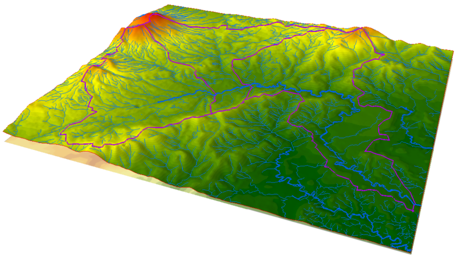

Preliminary Study of Mini Hydropower Sites in Manna Region, Bengkulu, Indonesia

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Thesis to obtain the Master of Science Degree in

Energy Engineering and management

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Dedicated to the advancement of renewable energy in Indonesia.

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Resumo

No futuro, as questões de produção e consumo de energia vão se tornar mais críticas. Para um futuro sustentável, o padrão de produção de energia tem de ser orientado pela energia renovável e soluções sustentáveis. Com as tendências actuais de produção e consumo de energia, o mundo caminha para tem futuro insustentável. Assim, o estudo e o desenvolvimento de recursos energéticos renováveis precisam ser priorizados.

Na Indonésia, apenas 10% do seu potencial hidroelétrico de 75000 MW está utilizado. Esta tese consiste num estudo preliminar sobre uma mini-hídrica a localizar em Sumatra, Indonésia. Esta dissertação inclui o estudo hidrológico, o dimensionamento e o estudo prévio, análise dos transitórios hidráulicos, e também o estudo de viabilidade técnico-económico. O estudo conclui que há um enorme potencial para o desenvolvimento deste tipo de solução.

A conclusões mostram que existe enorme potencial para desenvolvimentos futuros.

Palavras-chave: mini-hídrica, energia hidroelétrica, projeto de energia, energia renovável, energia sustentável

Abstract

For today and days to come, the issues of energy production and consumption will become more critical. In order to have sustainable future, the energy production pattern has to be shifted towards renewable and sustainable energy. With current trends of energy production and consumption, the world is heading to unsustainable future. Therefore, the study and development of renewable energy resource have to be prioritized.

In Indonesia, only 10% of its 75.000 MW hydropower potential is developed. This thesis report shows a preliminary study about a mini hydropower plant which is located in Sumatera Island, Indonesia. This thesis includes the literature review, the study of hydrology, basic power plant sizing, system transient study, and also the financial analysis. The output of this report is a recommendation that the sites have potential for further developments.

Keywords: minihydro, hydropower, energy project, renewable energy, sustainable energy

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Nomenclature

Greek symbols

α	Albedo value
δ	Solar declination angle.
ϵ_L	Singularity factor.
γ	Specific weight.
λ	Friction factor.
μ	Water viscocity.
ω	Sunset hour angle.
Φ	Latitude.
ρ	Water density.
σ	Thoma coefficient.

Roman symbols

$\dot{q}$	Volumetric flow.
c	Propagation speed.
C_{EC}	Coefficient of Energy Cost.
C_{MP}	Coefficient of Pipe Material.
D	Penstock diameter.
d_r	Relative distance of sun and earth.
E	Young' modulus of elasticity.
ET	Evapotranspiration.
f	Friction factor.
g	Gravitational acceleration.

H	Head level.
H_o	Net Head.
H_s	Admissible suction head.
H_t	Soil Moisture.
I	Yearly thermal index.
i	Monthly thermal index.
J	Hydraulic gradient
K	Fluid bulk modulus of elasticity.
L	Penstock length.
N	Rotational speed.
N_s	Specific speed.
n_{pp}	Numer of pole pair in synchronous generator.
n_{rw}	Runaway speed.
P	Power.
P_t	Precipitation.
PET	Potential Evapotranspiration.
Q	Water discharge.
R	Return of the project.
r	Discount rate.
Re	Reynolds number.
S	Submergence.
S_n	Amount of solar radiation.
S_o	Amount of solar extraterrestial radiation.
T	Temperature.
t	Time coefficient.
T_E	Elastic time coefficient.
T_L	Period of the wave.
v	Flow velocity.
x	Distance.

Chapter 1

Introduction

Energy has become an integral part of the modern world. In both developed and developing countries, energy is seen as a driving factor of economic progress and social development [1]. To accommodate this need of growth, the world energy consumption has almost always been increasing since last few decades [2]. Furthermore, the yearly global energy consumption has been rising at least for about twenty-two fold since year 1800 to 2008 [3].

For today and the days to come, the challenges and issues in energy production and consumption will become more critical and important to be tackled. One of the most important issues of our generation is about energy sustainability. To ensure that the future generations will have at least the same comfort in using energy as we are now, it is imperative that we maintain an energy system with a green energy resource, an efficient energy conversion, and an optimum energy utilization. However, with current trends in energy production and consumptions, the world is moving toward an unsustainable future [4].

Even though few measures have been taken to reduce the global greenhouse gases emission, the global emission showed no sign of slowing down in 2012, by reaching a global record high of CO_2 emission in 2012 [5]. Figure 1.1 shows the trend of a growing CO_2 emissions, with most of the emissions come from oil and coal combustion. In this scenario of energy production and consumption, greenhouse gases could be doubled in 2050, resulting in at least climate change, biodiversity loss, and rising sea level.

In this scenario, there are also another pressing factor that needs to be considered. Continuous use of energy derived from finite fossil fuel will also raise concern about energy security [6]. With the energy as an integral part in our lives, there are need to maintain energy usage at least in the same level, so that we can maintain our level of living comfort. One of the scenarios proposed by the International Energy Agency is to accelerate the deployment of low-carbon technologies and to increase the energy efficiency [6]. This thesis will focus to the application of low-carbon technology in form of small hydropower plant.

