DEVELOPMENT OF A COMPUTER SOFTWARE FOR HYDRAULIC DESIGN OF SMALL HYDROPOWER FACILITY

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DEVELOPMENT OF A COMPUTER SOFTWARE FOR HYDRAULIC DESIGN OF SMALL HYDROPOWER FACILITY

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

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

Prof. Dr. Güney Özcebe
Head of Department, **Civil Engineering** _____________

Prof. Dr. A. Melih Yanmaz
Supervisor, **Civil Engineering Dept., METU** _____________

Assoc. Prof. Dr. Zafer Bozkuş
Co-Supervisor, **Civil Engineering Dept., METU** _____________

Examining Committee Members

Prof. Dr. Doğan Altınbilek
Civil Engineering Dept., METU _____________

Prof. Dr. A. Melih Yanmaz
Supervisor, Civil Engineering Dept., METU _____________

Assoc. Prof. Dr. Zafer Bozkuş
Co-Supervisor, Civil Engineering Dept., METU _____________

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

Dr. Kamil Hakan Turan
Civil Engineer, Mimpaş A.Ş _____________

Date: 07 September 2012

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 :	Emir ALİMOĞLU
Signature :	

ABSTRACT

DEVELOPMENT OF A COMPUTER SOFTWARE FOR HYDRAULIC DESIGN OF SMALL HYDROPOWER FACILITY

Alimoğlu, Emir

M.Sc., Department of Civil Engineering

Supervisor: Prof. Dr. A. Melih Yanmaz

Co-Supervisor: Assoc. Prof. Dr. Zafer Bozkuş

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Run-of-river type hydroelectrical power plants are the facilities that use only the available flow on the river without storing it to generate electrical energy. These kind of facilities are composed of structural components such as diversion weir, conveyance line, forebay, penstock and power house. In this thesis, a computer program called “MiniHEPP Hydraulic Design” is developed in order to perform the hydraulic design of run-of-river type hydropower plants. This program which runs under the Windows operating system, was developed in C# programming language. MiniHEPP Hydraulic Design is capable of performing hydraulic design of structural components of diversion weir with sidewise intake and overflow spillway, canal, forebay, and penstock. In addition, it can determine the optimum design discharge and penstock diameter of this type of hydropower plants.

Keywords: Hydroelectrical Energy, Run-of-river Type Hydropower Plants, Computer Aided Design

ÖZ

KÜÇÜK HİDROELEKTRİK SANTRALLARIN HİDROLİK TASARIMI İÇİN BİLGİSAYAR YAZILIMI GELİŞTİRİLMESİ

Alimoğlu, Emir

Yüksek Lisans, İnşaat Mühendisliği Bölümü

Tez Yöneticisi: Prof. Dr. A. Melih Yanmaz

Ortak Tez Yöneticisi: Doç. Dr. Zafer Bozkuş

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Nehir tipi hidroelektrik santrallar, depolaması olmayan, sadece nehirdeki mevcut akımı kullanarak elektrik enerjisi üretilen tesislerdir. Bu tip sistemlerde, regülatör, isale hattı, yükleme havuzu, cebri boru ve santral binası yapı elemanları bulunmaktadır. Bu tezde, nehir tipi hidroelektrik santralların hidrolik tasarımı için "MiniHEPP Hydraulic Design" adında bir bilgisayar yazılımı geliştirilmiştir. C# programlama dilinde geliştirilen bu program, Windows işletim sistemi altında çalışabilmektedir. MiniHEPP Hydraulic Design, yandan alışlı dolu gövdeli regülatör, iletim kanalı, yükleme havuzu ve cebri boru yapı elemanlarının hidrolik tasarımını yapabilmektedir. Buna ek olarak, nehir tipi santral sisteminin optimum tasarım debisini ve cebri boru çapını da belirleyebilmektedir.

Anahtar Kelimeler: Hidroelektrik Enerji, Nehir Tipi Hidroelektrik Santrallar, Bilgisayar Destekli Tasarım

To my dear family,

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

A	: Area of flow
A_g	: Gross area of flow
A_n	: Net area of flow
a_w	: Wave speed of water hammer wave
a	: A coefficient as a function of d
b	: Width of canal
B_{fb}	: Width of forebay
B_{tr}	: Width of the thrashrack in front of the intake of forebay
B_{sn}	: Net width at the entrance of intake
B_s	: Width of settling basin
B_{3n}	: Net width at the entrance of canal
C_c	: Contraction coefficient
C_{ic}	: Cost of installed capacity
C_{icu}	: Unit cost of installed capacity
C_p	: Cost of penstock
C_{pu}	: Unit cost of penstock
C_{om}	: Overall modified discharge coefficient
C_t	: Head loss coefficient due to transition
C_e	: Cost of energy loss
C_T	: Total cost of penstock
C	: Discharge coefficient
c_1	: Dimensionless parameter that describes the support of penstock
CRF	: Capital recovery factor
D	: Penstock diameter

D_A	: Diameter of aeration pipe
D_{max}	: Maximum diameter of particles to be settled in the settling basin
D_m	: Median size of a particle
d_{sl}	: Depth of sluiceway gates
d	: Water depth in canal
E	: Modulus of elasticity
E_f	: Firm energy
E_s	: Secondary energy
E_t	: Total energy
E_{3s}	: Energy level at the downstream of the spillway
E_{3sl}	: Energy level at the downstream of the sluiceway
E_u	: Upstream energy level
e	: efficiency
e_h	: Efficiency of transformer
e_t	: Efficiency of turbine
e_g	: Efficiency of generator
f	: Friction factor through pipe
f_c	: Freeboard of canal
Fr	: Froude number
g	: Gravitational acceleration
G	: Weight of penstock
H_g	: Gross head
H_n	: Net head
H	: Water depth over the spillway
H_0	: Spillway design head
H_s	: Steady state head
h	: Water depth at the upstream of the spillway
h_a	: Velocity head at the upstream of the spillway
h_{fb}	: Difference between maximum and minimum water levels in forebay
h_e	: Total height of in front of intake

h_d	: Difference between upstream and downstream energy gradeline elevations
h_f	: Friction loss through the penstock
h_l	: Total head loss through the penstock
h_m	: Total minor losses through the penstock
K	: Orifice coefficient
K_{cd}	: Bottom elevation at the canal exit
K_{cu}	: Bottom elevation at the canal entrance
K_{ab}	: Contraction coefficients due to abutments
K_d	: Water surface elevation at riprap section
K_5	: Upstream water surface elevation for flood discharge Q_5
K_{10}	: Upstream water surface elevation for flood discharge Q_{10}
K_{25}	: Upstream water surface elevation for flood discharge Q_{25}
K_{50}	: Upstream water surface elevation for flood discharge Q_{50}
K_{100}	: Upstream water surface elevation for flood discharge Q_{100}
K_{d5}	: Water surface elevation at riprap section for flood discharge Q_5
K_{d10}	: Water surface elevation at riprap section for flood discharge Q_{10}
K_{d25}	: Water surface elevation at riprap section for flood discharge Q_{25}
K_{d50}	: Water surface elevation at riprap section for flood discharge Q_{50}
K_{d100}	: Water surface elevation at riprap section for flood discharge Q_{100}
K_m	: Minor loss coefficient
K_p	: Contraction coefficient due to piers
K_{pi}	: Penstock invert elevation
K_r	: Bottom elevation at riprap section
K_s	: Crest elevation of spillway
K_{sf}	: Crest elevation of side spillway in the forebay
K_{sl}	: Crest elevation of sluiceway gates
K_{st}	: Thalweg elevation at the entrance of intake
K_w	: Water surface elevation at a section of intake
K_{wi}	: Water surface elevation in front of intake
L	: Length of penstock

L_{spill}	: Length of spillway
L_{sspill}	: Length of side spillway of forebay
L_e	: Width of sluiceway gates
L_c	: Length of canal
L_T	: Total length of valley at spillway axis
L_{eff}	: Effective length of spillway
L_{fb}	: Length of forebay
m	: Horizontal inclination of canal sides
ME	: Marginal energy
MaxWL	: Maximum water level in forebay
MinWL	: Minimum water level in forebay
NWL	: Normal water level in forebay
n	: Manning's roughness coefficient
n_{br}	: Number of bridge piers
n_p	: number of piers at the entrance of canal
n_{pi}	: number of piers at the entrance of intake
n_s	: Manning's roughness coefficient in settling basin
n_{sl}	: number of sluiceway gates
P	: Height of spillway
P_{firm}	: Firm energy unit price
P_p	: Power generated by the plant
P_{sec}	: Secondary energy unit price
Q	: Discharge
Q_d	: Design discharge
Q_5	: Flood discharge with a return period of 5 years
Q_{10}	: Flood discharge with a return period of 10 years
Q_{25}	: Flood discharge with a return period of 25 years
Q_{50}	: Flood discharge with a return period of 50 years
Q_{100}	: Flood discharge with a return period of 100 years
Q_s	: Discharge over spillway
Q_{sl}	: Discharge through sluiceway

Q_{eq}	: Equivalent discharge
Q_{tur}	: Design discharge of a single turbine
R	: Hydraulic radius
R_b	: Radius of bend
s	: Degree of submergence
s_{tr}	: Maximum spacing between the rackbars at the entrance of intake
S_0	: Canal bottom slope
S_{0s}	: Bottom slope of settling basin
$\overline{S_{fs}}$	: Average friction slope
T	: Valve closure time
T_{cr}	: Critical closure time
t	: Wall thickness of penstock
t_{bp}	: Thickness of bridge piers
t_p	: Thickness of piers at the entrance of canal
t_{pi}	: Thickness of piers at the entrance of intake
t_{pf}	: Thickness of piers at the entrance of intake of forebay
t_{sl}	: Thickness of piers between the sluiceway gates
t_{tr}	: Thickness of rackbars at the entrance of intake
u	: Average flow velocity at a section
V	: Velocity
V_{max}	: Maximum allowed velocity in settling basin
V_{fb}	: Volume of forebay
V_f	: Final velocity
V_i	: Initial velocity
V_a	: Velocity in front of the thrashrack at the forebay intake
W_f	: Fall velocity of a particle
y	: Water depth at a section
Δ	: Sill height at the end of the stilling basin
Δ_a	: Upward step height at the entrance of forebay intake
Δ_b	: Angle of penstock bends

Δ_s	: End sill height at the stilling basin of spillway section
Δ_{sl}	: End sill height at the stilling basin of sluiceway section
Δ_{sd}	: Downward step at the settling basin entrance
Δ_{su}	: Height of upward sill at the end of stilling basin
Δ_u	: Height of upward sill at the end entrance of intake
ΔE_{3s}	: Head loss due to the hydraulic jump at the spillway downstream
ΔE_{3sl}	: Head loss due to the hydraulic jump at the sluiceway downstream
Δt	: Equal time interval on flow-duration curve
ΔQ	: Discharge difference between two consecutive time intervals
ΔH_{t1}	: Minor loss due to transition at section-2 of intake
ΔH_{t2}	: Minor loss due to transition at section-4 of intake
ΔH	: Head increase due to water hammer
ΔH_{tr}	: Minor loss due to trashracks
ΔH_i	: Minor loss above the upward sill, Δ_u
ΔH_{g1}	: Minor loss due to gates
ΔH_e	: Minor loss due to the upward sill, Δ_{su}
ΔH_{ei}	: Minor loss due to the submerged curtain wall at the entrance of intake
ΔH_{es}	: Minor loss due to the downward sill, Δ_{sd}
ΔH_s	: Friction loss through settling basin
σ_t	: Allowable tensile strength of pipe material
γ	: Specific weight of water
γ_p	: Specific weight of pipe material
ρ	: Density of water

CHAPTER 1

INTRODUCTION

Hydroelectric power is simply generated by releasing water with a certain discharge from a certain elevation, to a level with a relatively low elevation where a water turbine is operated. Hydroelectric power is considered one of the most important kinds of energy production because of the renewable and sustainable nature of hydroelectric energy generation. In the recent years, hydropower projects have gained significant importance in Turkey as a result of the increasing demand in energy consumption.

The design of hydroelectric power systems has difficulties since the systems include different components which have various hydraulic and structural requirements and functions. In addition, each project has multi-disciplinary engineering aspects including safety and economy. Hydroelectric power systems also have environmental and social issues associated with them which have significant importance on the final design of the projects.

Hydraulic design of hydroelectric power systems requires the application of various hydraulic concepts which are mostly calculation processes. The designer must seek the optimum design of all structural components because of the aforementioned reasons and the unique characteristics of each individual project. Therefore, the numerical procedures are carried out in an iterative manner in order to compare different design alternatives. The design is finalized by satisfying the safety, economy and also environmental and social issues.

The design of such a system requires time and effort. The utilization of computer softwares reduces the time required to perform complicated calculation processes as well as decreases the calculation errors. Furthermore, it enables quick comparison of several alternatives. Therefore, the aid of computer softwares is inevitable.

Although design companies use different packages for the design of different structural components, a computer program that includes the design of all components is a very useful tool in order to simulate the interaction between the parts of the hydroelectric power system. Development of a hydraulic design software for a particular type of system using the worldwide and Turkish specifications is of importance. Such a program enables a designer to perform quick runs such that several alternatives can be compared to each other. A computer program developed by Turan (2004), which performs optimum hydraulic design of diversion weirs, is considered as a good example serving for this purpose. The main aim of this study is to develop a computer software that includes the design of the whole hydropower system for small scaled projects. A user-friendly, visual computer program called MiniHEPP Hydraulic Design has been developed for this purpose. MiniHEPP Hydraulic Design includes typical hydraulic design of the main components of small scaled hydropower systems. The scope of this study is to allow the user to design the whole system using a single computer program in order to provide a better simulation of the interaction between the parts of the system and to increase the efficiency of the design engineer.

This study is divided into six chapters in the following way: In Chapter 1, the general scope of this study is explained. Chapter 2 provides the general definitions of hydroelectric power plants and the functions of the components of small scaled hydroelectric power systems. In Chapter 3, the computational flow of the software is explained in detail. Chapter 4 gives the algorithmic logic of the program modules. A case study is given in Chapter 5. Lastly, in Chapter 6, the recommendations and conclusions are provided. The user manual of MiniHEPP Hydraulic Design can be found in Appendix A and the source code of MiniHEPP Hydraulic Design is provided in Appendix B.

CHAPTER 2

HYDROELECTRIC POWER PLANTS

Hydroelectric power plant types can differ depending on the available water resources and topographic conditions. Generally, hydroelectric power plants can be characterized by the way they utilize the water and they may be divided into the categories given below (Yanmaz, 2006).

a) Pumped-storage plant

A pumped-storage plant consists of a headwater pond, penstock, a tailwater pond and a reversible pump-turbine unit. The water is pumped from the tailwater pond to headwater pond during low-demand hours using surplus power produced by a fuel-fired plant which has a relatively low cost. Then, releasing water through a penstock from headwater pond to a hydro turbine during peak hours to generate electricity (see Figure 2.1). The overall efficiency for these types of power plants is about 70% due to mechanical and electrical losses during the pumping and generating processes (Yanmaz, 2006).

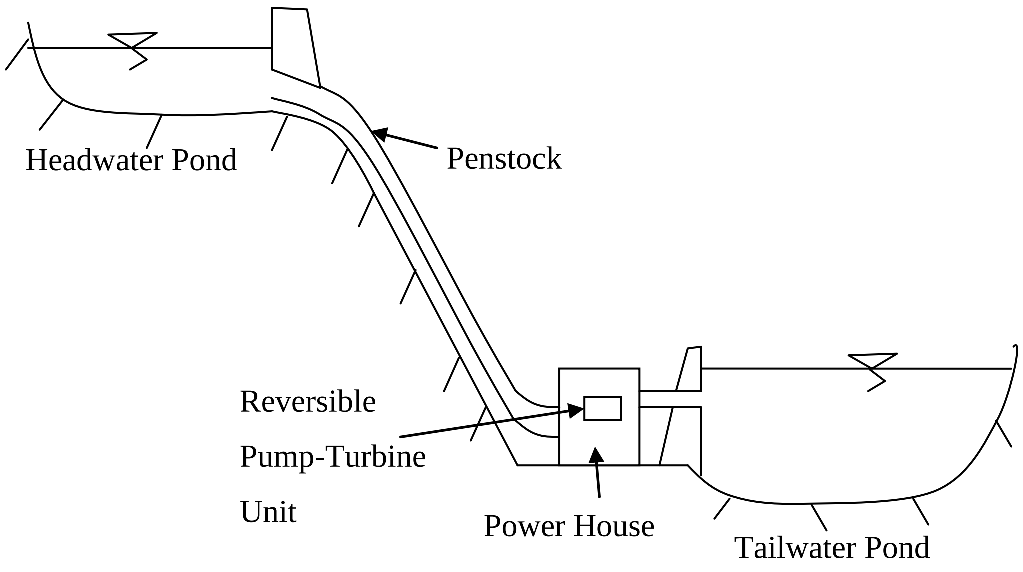

Figure 2.1 Definition sketch for a typical pumped-storage plant

b) Storage Plants

The most important component of a storage plant is the reservoir that stores water in order to regulate the natural flow in the river to create an increment in firm flow and thus in firm energy generation. The adequate amount of stored water is drawn from the reservoir and released through a penstock to a hydro turbine in order to generate the required power. For storage plants, the main factor affecting the power generated is the created head since the amount of flow that is utilized is controlled. The head can be created by a high dam. However, construction of a very high dam may be very expensive. In these cases, an application of power tunnels is considered to carry the desired amount of flow to a suitable location and release water to the power house.

c) Run-of-river Plant

Run-of-river plant usually uses the flow in the river rather than storing water. Therefore, the energy production for these kinds of plants is dependent on the amount of flow on the river whose path is changed with a diversion weir and water guided into a conveyance line, such as a channel or tunnel. Generally, the diverted flow is transmitted to a headwater pond called forebay and then released to a hydro turbine by means of a pipeline called penstock to generate power (Figure 2.2). Since the main scope of this study is run-of-river plants, the components of this kind of systems are explained in detail in this chapter.

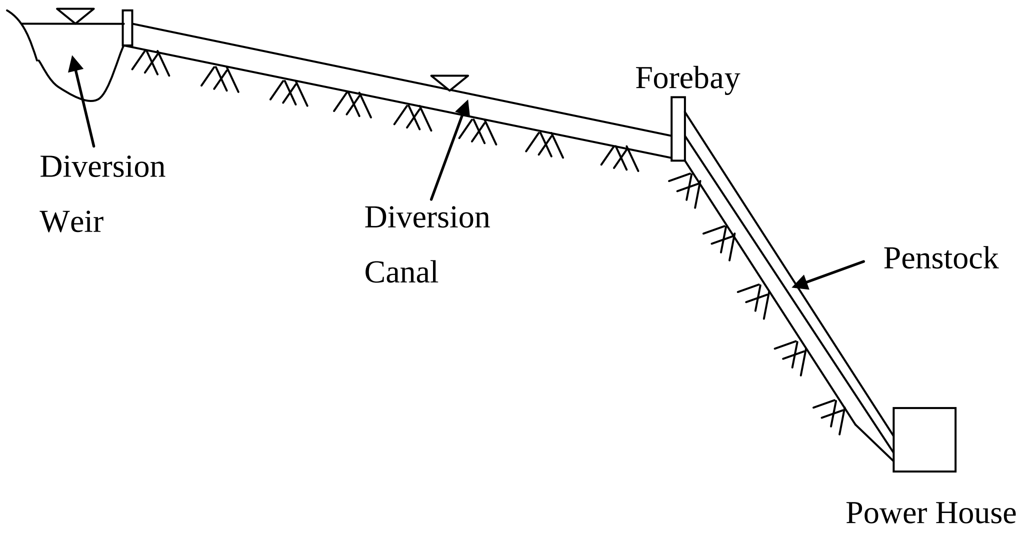

Figure 2.2 Definition sketch for a typical run-of-river plant

2.1 Components of Run-of-river Plants

The main components of run-of-river type of hydroelectric power plants are the following:

- Diversion Weir

- Conveyance Line
- Forebay
- Penstock
- Power Plant

2.1.1 Diversion Weirs

The main function of a diversion weis in run-of-river type of plants is to divert the flow of river. Then, the sediment is settled in a settling basin constructed after the intake structure to prevent the entrainment of particles to the system. After the settling basin, the flow is transmitted to the conveyance line.

Diversion weirs are classified according to (Yanmaz, 2006):

a) Magnitude of Q_{100}
   i. Small diversion weir ($Q_{100} < 100$ m^3/s)
   ii. Medium diversion weir ($100 \leq Q_{100} \leq 500$ m^3/s)
   iii. Large diversion weir ($Q_{100} > 500$ m^3/s)

b) Structural Design
   i. Diversion weir with spillway
   ii. Gated diversion weir

c) Orientation of Intake
   i. Diversion weir with sidewise intake
   ii. Diversion weir with frontal intake
   iii. Diversion weir with drop intake

where Q_{100} is peak discharge corresponding to a 100 year return period. Among these different types of diversion weirs, the most common design in Turkey is diversion weirs with sidewise intake (Yanmaz, 2006). Therefore, the diversion weirs of sidewise intake type is covered in this study. The plan view of a typical diversion weir with a sidewise intake is given in Figure 2.3. The main components of diversion weirs with sidewise intake are covered below.

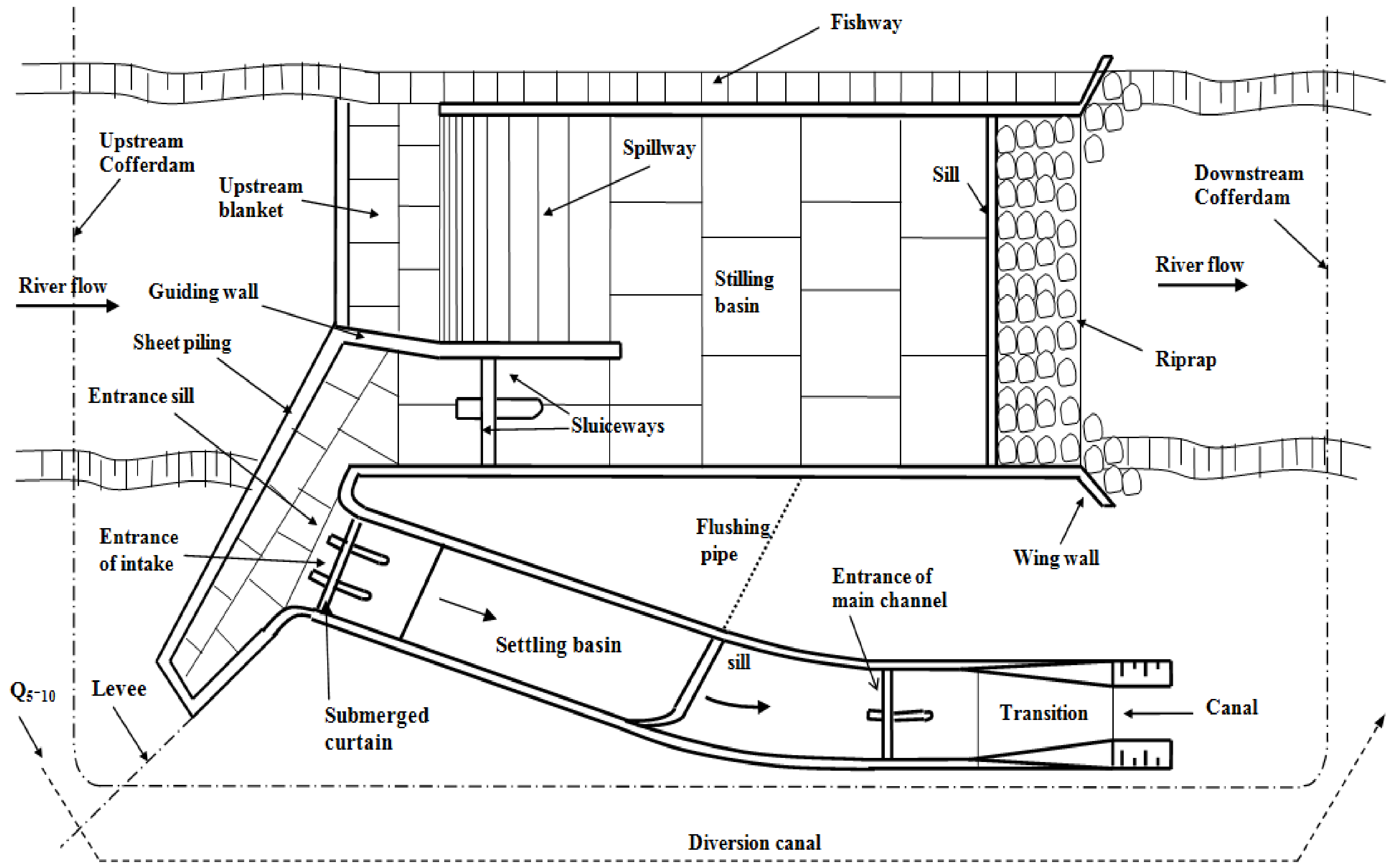

Figure 2.3 Typical plan view of a diversion weir with a sidewise intake (Yanmaz, 2006)

2.1.1.1 Intake

The basic function of intakes is to safely withdraw water from the source, i.e the river in our case. Different types of intake structures are used in practice. Figure 2.4 shows a longitudinal profile of a gate controlled intake.

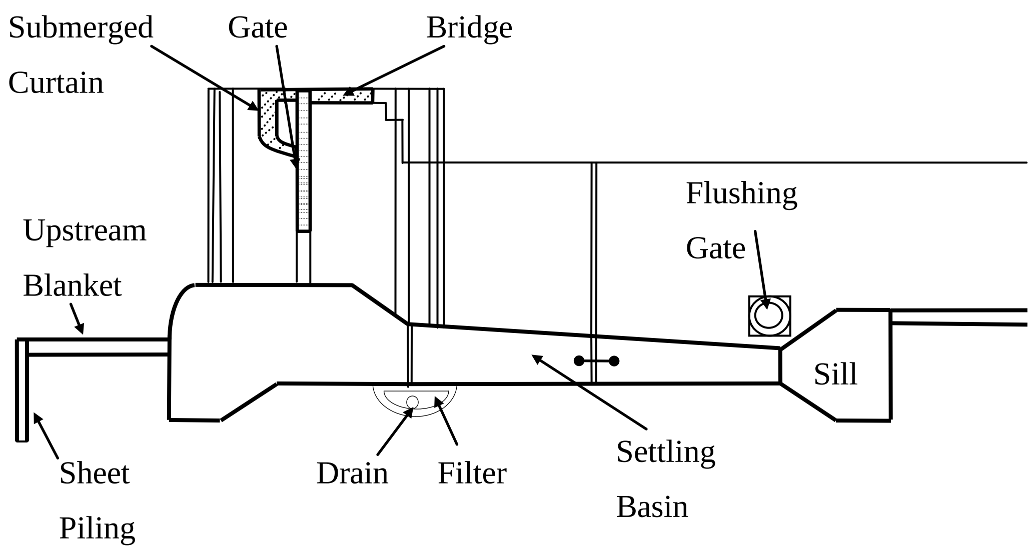

Figure 2.4 Typical cross-section of an intake structure (Yanmaz, 2006)

An intake structure is composed of following components from upstream to downstream:

i. The submerged curtain is the part of intake used for the prevention of the entraintment of floating objects, such as ice, logs, etc., into the intake of the system. The minimum height of a submerged curtain is about 50-60 cm from the top of the intake and the orientation is perpendicular to the direction of the flow.

ii. The screens are the racks placed in front of the vertical gate at the entrance of intake structure. The screens are utilized in order to prevent the entrainment of floating objects or coarse sediment into the intake.

iii. A a settling basin is provided in order to capture the sediment with a desired size depending on the characteristics of the system.

iv. A flushing facility is placed at the end of the settling basin in order to release the captured sediment in the settling basin back to the river. For self-cleaning purposes, the flushing facility should have an adequate slope and a diameter with a minimum of 60 cm.

v. Before the entrance of the conveyance line, a transition is constructed in order to connect the settling basin to the conveyance line.

2.1.1.2 Spillway

A spillway is an important component of diversion weirs. Its main function is to raise water, divert the project discharge and transmit the remaining flow to the stilling basin (energy-dissipating basin) which is located just downstream of the spillway.

2.1.1.3 Stilling Basin

A stilling basin is constructed in order to dissipate the excessive energy of flow, generally in the occurance of a flood event. By doing so, the riverbed is protected by means of scour. The longitudinal profile of stilling basin and spillway is shown in Figure 2.5.

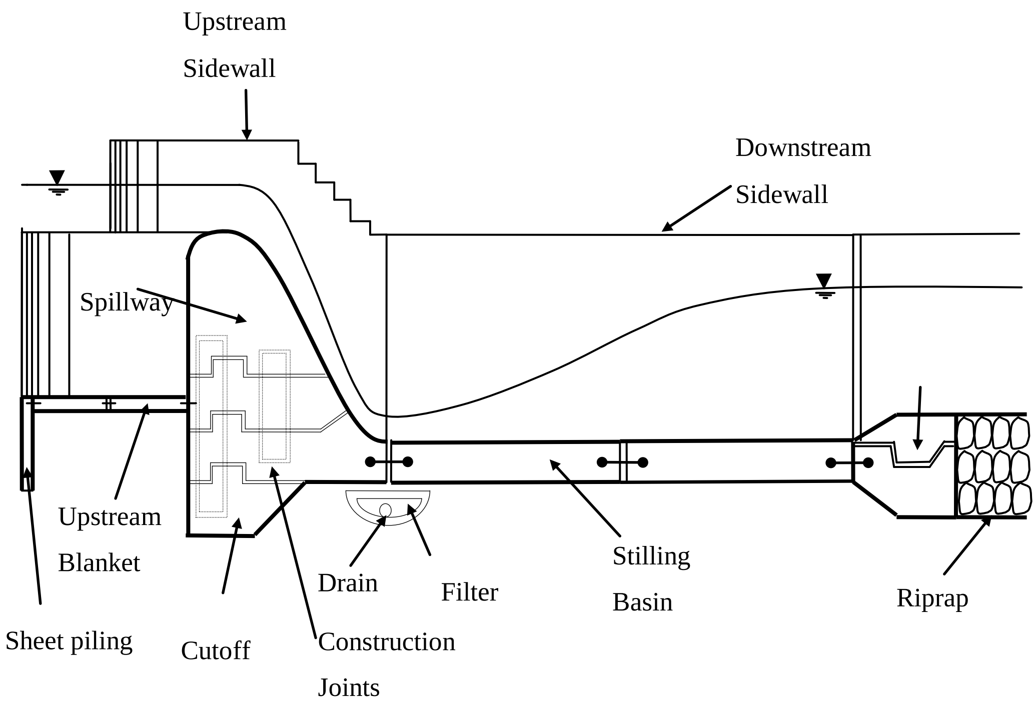

Figure 2.5 Longitudinal profile of stilling basin and spillway (Yanmaz, 2006)

2.1.1.4 Sluiceway

A sluiceway is the component that prevents the deposition of the captured sediment in front of the intake by flushing it downstream of the diversion weir. When the deposited sediment reaches to a certain elevation, the vertical lift gates of sluiceway are opened in order to release and guide the sediment downstream by flushing. The longitudinal profile of a sluiceway is given in Figure 2.6.

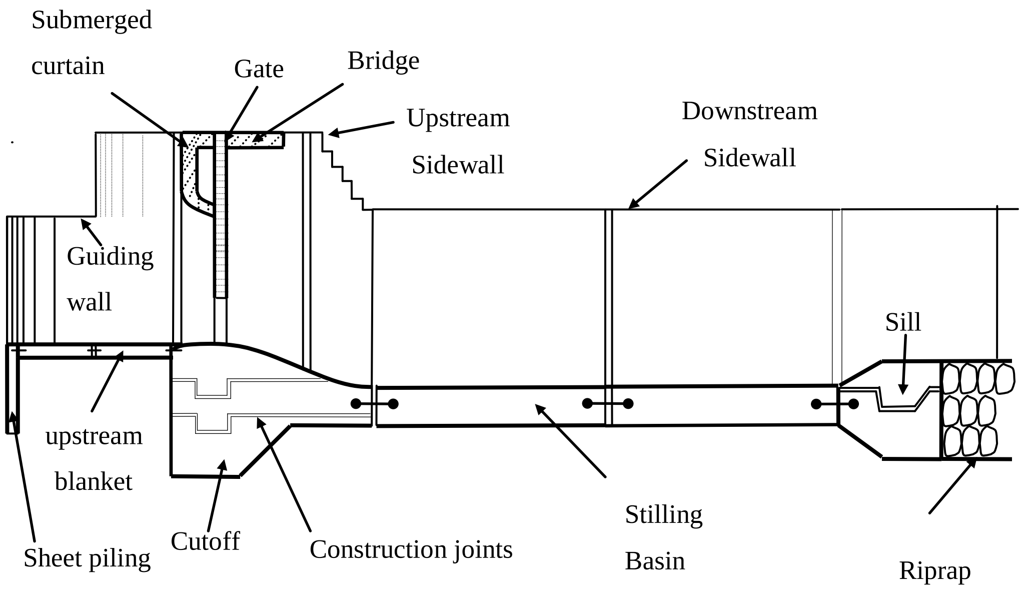

Figure 2.6 Longitudinal profile of sluiceway (Yanmaz, 2006)

2.1.1.5 Riprap

The riprap section is placed just the downstream of stilling basin. The stones are placed in this section with an adequate thickness and length to protect the riverbed.

2.1.1.6 Fish Passage

The fish passage is composed of successive pools that provides a passage for the fish to migrate along the river.

2.1.2 Conveyance Line

The conveyance line transports the desired amount of flow which has been diverted from the river, from intake to forebay. There are various types of conveyance lines, such as canals, tunnels, pipelines, etc. The governing factor for conveyance line type is economy and topographic conditions. Canals which usually have rectangular or trapezoidal cross-sections are the most common type utilized in hydropower systems. Therefore, in this study, canals are covered in detail.

In order to transport the design discharge from the intake to the forebay, the canal must have sufficient hydraulic capacity. This hydraulic capacity depends on the canal bed slope and canal cross-section. Since the governing factor for the canal bed slope is the hydraulic losses for hydropower plants, the cross-section of the canal must have adequate dimensions to satisfy hydraulic capacity by taking economy into account. Canals can be lined or unlined. Unlined canals are designed to have trapezoidal cross-sections with side slopes decided according to the material of foundation. The recommended side slopes for unlined canals are given in Table 2.1.

Table 2.1 Recommended side slopes for unlined canals (Chow, 1959)

Material	Side Slope (H : V)
Rock	Nearly vertical
Muck and peat soils	1/4 : 1
Stiff clay or earth with concrete lining	1/2 : 1 to 1 : 1
Earth with stone lining or earth for large channels	1 : 1
Firm clay or earth for small ditches	1.5 : 1
Loose sandy earth	2 : 1
Sandy loam or porous clay	3 : 1

For lined trapezoidal open canals, 1V : 1.5H side slopes are recommended by United States Bureau of Reclamation (USBR) and the Turkish State Hydraulic Works (DSİ) by considering the stability of side inclination as well as the construction techniques and equipment.

In order to prevent the overtopping of waves and fluctuations in water surface from the sides, a freeboard, f_c, which is the vertical distance between the top of the canal and the water surface at design conditions is provided. Generally, freeboards vary from less than 5% to greater than 30% of the depth of flow (Chow, 1959).

2.1.3 Forebay

The forebay is the structural component between the canal and penstock. The main purposes of forebay are the following:

1. Uniform distribution of flow to the penstock
2. Provide a gentle flow
3. Prevent the entrainment of floating objects and sediment to the penstock
4. Provide the sufficient discharge for turbines
5. Prevent the air entrainment to the penstock
6. Absorb the upsurges in case of a load rejection event

The main components of forebay are summarized below:

a) Intake

   The intake section of a forebay is located just upstream of the penstock. It consists of a sluice gate, trashrack and aeration pipe.

b) Bottom Outlet

   The bottom outlet is used for flushing of the sediment and the discharge of water in the forebay.

c) Side spillway and Side spillway Chute

   A side spillway is provided in a forebay in order to release the excessive flow back to the river through side spillway chute in case of a load rejection event while the turbines are operating at maximum capacity.

2.1.4 Penstock

A penstock is defined as a water conduit which carries pressurized flow between the forebay and the turbine. Usually, penstocks are made of steel since internal pressure is high.

2.1.4.1 Determination of Penstock Route

Penstock can be installed underground or on the ground surface. The governing factor for the determination of penstock route is the geological conditions. The penstock route must be on firm soil. If the geological conditions are unfavourable, shafts or tunnel can be considered.

The penstock route must be as short as possible. The cost of penstock and head losses, which decreases energy production, increase with penstock length. For the same reason, the penstock route must be straight as much as possible in order to avoid head losses at bends.

