	36.1	50.1	45.6	45.3	43.3	39.3	41.3	45.1	50.5	48.8	51.9	52.3	45.9	40.0	52.1	59.0	53.8	55.8	48.0	49.2	**42.0**	**58.8**
23	29.8	30.9	15.9	31.0	32.3	33.5	36.5	39.4	30.1	34.7	38.1	46.8	43.7	44.7	43.3	43.3	44.4	41.2	48.9	47.5	50.3	53.7	47.7	43.3	51.9	54.9	54.6	56.2	49.5	50.9	**42.3**	**59.2**
24	26.4	26.9	13.0	28.8	28.1	30.0	33.6	33.3	23.1	29.4	31.9	40.9	39.5	40.5	39.8	38.7	41.3	38.6	40.1	40.0	43.1	48.0	45.9	41.6	52.0	51.9	51.4	51.0	40.6	48.9	**37.9**	**53.1**

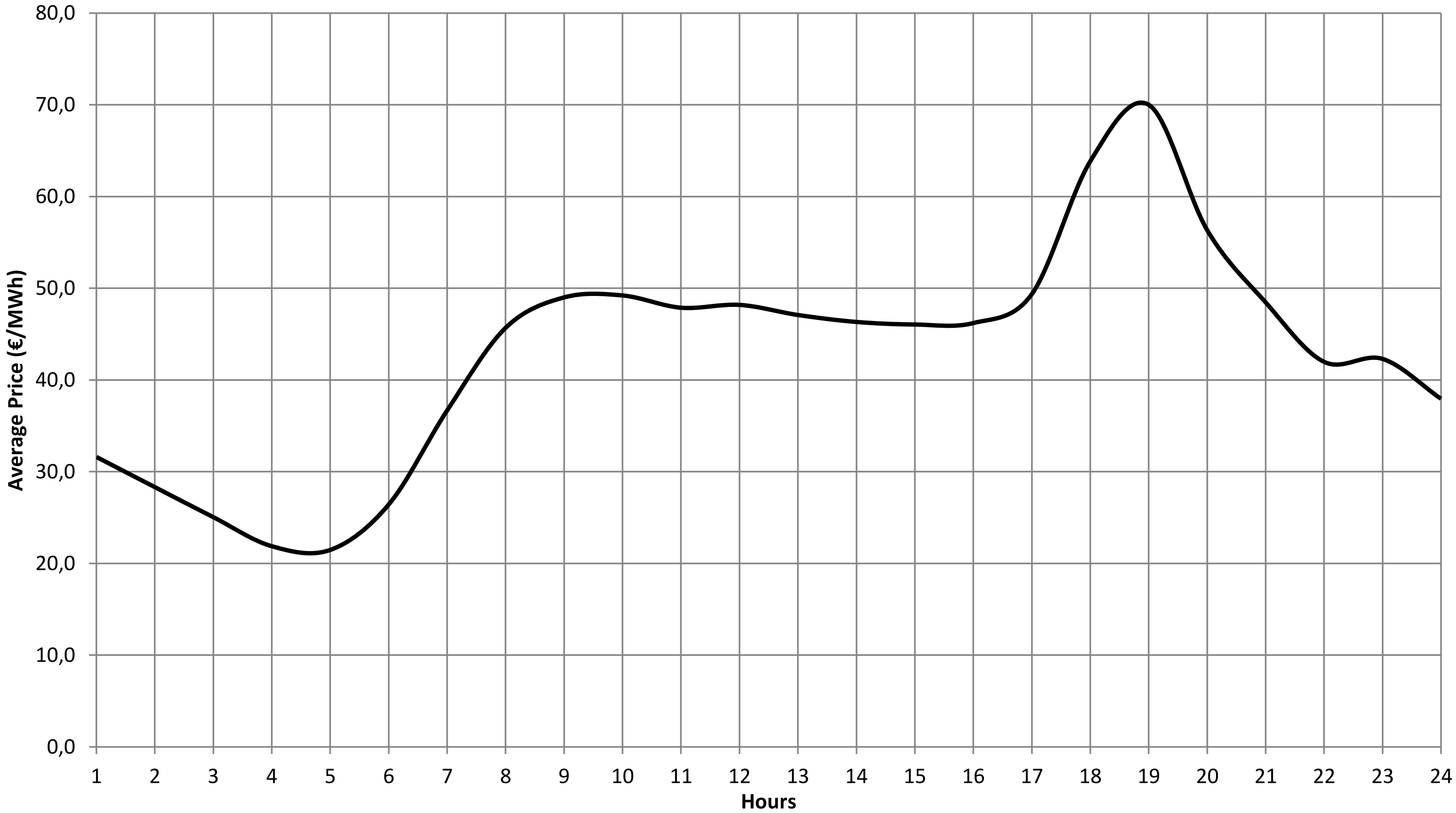


Figure G-2: Hourly Average of ELIX Prices

APPENDIX H

RESULTS OF PXSC ANALYSES

H.1. CASE 1 Results

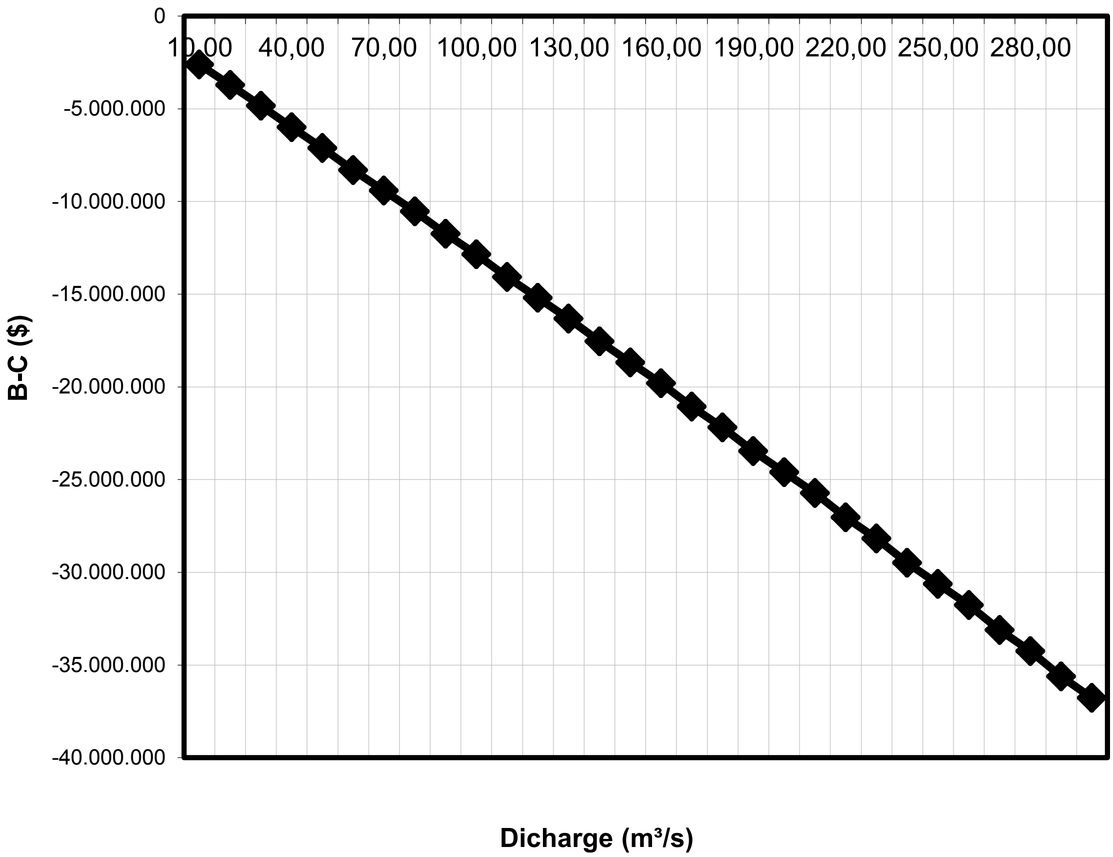


Figure H-1: Discharge vs. B-C Curve for Case 1

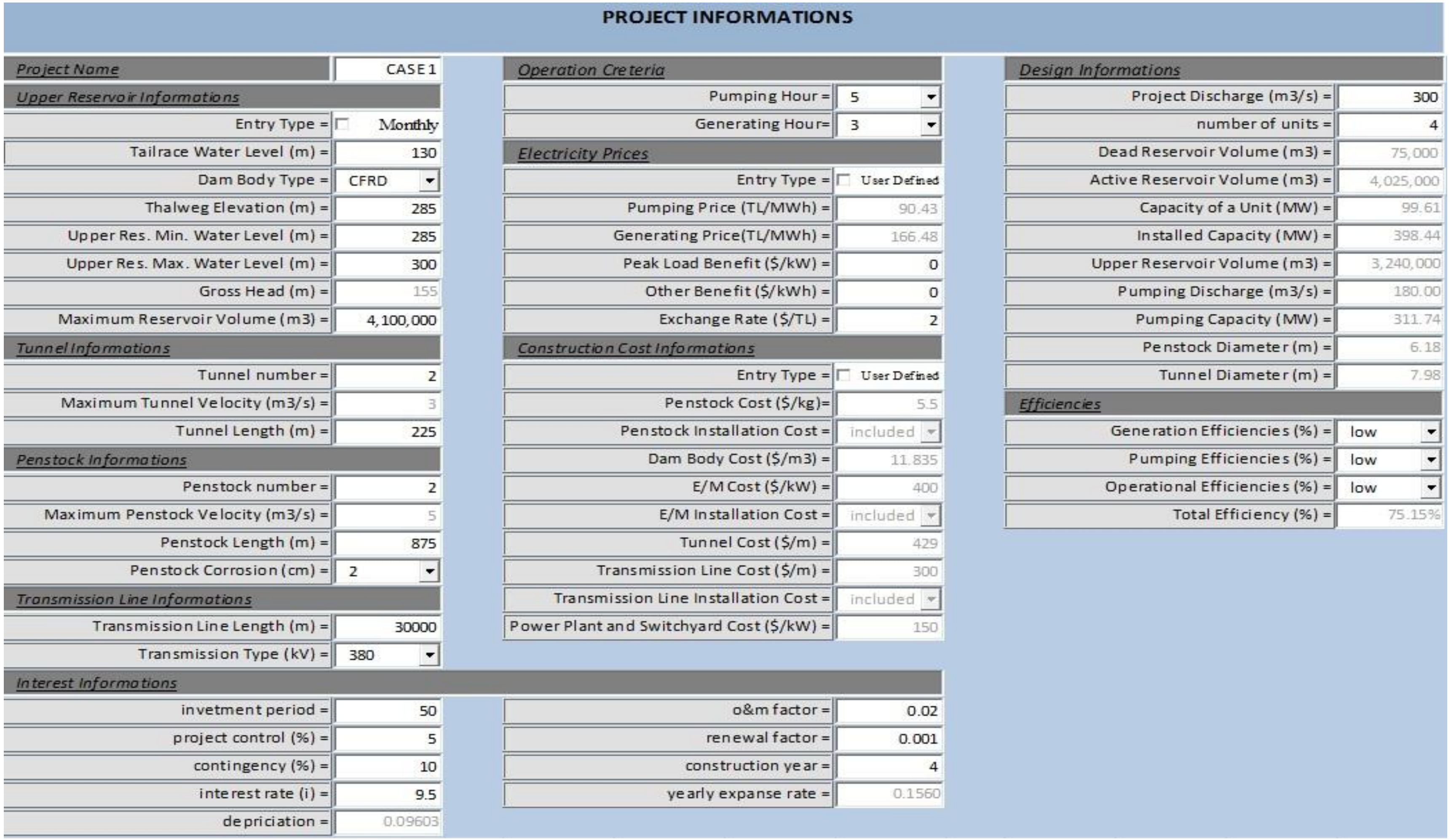


Figure H-2: User Data Interface for Case 1

CASE 1

PROJECT DISCHARGE OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION											Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diamete (m)	Penstock Diameter (m)	Tunnel Loss (m)	Penstock Loss (m)	Net Head (m)	Generating Discharge (m^3/s)	Pumping Discharge (m^3/s)	Installed Capacity (MW)	Pumping Capacity (MW)	Total G Energy (GWh)	Total P Energy (GWh)	Power Plant & Switchyard	E/M	Transmission Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
1.46	1.13	1.52	17.00	137.48	10.00	6.00	**11.78**	**9.22**	12.90	16.82	275,626	735,003	1,403,905	56,637	19,354	430,684	760,523	**3,681,731**	1,073,685	0	0	1,073,685	-2,608,047
2.06	1.60	0.96	10.71	144.33	20.00	12.00	**24.73**	**19.35**	27.08	35.32	578,739	1,543,303	1,403,905	101,313	19,354	726,793	1,596,887	**5,970,294**	2,254,441	0	0	2,254,441	-3,715,853
2.52	1.95	0.73	8.17	147.09	30.00	18.00	**37.81**	**29.58**	41.40	53.99	884,733	2,359,288	1,403,905	142,366	19,354	1,036,067	2,441,203	**8,286,915**	3,446,423	0	0	3,446,423	-4,840,493
2.91	2.26	0.60	6.75	149.65	40.00	24.00	**51.29**	**40.13**	56.16	73.24	1,200,128	3,200,340	1,403,905	181,229	43,261	1,338,775	3,311,458	**10,679,096**	4,675,023	0	0	4,675,023	-6,004,073
3.26	2.52	0.52	5.81	150.66	50.00	30.00	**64.55**	**50.50**	70.68	92.17	1,510,346	4,027,590	1,403,905	218,543	43,261	1,637,088	4,167,429	**13,008,161**	5,883,460	0	0	5,883,460	-7,124,702
3.57	2.76	0.46	5.15	152.39	60.00	36.00	**78.35**	**61.30**	85.79	111.87	1,833,167	4,888,445	1,403,905	254,665	71,722	1,932,280	5,058,174	**15,442,359**	7,140,989	0	0	7,140,989	-8,301,370
3.86	2.99	0.42	4.65	152.94	70.00	42.00	**91.73**	**71.77**	100.45	130.98	2,146,384	5,723,692	1,403,905	289,826	71,722	2,225,106	5,922,421	**17,783,057**	8,361,108	0	0	8,361,108	-9,421,949
4.12	3.19	0.38	4.25	153.37	80.00	48.00	**105.13**	**82.25**	115.12	150.12	2,459,926	6,559,804	1,403,905	324,185	71,722	2,516,060	6,787,563	**20,123,165**	9,582,491	0	0	9,582,491	-10,540,674
4.37	3.39	0.35	3.93	154.72	90.00	54.00	**119.31**	**93.35**	130.65	170.37	2,791,772	7,444,725	1,403,905	357,857	104,737	2,805,483	7,703,210	**22,611,690**	10,875,176	0	0	10,875,176	-11,736,514
4.61	3.57	0.33	3.66	155.01	100.00	60.00	**132.82**	**103.92**	145.44	189.65	3,107,791	8,287,444	1,403,905	390,931	104,737	3,093,625	8,575,187	**24,963,621**	12,106,209	0	0	12,106,209	-12,857,412
4.83	3.74	0.31	3.44	156.25	110.00	66.00	**147.28**	**115.23**	161.27	210.29	3,446,043	9,189,448	1,403,905	423,476	142,306	3,380,674	9,508,510	**27,494,363**	13,423,848	0	0	13,423,848	-14,070,515
5.05	3.91	0.29	3.24	156.47	120.00	72.00	**160.88**	**125.87**	176.17	229.72	3,764,398	10,038,394	1,403,905	455,547	142,306	3,666,776	10,386,932	**29,858,259**	14,663,980	0	0	14,663,980	-15,194,279
5.25	4.07	0.28	3.07	156.65	130.00	78.00	**174.49**	**136.52**	191.07	249.16	4,082,884	10,887,691	1,403,905	487,191	142,306	3,952,047	11,265,717	**32,221,742**	15,904,624	0	0	15,904,624	-16,317,118
5.45	4.22	0.26	2.93	157.81	140.00	84.00	**189.31**	**148.12**	207.29	270.31	4,429,554	11,812,145	1,403,905	518,444	184,429	4,236,582	12,222,268	**34,807,328**	17,255,056	0	0	17,255,056	-17,552,272
5.64	4.37	0.25	2.80	157.95	150.00	90.00	**203.02**	**158.84**	222.30	289.88	4,750,263	12,667,367	1,403,905	549,340	184,429	4,520,458	13,107,183	**37,182,944**	18,504,354	0	0	18,504,354	-18,678,589
5.83	4.51	0.24	2.68	158.08	160.00	96.00	**216.73**	**169.57**	237.32	309.46	5,071,061	13,522,830	1,403,905	579,905	184,429	4,803,739	13,992,348	**39,558,218**	19,754,006	0	0	19,754,006	-19,804,212
6.01	4.65	0.23	2.57	159.20	170.00	102.00	**231.90**	**181.44**	253.93	331.12	5,426,025	14,469,399	1,403,905	610,165	231,105	5,086,482	14,971,783	**42,198,864**	21,136,744	0	0	21,136,744	-21,062,120
6.18	4.79	0.22	2.48	159.30	180.00	108.00	**245.70**	**192.23**	269.04	350.83	5,748,983	15,330,622	1,403,905	640,139	231,105	5,368,732	15,862,907	**44,586,394**	22,394,809	0	0	22,394,809	-22,191,585