Small hydropower plant is one of the proven way to develop a potential energy in many regions. There are some advantages in developing a small hydropower [7]:

- Small hydropower provides a clean and green energy. Since a small hydropower utilizes a relatively small or medium river with not much water concentration, then it will have reduced impact in living

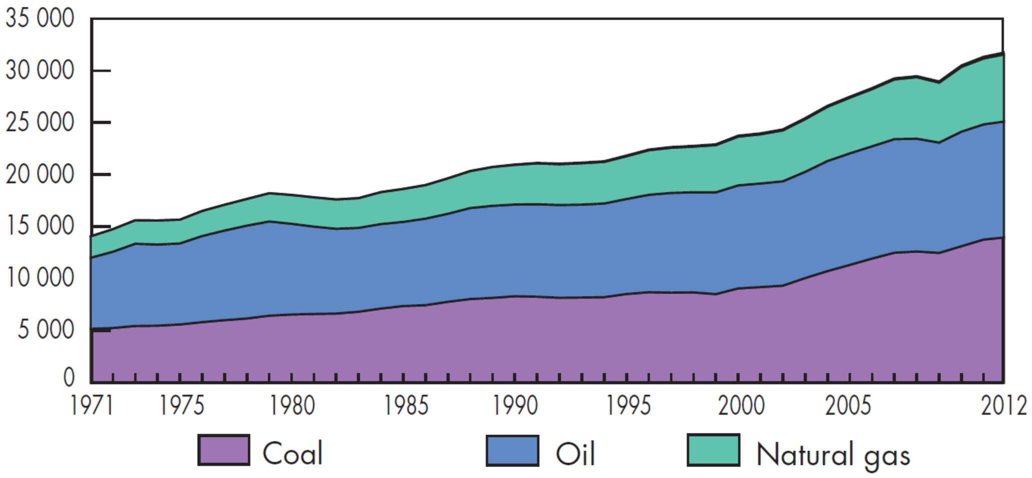


Figure 1.1: World CO_2 Emissions from 1971 to 2012 by Fuel (Mt of CO_2) [5]

organisms and ecology surrounding the hydropower plant. In addition, while in operation, the hydropower plant does not produce any greenhouse gases.

- Small hydropower technology is matured. Since the hydropower technology has existed more than 100 years ago, the design, construction, and maintenance of the hydropower plant is already well known. Consequently the risk associated with engineering side of hydropower plant development is relatively tiny.
- Small hydropower can serve another added value. In some cases of small hydropower development, the small dam or water regulator can serve as flood control.
- In some remote areas, very often small hydropower is the best choice in producing electricity.

1.1 Motivation

As a country with a high yearly economy growth rate of 5-7% for the last decade [8], coupled with rising demand for electrification in developing rural areas, Indonesia need to provide a continuous electrical power, in a reliable and sufficient manner. Referring to article 28 and article 29 of No.30 Law year 2009 in Indonesia's Electrical Power Law, the permit to provide this electrical power service is granted to state-owned company, Perusahaan Listrik Negara (PLN).

However, with vast development of the electricity demand in Indonesia, especially in Java region, quite often the supply of electricity cannot match the electricity demand. Yearly electricity demand growth of 8,5% is outpacing the electricity supply growth which only grows at 6,5% [9]. Consequently, this fact led to a series of rolling blackouts in some regions in order to keep the electrical power grid working at national level. A tireless effort and breakthrough ideas need to be implemented in order to avoid further crisis in the future, since it can hinder the development of economic growth and also diminish industrial competitiveness in Indonesia.

With current installed capacity around 50.000 MW, the projected demand growth of electricity is

35.000 MW in the next five years. In this program, PLN has already put a power plant development plan in place [8], by putting out coal fired power plant as a majority of its future power plan, at 56%. Along with another fossil fuel energy source, the plan shows a huge dependency on fossil fuel, with staggering 93% of energy souce coming from fossil fuel based energy. The detail breakdown of 35.000 MW programs is described in Figure 1.2.

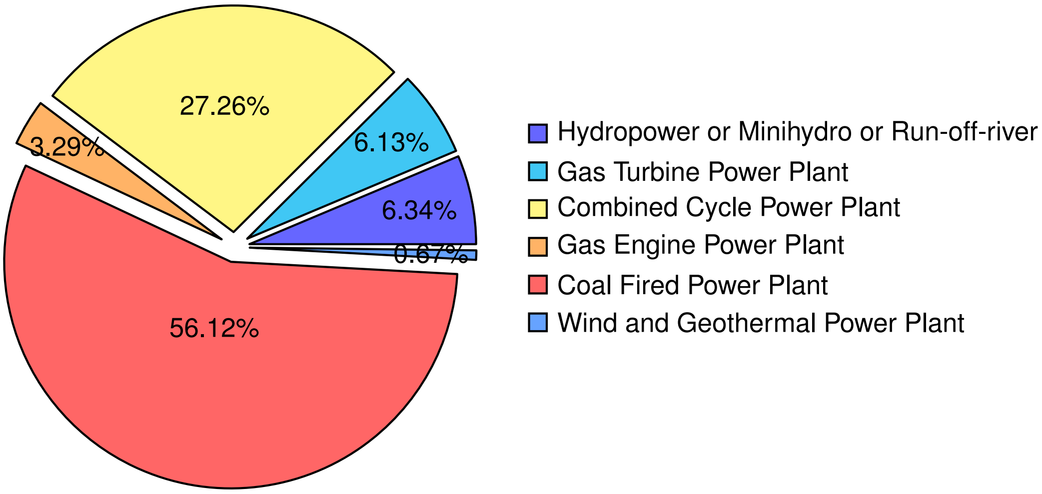


Figure 1.2: Breakdown of 35.000 MW Power Plant According to Power Plant Type

While this solution might be able to serve electricity demand in the short term, the author believes that in the long run the plan will be detrimental to the future of Indonesia's energy security. The first reason of that, is because of the polluting nature of fossil fuel energy. The rising energy production from fossil fuel will further push the emission level from Indonesia's power plant, and in the long run this will expose Indonesia's government to international pressure of reducing pollution level. The second reason is due to the fact that despite Indonesia is today the largest coal exporter in the world [8], at current (2015) rate, the coal will run out in 75 years, with no new field exploration.

The fact that Indonesia still rely on fossil fuel for the new power plant plan is very unfortunate, because actually there are alternative energy in form of renewable energy. The renewable energy resource in Indonesia is listed in Table 1.1.

Table 1.1: Renewable Energy Resources in Indonesia (2015) [8]

No	Energy Resources	Energy Potential	Installed Capacity
1	Geothermal	16.502 MW	1.341 MW
2	Hydropower	75.000 MW	7.059 MW
3	Mini/Microhydro	769,7 MW	269 MW
4	Biomass	13.662 MWe	1.364 MWe
5	Solar Energy	4,8 kWh/m2/day	42,78 MW
6	Wind Energy	3-6 m/s*	1,33 MW

*Wind energy energy resource data is not available, therefore it is presented based on the wind speed of the installed plant.

From the Table 1.1, we notice that as of 2014, the installed hydropower capacity is only about 10%

of its potential (7.059 MW out of its 75.000 MW potential). On the other hand, there is still some area for improvement to realize mini hydro power energy potential. Currently, the potential for the mini/micro hydropower of around 770 MW exist, with 30% of it already developed [10]. Author believes that in order to push renewable energy mix in the power plant development plan, more hydropower/mini hydro potential sites have to be studied. In case that more sites are proven to be feasible both technically and economically, then more sites can be further proposed to be included in PLN's plan of power plant development.