2.1.4.2 Number of Penstocks and Branches

As a general rule, utilization of a single penstock with branches depending on the number of turbines in the power plant, is the most economic solution. Types of branches are shown in Figure 2.7.

The design of penstock with branches rises the problem of hydraulic losses at these branches which depends on the deflection angle. These losses can be reduced by joining the branch to the main pipe with a deflection angle less than 90^o. Therefore, the deflection angle usually varies between 30^o and 75^o. The hydraulic efficiency is increases for smaller deflection angles. However, at angles less than 45^o, the reinforcing of branch outles becomes more difficult (USBR, 1977).

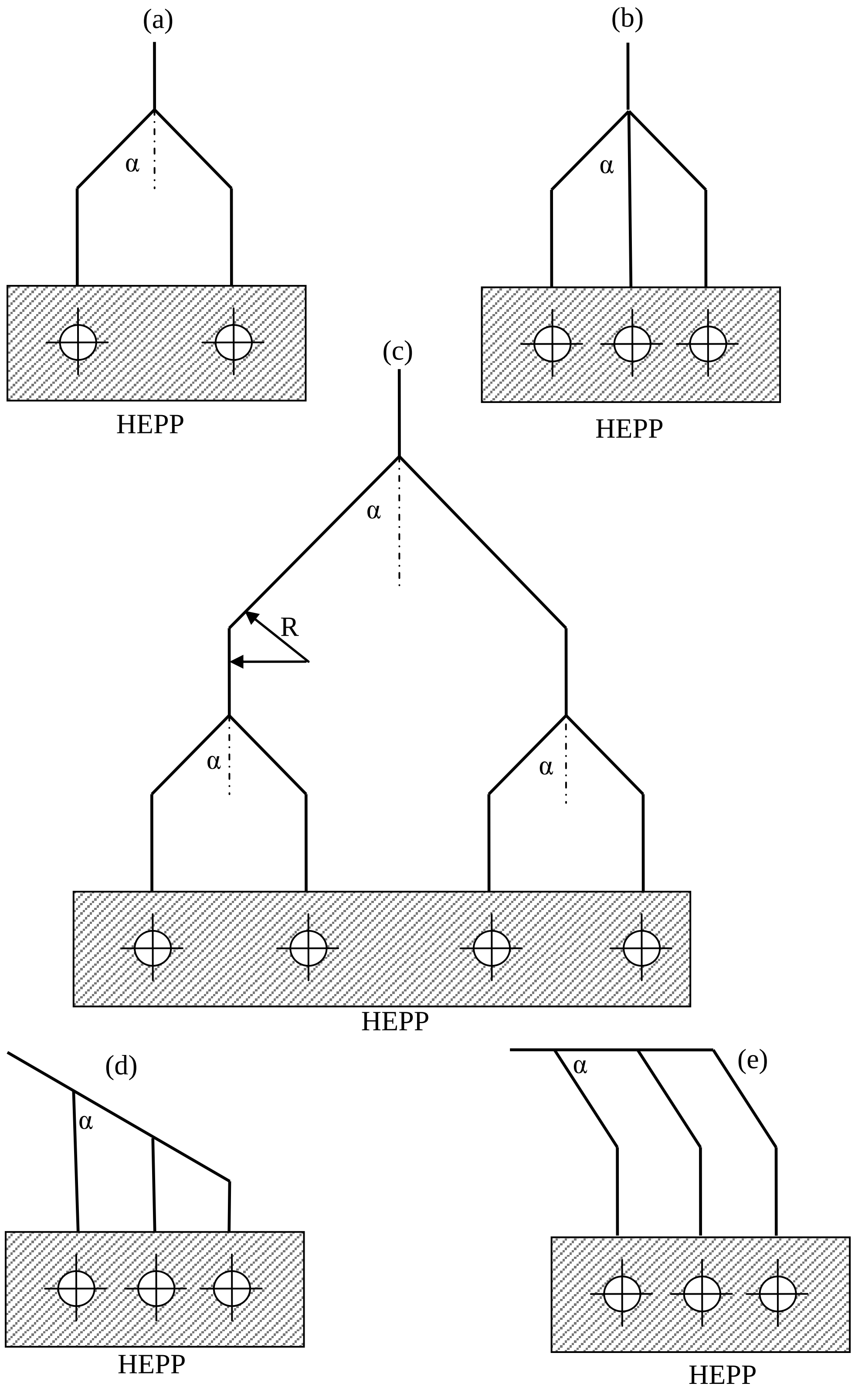

Figure 2.7 Types of penstock branches (Yıldız, 1992)

2.1.4.3 Support of Penstock

A long pipe with a number of supports acts like a continuous beam except for the expansion joints. Therefore, ring girders or stiffener rings used to limit the deformation of shell at the supports. The shell is subjected to direct beam and hoop stresses with loads transmitted to supports by shear. In addition, secondary bending stresses occur in the pipe shell near the ring girder or anchor because of the restraint imposed by a rigid ring girder or concrete anchor. In order to design the pipeline to have sufficient resistance to bending and shear forces, the following methods may be utilized (USBR, 1977):

a. Shell vaving sufficient stiffness.

b. Continuous embedment of part of periphery of the pipe

c. Support cradles or saddles

d. Stiffener rings that carries the load to concrete piers by means of support columns

2.1.5 Power Plant

The power plant is the structure where the energy is generated. The power plant contains the necessary electromechanic equipment for energy production, such as turbines, generators, and transformers. The location of power plant is determined according to (Yıldız, 1992):

1. The power plant should be on a firm soil or rock. In order to maintain this, half-buried or buried power plants can be considered.
2. The length of penstock and head losses must be reduced as much as possible.
3. The excavation costs should be minimized by placing the power plant on a large and plain location.
4. Should be close to a switchyard.

5. The tailwater canal should be connected to the river economically.
6. The transportation to power plant should be suitable.

CHAPTER 3

HYDRAULIC DESIGN OF A SMALL HYDROPOWER FACILITY

The hydraulic design process of a small scaled run-of-river type hydroelectric power plant is explained in this chapter. The design of such a system is relatively complicated because of the number and interaction of different structural components. Therefore, the calculations must be carried out step by step and in a systematical manner. The general steps of computations can be summarized as follows:

- Determination of flow-duration curve and flood discharges
- Determination of optimum design discharge
- Determination of optimum penstock diameter
    - Design of penstock
- Design of forebay and canal
- Design of diversion weir
    - Intake
    - Spillway
    - Sluiceway
    - Energy dissipators

3.1 Determination of Flow-Duration Curve and Flood Discharges

The design process of a hydropower system starts with hydrological analysis of the basin. The estimation of water potential i.e. the available flow in the river to be utilized in energy production is essential since the design of structural components is directly affected with the available amount of water in the river. The effect of a possible drought period needs to be considered in the economic analysis of the system. The accuracy of the flow duration curve can be tested using a sensitivity analysis. In addition, the flood discharges are also needed for the design of a spillway to transmit the excessive discharge downstream safely.

3.1.1 Determination of Flow-Duration Curve

The flow-duration curve represents the discharges on the river according to their occurance percentages. Since the available flow is one of the governing variables for the design of the system, the accurate estimation of flow-duration curve is very important.

In Turkey, State Hydraulic Works (DSI) and General Directorate of Electrical Power Resources Survey and Development Administration (EIE) have constructed Stream Gaging Stations (SGS) on rivers and collected data throughout the years. By the hydrological analysis of the data of nearby stations the flow-duration curve i.e the water potential of the river is determined. In addition to the flow-duration method, sequential stream routing based on daily flow data can also be used in the determination of the river potential. Such a hydrological analysis is not in the scope of this study hence the flow duration curve is assumed to be determined in advance.

3.1.2 Determination of Flood Discharges and Water Surface Profile

After locating structural elements of the system, the flood discharges that may occur on the river must be determined and especially the design of diversion weir must be made accordingly. In addition, water surface profile of the river is also needed for checking hydraulic performance of the diversion weir under various flow conditions having different return periods. In Turkish practice, return periods ranging between 2 to 100 years are used (Yanmaz, 2006). Therefore, Q_5, Q_{10}, Q_{25}, Q_{50} and Q_{100} flood discharges are obtained by the hydrological analysis of the basin and the corresponding water surface profile can be obtained. The determination of flood discharges and water surface profile are also not covered in this thesis.

3.2 Determination of Optimum Design Discharge

The determination of optimum design discharge is based on comparison of net benefits of different alternatives. For each design discharge alternative on the flow-duration curve, the costs of penstock and installed capacity, the energy production and corresponding benefits are calculated and the net benefits of aforementioned alternatives are compared. The optimum design discharge is decided based on the maximum net benefit. This process is explained in this subsection.

- Step 1: In order to calculate generated power and corresponding energy generation, there is a need for an approximate penstock diameter since the significant part of head losses occurs as the frictional losses through penstock. In order to determine these initial penstock diameters for each design discharge alternative the following velocity, V, can be used (Yıldız, 1992):

$$V = 0.125\sqrt{2gH_g} \tag{3.1}$$

  where, V is in m/s, H_g is the gross head of the power plant (m) which is defined as the vertical distance between the water surface of forebay and the water surface of tailwater downstream of the turbines. For each discharge on the flow-duration curve, a corresponding penstock diameter is obtained by satisfying the the velocity obtained in Equation (3.1).

- Step 2: After determination of penstock diameters, corresponding wall thickness of each penstock diameter is obtained. The process for determination of wall thickness of penstock is explained in Section 3.3.1.

- Step 3: In this step, the flow-duration curve is converted into power-duration curve. Hydroelectric power generated by a plant can be expressed as:

$$P_p = \gamma Q H_n e \tag{3.2}$$

where, P_p is the power generated by the plant (Watts), H_n is the net head (m), γ is the specific weight of water (N/m^3) and e is the total efficiency which is equal to $e = e_h e_g e_t$ where e_h is the efficiency of transformer, e_g is the efficiency of generator, and e_t is the efficiency of turbine.

The hydraulic losses occured through the penstock is the summation of frictional losses, h_f, and minor losses, h_m, which is caused by trashracks, bends, transitions, etc. The net head, H_n, is calculated by subtracting the frictional head loss, h_f, and total minor losses, h_m, through the penstock from gross head, H_g.

$$h_f = \frac{8fL}{g\,\pi^2\,D^5}\,Q^2 \tag{3.3}$$

$$h_{m_i} = K_{m_i}\frac{V^2}{2g} \tag{3.4}$$

$$H_n = H_g - \sum h_f - \sum h_m \tag{3.5}$$

where, f is the friction factor through penstock, L is the length of penstock, D is the diameter of penstock, Q is the discharge and K_{m_i} is the minor loss coefficient for a section concerned. For each value of Q on flow-duration curve, the corresponding installed capacity is calculated by using Equations (3.2), (3.3), (3.4) and (3.5). In other words, the power generated for each of the occurence percentage is determined and power-duration curve is obtained.

- Step 4: The energy generation for each alternative is calculated by means of firm energy, E_f, secondary energy, E_s and total energy, E_t. For the sake of simplicity, the flow duration curve is divided into equal time intervals, Δt, which corresponds to a total of 8760 hours. In order to calculate the marginal energy generation between these equal time intervals, an equivalent discharge, Q_{eq} is computed to represent the average discharge as Q_{eq} = duration (%) * ΔQ, where ΔQ is the discharge difference between two consecutive time intervals. Then, marginal energy produced between time intervals, ME, is expressed as:

$$ME = \gamma Q_{eq} H_n e * 8760 \tag{3.6}$$

  Firm energy generation, E_f, is taken as the energy production which corresponds to the 95% occurence on the power-duration curve. The remaining energy generation is taken as secondary energy generation, E_s.

- Step 5: The costs of penstock and installed capacity are calculated. The weight of penstock for circular cross-section is:

$$G = \gamma_p \pi D L t \tag{3.7}$$

  where, γ_p : specific weight of pipe material (kg/m^3);
  D : penstock diameter (m);
  L : penstock length (m);
  t : penstock wall thickness (m).

  The cost of penstock, C_p for a yearly basis is calculated by:

$$C_p = C_{pu} * CRF * G \tag{3.8}$$

  where, C_{pu} is the unit cost of penstock (\$/kg) and CRF is the capital recovery factor. Similarly, the cost of installed capacity, C_{ic} is obtained by:

$$C_{ic} = C_{icu} * P_p * CRF \tag{3.9}$$

where, C_{icu} is the unit cost of installed capacity (\$/MW) and P_p is the installed capacity (MW).

- Step 6: After determination of the costs of penstock and installed capacity, the total cost is obtained by adding these two values. In addition, the values of firm and secondary energy generations are multiplied by their corresponding energy benefits and by doing so the total energy benefit is obtained. In order to determine the net benefit for each alternative discharge value, the total cost is subtracted from its corresponding energy benefit.

- Step 7: Finally, the candidate discharge value on flow duration curve which gives the maximum net benefit after following the above steps is selected as the design discharge.

3.3 Determination of Optimum Penstock Diameter

The optimum penstock diameter is decided according to the design discharge determined as explained in Section 3.2. The main reason to select an optimum penstock diameter is that the frictional head loss is reduced with the incrementation of penstock diameter for a constant discharge hence the energy generation and energy benefit are increased.

In order to obtain an accurate optimum penstock diameter, the design of penstock is also made simultaneously by means of the determination of wall thickness by considering the water hammer effects. The calculation of wall thickness and the concept of water hammer are explained in the following subsections.

3.3.1 Water Hammer

A sudden change of the rate of flow due to opening or closing valves creates a pressure wave of high magnitude. Pressure wave travels back and forth in the pipe until it vanishes due to friction or damped out. This pressure changes in the pipe, can be several times larger than the steady state pressures, therefore the design of such pipeline must include the consideration of water hammer phenomenon.

The speed of pressure wave depends on the elasticity of water, pipe dimensions and the Young's modulus of elasticity of pipe material. Wave speed, a_w, is expressed as (Wylie et al., 1993):

$$a_w = \sqrt{\frac{\frac{K}{\rho}}{1 + \left(\frac{K}{E}\right)\left(\frac{D}{t}\right)c_1}} \tag{3.10}$$

where, K : bulk modulus of water;

ρ : density of water;

E : elasticity modulus of pipe material;

D : pipe diameter;

t : wall thickness of the pipe;

c_1 : a dimensionless parameter that describes the effect of pipe anchor on the wave speed. In case of pipes anchored with expansion joints throughout, this parameter can be taken as unity.

The pressure wave, starts to travel upstream from valve with speed a_w, immeadiately after the closure of valve. The total time for the pressure wave to travel to upstream end of a pipe with a length of L and return to the downstream end of pipe which is called critical time is expressed as:

$$T_{cr} = \frac{2L}{a_w} \tag{3.11}$$

where, T_{cr} is the critical time and L is the pipe length. A valve movement that takes place in less than the critical time is called rapid valve closure. The maximum change in head for such a case is calculated by (Wylie et al., 1993):

$$\Delta H = -\left(\frac{a_w}{g}\right)\left(V_f - V_i\right) \tag{3.12}$$

where, ΔH is the change in head, V_f is the final velocity in the pipe in the end of valve movement and V_i is the initial velocity in the pipe at the beginning of valve movement. For cases that the valve closure time is greater than critical time, the head rise due to water hammer is calculated by:

$$\Delta H = -\left(\frac{2L}{gT}\right)\left(V_f - V_i\right) \tag{3.13}$$

where, T is the valve closure time.

3.3.2 Determination of Penstock Wall Thickness

The penstock wall thickness, t, mainly depends on the maximum tensile strength of pipe material, σ_t, pipe diameter, D, and the operating pressure. However, in case of water hammer events the pressure on the penstock is increased dramatically, hence the wall thickness must be selected by taking into account the head increase on the penstock due to water hammer. The wall thickness of penstock is calculated by:

$$t = \frac{\gamma(\Delta H + H_s) * D}{2\sigma_t} \tag{3.14}$$

where, t : wall thickness of penstock;

γ : specific weight of water;

ΔH : head increase due to water hammer;

H_s : steady state head;

D : penstock diameter;

σ_t : tensile strength.

The pipe must be appropriately rigid in order to manage deformations in the field sufficiently. Therefore, ASME suggests a minimum wall thickness in mm that is equal to the 2.5 times of the pipe diameter in meters plus 1.2 mm (ESHA, 2004).

For a certain penstock diameter, the speed of pressure wave and head rise due to water hammer are calculated by using Equations (3.10), (3.11), (3.12) and (3.13). If the tensile strength of penstock requires greater wall thickness, then the process is repeated by increasing wall thickness until Equation (3.14) is satisfied.

Generally, penstocks are made of steel hence subjected to corrosion. Therefore, after the wall thickness of penstock determined with the above procedure, it is increased by additional 2 mm to provide safety.

3.3.3 Penstock Diameter Optimization

Following the determination of design discharge, the optimum penstock diameter is obtained by comparing various diameter alternatives. For each alternative, the cost of penstock, C_p is calculated by using Equation (3.8). Then, the total hydraulic losses in the penstock, h_l, is calculated by summing the frictional head loss and minor head losses obtained by using Equations (3.3) and (3.4). By putting the total hydraulic loss, $h_{l,}$ instead of H_n in Equation (3.6), the loss in energy generation of the plant is obtained. The cost of energy loss, C_e is obtained by multiplying the cost of energy benefit with the loss in energy generation. Total cost for each individual diameter candidate, C_T is calculated with the summation of C_p and C_e. The diameter alternative with the minimum C_T value is selected as the optimum penstock diameter.

3.4 Design of Forebay and Canal

The design of forebay and canal is handled simultaneously in this study since the dimensions and locations of these two components affect the design of each other significantly. The plan and cross section of a typical forebay is given in Figure 3.1.

The best hydraulic section approach is utilized to determine the dimensions of the canal which has a trapezoidal cross-section with side slopes m in the present study. The relationship between the canal bottom width, b and water depth in the canal, d is given as:

$$b = 2\, d \left(\sqrt{m^2 + 1} - m\right) \tag{3.15}$$

Fluctuations may occur on the water surface due to winds or some other disturbances. A freeboard which is the height between the water surface and the top elevation of the canal is provided to handle these fluctuations. An emprical equation is proposed by USBR for the determination of freeboard, f_c, as:

$$f_c = 0.2(1 + d) \tag{3.16}$$

where, d is the water depth in the canal.

After obtaining the dimensions of canal, the water depth in the canal that corresponds to the design discharge is computed by Manning's Equation. The obtained water surface elevation at this depth also corresponds to the normal water level, NWL, in the forebay.

The next step in the design of forebay is the determination of minimum water level, MinWL in the forebay. The purpose of assigning a minimum water level is to provide sufficient submergence in order to prevent the formation of severe vortices in the intake. In addition, it provides safety against the air entrainment into the penstock which would create cavitation problem in the turbines. Therefore, a minimum submergence height between the centerline of the penstock and the water surface, s, is provided as in Figure 3.1.

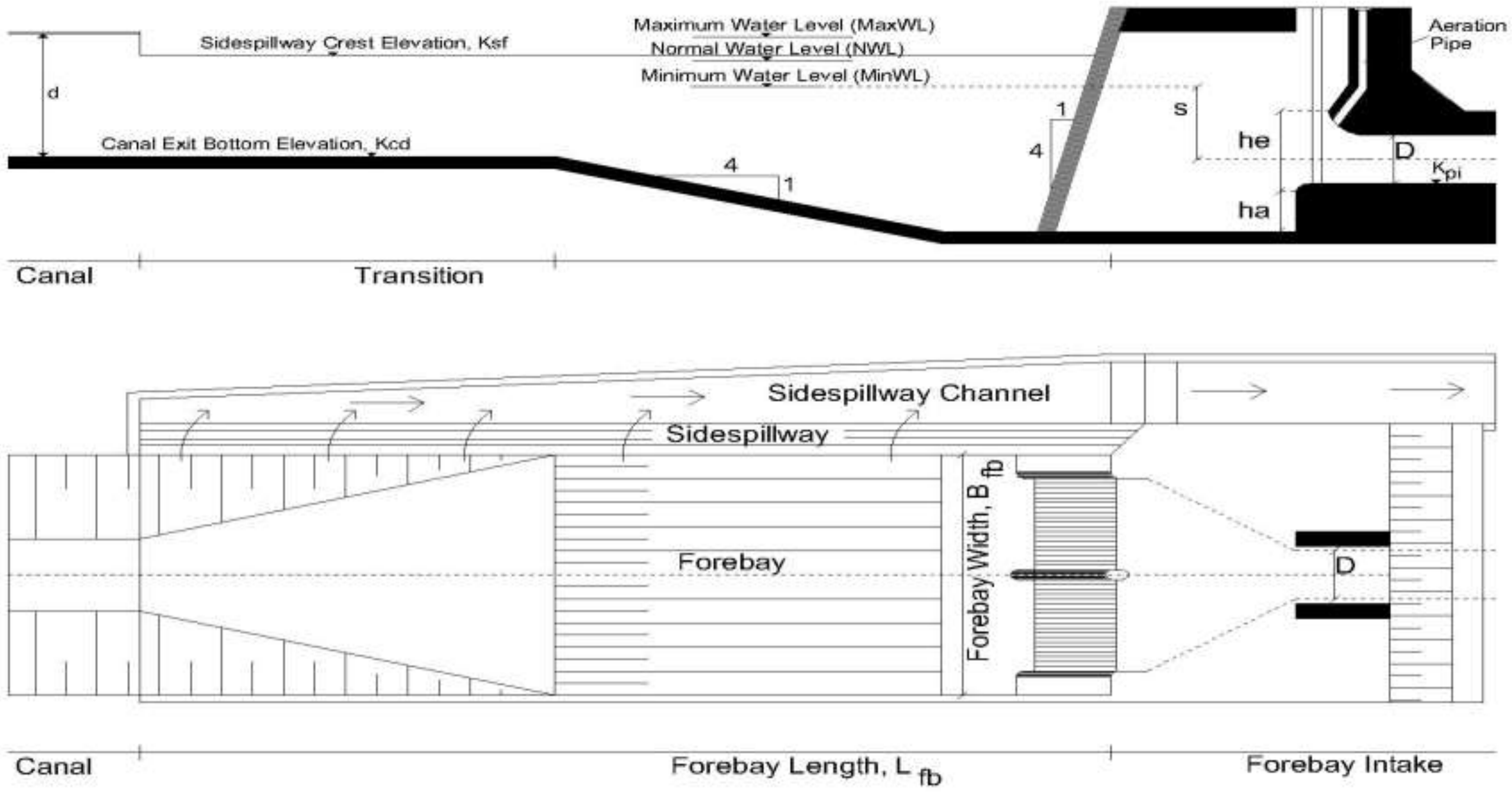

Figure 3.1 Plan view and cross section of a forebay

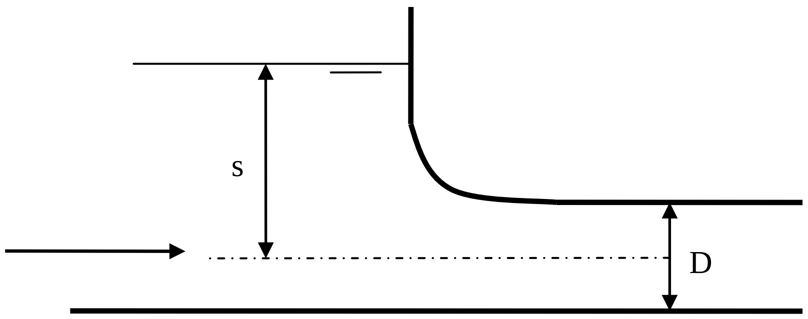

Figure 3.2 Submergence depth

To provide sufficient submergence, Knauss (1987) suggested following minimum water depth expressions with respect to Figure 3.2:

For Fr $\leq$ 0.25 $$s = D \sim 1.5\,D \tag{3.17}$$

For Fr > 0.25 $$s = (0.5 + 2 * Fr)\,D \tag{3.18}$$

where, s : submergence depth;

D : pipe diameter;

V : velocity in the pipe;

g : gravitational acceleration.

Fr: Froude number which is equal to V / $\sqrt{gD}$

A certain portion of penstock may remain under the hydraulic grade line and collapse by sub-atmospheric pressure. The negative pressure can be avoided by an installation of an aeration pipe. The collapsing depression, P_c, is given as (ESHA, 2004):

$$P_c = 882500\left(\frac{t}{D}\right)^3 \tag{3.19}$$

where, t is the wall thickness of the penstock in mm, D is the penstock diameter in mm, and P_c is in GPa. The diameter of aeration pipe in m, D_A, can be calculated by the following expressions (ESHA, 2004):

$$D_A = 7.47\sqrt{\frac{Q}{\sqrt{P_c}}} \qquad \text{for } P_c \leq 0.49 \tag{3.20}$$

$$D_A = 8.94\sqrt{Q} \qquad \text{for } P_c > 0.49 \tag{3.21}$$

Assuming all of the turbines having same design discharge, the design discharge of a single turbine, Q_{tur}, is equal to the total design discharge, Q_d, divided by the number of turbines, n_{tur}. The minimum water depth in the canal is calculated by Manning's Equation for $0.75Q_{tur}$ (Yıldız, 1992) in order to prevent sedimentation in the canal. The water surface elevation in the canal exit at this depth, corresponds to the minimum water level, NWL, in the forebay. Hence, with a known invert elevation of penstock, the bottom elevation at the canal exit, K_{cd}, can be determined.

A transition at the entrance of penstock is provided in order to create a gentle approach flow (see Figure 3.1). The total height at the just upstream of the transition, h_e, (see Figure 3.1) is computed from:

$$h_e = \frac{\pi D^2}{4bC_c} \tag{3.22}$$

where, b : width of intake section;

D : penstock diameter;

C_c : contraction coefficient.

The contraction coefficient, C_c, can be taken as 0.6 (Yıldız, 1992) and since the width of intake section, b is equal to the penstock diameter, therefore the only unknown, h_e, can be obtained from Equation (3.22).

As can be seen in Figure 3.1, an upward step is placed to accumulate sediment. The height of upward step, Δ_a, is suggested as at least $0.3h_e$ by USBR. In addition, in front of the intake section of forebay, a trashrack is provided in order to capture floating objects. The width of the trashrack is computed by:

$$B_{tr} = \frac{Q}{V_a\left(\Delta_a + s + \left(\frac{h_e}{2}\right)\right)} \tag{3.23}$$

where, B_{tr} : width of the trashrack;

Q : total design discharge;

V_a : velocity in front of the trashrack, can be taken as 0.6 – 0.9 m/s;

Δ_a : height of upward step;

In addition, an increment at least as much as Δ_a is suggested by USBR from the both sides of the intake sections to determine the total width of forebay, B_{fb}. In case of a very wide forebay width, the intake section can be divided into two sections with a pier in order to provide a gentle flow to penstock. Therefore, B_{fb} is calculated as:

$$B_{fb} = B_{tr} + t_{pf} + 2\Delta_a \tag{3.24}$$

where, t_{pf} is the thickness of the pier.

The volume of forebay is the governing factor for the determination of forebay length, L_{fb}. As a rule of thumb, the required volume in m^3 can be taken as 90 times the total design discharge in m^3/s (Yıldız, 1992). The length of forebay, L_{fb} is expressed by:

$$L_{fb} = \frac{V_{fb}}{B_{fb}h_{fb}} \tag{3.25}$$

where, V_{fb} is the forebay volume and h_{fb} is the difference between maximum and minimum water levels in forebay. The ratio of L_{fb} to B_{fb} can be taken about 2.5 ~ 3, however, the main factor at the stage of the determination of forebay dimensions is the topographic conditions and the availability of land space (Yıldız, 1992).

To determine the crest elevation of side spillway, K_{sf}, normal water level in the forebay, NWL, is incremented by 10 cm in order to handle fluctuations of water surface in the forebay tank. The head on the side spillway at the design discharge, H, needs to be calculated. The head on the side spillway is computed approximately by:

$$H^{3/2} = \frac{Q_d}{CL_{sspill}} \tag{3.26}$$

where, Q_d : design discharge;

C : discharge coefficient which can be taken 2;

L_{sspill} : length of side spillway;

H : head on side spillway.

By taking the length of side spillway equal to the length of forebay and following the iterative process that solves Equations (3.25) and (3.26) simultaneously the unknowns H and L_{fb} are calculated. After determining H, the maximum water level in the forebay, MaxWL, can be obtained by:

$$MaxWL = H + K_{sf} \tag{3.27}$$

3.5 Design of Diversion Weir

After the design of forebay and canal are completed, the next structural element to be designed is the diversion weir. Since the computations are performed from downstream to upstream, the boundary condition for the design of diversion weir is the water level at the entrance of canal which is at the end of the intake structure of diversion weir. Assuming uniform open channel flow conditions throughout the length of the canal, the entrance bottom elevation and the water level at that section are known since the related elevations are obtained at the stage of forebay design.

3.5.1 Design of Intake

Starting from the canal entrance, the related head losses and water surface elevations in the intake section are calculated in order to determine the crest elevation of the overflow spillway. Since the flow between the intake section and the canal entrance is in subcritical regime and the boundary condition at the downstream is known, the calculations are performed from downstream to upstream. The computation process for the crest elevation is explained by dividing the relevant reach into 9 sections as the section-1 being the canal entrance at the end of intake. The plan and cross-sectional view of the intake is given in Figure 3.3. All the computations explained in this section are made according to Figure 3.3 (Yanmaz, 2006).

- Section-1: The bottom elevation at the entrance of the canal is calculated with the known bottom elevation at the end of the canal which is calculated in the stage of forebay design along with the water depth in the canal at design discharge. With the input variables of canal bottom slope, S_0 and canal length, L_c, the canal entrance bottom elevation, K_{cu}, is calculated as:

$$K_{cu} = K_{cd} + S_0 L_c \tag{3.28}$$

  where, K_{cd} is the canal bottom elevation at the downstream end. The water surface elevation in section-1, K_{w1}, is calculated by:

$$K_{w1} = K_{cd} + y_1 \tag{3.29}$$

  where, y_1 is the water depth in the canal at the design discharge.

- Section-2: A transition is provided between the canal with bottom width of b, and section-2 since the intake and settling basin is generally designed with rectangular cross section. The head loss due to transition, ΔH_{t1} is computed from:

$$\Delta H_{t1} = C_t \left(\frac{u_1^2 - u_2^2}{2g} \right) \tag{3.30}$$

where, C_t is the contraction coefficient of the transition, u_1 and u_2 are flow velocities at sections 1 and 2 respectively. By the use of energy equation between sections 1 and 2, the flow depth at section 2, y_2, is determined from:

$$y_1 + \frac{u_1^2}{2g} + C_t \left(\frac{u_1^2 - u_2^2}{2g} \right) = y_2 + \frac{u_2^2}{2g} \tag{3.31}$$

in which, $y_2 = Q / (B_1u_2)$ where B_1 is the width at section-2. The minimum value of B_1 is recommended as 2b (Yanmaz and Cihangir, 1996). If the condition $u_1 \geq u_2$ is not satisfied, B_1 is incremented beyond 2b until the condition is satisfied. After obtaining y_2 from Equation (3.31), the water surface elevation at section 2, K_{w2}, is calculated from:

$$K_{w1} + \frac{u_1^2}{2g} + C_t \left(\frac{u_1^2 - u_2^2}{2g} \right) = K_{w2} + \frac{u_2^2}{2g} \tag{3.32}$$

In addition, the length of transition, L_t is obtained from (French, 1987):

$$L_t = 2.35\,(B_1 - b) + 1.65 m y_2 \tag{3.33}$$

where, m is the horizontal value of the side slopes of the canal.

- Section-3: In order to adjust the flow and prevent flow entrainment to the canal during the flushing of the settling basin, a gate, which is installed between piers, is placed at section 3 (see Figure 3.3). Therefore, flow velocity at section 3, u_3, is determined from:

$$u_3 = \frac{Q}{B_{3n} y_2} = K \sqrt{2g\Delta H_{g1}} \tag{3.34}$$

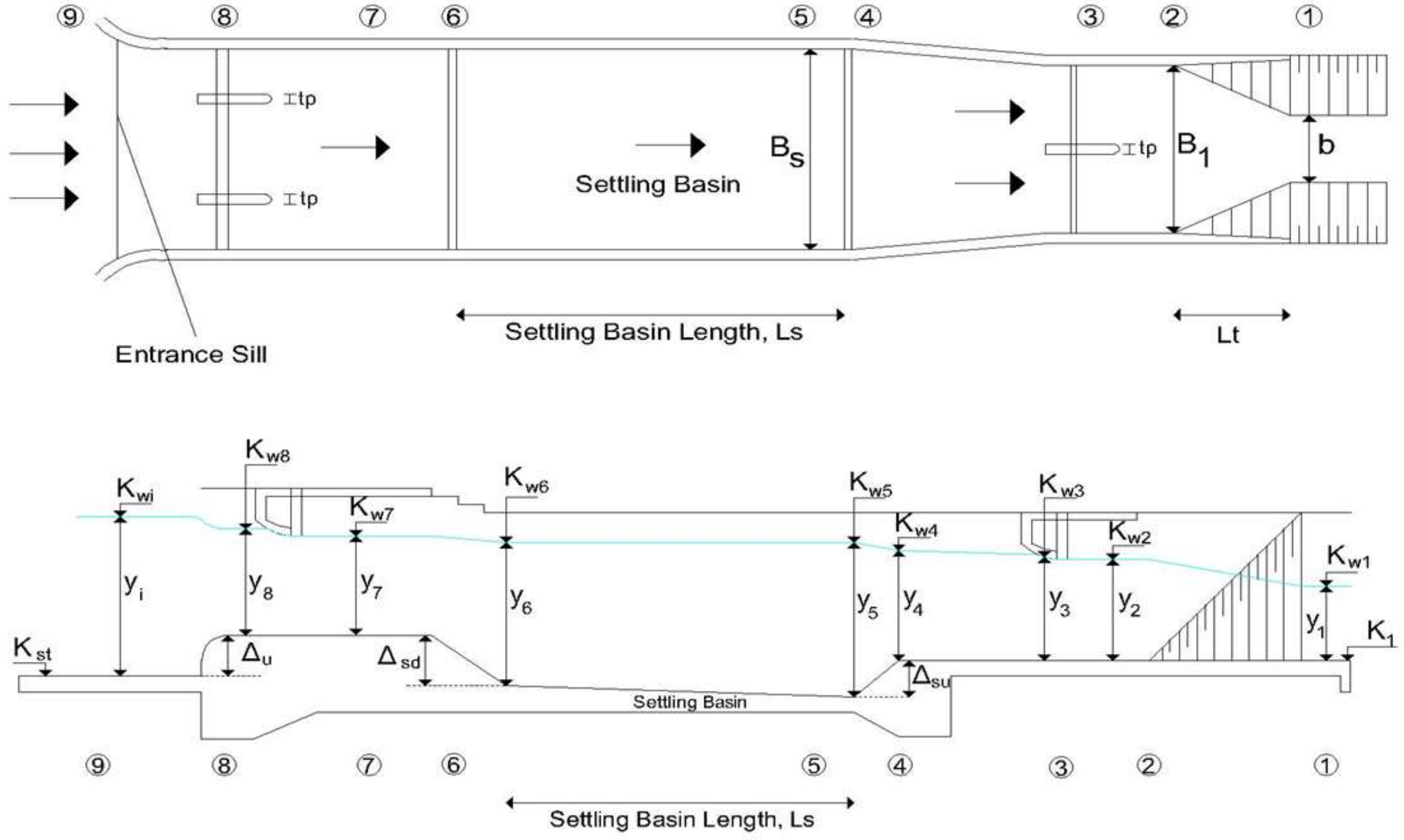

Figure 3.3 Plan and cross sectional view of intake (Yanmaz, 2006)

in which, the net width of the canal at section 3, $B_{3n} = B_1 - n_p t_p$ where, n_p is the number of piers; t_p is the thickness of piers; K is the orifice coefficient and ΔH_{g1} is the minor loss due to gate. The orifice coefficient, K, can be taken as 0.65 (Sungur, 1988).