6.35	4.92	0.21	2.39	160.40	190.00	114.00	**261.13**	**204.31**	285.94	372.86	6,110,102	16,293,605	1,403,905	669,846	282,336	5,650,531	16,859,325	**47,269,649**	23,801,524	0	0	23,801,524	-23,468,125
6.52	5.05	0.21	2.31	160.49	200.00	120.00	**275.03**	**215.18**	301.15	392.70	6,435,193	17,160,515	1,403,905	699,302	282,336	5,931,914	17,756,335	**49,669,498**	25,067,897	0	0	25,067,897	-24,601,602
6.68	5.17	0.20	2.23	160.57	210.00	126.00	**288.92**	**226.05**	316.37	412.55	6,760,340	18,027,574	1,403,905	728,522	282,336	6,212,910	18,653,499	**52,069,086**	26,334,488	0	0	26,334,488	-25,734,598
6.83	5.29	0.19	2.17	161.64	220.00	132.00	**304.71**	**238.40**	333.65	435.08	7,129,647	19,012,393	1,403,905	757,518	338,120	6,493,549	19,672,511	**54,807,643**	27,773,101	0	0	27,773,101	-27,034,542
6.99	5.41	0.19	2.10	161.71	230.00	138.00	**318.69**	**249.34**	348.97	455.05	7,456,899	19,885,064	1,403,905	786,303	338,120	6,773,853	20,575,482	**57,219,626**	29,047,890	0	0	29,047,890	-28,171,736
7.14	5.53	0.18	2.04	162.77	240.00	144.00	**334.74**	**261.90**	366.54	477.96	7,832,313	20,886,168	1,403,905	814,888	398,457	7,053,845	21,611,345	**60,000,920**	30,510,291	0	0	30,510,291	-29,490,629
7.29	5.64	0.18	1.99	162.83	250.00	150.00	**348.81**	**272.91**	381.95	498.06	8,161,655	21,764,414	1,403,905	843,281	398,457	7,333,543	22,520,084	**62,425,340**	31,793,224	0	0	31,793,224	-30,632,116
7.43	5.76	0.17	1.94	162.89	260.00	156.00	**362.89**	**283.92**	397.36	518.16	8,491,036	22,642,764	1,403,905	871,491	398,457	7,612,966	23,428,930	**64,849,550**	33,076,308	0	0	33,076,308	-31,773,242
7.57	5.86	0.17	1.89	163.94	270.00	162.00	**379.28**	**296.75**	415.31	541.57	8,874,586	23,665,563	1,403,905	899,528	463,349	7,892,128	24,487,242	**67,686,301**	34,570,402	0	0	34,570,402	-33,115,899
7.71	5.97	0.17	1.84	163.99	280.00	168.00	**393.45**	**307.83**	430.82	561.79	9,206,042	24,549,446	1,403,905	927,398	463,349	8,171,045	25,401,813	**70,122,999**	35,861,569	0	0	35,861,569	-34,261,430
7.85	6.08	0.16	1.80	165.04	290.00	174.00	**410.10**	**320.86**	449.06	585.57	9,595,673	25,588,461	1,403,905	955,108	532,795	8,449,729	26,476,903	**73,002,573**	37,379,351	0	0	37,379,351	-35,623,222
7.98	6.18	0.16	1.76	165.08	300.00	180.00	**424.35**	**332.01**	464.67	605.92	9,929,196	26,477,856	1,403,905	982,664	532,795	8,728,193	27,397,178	**75,451,787**	38,678,569	0	0	38,678,569	-36,773,217

Figure H-3: Project Discharge Selection Page for Case 1

H.2. CASE 2 Results

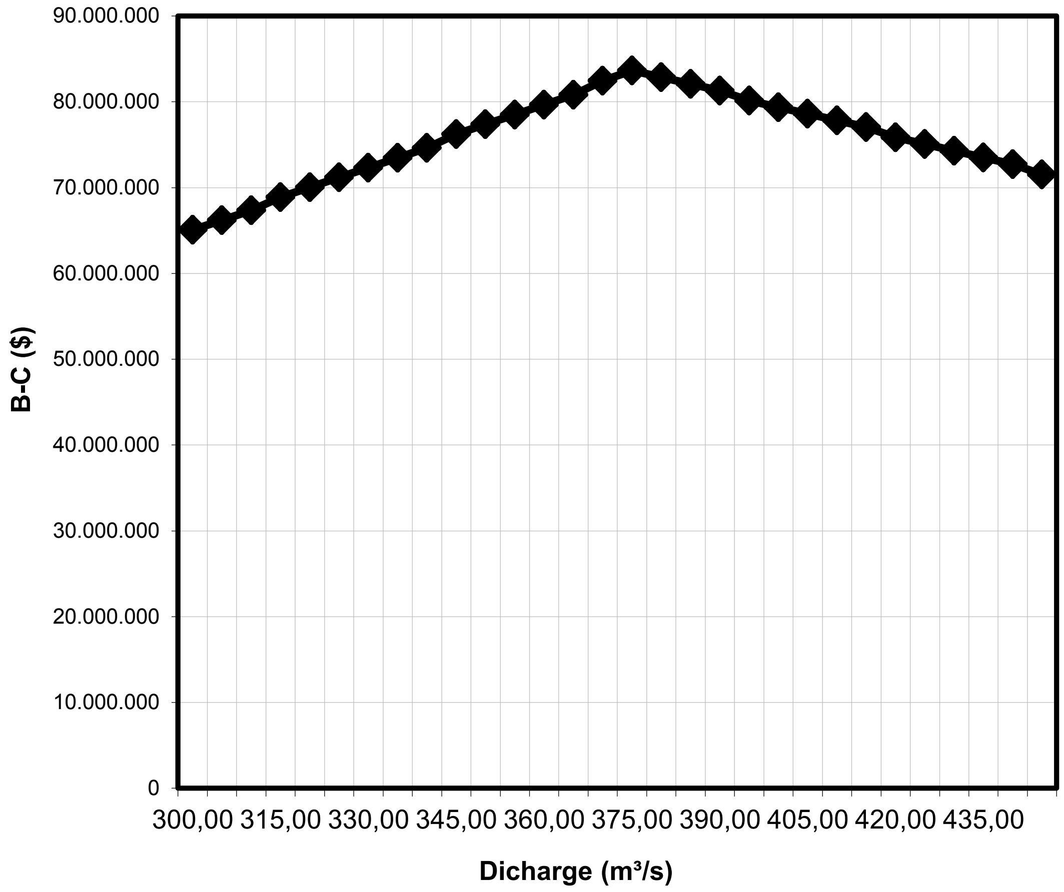
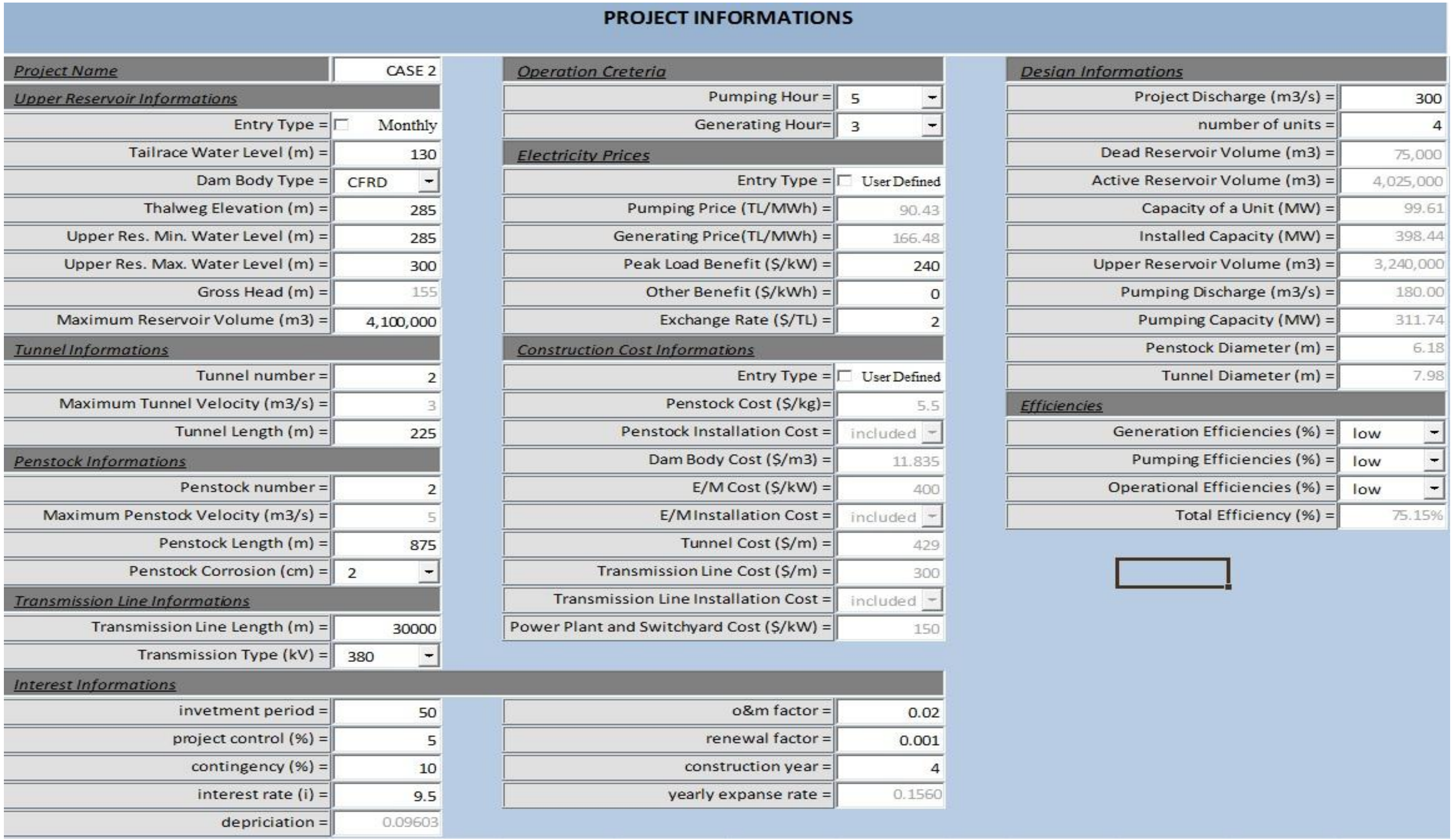


Figure H-4: Discharge vs. B-C Curve for Case 2



PROJECT INFORMATIONS

Project Name	CASE 2
Upper Reservoir Informations	
Entry Type =	☐ Monthly
Tailrace Water Level (m) =	130
Dam Body Type =	CFRD
Thalweg Elevation (m) =	285
Upper Res. Min. Water Level (m) =	285
Upper Res. Max. Water Level (m) =	300
Gross Head (m) =	155
Maximum Reservoir Volume (m3) =	4,100,000
Tunnel Informations	
Tunnel number =	2
Maximum Tunnel Velocity (m3/s) =	3
Tunnel Length (m) =	225
Penstock Informations	
Penstock number =	2
Maximum Penstock Velocity (m3/s) =	5
Penstock Length (m) =	875
Penstock Corrosion (cm) =	2
Transmission Line Informations	
Transmission Line Length (m) =	30000
Transmission Type (kV) =	380

Operation Creteria	
Pumping Hour =	5
Generating Hour=	3
Electricity Prices	
Entry Type =	☐ User Defined
Pumping Price (TL/MWh) =	90.43
Generating Price(TL/MWh) =	166.48
Peak Load Benefit ($/kW) =	240
Other Benefit ($/kWh) =	0
Exchange Rate ($/TL) =	2
Construction Cost Informations	
Entry Type =	☐ User Defined
Penstock Cost ($/kg)=	5.5
Penstock Installation Cost =	included
Dam Body Cost ($/m3) =	11.835
E/M Cost ($/kW) =	400
E/M Installation Cost =	included
Tunnel Cost ($/m) =	429
Transmission Line Cost ($/m) =	300
Transmission Line Installation Cost =	included
Power Plant and Switchyard Cost ($/kW) =	150

Design Informations	
Project Discharge (m3/s) =	300
number of units =	4
Dead Reservoir Volume (m3) =	75,000
Active Reservoir Volume (m3) =	4,025,000
Capacity of a Unit (MW) =	99.61
Installed Capacity (MW) =	398.44
Upper Reservoir Volume (m3) =	3,240,000
Pumping Discharge (m3/s) =	180.00
Pumping Capacity (MW) =	311.74
Penstock Diameter (m) =	6.18
Tunnel Diameter (m) =	7.98
Efficiencies	
Generation Efficiencies (%) =	low
Pumping Efficiencies (%) =	low
Operational Efficiencies (%) =	low
Total Efficiency (%) =	75.15%

Interest Informations

invetment period =	50	o&m factor =	0.02
project control (%) =	5	renewal factor =	0.001
contingency (%) =	10	construction year =	4
interest rate (i) =	9.5	yearly expanse rate =	0.1560
depriciation =	0.09603		