1.2 Objectives

The main objective of the thesis is to work on field study, in form of preliminary study of one of the potential mini hydropower site in Bengkulu (Manna River, Lahat) region in Indonesia. The preliminary study will consist of comprehensive study of the potential site, including study of hydrology, preliminary hydraulic design, system dynamics study, and economic analysis.

Following is the more detailed scope of the preliminary work:

- Preliminary hydrology study done based on region data and river discharge measurement. The mentioned region data includes topography map (1:50K) from indonesia geospatial portal (INA-SDI), and watershed data from Directorate of Planning and Evaluation of Watershed (Indonesia's Ministry of Forestry). This data was then analyzed in order to obtain the river discharge value.

- Preliminary topography map study. Study conducted in order to determine the location of the civil works and mechanical-electrical apparatus. Accurate coordinate location recorded by the Global Positioning System (GPS), was used as basis to decide on preliminary lay out of mini hydropower plant.

- System dynamics study. The scope of the study includes a transient condition analysis, specifically in water hammer calculations. These calculations will determine the design criteria for hydraulic system so that it can withstand the effect of pressure spike in transient condition.

- Preliminary generated power calculation. Based on the preliminary hydrology study, the preliminary layout of mini hydropower plant, a size of electrical power generated is calculated. The calculation results will also determine the choice of the mechanical-electrical apparatus and structure sizing.

- Preliminary financial analysis. The scope of this analysis is including financial aspect of the preliminary study, such as investment cost, working capital, tariff structure, cost structure, and revenue projection.

1.3 Thesis Outline

The thesis consists of six chapters. The first chapter, introduction chapter, explained the objectives and motivations of the work. In the second chapter, the literature review related to the topic of work is presented, including the hydrology, hydropower technologies, power grid analysis theory, and financial aspect of hydropower plant development.

In chapter three, the presentation of the hydropower potential site location, hydrology data processing, and the preliminary lay out consideration of the mini hydropower plant is described. In chapter four, the system dynamics study is presented, with the water hammer numerical equation models, calculations, and results. Furthermore, energy production value from power plant is calculated, presented, and analyzed in the chapter five. In addition, this chapter also presents financial sensitivity study based on the annual energy production and also local policy in Indonesia related to energy pricing and contracting.

In the last chapter, a conclusion of the study and the recommended future works are presented.

Chapter 2

Literature Review

2.1 Hydropower

Hydropower is a mature renewable energy source. Having a widespread implementation, this source of energy is used in at least 159 countries [4]. In 2010, about 16,3% [4] of the world electricity was generated from hydropower. The main benefits from this energy source is that we can harness a clean and renewable electricity that is safe, reliable, and inexpensive. In the coming future, the role of the hydropower energy as the stabilizer in the demand and supply of energy will become more important, since the number of intermittent renewable energy source such as wind power and solar photovoltaic will continue to increase greatly.

The primary prerequisite for the hydropower plant development is the availability of the potential resource in the proposed site. As a site specific energy resource, there are few factors that need to be considered in the technical development of a hydropower plant. First of all, the characteristic of the project will rely on the site's topography [11]. The next characteristic is related to the hydrology and the hydraulics, which is the volume of water discharge rate and the available head. The water discharge rate is defined as the volume of water that flows in unit of time (m^3/s), while the head is defined as the difference between two water levels, measured in m.

Subsequently, once the topography, hydrology, and hydraulic data are collected and verified, it will be accounted as the base of plant design.

There are three main types of hydropower plant design:

- Run of River (RoR) hydropower plants. As the simplest hydropower plant design, this type of plant do not requires a dam. As a result, RoR hydropower plant is one of the cheapest options of hydropower development. In this plant, the discharge come from the river flow that is available at the time. Therefore, the energy available from this type of power plant will heavily depend on the natural river flow conditions. This reliance to the river flow is the main argument against the development of RoR hydropower plants [11]. The general scheme of this hydropower plant is described in Figure 2.1.

- Reservoir hydropower plants. A larger type of hydropower plant is usually achieved by creating

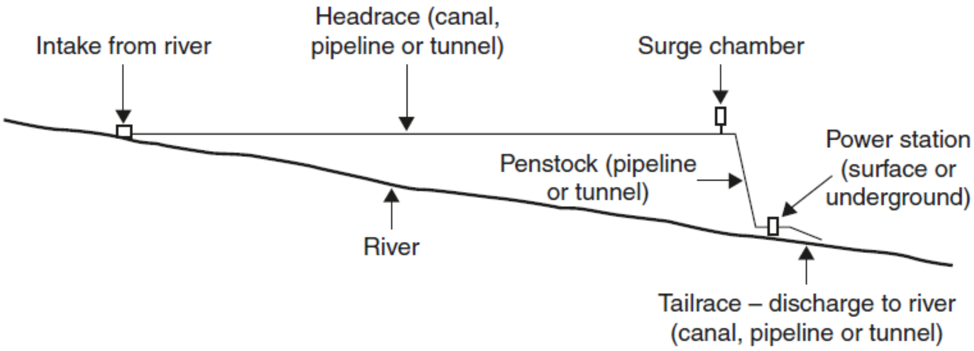


Figure 2.1: General Scheme of Run of River Hydropower Plant [11]

a reservoir to build up a large storage of water potential energy. This kind of plants will involve a major works in civil engineering, while also need to consider the geological configurations on the site. The main benefit of the reservoir construction is that it can retain months of water discharge in it. In addition, the dam construction can also adapt to the environment and social needs in the region, by providing additional benefit such as flood control and irrigation resources. However, the status of reservoir hydropower plant as the renewable energy source is still debated. There are many concerns and criticisms on the large reservoir hydropower plant that lead to harmful environmental effects, such as wildlife deterioration [11].

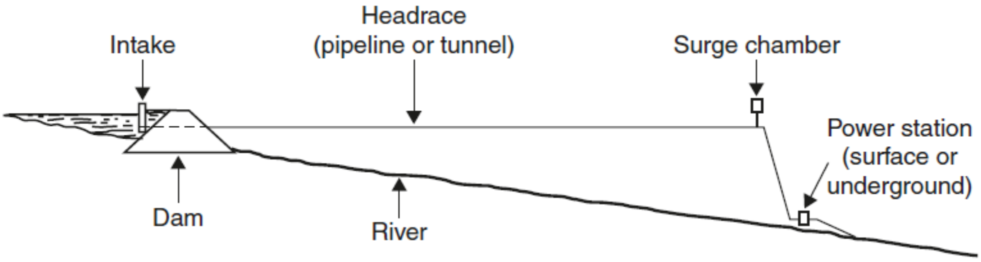


Figure 2.2: General Scheme of Reservoir Hydropower Plant [11]

- Pumped Storage plant (PSP) is a type of hydropower plant that is used specifically for energy storage. This type of plant is the most widely applied energy storage technology [12]. In 2009, about 100 GW of pumped storage plant was installed worldwide [13]. In PSP, there are at least two reservoirs, which is the upper reservoir and the lower reservoir. Water is pumped to upper reservoir to store energy when there are excess energy. The stored water in upper reservoir (Figure 2.3) then can be released to lower reservoir to move turbine, thus providing energy. The main limitation of this type of plant is that it relies heavily on topographic features, and only economically available on limited system characteristics.