After obtaining u_3, the water depth, y_3, and water surface elevation, K_{w3}, at section 3 are determined by the Equation (3.35) and (3.36) respectively.

$$y_3 + \frac{u_3^2}{2g} = y_2 + \frac{u_2^2}{2g} + \Delta H_{g1} \tag{3.35}$$

$$K_{w3} + \frac{u_3^2}{2g} = K_{w2} + \frac{u_2^2}{2g} + \Delta H_{g1} \tag{3.36}$$

- Section-4: Section 3 is connected with a transition to the settling basin since the width of settling basin is greater than the width of section 3. The width of settling basin can be taken 1-2 m greater than the width of section 3 in order to provide the sufficient flow area to satisfy the velocity condition in the settling basin. The minor head loss caused by this transition, ΔH_{t2} is computed similarly with section 2:

$$\Delta H_{t2} = C_t \left(\frac{u_3^2 - u_4^2}{2g} \right) \tag{3.37}$$

where, u_3 and u_4 are flow velocities at sections 3 and 4 respectively, C_t is the contraction coefficient of the transition. Similarly with section 2, the water depth, y_4, and water surface elevation, K_{w4}, just downstream of the upward step at the end of the settling basin is computed as follows:

$$y_4 + \frac{u_4^2}{2g} = y_3 + \frac{u_3^2}{2g} + \Delta H_{t2} \tag{3.38}$$

$$K_{w4} + \frac{u_4^2}{2g} = K_{w3} + \frac{u_3^2}{2g} + \Delta H_{t2} \tag{3.39}$$

- Section-5: In order to prevent the entrainment of sediment to the canal and divert the accumulated sediment to the flushing pipe, an upward sill is provided at the end of the settling basin. A relatively low flow velocity is required for the suspended particles to settle in the settling basin. The relationship between the maximum permissible flow velocity in the settling basin and the maximum diameter of the particle to be settled is defined as (Camp, 1946):

$$V_{max} = a\sqrt{D_{max}} \tag{3.40}$$

where, V_{max} : maximum velocity in the settling basin in cm/s;

D_{max} : maximum diameter of the particle in mm;

a : a coefficient determined according to the particle diameter. The value of a for different particle diameters are (Camp, 1946):

$a = 36$ for $D_{max} \geq 1$ mm;

$a = 44$ for 0.1 mm $< D_{max} < 1$ mm;

$a = 51$ for $D_{max} \leq 0.1$.

By selecting the height of upward sill at the end of the settling basin, Δ_{su}, between 0.5 m and 1.0 m and applying the energy equation between sections 4 and 5:

$$y_5 + \frac{u_5^2}{2g} = y_4 + \frac{u_4^2}{2g} + \Delta H_e + \Delta_{su} \tag{3.41}$$

where, $u_5 = Q / (B_s y_5)$, and ΔH_e is the minor loss caused by the upward sill. ΔH_e is computed from (Sungur, 1988):

$$Q = 2.88 B_s \left(\frac{2}{3} \Delta H_e^{3/2} + y_4 \sqrt{\Delta H_e} \right) \tag{3.42}$$

where, B_s is the width of the settling basin. The water depth at section 5, y_5, can be computed from Equations (3.41) and (3.42) while u_5 is smaller than the maximum velocity, V_{max}, obtained from Equation (3.40). In case of $u_5 > V_{max}$, firstly, Δ_{su} is increased up to 1 m. If the condition of $u_5 \le V_{max}$ is not satisfied, the width of settling basin, B_s, is incremented until $u_5 \le V_{max}$ and the computations are repeated from section 4 since the value of B_s is also used in calculations at section 4. After obtaining u_5 and y_5, the water surface elevation K_{w5} is obtained from:

$$K_{w5} + \frac{u_5^2}{2g} = K_{w4} + \frac{u_4^2}{2g} + \Delta H_e \tag{3.43}$$

- Section-6: The settling basin starts from section 6 and ends at section 5. In order to determine the water depth at section 6, the length of settling basin, L_s, should be determined. To divert the settled sediment to the flushing pipe at the end of the settling basin, a relatively steep slope of $S_{0s} = 0.01$ (Sungur, 1988) is assigned through the length of the settling basin. In addition, the settling basin should have sufficient length and depth to capture the sediment particles. For this reason, the length of settling basin, L_s, is determined from:

$$L_s = \frac{Q_d}{W_f B_s} \tag{3.44}$$

where, Q_d	: design discharge;
B_s	: width of the settling basin;
W_f	: Fall velocity of the particle;

The relation between the size of the particle and fall velocity (W_f) for quartz sand in water at 20^o is given as (Breuser and Raudviki, 1991):

for $D_m < 0.15$ mm; $$W_f = 663{D_m}^2 \qquad (3.45)$$

for $D_m > 1.5$ mm; $$W_f = 134.5\sqrt{D_m} \qquad (3.46)$$

where, D_m is median sediment size in mm and W_f is in mm/s. For the particle sizes within the range of $0.15 \leq D_m \leq 1.5$ mm, the values of W_f are given in Table 3.1.

Table 3.1 Fall velocities for quartz sand (Breuser and Raudviki, 1991)

D_m (mm)	W_f (mm/s)
0.15	14.8
0.20	21.0
0.30	36.0
0.40	50.0
0.50	64.0
0.60	76.4
0.70	88.6
0.80	99.0
0.90	110.0
1.00	121.0
1.20	137.3
1.50	166.0

Particles of considerable size can damage the penstock and the turbines. Therefore, the median size of the particles to be settled in the settling basin, D_m, should be determined according to the head of the plant along with the turbine type and operational conditions. Since the damage caused by the entrainment of particles to the turbine can be devastating, the median particle size must be determined carefully by consulting the turbine manufacturer. After the fall velocity is obtained for the particle size, D_m, the length of the settling basin, L_s, is calculated by using Equation (3.44). To be on the safe side, the obtained value of L_s may be incremented by 2.0 m (Yanmaz, 2006). After the determination of L_s, the water depth at the beginning of settling basin, y_6, is obtained from:

$$y_6 + \frac{u_6^2}{2g} L_s S_{0s} = y_5 + \frac{u_5^2}{2g} + \Delta H_s \tag{3.47}$$

where, ΔH_s is the head loss caused by friction through the settling basin which is calculated by:

$$\Delta H_s = \overline{S_{fs}} L_s \tag{3.48}$$

where, $\overline{S_{fs}}$ is the average friction slope between section 5 and 6 which is calculated from:

$$\overline{S_{fs}} = \frac{\left(\frac{n^2 u_5^2}{R_5^{4/3}} + \frac{n^2 u_6^2}{\left(\frac{A_6}{B_s + 2y_6} \right)^{4/3}} \right)}{2} \tag{3.49}$$

where, $A_6 = Q / u_6$ and $y_6 = Q / (B_s u_6)$ and R_5 is the hydraulic radius at section 5. Therefore, by solving Equations (3.47) and (3.49) simultaneously, water depth, y_6, and flow velocity, u_6, at section 6 can be determined. Then the water surface elevation at section 6, K_{w6} is calculated by the following equation:

$$K_{w6} + \frac{u_6^2}{2g} = K_{w5} + \frac{u_5^2}{2g} + \Delta H_s \tag{3.50}$$

- Section-7: As seen in Figure 3.3, a downward step with a height of Δ_{sd} is placed at the beginning of the settling basin. The minor loss caused by this step can be taken as ΔH_{es} = 0.02 m (Sungur, 1988). Therefore, the water depth in section 7, y_7, is obtained from:

$$y_7 + \frac{u_7^2}{2g} + \Delta_{sd} = y_6 + \frac{u_6^2}{2g} + \Delta H_{es} \tag{3.51}$$

where, $u_7 = Q / (B_s y_7)$. The water surface elevation at section 7, K_{w7}, is computed from:

$$K_{w7} + \frac{u_7^2}{2g} = K_{w6} + \frac{u_6^2}{2g} + \Delta H_{es} \tag{3.52}$$

- Section-8: Similarly with section 3, a minor loss, ΔH_{ei}, which is caused by the submerged curtain wall located at the entrance of the intake is computed from:

$$u_8 = \frac{Q}{B_{sn} y_7} = K\sqrt{2g\Delta H_{ei}} \tag{3.53}$$

in which, the net width, $B_{sn} = B_s - n_{pi}t_{pi}$ where, n_{pi} is the number of piers; t_{pi} is the thickness of piers; K is equal to 0.65 (Sungur, 1988). The water depth, y_8, and water surface elevation, K_{w8}, at section 8 are determined by the following equations:

$$y_8 + \frac{u_8^2}{2g} = y_7 + \frac{u_7^2}{2g} + \Delta H_{ei} \tag{3.54}$$

$$K_{w8} + \frac{u_8^2}{2g} = K_{w7} + \frac{u_7^2}{2g} + \Delta H_{ei} \tag{3.55}$$

- Section-9: This is the entrance of the intake. An upward sill is provided with a height of Δ_u at this section. The reason for this upward sill is that to prevent the entrainment of bed material into the intake. Similarly with section 4, the minor loss caused by this sill, ΔH_i, is calculated by (Sungur, 1988):

$$Q = 2.88B_s\left(\frac{2}{3}\Delta H_i^{3/2} + y_8\sqrt{\Delta H_i}\right) \tag{3.56}$$

In addition to this minor loss at this section, the minor loss caused by the trashracks, ΔH_{tr} can be determined by (Baban, 1995):

$$\Delta H_{tr} = \left[1.45 - \frac{0.45A_n}{A_g} - \left(\frac{A_n}{A_g}\right)^2\right]\frac{u_n^2}{2g} \tag{3.57}$$

where A_n is the net area through the rack bars, A_g is the gross area at the beginning of the intake and $u_n = Q / A_n$. Then, the water surface elevation, K_{wi} is calculated by the following equation:

$$K_{wi} = K_{w7} + \frac{u_7^2}{2g} + \Delta H_{ei} + \Delta H_i + \Delta H_{tr} - \frac{u_8^2}{2g} \tag{3.58}$$

After K_{wi} is obtained, the height of the upward sill at the entrance of the intake, Δ_u, which is in the range of 0.5 m to 1.0 m (Sungur, 1988), is calculated by:

$$\Delta_u = K_{wi} - K_{st} - y_8 - \Delta H_{tr} \tag{3.59}$$

where, K_{st} is the thalweg elevation at the entrance of the intake. If the value of Δ_u is not in the mentioned range, the calculations from section 7 to section 9 are repeated by changing the value of Δ_{sd}, until the condition is satisfied.

For the fluctuations of water level in front of the intake, the value of K_{wi} is increased by 10 cm in order to determine the required crest elevation of the overflow spillway, K_s. The height of the spillway, P, is determined by subtracting the thalweg elevation at the spillway axis, K_{st} from the crest elevation of the spillway, K_s.

3.5.2 Design of Spillway and Sluiceway

The river discharge is transmitted to downstream through sluiceway and over the spillway. Before the design of energy dissipators, the spillway and sluiceway discharges, Q_s, Q_{sl}, respectively, should be determined. Since the design discharge, Q_{100}, is transmitted by the sluiceway and spillway simultaneously, the determination of Q_s and Q_{sl} is an iterative process (Yanmaz, 2006). This process is explained below with reference to Figure 3.4 and 3.5. The condition to be satisfied is expressed as:

$$Q_{100} = Q_s + Q_{sl} \tag{3.60}$$

The discharge over the spillway, Q_s, can be computed from:

$$Q_s = C_{om} L_{eff} H_0^{3/2} \tag{3.61}$$

where C_{om} is the overall modified discharge coefficient according to USBR (1987) requirements, L_{eff} is the effective length of spillway and H_0 is the design spillway head. The discharge through the sluiceway can be determined from:

$$Q_{sl} = C' n_{sl} L_e d_{sl} \sqrt{2gh} \tag{3.62}$$

where, C′ is the orifice coefficient which can be taken as 0.65, n_{sl}, L_e and d_{sl} are the number of sluiceways, width and depth of sluiceway gates, respectively, and h is the upstream water depth.

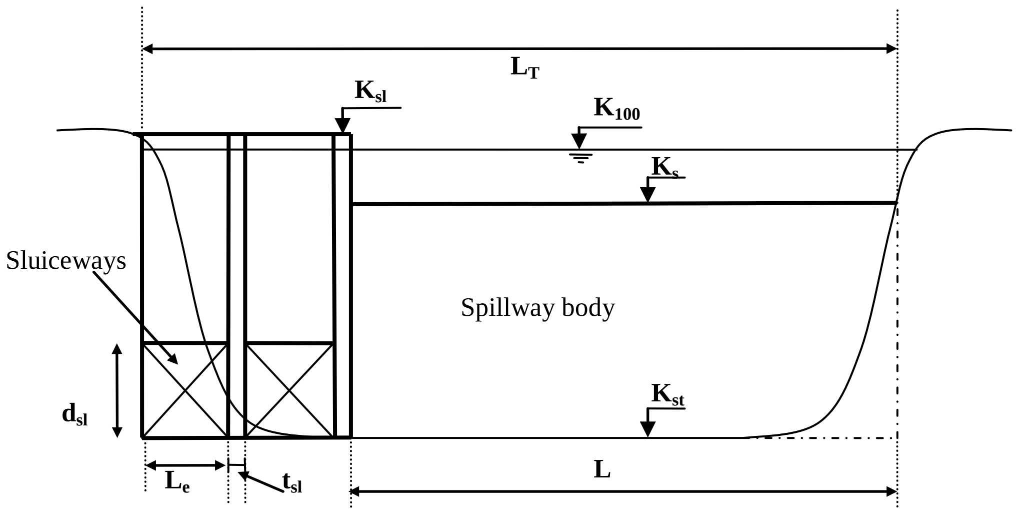

Figure 3.4 Cross-sectional view of spillway axis (Yanmaz, 2006)

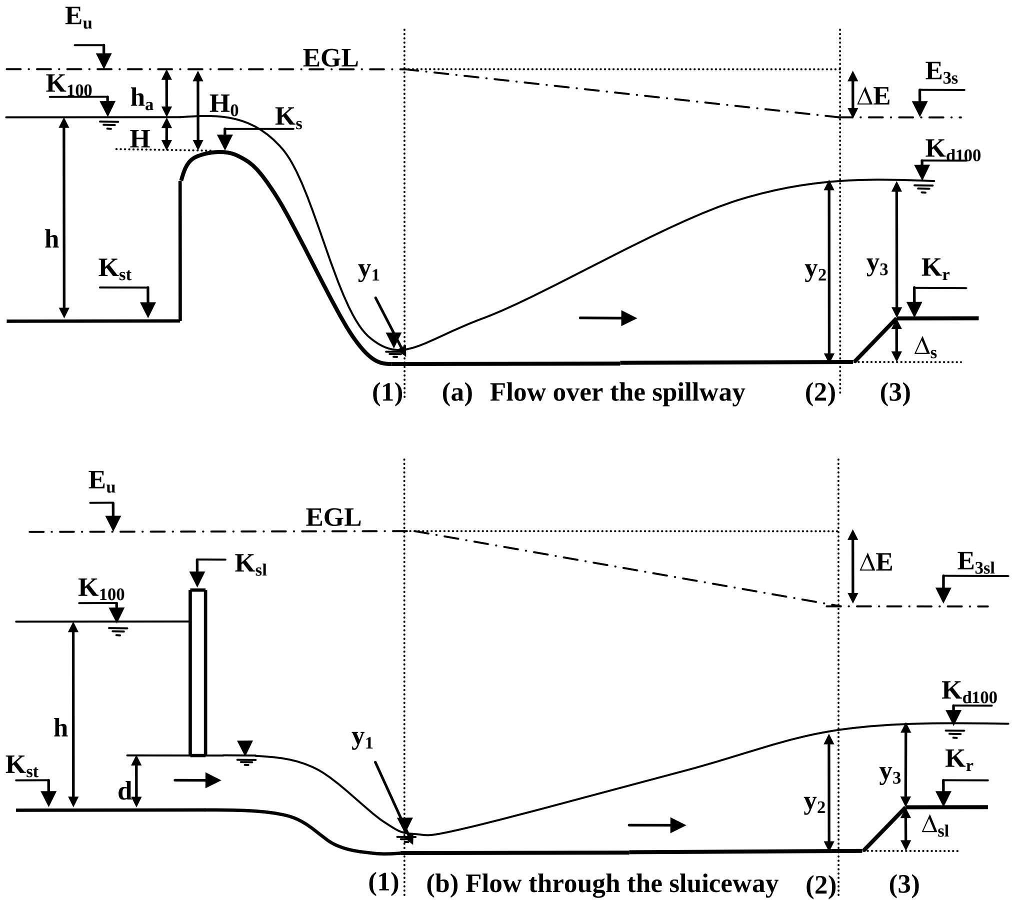

Figure 3.5 Flow over the spillway and through the sluiceway (Yanmaz, 2006)

For an assumed value of upstream water level, K_{100}, the necessary variables of upstream water depth, h, velocity head, h_a, and design spillway head, H_0, are determined from the following equations:

$$h = K_{100} - K_{st} \tag{3.63}$$

$$h_a = \frac{\left(\frac{Q_{100}}{hL_T}\right)^2}{2g} \tag{3.64}$$

$$H_0 = H + h_a \tag{3.65}$$

where, L_T is the total length of the valley. If Equation (3.60) is not satisfied for the assumed value of K_{100}, the calculations are made for new values of K_{100} until Equation (3.60) holds true. The same process is applied for all of the flood discharges and the corresponding Q_s and Q_{sl} values are obtained (Yanmaz, 2006).

3.5.3 Design of Energy Dissipators

The river flow that is transmitted over the spillway and through the sluiceway creates different flow conditions at the toe of the structure. Therefore, the analysis of these sections must be carried out separately. Furthermore, these two different flow conditions may result in different types of energy dissipators for their respective sections. The procedure for the design of energy dissipators is as follows with reference to Figure 3.5:

The relationship between the conjugate depths for a rectangular basin with known upstream conditions is given as:

$$\frac{y_1}{y_2} = \frac{1}{2}\left(\sqrt{1 + 8F_{r1}^2} - 1\right) \tag{3.66}$$

where, $F_{r1} = u_1 / \sqrt{gy_1}$ is the Froude number of the flow at section 1 (see Figure 3.5). The upstream energy level, E_u, the energy level downstream of the spillway, E_{3s}, and sluiceway, E_{3sl}, are computed by the following equations respectively (Yanmaz, 2006):

$$E_u = K_{100} + h_a \tag{3.67}$$

$$E_{3s} = y_3 + \frac{\left(\frac{Q_s}{Ly_3}\right)^2}{2g} \tag{3.68}$$

$$E_{3sl} = y_3 + \frac{\left(\frac{Q_{sl}}{(n_{sl}L_e + (n_{sl} - 1)t_{sl})y_3}\right)^2}{2g} \tag{3.69}$$

where, y_3 is the water depth at the riprap section, L is the crest length of the spillway, n_{sl} is the number of sluiceways, L_e is the width of the sluiceway and t_{sl} is the thickness of one pier.

After the computation of upstream and downstream energy levels for both spillway and sluiceway, the energy loss caused by hydraulic jump can be calculated if the head loss at the face of the spillway is ignored. By writing the energy equation between the upstream and riprap section, the head losses can be determined by the following equations:

$$\Delta E_{3s} = E_u - E_{3s} \tag{3.70}$$

$$\Delta E_{3sl} = E_u - E_{3sl} \tag{3.71}$$

The energy loss caused by a hydraulic jump in a rectangular basin is calculated by:

$$\Delta E = E_1 - E_2 = \frac{(y_2 - y_1)^3}{4y_1y_2} \tag{3.72}$$

By inserting Equation (3.72) into Equation (3.66), the following expression is obtained (Yanmaz, 2006):

$$\Delta E = \frac{\left[\frac{y_1}{2}\left(\sqrt{1+\frac{8q^2}{gy_1^3}}-1\right)-y_1\right]^3}{2y_1^2\left(\sqrt{1+\frac{8q^2}{gy_1^3}}-1\right)} \tag{3.73}$$

in which, y_1 is the water depth at section 1, q = Q / L where L is the width of the stilling basin. Equation (3.73) can be solved for y_1 and the sequent depth of hydraulic jump, y_2, is obtained from Equation (3.66). The required sill height at the end of the stilling basin, Δ, is obtained by applying energy equation between sections 2 and 3. In addition, the stilling basin type is selected according to the values of Froude Number, F_{r1}, and velocity, u_1, at section 1 (USBR, 1987). The above process is applied for both spillway and sluiceway. If the final design of stilling basins at the toe of the spillway and sluiceway are one of USBR Type II, III or IV, then the below inequality is checked in order to decide whether a separate or common stilling basin is to be constructed (Yanmaz, 2006).

$$|\Delta_s - \Delta_{sl}| < 50\ cm \qquad (3.74)$$

where, Δ_s is the end sill height for spillway section and Δ_{sl} is the end sill height for sluiceway section. If the above inequality does not hold true, a separate design of stilling basins should be considered for sluiceway and spillway sections. If inequality (3.74) is satisfied, then a common design should be considered with a end sill having the greater magnitude of Δ_s and Δ_{sl} values.

CHAPTER 4

DEVELOPMENT OF COMPUTER SOFTWARE

In this study, a computer software is developed which aims the hydraulic design of small scaled run-of-river type hydropower projects. The computer software called MiniHEPP Hydraulic Design is capable of determining optimum design discharge of the system using the available flow-duration data and designing the diversion weir, canal, forebay, and penstock from the hydraulics point of view. The general algorithms of the program and each of its modules are explained in this chapter.

MiniHEPP Hydraulic Design is developed in C# programming language and works under Microsoft Windows operating system. It is a user-friendly computer program that provides a simple and easy to use working environment to the user. Mainly, the program consists of a main input window backed up with several output windows.

Hydropower projects include many different structural components and each structural component has a different purpose in the system. However, the characteristics of these structural components differ from project to project depending on the topographic and geological conditions of the site. Therefore, the properties of components are limited in the scope of the computer program. The main types of components that are considered in the software are listed as:

- Diversion Weir : Overflow spillway, sidewise intake.
- Conveyance Line : Canal with rectangular or trapezoidal cross-section.
- Forebay : Since the conveyance line is operating under open channel flow conditions, a forebay is considered instead of a surge tank.

- Penstock : Single penstock is taken into account.

4.1 Algorithms of the Program

The hydraulic design of a small hydropower plant is carried out in a logical sequential manner. The calculations that are explained in Chapter 3 are needed to be performed in the right order to satisfy the hydraulic requirements of the structural components. In this chapter, the algorithms that are utilized to carry out the aforementioned calculations are explained.

4.1.1 General Flow of the Program

MiniHEPP Hydraulic Design is developed to carry out the hydraulic design of diversion weir, canal, forebay, and penstock components of small scaled run-of-river hydropower plants. In addition, the program is capable of calculating the optimum design discharge and penstock diameter. After the related input data are entered, the design process begins with the optimization of the design discharge and follows with the design of the components. Since the system is in subcritical flow conditions, the computations of the hydraulic design of the system are carried out from the downstream to the upstream direction. Therefore, after the design discharge is obtained, the calculations start with the design of penstock and end with the design of diversion weir. The general flowchart of the program is given in Figure 4.1. The algorithm for the design of different components, which are carried out by different program modules, are explained in this chapter.

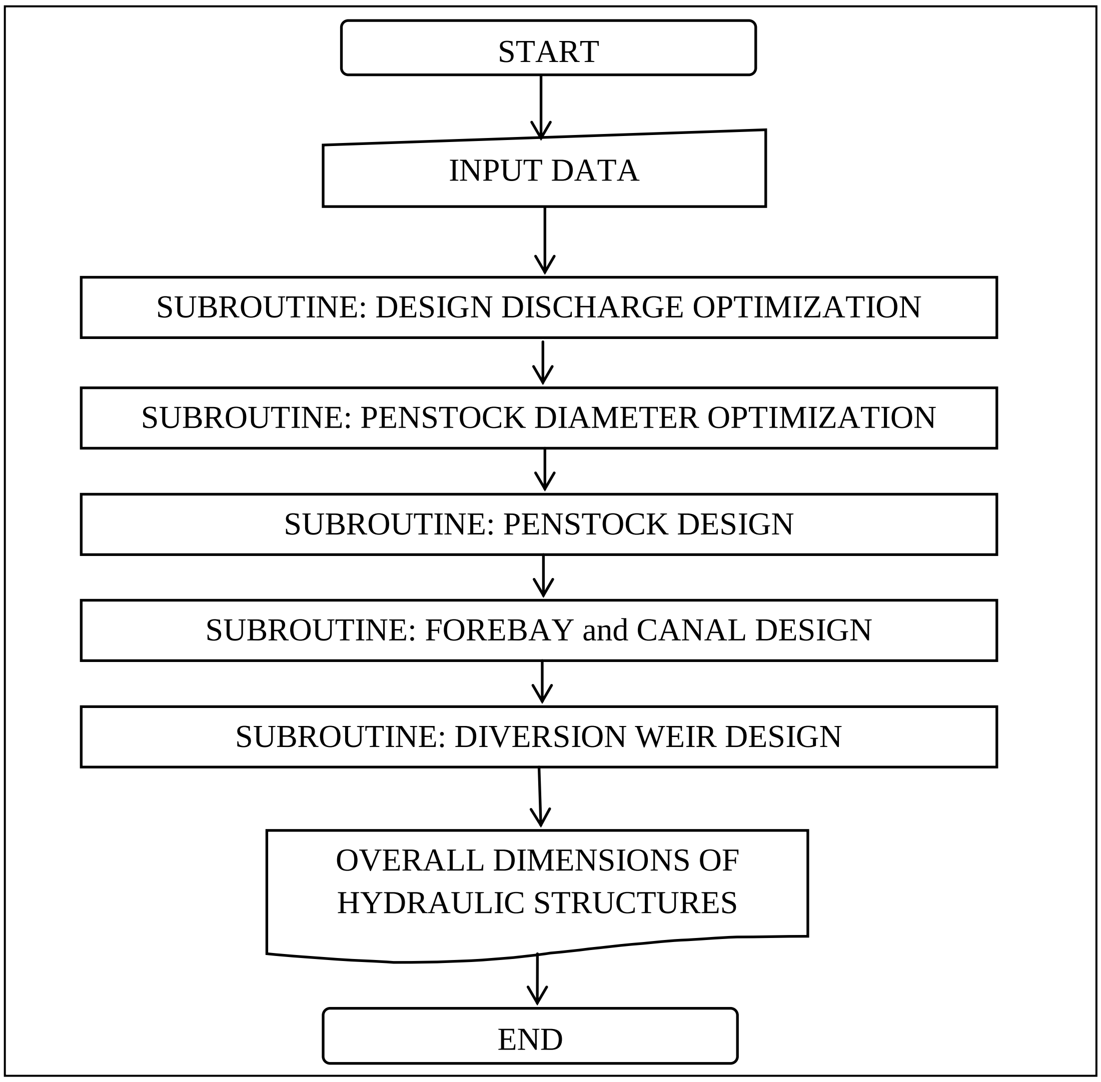
START
INPUT DATA
SUBROUTINE: DESIGN DISCHARGE OPTIMIZATION
SUBROUTINE: PENSTOCK DIAMETER OPTIMIZATION
SUBROUTINE: PENSTOCK DESIGN
SUBROUTINE: FOREBAY and CANAL DESIGN
SUBROUTINE: DIVERSION WEIR DESIGN
OVERALL DIMENSIONS OF HYDRAULIC STRUCTURES
END

Figure 4.1 General flowchart of the software

4.1.2 Algorithm for the Determination of Optimum Design Discharge and Optimum Penstock Diameter

In order to make a selection between different design discharge alternatives, the corresponding energy generation benefits and related costs are needed to be calculated. However, one the most important factors in the process of optimization of design discharge is the characteristics of penstock. The main reason is that the great portion of the hydraulic losses are caused by the flow through the penstock. Also, the cost of penstock changes dramatically by the change of its diameter. Therefore, the design of penstock should be made in detail in order to obtain a more accurate optimization result. In order to carry out the process explained in Chapter 3, this part of the program requires inputs related hydroelectrical outputs as well as the penstock characteristics. The inputs for this module are:

- Flow-Duration curve,
- Gross head, H_g,
- Unit cost of penstock, C_{up},
- Unit cost of installed capacity, C_{icu},
- Firm energy unit price, P_{firm},
- Secondary energy unit price, P_{sec},
- Capital recovery factor, CRF,
- Average turbine efficiency, e_t,
- Average generator efficiency, e_g,
- Average transformer efficiency, e_h,
- Penstock length, L,
- Friction factor in the penstock, f,
- Allowable tensile strength of penstock material, σ_t,
- Elasticity modulus of penstock material, E,
- Number of bends in the penstock route with their respective bend angles,
- Turbine closure time T_c.

The flow-duration curve is an input by means of river discharges with their respective exceedence probabilities. The values of flow-duration curve are entered with 5% increments of exceedence probability.

Although there are many types of minor losses occuring between the intake section of the forebay and the turbine in the power house, the only type of minor losses considered in this study are the bend losses. The minor losses caused by trashracks and transitions are not considered by this program. The minor loss coefficient, K_m, may be determined by the following expressions (Yıldız, 1992):

for $\Delta_b \leq 25^o$; $$K_m = 0.05 \tag{4.1}$$

for $\Delta_b \leq 90^o$ and $R_b/D > 2$; $$K_m = 0.14 \tag{4.2}$$

where, Δ_b is the angle of bend, R_b is the radius of bend and D is the penstock diameter. After K_m is obtained, the hydraulic loss caused by bends is calculated using Equation (3.4).

After the input variables are entered, the process explained in detail in Chapter 3 is carried out by the program. The design discharge is obtained by selecting the one that gives the maximum net benefit. After the design discharge is obtained, the calculated value of penstock diameter while optimizing the design discharge, is taken as the initial value of penstock diameter. By increasing the penstock diameter with 10 cm increments and calculating the necessary values, the program compares 10 alternatives and selects the penstock diameter alternative that gives minimum total cost. The general flowchart for this module is given in Figure 4.2.

The outputs for this part are:

- Design discharge, Q_d,
- Penstock Diameter, D,
- Net head at design discharge, H_n,
- Power generated by the plant, P_p,
- Firm, secondary, and total energy generation, E_f, E_s, E_t.

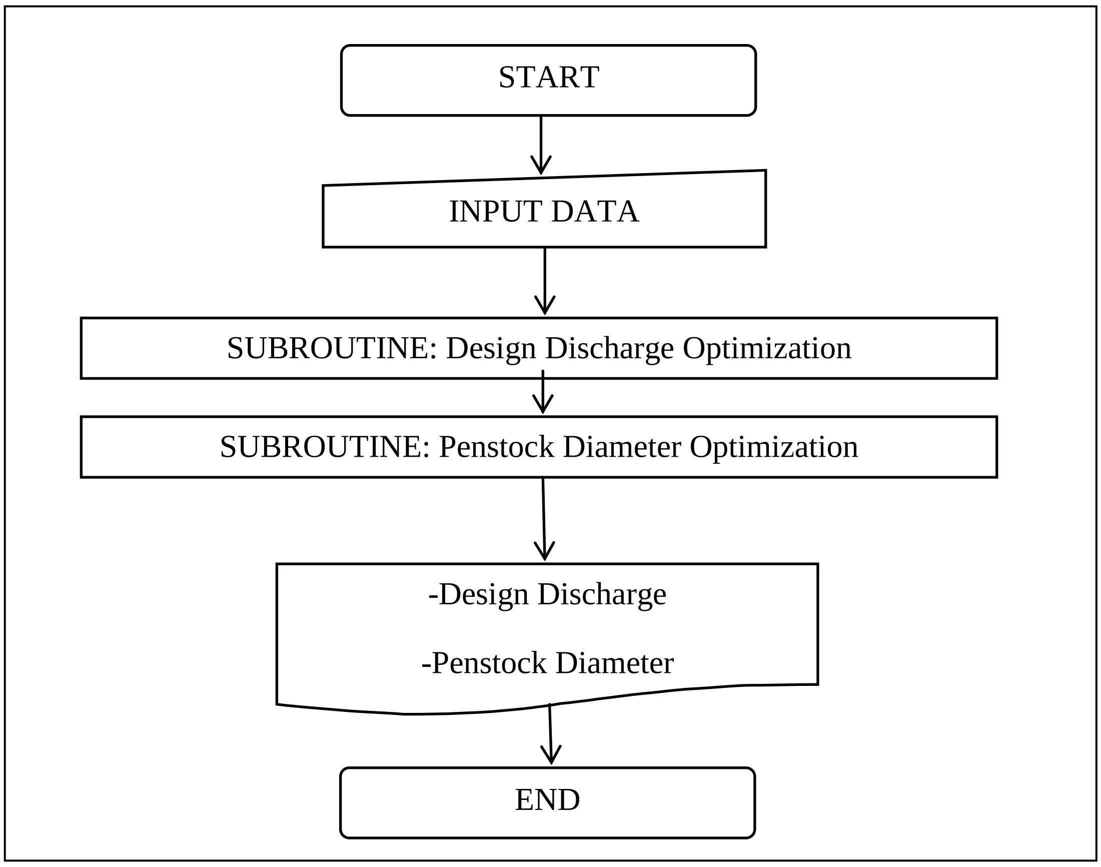
START
INPUT DATA
SUBROUTINE: Design Discharge Optimization
SUBROUTINE: Penstock Diameter Optimization
-Design Discharge
-Penstock Diameter
END

Figure 4.2 Flowchart describing design discharge and penstock diameter optimization

4.1.3 Program Module for Penstock Design

The input data related to penstock are also needed for design discharge and penstock diameter optimization processes. After the penstock diameter optimization results are obtained, these input data, are transferred to penstock design module. The most important output for penstock design is the wall thickness, t. The flowchart representing the determination of wall thickness is given in Figure 4.3. After the wall thickness of penstock is determined, the following parameters are computed:

- Wave speed, a_w,
- Pressure increase due to water hammer, ΔH,
- Maximum head at the end of penstock, $H_0 + \Delta H$,
- Aeration pipe diameter, D_A,
- Head loss due to friction and bends through penstock, h_l.

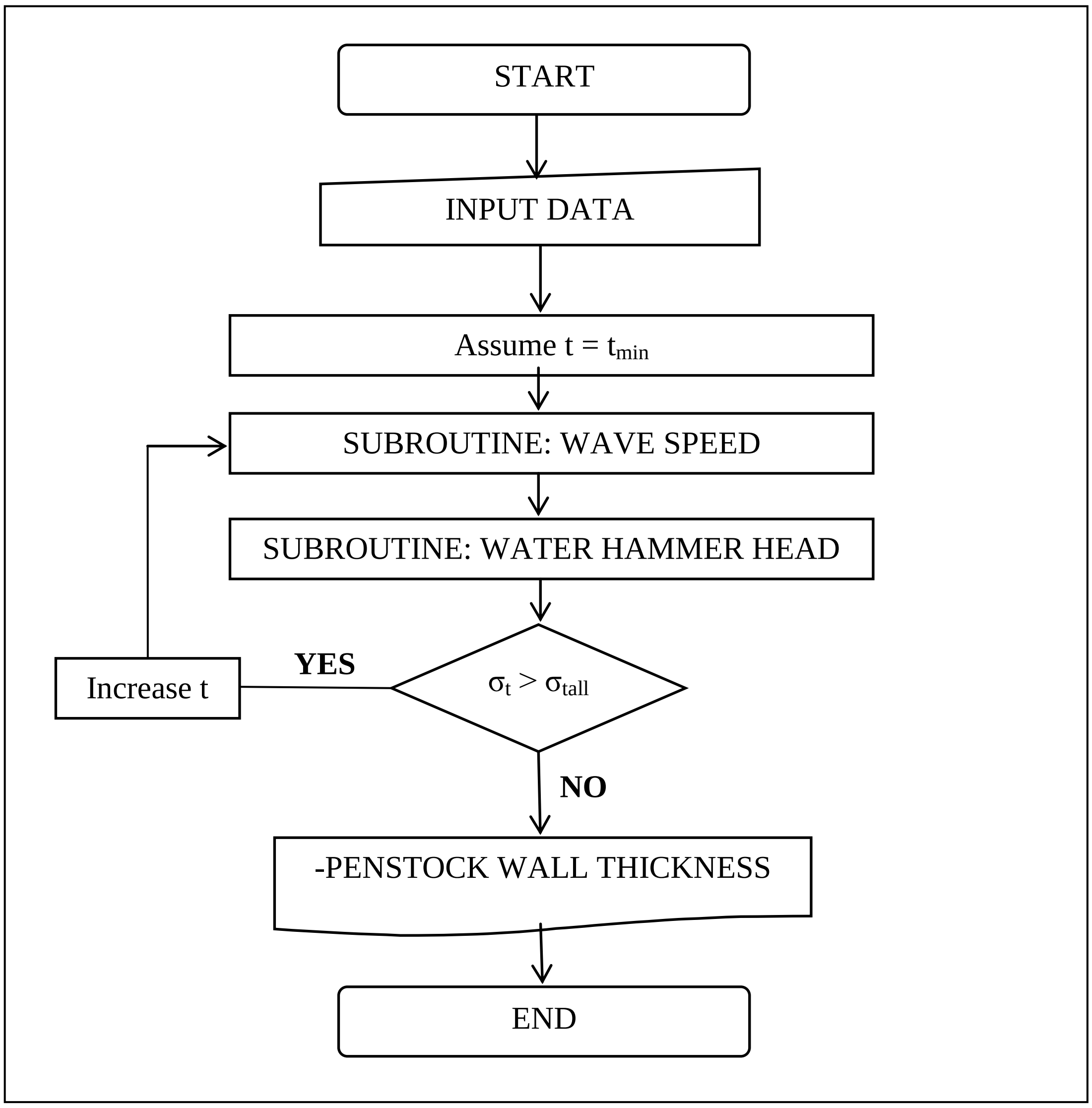

Figure 4.3 Flowchart describing determination of penstock wall thickness

4.1.4 Program Module for Forebay and Canal Design

As explained in Chapter 3, the designs of forebay and canal are made simultaneously in the present study. Therefore, the design of both structural component is included in the same module. The input variables for this module are:

- Penstock invert elevation, K_{pi},
- Required volume of forebay,
- Canal bed slope, S_o,
- Canal side slopes, m,
- Manning’s roughness coefficient through the canal, n.