Figure H-5: User Data Interface for Case 2

CASE 2
PROJECT DISCHARGE OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION											Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diamete (m)	Penstock Diameter (m)	Tunnel Loss (m)	Penstock Loss (m)	Net Head (m)	Generating Discharge (m^3/s)	Pumping Discharge (m^3/s)	Installed Capacity (MW)	Pumping Capacity (MW)	Total G Energy (GWh)	Total P Energy (GWh)	Power Plant & Switchyard	E/M	Transmission Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
7.98	6.18	0.16	1.76	165.08	300.00	180.00	**424.35**	**332.01**	464.67	605.92	9,929,196	26,477,856	1,403,905	982,664	532,795	8,728,193	27,397,178	**75,451,787**	38,678,569	101,844,802	0	140,523,372	65,071,585
8.05	6.23	0.16	1.74	165.10	305.00	183.00	**431.48**	**337.59**	472.47	616.10	10,095,968	26,922,582	1,403,905	996,387	532,795	8,867,345	27,857,346	**76,676,328**	39,328,221	103,555,404	0	142,883,625	66,207,297
8.11	6.28	0.15	1.72	165.12	310.00	186.00	**438.61**	**343.17**	480.28	626.28	10,262,748	27,367,327	1,403,905	1,010,073	532,795	9,006,446	28,317,532	**77,900,826**	39,977,899	105,266,077	0	145,243,976	67,343,150
8.18	6.33	0.15	1.70	166.14	315.00	189.00	**448.44**	**350.85**	491.04	640.31	10,492,688	27,980,502	1,403,905	1,023,724	606,794	9,145,498	28,951,997	**79,605,108**	40,873,619	107,624,603	0	148,498,222	68,893,114
8.24	6.38	0.15	1.69	166.16	320.00	192.00	**455.61**	**356.46**	498.89	650.55	10,660,483	28,427,956	1,403,905	1,037,340	606,794	9,284,500	29,414,987	**80,835,965**	41,527,255	109,345,694	0	150,872,949	70,036,984
8.31	6.43	0.15	1.67	166.18	325.00	195.00	**462.78**	**362.08**	506.74	660.79	10,828,285	28,875,426	1,403,905	1,050,922	606,794	9,423,455	29,877,993	**82,066,781**	42,180,915	111,066,851	0	153,247,766	71,180,985
8.37	6.48	0.15	1.65	166.20	330.00	198.00	**469.95**	**367.69**	514.60	671.03	10,996,093	29,322,913	1,403,905	1,064,471	606,794	9,562,364	30,341,018	**83,297,557**	42,834,599	112,788,073	0	155,622,672	72,325,115
8.43	6.53	0.15	1.64	166.22	335.00	201.00	**477.12**	**373.30**	522.45	681.27	11,163,906	29,770,417	1,403,905	1,077,986	606,794	9,701,227	30,804,059	**84,528,293**	43,488,308	114,509,356	0	157,997,664	73,469,371
8.50	6.58	0.15	1.62	166.23	340.00	204.00	**484.29**	**378.91**	530.30	691.51	11,331,726	30,217,936	1,403,905	1,091,469	606,794	9,840,045	31,267,116	**85,758,991**	44,142,039	116,230,700	0	160,372,739	74,613,749
8.56	6.63	0.14	1.60	167.25	345.00	207.00	**494.42**	**386.83**	541.39	705.97	11,568,721	30,849,922	1,403,905	1,104,920	685,347	9,978,820	31,921,045	**87,512,680**	45,065,238	118,661,582	0	163,726,819	76,214,139
8.62	6.68	0.14	1.59	167.27	350.00	210.00	**501.64**	**392.48**	549.29	716.28	11,737,554	31,300,145	1,403,905	1,118,339	685,347	10,117,553	32,386,900	**88,749,744**	45,722,919	120,393,325	0	166,116,244	77,366,500
8.68	6.72	0.14	1.57	167.29	355.00	213.00	**508.85**	**398.13**	557.20	726.58	11,906,394	31,750,383	1,403,905	1,131,728	685,347	10,256,244	32,852,770	**89,986,770**	46,380,621	122,125,126	0	168,505,747	78,518,976
8.74	6.77	0.14	1.56	167.30	360.00	216.00	**516.07**	**403.77**	565.10	736.88	12,075,238	32,200,635	1,403,905	1,145,086	685,347	10,394,894	33,318,655	**91,223,760**	47,038,344	123,856,981	0	170,895,325	79,671,565
8.80	6.82	0.14	1.54	167.32	365.00	219.00	**523.29**	**409.42**	573.00	747.19	12,244,088	32,650,901	1,403,905	1,158,415	685,347	10,533,505	33,784,554	**92,460,714**	47,696,088	125,588,891	0	173,284,978	80,824,264
8.86	6.87	0.14	1.53	168.33	370.00	222.00	**533.67**	**417.54**	584.37	762.02	12,487,124	33,298,998	1,403,905	1,171,714	768,454	10,672,076	34,455,154	**94,257,425**	48,642,822	128,081,742	0	176,724,563	82,467,138
8.92	6.91	0.14	1.52	168.35	375.00	225.00	**540.93**	**423.22**	592.32	772.38	12,656,987	33,751,965	1,403,905	1,184,985	768,454	10,810,609	34,923,847	**95,500,751**	49,304,510	129,824,038	0	179,128,548	83,627,797
8.98	6.96	0.13	1.50	168.36	380.00	228.00	**548.19**	**428.90**	592.32	772.38	12,826,854	34,204,944	1,403,905	1,198,226	768,454	10,949,105	34,923,847	**96,275,335**	49,304,510	129,824,038	0	179,128,548	82,853,213
9.04	7.00	0.13	1.49	168.38	385.00	231.00	**555.45**	**434.58**	592.32	772.38	12,996,726	34,657,936	1,403,905	1,211,440	768,454	11,087,563	34,923,847	**97,049,872**	49,304,510	129,824,038	0	179,128,548	82,078,676
9.10	7.05	0.13	1.48	168.39	390.00	234.00	**562.71**	**440.26**	592.32	772.38	13,166,603	35,110,941	1,403,905	1,224,627	768,454	11,225,986	34,923,847	**97,824,362**	49,304,510	129,824,038	0	179,128,548	81,304,185
9.16	7.09	0.13	1.47	169.40	395.00	237.00	**573.36**	**448.59**	592.32	772.38	13,415,678	35,775,142	1,403,905	1,237,786	856,114	11,364,373	34,923,847	**98,976,845**	49,304,510	129,824,038	0	179,128,548	80,151,702
9.22	7.14	0.13	1.45	169.42	400.00	240.00	**580.66**	**454.31**	592.32	772.38	13,586,566	36,230,844	1,403,905	1,250,918	856,114	11,502,726	34,923,847	**99,754,921**	49,304,510	129,824,038	0	179,128,548	79,373,627
9.27	7.18	0.13	1.44	169.43	405.00	243.00	**587.97**	**460.02**	592.32	772.38	13,757,459	36,686,558	1,403,905	1,264,024	856,114	11,641,045	34,923,847	**100,532,952**	49,304,510	129,824,038	0	179,128,548	78,595,596
9.33	7.23	0.13	1.43	169.44	410.00	246.00	**595.27**	**465.74**	592.32	772.38	13,928,356	37,142,283	1,403,905	1,277,104	856,114	11,779,330	34,923,847	**101,310,939**	49,304,510	129,824,038	0	179,128,548	77,817,608
9.39	7.27	0.13	1.42	169.45	415.00	249.00	**602.57**	**471.45**	592.32	772.38	14,099,258	37,598,020	1,403,905	1,290,158	856,114	11,917,582	34,923,847	**102,088,884**	49,304,510	129,824,038	0	179,128,548	77,039,664
9.44	7.31	0.13	1.41	170.47	420.00	252.00	**613.48**	**479.98**	592.32	772.38	14,354,369	38,278,318	1,403,905	1,303,187	948,329	12,055,802	34,923,847	**103,267,757**	49,304,510	129,824,038	0	179,128,548	75,860,791
9.50	7.36	0.13	1.40	170.48	425.00	255.00	**620.82**	**485.73**	592.32	772.38	14,526,281	38,736,750	1,403,905	1,316,191	948,329	12,193,991	34,923,847	**104,049,293**	49,304,510	129,824,038	0	179,128,548	75,079,255
9.55	7.40	0.12	1.39	170.49	430.00	258.00	**628.17**	**491.48**	592.32	772.38	14,698,197	39,195,192	1,403,905	1,329,170	948,329	12,332,148	34,923,847	**104,830,788**	49,304,510	129,824,038	0	179,128,548	74,297,760
9.61	7.44	0.12	1.37	170.50	435.00	261.00	**635.52**	**497.23**	592.32	772.38	14,870,117	39,653,645	1,403,905	1,342,125	948,329	12,470,275	34,923,847	**105,612,243**	49,304,510	129,824,038	0	179,128,548	73,516,305
9.67	7.49	0.12	1.36	170.51	440.00	264.00	**642.87**	**502.98**	592.32	772.38	15,042,041	40,112,108	1,403,905	1,355,056	948,329	12,608,372	34,923,847	**106,393,657**	49,304,510	129,824,038	0	179,128,548	72,734,890
9.72	7.53	0.12	1.35	171.52	445.00	267.00	**654.03**	**511.71**	592.32	772.38	15,303,187	40,808,497	1,403,905	1,367,963	1,045,097	12,746,439	34,923,847	**107,598,935**	49,304,510	129,824,038	0	179,128,548	71,529,612

Figure H-6: Project Discharge Selection Page for Case 2

CASE 2
PENSTOCK DIAMETER OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION												Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diamete m	Penstoc k m	Penstoc k Speed m³/s	Tunnel Loss m	Penstoc k Loss m	Net Head m	Generatin g m³/s	Pumping Discharge m³/s	Installed Capacity MW	Pumping Capacity MW	Total G Energy GWh	Total P Energy GWh	Power Plant & Switchyard	E/M	Transmissio n Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
8.92	5.00	9.55	0.14	8.53	161.33	375.00	225.00	518.40	405.59	567.64	740.20	12,129,646	32,345,723	1,403,905	1,184,985	768,454	5,826,442	33,468,780	87,127,935	47,250,287	124,415,050	0	171,665,337	84,537,403
8.92	5.10	9.18	0.14	7.68	162.19	375.00	225.00	521.14	407.74	570.65	744.13	12,193,935	32,517,159	1,403,905	1,184,985	768,454	6,049,373	33,646,169	87,763,979	47,500,720	125,074,465	0	172,575,185	84,811,205
8.92	5.20	8.83	0.14	6.92	162.94	375.00	225.00	523.57	409.64	573.31	747.59	12,250,714	32,668,570	1,403,905	1,184,985	768,454	6,276,477	33,802,837	88,355,940	47,721,899	125,656,853	0	173,378,752	85,022,811
8.92	5.30	8.50	0.14	6.25	163.61	375.00	225.00	525.72	411.32	575.66	750.66	12,300,980	32,802,614	1,403,905	1,184,985	768,454	6,507,753	33,941,535	88,910,226	47,917,709	126,172,443	0	174,090,152	85,179,926
8.92	5.40	8.19	0.14	5.66	164.20	375.00	225.00	527.62	412.81	577.75	753.38	12,345,584	32,921,557	1,403,905	1,184,985	768,454	6,743,202	34,064,608	89,432,294	48,091,459	126,629,946	0	174,721,406	85,289,112
8.92	5.50	7.90	0.14	5.13	164.73	375.00	225.00	529.32	414.14	579.61	755.80	12,385,250	33,027,334	1,403,905	1,184,985	768,454	6,982,824	34,174,057	89,926,808	48,245,977	127,036,808	0	175,282,785	85,355,977
8.92	5.60	7.62	0.14	4.66	165.20	375.00	225.00	530.83	415.32	581.26	757.96	12,420,601	33,121,603	1,403,905	1,184,985	768,454	7,226,618	34,271,599	90,397,765	48,383,684	127,399,406	0	175,783,090	85,385,326
8.92	5.70	7.35	0.14	4.24	165.62	375.00	225.00	532.18	416.38	582.74	759.88	12,452,171	33,205,789	1,403,905	1,184,985	768,454	7,474,585	34,358,709	90,848,598	48,506,663	127,723,222	0	176,229,885	85,381,287
8.92	5.80	7.10	0.14	3.87	166.00	375.00	225.00	533.39	417.32	584.06	761.61	12,480,420	33,281,121	1,403,905	1,184,985	768,454	7,726,725	34,436,656	91,282,265	48,616,707	128,012,978	0	176,629,685	85,347,419
8.92	5.90	6.86	0.14	3.53	166.33	375.00	225.00	534.47	418.17	585.24	763.15	12,505,747	33,348,658	1,403,905	1,184,985	768,454	7,983,037	34,506,538	91,701,324	48,715,364	128,272,755	0	176,988,119	85,286,795
8.92	6.00	6.63	0.14	3.23	166.64	375.00	225.00	535.44	418.93	586.31	764.54	12,528,495	33,409,320	1,403,905	1,184,985	768,454	8,243,522	34,569,306	92,107,987	48,803,979	128,506,085	0	177,310,064	85,202,077
8.92	6.10	6.42	0.14	2.95	166.91	375.00	225.00	536.32	419.61	587.27	765.79	12,548,964	33,463,904	1,403,905	1,184,985	768,454	8,508,180	34,625,785	92,504,176	48,883,714	128,716,038	0	177,599,752	85,095,576
8.92	6.20	6.21	0.14	2.71	167.16	375.00	225.00	537.11	420.23	588.13	766.92	12,567,414	33,513,104	1,403,905	1,184,985	768,454	8,777,010	34,676,693	92,891,565	48,955,585	128,905,281	0	177,860,867	84,969,302
8.92	6.30	6.02	0.14	2.49	167.38	375.00	225.00	537.82	420.79	588.91	767.93	12,584,072	33,557,526	1,403,905	1,184,985	768,454	9,050,013	34,722,657	93,271,611	49,020,476	129,076,145	0	178,096,621	84,825,010
8.92	6.40	5.83	0.14	2.29	167.58	375.00	225.00	538.46	421.29	589.61	768.85	12,599,137	33,597,698	1,403,905	1,184,985	768,454	9,327,188	34,764,225	93,645,591	49,079,159	129,230,665	0	178,309,824	84,664,233
8.92	6.50	5.65	0.14	2.11	167.76	375.00	225.00	539.04	421.75	590.25	769.69	12,612,782	33,634,085	1,403,905	1,184,985	768,454	9,608,536	34,801,875	94,014,621	49,132,312	129,370,623	0	178,502,936	84,488,315
8.92	6.60	5.48	0.14	1.94	167.92	375.00	225.00	539.57	422.16	590.83	770.44	12,625,160	33,667,093	1,403,905	1,184,985	768,454	9,894,057	34,836,029	94,379,682	49,180,530	129,497,586	0	178,678,116	84,298,434
8.92	6.70	5.32	0.14	1.79	168.07	375.00	225.00	540.05	422.54	591.36	771.13	12,636,405	33,697,080	1,403,905	1,184,985	768,454	10,183,751	34,867,057	94,741,637	49,224,336	129,612,930	0	178,837,266	84,095,629
8.92	6.80	5.17	0.14	1.66	168.21	375.00	225.00	540.49	422.88	591.84	771.75	12,646,636	33,724,362	1,403,905	1,184,985	768,454	10,477,617	34,895,287	95,101,245	49,264,189	129,717,869	0	178,982,058	83,880,813
8.92	6.90	5.02	0.14	1.53	168.33	375.00	225.00	540.89	423.19	592.27	772.32	12,655,957	33,749,218	1,403,905	1,184,985	768,454	10,775,656	34,921,005	95,459,179	49,300,498	129,813,474	0	179,113,972	83,654,793
8.92	7.00	4.87	0.14	1.42	168.45	375.00	225.00	541.25	423.47	592.67	772.84	12,664,460	33,771,894	1,403,905	1,184,985	768,454	11,077,867	34,944,468	95,816,032	49,333,622	129,900,693	0	179,234,315	83,418,283
8.92	7.10	4.74	0.14	1.31	168.55	375.00	225.00	541.58	423.73	593.04	773.31	12,672,228	33,792,607	1,403,905	1,184,985	768,454	11,384,251	34,965,901	96,172,330	49,363,880	129,980,367	0	179,344,247	83,171,917
8.92	7.20	4.61	0.14	1.22	168.64	375.00	225.00	541.89	423.97	593.37	773.75	12,679,332	33,811,553	1,403,905	1,184,985	768,454	11,694,807	34,985,505	96,528,541	49,391,556	130,053,240	0	179,444,796	82,916,255
8.92	7.30	4.48	0.14	1.13	168.73	375.00	225.00	542.17	424.19	593.67	774.14	12,685,839	33,828,903	1,403,905	1,184,985	768,454	12,009,537	35,003,457	96,885,079	49,416,901	130,119,976	0	179,536,877	82,651,798
8.92	7.40	4.36	0.14	1.05	168.81	375.00	225.00	542.42	424.39	593.95	774.51	12,691,804	33,844,811	1,403,905	1,184,985	768,454	12,328,438	35,019,918	97,242,315	49,440,140	130,181,166	0	179,621,305	82,378,990
8.92	7.50	4.25	0.14	0.98	168.88	375.00	225.00	542.66	424.57	594.21	774.84	12,697,281	33,859,415	1,403,905	1,184,985	768,454	12,651,513	35,035,028	97,600,579	49,461,472	130,237,336	0	179,698,807	82,098,228
8.92	7.60	4.14	0.14	0.91	168.95	375.00	225.00	542.87	424.74	594.44	775.15	12,702,313	33,872,835	1,403,905	1,184,985	768,454	12,978,760	35,048,915	97,960,166	49,481,077	130,288,956	0	179,770,033	81,809,867
8.92	7.70	4.03	0.14	0.85	169.01	375.00	225.00	543.07	424.89	594.66	775.43	12,706,943	33,885,183	1,403,905	1,184,985	768,454	13,310,180	35,061,691	98,321,340	49,499,113	130,336,449	0	179,835,563	81,514,223
8.92	7.80	3.93	0.14	0.80	169.07	375.00	225.00	543.25	425.04	594.86	775.69	12,711,208	33,896,555	1,403,905	1,184,985	768,454	13,645,772	35,073,458	98,684,336	49,515,726	130,380,192	0	179,895,918	81,211,582
8.92	7.90	3.83	0.14	0.74	169.12	375.00	225.00	543.42	425.17	595.04	775.93	12,715,140	33,907,040	1,403,905	1,184,985	768,454	13,985,537	35,084,307	99,049,368	49,531,043	130,420,523	0	179,951,566	80,902,198