In the last century, the construction of hydropower plants tends to favor the construction of centralized and big plants. This model of development was able to provide a reliable power supply. However, few problems arise following the constructions of these hydropower plants. Some of the pressing issues

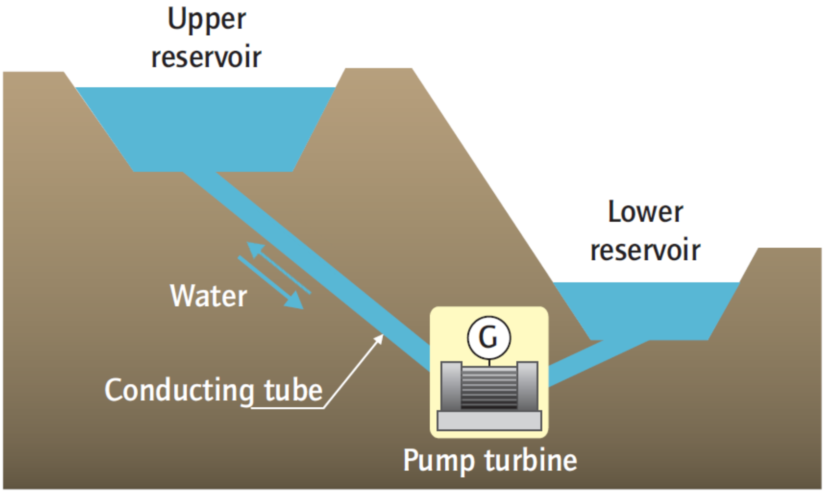


Figure 2.3: General Scheme of Pumped Storage Hydropower Plant [12]

are the displacement of the local populations, flooded fertile lands, and the diminishing performance of plants due to silting problem [14]. These conditions made the image of reservoir hydropower plant dimmed when compared to other type of hydropower plants development.

Small hydropower plants, on the other hand, is considered as the options that give minimal or even no impact to the environments. Since its capacity is usually less than 10 MW (altough there are no internationally accepted definition[15]), this type of plant is mainly designed as a run of river plants. Small hydropower plants requires a small dam or a weir. In general cases, very minimum or no water is stored in the plants [15].

2.1.1 Small Hydropower Plants

The small hydropower is typically located in a river that is associated with a watershed area that is less than 200 km^2 [16]. The available energy from the river is related to the water head, and its potential energy will be transformed into useful energy. The hydraulic gross power that is available between two points in the river can be calculated by equation 2.1 [17]:

$$P_{Wa,th} = \rho_{Wa}\, \mathrm{g}\, \dot{q}_{Wa} (H_{HW} - H_{TW}) \tag{2.1}$$

where ρ_{Wa} is the water density, g is the gravitational constant, $\dot{q}_{Wa}$ is the volumetric flow rate that going through the plants. The h constants, h_{HW} and h_{TW} are the head level of headwater and tailwater. In the small hydropower plants, the energy from the river is generally utilized by using following components [16]:

- Weir - in the small hydropower plant, weir will provide a mechanism for the incoming water to be diverted from the upstream river to the intake.
- Conveyance system - the system consists of water intake which will take the incoming water from upstream to the conveyance canal, tunnel, or pipe, and then continues the water discharge to the

penstock, hydraulic turbine, and the tailrace. The main purpose of these components is to direct the available energy in the water as the useful energy that can be used to rotate the turbine.

- Water turbine - the flow that comes from conveyance system is used to rotate the turbine.
- Generator rotor - the mechanical energy in the form of rotation is transferred to the generator using a shaft. The generator then produces electric energy that will be transmitted to the grid.
- Connection to the grid - in order for the generator to be able to transfer energy to the grid, an electric transmission and distribution line to the end customer is required.

2.1.2 Weir

The main feature of a weir is to regulate the water discharge through the intake. As some amount of the water discharge is pooled in the weir, the supply of water can be controlled, providing a regulated gross head. Depending on the head, the amount of the water that needs to be retained is varied [17]. For the low head plants, usually the water discharge is kept so that the water level in upstream is constant by using fixed weirs with movable gates or by using the gated spillways. The turbines will also regulate so that the water level is maintained in some level. In the case the water discharge to the turbines exceeds the turbines design discharge, the excess flows have to be spilled to the riverbed.

In the case the site has a higher head, fixed structure such as weirs and non-gated spillways is also applicable [17]. Since the impact of varying headwater in higher head is not too significant, this type of structure is acceptable. In addition, the fixed structure is also have the advantage of being low cost and easy to be maintained [18].

2.1.3 Conveyance System

Regulated water discharge enters the water intake, that will send water to the settling tank. One of the most important criteria in designing intake is related to the minimum submergence value. Depending on the geometry of the intake, a vortex formation may appear if the submergence value is lower than the minimum submergence value. The appearance of vortex is undesirable, since it can drag air and solid material to the intake, reducing the system efficiency [16]. One of the methods to determine the minimum submergence value for vortex formation avoidance is by using equation 2.2 [16]:

$$\frac{S}{d} = C\,\frac{v}{\sqrt{\mathrm{gd}}} \tag{2.2}$$

where S is the submergence (m), d is the intake opening (m), V is the inlet mean flow velocity (m/s), g is 9,8 m/s^2, C is 1,7 for symmetric flow, and C is 2,3 for asymmetric flow.

Afterwards, the water enters the settling tank. This tank slows down the passing water, in order to settle down the particulate matter that is contained in the passing water. In addition, a set of trash rack is placed near the settling tank, in order to filter larger object in the water such as dead leaves and garbages.