This program module gives the following outputs:

- Forebay length, L_{fb},
- Forebay width, B_{fb},
- Minimum water level in forebay, MinWL,
- Normal operating water level in forebay, NWL,
- Maximum water level in forebay, MaxWL,
- Trashrack width at the forebay intake, B_{tr},
- Side spillway crest elevation, K_{sf},
- Forebay wall crest elevation,
- Forebay bottom elevation,
- Step height in front of the forebay intake, Δ_e,
- Canal width, b,
- Canal water depth at design discharge, d,
- Canal bottom elevation at the exit, K_{cd},
- Water surface elevation at the canal exit.

4.1.5 Program Module for Design of Diversion Weir

In this study, the design of diversion weir with the overflow spillway having a lateral intake is considered. In this module, the design of intake structure and energy dissipators are included.

4.1.5.1 Algorithm for Design of Intake

Since the calculations are made from the dowstream to the upstream, the design of intake is performed after the design of forebay and canal. Therefore, starting boundary condition for intake design is the water surface elevation at the entrance of the canal. In order to obtain the water level and bottom elevation at the entrance of the canal, the only remaining input is the canal length, since the required information regarding the canal is obtained at the stage of canal design. The necessary input variables for this module are listed as:

- Length of canal, L_c,
- Number of piers at the canal entrance, n_p,
- Thickness of piers at the canal entrance, t_p,
- Number of piers at the intake entrance, n_{pi},
- Thickness of piers at the intake entrance, t_{pi},
- Maximum settlement diameter, D_{max},
- Manning's roughness coefficient in the settling basin, n_s,
- Maximum spacing between rackbars at the intake entrance, s_{tr},
- Thickness of rackbars at the intake entrance, t_{tr},
- Thalweg elevation, K_{st}.

Starting from the canal entrance, the head losses occured in all of the sections are calculated. The water surface profile between the intake structure and the canal entrance is determined and the dimensions of each section are obtained as explained in Chapter 3. At the end of this procedure, the crest elevation of overflow spillway is also determined. The flowchart representing the design of intake is given in Figure 4.4.

After the mentioned procedure is processed, the following outputs are obtained from this module:

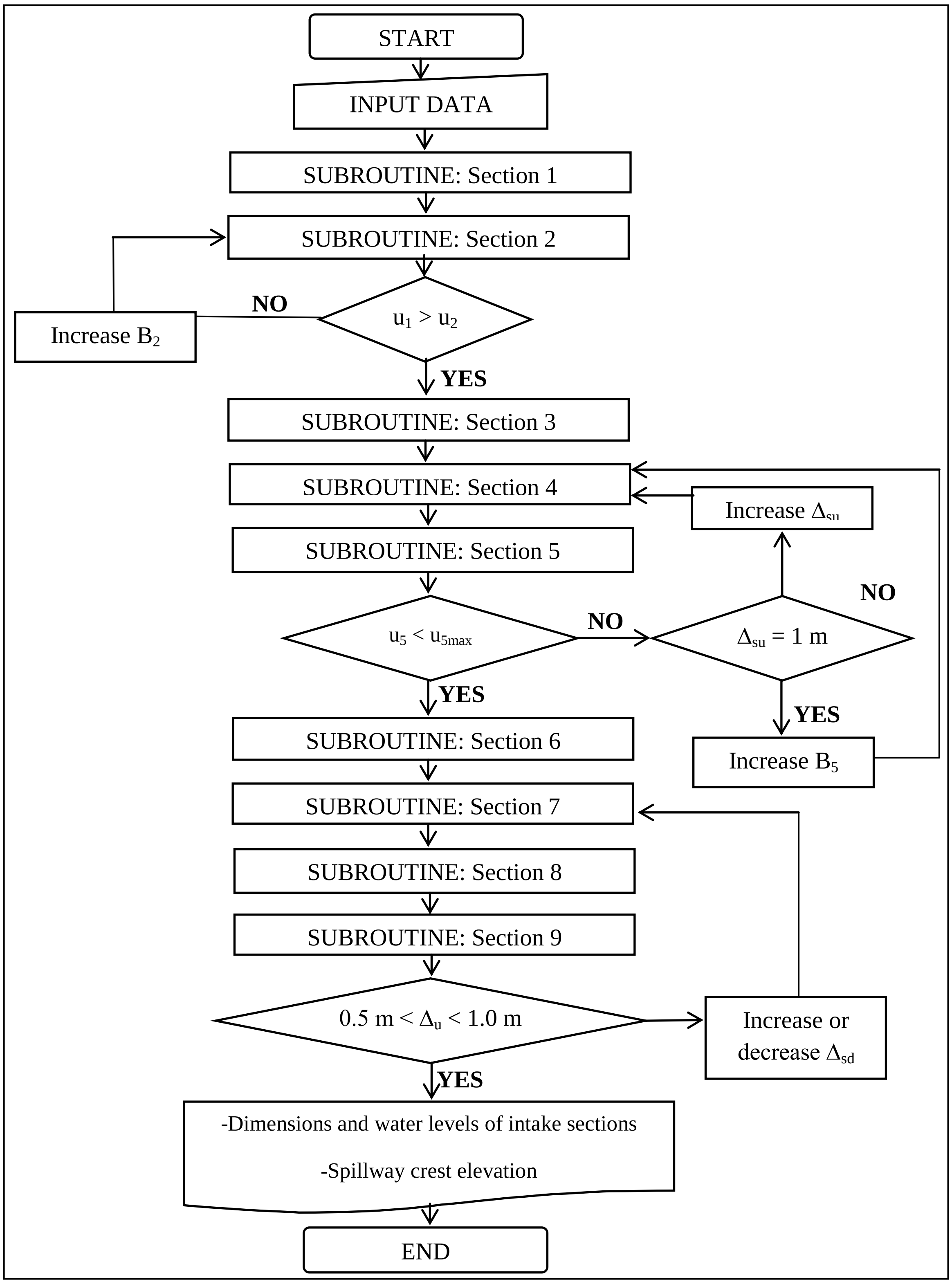

Figure 4.4 Flowchart describing the design of intake

- Water levels for each of the intake sections,
- Overall dimensions for each of the intake sections,
- Spillway crest elevation, K_s.

4.1.5.2 Program Module for the Design of Energy Dissipator

In order to design the energy dissipator, the discharge that will pass through the sluiceway, Q_{sl}, and over the spillway, Q_s, need to be determined, as explained in Chapter 3. For each flood discharge, Q_5, Q_{10}, Q_{25}, Q_{50} and Q_{100}, the values of Q_s and Q_{sl} are determined along with the corresponding upstream water level, K_i. The flowchart that represents the determination of Q_s and Q_{sl} is given in Figure 4.5.

After the values of Q_s, Q_{sl} and K_i are determined for each flood discharge, this module designs energy dissipators according to USBR (1987) specifications for stilling basins having rectangular cross-sections. USBR Type II, III and IV stilling basins are included in this module since these types are the most common. The flowchart for the design of energy dissipator is given in Figure 4.6.

The input data needed for this module are:

- Flood discharges, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100},
- Riprap section water level for each flood discharge, K_{d5}, K_{d10}, K_{d25}, K_{d50}, K_{d100},
- Riprap section bottom elevation, K_r,
- Spillway crest elevation, K_s,
- Spillway crest length, L_{spill},
- Depth of sluiceway gates, d_{sl},
- Width of sluiceway gates, L_e,
- Number of sluiceway gates, n_{sl},
- Thickness of walls between sluiceway gates, t_{sl}.

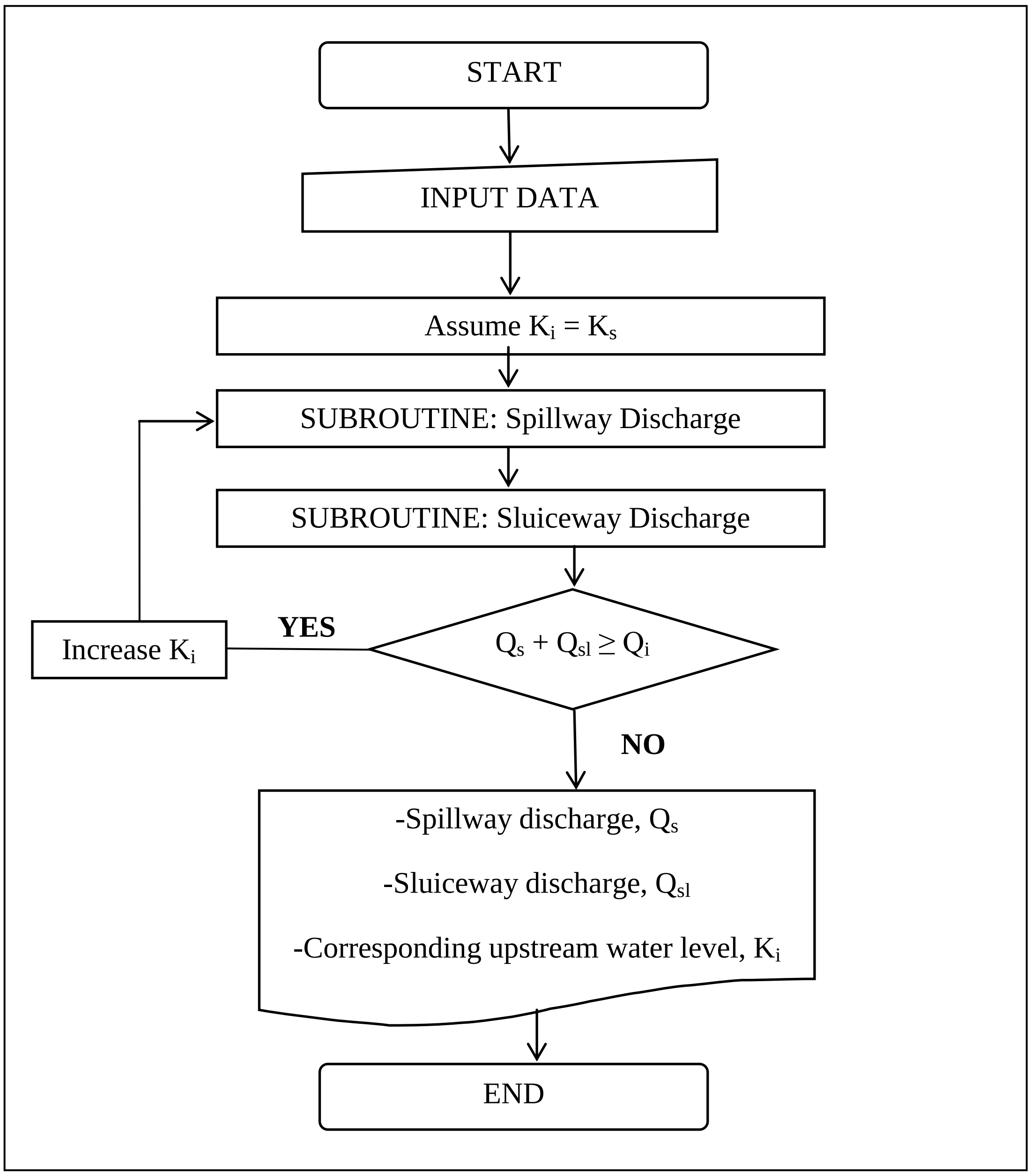
START
INPUT DATA
Assume $K_i = K_s$
SUBROUTINE: Spillway Discharge
SUBROUTINE: Sluiceway Discharge
$Q_s + Q_{sl} \geq Q_i$
YES
Increase K_i
NO
-Spillway discharge, Q_s
-Sluiceway discharge, Q_{sl}
-Corresponding upstream water level, K_i
END

Figure 4.5 Flowchart describing the determination of sluiceway and spillway discharges

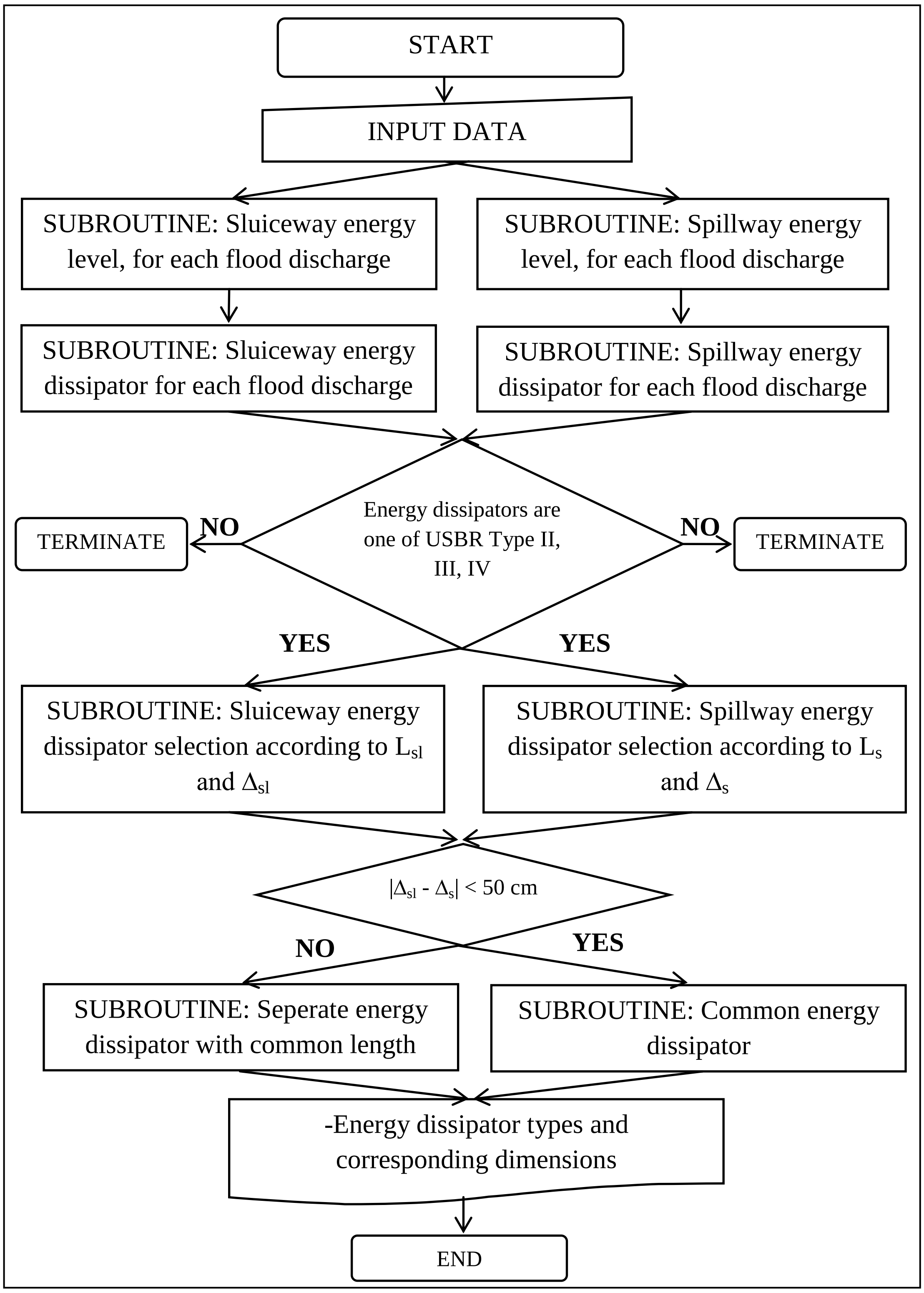
START
INPUT DATA
SUBROUTINE: Sluiceway energy level, for each flood discharge
SUBROUTINE: Spillway energy level, for each flood discharge
SUBROUTINE: Sluiceway energy dissipator for each flood discharge
SUBROUTINE: Spillway energy dissipator for each flood discharge
Energy dissipators are one of USBR Type II, III, IV
NO
TERMINATE
NO
TERMINATE
YES
YES
SUBROUTINE: Sluiceway energy dissipator selection according to L_{sl} and Δ_{sl}
SUBROUTINE: Spillway energy dissipator selection according to L_s and Δ_s
$|\Delta_{sl} - \Delta_s| < 50$ cm
NO
YES
SUBROUTINE: Seperate energy dissipator with common length
SUBROUTINE: Common energy dissipator
-Energy dissipator types and corresponding dimensions
END

Figure 4.6 Flowchart describing the design of energy dissipators

In addition, in case of an existence of a bridge over the spillway, the following input variables are also needed:

- Thickness of piers of bridge, t_{bp},
- Number of piers of bridge, n_{bp},
- Contraction coefficient due to abutments, K_{ab},
- Contraction coefficient due to piers, K_p.

This module gives the following outputs after execution:

- Discharge over spillway for each flood discharge,
- Discharge through sluiceway for each flood discharge,
- Upstream water level for each flood discharge,
- Spillway and sluiceway energy dissipator types and corresponding dimensions considering separate or common design decision.

4.2 Interface of the Program

MiniHEPP Hydraulic Design is a user-friendly program. The user interface is simple and easy to use. The detailed information about the interface along with user manual is given in Appendix A.

CHAPTER 5

APPLICATION

The hydraulic design of a run-of-river type hydropower plant is to be performed with MiniHEPP Hydraulic Design. The characteristics of the structural components and the input data necessary to execute the program are given in this chapter. In addition, the obtained dimensions and related outputs are also given.

5.1 Characteristics of the System and Input Data

5.1.1 Hydrological Data

As mentioned before, MiniHEPP Hydraulic Design is not capable of performing hydrological analysis. At the start of the execution of the program, it is assumed that the hydrological analysis of the river has been completed. Hence, the flow duration curve and flood data are input for the execution of the program. In this chapter, data of an existing project will be used to demonstrate the use of the software developed in the present study, Paşa HPP located in Bolu, Turkey. It's a run-of-river type hydropower plant. The flow duration curve for Paşa HPP is provided in Figure 5.1 and flood discharges and water surface elevations at riprap section can be found in Table 5.1.

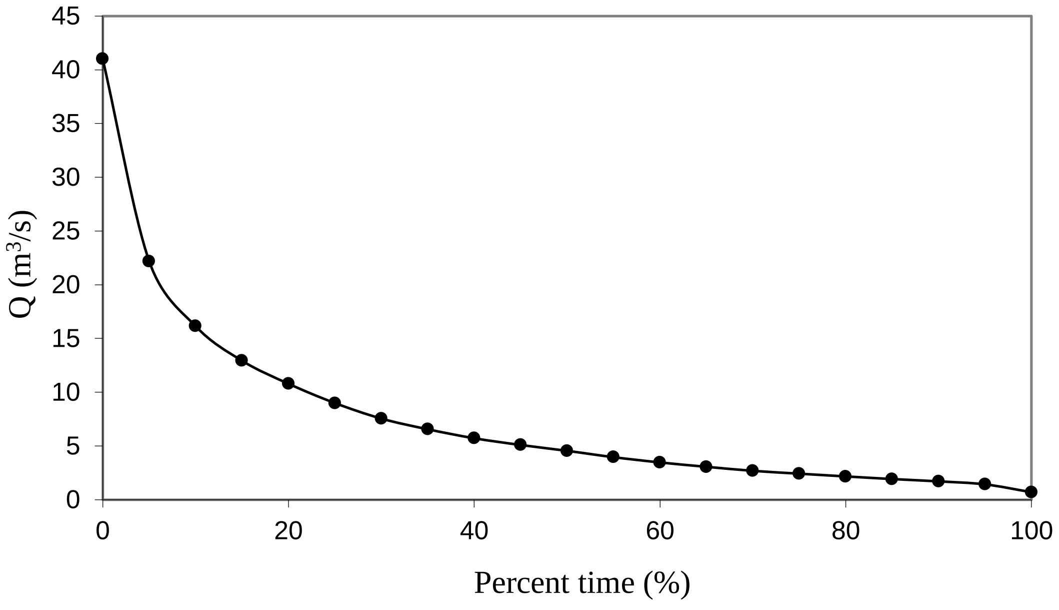

Figure 5.1 Flow duration curve

The power duration curve is generated from the flow duration curve represented in Figure 5.1. The power duration curve is given in Figure 5.2.

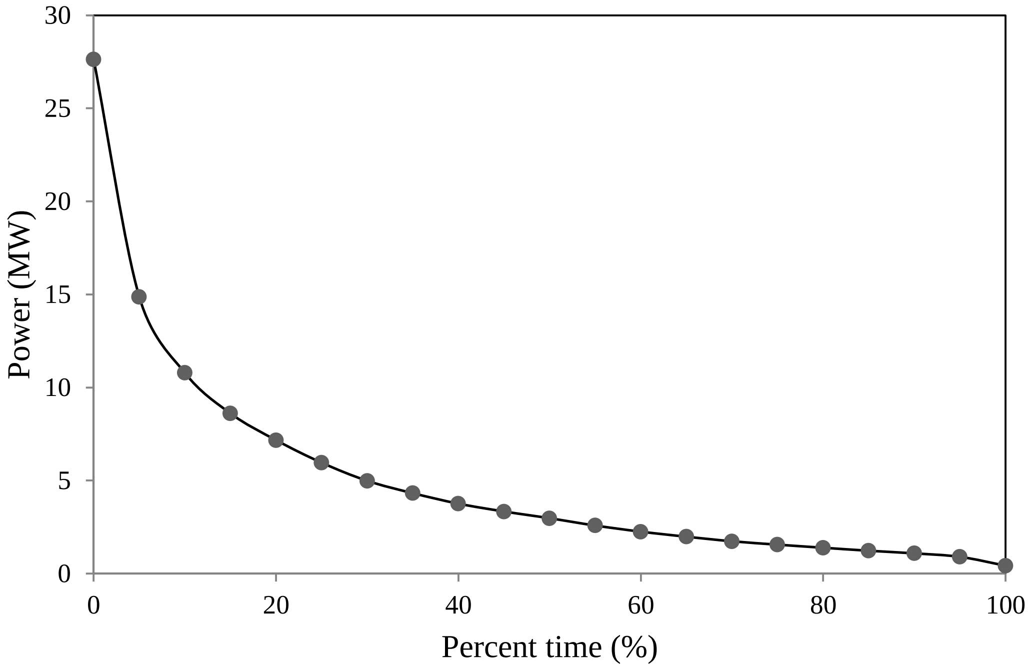

Figure 5.2 Power duration curve

Table 5.1 Flood discharges and water surface elevations at riprap section

Flood Discharge	Discharge (m^3/s)	Water Surface Elevations at Riprap Section (m)
Q_5	113.6	589.49
Q_{10}	139.7	589.85
Q_{25}	175.7	590.32
Q_{50}	205.2	590.68
Q_{100}	237.4	591.06

5.1.2 Penstock Inputs

A single penstock connected with two branches to the turbines is to be constructed between the forebay and power house. The related input variables regarding penstock are listed as follows:

- Length of penstock, L_{pen} = 254.00 m,
- Friction factor, f = 0.012,
- Elasticity modulus of pipe material, E = 206 GPa,
- Allowable tensile stress, σ_t = 400 MPa,
- Unit price of penstock, C_{pu} = 7.52 \$/kg,
- Turbine closure time, T_c = 5 sec,
- Number of penstocks, n_{pen} = 1,
- Penstock invert elevation, K_{pi} = 581.25 m,
- Bulk modulus of elasticity of water, K = 2200 GPa.

The annual cost of penstock, C_p, in US dollars is determined using Equation (3.7) and (3.8) as explained in Chapter 3. For the sake of simplicity in calculations, the following power equation is fitted to the results having a correlation coefficient of 0.99:

$$C_p = 26330\ D^{1.6583} \tag{5.1}$$

where D is penstock diameter in m.

5.1.3 Canal and Forebay Inputs

The canal between the diversion weir and forebay has a trapezoidal cross-section having side slopes 1V:1.5H. The other necessary information for canal design is listed below:

- Canal side slope, m = 1.5,
- Roughness coefficient, n = 0.016,
- Canal bottom slope, S_0 = 0.0003,
- Canal length, L_{canal} = 17214 m.

5.1.4 Intake Inputs

The sidewise intake structure will divert the flow at the left bank. The necessary input variables for the design of intake are given as:

- Number of piers at section 3, n_p = 1,
- Thickness of piers at section 3, t_p = 0.5 m,
- Number of piers at section 8, n_{pi} = 1,
- Thickness of piers at section 8, t_{pi} = 0.5 m,
- Maximum settlement diameter, D_{max} = 0.2 mm,
- Thickness of rackbars at section 8, t_{tr} = 0.015 m,
- Maximum spacing between rackbars at section 8, s_{tr} = 0.10 m,
- Roughness coefficient at settling basin, n_s = 0.016.

5.1.5 Spillway, Sluiceway and Energy Dissipator Inputs

For the design of energy dissipators, the dimensions of overflow spillway and sluiceway are needed. A bridge is not preferred to be constructed on the spillway and the upstream face of spillway is not inclined. The remaining data are listed as:

- Number of sluiceway gates, n_{sl} = 1,
- Width of sluiceway gate, w_{sl} = 4.50 m,
- Height of sluiceway gate, d_{sl} = 2.00 m,
- Spillway crest length, L_{spill} = 60 m,
- Bed elevation at riprap section, K_r = 587.00 m,
- Thalweg elevation at the entrance of intake, K_{st} = 589.40 m.

5.1.6 Power House and General System Inputs

Finally, the remaining necessary input variables are given as follows:

- Gross head, H_g = 78.00 m,
- Number of turbines, n_{tur} = 2,
- Turbine efficiency, e_t = 0.94,
- Generator efficiency, e_g = 0.97,
- Transformer efficiency, e_h = 0.98,
- Firm energy unit price, P_{firm} = 8 $/kWh,
- Secondary energy unit price, P_{sec} = 8 $/kWh,
- Unit cost of installed capacity, C_{icu} = 1,200,000 $/MW,
- Capital recovery factor, CRF = 0.11.

5.2 Calculations and Outputs

MiniHEPP Hydraulic Design was executed in order to perform the hydraulic design of structures with the input data given in previous sections. The program follows the procedure explained in detail in Chapter 3.

After the program is executed, the optimum design discharge, Q_d, is obtained as 10.79 m^3/s (see Figure 5.3) and the corresponding optimum penstock diameter, D, and installed capacity, P_p, are calculated as 1.70 m (see Figure 5.4), 7.18 MW (see Figure 5.5) respectively. The outputs of the program are presented in Table 5.2.

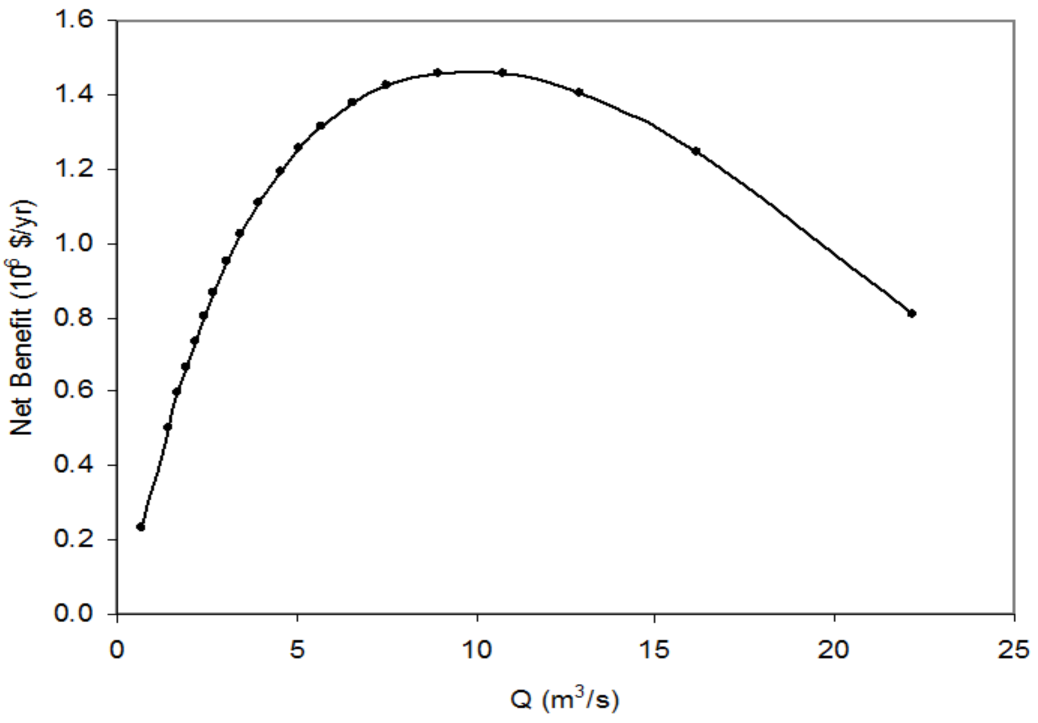

Figure 5.3 Determination of optimum discharge

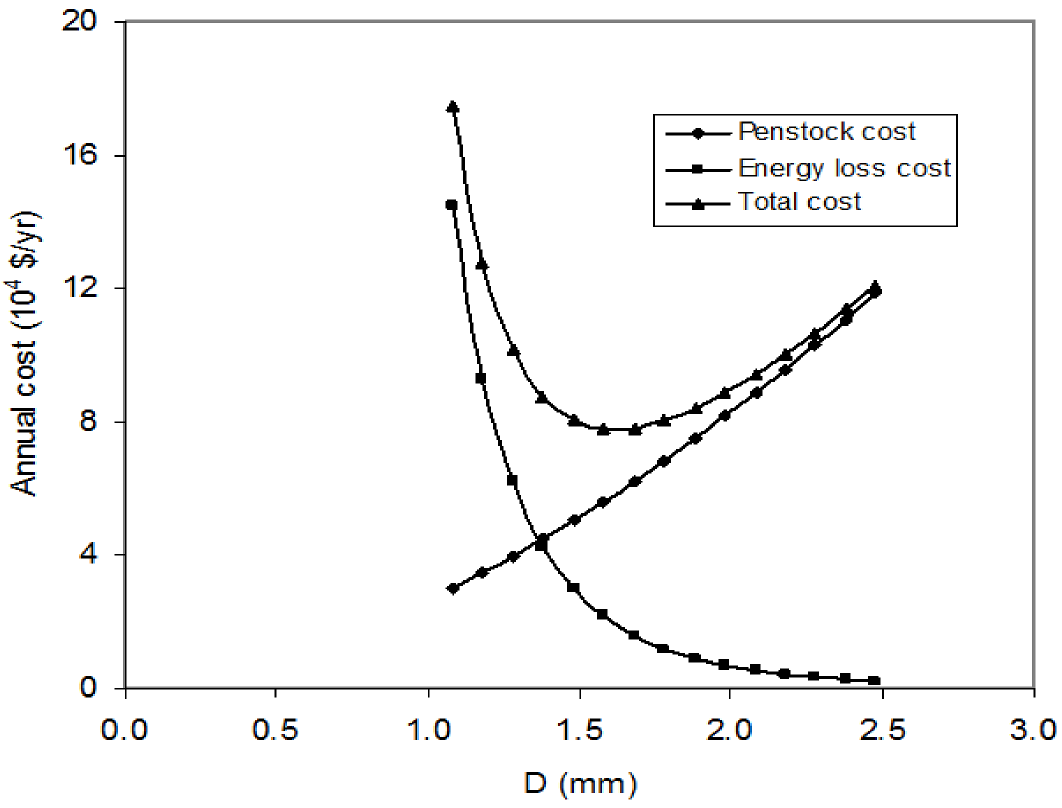

Figure 5.4 Determination of optimum penstock diameter

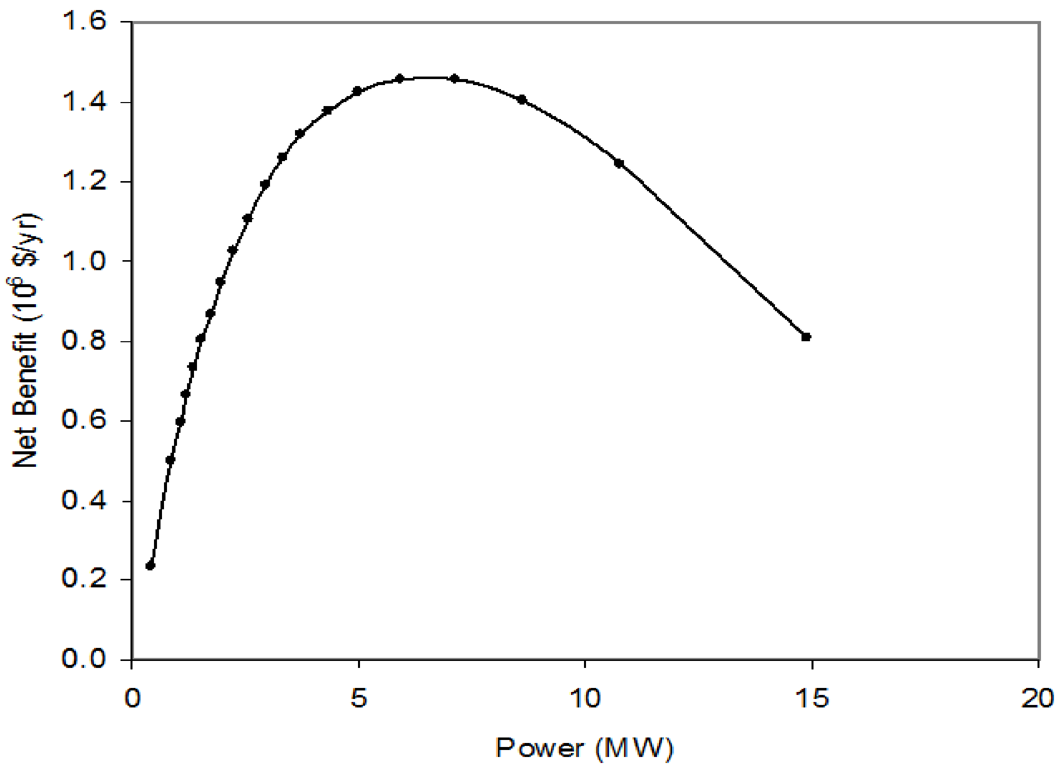

Figure 5.5 Determination of optimum installed capacity

Table 5.2 Outputs of execution

	Unit	MiniHEPP HD Outputs
Design Discharge, Q_d	m^3/s	10.79
Penstock Diameter, D	m	1.70
Crest elevation of spillway, K_s	m	593.24
Maximum water level for Q_{100}, K_{100}	m	594.44
Intake entrance bottom elevation	m	590.55
Settling basin length, L_s	m	33.76
Settling basin width, B_s	m	16.18
Velocity in settling basin, u_5	m/s	0.197
Forebay width, B_{fb}	m	18.10
Forebay length, L_{fb}	m	52.80
Minimum water level in the forebay, MinWL	m	586.90
Normal water level in the forebay, NWL	m	587.66
Maximum water level in the forebay, MaxWL	m	587.98
Forebay wall crest elevation	m	588.08
Penstock wall thickness, t	mm	8.00
Installed capacity, P_p	MW	7.18
Firm Energy, E_f	GWh/year	8.34
Seconder Energy, E_s	GWh/year	22.97
Total Energy, E_t	GWh/year	31.31
Energy dissipator length	m	31.00
Energy dissipator type	USBR	Type IV

However, in Paşa HPP the design discharge is taken as 13.50 m^3/s and the penstock diameter is taken as 2.40 m. The reason for these differences may be caused by the selection of different unit costs for penstock and installed capacity or different energy benefit values for firm and secondary energy generation. Therefore, to provide a better comparison with an existing project, the program is executed with the design discharge of 13.50 m^3/s and penstock diameter of 2.40 m. As a result of this execution of the program the outputs respresented in Table 5.3 are obtained.