Figure H-7: Penstock Diameter Selection for Case 2

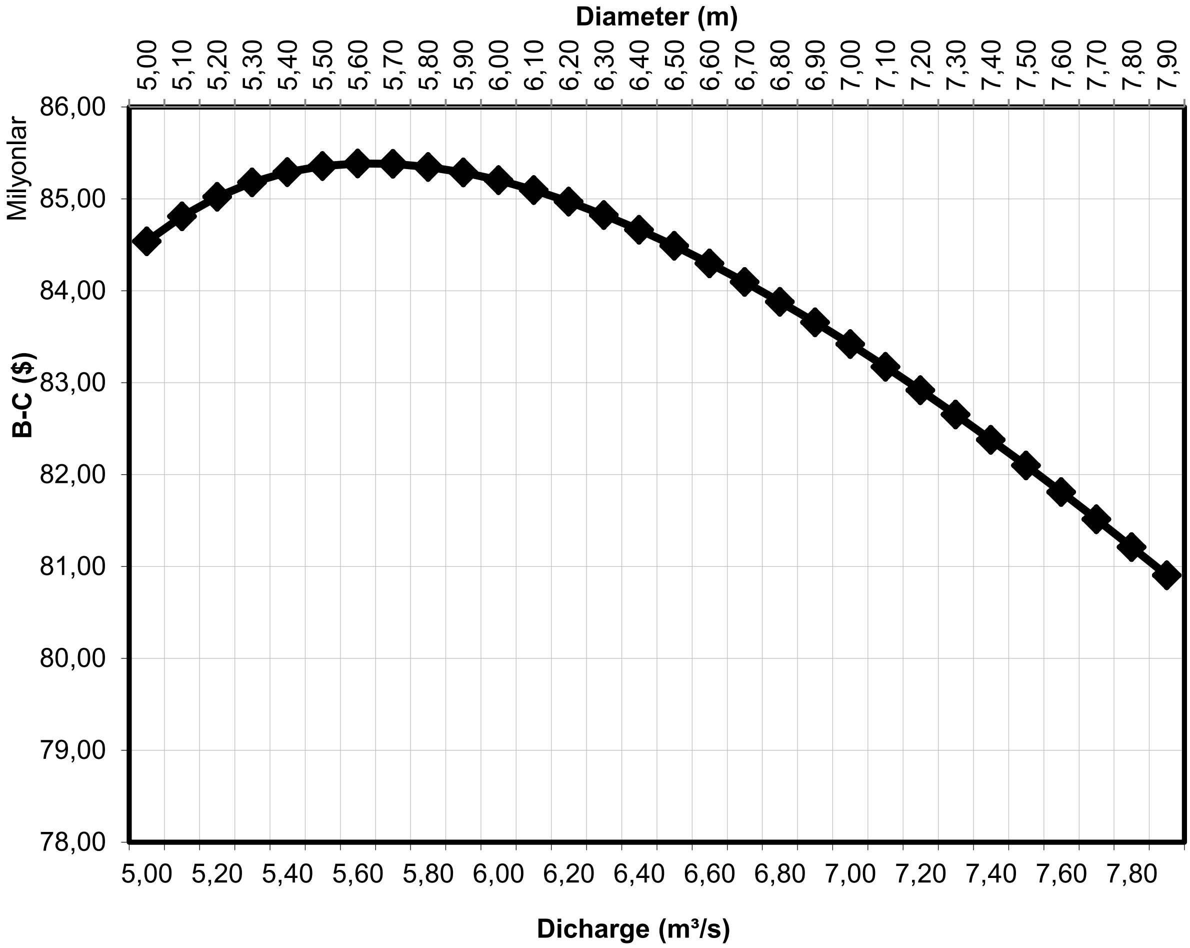


Figure H-8: Discharge vs. B-C Curve against Penstock Diameter for Case 2

CASE 2

TUNNEL DIAMETER OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION												Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diamete	Penstoc k	Tunnel Speed	Tunnel Loss	Penstoc k Loss	Net Head	Generatin g	Pumping Discharg	Installed Capacity	Pumping Capacity	Total G Energy	Total P Energy	Power Plant & Switchyard	E/M	Transmissio n Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
m	m	m³/s	m	m	m	m³/s	m³/s	MW	MW	GWh	GWh													
6.00	5.70	6.63	1.13	4.24	164.63	375.00	225.00	**528.99**	**413.88**	579.24	755.33	12,377,465	33,006,573	1,403,905	608,839	768,454	7,474,587	34,152,576	**89,792,399**	48,215,650	126,956,955	0	175,172,605	85,380,206
6.10	5.70	6.42	1.03	4.24	164.72	375.00	225.00	**529.29**	**414.12**	579.58	755.76	12,384,632	33,025,686	1,403,905	625,963	768,454	7,474,587	34,172,352	**89,855,578**	48,243,569	127,030,468	0	175,274,038	85,418,460
6.20	5.70	6.21	0.95	4.24	164.81	375.00	225.00	**529.57**	**414.33**	579.88	756.16	12,391,092	33,042,913	1,403,905	643,277	768,454	7,474,587	34,190,177	**89,914,405**	48,268,735	127,096,731	0	175,365,465	85,451,060
6.30	5.70	6.02	0.87	4.24	164.89	375.00	225.00	**529.82**	**414.53**	580.15	756.51	12,396,925	33,058,467	1,403,905	660,782	768,454	7,474,587	34,206,271	**89,969,391**	48,291,456	127,156,558	0	175,448,013	85,478,623
6.40	5.70	5.83	0.80	4.24	164.96	375.00	225.00	**530.04**	**414.70**	580.40	756.84	12,402,200	33,072,533	1,403,905	678,477	768,454	7,474,587	34,220,825	**90,020,980**	48,312,003	127,210,662	0	175,522,665	85,501,685
6.50	5.70	5.65	0.74	4.24	165.02	375.00	225.00	**530.25**	**414.86**	580.62	757.13	12,406,978	33,085,273	1,403,905	696,360	768,454	7,474,587	34,234,008	**90,069,565**	48,330,615	127,259,668	0	175,590,282	85,520,718
6.60	5.70	5.48	0.68	4.24	165.08	375.00	225.00	**530.43**	**415.01**	580.83	757.39	12,411,312	33,096,831	1,403,905	714,430	768,454	7,474,587	34,245,967	**90,115,486**	48,347,498	127,304,123	0	175,651,621	85,536,135
6.70	5.70	5.32	0.63	4.24	165.13	375.00	225.00	**530.60**	**415.14**	581.01	757.63	12,415,249	33,107,331	1,403,905	732,687	768,454	7,474,587	34,256,832	**90,159,044**	48,362,836	127,344,510	0	175,707,346	85,548,301
6.80	5.70	5.17	0.58	4.24	165.18	375.00	225.00	**530.76**	**415.26**	581.18	757.85	12,418,831	33,116,884	1,403,905	751,130	768,454	7,474,587	34,266,716	**90,200,506**	48,376,791	127,381,254	0	175,758,044	85,557,538
6.90	5.70	5.02	0.54	4.24	165.22	375.00	225.00	**530.89**	**415.37**	581.33	758.05	12,422,095	33,125,587	1,403,905	769,757	768,454	7,474,587	34,275,721	**90,240,106**	48,389,504	127,414,729	0	175,804,233	85,564,127
7.00	5.70	4.87	0.50	4.24	165.26	375.00	225.00	**531.02**	**415.47**	581.47	758.23	12,425,072	33,133,526	1,403,905	788,568	768,454	7,474,587	34,283,937	**90,278,050**	48,401,102	127,445,268	0	175,846,371	85,568,321
7.10	5.70	4.74	0.46	4.24	165.30	375.00	225.00	**531.14**	**415.56**	581.60	758.40	12,427,792	33,140,779	1,403,905	807,563	768,454	7,474,587	34,291,441	**90,314,521**	48,411,697	127,473,166	0	175,884,862	85,570,341
7.20	5.70	4.61	0.43	4.24	165.33	375.00	225.00	**531.24**	**415.64**	581.71	758.55	12,430,280	33,147,413	1,403,905	826,740	768,454	7,474,587	34,298,305	**90,349,684**	48,421,387	127,498,682	0	175,920,069	85,570,386
7.30	5.70	4.48	0.40	4.24	165.36	375.00	225.00	**531.34**	**415.72**	581.82	758.69	12,432,558	33,153,488	1,403,905	846,098	768,454	7,474,587	34,304,591	**90,383,681**	48,430,262	127,522,049	0	175,952,311	85,568,630
7.40	5.70	4.36	0.37	4.24	165.39	375.00	225.00	**531.43**	**415.79**	581.92	758.82	12,434,647	33,159,058	1,403,905	865,637	768,454	7,474,587	34,310,355	**90,416,642**	48,438,399	127,543,474	0	175,981,873	85,565,230
7.50	5.70	4.25	0.34	4.24	165.41	375.00	225.00	**531.51**	**415.85**	582.01	758.93	12,436,564	33,164,171	1,403,905	885,355	768,454	7,474,587	34,315,646	**90,448,683**	48,445,868	127,563,142	0	176,009,010	85,560,327
7.60	5.70	4.14	0.32	4.24	165.44	375.00	225.00	**531.59**	**415.91**	582.09	759.04	12,438,326	33,168,871	1,403,905	905,253	768,454	7,474,587	34,320,508	**90,479,904**	48,452,732	127,581,217	0	176,033,949	85,554,045
7.70	5.70	4.03	0.30	4.24	165.46	375.00	225.00	**531.66**	**415.97**	582.17	759.14	12,439,948	33,173,194	1,403,905	925,329	768,454	7,474,587	34,324,981	**90,510,398**	48,459,048	127,597,846	0	176,056,894	85,546,496
7.80	5.70	3.93	0.28	4.24	165.48	375.00	225.00	**531.72**	**416.02**	582.24	759.23	12,441,441	33,177,176	1,403,905	945,583	768,454	7,474,587	34,329,102	**90,540,247**	48,464,865	127,613,162	0	176,078,027	85,537,780
7.90	5.70	3.83	0.26	4.24	165.50	375.00	225.00	**531.78**	**416.06**	582.30	759.31	12,442,818	33,180,847	1,403,905	966,013	768,454	7,474,587	34,332,900	**90,569,524**	48,470,228	127,627,284	0	176,097,512	85,527,987
8.00	5.70	3.73	0.24	4.24	165.51	375.00	225.00	**531.83**	**416.11**	582.36	759.39	12,444,088	33,184,236	1,403,905	986,620	768,454	7,474,587	34,336,407	**90,598,296**	48,475,178	127,640,318	0	176,115,495	85,517,199
8.10	5.70	3.64	0.23	4.24	165.53	375.00	225.00	**531.88**	**416.14**	582.41	759.46	12,445,262	33,187,366	1,403,905	1,007,402	768,454	7,474,587	34,339,646	**90,626,622**	48,479,751	127,652,359	0	176,132,110	85,505,488
8.20	5.70	3.55	0.21	4.24	165.54	375.00	225.00	**531.93**	**416.18**	582.46	759.53	12,446,348	33,190,261	1,403,905	1,028,359	768,454	7,474,587	34,342,642	**90,654,555**	48,483,980	127,663,495	0	176,147,475	85,492,920
8.30	5.70	3.47	0.20	4.24	165.56	375.00	225.00	**531.97**	**416.21**	582.51	759.59	12,447,353	33,192,941	1,403,905	1,049,489	768,454	7,474,587	34,345,414	**90,682,144**	48,487,895	127,673,803	0	176,161,697	85,479,554
8.40	5.70	3.39	0.19	4.24	165.57	375.00	225.00	**532.01**	**416.25**	582.56	759.65	12,448,284	33,195,424	1,403,905	1,070,793	768,454	7,474,587	34,347,984	**90,709,431**	48,491,522	127,683,353	0	176,174,875	85,465,444
8.50	5.70	3.31	0.18	4.24	165.58	375.00	225.00	**532.05**	**416.27**	582.60	759.70	12,449,148	33,197,727	1,403,905	1,092,270	768,454	7,474,587	34,350,366	**90,736,456**	48,494,886	127,692,210	0	176,187,096	85,450,639
8.60	5.70	3.23	0.17	4.24	165.59	375.00	225.00	**532.09**	**416.30**	582.63	759.75	12,449,949	33,199,864	1,403,905	1,113,919	768,454	7,474,587	34,352,578	**90,763,255**	48,498,008	127,700,431	0	176,198,439	85,435,183
8.70	5.70	3.16	0.16	4.24	165.60	375.00	225.00	**532.12**	**416.33**	582.67	759.79	12,450,694	33,201,850	1,403,905	1,135,739	768,454	7,474,587	34,354,632	**90,789,860**	48,500,908	127,708,068	0	176,208,976	85,419,117
8.80	5.70	3.08	0.15	4.24	165.61	375.00	225.00	**532.15**	**416.35**	582.70	759.84	12,451,386	33,203,696	1,403,905	1,157,729	768,454	7,474,587	34,356,542	**90,816,299**	48,503,605	127,715,169	0	176,218,774	85,402,475
8.90	5.70	3.02	0.14	4.24	165.62	375.00	225.00	**532.17**	**416.37**	582.73	759.88	12,452,030	33,205,414	1,403,905	1,179,890	768,454	7,474,587	34,358,320	**90,842,600**	48,506,114	127,721,777	0	176,227,891	85,385,292