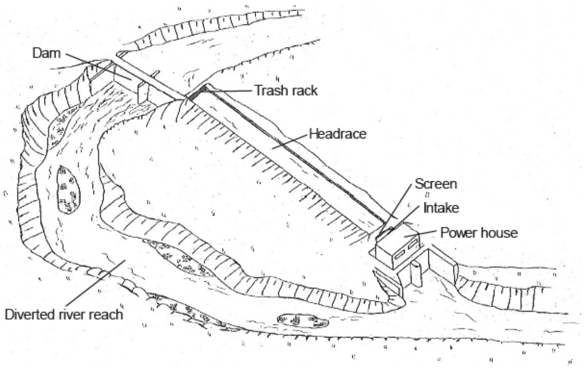


Figure 2.4: Example of Run of River Hydropower Plant with Diversion Scheme as its Conveyance System[17]

2.1.4 Penstock

To convey the water from the forebay to the turbine, a pressurised pipe system, and penstock is used [19]. The features of penstock includes a valve at the entrance of the penstock, which will be able to empty water in the pipe in case of a plant shutdown or a maintenance. In the case this situation happen, the water discharge diverts to the spillway or the canal.

The most crucial parameter that related to the penstock is the head losses. In mini hydropower plant, not all of the water energy mentioned in equation 2.1 can be harnessed. Some of the power is lost in the process of water conveyance and water discharge. The amount of head that is not considering these losses is called the gross head ($\mathrm{H_g}$), which is measured by vertical distance between upstream water level and the tailwater level. On the other hand, the head that is considering these losses is called the net head (H). The net head is determined by the gross head and the losses caused by the friction and the turbulence in the penstock $(\Delta\mathrm{H_{AB}})$ [20].

$$\mathrm{H} = \mathrm{H_g} - \Delta\mathrm{H_{AB}} \tag{2.3}$$

The friction loss in a penstock is a product of the the length of the penstock (L), and the hydraulic gradient (J) as written in equation 2.4 [21]:

$$\Delta\mathrm{H_f} = JL \tag{2.4}$$

The hydraulic gradient is defined by

$$J = f\frac{V^2}{2gD} \tag{2.5}$$

where V is the mean velocity of water in the penstock (m/s), D is the penstock diameter, and f is the friction factor f that is given by [21]:

$$f = \frac{1}{(-2log[\frac{k}{3{,}7D} - \frac{5{,}16}{Re}log[\frac{k}{3{,}7D} + \frac{5{,}09}{Re^{0{,}87}}]])^2} \tag{2.6}$$

where Re is the Reynolds number, which is given by the equation

$$Re = \frac{Dv\rho}{\mu} \tag{2.7}$$

where ρ is the density of water (kg/m^3), μ is the viscocity of water (kg/ms), and V is the mean velocity of water (m/s), and k is the absolute roughness value of the pipe, as listed in Table 2.1.

Table 2.1: Absolute roughness (k) Typical Values of Different Materials [16]

Material	k (mm)
New Cast Iron	0,25
Strongly Rusty Cast Iron	1,50
New Steel	0,10
Rusty Steel	0,40
Rough Concrete	0,6
Smooth Concrete	0,18

In the penstock, hydraulic losses also happen in the bends, valves, and connections in the hydraulic systems. In these parts, the hydraulic gradients could also be calculated using a similiar equation as the equation (2.5). However, instead of using friction factor f, the singularity factor ϵ_L is used.

$$\Delta H_{sing} = \epsilon_L \frac{V^2}{2gD}\text{[21]} \tag{2.8}$$

The singularity factor depend on the geometry and the Reynolds number. The typical values of ϵ_L are as presented in Table 2.2 to 2.4 [22].

Table 2.2: Typical values of ϵ_L in Contractions

Contraction type	ϵ_L
Sharp Edge	0,5
Rounded Edge	0,25
Conical Hord	0,1
Gradual (5^o)	0,06
Gradual (45^o)	0,30
Gradual (75^o)	0,34

Table 2.3: Typical values of ϵ_L in Bends

α	ϵ_L
30^o	0,20
40^o	0,30
60^o	0,55
80^o	0,99
90^o	1,10

Table 2.4: Typical values of ϵ_L in Valves

α (valve)	ϵ_L
5^o	0,24
20^o	1,54
40^o	10,8
60^o	118

2.1.5 Water Turbine

There are many types, sizes, and shapes of turbines that are used in hydropower systems, but in general, there are two categories of turbines: impulse turbines and reaction turbines. Depending on the head and the water discharge on the site, the selection of the turbine type is site specific. On Figure 2.5, it is shown the application of different turbines on different sites based on head and flow rate.

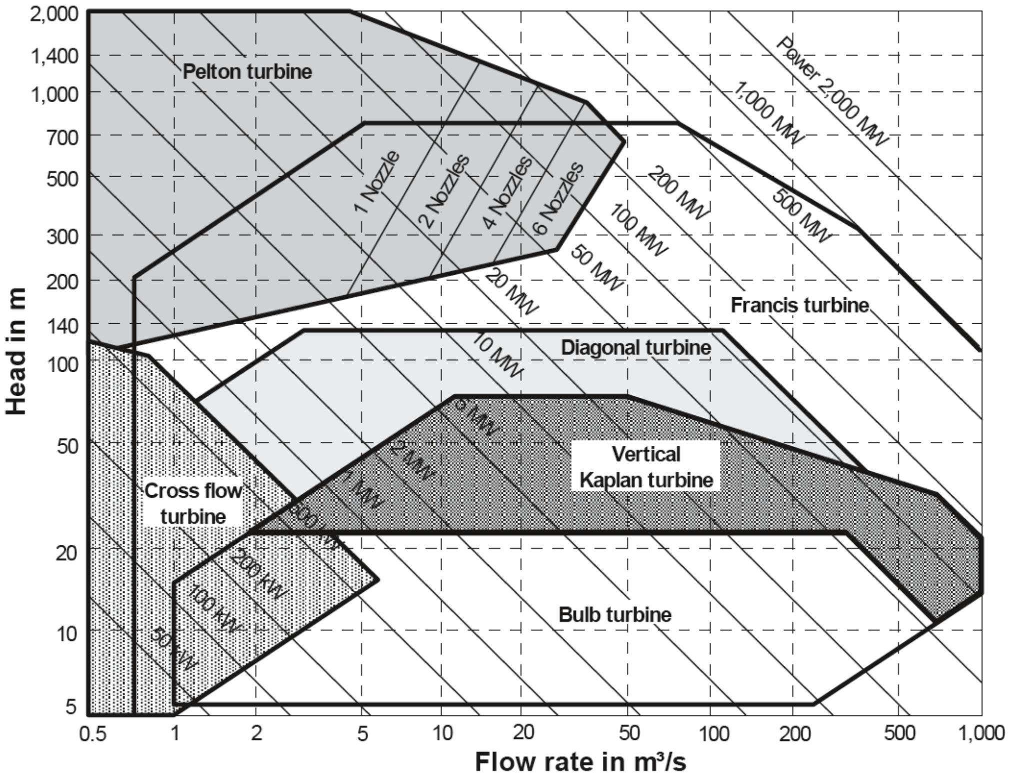


Figure 2.5: Different Turbine Application based on Head and Flow Rate [17]

Since there are many turbine types and sizes, the practical efficiencies also varies between different turbines. However, on its rated design discharge, efficiencies of turbines is ranged between 85-93% [17]. On Figure 2.6, it is shown the efficiency curve between different type of turbines. Some of the turbine like Pelton turbine have a relatively flat efficiency curve between 20-100% of maximum discharge. While on the other hand, some turbines like propeller and Francis turbines have a very steep change in efficiency when the turbine is operated far from design flows.