Table 5.3 Comparison of results

	Unit	MiniHEPP HD Outputs	Paşa HPP
Crest elevation of spillway, K_s	m	593.04	593.00
Maximum water level for Q_{100}, K_{100}	m	594.25	594.50
Intake entrance bottom elevation	m	590.16	590.00
Settling basin length, L_s	m	35.83	46.75
Settling basin width, B_s	m	19.00	16.80
Velocity in settling basin, u_5	m/s	0.197	0.27
Forebay width, B_{fb}	m	19.30	12.00
Forebay length, L_{fb}	m	57.00	36.30
Minimum water level in the forebay, MinWL	m	586.60	586.60
Normal water level in the forebay, NWL	m	587.42	589.40
Maximum water level in the forebay, MaxWL	m	587.76	593.47
Forebay wall crest elevation	m	587.86	594.24
Penstock wall thickness, t	mm	10.00	10.00
Installed capacity, P_p	MW	9.16	9.43
Firm Energy, E_f	GWh/year	8.35	7.18
Seconder Energy, E_s	GWh/year	25.03	26.78
Total Energy, E_t	GWh/year	33.37	33.96
Energy dissipator length	m	30.40	17.00
Energy dissipator type	USBR	Type IV	Type III

5.3 Summary and Discussion of Outputs

As in Table 5.3, the main outputs are close to the values given in Paşa HPP. After the program is executed with the same Q_d and D values, the yearly total energy generation, E_t, values are close to each other. The difference in the firm energy generation may come from the different operation technique. The analysis of energy generation on a daily basis can give a more accurate result when compared to the utilization of flow-duration curve with 5% increments of exceedence probability.

The penstock wall thickness, t, is calculated as 10 mm, when the program is executed with a penstock diameter, D, of 2.40 m.

The crest elevation of spillway, K_s, the intake entrance bottom elevation and the maximum water surface elevation during Q_{100}, K_{100}, calculated by MiniHEPP Hydraulic Design, are about the same as the values obtained in Paşa HPP.

The difference in the length and width of settling basin, L_s and B_s, is caused by the selection of cross-section for settling basin. As mentioned in Chapter 3, the program designs the settling basin with a rectangular cross-section whereas in Paşa HPP the settling basin is designed with a trapezoidal cross-section. In addition, the maximum velocity condition in the settling basin is different from each other. As seen in Table 5.1, the velocity in the settling basin is 0.197 m/s for Mini HEPP Hydraulic Design whereas 0.27 m/s for Paşa HPP. This differences result with different settling basin dimensions.

The minimum water level in the forebay, MinWL, is calculated equal for both cases. However, the normal water level is calculated as 587.42 m. This is a result of the different type of conveyance line utilized in the project which leads different dimensions and water levels except for minimum water level. Nevertheless, the desired volume is satisfied in the design of Mini HEPP Hydraulic Design.

As the results of this case study, it is believed that MiniHEPP Hydraulic Design gives reasonable outputs. The one that desires to design such a system can execute the program for different alternatives and make the decisions accordingly.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and Conclusions

In this study, a computer software called MiniHEPP Hydraulic Design is developed for the hydraulic design of run-of-river hydropower plants. The program is capable of selecting optimum design discharge and penstock diameter and performing the hydraulic design of structural components, such as diversion weir, canal, forebay, and penstock accordingly.

The main objective for this thesis is to create a guideline for the hydraulic design of small run-of-river type hydropower plants and process this guideline in a logical manner. Therefore, almost every structural component of these type of systems are considered.

The program runs with the assumptions that the locations of the structures are pre-determined and fairly close to their final locations and the topographic and geological conditions are suitable. It is believed that one may run the program succesively to include these kinds of effects, however limited, by changing the input variables and make decisions for the final design of the project.

A case study was used to demonstrate the capabilities of the program developed in the present study. The results showed that the program has achived the objectives of the study within an acceptable accuracy.

6.2 Recommendations for Further Development

The computer program that is developed in this study is a basic introductory guideline and software for the hydraulic design of small run-of-river type hydropower plants. Since there are various kinds for each structural component, the inclusion of different types of these components that is not considered in this study can be suggested. In addition, the effect of topographic and geological conditions can also be studied which leads to a need to design the components from a structural point of view rather than only hydraulic. The possible inclusions can be summarized as follows:

- Different types of diversion weir intakes such as tyrolean or radial gates,
- Appurtenant facilities of diversion weir and other structural components,
- Conveyance line options other than canal and composite systems,
- Design of forebay and penstock according to multiple number of penstocks,
- Design of power house,
- Design of turbines.

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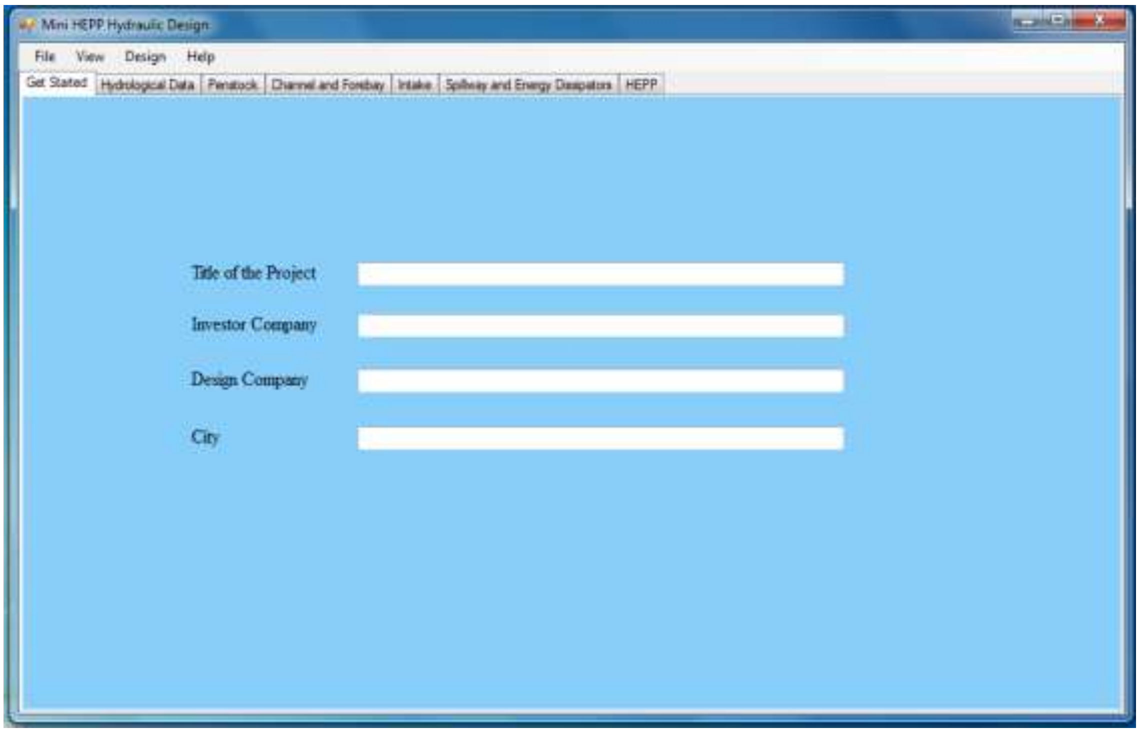
APPENDIX A

USER-MANUAL FOR MINIHEPP HYDRAULIC DESIGN

A.1 Main Window of MiniHEPP Hydraulic Design

The window that appears after the program is started is the main window. It contains the menu items and the input data pages as seen in Figure A.1.



Title of the Project

Investor Company

Design Company

City

Figure A.1 Main window of MiniHEPP Hydraulic Design

A.2 Menu Items

There are four menu item in the main window of MiniHEPP Hydraulic Design. Each of these individual menu items have sub-menu items to group the related functions. These menu items can be listed as:

- File

  Contains the related sub-menu items regarding file management.
- View

  Output windows are included in this menu item.
- Design

  The "Run" item, which will be activated by the user to make the program to calculate the desired outputs, can be found under "Design".
- Help

  The general information regarding the program can be found under the "Help" item.

A.2.1 File Menu Item

Under this menu item, there exist three different sub-items as seen in Figure A.2. These items are listed as follows:

- Open

  Opens a existing MiniHEPP Hydraulic Design file.
- Save

  Creates a MiniHEPP Hydraulic Design file under the desired location with a desired name. The extension of files created by MiniHEPP Hydraulic Design is ".hpp". If there is a file with the same name entered in the save file dialog, the existed file is overwritten by the new one.
- Quit

  Closes all the windows and quits the program.

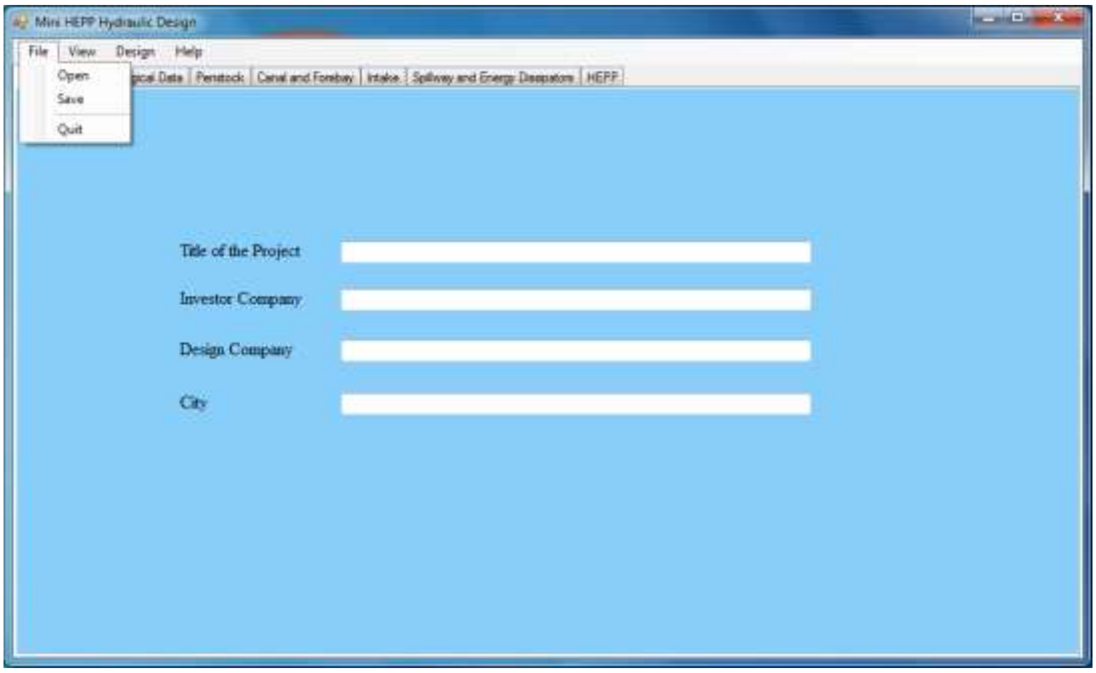


Figure A.2 File menu items

A.2.2 View Menu Item

View menu item contains the output windows. Each of these seven output window can be opened and closed seperately. The output windows, as can be seen in Figure A.3, are:

- General Characteristics of the Project
- Optimization Results
    - Installed Capacity Optimization
    - Penstock Diameter Optimization
- Penstock Characteristics
- Canal and Forebay Characteristics
- Intake Characteristics
- Spillway and Energy Dissipators

These windows display the resulting values and dimensions regarding the part of the calculations as their name implies. A typical output window is given in Figure A.4.

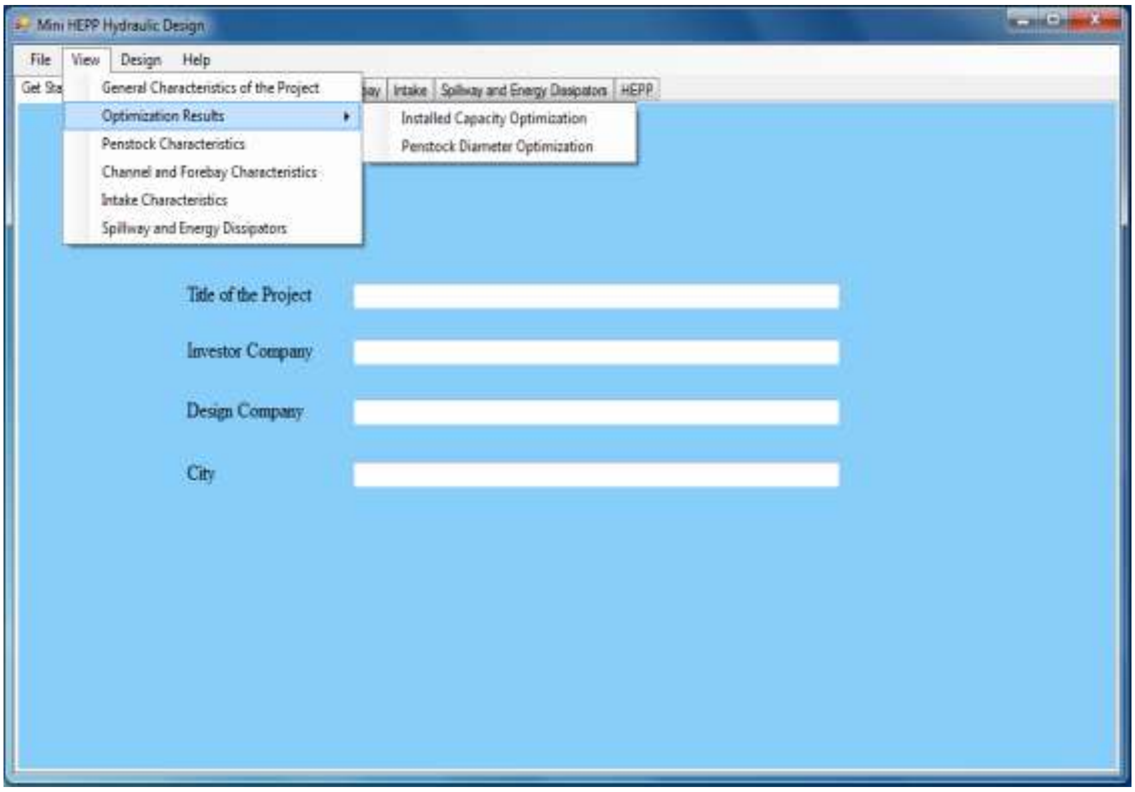
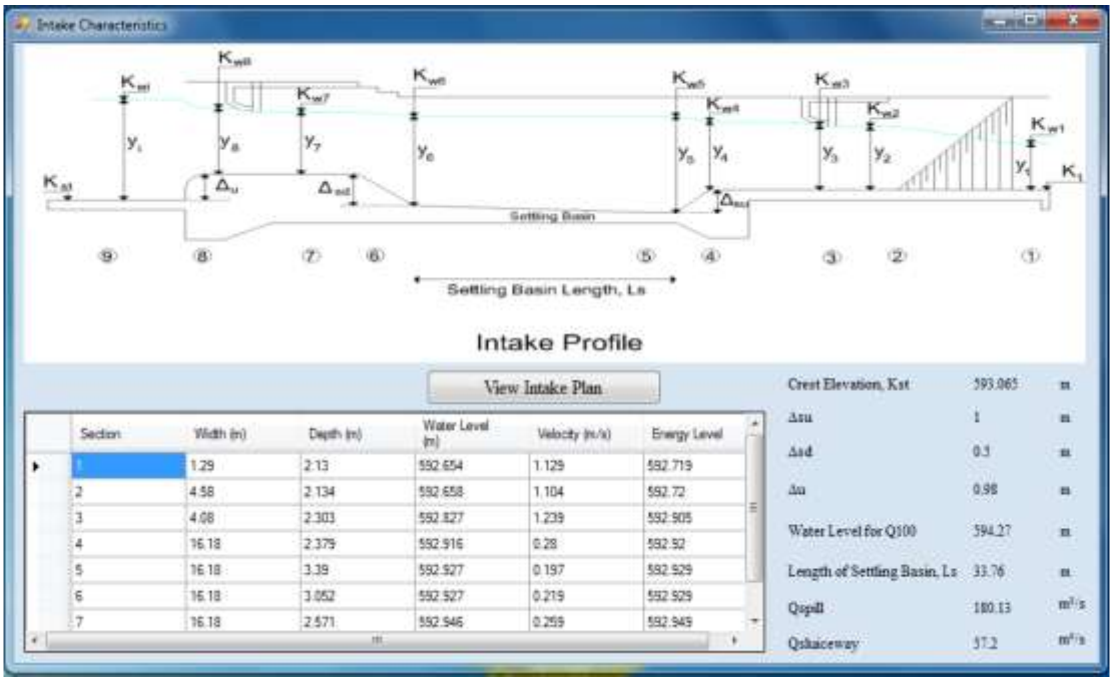

Mini HEPP Hydraulic Design
File
View
Design
Help
Get Sta
General Characteristics of the Project
Optimization Results
Penstock Characteristics
Channel and Forebay Characteristics
Intake Characteristics
Spillway and Energy Dissipators
Installed Capacity Optimization
Penstock Diameter Optimization
Intake
Spillway and Energy Dissipators
HEPP
Title of the Project
Investor Company
Design Company
City

Figure A.3 View menu items



Section	Width (m)	Depth (m)	Water Level (m)	Velocity (m/s)	Energy Level
1	1.29	2.13	592.654	1.129	592.719
2	4.58	2.134	592.658	1.104	592.72
3	4.08	2.303	592.827	1.239	592.905
4	16.18	2.379	592.916	0.28	592.92
5	16.18	3.39	592.927	0.197	592.929
6	16.18	3.052	592.927	0.219	592.929
7	16.18	2.571	592.946	0.259	592.949

Crest Elevation, Kst	593.065	m
Δsu	1	m
Δsd	0.5	m
Δu	0.98	m
Water Level for Q100	594.27	m
Length of Settling Basin, Ls	33.76	m
Qspill	180.13	m³/s
Qsluiceway	37.2	m³/s

Figure A.4 A typical output window of MiniHEPP Hydraulic Design

A.3 Input Pages

The input pages are located in the main window of MiniHEPP Hydraulic Design. The input pages are seperated and each of these pages have related sections for the data to be entered regarding their corresponding parts. There are seven different pages for input data which are as follows:

- Get Started
- Hydrological Data
- Penstock
- Canal and Forebay
- Intake
- Spillway and Energy Dissipators
- HEPP

A typical input page is given in Figure A.5. After all the necessary input variables are entered, the calculation process is started by clicking the “Run” item in the “Design” menu. In order to obtain the outputs, all of the input data must be entered.

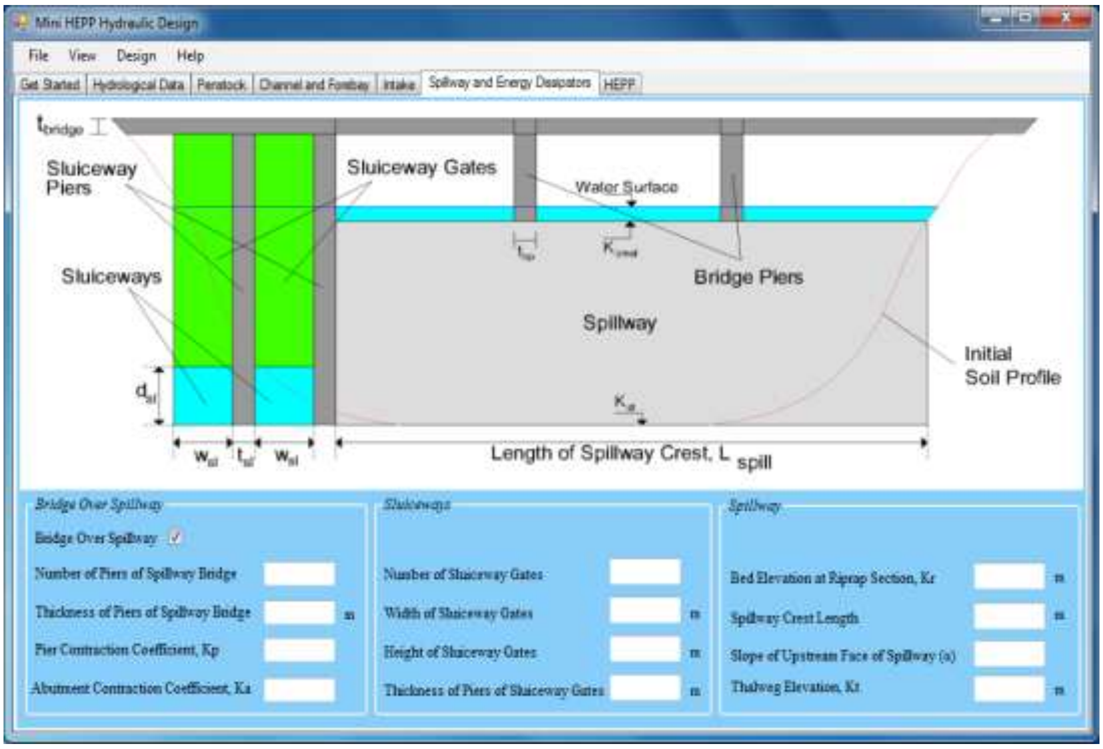
A.4 Tips for User

The MiniHEPP Hydraulic Design is capable of designing the system for a specified design discharge and / or penstock diameter by ignoring the optimization results if desired. By checking the coressponding box in the hydrological data page and entering the desired values in the text box next to the check box, the program can be run according to these values. This gives flexibility to the user in four different design choice:

- Design accoding to the optimization results for both design discharge and penstock diameter
- Design according to a design discharge specified by the user and penstock optimization for this discharge
- Design according to a penstock diameter specified by the user with the

design discharge taken from optimization results.

- Design according to design discharge and penstock diameter choosen by the user



Bridge Over Spillway		
Bridge Over Spillway ✓		
Number of Piers of Spillway Bridge		
Thickness of Piers of Spillway Bridge		m
Pier Contraction Coefficient, Kp		
Abutment Contraction Coefficient, Ka		

Sluiceways		
Number of Sluiceway Gates		
Width of Sluiceway Gates		m
Height of Sluiceway Gates		m
Thickness of Piers of Sluiceway Gates		m

Spillway		
Bed Elevation at Riprap Section, Kr		m
Spillway Crest Length		m
Slope of Upstream Face of Spillway (α)		
Thalweg Elevation, Kt		m