Figure H-9: Tunnel Diameter Selection for Case 2

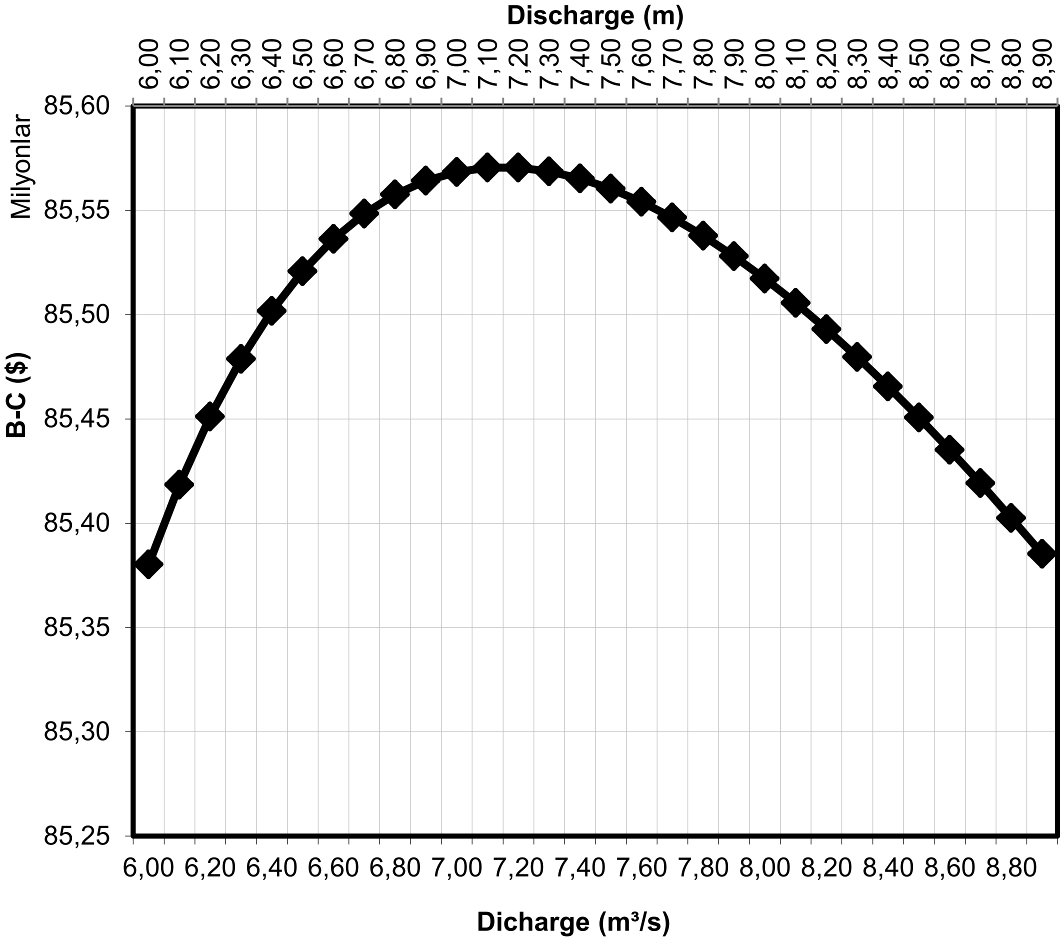


Figure H-10: Discharge vs. B-C Curve against Tunnel Diameter for Case 2

Table H-1: Estimated Cost for Case 2

NAME	ESTIMATED COST($)
Upper Reservoir	4,926,319
Tunnel	5,299,973
Penstock	47,917,264
Power Plant and Tailrace	79,686,676
Electromechanical Equipments	212,497,803
Transmission Line	9,000,000
TOTAL ESTIMATED COST	**359,328,035**

Table H-2: Investment Cost and Annual Expense Table for Case 2

contingency = 10%

project control = 5%

NAME	Estimated Cost	Construction Cost	Project Control	Project Cost	Interest During Constructio	Investment Cost	Depriciation Factor	Depriciation Expenditure	O&M Factor	O&M Expenditure	Renewal Factor	Renewal Expenditure	Total Expenditure
Upper Reservoir	4,926,319	5,418,951	270,948	5,689,898	1,132,432	6,822,330	0.09603	655,148	0.020	108,379	0.001000	5,418.95	768,946
Tunnel	5,299,973	5,829,970	291,498	6,121,468	581,539	6,703,008	0.09603	643,690	0.020	116,599	0.001000	5,829.97	766,119
Penstock	47,917,264	52,708,991	2,635,450	55,344,440	11,014,927	66,359,368	0.09603	6,372,490	0.020	1,054,180	0.001000	52,708.99	7,479,379
Power Plant and Tailrace	79,686,676	87,655,344	4,382,767	92,038,111	18,317,885	110,355,996	0.09603	10,597,486	0.020	1,753,107	0.001000	87,655.34	12,438,249
Electromechanical Equipments	212,497,803	233,747,583	11,687,379	245,434,962	48,847,693	294,282,656	0.09603	28,259,963	0.020	4,674,952	0.001000	233,747.58	33,168,663
Transmission Line	9,000,000	9,900,000	495,000	10,395,000	987,525	11,382,525	0.09603	1,093,064	0.020	198,000	0.001000	9,900.00	1,300,964
TOTAL	**359,328,035**	**395,260,838**	**19,763,042**	**415,023,880**	**80,882,002**	**495,905,882**		**47,621,842**		**7,905,217**		**395,261**	**55,922,319**

Pumping Cost=	34,298,305
Cost=	90,220,625
Benefit=	175,920,069
Net Benefit=	85,699,444
Benefit / Cost Ratio =	1.95

Table H-3: Replacement Cost Table for Case 2

NAME	CONSTRUCTION COST	RENEWAL TIME(year)	RENEWAL RATIO	YEARS			
				20 YEAR	**35 YEAR**	**40 YEAR**	**45 YEAR**
Upper Reservoir	5,418,951	45	0.02				108,379
Tunnel	5,829,970	45	0.02				116,599
Penstock	52,708,991	45	0.50				26,354,495
Power Plant and Tailrace	87,655,344	20	0.10	8,765,534		8,765,534	
Electromechanical Equipments	233,747,583	35	0.80		186,998,067		
Transmission Line	9,900,000	45	0.80				7,920,000
TOTAL				**8,765,534**	**186,998,067**	**8,765,534**	**34,499,474**

Table H-4: Investment over Years for Case 2

	PROJECT COST				PROJECT COST	INVESTMENT COST
NAME	**1st YEAR**	**2nd YEAR**	**3rd YEAR**	**4th YEAR**		
Upper Reservoir	2,844,949	2,844,949	0		5,689,898	6,822,330
Tunnel	0	0	6,121,468		6,121,468	6,703,008
Penstock	0	27,672,220	27,672,220		55,344,440	66,359,368
Power Plant and Tailrace	23,009,528	46,019,055	23,009,528		92,038,111	110,355,996
Electromechanical Equipments	0	61,358,741	122,717,481	61,358,741	245,434,962	294,282,656
Transmission Line	0	0	0	10,395,000	10,395,000	11,382,525
TOTAL	**25,854,477**	**137,894,965**	**179,520,697**	**71,753,741**	**415,023,880**	**495,905,882**

Table H-5: Revenue/Expenditure Ratio for Case 2

	Expenditure			Revenue	Present Value	9.50%
	Project Cost	Oper. & Main.	Total		Expenditure	Revenue
1	25,854,477	0	25,854,477	0	23,611,394	0
2	137,894,965	0	137,894,965	0	115,005,913	0
3	179,520,697	0	179,520,697	0	136,732,631	0
4	71,753,741	0	71,753,741	0	49,910,057	0
4	0	42,203,522	42,203,522	175,920,069	29,355,685	122,365,478
5	0	42,203,522	42,203,522	175,920,069	26,808,845	111,749,295
6	0	42,203,522	42,203,522	175,920,069	24,482,963	102,054,151
7	0	42,203,522	42,203,522	175,920,069	22,358,871	93,200,137
8	0	42,203,522	42,203,522	175,920,069	20,419,060	85,114,281
9	0	42,203,522	42,203,522	175,920,069	18,647,543	77,729,937
10	0	42,203,522	42,203,522	175,920,069	17,029,720	70,986,244
11	0	42,203,522	42,203,522	175,920,069	15,552,256	64,827,620
12	0	42,203,522	42,203,522	175,920,069	14,202,973	59,203,306
13	0	42,203,522	42,203,522	175,920,069	12,970,752	54,066,946
14	0	42,203,522	42,203,522	175,920,069	11,845,435	49,376,206
15	0	42,203,522	42,203,522	175,920,069	10,817,749	45,092,426
16	0	42,203,522	42,203,522	175,920,069	9,879,223	41,180,298
17	0	42,203,522	42,203,522	175,920,069	9,022,121	37,607,578
18	0	42,203,522	42,203,522	175,920,069	8,239,380	34,344,820
19	0	42,203,522	42,203,522	175,920,069	7,524,548	31,365,132
20	0	42,203,522	42,203,522	175,920,069	6,871,734	28,643,956
21	0	42,203,522	42,203,522	175,920,069	6,275,556	26,158,864
22	0	42,203,522	42,203,522	175,920,069	5,731,101	23,889,374
23	0	42,203,522	42,203,522	175,920,069	5,233,882	21,816,780
24	8,765,534	42,203,522	50,969,056	175,920,069	5,772,550	19,924,000
25	0	42,203,522	42,203,522	175,920,069	4,365,115	18,195,434
26	0	42,203,522	42,203,522	175,920,069	3,986,407	16,616,834
27	0	42,203,522	42,203,522	175,920,069	3,640,554	15,175,191
28	0	42,203,522	42,203,522	175,920,069	3,324,707	13,858,622
29	0	42,203,522	42,203,522	175,920,069	3,036,262	12,656,276
30	0	42,203,522	42,203,522	175,920,069	2,772,842	11,558,243
31	0	42,203,522	42,203,522	175,920,069	2,532,276	10,555,473
32	0	42,203,522	42,203,522	175,920,069	2,312,581	9,639,701
33	0	42,203,522	42,203,522	175,920,069	2,111,946	8,803,380
34	0	42,203,522	42,203,522	175,920,069	1,928,718	8,039,617
35	0	42,203,522	42,203,522	175,920,069	1,761,386	7,342,116
36	0	42,203,522	42,203,522	175,920,069	1,608,572	6,705,128
37	0	42,203,522	42,203,522	175,920,069	1,469,015	6,123,405
38	0	42,203,522	42,203,522	175,920,069	1,341,566	5,592,151
39	186,998,067	42,203,522	229,201,589	175,920,069	6,653,758	5,106,987
40	0	42,203,522	42,203,522	175,920,069	1,118,881	4,663,915
41	0	42,203,522	42,203,522	175,920,069	1,021,809	4,259,283
42	0	42,203,522	42,203,522	175,920,069	933,159	3,889,756
43	0	42,203,522	42,203,522	175,920,069	852,200	3,552,289
44	8,765,534	42,203,522	50,969,056	175,920,069	939,908	3,244,099
45	0	42,203,522	42,203,522	175,920,069	710,744	2,962,648
46	0	42,203,522	42,203,522	175,920,069	649,081	2,705,614
47	0	42,203,522	42,203,522	175,920,069	592,768	2,470,881
48	0	42,203,522	42,203,522	175,920,069	541,341	2,256,512
49	34,499,474	42,203,522	76,702,996	175,920,069	898,505	2,060,742
50	0	42,203,522	42,203,522	175,920,069	451,484	1,881,956
51	0	42,203,522	42,203,522	175,920,069	412,315	1,718,681
52	0	42,203,522	42,203,522	175,920,069	376,543	1,569,572
53	0	42,203,522	42,203,522	175,920,069	343,875	1,433,399
54	0	42,203,522	42,203,522	175,920,069	314,041	1,309,040
				TOTAL	**667,304,303**	**1,396,643,770**
				Revenue / Expenditure	**2.09**	

Table H-6: Internal Rate of Return for Case 2

N	REVENUE	EXPENDITURE		EXPENDITURE FLOW	CASH FLOW	PRESENT VALUE	
	BENEFIT	PROJECT COST	O&M			0.095	0.2929
1	2	3	4	(3+4) = 5	(2-5) = 6	7	7
1	0	25,854,477	0	25,854,477	-25,854,477	-23,611,394	-19,997,765
2	0	137,894,965	0	137,894,965	-137,894,965	-115,005,913	-82,497,314
3	0	179,520,697	0	179,520,697	-179,520,697	-136,732,631	-83,071,418
4	0	71,753,741	0	71,753,741	-71,753,741	-49,910,057	-25,681,912
4	175,920,069	0	42,203,522	42,203,522	133,716,547	93,009,793	47,859,477
5	175,920,069	0	42,203,522	42,203,522	133,716,547	84,940,450	37,018,060
6	175,920,069	0	42,203,522	42,203,522	133,716,547	77,571,187	28,632,505
7	175,920,069	0	42,203,522	42,203,522	133,716,547	70,841,267	22,146,498
8	175,920,069	0	42,203,522	42,203,522	133,716,547	64,695,221	17,129,739
9	175,920,069	0	42,203,522	42,203,522	133,716,547	59,082,393	13,249,407
10	175,920,069	0	42,203,522	42,203,522	133,716,547	53,956,524	10,248,072
11	175,920,069	0	42,203,522	42,203,522	133,716,547	49,275,364	7,926,617
12	175,920,069	0	42,203,522	42,203,522	133,716,547	45,000,333	6,131,032
13	175,920,069	0	42,203,522	42,203,522	133,716,547	41,096,194	4,742,193
14	175,920,069	0	42,203,522	42,203,522	133,716,547	37,530,771	3,667,963
15	175,920,069	0	42,203,522	42,203,522	133,716,547	34,274,677	2,837,074
16	175,920,069	0	42,203,522	42,203,522	133,716,547	31,301,075	2,194,403
17	175,920,069	0	42,203,522	42,203,522	133,716,547	28,585,456	1,697,313
18	175,920,069	0	42,203,522	42,203,522	133,716,547	26,105,439	1,312,828
19	175,920,069	0	42,203,522	42,203,522	133,716,547	23,840,584	1,015,438
20	175,920,069	0	42,203,522	42,203,522	133,716,547	21,772,223	785,415
21	175,920,069	0	42,203,522	42,203,522	133,716,547	19,883,308	607,498
22	175,920,069	0	42,203,522	42,203,522	133,716,547	18,158,273	469,884
23	175,920,069	0	42,203,522	42,203,522	133,716,547	16,582,897	363,443
24	175,920,069	8,765,534	42,203,522	50,969,056	124,951,013	14,151,449	262,686
25	175,920,069	0	42,203,522	42,203,522	133,716,547	13,830,318	217,434
26	175,920,069	0	42,203,522	42,203,522	133,716,547	12,630,428	168,180
27	175,920,069	0	42,203,522	42,203,522	133,716,547	11,534,637	130,083
28	175,920,069	0	42,203,522	42,203,522	133,716,547	10,533,915	100,615
29	175,920,069	0	42,203,522	42,203,522	133,716,547	9,620,014	77,823
30	175,920,069	0	42,203,522	42,203,522	133,716,547	8,785,401	60,194
31	175,920,069	0	42,203,522	42,203,522	133,716,547	8,023,197	46,559
32	175,920,069	0	42,203,522	42,203,522	133,716,547	7,327,121	36,012
33	175,920,069	0	42,203,522	42,203,522	133,716,547	6,691,434	27,854
34	175,920,069	0	42,203,522	42,203,522	133,716,547	6,110,899	21,545
35	175,920,069	0	42,203,522	42,203,522	133,716,547	5,580,730	16,664
36	175,920,069	0	42,203,522	42,203,522	133,716,547	5,096,557	12,889
37	175,920,069	0	42,203,522	42,203,522	133,716,547	4,654,390	9,970
38	175,920,069	0	42,203,522	42,203,522	133,716,547	4,250,584	7,711
39	175,920,069	186,998,067	42,203,522	229,201,589	-53,281,520	-1,546,771	-2,377
40	175,920,069	0	42,203,522	42,203,522	133,716,547	3,545,034	4,613
41	175,920,069	0	42,203,522	42,203,522	133,716,547	3,237,474	3,568
42	175,920,069	0	42,203,522	42,203,522	133,716,547	2,956,597	2,760
43	175,920,069	0	42,203,522	42,203,522	133,716,547	2,700,089	2,135
44	175,920,069	8,765,534	42,203,522	50,969,056	124,951,013	2,304,191	1,543
45	175,920,069	0	42,203,522	42,203,522	133,716,547	2,251,904	1,277
46	175,920,069	0	42,203,522	42,203,522	133,716,547	2,056,533	988
47	175,920,069	0	42,203,522	42,203,522	133,716,547	1,878,112	764
48	175,920,069	0	42,203,522	42,203,522	133,716,547	1,715,171	591
49	175,920,069	34,499,474	42,203,522	76,702,996	99,217,073	1,162,237	339
50	175,920,069	0	42,203,522	42,203,522	133,716,547	1,430,471	354
51	175,920,069	0	42,203,522	42,203,522	133,716,547	1,306,367	273
52	175,920,069	0	42,203,522	42,203,522	133,716,547	1,193,029	212
53	175,920,069	0	42,203,522	42,203,522	133,716,547	1,089,524	164
54	175,920,069	0	42,203,522	42,203,522	133,716,547	994,999	127
					TOTAL	729,339,467	0
					INTERNAL RATE OF RETURN (IRR) %		29.29%