Impulse Turbine

The impulse turbine utilizes the kinetic energy of water to move the runner, and discharges the water in atmospheric pressure, by using jets of water. Impulse turbine is generally applied to the site with high head and low water volume flow. The high head of water produces a huge water pressure in the base, which is utilized to produce a jet of water. The main example of this type of turbine is the Pelton, turgo, and cross-flow turbines.

The Pelton turbine consists of series of cups that attached around its wheel. To move the turbine, the

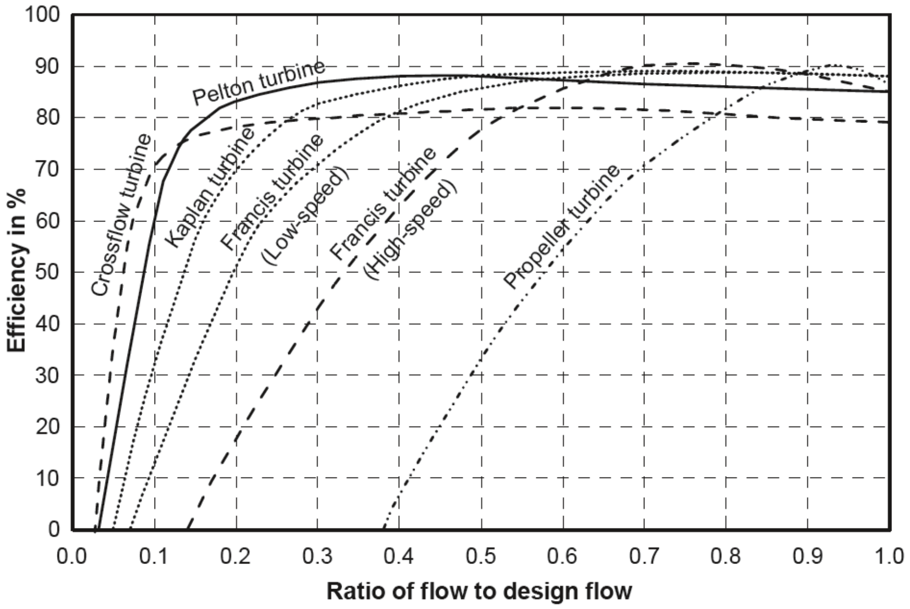


Figure 2.6: Different Turbine Types Efficiency Curve [17]

jets of water directed to the series of cups, thus providing a tangential force to the turbine. The number of jets can be varied from one to multiple jets [16].

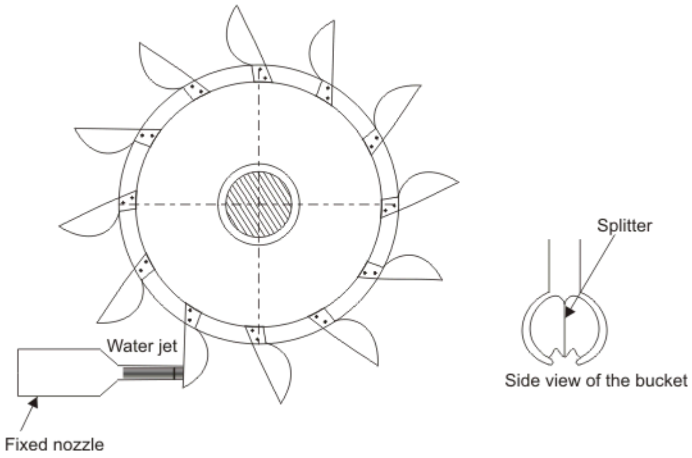


Figure 2.7: Pelton Turbine Side View with Fixed Nozzle [23]

As shown in side view of the bucket in the Figure 2.7, the cups consist of split bucket which split the jets in half. The jets then deflected at atmospheric pressure by the split buckets, turned back almost 180^o in the process. To control the strength of the water jets, the flow of water through the nozzle is controlled by a spear valve built in the nozzle.

For the safety measure, in the case of the runaway speed happen, the turbine needs to stop. In order to stop the turbine, a deflector, usually in a form of plate is placed after the nozzle to deflect the water jets. Meanwhile, the spear valve is closed slowly in order to maintain the surge in the pipeline at acceptable value [24].

Another type of impulse turbine, turgo (Figure 2.8), is designed for the medium head applications (50-250m) [16]. Compared to a Pelton turbine, turgo turbine have different shape of buckets, while also having water jets at 20^o angle. In this type of turbine, the water jets hits one side of the runner disk, and comes out on the other part of the runner.

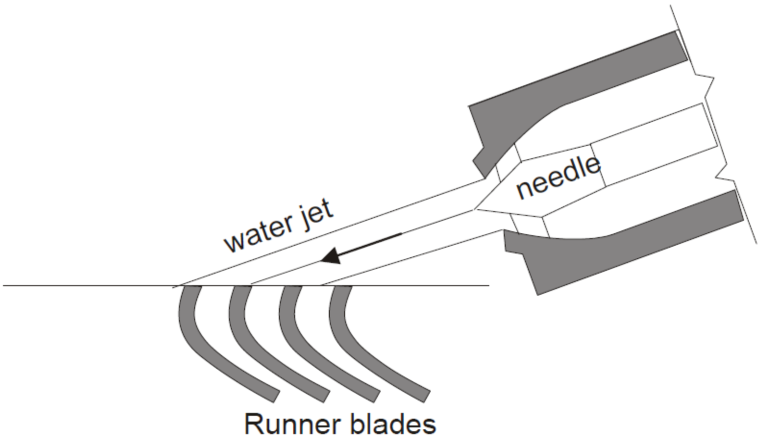


Figure 2.8: Turgo Turbine Scheme [18]

The Cross-Flow type (Figure 2.9), on the other hand, is designed for lower heads. Compared to the other impulse turbine such as Pelton and turgo, this type of turbine provides lower efficiencies, but it can utilize larger water discharges [24]. The water discharges come through an rectangular shaped nozzle output, directed to a cylindric runner by one or more guide vanes.