Figure A.5 A typical input page of MiniHEPP Hydraulic Design

APPENDIX B

SOURCE CODE OF MINIHEPP HYDRAULIC DESIGN

```
/////////////////////////////////////////////////////////////////////////////////////////
//Form Decleration: Form 1: Main and Input Page                    //
/////////////////////////////////////////////////////////////////////////////////////////
namespace WindowsFormsApplication1
{
    public partial class Form1 : Form
    {
        public Form1()
        {
            Application.CurrentCulture                                                    =
System.Globalization.CultureInfo.CreateSpecificCulture("en-US");
            InitializeComponent();
        }
/////////////////////////////////////////////////////////////////////////////////////////
//Decleration: Main and Input Page                                  //
//Menu Items and Page Functionalities                               //
/////////////////////////////////////////////////////////////////////////////////////////
```

```
private void menuQuit_Click(object sender, EventArgs e)
{
    Application.Exit();
}
private void menuOpen_Click(object sender, EventArgs e)
{
    openFD1.InitialDirectory = "C:";
    openFD1.FileName = "";
    openFD1.Filter = "MiniHEPP Projects|*.hpp";
    openFD1.FileName = String.Empty;
    DialogResult result = openFD1.ShowDialog();
    if (result == DialogResult.OK)
    {
        Stream fs = openFD1.OpenFile();
        StreamReader reader = new StreamReader(fs);
        TitleBox.Text = reader.ReadLine();
        InvestorBox.Text = reader.ReadLine();
        DesignCoBox.Text = reader.ReadLine();
        CityBox.Text = reader.ReadLine();
        flowBox1.Text = reader.ReadLine();
        flowBox2.Text = reader.ReadLine();
        flowBox3.Text = reader.ReadLine();
        flowBox4.Text = reader.ReadLine();
        flowBox5.Text = reader.ReadLine();
        flowBox6.Text = reader.ReadLine();
```

```
flowBox7.Text = reader.ReadLine();

flowBox8.Text = reader.ReadLine();

flowBox9.Text = reader.ReadLine();

flowBox10.Text = reader.ReadLine();

flowBox11.Text = reader.ReadLine();

flowBox12.Text = reader.ReadLine();

flowBox13.Text = reader.ReadLine();

flowBox14.Text = reader.ReadLine();

flowBox15.Text = reader.ReadLine();

flowBox16.Text = reader.ReadLine();

flowBox17.Text = reader.ReadLine();

flowBox18.Text = reader.ReadLine();

flowBox19.Text = reader.ReadLine();

flowBox20.Text = reader.ReadLine();

flowBox21.Text = reader.ReadLine();

PenLenBox.Text = reader.ReadLine();

FrictionFBox.Text = reader.ReadLine();

ElasticityBox.Text = reader.ReadLine();

StressBox.Text = reader.ReadLine();

PenCurveBigBox.Text = reader.ReadLine();

PenCurveSmallBox.Text = reader.ReadLine();

PenQuanBox.Text = reader.ReadLine();

PenEntElevBox.Text = reader.ReadLine();

RVCoeffBox.Text = reader.ReadLine();

PierNumberBox.Text = reader.ReadLine();
```

```
PierThickBox.Text = reader.ReadLine();

MaxSettDiaBox.Text = reader.ReadLine();

RemovalRatioBox.Text = reader.ReadLine();

RoughnessBox.Text = reader.ReadLine();

DRackBox.Text = reader.ReadLine();

tRackBox.Text = reader.ReadLine();

PierIntakeThickBox.Text = reader.ReadLine();

PierIntakeNumberBox.Text = reader.ReadLine();

KthalwegBox.Text = reader.ReadLine();

LspillBox.Text = reader.ReadLine();

AlphaBox.Text = reader.ReadLine();

wslBox.Text = reader.ReadLine();

nslBox.Text = reader.ReadLine();

dslBox.Text = reader.ReadLine();

tslBox.Text = reader.ReadLine();

KrBox.Text = reader.ReadLine();

Q5Box.Text = reader.ReadLine();

Kd5Box.Text = reader.ReadLine();

Q10Box.Text = reader.ReadLine();

Kd10Box.Text = reader.ReadLine();

Q25Box.Text = reader.ReadLine();

Kd25Box.Text = reader.ReadLine();

Q50Box.Text = reader.ReadLine();

Kd50Box.Text = reader.ReadLine();

Q100Box.Text = reader.ReadLine();
```

```
Kd100Box.Text = reader.ReadLine();

PenUnitCostBox.Text = reader.ReadLine();

TcBox.Text = reader.ReadLine();

headBox.Text = reader.ReadLine();

TurEffBox.Text = reader.ReadLine();

GenEffBox.Text = reader.ReadLine();

TranEffBox.Text = reader.ReadLine();

EnergyFPriceBox.Text = reader.ReadLine();

EnergySPriceBox.Text = reader.ReadLine();

CapCostBox.Text = reader.ReadLine();

CRFBox.Text = reader.ReadLine();

ChanSlopeBox.Text = reader.ReadLine();

ChanLenBox.Text = reader.ReadLine();

ChanSSlopeBox.Text = reader.ReadLine();

ChanRoughBox.Text = reader.ReadLine();

TurQuanBox.Text = reader.ReadLine();

TurTypeBox.Text = reader.ReadLine();

BridgePierNumberBox.Text = reader.ReadLine();

BridgePierThickBox.Text = reader.ReadLine();

KpBox.Text = reader.ReadLine();

KaBox.Text = reader.ReadLine();

DsgnDischargeBox.Text = reader.ReadLine();

PenDiaDsgnBox.Text = reader.ReadLine();

DsuMaxBox.Text = reader.ReadLine();

DsuMinBox.Text = reader.ReadLine();
```

```
            DsdMaxBox.Text = reader.ReadLine();
            DsdMinBox.Text = reader.ReadLine();
            DuMaxBox.Text = reader.ReadLine();
            DuMinBox.Text = reader.ReadLine();
            reader.Close();
            fs.Close();
        }
    }
private void menuSave_Click(object sender, EventArgs e)
    {
    string name = saveFD1.FileName;
        saveFD1.Filter = "MiniHEPP Project|*.hpp";
        saveFD1.FileName = String.Empty;
        saveFD1.DefaultExt = ".hpp";
        DialogResult result = saveFD1.ShowDialog();
        if (result == DialogResult.OK)
        {
            FileStream fs = new FileStream(saveFD1.FileName, FileMode.Create);
            StreamWriter writer = new StreamWriter(fs);
            writer.WriteLine(TitleBox.Text);
            writer.WriteLine(InvestorBox.Text);
            writer.WriteLine(DesignCoBox.Text);
            writer.WriteLine(CityBox.Text);
            writer.WriteLine(flowBox1.Text);
            writer.WriteLine(flowBox2.Text);
writer.WriteLine(flowBox3.Text);
writer.WriteLine(flowBox4.Text);
writer.WriteLine(flowBox5.Text);
writer.WriteLine(flowBox6.Text);
writer.WriteLine(flowBox7.Text);
writer.WriteLine(flowBox8.Text);
writer.WriteLine(flowBox9.Text);
writer.WriteLine(flowBox10.Text);
writer.WriteLine(flowBox11.Text);
writer.WriteLine(flowBox12.Text);
writer.WriteLine(flowBox13.Text);
writer.WriteLine(flowBox14.Text);
writer.WriteLine(flowBox15.Text);
writer.WriteLine(flowBox16.Text);
writer.WriteLine(flowBox17.Text);
writer.WriteLine(flowBox18.Text);
writer.WriteLine(flowBox19.Text);
writer.WriteLine(flowBox20.Text);
writer.WriteLine(flowBox21.Text);
writer.WriteLine(PenLenBox.Text);
writer.WriteLine(FrictionFBox.Text);
writer.WriteLine(ElasticityBox.Text);
writer.WriteLine(StressBox.Text);
writer.WriteLine(PenCurveBigBox.Text);
writer.WriteLine(PenCurveSmallBox.Text);
writer.WriteLine(PenQuanBox.Text);

writer.WriteLine(PenEntElevBox.Text);

writer.WriteLine(RVCoeffBox.Text);

writer.WriteLine(PierNumberBox.Text);

writer.WriteLine(PierThickBox.Text);

writer.WriteLine(MaxSettDiaBox.Text);

writer.WriteLine(RemovalRatioBox.Text);

writer.WriteLine(RoughnessBox.Text);

writer.WriteLine(DRackBox.Text);

writer.WriteLine(tRackBox.Text);

writer.WriteLine(PierIntakeThickBox.Text);

writer.WriteLine(PierIntakeNumberBox.Text);

writer.WriteLine(KthalwegBox.Text);

writer.WriteLine(LspillBox.Text);

writer.WriteLine(AlphaBox.Text);

writer.WriteLine(wslBox.Text);

writer.WriteLine(nslBox.Text);

writer.WriteLine(dslBox.Text);

writer.WriteLine(tslBox.Text);

writer.WriteLine(KrBox.Text);

writer.WriteLine(Q5Box.Text);

writer.WriteLine(Kd5Box.Text);

writer.WriteLine(Q10Box.Text);

writer.WriteLine(Kd10Box.Text);

writer.WriteLine(Q25Box.Text);
writer.WriteLine(Kd25Box.Text);
writer.WriteLine(Q50Box.Text);
writer.WriteLine(Kd50Box.Text);
writer.WriteLine(Q100Box.Text);
writer.WriteLine(Kd100Box.Text);
writer.WriteLine(PenUnitCostBox.Text);
writer.WriteLine(TcBox.Text);
writer.WriteLine(headBox.Text);
writer.WriteLine(TurEffBox.Text);
writer.WriteLine(GenEffBox.Text);
writer.WriteLine(TranEffBox.Text);
writer.WriteLine(EnergyFPriceBox.Text);
writer.WriteLine(EnergySPriceBox.Text);
writer.WriteLine(CapCostBox.Text);
writer.WriteLine(CRFBox.Text);
writer.WriteLine(ChanSlopeBox.Text);
writer.WriteLine(ChanLenBox.Text);
writer.WriteLine(ChanSSlopeBox.Text);
writer.WriteLine(ChanRoughBox.Text);
writer.WriteLine(TurQuanBox.Text);
writer.WriteLine(TurTypeBox.Text);
writer.WriteLine(BridgePierNumberBox.Text);
writer.WriteLine(BridgePierThickBox.Text);
writer.WriteLine(KpBox.Text);
writer.WriteLine(KaBox.Text);
```

```
            writer.WriteLine(DsgnDischargeBox.Text);

            writer.WriteLine(PenDiaDsgnBox.Text);

            writer.WriteLine(DsuMaxBox.Text);

            writer.WriteLine(DsuMinBox.Text);

            writer.WriteLine(DsdMaxBox.Text);

            writer.WriteLine(DsdMinBox.Text);

            writer.WriteLine(DuMaxBox.Text);

            writer.WriteLine(DuMinBox.Text);

            writer.Close();

            fs.Close();

         }

      }

      private void ınstalledCapacityOptimizationToolStripMenuItem_Click(object
sender, EventArgs e)

      {

         Form2 CapOpt = new Form2();

         CapOpt.Show();

      }

      private void penstockDiameterOptimizationToolStripMenuItem_Click(object
sender, EventArgs e)

      {

         Form3 PenOpt = new Form3();

         PenOpt.Show();

      }

      private void menuIntakeChar_Click(object sender, EventArgs e)

      {
            Form4 IntakeChar = new Form4();
            IntakeChar.Show();
        }
        private void menuSpillwayChar_Click(object sender, EventArgs e)
        {
            Form5 SpillwayChar = new Form5();
            SpillwayChar.Show();
        }
        private void menuForebayChar_Click(object sender, EventArgs e)
        {
            Form6 ForebayChar = new Form6();
            ForebayChar.Show();
        }
        private void menuPenChar_Click(object sender, EventArgs e)
        {
            Form7 PenChar = new Form7();
            PenChar.Show();
        }
        private void menuGenChar_Click(object sender, EventArgs e)
        {
            Form8 GenChar = new Form8();
            GenChar.Show();
        }
private void IntakeImageButton_Click(object sender, EventArgs e)
        {
            if (boolIntake == true)
            {
                IntakeImagePB.Image                                        =
        WindowsFormsApplication1.Properties.Resources.IntakePlan;
                IntakeImageButton.Text = "View Intake Profile";
                boolIntake = false;
            }
            else
            {
                IntakeImagePB.Image                                        =
        WindowsFormsApplication1.Properties.Resources.IntakeProfile;
                IntakeImageButton.Text = "View Intake Plan";
                boolIntake = true;
            }
        }
        private void ForebayImageButton_Click(object sender, EventArgs e)
        {
            if (boolForebay == true)
            {
                ForebayImagePB.Image                                       =
        WindowsFormsApplication1.Properties.Resources.ForebayPlan;
                ForebayImageButton.Text = "View Forebay Cross Section";
                boolForebay = false;
            }
            else
            {
                ForebayImagePB.Image                                       =
        WindowsFormsApplication1.Properties.Resources.ForebaySide;
                ForebayImageButton.Text = "View Forebay Plan";
                boolForebay = true;
            }
        }
        private void BridgeCheckBox_CheckStateChanged(object sender, EventArgs
        e)
        {
            if (BridgeCheckBox.Checked == true)
            {
                SpillwayImagePB.Image                                          =
        WindowsFormsApplication1.Properties.Resources.SpillwayCrossSectionBridge;
                boolBridge = true;
            }
            else
            {
                SpillwayImagePB.Image                                          =
        WindowsFormsApplication1.Properties.Resources.SpillwayCrossSection;
                boolBridge = false;
            }


        /////////////////////////////////////////////////////////////////////////////////////////////
        //Installed Capacity and Penstock Diameter Optimization Variables   //
        //Written by: EMIR ALIMOGLU                                          //
        //Date: 15.01.2011                                                   //
        //////////////////////////////////////////////////////////////////////////////////////////
        double PenUnitCost, CapUnitCost, EnergyFPrice, EnergySPrice, FrictionF,
TurEff, GenEff, TranEff, CRF, Elasticity, StressAll, PenCurveBig, PenCurveSmall, Tc;

        public const double g = 9.81;

        double PenDiaTrial, TE, Ct;

        public static double DsgnDischarge, PenDiaDsgn, PenLen, GrossHead, FlowOccurPercent, NetHeadDsgn, PowerDsgn, WaveSpeed, PenThickDsgn, PenThickTrial, DeltaHead, MaxHeadValve, PenVel, FirmEnergy, SecondaryEnergy, TotalEnergy, TotalEff, FrictionLoss, AerDia, Pc;

        public static double[] FlowData = new double[21];

        double[] Qeq = new double[21];

        double[] FricLoss = new double[21];

        public static double[] NetHead = new double[21];

        public static double[] Power = new double[21];

        public static double[] Diameter = new double[21];

        double[] MEnergy = new double[21];

        public static double[] TEnergy = new double[21];

        public static double[] SEnergy = new double[21];

        public static double[] FEnergy = new double[21];

        public static double[] PenCost = new double[21];

        public static double[] CapCost = new double[21];

        public static double[] Benefit = new double[21];

        public static double[] NetBenefit = new double[21];

        public static double[] TotalCost = new double[21];

        public static double[] TrialPenDia = new double[10];

        public static double[] TrialPenThick = new double[10];

        public static double[] TrialPenCost = new double[10];

        public static double[] EnergyLoss = new double[10];
        public static double[] CostEnergyLoss = new double[10];

        public static double[] TotalLossCost = new double[10];

        public static double[] PenThickness = new double[21];

        public static bool RunCondition = false;

        int i, k;

        bool boolIntake = true;

        bool boolForebay = true;

        bool boolBridge = true;

////////////////////////////////////////////////////////////////////////////////////////////

//Functions related to optimization and penstock design            //

///////////////////////////////////////////////////////////////////////////////////////////

        static double f_NetHead(double Q, double PenLen, double GrossHead, double
FrictionF, double PenDia)

        {

            double NetHead;

            if (PenDia == 0 || Q == 0)

            {

                NetHead = GrossHead;

            }

            else

            {

                NetHead = GrossHead - f_hf(Q, PenLen, FrictionF, PenDia);

            }

            if (NetHead < 0)

            {

                NetHead = 0;
            }

            return NetHead;

        }

        static double f_TenStress(double NetHead, double DeltaHead, double PenDia,
double PenThick)

        {

            double TenStress;

            TenStress = (DeltaHead + NetHead) * g * PenDia / 2 / PenThick;

            return TenStress;

        }

        static double f_hf(double Q, double PenLen, double FrictionF, double PenDia)

        {

            double hf;

            hf = 8 * FrictionF * PenLen * Math.Pow(Q, 2) / (g * Math.Pow(Math.PI, 2)
* Math.Pow(PenDia, 5));

            return hf;

        }

        static double f_Power(double Q, double NetHead, double TotalEff)

        {

            double Power;

            Power = Q * NetHead * TotalEff * g / 1000;

            return Power;

        }

        static double f_ME(double Qeq, double Efficiency, double NetHead)

        {

            double ME;
            ME = Qeq * Efficiency * NetHead * g * 8.76 / 1000;
            return ME;
        }
        static double f_PenWeight(double PenDia, double PenThickness, double
PenLen)
        {
            double PenWeight, UWeight = 7850;
            if (PenDia == 0)
            {
                PenWeight = 0;
            }
            else
            {
                PenWeight = (UWeight * Math.PI * PenDia * PenLen * PenThickness /
1000) * 1.20;
            }
            return PenWeight;
        }
        static double f_area(double Diameter)
        {
            double area;
            area = Math.PI * Math.Pow(Diameter, 2) / 4;
            return area;
        }
        static double f_Velocity(double Discharge, double Area)
        {
            double Velocity;

            Velocity = Discharge / Area;

            return Velocity;

        }

        static double f_WaveSpeed(double PenDia, double PenThick, double
Elasticity)

        {

            double WaveSpeed, BulkModulus = 2200000, Density = 1, AnchorCoeff =
1;

            WaveSpeed = Math.Sqrt(BulkModulus / Density) / Math.Sqrt(1 +
((BulkModulus / 1000 / Elasticity) * (PenDia * 1000 / PenThick) * AnchorCoeff));

            return WaveSpeed;

        }

        static double f_DeltaHead(double WaveSpeed, double Velocity, double
PenLen, double Tc)

        {

            double DeltaHead;

            if (Tc < 2 * PenLen / WaveSpeed) //Sudden Closure

            {

                DeltaHead = WaveSpeed * Velocity / g;

            }

            else

            {

                DeltaHead = WaveSpeed * Velocity / g / Tc * (2 * PenLen / WaveSpeed);

            }

            return DeltaHead;

        }
```

```
    static double f_PenThick(double PenDia, double GrossHead, double PenLen,
double Discharge, double FrictionF, double StressAll, double Elasticity, double Tc)

    {

        double PenThick, WaveSpeed, PenVel, DeltaHead;

        PenVel = f_Velocity(Discharge, f_area(PenDia));

        PenThick = Math.Ceiling((PenDia * 1000 + 480) / 400);

        do

        {

            WaveSpeed = f_WaveSpeed(PenDia, PenThick, Elasticity);

            DeltaHead = f_DeltaHead(WaveSpeed, PenVel, PenLen, Tc);

            if (StressAll >= (f_TenStress(f_NetHead(Discharge, PenLen, GrossHead,
FrictionF, PenDia), DeltaHead, PenDia, PenThick)))

            {

                break;

            }

            PenThick++;

        } while (StressAll < (f_TenStress(f_NetHead(Discharge, PenLen,
GrossHead, FrictionF, PenDia), DeltaHead, PenDia, PenThick)));

        return PenThick;

    }

////////////////////////////////////////////////////////////////////////////////////////////////////

//Forebay and Canal Design Variables                                  //

//Written by: EMIR ALIMOGLU                                           //

//Date: 01.03.2011                                                    //

////////////////////////////////////////////////////////////////////////////////////////////////////

    public static double ForebayLen, ForebayWidth, ForBottomElev, ForTopElev,
ForSpillCrest, ForH0, ForStep, TrashRackWidth, VortexH, MinWL, MaxWL,
NorWL, he;
```

```
    public static double ChanSlope, ChanSSlope, ChanLen, ChanEntWL,
ChanEntElev, ChanExitElev, ChanWidth, ChanWDepth, ChanExitWL,
ChanFreeboard, ReqVol, RVCoeff, FRPen;

    public static int TurQuan;

    public static string TurType;

    double TrashRackVel = 0.6, PenEntElev, CForCont = 0.6, ChanRough;

///////////////////////////////////////////////////////////

//Intake and Energy Dissipator Design Variables                //

//Written by: EMIR ALIMOGLU                                    //

//Date: 11.04.2011                                             //

//////////////////////////////////////////////////////////

    double PierThick, PierIntakeThick, MaxSettDia, SettVel, Roughness,
IntakeGrossArea, IntakeNetArea, Kd5, Kd10, Kd25, Kd50, Kd100, Q5, Q10, Q25,
Q50, Lsluice, Kr, Alpha, wsl, dsl, tsl, DRack, tRack;

    double BridgePierThick, Kp, Ka;

    double DsuMax, DsuMin, DuMax, DuMin, DsdMin, DsdMax;

    int BridgePierNumber, nRack;

    double OrificeCoeff = 0.65, CSettContraction = 0.2, CTransition = 0.3;

    public static double[] IntakeDepths = new double[8];

    public static double[] IntakeWidths = new double[8];

    public static double[] IntakeWL = new double[8];

    public static double[] IntakeVelocity = new double[8];

    public static double[] IntakeEGL = new double[8];

    public static double[] EDSpillDepths5 = new double[3];

    public static double[] EDSluiceDepths5 = new double[3];

    public static double[] EDSpillDepths10 = new double[3];

    public static double[] EDSluiceDepths10 = new double[3];
```

```
     public static double[] EDSpillDepths25 = new double[3];

     public static double[] EDSluiceDepths25 = new double[3];

     public static double[] EDSpillDepths50 = new double[3];

     public static double[] EDSluiceDepths50 = new double[3];

     public static double[] EDSpillDepths100 = new double[3];

     public static double[] EDSluiceDepths100 = new double[3];

     double HeadLossGate, HeadLossGate2, HeadLossTrash, HeadLossContraction,
VMaxSett;

     double Kv = 0.42, ustar, lamda, beta, RemovalRatio;

     public static double Lspill, Q100, Kthalweg;

     public static double LEDSpill, LEDSpill5, LEDSpill10, LEDSpill25,
LEDSpill50, LEDSpill100, LEDSluice, LEDSluice5, LEDSluice10, LEDSluice25,
LEDSluice50, LEDSluice100, Eu5, Eu10, Eu25, Eu50, Eu100, ha5, ha10, ha25,
ha50, ha100, E3sl5, E3sl10, E3sl25, E3sl50, E3sl100, E3s5, E3s10, E3s25, E3s50,
E3s100;

     public static double DeltaEs5, DeltaEs10, DeltaEs25, DeltaEs50, DeltaEs100,
DeltaEsl5, DeltaEsl10, DeltaEsl25, DeltaEsl50, DeltaEsl100, SpillwaySill,
SpillwaySill5, SpillwaySill10, SpillwaySill25, SpillwaySill50, SpillwaySill100,
SluiceSill, SluiceSill5, SluiceSill10, SluiceSill25, SluiceSill50, SluiceSill100;

     public static double Qspill, Qspill5, Qspill10, Qspill25, Qspill50, Qspill100,
Qsluice, Qsluice5, Qsluice10, Qsluice25, Qsluice50, Qsluice100, EDSpilly1,
EDSpilly2, EDSluicey1, EDSluicey2;

     public static double s1spill, s2spill, s3spill, h1spill, h2spill, h3spill, h4spill,
w1spill, w2spill, w3spill, s1sluice, s2sluice, s3sluice, h1sluice, h2sluice, h3sluice,
h4sluice, w1sluice, w2sluice, w3sluice;

     public static double FR1Spill, U1Spill, FR1Sluice, U1Sluice;

     public static double  Kcrest, KcrestWL, SettUpStep, SettDownStep,
LSettBasin, IntakeStep, K5, K10, K25, K50, K100;

     public static int a, PierNumber, PierIntakeNumber, nsl;

     public static string BasinTypeSpill, BasinTypeSluice;
```

```
/////////////////////////////////////////////////////////////////////////////////
//Open Channel Hydraulic Functions                                   //
/////////////////////////////////////////////////////////////////////////////////
      static double f_area(double width, double depth, double m)
      {
         double A;
         A = width * depth + m * Math.Pow(depth, 2);
         return A;
      }
      static double f_wettedP(double depth, double width, double m)
      {
         double P;
         P = 2 * Math.Sqrt(Math.Pow(m, 2) + 1) * depth + width;
         return P;
      }

      static double f_hydRadius(double depth, double width, double m)
      {
         double hydRadius;
         hydRadius = f_area(width, depth, m) / f_wettedP(depth, width, m);
         return hydRadius;
      }
      static double f_hydDia(double width, double depth, double sideslope)
      {
         double hydDia;
```

```
            hydDia = f_area(width, depth, sideslope) / f_topwidth(width, depth, sideslope);

            return hydDia;

        }

        static double f_wBHS(double depth, double sideslope)

        {

            double w;

            w = 2 * depth * (Math.Sqrt(1 + Math.Pow(sideslope, 2)) - sideslope);

            return w;

        }

        static double f_topwidth(double width, double depth, double m)

        {

            double T;

            T = width + 2 * depth * m;

            return T;

        }

        static double f_vel(double Q, double A)

        {

            double u;

            u = Q / A;

            return u;

        }

        static double f_Qmanning(double roughness, double y, double b, double m, double S)

        {

            double Q;
            Q = f_area(b, y, m) / roughness * Math.Pow(f_hydRadius(y, b, m), 0.66667) * Math.Sqrt(S);

            return Q;

        }

        static double f_yBHS(double Q, double roughness, double ChanSideSlope, double ChanSlope) //Depth in channel according to the best hydraulic section

        {

            double y1, y0, func_val0, func_val1, trial_val;

            y0 = 20;

            y1 = 10;

            while (Math.Abs(y1 - y0) >= 0.001)

            {

                func_val0 = Q - f_Qmanning(roughness, y0, f_wBHS(y0, ChanSideSlope), ChanSideSlope, ChanSlope);

                func_val1 = Q - f_Qmanning(roughness, y1, f_wBHS(y1, ChanSideSlope), ChanSideSlope, ChanSlope);

                trial_val = y1 - (func_val1 * (y1 - y0) / (func_val1 - func_val0));

                y0 = Math.Round(y1, 3);

                y1 = Math.Round(trial_val, 3);

            }

            return y1;

        }

        static double f_yQmanning(double Q, double roughness, double ChanSideSlope, double ChanSlope, double width) //Depth in channel for known width

        {

            double y1, y0, func_val0, func_val1, trial_val;

            y0 = 20;
            y1 = 10;

            while (Math.Abs(y1 - y0) >= 0.001)

            {

                func_val0 = Q - f_Qmanning(roughness, y0, width, ChanSideSlope, ChanSlope);

                func_val1 = Q - f_Qmanning(roughness, y1, width, ChanSideSlope, ChanSlope);

                trial_val = y1 - (func_val1 * (y1 - y0) / (func_val1 - func_val0));

                y0 = Math.Round(y1,3);

                y1 = Math.Round(trial_val,3);

            }

            return y1;

        }

        static double f_vel_head(double u)

        {

            double vel_head;

            vel_head = Math.Pow(u, 2) / 2 / g;

            return vel_head;

        }

        static double f_Froude(double Q, double width, double depth, double m)

        {

            double Fr;

            Fr = Q / f_area(width, depth, m) / Math.Sqrt(g * f_hydDia(width, depth, m));

            return Fr;

        }

        static double f_AvgFricSlope(double uDownstr, double uUpstr, double yUpstr, double yDownstr, double roughness, double width, double sideslope)
        {

            double AvgFricSlope;

            AvgFricSlope = (Math.Pow(roughness, 2) * Math.Pow(uDownstr, 2) / Math.Pow(f_hydRadius(yDownstr,width, sideslope), 1.33333) + (Math.Pow(roughness, 2) * Math.Pow(uUpstr, 2)) / Math.Pow(f_area(width, yUpstr, sideslope) / (width + 2 * yUpstr), 4 / 3)) / 2;

            return AvgFricSlope;

        }

        static double f_depth_iter(double Q, double BUpstr, double BDownstr, double yDownstr, double slope, double coeff)

        {

            //secant method is utilized

            double y1, y0, func_val0, func_val1, trial_val, hl;

            y0 = 20;

            y1 = 10;

            while (Math.Abs(y1 - y0) >= 0.001)

            {

                hl = coeff * (f_vel_head(f_vel(Q, f_area(BDownstr, yDownstr, slope))) - f_vel_head(f_vel(Q, f_area(BUpstr, y0, 0))));

                func_val0 = (yDownstr + f_vel_head(f_vel(Q, f_area(BDownstr, yDownstr, slope)))) + hl - y0 - f_vel_head(f_vel(Q, f_area(BUpstr, y0, 0)));

                hl = coeff * (f_vel_head(f_vel(Q, f_area(BDownstr, yDownstr, slope))) - f_vel_head(f_vel(Q, f_area(BUpstr, y1, 0))));

                func_val1 = (yDownstr + f_vel_head(f_vel(Q, f_area(BDownstr, yDownstr, slope)))) + hl - y1 - f_vel_head(f_vel(Q, f_area(BUpstr, y1, 0)));

                trial_val = y1 - (func_val1 * (y1 - y0) / (func_val1 - func_val0));

                y0 = Math.Round(y1, 3);

                y1 = Math.Round(trial_val, 3);

            }
            return y1;
        }
        static double f_settbegin(double Q, double uDownstr, double yDownstr, double
roughness, double length, double width, double sideslope)
        {
            double y1, y0, func_val0, func_val1, trial_val, hl, SettBasinSlope = 0.01;
            y0 = 20;
            y1 = 10;
            while (Math.Abs(y1 - y0) >= 0.001)
            {
                hl = f_AvgFricSlope(uDownstr, f_vel(Q, f_area(width, y0, sideslope)), y0,
yDownstr, roughness, width, sideslope) * length;
                func_val0 = SettBasinSlope * length + y0 + f_vel_head(f_vel(Q,
f_area(width, y0, sideslope))) - hl - yDownstr - f_vel_head(uDownstr);
                hl = f_AvgFricSlope(uDownstr, f_vel(Q, f_area(width, y1, sideslope)), y1,
yDownstr, roughness, width, sideslope) * length;
                func_val1 = SettBasinSlope * length + y1 + f_vel_head(f_vel(Q,
f_area(width, y1, sideslope))) - hl - yDownstr - f_vel_head(uDownstr);
                trial_val = y1 - (func_val1 * (y1 - y0) / (func_val1 - func_val0));
                y0 = Math.Round(y1, 3);
                y1 = Math.Round(trial_val, 3);
            }
            return y1;
        }
        static double f_section7_depth(double Q, double u6, double y6, double width,
double DownSillSize)
        {
            double y1, y0, func_val0, func_val1, trial_val;
            y0 = 20;

            y1 = 10;

            while (Math.Abs(y1 - y0) >= 0.001)

            {

                func_val0 = y6 + f_vel_head(f_vel(Q, f_area(width, y6, 0))) + 0.02 -
DownSillSize - y0 - f_vel_head(f_vel(Q, f_area(width, y0, 0)));

                func_val1 = y6 + f_vel_head(f_vel(Q, f_area(width, y6, 0))) + 0.02 -
DownSillSize - y1 - f_vel_head(f_vel(Q, f_area(width, y1, 0)));

                trial_val = y1 - (func_val1 * (y1 - y0) / (func_val1 - func_val0));

                y0 = Math.Round(y1, 3);

                y1 = Math.Round(trial_val, 3);

            }

            return y1;

        }

        static double f_UpSill_loss(double Q, double Bs, double yDownstr)

        {

            double hl0, hl1, func_val0, func_val1, trial_val;

            hl0 = 0.005;

            hl1 = 0.001;

            while (Math.Abs(hl1 - hl0) >= 0.0001)

            {

                func_val0 = 2.88 * Bs * (2 / 3 * Math.Pow(hl0, 1.5) + yDownstr *
Math.Pow(hl0, 0.5)) - Q;

                func_val1 = 2.88 * Bs * (2 / 3 * Math.Pow(hl1, 1.5) + yDownstr *
Math.Pow(hl1, 0.5)) - Q;

                trial_val = hl1 - (func_val1 * (hl1 - hl0) / (func_val1 - func_val0));

                hl0 = Math.Round(hl1, 3);
                hl1 = Math.Round(trial_val, 3);
            }
            return hl1;
        }
        static double f_sett_depth(double Q, double UpSillLoss, double BDownstr, double Bs, double yDownstr, double SillSize)
        {
            double y1, y0, func_val0, func_val1, trial_val;
            y0 = 20;
            y1 = 10;
            while (Math.Abs(y1 - y0) >= 0.001)
            {
                func_val0 = yDownstr + f_vel_head(f_vel(Q, f_area(BDownstr, yDownstr, 0))) + f_UpSill_loss(Q, Bs, yDownstr) + SillSize - y0 - f_vel_head(f_vel(Q, f_area(Bs, y0, 0)));
                func_val1 = yDownstr + f_vel_head(f_vel(Q, f_area(BDownstr, yDownstr, 0))) + f_UpSill_loss(Q, Bs, yDownstr) + SillSize - y1 - f_vel_head(f_vel(Q, f_area(Bs, y1, 0)));
                trial_val = y1 - (func_val1 * (y1 - y0) / (func_val1 - func_val0));
                y0 = Math.Round(y1, 3);
                y1 = Math.Round(trial_val, 3);
            }
            return y1;
        }
        static double f_Co(double P, double Ho)
        {
            double Co;
            if (P / Ho > 2.75)
```

```
            {
                Co = 2.18;
            }
            else
            {
                Co = -0.0201 * Math.Pow(P / Ho, 6) + 0.2148 * Math.Pow(P / Ho, 5) - 0.915 * Math.Pow(P / Ho, 4) + 1.982 * Math.Pow(P / Ho, 3) - 2.3081 * Math.Pow(P / Ho, 2) + 1.414 * Math.Pow(P / Ho, 1) + 1.7719;
            }
            return Co;
        }
        static double f_Cinc(double P, double Ho, double Alpha)
        {
            double Cinc;
            if (Alpha == 33)
            {
                Cinc = 1.04 - 0.06 * P / Ho + 0.04 * Math.Pow(P / Ho, 2) - 0.01 * Math.Pow(P / Ho, 3);
            }
            else if (Alpha == 18)
            {
                Cinc = 1.01 - 0.02 * P / Ho + 0.01 * Math.Pow(P / Ho, 2) - 0.004 * Math.Pow(P / Ho, 3);
            }
            else if (Alpha == 0)
            {
                Cinc = 1;
```

```
    }
    else
    {
        Cinc = 1;
    }
    return Cinc;
}
static double f_Cma(double hd, double d, double He)
{
    double Cma;
    if ((hd + d) / He > 1.7)
    {
        Cma = 1;
    }
    else
    {
        Cma = -30.015 * Math.Pow((hd + d) / He, 6) + 246.11 * Math.Pow((hd + d) / He, 5) - 836.08 * Math.Pow((hd + d) / He, 4) + 1506.7 * Math.Pow((hd + d) / He, 3) - 1520.1 * Math.Pow((hd + d) / He, 2) + 815.14 * (hd + d) / He - 180.98;
    }
    return Cma;
}
static double f_Cms(double hd, double He)
{
    double Cms;
    if (hd / He > 0.7)
```

```
            {
                Cms = 1;
            }
            else
            {
                Cms = -161.95 * Math.Pow(hd / He, 6) + 416.35 * Math.Pow(hd / He, 5) -
426.22 * Math.Pow(hd / He, 4) + 224.51 * Math.Pow(hd / He, 3) - 66.258 *
Math.Pow(hd / He, 2) + 11.212 * hd / He + 0.0242;
            }
            return Cms;
        }
        static double f_Cme(double Ho, double He)
        {
            double Cme;
            Cme = 0.03 * Math.Pow(He / Ho, 3) - 0.14 * Math.Pow(He / Ho, 2) + 0.32 *
He / Ho + 0.79;
            return Cme;
        }
        static double f_Ki(double Qi, double Lspill, double wsl, double Kdi, double Kr,
double Kcrest, double Kthalweg, double Alpha, int nsl, double dsl, double tsl, int
BridgePierNumber, double BridgePierThick, double Kp, double Ka)
        {
            double Ki, Qspill, Qsluice, Ki1, Ki2, func_val1, func_val2, func_valnew;
            Ki1 = Kthalweg + 0.001;
            Ki2 = Kthalweg + 0.001;
            do
            {
                Ki2 = Ki2 + 5;
                Qspill = f_QSpill(Ki2, Kthalweg, Qi, Lspill, wsl, Kr, Kcrest, Kdi, Alpha,
nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

                Qsluice = f_QSluice(Ki2, Kthalweg, wsl, nsl, dsl);

            } while (Qi - Qspill - Qsluice > 0);

            do

            {

                Qspill = f_QSpill(Ki1, Kthalweg, Qi, Lspill, wsl, Kr, Kcrest, Kdi, Alpha,
nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

                Qsluice = f_QSluice(Ki1, Kthalweg, wsl, nsl, dsl);

                func_val1 = Qi - Qspill - Qsluice;

                Qspill = f_QSpill(Ki2, Kthalweg, Qi, Lspill, wsl, Kr, Kcrest, Kdi, Alpha,
nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

                Qsluice = f_QSluice(Ki2, Kthalweg, wsl, nsl, dsl);

                func_val2 = Qi - Qspill - Qsluice;

                Ki = (func_val2 * Ki1 - func_val1 * Ki2) / (func_val2 - func_val1);

                Qspill = f_QSpill(Ki, Kthalweg, Qi, Lspill, wsl, Kr, Kcrest, Kdi, Alpha,
nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

                Qsluice = f_QSluice(Ki, Kthalweg, wsl, nsl, dsl);

                func_valnew = Qi - Qspill - Qsluice;

                if (Math.Sign(func_val1) == Math.Sign(func_valnew))

                {

                    Ki1 = Ki;

                }

                else if (Math.Sign(func_val2) == Math.Sign(func_valnew))

                {

                    Ki2 = Ki;

                }
            } while (Math.Abs(func_valnew) >= 0.1);

            return Ki;

        }

        static double f_Ho(double Q, double L, double C)

        {

            double Ho;

            Ho = Math.Pow(Q / L / C, 0.66667);

            return Ho;

        }

        static double f_ForLen(double Q, double ReqVol, double ForWidth, double
CrestElev, double MinWL, double C)

        {

            double L0, L1, func_val0, func_val1, trial_val;

            L0 = 100;

            L1 = 90;

            while (Math.Abs(L1 - L0) >= 0.001)

            {

                func_val0 = L0 - (ReqVol / ForWidth / (CrestElev - MinWL + f_Ho(Q,
L0, C)));

                func_val1 = L1 - (ReqVol / ForWidth / (CrestElev - MinWL + f_Ho(Q,
L1, C)));

                trial_val = L1 - (func_val1 * (L1 - L0) / (func_val1 - func_val0));

                L0 = Math.Round(L1,3);

                L1 = Math.Round(trial_val,3);