H.3. CASE 3 Results

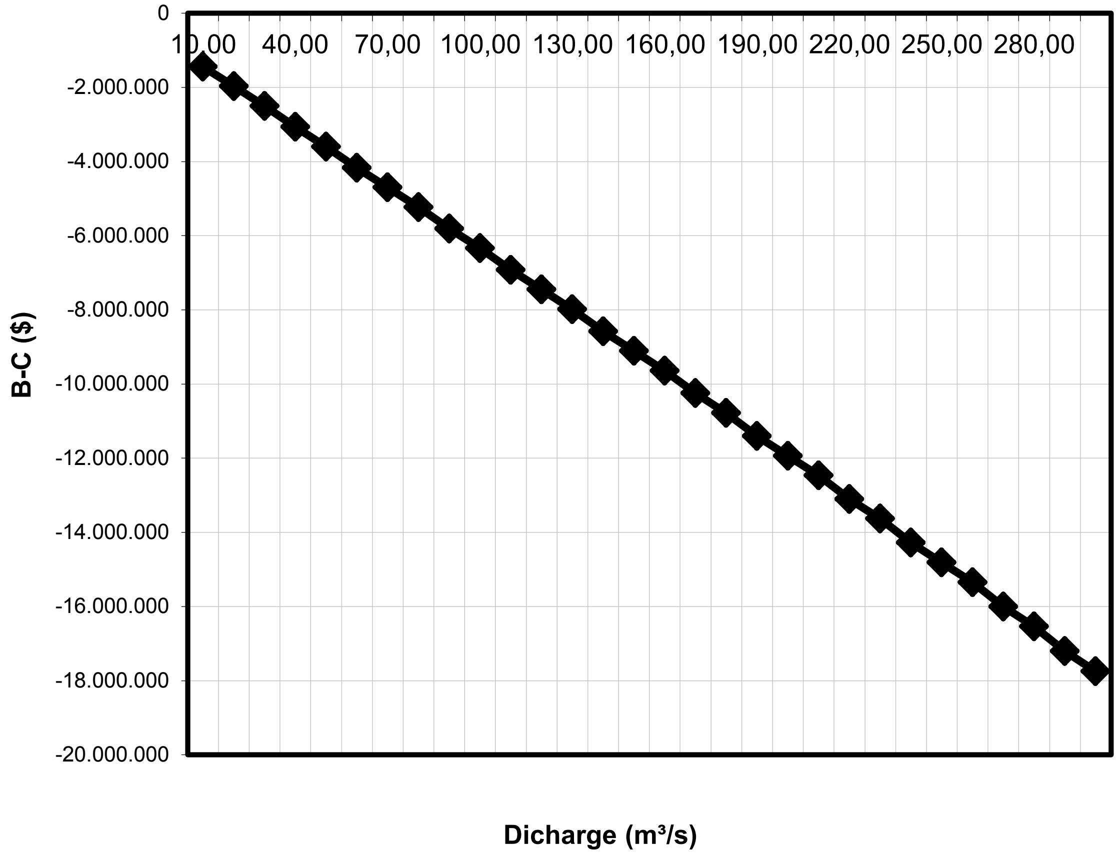


Figure H-11: Discharge vs. B-C Curve for Case 3

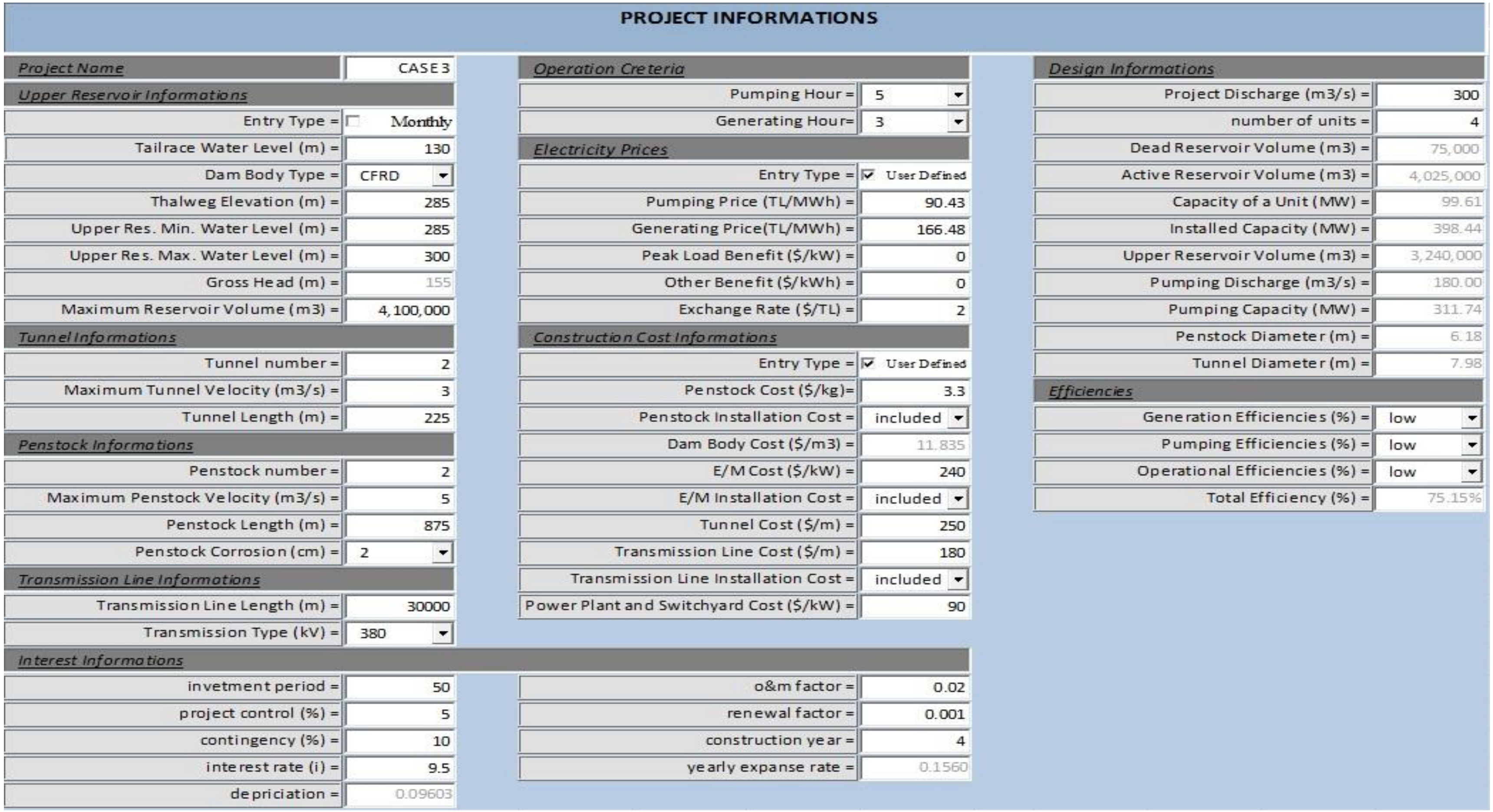


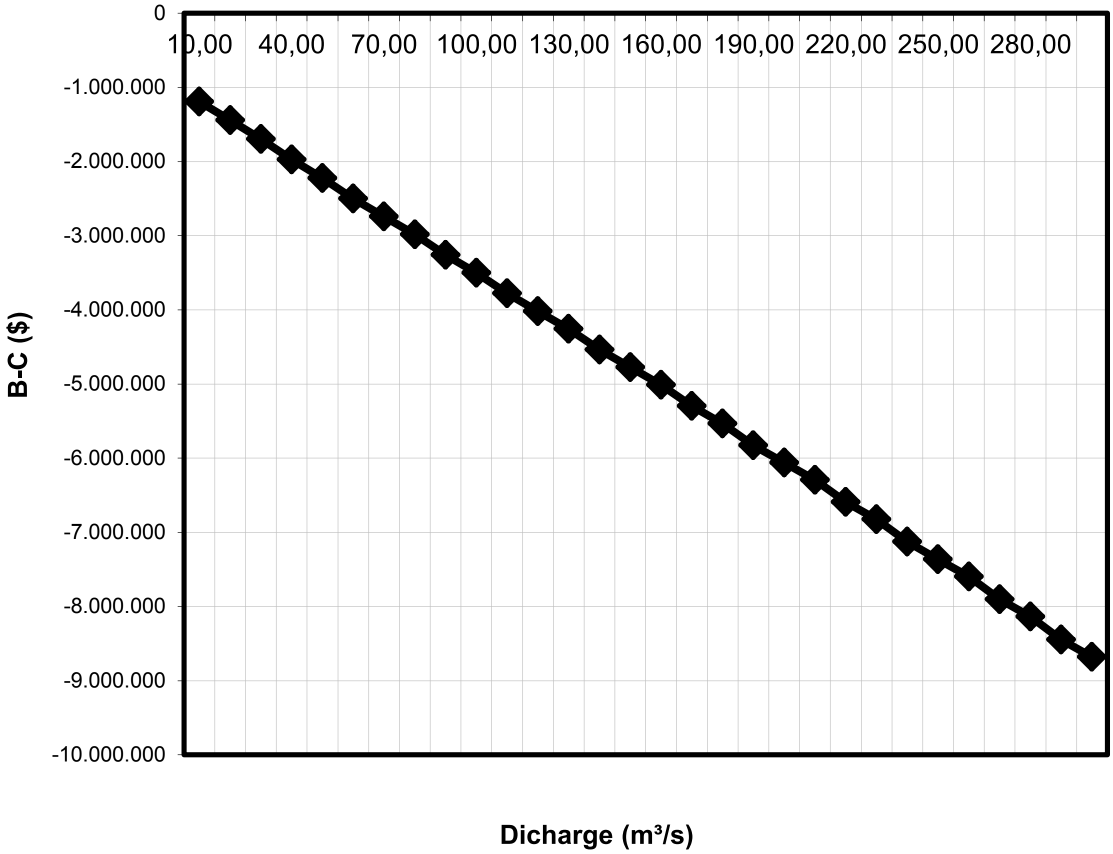
Figure H-12: User Data Interface for Case 3