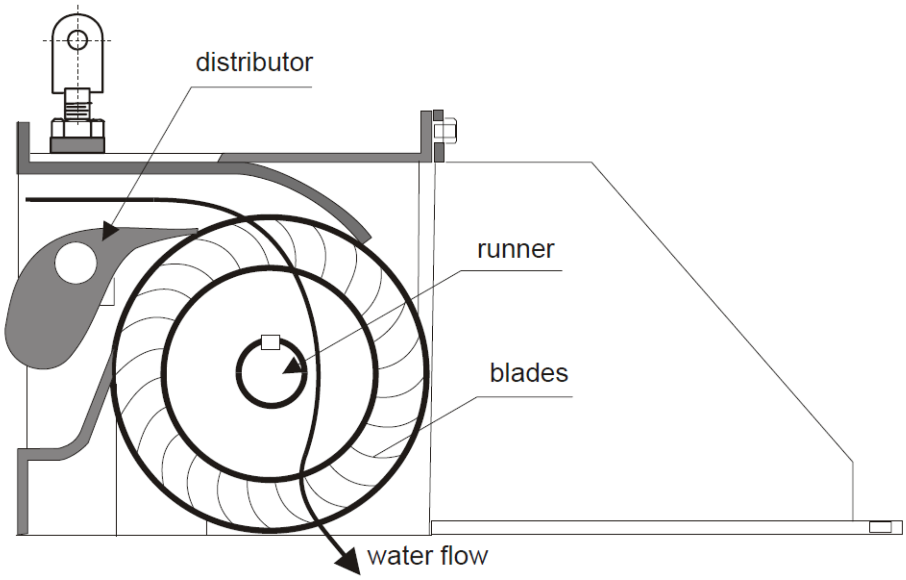
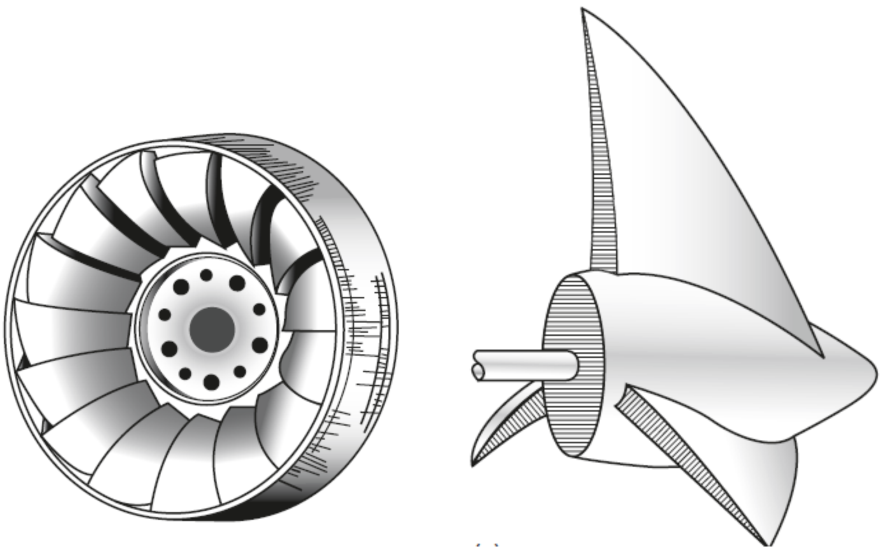


Figure 2.9: Cross Flow Turbine [18]

Reaction Turbine

Reaction turbine is the type of turbine that works in submerged water, and utilizes the energy potential that is converted into turbine rotation. For the lower head (below 450m), reaction turbine is the standard choice [11]. The most generally used reaction turbine is the Francis turbine, with propeller and Kaplan



(a) Francis Turbine (b) Propeller Turbine

Figure 2.10: Reaction Turbines

turbine are also used for the lower heads.

In the Francis turbine, the water discharges radially in the spiral casing, from the guide vane to the runner and exits axially (Figure 2.10(a)). This redirection of the flow causes the turbine to move. The blades in Francis turbine are fixed, so to regulate the flow, guide vane is used. In its operation, the runner is expected to have a high rotational speed, in order to achieve low torques at the axis, thus smaller turbine size.

The propeller and Kaplan turbines, are advantageous for low head applications, thus enable sites that are previously cannot be harnessed by Francis turbine. Propeller turbine is used when the flow and head remain relatively constant [16]. Kaplan turbines have adjustable runner blades, thus providing better efficiency to the different flow rates. On the other hand, propeller turbines (Figure 2.10(b)) have fixed blades, which are not able to provide flexibility at changing flows, but provides high efficiency at design discharge.

In turbine diameter sizing, few equations can be used to predict turbine dimensions. For the Francis turbine, the runner diameter can be calculated as [21]:

$$D = 84,5(0,31 + 2,5\,10^{-}3N_s)\frac{\sqrt{H_o}}{60\,N} \tag{2.9}$$

For the axial/propeller turbine, the runner diameter is calculated as [21]:

$$D = 84,5(0,79 + 1,602\,10^{-}3N_s)\frac{\sqrt{H_o}}{60\,N} \tag{2.10}$$

Turbine Specific Speed

The specific speed shows the speed of the turbine at its maximum efficiency related to the power and flow rate. Using these number, supported with turbine discharge and expected shaft speed design value, the optimum design of turbine is selected. The specific speed is calculated in equation 2.11 [21].

$$N_s = N\frac{\sqrt{P}}{{H_o}^{\frac{5}{4}}} \tag{2.11}$$

where N_s is the specific speed (rpm), N is the rotational speed of generator (rpm), P is the power produced by the turbine, and H_o is the net head.

For each of turbine types, the specific speed can also be calculated by empirical equations. For the Kaplan turbine, the formula is as follow [21]:

$$N_s = \frac{2700}{\sqrt{H_o}} \tag{2.12}$$

For the Francis turbine, the specific speed can be obtained as [21]:

$$N_s = \frac{1}{2}(\frac{2330 + 1550}{\sqrt{H_o}}) \tag{2.13}$$

In irregular conditions, the turbine runner can accelerate because of hydraulic conditions until it reach a maximum speed, which is called runaway speed ($N_r w$). These value depends on the specific speed (N_s) and the head values. The value of runaway speed estimated as follows:

$$n_{rw} = 0,63N_s^{0,2}N_o\frac{H^*}{H_o} \tag{2.14}$$

where H^* is the turbine head, H_o is the net head, and N_o is the rotational speed.