            }

            return L1;

        }
        static double f_QSpill(double Ki, double Kthalweg, double Qi, double Lspill, double wsl, double Kr, double Kcrest, double Kdi, double Alpha, int nsl, double dsl, double tsl, int BridgePierNumber, double BridgePierThick, double Kp, double Ka)

        {

            double H, h, ha, Ho, hd, d, Cmo, P, Qspill, Cinc, Cma, Cme, Cms, Co, LspillNet, LspillEff;

            if (Ki > Kcrest)

            {

                h = Ki - Kthalweg;

                H = Ki - Kcrest;

                ha = Math.Pow(Qi / h / (Lspill + wsl * nsl + (nsl - 1) * tsl), 2) / 2 / g;

                Ho = H + ha;

                hd = Kcrest + Ho - Kdi;

                d = Kdi - Kr;

                P = Kcrest - Kthalweg;

                Cinc = f_Cinc(P, Ho, Alpha);

                Cma = f_Cma(hd, d, Ho);

                Cme = f_Cme(Ho, Ho);

                Cms = f_Cms(hd, Ho);

                Co = f_Co(P, Ho);

                Cmo = Cinc * Cma * Cme * Cms * Co;

                LspillNet = Lspill - BridgePierNumber * BridgePierThick;

                LspillEff = LspillNet - 2 * (BridgePierNumber * Kp + Ka) * Ho;

                Qspill = 2.18 * LspillEff * Math.Pow(Ho, 1.5);

            }

            else

            {
                Qspill = 0;
            }
            return Qspill;
        }
        static double f_QSluice(double Ki, double Kthalweg, double wsl, int nsl,
    double dsl)
        {
            double h, Qsluice;
            h = Ki - Kthalweg;
            if (h > 0)
            {
                Qsluice = 0.65 * nsl * wsl * dsl * Math.Sqrt(2 * g * h);
            }
            else
            {
                Qsluice = 0;
            }
            return Qsluice;
        }
        static double f_ycritic(double Q, double width, double sideslope)
        {
            double y1, y0, func_val0, func_val1, trial_val;
            y0 = 20;
            y1 = 10;
            while (Math.Abs(y1 - y0) >= 0.001)
            {
                func_val0 = Math.Pow(Q, 2) * f_topwidth(width, y0, sideslope) - Math.Pow(f_area(width, y0, sideslope), 2) * g;

                func_val1 = Math.Pow(Q, 2) * f_topwidth(width, y1, sideslope) - Math.Pow(f_area(width, y1, sideslope), 2) * g;

                trial_val = y1 - (func_val1 * (y1 - y0) / (func_val1 - func_val0));

                y0 = Math.Round(y1, 3);

                y1 = Math.Round(trial_val, 3);

            }

            return y1;

        }

        static double f_hydjumpy1(double Qi, double width, double deltaE)

        {

            double y1, y0, func_val0, func_val1, trial_val;

            y0 = 0.01;

            y1 = 0.005;

            while (Math.Abs(y1 - y0) >= 0.001)

            {

                func_val0 = (Math.Pow(y0 / 2 * (Math.Sqrt(1 + Math.Pow(Qi / width, 2) * 8 / (g * Math.Pow(y0, 3))) - 1) - y0, 3)) - (2 * Math.Pow(y0, 2) * (Math.Sqrt(1 + Math.Pow(Qi / width, 2) * 8 / (g * Math.Pow(y0, 3))) - 1)) * deltaE;

                func_val1 = (Math.Pow(y1 / 2 * (Math.Sqrt(1 + Math.Pow(Qi / width, 2) * 8 / (g * Math.Pow(y1, 3))) - 1) - y1, 3)) - (2 * Math.Pow(y1, 2) * (Math.Sqrt(1 + Math.Pow(Qi / width, 2) * 8 / (g * Math.Pow(y1, 3))) - 1)) * deltaE;

                trial_val = y1 - (func_val1 * (y1 - y0) / (func_val1 - func_val0));

                y0 = Math.Round(y1, 3);

                y1 = Math.Round(trial_val, 3);

            }

            return y1;
        }

        static double f_hydjumpsequent(double Q, double width, double y1)

        {

            double y2;

            y2 = (Math.Sqrt(1 + Math.Pow(Q / width, 2) * 8 / (g * Math.Pow(y1, 3))) -
    1) / 2 * y1;

            return y2;

        }

        static string f_BasinType(double Froude, double Velocity)

        {

            string BasinType;

            if (Froude >= 4.5)

            {

                if (Velocity >= 15)

                {

                    BasinType = "TypeII";

                }

                else

                {

                    BasinType = "TypeIII";

                }

            }

            else if (Froude < 4.5 && Froude > 2.5)

            {

                BasinType = "TypeIV";

            }
            else
            {
                BasinType = "Type N/A";
            }
            return BasinType;
        }
        static double f_BasinLength(string BasinType, double y2)
        {
            double BasinLength;
            if (BasinType == "TypeII")
            {
                BasinLength = 4.3 * y2;
            }
            else if (BasinType == "TypeIII")
            {
                BasinLength = 2.7 * y2;
            }
            else if (BasinType == "TypeIV")
            {
                BasinLength = 6.1 * y2;
            }
            else
            {
                BasinLength = 0;
            }
            return BasinLength;
        }
        static double f_FallVel(double ParticleDiameter)
        {
            double FallVel;
            if (ParticleDiameter == 0.15)
            {
                FallVel = 14.8;
            }
            else if (ParticleDiameter == 0.20)
            {
                FallVel = 21;
            }
            else if (ParticleDiameter == 0.30)
            {
                FallVel = 36;
            }
            else if (ParticleDiameter == 0.40)
            {
                FallVel = 50;
            }
            else if (ParticleDiameter == 0.50)
            {
                FallVel = 64;
        }
        else if (ParticleDiameter == 0.60)
        {
           FallVel = 76.4;
        }
        else if (ParticleDiameter == 0.70)
        {
           FallVel = 88.6;
        }
        else if (ParticleDiameter == 0.80)
        {
           FallVel = 99;
        }
        else if (ParticleDiameter == 0.90)
        {
           FallVel = 110;
        }
        else if (ParticleDiameter == 1.00)
        {
           FallVel = 121;
        }
        else if (ParticleDiameter == 1.20)
        {
           FallVel = 137.3;
        }
```

```
            else if (ParticleDiameter == 1.50)
            {
                FallVel = 166;
            }
            else
            {
                FallVel = 0;
            }
            return FallVel;
        }
////////////////////////////////////////////////////////////////////////////////////////////
//Module Decleration: Calculation Module                              //
//Note: All of the calculations for the whole design are made in   //
//this module after the "Run" button is clicked                        //
//Written by: EMIR ALIMOGLU                                              //
//Date: 14.06.2012                                                       //
////////////////////////////////////////////////////////////////////////////////////////
        private void runToolStripMenuItem1_Click(object sender, EventArgs e)
        {

//////////////////////////////////////////////////////////////////////////////////////////
//Module Decleration: Optimization Module                            //
//Note: All of the calculations regarding the installed capacity   //
//(design discharge) and penstock diameter                            //
//Written by: EMIR ALIMOGLU                                              //
```

```
//Date: 14.02.2011                                                    //
/////////////////////////////////////////////////////////////////////////////////////////
            FlowData[0] = Double.Parse(flowBox1.Text);
            FlowData[1] = Double.Parse(flowBox2.Text);
            FlowData[2] = Double.Parse(flowBox3.Text);
            FlowData[3] = Double.Parse(flowBox4.Text);
            FlowData[4] = Double.Parse(flowBox5.Text);
            FlowData[5] = Double.Parse(flowBox6.Text);
            FlowData[6] = Double.Parse(flowBox7.Text);
            FlowData[7] = Double.Parse(flowBox8.Text);
            FlowData[8] = Double.Parse(flowBox9.Text);
            FlowData[9] = Double.Parse(flowBox10.Text);
            FlowData[10] = Double.Parse(flowBox11.Text);
            FlowData[11] = Double.Parse(flowBox12.Text);
            FlowData[12] = Double.Parse(flowBox13.Text);
            FlowData[13] = Double.Parse(flowBox14.Text);
            FlowData[14] = Double.Parse(flowBox15.Text);
            FlowData[15] = Double.Parse(flowBox16.Text);
            FlowData[16] = Double.Parse(flowBox17.Text);
            FlowData[17] = Double.Parse(flowBox18.Text);
            FlowData[18] = Double.Parse(flowBox19.Text);
            FlowData[19] = Double.Parse(flowBox20.Text);
            FlowData[20] = Double.Parse(flowBox21.Text);
            GrossHead = Double.Parse(headBox.Text);
            PenLen = Double.Parse(PenLenBox.Text);
```

```
FrictionF = Double.Parse(FrictionFBox.Text);
TurEff = Double.Parse(TurEffBox.Text);
GenEff = Double.Parse(GenEffBox.Text);
TranEff = Double.Parse(TranEffBox.Text);
PenUnitCost = Double.Parse(PenUnitCostBox.Text);
EnergyFPrice = Double.Parse(EnergyFPriceBox.Text);
EnergySPrice = Double.Parse(EnergySPriceBox.Text);
CapUnitCost = Double.Parse(CapCostBox.Text);
CRF = Double.Parse(CRFBox.Text);
Elasticity = Double.Parse(ElasticityBox.Text);
StressAll = Double.Parse(StressBox.Text);
PenCurveBig = Double.Parse(PenCurveBigBox.Text);
PenCurveSmall = Double.Parse(PenCurveSmallBox.Text);
Tc = Double.Parse(TcBox.Text);
TotalEff = TurEff * GenEff * TranEff;
for (i = 20; i >= 0; i--)
{
   if (i == 20)
   {
      Qeq[i] = FlowData[i] * i * 5 / 100;
   }
   else
   {
      Qeq[i] = (FlowData[i] - FlowData[i + 1]) * i * 5 / 100;
   }
```

```
}
for (i = 0; i < 21; i++)
{
   if (FlowData[i] == 0)
   {
      Diameter[i] = 0;
      NetHead[i] = GrossHead;
      Power[i] = 0;
      PenThickness[i] = 0;
   }
   else
   {
      Diameter[i] = Math.Sqrt(4 * FlowData[i] / 0.125 / Math.PI / Math.Sqrt(2 * g * GrossHead));
      Diameter[i] = Math.Round(Diameter[i], 2);
      PenThickness[i] = f_PenThick(Diameter[i], GrossHead, PenLen, FlowData[i], FrictionF, StressAll, Elasticity, Tc);
      NetHead[i] = f_NetHead(FlowData[i], PenLen, GrossHead, FrictionF, Diameter[i]);
      Power[i] = f_Power(FlowData[i], f_NetHead(FlowData[i], PenLen, GrossHead, FrictionF, Diameter[i]), TotalEff);
   }
}
for (k = 20; k >= 0; k--)
{
   for (i = 20; i >= k; i--)
   {
```

```
                if (i == 20)
                {
                   TEnergy[k] = f_Power(FlowData[i], f_NetHead(FlowData[i], PenLen, GrossHead, FrictionF, Diameter[k]), TotalEff) * 8.76;
                }
                else
                {
                   TEnergy[k] = TEnergy[k] + f_ME(Qeq[i], TotalEff, f_NetHead(FlowData[i], PenLen, GrossHead, FrictionF, Diameter[k]));
                }
                if (i == 20 || i == 19)
                {
                   FEnergy[k] = TEnergy[k];
                }
             }
          }
          for (i = 20; i >= 0; i--)
          {
             SEnergy[i] = TEnergy[i] - FEnergy[i];
          }
          for (i = 20; i >= 0; i--)
          {
             PenCost[i] = f_PenWeight(Diameter[i], PenThickness[i], PenLen) * PenUnitCost * CRF;
             CapCost[i] = Power[i] * CapUnitCost * CRF;
             TotalCost[i] = CapCost[i] + PenCost[i];
             Benefit[i] = (FEnergy[i] * EnergyFPrice + SEnergy[i] * EnergySPrice) *
```

```
Math.Pow(10, 6);
            NetBenefit[i] = Benefit[i] - TotalCost[i];
        }
        for (i = 0; i < 21; i++)
        {
            FlowData[i] = Math.Round(FlowData[i], 2);
            Diameter[i] = Math.Round(Diameter[i], 2);
            NetHead[i] = Math.Round(NetHead[i], 2);
            Power[i] = Math.Round(Power[i], 3);
            FEnergy[i] = Math.Round(FEnergy[i], 3);
            SEnergy[i] = Math.Round(SEnergy[i], 3);
            TEnergy[i] = Math.Round(TEnergy[i], 3);
            PenCost[i] = Math.Round(PenCost[i], 0);
            CapCost[i] = Math.Round(CapCost[i], 0);
            TotalCost[i] = Math.Round(TotalCost[i], 0);
            Benefit[i] = Math.Round(Benefit[i], 0);
            NetBenefit[i] = Math.Round(NetBenefit[i], 0);
        }

        for (i = 20; i >= 0; i--)
        {
            if (i == 20)
            {
                DsgnDischarge = FlowData[i];
                NetHeadDsgn = NetHead[i];
                PowerDsgn = Power[i];
                FlowOccurPercent = i * 5;
                PenDiaDsgn = Diameter[i];
                FirmEnergy = FEnergy[i];
                SecondaryEnergy = SEnergy[i];
                TotalEnergy = TEnergy[i];
                PenThickDsgn = PenThickness[i];
            }
            else if (NetBenefit[i] >= NetBenefit[i + 1])
            {
                DsgnDischarge = FlowData[i];
                FlowOccurPercent = i * 5;
                TotalEnergy = TEnergy[i];
                PenDiaDsgn = Diameter[i];
                PenThickDsgn = PenThickness[i];
            }
        }
        if (DischargeCheckBox.Checked == true)
        {
            DsgnDischarge = Double.Parse(DsgnDischargeBox.Text);
        }
        PenDiaTrial = PenDiaDsgn;           // Initial values for    //
        PenThickTrial = PenThickDsgn;       // Penstock Optimization //
        for (k = 0; k < 10; k++)
        {
```

```
            for (i = 20; i >= 0; i--)
            {
               if (i == 20 && DsgnDischarge >= FlowData[i])
               {
                  TE = f_ME(Qeq[i], TotalEff, f_hf(FlowData[i], PenLen, FrictionF,
PenDiaTrial));
               }
               else if (DsgnDischarge >= FlowData[i])
               {
                  TE = TE + f_ME(Qeq[i], TotalEff, f_hf(FlowData[i], PenLen,
FrictionF, PenDiaTrial));
               }
               else
               {
                  EnergyLoss[k] = Math.Round(TE, 3);
                  TrialPenCost[k] = Math.Round(f_PenWeight(PenDiaTrial,
PenThickTrial, PenLen) * PenUnitCost * CRF, 0);
                  CostEnergyLoss[k] = Math.Round(TE * EnergySPrice *
Math.Pow(10, 6), 0);
                  TotalLossCost[k] = Math.Round(TrialPenCost[k] +
CostEnergyLoss[k], 0);
                  TrialPenDia[k] = PenDiaTrial;
                  TrialPenThick[k] = PenThickTrial;
                  PenDiaTrial = PenDiaTrial + 0.1;
                  PenThickTrial = f_PenThick(PenDiaTrial, GrossHead, PenLen,
DsgnDischarge, FrictionF, StressAll, Elasticity, Tc);
                  break;
               }
```

```
    }
}
for (k = 0; k < 10; k++)
{
    if (k == 0)
    {
        PenDiaDsgn = TrialPenDia[k];
        PenThickDsgn = TrialPenThick[k];
        Ct = TotalLossCost[k];
    }
    else if (Ct >= TotalLossCost[k])
    {
        PenDiaDsgn = TrialPenDia[k];
        PenThickDsgn = TrialPenThick[k];
        Ct = TotalLossCost[k];
    }
}
if (PenDiaCheckBox.Checked == true)
{
    PenDiaDsgn = Double.Parse(PenDiaDsgnBox.Text);
    PenThickDsgn = f_PenThick(PenDiaDsgn, GrossHead, PenLen,
DsgnDischarge, FrictionF, StressAll, Elasticity, Tc);
}
for (i = 20; i >= 0; i--)
{
    if (i == 20 && DsgnDischarge >= FlowData[i])
```

```
            {
              TotalEnergy = f_ME(Qeq[i], TotalEff, f_NetHead(FlowData[i],
PenLen, GrossHead, FrictionF, PenDiaDsgn));
            }
            else if (DsgnDischarge >= FlowData[i])
            {
              TotalEnergy = TotalEnergy + f_ME(Qeq[i], TotalEff,
f_NetHead(FlowData[i], PenLen, GrossHead, FrictionF, PenDiaDsgn));
            }
            if (i == 20 || i == 19)
            {
              FirmEnergy = TotalEnergy;
            }
            if (DsgnDischarge < FlowData[i])
            {
              SecondaryEnergy = TotalEnergy - FirmEnergy;
              break;
            }
          }
          PowerDsgn = f_Power(DsgnDischarge, f_NetHead(DsgnDischarge, PenLen,
GrossHead, FrictionF, PenDiaDsgn), TotalEff);
          NetHeadDsgn = f_NetHead(DsgnDischarge, PenLen, GrossHead, FrictionF,
PenDiaDsgn);
//////////////////////////////////////////////////////////////////////////////////////////////////
//Module Decleration: Penstock Design Module                              //
//Note: The calculations for the decided penstock diameter are           //
//carried out                                                             //
```

```
//Written by: EMIR ALIMOGLU                                          //
//Date: 17.02.2011                                                   //
//////////////////////////////////////////////////////////////////////////////////////////////////

        PenVel = f_Velocity(DsgnDischarge, f_area(PenDiaDsgn));

        FrictionLoss = f_hf(DsgnDischarge, PenLen, FrictionF, PenDiaDsgn) +
f_vel_head(PenVel) * PenCurveSmall * 0.05 + f_vel_head(PenVel) * PenCurveBig
* 0.14;

        WaveSpeed = f_WaveSpeed(PenDiaDsgn, PenThickDsgn, Elasticity);

        DeltaHead = f_DeltaHead(WaveSpeed, PenVel, PenLen, Tc);

        MaxHeadValve = GrossHead + DeltaHead - FrictionLoss;

        Pc = 882500 * Math.Pow(PenThickDsgn / (PenDiaDsgn * 1000),3);

        if (Pc <= 0.49)

        {

           AerDia = 7.47 * Math.Sqrt(DsgnDischarge / Math.Sqrt(Pc));

        }

        else

        {

           AerDia = 8.94 * Math.Sqrt(DsgnDischarge);

        }

        PenThickDsgn = PenThickDsgn + 2; //Corrosion

        FirmEnergy = Math.Round(FirmEnergy, 2);

        SecondaryEnergy = Math.Round(SecondaryEnergy, 2);

        TotalEnergy = Math.Round(TotalEnergy, 2);

        PowerDsgn = Math.Round(PowerDsgn, 2);

        NetHeadDsgn = Math.Round(NetHeadDsgn, 2);

        MaxHeadValve = Math.Round(MaxHeadValve, 2);
```

```
            FrictionLoss = Math.Round(FrictionLoss, 2);
            PenVel = Math.Round(PenVel, 2);
            WaveSpeed = Math.Round(WaveSpeed, 2);
            DeltaHead = Math.Round(DeltaHead, 2);
            AerDia = Math.Round(AerDia, 2);
////////////////////////////////////////////////////////////////////////////////////////////////
//Module Decleration: Forebay and Canal Design Module              //
//Written by: EMIR ALIMOGLU                                         //
//Date: 12.03.2012                                                  //
////////////////////////////////////////////////////////////////////////////////////////////////
            ChanRough = Double.Parse(ChanRoughBox.Text);
            PenEntElev = Double.Parse(PenEntElevBox.Text);
            RVCoeff = Double.Parse(RVCoeffBox.Text);
            ChanSSlope = Double.Parse(ChanSSlopeBox.Text);
            ChanLen = Double.Parse(ChanLenBox.Text);
            ChanSlope = Double.Parse(ChanSlopeBox.Text);
            TurType = TurTypeBox.Text;
            TurQuan = Int16.Parse(TurQuanBox.Text);
            ChanWDepth = f_yBHS(DsgnDischarge, ChanRough, ChanSSlope,
ChanSlope);
            ChanWidth = 2 * ChanWDepth * (Math.Sqrt(1 + Math.Pow(ChanSSlope,
2)) - ChanSSlope);
            FRPen = PenVel / Math.Sqrt(g * PenDiaDsgn);
            if (FRPen <= 0.25)
            {
                VortexH = 1.5 * PenDiaDsgn;
```

```
    }
    else
    {
        VortexH = (0.5 + 2 * FRPen) * PenDiaDsgn;
    }
    he = Math.Round(f_area(PenDiaDsgn) / CForCont / PenDiaDsgn,1);
    ForStep = 0.3 * he;
    ForBottomElev = PenEntElev - (he - PenDiaDsgn) / 2 - ForStep;
    MinWL = PenEntElev + PenDiaDsgn / 2 + VortexH;
    ReqVol = RVCoeff * DsgnDischarge;
    TrashRackWidth = DsgnDischarge / TrashRackVel / (0.3 * he + VortexH +
he / 2);
    ForebayWidth = TrashRackWidth + 1 + 2 * 0.3 * he;
    ChanExitElev = MinWL - f_yQmanning(0.75 * DsgnDischarge / TurQuan,
ChanRough, ChanSSlope, ChanSlope, ChanWidth);
    ChanExitWL = ChanExitElev + ChanWDepth;
    ForSpillCrest = 0.1 + ChanExitWL;
    do
    {
        ForebayLen = f_ForLen(DsgnDischarge, ReqVol, ForebayWidth,
ForSpillCrest, MinWL, 2);
        if (ForebayLen / ForebayWidth > 3)
        {
            ForebayWidth = ForebayWidth + 1;
        }
        else
        {
```

```
        break;
    }
} while (ForebayLen / ForebayWidth > 3);
ForH0 = f_Ho(DsgnDischarge,ForebayLen,2);
ForTopElev = ForSpillCrest + ForH0 + 0.1;
MaxWL = ForSpillCrest + ForH0;
NorWL = ChanExitWL;
ChanFreeboard = 0.2 * (ChanWDepth + 1);
NorWL = Math.Round(NorWL, 2);
MaxWL = Math.Round(MaxWL, 2);
TrashRackWidth = Math.Round(TrashRackWidth, 2);
ForSpillCrest = Math.Round(ForSpillCrest,2);
ForTopElev = Math.Round(ForTopElev, 2);
ForBottomElev = Math.Round(ForBottomElev, 2);
ForebayWidth = Math.Round(ForebayWidth, 1);
ForebayLen = Math.Round(ForebayLen, 1);
ChanWidth = Math.Round(ChanWidth, 2);
ChanWDepth = Math.Round(ChanWDepth, 2);
ChanExitElev = Math.Round(ChanExitElev, 2);
ChanExitWL = Math.Round(ChanExitWL, 2);
MinWL = Math.Round(MinWL, 2);
MaxWL = Math.Round(MaxWL, 2);
NorWL = Math.Round(NorWL, 2);
VortexH = Math.Round(VortexH, 2);
ChanFreeboard = Math.Round(ChanFreeboard, 2);
```

```
//////////////////////////////////////////////////////////////////////////////////////////////
//Module Decleration: Diversion Weir Intake Design Module         //
//Written by: EMIR ALIMOGLU                                                        //
//Date: 19.04.2011                                                                        //
/////////////////////////////////////////////////////////////////////////////////////////////
            PierNumber = Int16.Parse(PierNumberBox.Text);
            PierThick = Double.Parse(PierThickBox.Text);
            MaxSettDia = Double.Parse(MaxSettDiaBox.Text);
            RemovalRatio = Double.Parse(RemovalRatioBox.Text);
            Roughness = Double.Parse(RoughnessBox.Text);
            DRack = Double.Parse(DRackBox.Text);
            tRack = Double.Parse(tRackBox.Text);
            PierIntakeThick = Double.Parse(PierIntakeThickBox.Text);
            PierIntakeNumber = Int32.Parse(PierIntakeNumberBox.Text);
            Kthalweg = Double.Parse(KthalwegBox.Text);
            DuMax = Double.Parse(DuMaxBox.Text);
            DuMin = Double.Parse(DuMinBox.Text);
            DsuMax = Double.Parse(DsuMaxBox.Text);
            DsuMin = Double.Parse(DsuMinBox.Text);
            DsdMax = Double.Parse(DsdMaxBox.Text);
            DsdMin = Double.Parse(DsdMinBox.Text);
            Lspill = Double.Parse(LspillBox.Text);
            Alpha = Double.Parse(AlphaBox.Text);
            wsl = Double.Parse(wslBox.Text);
            nsl = Int16.Parse(nslBox.Text);
```

```
dsl = Double.Parse(dslBox.Text);
tsl = Double.Parse(tslBox.Text);
Kr = Double.Parse(KrBox.Text);
Kd5 = Double.Parse(Kd5Box.Text);
Kd10 = Double.Parse(Kd10Box.Text);
Kd25 = Double.Parse(Kd25Box.Text);
Kd50 = Double.Parse(Kd50Box.Text);
Kd100 = Double.Parse(Kd100Box.Text);
Q5 = Double.Parse(Q5Box.Text);
Q10 = Double.Parse(Q10Box.Text);
Q25 = Double.Parse(Q25Box.Text);
Q50 = Double.Parse(Q50Box.Text);
Q100 = Double.Parse(Q100Box.Text);
if (BridgeCheckBox.Checked == true)
{
    BridgePierNumber = Int16.Parse(BridgePierNumberBox.Text);
    BridgePierThick = Double.Parse(BridgePierThickBox.Text);
    Kp = Double.Parse(KpBox.Text);
    Ka = Double.Parse(KaBox.Text);
}
else
{
    BridgePierNumber = 0;
    BridgePierThick = 0;
    Kp = 0;
    Ka = 0;
}
//Section 1-2
ChanEntElev = ChanExitElev + ChanSlope * ChanLen;
ChanEntWL = ChanEntElev + ChanWDepth;
IntakeDepths[0] = ChanWDepth;
IntakeWL[0] = ChanEntWL;
IntakeWidths[0] = ChanWidth;
IntakeWidths[1] = 2 * ChanWidth;
IntakeVelocity[0] = f_vel(DsgnDischarge, f_area(IntakeWidths[0], IntakeDepths[0], ChanSSlope));
do
{
    IntakeDepths[1] = f_depth_iter(DsgnDischarge, IntakeWidths[1], IntakeWidths[0], IntakeDepths[0], ChanSSlope, CTransition);
    IntakeVelocity[1] = f_vel(DsgnDischarge, f_area(IntakeWidths[1], IntakeDepths[1], 0));
    if (IntakeVelocity[0] < IntakeVelocity[1])
    {
        IntakeWidths[1] = IntakeWidths[1] + 0.1;
    }
} while (IntakeVelocity[0] < IntakeVelocity[1]);
IntakeWL[1] = IntakeWL[0] + f_vel_head(IntakeVelocity[0]) + CTransition * (f_vel_head(IntakeVelocity[0]) - f_vel_head(IntakeVelocity[1])) - f_vel_head(IntakeVelocity[1]);
//Section 2-3
IntakeWidths[2] = IntakeWidths[1] - PierNumber * PierThick;
IntakeVelocity[2] = DsgnDischarge / IntakeWidths[2] / IntakeDepths[1];
```

```
        HeadLossGate = Math.Pow(IntakeVelocity[2] / OrificeCoeff, 2) / 2 / g;

        IntakeDepths[2] = f_vel_head(IntakeVelocity[1]) + IntakeDepths[1] +
HeadLossGate - f_vel_head(IntakeVelocity[2]);

        IntakeWL[2] = IntakeWL[1] + f_vel_head(IntakeVelocity[1]) +
HeadLossGate - f_vel_head(IntakeVelocity[2]);

        //Section 3-4

        IntakeWidths[3] = IntakeWidths[2] + 1;

        IntakeDepths[3] = f_depth_iter(DsgnDischarge, IntakeWidths[3],
IntakeWidths[2], IntakeDepths[2], 0, CSettContraction);

        IntakeVelocity[3] = f_vel(DsgnDischarge, f_area(IntakeWidths[3],
IntakeWidths[3], 0));

        HeadLossContraction = CSettContraction * (f_vel_head(IntakeVelocity[2]) -
f_vel_head(IntakeVelocity[3]));

        IntakeWL[3] = IntakeWL[2] + f_vel_head(IntakeVelocity[2]) +
HeadLossContraction - f_vel_head(IntakeVelocity[3]);

        //Section 4-5

        if (MaxSettDia > 1)

        {

           a = 36;

        }

        else if (MaxSettDia < 1 && MaxSettDia > 0.1)

        {

           a = 44;

        }

        else

        {

           a = 51;

        }
```

```
VMaxSett = (Math.Sqrt(MaxSettDia) * a) / 100;

IntakeWidths[4] = IntakeWidths[3];

SettUpStep = DsuMin;

do

{

   IntakeDepths[4] = f_sett_depth(DsgnDischarge, f_UpSill_loss(DsgnDischarge, IntakeWidths[4], IntakeDepths[3]), IntakeWidths[3], IntakeWidths[4], IntakeDepths[3], SettUpStep);

   IntakeVelocity[4] = f_vel(DsgnDischarge, f_area(IntakeWidths[4], IntakeDepths[4], 0));

   if (IntakeVelocity[4] > VMaxSett)

   {

      if (SettUpStep >= DsuMax)

      {

         IntakeWidths[4] = IntakeWidths[4] + 0.05;

         IntakeWidths[3] = IntakeWidths[4];

         IntakeDepths[3] = f_depth_iter(DsgnDischarge, IntakeWidths[3], IntakeWidths[2], IntakeDepths[2], 0, CSettContraction);

         IntakeVelocity[3] = f_vel(DsgnDischarge, f_area(IntakeWidths[3], IntakeDepths[3], 0));

         HeadLossContraction = CSettContraction * (f_vel_head(IntakeVelocity[2]) - f_vel_head(IntakeVelocity[3]));

         IntakeWL[3] = IntakeWL[2] + f_vel_head(IntakeVelocity[2]) + HeadLossContraction - f_vel_head(IntakeVelocity[3]);

      }

      else

      {

         SettUpStep = SettUpStep + 0.05;

      }
```

```
        }
        else
        {
            IntakeDepths[4] = f_sett_depth(DsgnDischarge, f_UpSill_loss(DsgnDischarge, IntakeWidths[4], IntakeDepths[3]), IntakeWidths[3], IntakeWidths[4], IntakeDepths[3], SettUpStep);
            IntakeVelocity[4] = f_vel(DsgnDischarge, f_area(IntakeWidths[4], IntakeDepths[4], 0));
            break;
        }
    } while (IntakeVelocity[4] > VMaxSett);
    if (MaxSettDia < 0.15)
    {
        SettVel = 663 * Math.Pow(MaxSettDia, 2);
    }
    else if (MaxSettDia > 1.5)
    {
        SettVel = 134.5 * Math.Sqrt(MaxSettDia);
    }
    else
    {
        SettVel = f_FallVel(MaxSettDia);
    }
    LSettBasin = (DsgnDischarge / (SettVel / 1000) / IntakeWidths[4]) + 2;
    IntakeWL[4] = IntakeWL[3] + f_vel_head(IntakeVelocity[3]) + f_UpSill_loss(DsgnDischarge, IntakeWidths[4], IntakeDepths[3]) - f_vel_head(IntakeVelocity[4]);
    //Section 5-6
```

```
        IntakeWidths[5] = IntakeWidths[4];

        IntakeDepths[5] = f_settbegin(DsgnDischarge, IntakeVelocity[4],
IntakeDepths[4], Roughness, LSettBasin, IntakeWidths[4], 0);

        IntakeVelocity[5] = f_vel(DsgnDischarge, f_area(IntakeWidths[5],
IntakeDepths[5], 0));

        IntakeWL[5] = IntakeWL[4] + f_vel_head(IntakeVelocity[4]) +
f_AvgFricSlope(IntakeVelocity[4], IntakeVelocity[5], IntakeDepths[5],
IntakeDepths[4], Roughness, IntakeWidths[4], 0) * LSettBasin -
f_vel_head(IntakeVelocity[5]);

        //Section 6-7

        IntakeWidths[6] = IntakeWidths[5];

        IntakeWidths[7] = IntakeWidths[6] - PierIntakeNumber * PierIntakeThick;

        SettDownStep = DsdMin;

        do

        {

          IntakeDepths[6] = f_section7_depth(DsgnDischarge, IntakeVelocity[5],
IntakeDepths[5], IntakeWidths[6], SettDownStep);

          IntakeVelocity[6] = f_vel(DsgnDischarge, f_area(IntakeWidths[6],
IntakeDepths[6], 0));

          IntakeWL[6] = IntakeWL[5] + f_vel_head(IntakeVelocity[5]) + 0.02 -
f_vel_head(IntakeVelocity[6]);

          //Section 7-8

          IntakeVelocity[7] = DsgnDischarge / IntakeWidths[7] / IntakeDepths[6];

          HeadLossGate2 = Math.Pow(IntakeVelocity[7] / OrificeCoeff, 2) / 2 / g;

          IntakeDepths[7] = f_vel_head(IntakeVelocity[6]) + IntakeDepths[6] +
HeadLossGate2 - f_vel_head(IntakeVelocity[7]);

          IntakeWL[7] = IntakeWL[6] + f_vel_head(IntakeVelocity[6]) +
HeadLossGate2 - f_vel_head(IntakeVelocity[7]);

          //Section 8-9

          nRack = (int) Math.Floor(IntakeWidths[7] / (DRack + tRack));
```

```
            IntakeGrossArea = IntakeWidths[7] * IntakeDepths[6];

            IntakeNetArea = (IntakeWidths[7] - nRack * tRack) * IntakeDepths[6];

            HeadLossTrash = (1.45 - 0.45 * IntakeNetArea / IntakeGrossArea - Math.Pow(IntakeNetArea / IntakeGrossArea, 2)) * f_vel_head(DsgnDischarge / IntakeNetArea);

            KcrestWL = IntakeWL[6] + f_vel_head(IntakeVelocity[6]) + HeadLossGate2 + HeadLossTrash + f_UpSill_loss(DsgnDischarge, IntakeWidths[7], IntakeDepths[7]) - f_vel_head(IntakeVelocity[7]);

            IntakeStep = KcrestWL - Kthalweg - IntakeDepths[7] - HeadLossTrash;

          if (IntakeStep < DuMin)

          {

            SettDownStep = SettDownStep + 0.05;

          }

          else if (IntakeStep > DuMax)

          {

            SettDownStep = SettDownStep - 0.05;

          }

        } while (IntakeStep < DuMin || IntakeStep > DuMax);

        for (i = 0; i < 8; i++)

        {

            IntakeEGL[i] = IntakeWL[i] + f_vel_head(IntakeVelocity[i]);

        }

        Kcrest = KcrestWL + 0.10;

        Lsluice = nsl * wsl + (nsl - 1) * tsl;

/////////////////////////////////////////////////////////////////////////////////////////////////

//Module Decleration: Energy Dissipator Design Module            //

//Written by: EMIR ALIMOGLU                                      //
```

```
//Date: 22.08.2011                                        //
////////////////////////////////////////////////////////////////////////////////////////

        // 100 years frequency

        K100 = f_Ki(Q100, Lspill, wsl, Kd100, Kr, Kcrest, Kthalweg, Alpha, nsl,
dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

        Qspill100 = f_QSpill(K100, Kthalweg, Q100, Lspill, wsl, Kr, Kcrest, Kd100,
Alpha, nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

        Qsluice100 = f_QSluice(K100, Kthalweg, wsl, nsl, dsl);

        ha100 = Math.Pow(Q100 / (K100 - Kthalweg) / (Lsluice + Lspill), 2) / 2 / g;

        Eu100 = K100 + ha100;

        EDSpillDepths100[2] = Kd100 - Kr;

        E3s100 = EDSpillDepths100[2] + f_vel_head(f_vel(Qspill100, f_area(Lspill,
EDSpillDepths100[2], 0))) + Kr;

        DeltaEs100 = Eu100 - E3s100;

        EDSpillDepths100[0] = f_hydjumpy1(Qspill100, Lspill, DeltaEs100);

        EDSpillDepths100[1]       =       f_hydjumpsequent(Qspill100,       Lspill,
EDSpillDepths100[0]);

        SpillwaySill100  =  EDSpillDepths100[1]  +  f_vel_head(f_vel(Qspill100,
f_area(Lspill,     EDSpillDepths100[1],     0)))     -     EDSpillDepths100[2]     +
f_vel_head(f_vel(Qspill100, f_area(Lspill, EDSpillDepths100[2], 0)));

        LEDSpill100  =  f_BasinLength(f_BasinType(f_Froude(Qspill100,  Lspill,
EDSpillDepths100[0],  0),  f_vel(Qspill100,  f_area(Lspill,  EDSpillDepths100[0],
0))), EDSpillDepths100[1]);

        EDSluiceDepths100[2] = EDSpillDepths100[2];

        E3sl100    =    EDSluiceDepths100[2]    +    f_vel_head(f_vel(Qsluice100,
f_area(Lsluice, EDSluiceDepths100[2], 0))) + Kr;

        DeltaEsl100 = Eu100 - E3sl100;

        EDSluiceDepths100[0] = f_hydjumpy1(Qsluice100, Lsluice, DeltaEsl100);

        EDSluiceDepths100[1]      =      f_hydjumpsequent(Qsluice100,      Lsluice,
EDSluiceDepths100[0]);
```

```
        SluiceSill100 = EDSluiceDepths100[1] + f_vel_head(f_vel(Qsluice100,
f_area(Lsluice, EDSluiceDepths100[1], 0))) - EDSluiceDepths100[2] +
f_vel_head(f_vel(Qsluice100, f_area(Lsluice, EDSluiceDepths100[2], 0)));

        LEDSluice100 = f_BasinLength(f_BasinType(f_Froude(Qsluice100,
Lsluice, EDSluiceDepths100[0], 0), f_vel(Qsluice100, f_area(Lsluice,
EDSluiceDepths100[0], 0))), EDSluiceDepths100[1]);

        // 50 years frequency

        K50 = f_Ki(Q50, Lspill, wsl, Kd50, Kr, Kcrest, Kthalweg, Alpha, nsl, dsl,
tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

        Qspill50 = f_QSpill(K50, Kthalweg, Q50, Lspill, wsl, Kr, Kcrest, Kd50,
Alpha, nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

        Qsluice50 = f_QSluice(K50, Kthalweg, wsl, nsl, dsl);

        ha50 = Math.Pow(Q50 / (K50 - Kthalweg) / (Lsluice + Lspill), 2) / 2 / g;

        Eu50 = K50 + ha50;

        EDSpillDepths50[2] = Kd50 - Kr;

        E3s50 = EDSpillDepths50[2] + f_vel_head(f_vel(Qspill50, f_area(Lspill,
EDSpillDepths50[2], 0))) + Kr;

        DeltaEs50 = Eu50 - E3s50;

        EDSpillDepths50[0] = f_hydjumpy1(Qspill50, Lspill, DeltaEs50);

        EDSpillDepths50[1] = f_hydjumpsequent(Qspill50, Lspill,
EDSpillDepths50[0]);

        SpillwaySill50 = EDSpillDepths50[1] + f_vel_head(f_vel(Qspill50,
f_area(Lspill, EDSpillDepths50[1], 0))) - EDSpillDepths50[2] +
f_vel_head(f_vel(Qspill50, f_area(Lspill, EDSpillDepths50[2], 0)));

        LEDSpill50 = f_BasinLength(f_BasinType(f_Froude(Qspill50, Lspill,
EDSpillDepths50[0], 0), f_vel(Qspill50, f_area(Lspill, EDSpillDepths50[0], 0))),
EDSpillDepths50[1]);

        EDSluiceDepths50[2] = EDSpillDepths50[2];

        E3sl50 = EDSluiceDepths50[2] + f_vel_head(f_vel(Qsluice50,
f_area(Lsluice, EDSluiceDepths50[2], 0))) + Kr;

        DeltaEsl50 = Eu50 - E3sl50;
```

```
    EDSluiceDepths50[0] = f_hydjumpy1(Qsluice50, Lsluice, DeltaEsl50);

    EDSluiceDepths50[1] = f_hydjumpsequent(Qsluice50, Lsluice,
EDSluiceDepths50[0]);

    SluiceSill50 = EDSluiceDepths50[1] + f_vel_head(f_vel(Qsluice50,
f_area(Lsluice, EDSluiceDepths50[1], 0))) - EDSluiceDepths50[2] +
f_vel_head(f_vel(Qsluice50, f_area(Lsluice, EDSluiceDepths50[2], 0)));

    LEDSluice50 = f_BasinLength(f_BasinType(f_Froude(Qsluice50, Lsluice,
EDSluiceDepths50[0], 0), f_vel(Qsluice50, f_area(Lsluice, EDSluiceDepths50[0],
0))), EDSluiceDepths50[1]);

    // 25 years frequency

    K25 = f_Ki(Q25, Lspill, wsl, Kd25, Kr, Kcrest, Kthalweg, Alpha, nsl, dsl,
tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

    Qspill25 = f_QSpill(K25, Kthalweg, Q25, Lspill, wsl, Kr, Kcrest, Kd25,
Alpha, nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

    Qsluice25 = f_QSluice(K25, Kthalweg, wsl, nsl, dsl);

    ha25 = Math.Pow(Q25 / (K25 - Kthalweg) / (Lsluice + Lspill), 2) / 2 / g;

    Eu25 = K25 + ha25;

    EDSpillDepths25[2] = Kd25 - Kr;

    E3s25 = EDSpillDepths25[2] + f_vel_head(f_vel(Qspill25, f_area(Lspill,
EDSpillDepths25[2], 0))) + Kr;

    DeltaEs25 = Eu25 - E3s25;

    EDSpillDepths25[0] = f_hydjumpy1(Qspill25, Lspill, DeltaEs25);

    EDSpillDepths25[1] = f_hydjumpsequent(Qspill25, Lspill,
EDSpillDepths25[0]);

    SpillwaySill25 = EDSpillDepths25[1] + f_vel_head(f_vel(Qspill25,
f_area(Lspill, EDSpillDepths25[1], 0))) - EDSpillDepths25[2] +
f_vel_head(f_vel(Qspill25, f_area(Lspill, EDSpillDepths25[2], 0)));

    LEDSpill25 = f_BasinLength(f_BasinType(f_Froude(Qspill25, Lspill,
EDSpillDepths25[0], 0), f_vel(Qspill25, f_area(Lspill, EDSpillDepths25[0], 0))),
EDSpillDepths25[1]);

    EDSluiceDepths25[2] = EDSpillDepths25[2];
```

```
E3sl25 = EDSluiceDepths25[2] + f_vel_head(f_vel(Qsluice25, f_area(Lsluice, EDSluiceDepths25[2], 0))) + Kr;

DeltaEsl25 = Eu25 - E3sl25;

EDSluiceDepths25[0] = f_hydjumpy1(Qsluice25, Lsluice, DeltaEsl25);

EDSluiceDepths25[1] = f_hydjumpsequent(Qsluice25, Lsluice, EDSluiceDepths25[0]);

SluiceSill25 = EDSluiceDepths25[1] + f_vel_head(f_vel(Qsluice25, f_area(Lsluice, EDSluiceDepths25[1], 0))) - EDSluiceDepths25[2] + f_vel_head(f_vel(Qsluice25, f_area(Lsluice, EDSluiceDepths25[2], 0)));

LEDSluice25 = f_BasinLength(f_BasinType(f_Froude(Qsluice25, Lsluice, EDSluiceDepths25[0], 0), f_vel(Qsluice25, f_area(Lsluice, EDSluiceDepths25[0], 0))), EDSluiceDepths25[1]);

// 10 years frequency

K10 = f_Ki(Q10, Lspill, wsl, Kd10, Kr, Kcrest, Kthalweg, Alpha, nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

Qspill10 = f_QSpill(K10, Kthalweg, Q10, Lspill, wsl, Kr, Kcrest, Kd10, Alpha, nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

Qsluice10 = f_QSluice(K10, Kthalweg, wsl, nsl, dsl);

ha10 = Math.Pow(Q10 / (K10 - Kthalweg) / (Lsluice + Lspill), 2) / 2 / g;

Eu10 = K10 + ha10;

EDSpillDepths10[2] = Kd10 - Kr;