CASE 3
PROJECT DISCHARGE OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION											Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diamete (m)	Penstock Diameter (m)	Tunnel Loss (m)	Penstock Loss (m)	Net Head (m)	Generating Discharge (m^3/s)	Pumping Discharge (m^3/s)	Installed Capacity (MW)	Pumping Capacity (MW)	Total G Energy (GWh)	Total P Energy (GWh)	Power Plant & Switchyard	E/M	Transmission Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
1.46	1.13	1.52	17.00	137.48	10.00	6.00	**11.78**	**9.22**	12.90	16.82	165,376	441,002	842,343	33,005	19,354	258,410	760,511	**2,520,001**	1,073,693	0	0	1,073,693	-1,446,308
2.06	1.60	0.96	10.71	144.33	20.00	12.00	**24.73**	**19.35**	27.08	35.32	347,243	925,982	842,343	59,040	19,354	436,076	1,596,864	**4,226,901**	2,254,459	0	0	2,254,459	-1,972,443
2.52	1.95	0.73	8.17	147.09	30.00	18.00	**37.81**	**29.58**	41.40	53.99	530,840	1,415,573	842,343	82,964	19,354	621,640	2,441,167	**5,953,880**	3,446,450	0	0	3,446,450	-2,507,430
2.91	2.26	0.60	6.75	149.65	40.00	24.00	**51.29**	**40.13**	56.16	73.24	720,077	1,920,204	842,343	105,612	43,261	803,265	3,311,408	**7,746,170**	4,675,060	0	0	4,675,060	-3,071,110
3.26	2.52	0.52	5.81	150.66	50.00	30.00	**64.55**	**50.50**	70.68	92.17	906,208	2,416,554	842,343	127,356	43,261	982,253	4,167,367	**9,485,341**	5,883,506	0	0	5,883,506	-3,601,835
3.57	2.76	0.46	5.15	152.39	60.00	36.00	**78.35**	**61.30**	85.79	111.87	1,099,900	2,933,067	842,343	148,406	71,722	1,159,368	5,058,099	**11,312,906**	7,141,045	0	0	7,141,045	-4,171,861
3.86	2.99	0.42	4.65	152.94	70.00	42.00	**91.73**	**71.77**	100.45	130.98	1,287,831	3,434,215	842,343	168,896	71,722	1,335,064	5,922,333	**13,062,404**	8,361,174	0	0	8,361,174	-4,701,230
4.12	3.19	0.38	4.25	153.37	80.00	48.00	**105.13**	**82.25**	115.12	150.12	1,475,956	3,935,882	842,343	188,919	71,722	1,509,636	6,787,462	**14,811,921**	9,582,567	0	0	9,582,567	-5,229,354
4.37	3.39	0.35	3.93	154.72	90.00	54.00	**119.31**	**93.35**	130.65	170.37	1,675,063	4,466,835	842,343	208,542	104,737	1,683,290	7,703,095	**16,683,906**	10,875,261	0	0	10,875,261	-5,808,645
4.61	3.57	0.33	3.66	155.01	100.00	60.00	**132.82**	**103.92**	145.44	189.65	1,864,675	4,972,466	842,343	227,815	104,737	1,856,175	8,575,060	**18,443,272**	12,106,304	0	0	12,106,304	-6,336,967
4.83	3.74	0.31	3.44	156.25	110.00	66.00	**147.28**	**115.23**	161.27	210.29	2,067,626	5,513,669	842,343	246,781	142,306	2,028,405	9,508,369	**20,349,498**	13,423,954	0	0	13,423,954	-6,925,545
5.05	3.91	0.29	3.24	156.47	120.00	72.00	**160.88**	**125.87**	176.17	229.72	2,258,639	6,023,037	842,343	265,470	142,306	2,200,066	10,386,778	**22,118,638**	14,664,095	0	0	14,664,095	-7,454,544
5.25	4.07	0.28	3.07	156.65	130.00	78.00	**174.49**	**136.52**	191.07	249.16	2,449,731	6,532,615	842,343	283,911	142,306	2,371,228	11,265,550	**23,887,683**	15,904,749	0	0	15,904,749	-7,982,935
5.45	4.22	0.26	2.93	157.81	140.00	84.00	**189.31**	**148.12**	207.29	270.31	2,657,733	7,087,287	842,343	302,124	184,429	2,541,949	12,222,087	**25,837,951**	17,255,192	0	0	17,255,192	-8,582,760
5.64	4.37	0.25	2.80	157.95	150.00	90.00	**203.02**	**158.84**	222.30	289.88	2,850,158	7,600,420	842,343	320,128	184,429	2,712,275	13,106,989	**27,616,741**	18,504,500	0	0	18,504,500	-9,112,241
5.83	4.51	0.24	2.68	158.08	160.00	96.00	**216.73**	**169.57**	237.32	309.46	3,042,637	8,113,698	842,343	337,940	184,429	2,882,244	13,992,141	**29,395,431**	19,754,161	0	0	19,754,161	-9,641,270
6.01	4.65	0.23	2.57	159.20	170.00	102.00	**231.90**	**181.44**	253.93	331.12	3,255,615	8,681,639	842,343	355,574	231,105	3,051,889	14,971,561	**31,389,726**	21,136,910	0	0	21,136,910	-10,252,816
6.18	4.79	0.22	2.48	159.30	180.00	108.00	**245.70**	**192.23**	269.04	350.83	3,449,390	9,198,373	842,343	373,041	231,105	3,221,239	15,862,672	**33,178,164**	22,394,985	0	0	22,394,985	-10,783,179
6.35	4.92	0.21	2.39	160.40	190.00	114.00	**261.13**	**204.31**	285.94	372.86	3,666,061	9,776,163	842,343	390,353	282,336	3,390,319	16,859,075	**35,206,649**	23,801,711	0	0	23,801,711	-11,404,938
6.52	5.05	0.21	2.31	160.49	200.00	120.00	**275.03**	**215.18**	301.15	392.70	3,861,116	10,296,309	842,343	407,519	282,336	3,559,148	17,756,072	**37,004,841**	25,068,094	0	0	25,068,094	-11,936,747
6.68	5.17	0.20	2.23	160.57	210.00	126.00	**288.92**	**226.05**	316.37	412.55	4,056,204	10,816,544	842,343	424,546	282,336	3,727,746	18,653,223	**38,802,942**	26,334,695	0	0	26,334,695	-12,468,247
6.83	5.29	0.19	2.17	161.64	220.00	132.00	**304.71**	**238.40**	333.65	435.08	4,277,788	11,407,436	842,343	441,444	338,120	3,896,129	19,672,219	**40,875,479**	27,773,319	0	0	27,773,319	-13,102,160
6.99	5.41	0.19	2.10	161.71	230.00	138.00	**318.69**	**249.34**	348.97	455.05	4,474,139	11,931,038	842,343	458,219	338,120	4,064,312	20,575,177	**42,683,348**	29,048,118	0	0	29,048,118	-13,635,230
7.14	5.53	0.18	2.04	162.77	240.00	144.00	**334.74**	**261.90**	366.54	477.96	4,699,388	12,531,701	842,343	474,876	398,457	4,232,307	21,611,024	**44,790,096**	30,510,531	0	0	30,510,531	-14,279,565
7.29	5.64	0.18	1.99	162.83	250.00	150.00	**348.81**	**272.91**	381.95	498.06	4,896,993	13,058,649	842,343	491,422	398,457	4,400,126	22,519,750	**46,607,741**	31,793,474	0	0	31,793,474	-14,814,266
7.43	5.76	0.17	1.94	162.89	260.00	156.00	**362.89**	**283.92**	397.36	518.16	5,094,622	13,585,658	842,343	507,862	398,457	4,567,779	23,428,583	**48,425,305**	33,076,568	0	0	33,076,568	-15,348,737
7.57	5.86	0.17	1.89	163.94	270.00	162.00	**379.28**	**296.75**	415.31	541.57	5,324,752	14,199,338	842,343	524,200	463,349	4,735,277	24,486,878	**50,576,138**	34,570,674	0	0	34,570,674	-16,005,463
7.71	5.97	0.17	1.84	163.99	280.00	168.00	**393.45**	**307.83**	430.82	561.79	5,523,625	14,729,668	842,343	540,442	463,349	4,902,627	25,401,437	**52,403,490**	35,861,851	0	0	35,861,851	-16,541,639
7.85	6.08	0.16	1.80	165.04	290.00	174.00	**410.10**	**320.86**	449.06	585.57	5,757,404	15,353,076	842,343	556,590	532,795	5,069,838	26,476,510	**54,588,555**	37,379,645	0	0	37,379,645	-17,208,911
7.98	6.18	0.16	1.76	165.08	300.00	180.00	**424.35**	**332.01**	464.67	605.92	5,957,518	15,886,713	842,343	572,648	532,795	5,236,916	27,396,772	**56,425,704**	38,678,874	0	0	38,678,874	-17,746,831

Figure H-13: Project Discharge Selection Page for Case 3

H.4. CASE 5 Results



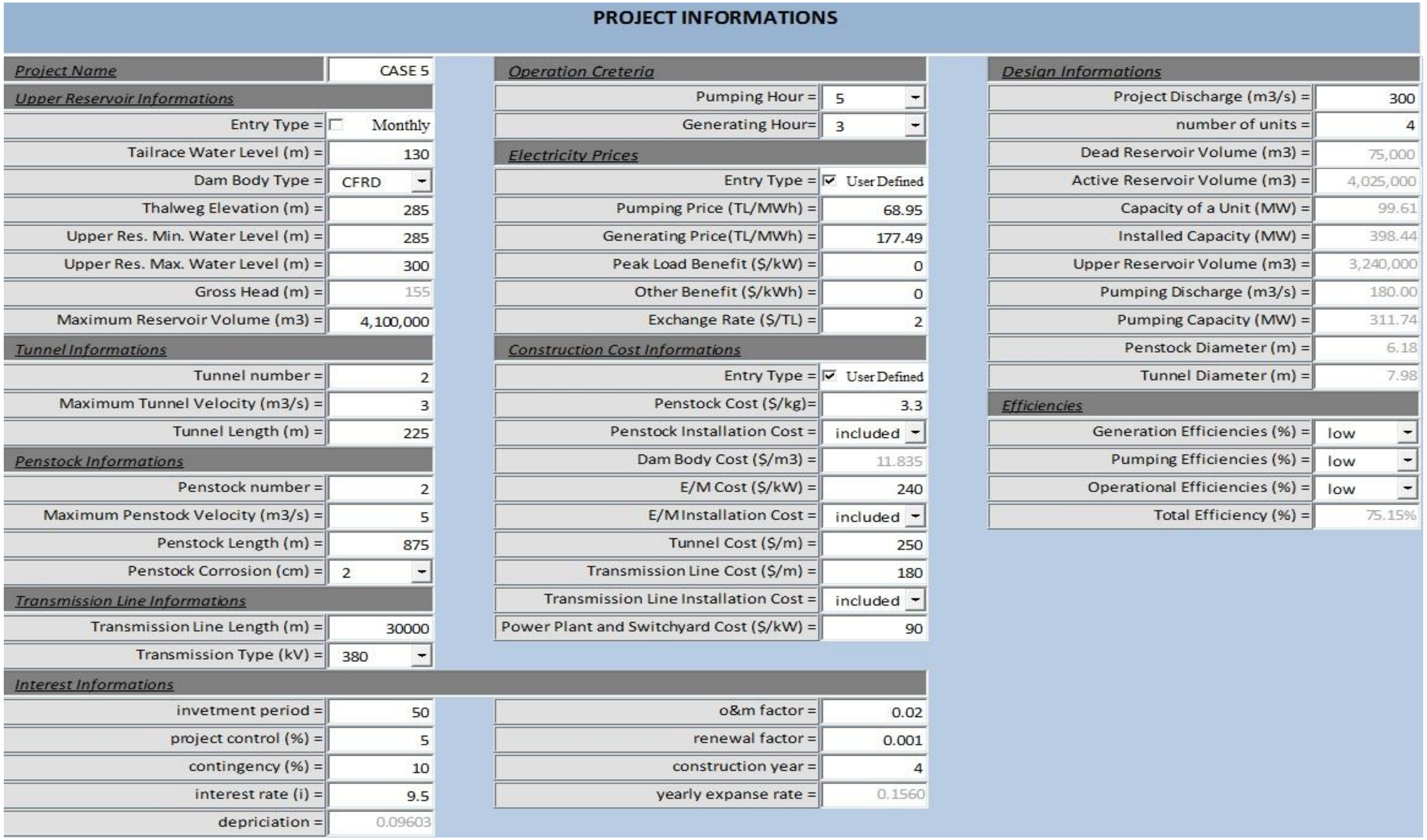


Figure H-14: User Data Interface for Case 5

CASE 5
PROJECT DISCHARGE OPTIMIZATION

INSTALLED CAPACITY OPTIMIZATION											Yearly Cost ($)								Yearly Benefit (YTL)				B - C
Tunnel Diamete	Penstock Diameter	Tunnel Loss	Penstock Loss	Net Head	Generating Discharge	Pumping Discharge	Installed Capacity	Pumping Capacity	Total G Energy	Total P Energy	Power Plant & Switchyard	E/M	Transmission Line	Tunnel	Upper Reservoir	Penstock	Average Pumping	Total	Average Turbining	Peak Load Benefit	Other Benefit	Total	
m	m	m	m	m	m^3/s	m^3/s	MW	MW	GWh	GWh													
1.46	1.13	1.52	17.00	137.48	10.00	6.00	**11.78**	**9.22**	12.90	16.82	165,376	441,002	842,343	33,005	19,354	258,410	579,866	**2,339,356**	1,144,701	0	0	1,144,701	-1,194,655
2.06	1.60	0.96	10.71	144.33	20.00	12.00	**24.73**	**19.35**	27.08	35.32	347,243	925,982	842,343	59,040	19,354	436,076	1,217,558	**3,847,596**	2,403,555	0	0	2,403,555	-1,444,040
2.52	1.95	0.73	8.17	147.09	30.00	18.00	**37.81**	**29.58**	41.40	53.99	530,840	1,415,573	842,343	82,964	19,354	621,640	1,861,312	**5,374,025**	3,674,378	0	0	3,674,378	-1,699,648
2.91	2.26	0.60	6.75	149.65	40.00	24.00	**51.29**	**40.13**	56.16	73.24	720,077	1,920,204	842,343	105,612	43,261	803,265	2,524,844	**6,959,605**	4,984,241	0	0	4,984,241	-1,975,364
3.26	2.52	0.52	5.81	150.66	50.00	30.00	**64.55**	**50.50**	70.68	92.17	906,208	2,416,554	842,343	127,356	43,261	982,253	3,177,485	**8,495,459**	6,272,606	0	0	6,272,606	-2,222,853
3.57	2.76	0.46	5.15	152.39	60.00	36.00	**78.35**	**61.30**	85.79	111.87	1,099,900	2,933,067	842,343	148,406	71,722	1,159,368	3,856,640	**10,111,447**	7,613,312	0	0	7,613,312	-2,498,135
3.86	2.99	0.42	4.65	152.94	70.00	42.00	**91.73**	**71.77**	100.45	130.98	1,287,831	3,434,215	842,343	168,896	71,722	1,335,064	4,515,591	**11,655,662**	8,914,132	0	0	8,914,132	-2,741,530
4.12	3.19	0.38	4.25	153.37	80.00	48.00	**105.13**	**82.25**	115.12	150.12	1,475,956	3,935,882	842,343	188,919	71,722	1,509,636	5,175,224	**13,199,683**	10,216,301	0	0	10,216,301	-2,983,382
4.37	3.39	0.35	3.93	154.72	90.00	54.00	**119.31**	**93.35**	130.65	170.37	1,675,063	4,466,835	842,343	208,542	104,737	1,683,290	5,873,365	**14,854,176**	11,594,486	0	0	11,594,486	-3,259,689
4.61	3.57	0.33	3.66	155.01	100.00	60.00	**132.82**	**103.92**	145.44	189.65	1,864,675	4,972,466	842,343	227,815	104,737	1,856,175	6,538,211	**16,406,422**	12,906,944	0	0	12,906,944	-3,499,479
4.83	3.74	0.31	3.44	156.25	110.00	66.00	**147.28**	**115.23**	161.27	210.29	2,067,626	5,513,669	842,343	246,781	142,306	2,028,405	7,249,829	**18,090,958**	14,311,734	0	0	14,311,734	-3,779,224
5.05	3.91	0.29	3.24	156.47	120.00	72.00	**160.88**	**125.87**	176.17	229.72	2,258,639	6,023,037	842,343	265,470	142,306	2,200,066	7,919,588	**19,651,449**	15,633,891	0	0	15,633,891	-4,017,557
5.25	4.07	0.28	3.07	156.65	130.00	78.00	**174.49**	**136.52**	191.07	249.16	2,449,731	6,532,615	842,343	283,911	142,306	2,371,228	8,589,623	**21,211,757**	16,956,594	0	0	16,956,594	-4,255,163
5.45	4.22	0.26	2.93	157.81	140.00	84.00	**189.31**	**148.12**	207.29	270.31	2,657,733	7,087,287	842,343	302,124	184,429	2,541,949	9,318,953	**22,934,817**	18,396,348	0	0	18,396,348	-4,538,469
5.64	4.37	0.25	2.80	157.95	150.00	90.00	**203.02**	**158.84**	222.30	289.88	2,850,158	7,600,420	842,343	320,128	184,429	2,712,275	9,993,662	**24,503,414**	19,728,278	0	0	19,728,278	-4,775,137
5.83	4.51	0.24	2.68	158.08	160.00	96.00	**216.73**	**169.57**	237.32	309.46	3,042,637	8,113,698	842,343	337,940	184,429	2,882,244	10,668,562	**26,071,853**	21,060,584	0	0	21,060,584	-5,011,269
6.01	4.65	0.23	2.57	159.20	170.00	102.00	**231.90**	**181.44**	253.93	331.12	3,255,615	8,681,639	842,343	355,574	231,105	3,051,889	11,415,339	**27,833,505**	22,534,780	0	0	22,534,780	-5,298,725
6.18	4.79	0.22	2.48	159.30	180.00	108.00	**245.70**	**192.23**	269.04	350.83	3,449,390	9,198,373	842,343	373,041	231,105	3,221,239	12,094,783	**29,410,275**	23,876,056	0	0	23,876,056	-5,534,219
6.35	4.92	0.21	2.39	160.40	190.00	114.00	**261.13**	**204.31**	285.94	372.86	3,666,061	9,776,163	842,343	390,353	282,336	3,390,319	12,854,509	**31,202,083**	25,375,815	0	0	25,375,815	-5,826,268
6.52	5.05	0.21	2.31	160.49	200.00	120.00	**275.03**	**215.18**	301.15	392.70	3,861,116	10,296,309	842,343	407,519	282,336	3,559,148	13,538,440	**32,787,210**	26,725,949	0	0	26,725,949	-6,061,261
6.68	5.17	0.20	2.23	160.57	210.00	126.00	**288.92**	**226.05**	316.37	412.55	4,056,204	10,816,544	842,343	424,546	282,336	3,727,746	14,222,489	**34,372,209**	28,076,316	0	0	28,076,316	-6,295,893
6.83	5.29	0.19	2.17	161.64	220.00	132.00	**304.71**	**238.40**	333.65	435.08	4,277,788	11,407,436	842,343	441,444	338,120	3,896,129	14,999,442	**36,202,702**	29,610,082	0	0	29,610,082	-6,592,620
6.99	5.41	0.19	2.10	161.71	230.00	138.00	**318.69**	**249.34**	348.97	455.05	4,474,139	11,931,038	842,343	458,219	338,120	4,064,312	15,687,918	**37,796,089**	30,969,188	0	0	30,969,188	-6,826,901
7.14	5.53	0.18	2.04	162.77	240.00	144.00	**334.74**	**261.90**	366.54	477.96	4,699,388	12,531,701	842,343	474,876	398,457	4,232,307	16,477,719	**39,656,791**	32,528,317	0	0	32,528,317	-7,128,474
7.29	5.64	0.18	1.99	162.83	250.00	150.00	**348.81**	**272.91**	381.95	498.06	4,896,993	13,058,649	842,343	491,422	398,457	4,400,126	17,170,594	**41,258,584**	33,896,106	0	0	33,896,106	-7,362,478
7.43	5.76	0.17	1.94	162.89	260.00	156.00	**362.89**	**283.92**	397.36	518.16	5,094,622	13,585,658	842,343	507,862	398,457	4,567,779	17,863,549	**42,860,272**	35,264,056	0	0	35,264,056	-7,596,215
7.57	5.86	0.17	1.89	163.94	270.00	162.00	**379.28**	**296.75**	415.31	541.57	5,324,752	14,199,338	842,343	524,200	463,349	4,735,277	18,670,466	**44,759,725**	36,856,974	0	0	36,856,974	-7,902,752
7.71	5.97	0.17	1.84	163.99	280.00	168.00	**393.45**	**307.83**	430.82	561.79	5,523,625	14,729,668	842,343	540,442	463,349	4,902,627	19,367,788	**46,369,842**	38,233,541	0	0	38,233,541	-8,136,300
7.85	6.08	0.16	1.80	165.04	290.00	174.00	**410.10**	**320.86**	449.06	585.57	5,757,404	15,353,076	842,343	556,590	532,795	5,069,838	20,187,497	**48,299,542**	39,851,713	0	0	39,851,713	-8,447,830
7.98	6.18	0.16	1.76	165.08	300.00	180.00	**424.35**	**332.01**	464.67	605.92	5,957,518	15,886,713	842,343	572,648	532,795	5,236,916	20,889,168	**49,918,100**	41,236,865	0	0	41,236,865	-8,681,235