E3s10 = EDSpillDepths10[2] + f_vel_head(f_vel(Qspill10, f_area(Lspill, EDSpillDepths10[2], 0))) + Kr;

DeltaEs10 = Eu10 - E3s10;

EDSpillDepths10[0] = f_hydjumpy1(Qspill10, Lspill, DeltaEs10);

EDSpillDepths10[1] = f_hydjumpsequent(Qspill10, Lspill, EDSpillDepths10[0]);

SpillwaySill10 = EDSpillDepths10[1] + f_vel_head(f_vel(Qspill10, f_area(Lspill, EDSpillDepths10[1], 0))) - EDSpillDepths10[2] + f_vel_head(f_vel(Qspill10, f_area(Lspill, EDSpillDepths10[2], 0)));

LEDSpill10 = f_BasinLength(f_BasinType(f_Froude(Qspill10, Lspill,
EDSpillDepths10[0], 0), f_vel(Qspill10, f_area(Lspill, EDSpillDepths10[0], 0))),
EDSpillDepths10[1]);

        EDSluiceDepths10[2] = EDSpillDepths10[2];

        E3sl10 = EDSluiceDepths10[2] + f_vel_head(f_vel(Qsluice10,
f_area(Lsluice, EDSluiceDepths10[2], 0))) + Kr;

        DeltaEsl10 = Eu10 - E3sl10;

        EDSluiceDepths10[0] = f_hydjumpy1(Qsluice10, Lsluice, DeltaEsl10);

        EDSluiceDepths10[1] = f_hydjumpsequent(Qsluice10, Lsluice,
EDSluiceDepths10[0]);

        SluiceSill10 = EDSluiceDepths10[1] + f_vel_head(f_vel(Qsluice10,
f_area(Lsluice, EDSluiceDepths10[1], 0))) - EDSluiceDepths10[2] +
f_vel_head(f_vel(Qsluice10, f_area(Lsluice, EDSluiceDepths10[2], 0)));

        LEDSluice10 = f_BasinLength(f_BasinType(f_Froude(Qsluice10, Lsluice,
EDSluiceDepths10[0], 0), f_vel(Qsluice10, f_area(Lsluice, EDSluiceDepths10[0],
0))), EDSluiceDepths10[1]);

        // 5 years frequency

        K5 = f_Ki(Q5, Lspill, wsl, Kd5, Kr, Kcrest, Kthalweg, Alpha, nsl, dsl, tsl,
BridgePierNumber, BridgePierThick, Kp, Ka);

        Qspill5 = f_QSpill(K5, Kthalweg, Q5, Lspill, wsl, Kr, Kcrest, Kd5, Alpha,
nsl, dsl, tsl, BridgePierNumber, BridgePierThick, Kp, Ka);

        Qsluice5 = f_QSluice(K5, Kthalweg, wsl, nsl, dsl);

        ha5 = Math.Pow(Q5 / (K5 - Kthalweg) / (Lsluice + Lspill), 2) / 2 / g;

        Eu5 = K5 + ha5;

        EDSpillDepths5[2] = Kd5 - Kr;

        E3s5 = EDSpillDepths5[2] + f_vel_head(f_vel(Qspill5, f_area(Lspill,
EDSpillDepths5[2], 0))) + Kr;

        DeltaEs5 = Eu5 - E3s5;

        EDSpillDepths5[0] = f_hydjumpy1(Qspill5, Lspill, DeltaEs5);

        EDSpillDepths5[1] = f_hydjumpsequent(Qspill5, Lspill,
EDSpillDepths5[0]);

        SpillwaySill5 = EDSpillDepths5[1] + f_vel_head(f_vel(Qspill5,
f_area(Lspill, EDSpillDepths5[1], 0))) - EDSpillDepths5[2] +
f_vel_head(f_vel(Qspill5, f_area(Lspill, EDSpillDepths5[2], 0)));

        LEDSpill5 = f_BasinLength(f_BasinType(f_Froude(Qspill5, Lspill,
EDSpillDepths5[0], 0), f_vel(Qspill5, f_area(Lspill, EDSpillDepths5[0], 0))),
EDSpillDepths5[1]);

        EDSluiceDepths5[2] = EDSpillDepths5[2];

        E3sl5 = EDSluiceDepths5[2] + f_vel_head(f_vel(Qsluice5, f_area(Lsluice,
EDSluiceDepths5[2], 0))) + Kr;

        DeltaEsl5 = Eu5 - E3sl5;

        EDSluiceDepths5[0] = f_hydjumpy1(Qsluice5, Lsluice, DeltaEsl5);

        EDSluiceDepths5[1] = f_hydjumpsequent(Qsluice5, Lsluice,
EDSluiceDepths5[0]);

        SluiceSill5 = EDSluiceDepths5[1] + f_vel_head(f_vel(Qsluice5,
f_area(Lsluice, EDSluiceDepths5[1], 0))) - EDSluiceDepths5[2] +
f_vel_head(f_vel(Qsluice5, f_area(Lsluice, EDSluiceDepths5[2], 0)));

        LEDSluice5 = f_BasinLength(f_BasinType(f_Froude(Qsluice5, Lsluice,
EDSluiceDepths5[0], 0), f_vel(Qsluice5, f_area(Lsluice, EDSluiceDepths5[0], 0))),
EDSluiceDepths5[1]);

        //Searching the worst hydraulic conditions for spillway section

        LEDSpill = LEDSpill5;

        SpillwaySill = SpillwaySill5;

        Qspill = Qspill5;

        EDSpilly1 = EDSpillDepths5[0];

        EDSpilly2 = EDSpillDepths5[1];

        if (LEDSpill <= LEDSpill10)

        {

           LEDSpill = LEDSpill10;

           SpillwaySill = SpillwaySill10;

           Qspill = Qspill10;

           EDSpilly1 = EDSpillDepths10[0];
```

```
    EDSpilly2 = EDSpillDepths10[1];
}
if (LEDSpill <= LEDSpill25)
{
    LEDSpill = LEDSpill25;
    SpillwaySill = SpillwaySill25;
    Qspill = Qspill25;
    EDSpilly1 = EDSpillDepths25[0];
    EDSpilly2 = EDSpillDepths25[1];
}
if (LEDSpill <= LEDSpill50)
{
    LEDSpill = LEDSpill50;
    SpillwaySill = SpillwaySill50;
    Qspill = Qspill50;
    EDSpilly1 = EDSpillDepths50[0];
    EDSpilly2 = EDSpillDepths50[1];
}
if (LEDSpill <= LEDSpill100)
{
    LEDSpill = LEDSpill100;
    SpillwaySill = SpillwaySill100;
    Qspill = Qspill100;
    EDSpilly1 = EDSpillDepths100[0];
    EDSpilly2 = EDSpillDepths100[1];
```

```
}
//Searching the worst hydraulic conditions for sluiceway section
LEDSluice = LEDSluice5;
SluiceSill = SluiceSill5;
Qsluice = Qsluice5;
EDSluicey1 = EDSluiceDepths5[0];
EDSluicey2 = EDSluiceDepths5[1];
if (LEDSluice <= LEDSluice10)
{
   LEDSluice = LEDSluice10;
   SluiceSill = SluiceSill10;
   Qsluice = Qsluice10;
   EDSluicey1 = EDSluiceDepths10[0];
   EDSluicey2 = EDSluiceDepths10[1];
}
if (LEDSluice <= LEDSluice25)
{
   LEDSluice = LEDSluice25;
   SluiceSill = SluiceSill25;
   Qsluice = Qsluice25;
   EDSluicey1 = EDSluiceDepths25[0];
   EDSluicey2 = EDSluiceDepths25[1];
}
if (LEDSluice <= LEDSluice50)
{
        LEDSluice = LEDSluice50;

        SluiceSill = SluiceSill50;

        Qsluice = Qsluice50;

        EDSluicey1 = EDSluiceDepths50[0];

        EDSluicey2 = EDSluiceDepths50[1];

    }

    if (LEDSluice <= LEDSluice100)

    {

        LEDSluice = LEDSluice100;

        SluiceSill = SluiceSill100;

        Qsluice = Qsluice100;

        EDSluicey1 = EDSluiceDepths100[0];

        EDSluicey2 = EDSluiceDepths100[1];

    }

        if (LEDSpill >= LEDSluice)

        {

            BasinTypeSpill = f_BasinType(f_Froude(Qspill, Lspill, EDSpilly1, 0),
f_vel(Qspill, f_area(Lspill, EDSpilly1, 0)));

            switch (BasinTypeSpill)

            {

                case "TypeII":

                    s1spill = EDSpilly1;

                    w1spill = EDSpilly1;

                    h1spill = EDSpilly1;

                    h2spill = 0.2 * EDSpilly2;

                    s2spill = 0.15 * EDSpilly2;
                w2spill = 0.15 * EDSpilly2;
                s3spill = 0;
                w3spill = 0;
                h3spill = 0;
                h4spill = 0;
                break;
            case "TypeIII":
                s1spill = EDSpilly1;
                w1spill = EDSpilly1;
                h1spill = EDSpilly1;
                h3spill = EDSpilly1 * (4 + f_Froude(Qspill, Lspill, EDSpilly1, 0))
/ 6;
                h4spill = EDSpilly1 * (9 + f_Froude(Qspill, Lspill, EDSpilly1, 0))
/ 9;
                s3spill = 0.75 * h3spill;
                w3spill = 0.75 * h3spill;
                h2spill = 0;
                s2spill = 0;
                w2spill = 0;
                break;
            case "TypeIV":
                s1spill = 0;
                w1spill = 0;
                h1spill = 0;
                h3spill = 0;
                h4spill = EDSpilly1 * (9 + f_Froude(Qspill, Lspill, EDSpilly1, 0))
/ 9;
```

```
        s3spill = 0;
        w3spill = 0;
        h2spill = 0;
        s2spill = 0;
        w2spill = 0;
        break;
    case "Type N/A":
        s1spill = 0;
        w1spill = 0;
        h1spill = 0;
        h3spill = 0;
        h4spill = 0;
        s3spill = 0;
        w3spill = 0;
        h2spill = 0;
        s2spill = 0;
        w2spill = 0;
        break;
}
LEDSluice = LEDSpill;
BasinTypeSluice = BasinTypeSpill;
s1sluice = s1spill;
w1sluice = w1spill;
h1sluice = h1spill;
h3sluice = h3spill;
```

```
        h4sluice = h4spill;
        s3sluice = s3spill;
        w3sluice = w3spill;
        h2sluice = h2spill;
        s2sluice = s2spill;
        w2sluice = w2spill;
      }
      else
      {
        BasinTypeSluice = f_BasinType(f_Froude(Qsluice, Lsluice,
EDSluicey1, 0), f_vel(Qsluice, f_area(Lsluice, EDSluicey1, 0)));
        switch (BasinTypeSluice)
        {
          case "TypeII":
            s1sluice = EDSluicey1;
            w1sluice = EDSluicey1;
            h1sluice = EDSluicey1;
            h2sluice = 0.2 * EDSluicey2;
            s2sluice = 0.15 * EDSluicey2;
            w2sluice = 0.15 * EDSluicey2;
            s3sluice = 0;
            w3sluice = 0;
            h3sluice = 0;
            h4sluice = 0;
            break;
          case "TypeIII":
            s1sluice = EDSluicey1;
            w1sluice = EDSluicey1;
            h1sluice = EDSluicey1;
            h3sluice = EDSluicey1 * (4 + f_Froude(Qsluice, Lsluice,
EDSluicey1, 0)) / 6;
            h4sluice = EDSluicey1 * (9 + f_Froude(Qsluice, Lsluice,
EDSluicey1, 0)) / 9;
            s3sluice = 0.75 * h3sluice;
            w3sluice = 0.75 * h3sluice;
            h2sluice = 0;
            s2sluice = 0;
            w2sluice = 0;
            break;
          case "TypeIV":
            s1sluice = 0;
            w1sluice = 0;
            h1sluice = 0;
            h3sluice = 0;
            h4sluice = EDSluicey1 * (9 + f_Froude(Qsluice, Lsluice,
EDSluicey1, 0)) / 9;
            s3sluice = 0;
            w3sluice = 0;
            h2sluice = 0;
            s2sluice = 0;
            w2sluice = 0;
            break;
          case "Type N/A":
```

```
        s1sluice = 0;
        w1sluice = 0;
        h1sluice = 0;
        h3sluice = 0;
        h4sluice = 0;
        s3sluice = 0;
        w3sluice = 0;
        h2sluice = 0;
        s2sluice = 0;
        w2sluice = 0;
        break;
    }
    LEDSpill = LEDSluice;
    BasinTypeSpill = BasinTypeSluice;
    s1spill = s1sluice;
    w1spill = w1sluice;
    h1spill = h1sluice;
    h3spill = h3sluice;
    h4spill = h4sluice;
    s3spill = s3sluice;
    w3spill = w3sluice;
    h2spill = h2sluice;
    s2spill = s2sluice;
    w2spill = w2sluice;
}
```

```
for (i = 0; i < 8; i++)
{
    IntakeDepths[i] = Math.Round(IntakeDepths[i], 3);
    IntakeVelocity[i] = Math.Round(IntakeVelocity[i], 3);
    IntakeWidths[i] = Math.Round(IntakeWidths[i], 3);
    IntakeWL[i] = Math.Round(IntakeWL[i], 3);
    IntakeEGL[i] = Math.Round(IntakeEGL[i], 3);
}
FR1Spill = f_Froude(Qspill, Lspill, EDSpilly1, 0);
U1Spill = f_vel(Qspill, f_area(Lspill, EDSpilly1, 0));
FR1Sluice = f_Froude(Qsluice, Lsluice, EDSluicey1, 0);
U1Sluice = f_vel(Qsluice, f_area(Lsluice, EDSluicey1, 0));
s1spill = Math.Round(s1spill, 1);
s2spill = Math.Round(s2spill, 1);
s3spill = Math.Round(s3spill, 1);
w1spill = Math.Round(w1spill, 1);
w2spill = Math.Round(w2spill, 1);
w3spill = Math.Round(w3spill, 1);
h1spill = Math.Round(h1spill, 1);
h2spill = Math.Round(h2spill, 1);
h3spill = Math.Round(h3spill, 1);
h4spill = Math.Round(h4spill, 1);
s1sluice = Math.Round(s1sluice, 1);
s2sluice = Math.Round(s2sluice, 1);
s3sluice = Math.Round(s3sluice, 1);
```

```
w1sluice = Math.Round(w1sluice, 1);
w2sluice = Math.Round(w2sluice, 1);
w3sluice = Math.Round(w3sluice, 1);
h1sluice = Math.Round(h1sluice, 1);
h2sluice = Math.Round(h2sluice, 1);
h3sluice = Math.Round(h3sluice, 1);
h4sluice = Math.Round(h4sluice, 1);
LEDSluice = Math.Round(LEDSluice, 1);
LEDSpill = Math.Round(LEDSpill, 1);
EDSluicey1 = Math.Round(EDSluicey1, 2);
EDSluicey2 = Math.Round(EDSluicey2, 2);
EDSpilly1 = Math.Round(EDSpilly1, 2);
EDSpilly2 = Math.Round(EDSpilly2, 2);
FR1Spill = Math.Round(FR1Spill, 2);
U1Spill = Math.Round(U1Spill, 2);
FR1Sluice = Math.Round(FR1Sluice, 2);
U1Sluice = Math.Round(U1Sluice, 2);
Kcrest = Math.Round(Kcrest, 3);
SettDownStep = Math.Round(SettDownStep, 2);
SettUpStep = Math.Round(SettUpStep, 2);
IntakeStep = Math.Round(IntakeStep, 2);
K100 = Math.Round(K100, 2);
LSettBasin = Math.Round(LSettBasin, 2);
Qspill = Math.Round(Qspill,2);
Qsluice = Math.Round(Qsluice,2);
```

```
            Qspill100 = Math.Round(Qspill100, 2);

            Qsluice100 = Math.Round(Qsluice100, 2);

            ChanEntElev = Math.Round(ChanEntElev, 2);

            RunCondition = true; //Indicating the Run Button clicked and calculations
completed successfully

        }

        }

    }

}

//////////////////////////////////////////////////////////////////////////////////////////////////////////

//Form Decleration: Form 2: Installed Capacity Optimzation Output //

//Window                                                                //

//////////////////////////////////////////////////////////////////////////////////////////////////////////

namespace WindowsFormsApplication1

{

    public partial class Form2 : Form

    {

        public Form2()

        {

            InitializeComponent();

        }

        int i;

        private void Form2_Load(object sender, EventArgs e)

        {

            if (Form1.RunCondition)

            {
```

```
            OptTable.Rows.Clear();

            for (i = 20; i >= 0; i--)

            {

               OptTable.Rows.Add(i*5,Form1.FlowData[i], Form1.Diameter[i], Form1.PenThickness[i], Form1.NetHead[i], Form1.Power[i], Form1.FEnergy[i], Form1.SEnergy[i], Form1.TEnergy[i], Form1.PenCost[i].ToString("#,##0"), Form1.CapCost[i].ToString("#,##0"), Form1.TotalCost[i].ToString("#,##0"), Form1.Benefit[i].ToString("#,##0"), Form1.NetBenefit[i].ToString("#,##0"));



            }

            for (i = 0; i < 21; i++)

            {

               if (Form1.DsgnDischarge == Form1.FlowData[i])

               {

                  OptTable.Rows[20-i].DefaultCellStyle.BackColor = Color.Aqua;

                  break;

               }

            }

            FlowOccurPercentLabel.Text = Form1.FlowOccurPercent.ToString();

            OptDisLabel.Text = Form1.DsgnDischarge.ToString();

            FEnergyLabel.Text = Form1.FirmEnergy.ToString();

            SEnergyLabel.Text = Form1.SecondaryEnergy.ToString();

            TEnergyLabel.Text = Form1.TotalEnergy.ToString();

            PenDiaLabel.Text = Form1.PenDiaDsgn.ToString();

            PowerLabel.Text = Form1.PowerDsgn.ToString();

            NetHeadLabel.Text = Form1.NetHeadDsgn.ToString();

         }
```

```
        }
        private void CapOptGraphButton_Click(object sender, EventArgs e)
        {
            Form9 CapOptGraph = new Form9();
            CapOptGraph.Show();
        }
    }
}
//////////////////////////////////////////////////////////////////////////////////////////////////////
//Form Decleration: Form 3: Penstock Diameter Optimzation Output  //
//Window                                                          //
////////////////////////////////////////////////////////////////////////////////////////////////////
namespace WindowsFormsApplication1
{
    public partial class Form3 : Form
    {
        public Form3()
        {
            InitializeComponent();
        }
        int k;
        private void Form3_Load(object sender, EventArgs e)
        {
            if (Form1.RunCondition)
            {
```

```
            PenOptTable.Rows.Clear();

            for (k = 0; k < 10; k++)

            {

               PenOptTable.Rows.Add(Form1.TrialPenDia[k],
Form1.TrialPenThick[k],                    Form1.TrialPenCost[k].ToString("#,##0"),
Form1.EnergyLoss[k],                   Form1.CostEnergyLoss[k].ToString("#,##0"),
Form1.TotalLossCost[k].ToString("#,##0"));

            }

            for (k = 0; k < 10; k++)

            {

               if (Form1.PenDiaDsgn == Form1.TrialPenDia[k])

               {

                  PenOptTable.Rows[k].DefaultCellStyle.BackColor = Color.Aqua;

                  break;

               }

            }

            FlowOccurPercentLabel.Text = Form1.FlowOccurPercent.ToString();

            OptDisLabel.Text = Form1.DsgnDischarge.ToString();

            FEnergyLabel.Text = Form1.FirmEnergy.ToString();

            SEnergyLabel.Text = Form1.SecondaryEnergy.ToString();

            TEnergyLabel.Text = Form1.TotalEnergy.ToString();

            PenDiaLabel.Text = Form1.PenDiaDsgn.ToString();

            PowerLabel.Text = Form1.PowerDsgn.ToString();

            NetHeadLabel.Text = Form1.NetHeadDsgn.ToString();

         }

      }

      private void button1_Click(object sender, EventArgs e)
```

```
        {
            Form10 PenOptGraph = new Form10();
            PenOptGraph.Show();
        }
    }
}
/////////////////////////////////////////////////////////////////////////////////////////////////////
//Form Decleration: Form 4: Intake Charactersitics Output Window  //
/////////////////////////////////////////////////////////////////////////////////////////////////////
namespace WindowsFormsApplication1
{
    public partial class Form4 : Form
    {
        public Form4()
        {
            InitializeComponent();
        }
        int i;
        bool boolIntake = true;
        private void Form4_Load(object sender, EventArgs e)
        {
            if (Form1.RunCondition)
            {
                for (i = 0; i < 8; i++)
                {
```

```
                IntakeOutTbl.Rows.Add(i + 1, Form1.IntakeWidths[i], Form1.IntakeDepths[i], Form1.IntakeWL[i], Form1.IntakeVelocity[i], Form1.IntakeEGL[i]);

            }

            CrestLabel.Text = Form1.Kcrest.ToString();

            SettDownStepLabel.Text = Form1.SettDownStep.ToString();

            SettUpStepLabel.Text = Form1.SettUpStep.ToString();

            IntakeStepLabel.Text = Form1.IntakeStep.ToString();

            K100Label.Text = Form1.K100.ToString();

            LSettBasinLabel.Text = Form1.LSettBasin.ToString();

            QsluiceLabel.Text = Form1.Qsluice100.ToString();

            QspillLabel.Text = Form1.Qspill100.ToString();

        }

    }

    private void IntakeImageButton_Click(object sender, EventArgs e)

    {

        if (boolIntake == true)

        {

            IntakeImagePB.Image = WindowsFormsApplication1.Properties.Resources.IntakePlan;

            IntakeImageButton.Text = "View Intake Profile";

            boolIntake = false;

        }

        else

        {

            IntakeImagePB.Image = WindowsFormsApplication1.Properties.Resources.IntakeProfile;
```

```
                IntakeImageButton.Text = "View Intake Plan";
                boolIntake = true;
            }
        }
    }
}
////////////////////////////////////////////////////////////////////////////////////////////////////////
//Form Decleration: Form 5: Energy Dissipators Design Output Window //
////////////////////////////////////////////////////////////////////////////////////////////////////////
namespace WindowsFormsApplication1
{
    public partial class Form5 : Form
    {
        public Form5()
        {
            InitializeComponent();
        }
        private void Form5_Load(object sender, EventArgs e)
        {
            if (Form1.RunCondition)
            {
                BasinTypeSluiceLabel.Text = Form1.BasinTypeSluice;
                if (Form1.BasinTypeSpill == "TypeII")
                {
                    pictureBox1.Image                                                =
WindowsFormsApplication1.Properties.Resources.USBRTypeIIBasin;
```

```
        label40.Visible = false;

        h4SpillLabel.Visible = false;

        label8.Visible = false;

        y1SpillLabel.Text = Form1.EDSpilly1.ToString();

        y2SpillLabel.Text = Form1.EDSpilly2.ToString();

        s1SpillLabel.Text = Form1.s1spill.ToString();

        s2SpillLabel.Text = Form1.s2spill.ToString();

        h1SpillLabel.Text = Form1.h1spill.ToString();

        h2SpillLabel.Text = Form1.h2spill.ToString();

        w1SpillLabel.Text = Form1.w1spill.ToString();

        w2SpillLabel.Text = Form1.w2spill.ToString();

    }

    else if (Form1.BasinTypeSpill == "TypeIII")

    {

        pictureBox1.Image                                        =
WindowsFormsApplication1.Properties.Resources.USBRTypeIIIBasin;

        label13.Text = "W3";

        label15.Text = "h3";

        label11.Text = "s3";

        y1SpillLabel.Text = Form1.EDSpilly1.ToString();

        y2SpillLabel.Text = Form1.EDSpilly2.ToString();

        s1SpillLabel.Text = Form1.s1spill.ToString();

        s2SpillLabel.Text = Form1.s3spill.ToString();

        h1SpillLabel.Text = Form1.h1spill.ToString();

        h2SpillLabel.Text = Form1.h3spill.ToString();

        w1SpillLabel.Text = Form1.w1spill.ToString();
        w2SpillLabel.Text = Form1.w3spill.ToString();

        h4SpillLabel.Text = Form1.h4spill.ToString();

    }

    else if (Form1.BasinTypeSpill == "TypeIV")

    {

        pictureBox1.Image                                             =
WindowsFormsApplication1.Properties.Resources.USBRTypeIVBasin;

        label12.Text = "2 x y1";

        label13.Text = "h4";

        label14.Visible = false;

        h1SpillLabel.Visible = false;

        label22.Visible = false;

        label10.Visible = false;

        s1SpillLabel.Visible = false;

        label18.Visible = false;

        label15.Visible = false;

        h2SpillLabel.Visible = false;

        label23.Visible = false;

        label11.Visible = false;

        s2SpillLabel.Visible = false;

        label19.Visible = false;

        label40.Visible = false;

        h4SpillLabel.Visible = false;

        label8.Visible = false;

        y1SpillLabel.Text = Form1.EDSpilly1.ToString();

        y2SpillLabel.Text = Form1.EDSpilly2.ToString();
        w1SpillLabel.Text = (2*Form1.EDSpilly1).ToString();
        w2SpillLabel.Text = Form1.h4spill.ToString();
    }
    else
    {
        pictureBox1.Image                                         =
WindowsFormsApplication1.Properties.Resources.USBRTypeIIBasin;
    }
    BasinTypeSpillLabel.Text = Form1.BasinTypeSpill;
    if (Form1.BasinTypeSluice == "TypeII")
    {
        pictureBox2.Image                                         =
WindowsFormsApplication1.Properties.Resources.USBRTypeIIBasin;
        label42.Visible = false;
        h4SluiceLabel.Visible = false;
        label41.Visible = false;
        y1SluiceLabel.Text = Form1.EDSluicey1.ToString();
        y2SluiceLabel.Text = Form1.EDSluicey2.ToString();
        s1SluiceLabel.Text = Form1.s1sluice.ToString();
        s2SluiceLabel.Text = Form1.s2sluice.ToString();
        h1SluiceLabel.Text = Form1.h1sluice.ToString();
        h2SluiceLabel.Text = Form1.h2sluice.ToString();
        w1SluiceLabel.Text = Form1.w1sluice.ToString();
        w2SluiceLabel.Text = Form1.w2sluice.ToString();
    }
    else if (Form1.BasinTypeSluice == "TypeIII")
```

```
            {
                pictureBox2.Image                                                =
WindowsFormsApplication1.Properties.Resources.USBRTypeIIIBasin;

                label34.Text = "W3";

                label32.Text = "h3";

                label36.Text = "s3";

                y1SluiceLabel.Text = Form1.EDSluicey1.ToString();

                y2SluiceLabel.Text = Form1.EDSluicey2.ToString();

                s1SluiceLabel.Text = Form1.s1sluice.ToString();

                s2SluiceLabel.Text = Form1.s3sluice.ToString();

                h1SluiceLabel.Text = Form1.h1sluice.ToString();

                h2SluiceLabel.Text = Form1.h3sluice.ToString();

                w1SluiceLabel.Text = Form1.w1sluice.ToString();

                w2SluiceLabel.Text = Form1.w3sluice.ToString();

                h4SluiceLabel.Text = Form1.h4sluice.ToString();

            }

            else if (Form1.BasinTypeSluice == "TypeIV")

            {

                pictureBox2.Image                                                =
WindowsFormsApplication1.Properties.Resources.USBRTypeIVBasin;

                label35.Text = "2 x y1";

                label34.Text = "h4";

                label33.Visible = false;

                h1SluiceLabel.Visible = false;

                label25.Visible = false;

                label37.Visible = false;
```

```
        s1SluiceLabel.Visible = false;
        label29.Visible = false;
        label32.Visible = false;
        h2SluiceLabel.Visible = false;
        label24.Visible = false;
        label36.Visible = false;
        s2SluiceLabel.Visible = false;
        label28.Visible = false;
        label42.Visible = false;
        h4SluiceLabel.Visible = false;
        label41.Visible = false;
        y1SluiceLabel.Text = Form1.EDSluicey1.ToString();
        y2SluiceLabel.Text = Form1.EDSluicey2.ToString();
        w1SluiceLabel.Text = (2 * Form1.EDSluicey1).ToString();
        w2SluiceLabel.Text = Form1.h4sluice.ToString();
    }
    else
    {
        pictureBox1.Image                                              =
WindowsFormsApplication1.Properties.Resources.USBRTypeIIBasin;
    }
    LEDsluiceLabel.Text = Form1.LEDSluice.ToString();
    LEDspillwayLabel.Text = Form1.LEDSpill.ToString();
    FR1SluiceLabel.Text = Form1.FR1Sluice.ToString();
    U1SluiceLabel.Text = Form1.U1Sluice.ToString();
    FR1SpillLabel.Text = Form1.FR1Spill.ToString();
```

```
                U1SpillLabel.Text = Form1.U1Spill.ToString();
            }
        }
    }
}
////////////////////////////////////////////////////////////////////////////////////////////////////////
//Form Decleration: Form 6: Forebay and Canal Design Output Window//
////////////////////////////////////////////////////////////////////////////////////////////////////////
namespace WindowsFormsApplication1
{
    public partial class Form6 : Form
    {
        public Form6()
        {
            InitializeComponent();
        }
        bool boolForebay = true;
        private void Form6_Load(object sender, EventArgs e)
        {
            if (Form1.RunCondition)
            {
                ForebayWidthLabel.Text = Form1.ForebayWidth.ToString();
                ForebayLenLabel.Text = Form1.ForebayLen.ToString();
                MinWLLabel.Text = Form1.MinWL.ToString();
                MaxWLLabel.Text = Form1.MaxWL.ToString();
                NorWLLabel.Text = Form1.NorWL.ToString();
                ChanExitElevLabel.Text = Form1.ChanExitElev.ToString();
                ChanWDepthLabel.Text = Form1.ChanWDepth.ToString();
                ChanExitWLLabel.Text = Form1.ChanExitWL.ToString();
                ChanWidthLabel.Text = Form1.ChanWidth.ToString();
                TrashRackWidthLabel.Text = Form1.TrashRackWidth.ToString();
                ForSpillCrestLabel.Text = Form1.ForSpillCrest.ToString();
                ForTopElevLabel.Text = Form1.ForTopElev.ToString();
                ForBottomElevLabel.Text = Form1.ForBottomElev.ToString();
                ForStepLabel.Text = Form1.ForStep.ToString();
                AerDiaLabel.Text = Form1.AerDia.ToString();
                VortexHLabel.Text = Form1.VortexH.ToString();
                ChanFreeBoardLabel.Text = Form1.ChanFreeboard.ToString();
            }
        }
        private void ForebayImageButton_Click(object sender, EventArgs e)
        {
            if (boolForebay == true)
            {
                ForebayImagePB.Image                                    =
WindowsFormsApplication1.Properties.Resources.ForebayPlan;
                ForebayImageButton.Text = "View Forebay Cross Section";
                boolForebay = false;
            }
            else
            {
                ForebayImagePB.Image                                                                =
WindowsFormsApplication1.Properties.Resources.ForebaySide;

                ForebayImageButton.Text = "View Forebay Plan";

                boolForebay = true;

            }

        }

    }

}

/////////////////////////////////////////////////////////////////////////////////////////////////////

//Form Decleration: Form 7: Penstock Characteristics Output Window//

////////////////////////////////////////////////////////////////////////////////////////////////////

namespace WindowsFormsApplication1

{

    public partial class Form7 : Form

    {

        public Form7()

        {

            InitializeComponent();

        }

        private void Form7_Load(object sender, EventArgs e)

        {

            if (Form1.RunCondition)

            {

                PenDiaDsgnLabel.Text = Form1.PenDiaDsgn.ToString();

                DeltaHeadLabel.Text = Form1.DeltaHead.ToString();

                MaxHeadValveLabel.Text = Form1.MaxHeadValve.ToString();
            PenVelLabel.Text = Form1.PenVel.ToString();
            FrictionLossLabel.Text = Form1.FrictionLoss.ToString();
            PenThickLabel.Text = Form1.PenThickDsgn.ToString();
            WaveSpeedLabel.Text = Form1.WaveSpeed.ToString();
            AerDiaLabel.Text = Form1.AerDia.ToString();
        }
    }
  }
}
//////////////////////////////////////////////////////////////////////////////////////////////////////
//Form Decleration: Form 8: General Characteristics Output Window //
//////////////////////////////////////////////////////////////////////////////////////////////////////
namespace WindowsFormsApplication1
{
  public partial class Form8 : Form
  {
    public Form8()
    {
      InitializeComponent();
    }
    private void Form8_Load(object sender, EventArgs e)
    {
      GenCharTbl.Rows.Add("Weir Characteristics", "" , "");
      GenCharTbl.Rows.Add("Thalweg Elevation", "m", Form1.Kthalweg);
      GenCharTbl.Rows.Add("Crest Elevation", "m", Form1.Kcrest);
```

```
        GenCharTbl.Rows.Add("Flood Discharge Q100", "m3", Form1.Q100);

        GenCharTbl.Rows.Add("Maximum Water Level for Q100", "m",
Form1.K100);

        GenCharTbl.Rows.Add("Spillway Crest Length", "m", Form1.Lspill);

        GenCharTbl.Rows.Add("Intake Characteristics", "", "");

        GenCharTbl.Rows.Add("Intake Entrance Bottom Elevation", "m",
Form1.Kthalweg + Form1.IntakeStep);

        GenCharTbl.Rows.Add("Width of Intake Entrance Gates", "m",
Form1.IntakeWidths[7] / (Form1.PierIntakeNumber+1));

        GenCharTbl.Rows.Add("Height of Intake Entrance Gates", "m",
Form1.IntakeDepths[6]);

        GenCharTbl.Rows.Add("Design Discharge", "m3/s",
Form1.DsgnDischarge);

        GenCharTbl.Rows.Add("Settling Basin", "", "");

        GenCharTbl.Rows.Add("Length", "m", Form1.LSettBasin);

        GenCharTbl.Rows.Add("Width", "m", Form1.IntakeWidths[4]);

        GenCharTbl.Rows.Add("Bottom Slope", "m/m", 0.01);

        GenCharTbl.Rows.Add("Conveyance Channel", "", "");

        GenCharTbl.Rows.Add("Length", "m", Form1.ChanLen);

        GenCharTbl.Rows.Add("Width", "m", Form1.ChanWidth);

        GenCharTbl.Rows.Add("Water Depth", "m", Form1.ChanWDepth);

        GenCharTbl.Rows.Add("Side Slopes", "1V:H", Form1.ChanSSlope);

        GenCharTbl.Rows.Add("Entrance Bottom Elevation", "m",
Form1.ChanEntElev);

        GenCharTbl.Rows.Add("Exit Bottom Elevation", "m",
Form1.ChanExitElev);

        GenCharTbl.Rows.Add("Channel Bottom Slope", "m/m",
Form1.ChanSlope);

        GenCharTbl.Rows.Add("Forebay", "", "");
```

```
            GenCharTbl.Rows.Add("Width", "m", Form1.ForebayWidth);

            GenCharTbl.Rows.Add("Length", "m", Form1.ForebayLen);

            GenCharTbl.Rows.Add("Height",   "m",   Math.Round(Form1.ForTopElev   -
Form1.ForBottomElev,2));

            GenCharTbl.Rows.Add("Minimum Water Level", "m", Form1.MinWL);

            GenCharTbl.Rows.Add("Normal Water Level", "m", Form1.NorWL);

            GenCharTbl.Rows.Add("Maximum Water Level", "m", Form1.MaxWL);

            GenCharTbl.Rows.Add("Bottom Elevation", "m", Form1.ForBottomElev);

            GenCharTbl.Rows.Add("Top Elevation", "m", Form1.ForTopElev);

            GenCharTbl.Rows.Add("Volume", "m3", Form1.ReqVol);

            GenCharTbl.Rows.Add("Penstock", "", "");

            GenCharTbl.Rows.Add("Length", "m", Form1.PenLen);

            GenCharTbl.Rows.Add("Diameter", "m", Form1.PenDiaDsgn);

            GenCharTbl.Rows.Add("Thickness", "mm", Form1.PenThickDsgn);

            GenCharTbl.Rows.Add("Power Plant", "", "");

            GenCharTbl.Rows.Add("Installed Capacity", "MW", Form1.PowerDsgn);

            GenCharTbl.Rows.Add("Firm Energy", "GWh/year", Form1.FirmEnergy);

            GenCharTbl.Rows.Add("Seconder              Energy",              "GWh/year",
Form1.SecondaryEnergy);

            GenCharTbl.Rows.Add("Total Energy", "GWh/year", Form1.TotalEnergy);

            GenCharTbl.Rows.Add("Gross Head", "m", Form1.GrossHead);

            GenCharTbl.Rows.Add("Net Head", "m", Form1.NetHeadDsgn);

            GenCharTbl.Rows.Add("Turbine Type", "", Form1.TurType);

            GenCharTbl.Rows[0].DefaultCellStyle.BackColor = Color.GreenYellow;

            GenCharTbl.Rows[6].DefaultCellStyle.BackColor = Color.GreenYellow;

            GenCharTbl.Rows[11].DefaultCellStyle.BackColor = Color.GreenYellow;
            GenCharTbl.Rows[15].DefaultCellStyle.BackColor = Color.GreenYellow;
            GenCharTbl.Rows[23].DefaultCellStyle.BackColor = Color.GreenYellow;
            GenCharTbl.Rows[33].DefaultCellStyle.BackColor = Color.GreenYellow;
            GenCharTbl.Rows[37].DefaultCellStyle.BackColor = Color.GreenYellow;

        }
    }
}
//////////////////////////////////////////////////////////////////////////////////////////////////////
//Form Decleration: Form 9: Installed Capacity Optimzation Graphical//
//Output Window                                                      //
//Note: For the generating of graphical output, a patch for .NET     //
//called zedgraph is utilized (http://zedgraph.org/)                 //
/////////////////////////////////////////////////////////////////////////////////////////////////////
namespace WindowsFormsApplication1
{
    public partial class Form9 : Form
    {
        public Form9()
        {
            InitializeComponent();
        }
        private void Form9_Load(object sender, EventArgs e)
        {
            if (Form1.RunCondition == true)
            {
                CreateGraph(zedGraphControl1);
                SetSize();
            }
        }
        private void Form9_Resize(object sender, EventArgs e)
        {
            SetSize();
        }
        private void SetSize()
        {
            zedGraphControl1.Location = new Point(10, 20);
            zedGraphControl1.Size = new Size(ClientRectangle.Width - 20,
ClientRectangle.Height - 20);
        }
        private void CreateGraph(ZedGraphControl zgc)
        {
            GraphPane myPane = zgc.GraphPane;
            myPane.Title.Text = "Installed Capacity Optimization Graph";
            myPane.XAxis.Title.Text = "Power (MW)";
            myPane.YAxis.Title.Text = "Net Benefit ($/year)";
            double x, y;
            PointPairList list1 = new PointPairList();
            PointPairList list2 = new PointPairList();
            for (int i = 0; i < 21; i++)
            {
                x = Form1.Power[i];

                y = Form1.NetBenefit[i];

                list1.Add(x, y);


            }

            LineItem    myCurve    =    myPane.AddCurve("",    list1,    Color.Black,
SymbolType.Diamond);

            myCurve.Line.Width = 2.0F;

            myCurve.Symbol.Fill = new Fill(Color.Black);

            zgc.AxisChange();

        }

    }

}

//////////////////////////////////////////////////////////////////////////////////////////////////////

//Form Decleration: Form 10: Penstock Diameter Optimzation Graphical//

//Output Window                                                                    //

//Note: For the generating of graphical output, a patch for .NET            //

//called zedgraph is utilized (http://zedgraph.org/)                         //

//////////////////////////////////////////////////////////////////////////////////////////////////////

namespace WindowsFormsApplication1

{

    public partial class Form10 : Form

    {

        public Form10()

        {

            InitializeComponent();
        }
        private void Form10_Load_1(object sender, EventArgs e)
        {
            if (Form1.RunCondition == true)
            {
                CreateGraph(zedGraphControl1);
                SetSize();
            }
        }
        private void Form10_Resize(object sender, EventArgs e)
        {
            SetSize();
        }
        private void SetSize()
        {
            zedGraphControl1.Location = new Point(10, 20);
            zedGraphControl1.Size = new Size(ClientRectangle.Width - 20,
ClientRectangle.Height - 20);
        }
        private void CreateGraph(ZedGraphControl zgc)
        {
            GraphPane myPane2 = zgc.GraphPane;
            myPane2.Title.Text = "Penstock Diameter Optimization Graph";
            myPane2.XAxis.Title.Text = "Penstock Diameter (m)";
            myPane2.YAxis.Title.Text = "Total Cost ($/year)";
            double x, y;
            PointPairList list1 = new PointPairList();


            for (int i = 0; i < 10; i++)
            {
                x = Form1.TrialPenDia[i];
                y = Form1.TotalLossCost[i];
                list1.Add(x, y);
            }
            LineItem myCurve = myPane2.AddCurve("", list1, Color.Black,
SymbolType.Diamond);
            myCurve.Line.Width = 2.0F;
            myCurve.Symbol.Fill = new Fill(Color.Black);
            zgc.AxisChange();
        }


    }
}
```