Figure H-15: Project Discharge Selection Page for Case 5

APPENDIX İ

VOLUME ELEVATION CURVE

For calculation of water volume stored in upper reservoir in PXSC we created a dropdown menu for user. User can choose either polynomial or exponential equation type from menu which gives the water volume in reservoir. After investigation several existing dams and Aslantaş PHS upper reservoir, we fitted the best line in each volume-elevation curve with higgest "R" value (R is an statistical value which shows correlation). Polynomial and power curves has the biggest correlation with the real curve thats why we created an option in the menu. Some of the sample studies are shown in Figure İ-1 and Figure İ-2.

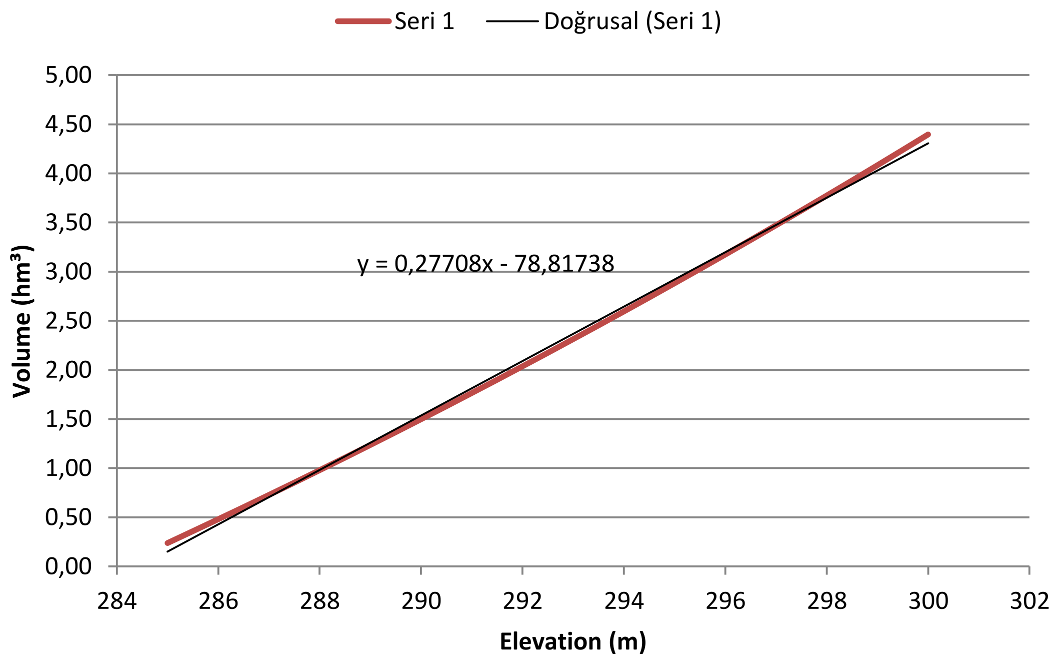


Figure İ-1: Aslantaş PHS Volume-Elevation Curve

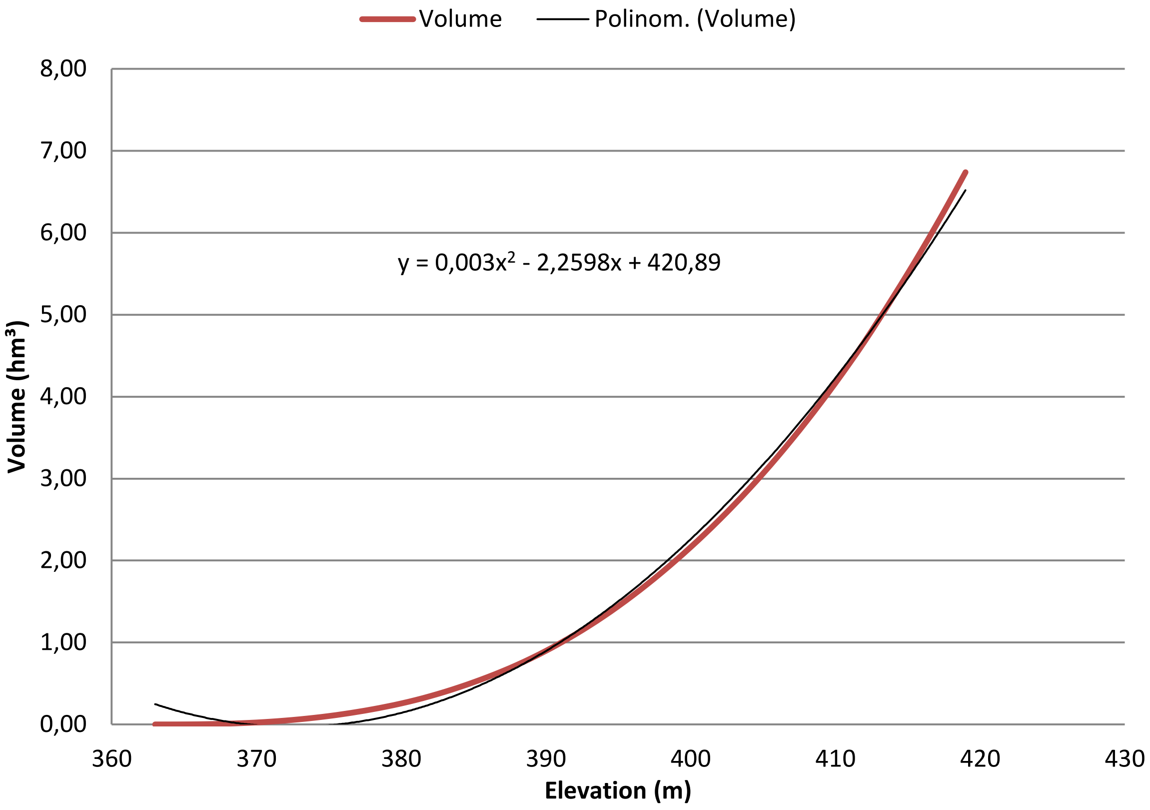


Figure İ-2: Example Volume-Elevation Curve

APPENDIX J

PXSC ALGORITHM

Data Entrance

1. User enters the electricity prices into the **"Electricity Prices"** sheet. If user has no price data available, skip to the step 4.
2. Monthly and hourly averages are calculated by PXSC and sorted from maximum to minimum and minimum to maximum in **"Average Electricity Prices"** sheet.
3. User determines the operation hours for pumping and generation tasks from sorted prices.
4. **"Tailrace Water Level", "Thalweg Elevation", "Upper Res. Min. Water Level", "Upper Res. Max. Water Level"** information is entered into the boxes for calculation of gross head. In default number of working days in a year is set as 365.
   4.1. If user has monthly water level information of the lower reservoir by clicking the checkbox actives the **"Tailrace Water Elevation"** user form. All the information boxes are filled in order to calculate the gross head and number of working days in a year.
5. User selects the dam type from dropdown menu and one of the user form ("**RCC Body", "CFRD Body", "ECRD Body"**) will pop-up.
   5.1. User enters the Dam Body information needed for calculation dam body volume.
   5.2. User selects the proper function from the dropdown menu in the user form and enters the function constants for drawing water-elevation curve of upper reservoir.
6. User enters the **"Peak Power Benefit"**, **"Other Benefit"** and **"Exchange Rate"** information into the corresponding boxes in the **"Project Information"** sheet.

6.1. In default **“Pumping Price”** and **“Generating Price”** are calculated from the sorted prices according to the **“Operation Criteria”** by taking averages of them and shown in the boxes. However, user can enter different prices for pumping and generation tasks by clicking the **“User Defined”** checkbox.

6.2. User selects the operation criteria from the dropdown menu in the **“Project Information”** sheet.

7. User enters the tunnel, penstock, and transmission line information of the project into the **“Project Information”** sheet.
8. User enters the **“Interest Information”** needed for calculation of project costs into the **“Project Information”** sheet.
9. User selects the efficiency values from the dropdown menu in the **“Project Information”** sheet.
10. In default PXSC has predefined unit costs for facilities. However, user can enter different prices for facilities by clicking the **“User Defined”** checkbox.

Discharge Selection

11. User proceeds to the **“Project Discharge Selection”** sheet.
12. User clicks the **“Get Installed Capacity”** button and enters the initial discharge and increment for discharge into the pop-up with initial assumptions of velocities for penstock and tunnel.
13. Step 12 is repeated until finding the optimum installed capacity.

Penstock Diameter Selection

14. User proceeds to the **“Penstock Diameter Selection”** sheet.
15. User clicks the **“Get Penstock Diameter”** button and enters the discharge (found from step 13), initial diameter and increment for diameter into the pop-up.
16. Step 15 is repeated until finding the best result.

Tunnel Diameter Selection

17. User proceeds to the **“Tunnel Diameter Selection”** sheet.
18. User clicks the **“Get Tunnel Diameter”** button and enters the discharge (found from step 13), penstock diameter (found from step 16), initial diameter and increment for diameter into the pop-up.
19. Step 18 is repeated until finding the best result.

20. Check velocities of penstock and tunnel found in step 16 and 19. If they are not same with initial assumptions go to step 11.

Economical Analysis

21. User highlights the optimum solution and clicks the **"Go to Economy"** button.

22. Using Microsoft Excel's **"Goal Seek"** function calculation of internal rate of return is performed.

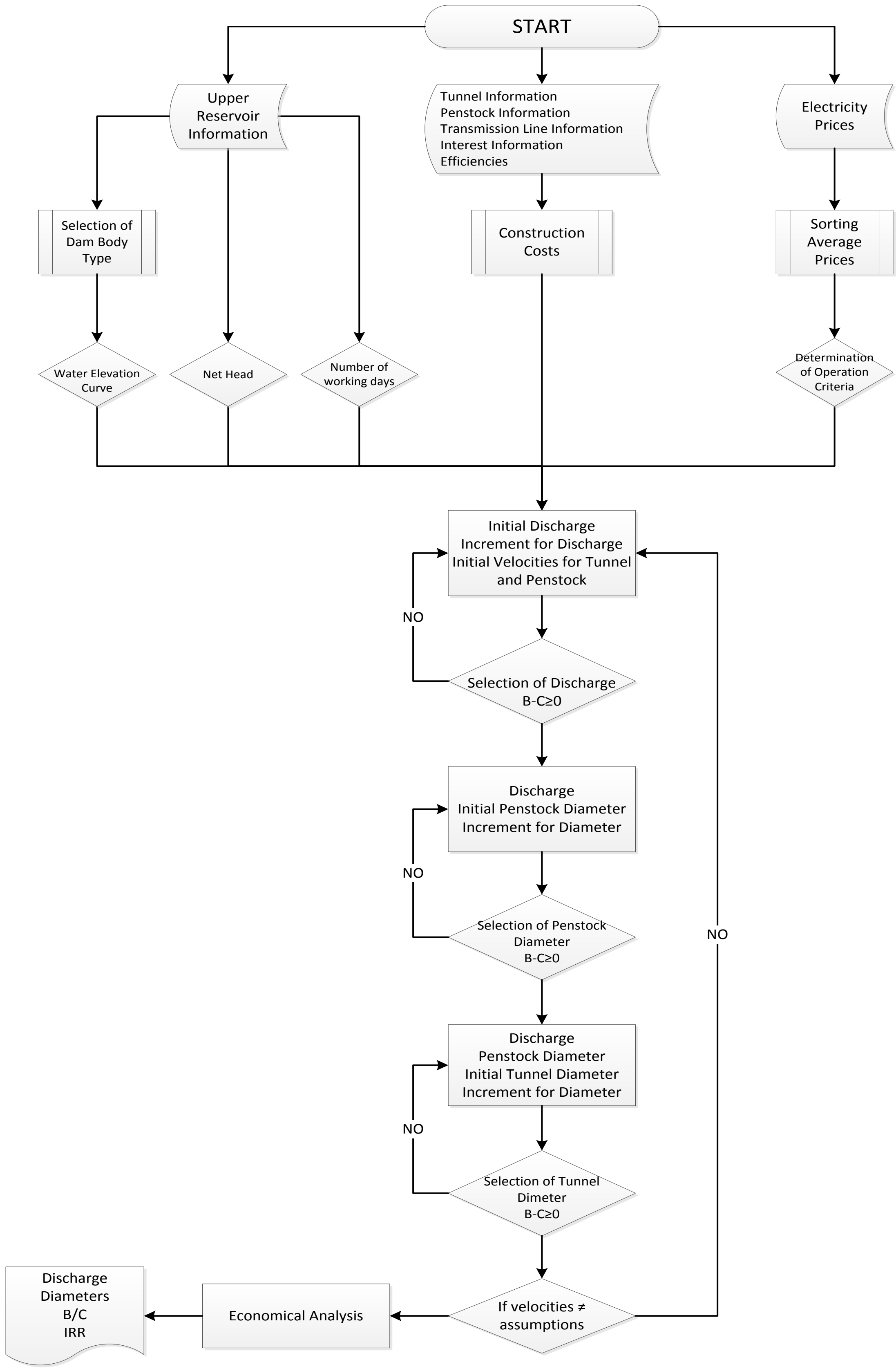


Figure J-1: Algorithm of PXSC

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name	**:** ÇETİNKAYA SEMİH
Nationality	**:** Turkish (T.C.)
Data and Place of Birth	**:** 25/10/1986 – Edirne
Marital Status	**:** Single
Tel	**:** +90 532 491 53 47
e-mail	**:** semihcetinkaya@gmail.com

EDUCATION

Degree	**Institution**	**Year of Graduation**
M.S.	Middle East Technical University	2014
B.S.	Middle East Technical University	2009
High School	Dalaman Anatolian High School	2004

PROFESSIONAL EXPERIENCE

Year	**Place**	**Enrollment**
Oct 2009 – Jan 2010	Denge Mim. Müh. İnş. San.Tic. Ltd. Şti.	Civil Engineer
Mar 2010 – present	Üründül Enerji Yatırımları AŞ	Civil Engineer