In overspeed conditions, the turbine discharge may or may not be affected. For impulse turbine, the discharge is independent of the runner speed. Meanwhile, for the Francis turbines, the effect of overspeed is varying. In the Francis turbine with low specific speed, the flow drops as the turbine reach overspeed conditions. On the case of Francis turbines with high specific speed, the discharge tends to increase as the turbine speed increases. For Kaplan turbines, these transient discharge also tends to increase as it reach overspeed conditions. The relation of overspeed effect on discharge variation are shown in Figure 2.11 [16].

Cavitation Effect and Turbine Suction Head

In the turbine passage way, the localized pressure level can go fall to a level that is lower than vapor pressure. In this condition, a water vapor bubbles is created. If these bubbles travel into area with higher pressure, they turn back into liquid. These phenomena is called cavitation, which can occurs to turbine surface and may damage them, as illustrated in Figure 2.12 [25].

In order to avoid these condition, the absolute pressure within the turbine must be maintained so that vapor pressures will not be created. One of the way to maintain proper pressures is by keeping the unit elevation low enough relative to the tailwater. In relation with turbine specific speed, cavitation tends to occur more on the turbine with higher operating speeds, thus lower pressures. In order to avoid cavitation, lower setting of unit elevation is needed [25].

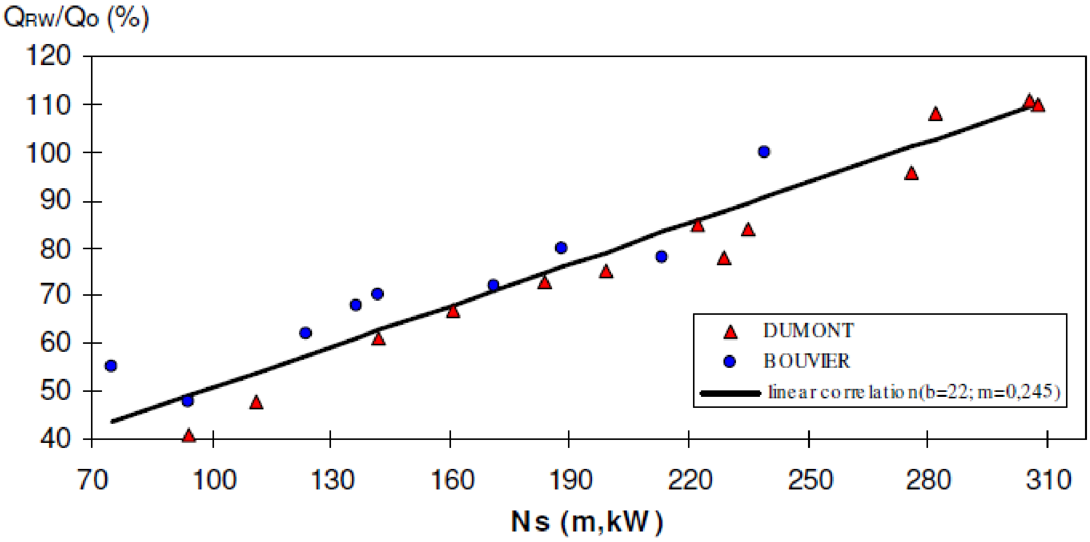


Figure 2.11: Overspeed Effect on Discharge Variation of Reaction Turbines

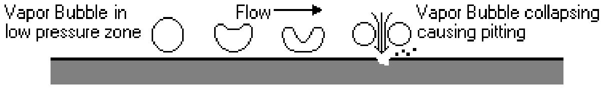


Figure 2.12: Cavitation Effect Process [25]

The maximum allowable difference between runner section and the tailrace level is defined as the admissible suction head ($h_s max$) [26]:

$$H_s = \frac{P_{atm}}{\gamma} - \frac{P_v}{\gamma} + \frac{v^2}{2g} - \sigma H_o \tag{2.15}$$

where $\frac{P_{atm}}{\gamma}$ is the local barometric head (m), $\frac{t_v}{\gamma}$ is the vapour pressure (m), H_o is the net head (m), and σ is the Thoma coefficient for each turbine, with the Thoma coefficient for Francis turbine is defined as [26]:

$$\sigma = 1,2715 \left[\frac{1,924}{H_o^{0,512}} \right]^{1,41} + \frac{v^2}{2gH_o} \tag{2.16}$$

while the Thoma coefficient for Kaplan turbine is defined as [26]:

$$\sigma = 1,5241 \left[\frac{1,924}{H_o^{0,512}} \right]^{1,46} + \frac{v^2}{2gH_o} \tag{2.17}$$

2.1.6 Generator

The generator in hydropower plant have the role to convert the mechanical energy from the turbine to the electrical energy. There are two types of generators, which are synchronous and asynchronous generators. The synchronous generator is suitable for the operation in an isolated grid, or if the hydropower plant is the main provider of the grids energy. In this case, the synchronous generator works as the grid regulator and also become the source of reactive current.

Asynchronous generator, on the other hand, needs a reactive power from the grids. Thus, it cannot generate energy when disconnected from the grid. However, asynchronous generators can provide a cheap solution when the required power quality of electricity is not very high [18], and the plant output does not significantly affect the power system. The efficiency of small hydropower generators when operating on rated capacity is between 90-95%. In the bigger plants, this value can be improved up to 99% [18].

The number of pole in synchronous generator can be calculated as follows:

$$n_{pp} = \frac{3000rpm}{N} \tag{2.18}$$

where n_{pp} is the number of pair of poles, f is the system frequency (50 Hz in Indonesia), and N is the rotational speed (rpm)

Capacity Factor

The capacity factor of a power plant is the ratio of generated energy output over a period of time, compared to the maximum potential energy output when the generator is operating at its rated capacity continuously. The formula for capacity factor (CF) is as follows:

$$CF = \frac{\text{Annual Energy Produced}(kWh)}{\text{Power Plant Capacity}(kW)\text{x}8760(h)} \tag{2.19}$$

2.2 System Dynamics

In the hydro power plant operations, surge or an unsteady flow in the pipelines may occur. Due to the water inertia, a change in the water volume flow will change the pressure in the turbine area [27]. In a preliminary design of hydro power plant, the hydraulic transients studies need to be carried in order to see if the plant could withstand the pressure change in the hydraulic circuit. Since the flow changes in the plant are expected, the impacted components such as pipe, turbine, and generator must be designed properly. In addition, unsteady condition that is caused by human errors or environmental conditions have to be considered.

Thus, in this early phase of power plant development, the preliminary transient (waterhammer) analysis for basic situations and manoeuvres has to be done. The objective of this study is to ”guarantee a feasible and economic solution without special protection devices, or to predict operational constraints or the type of protection to be specified later” [21].

2.2.1 Water Hammer

Water hammer is a transient condition which create sudden pressure changes in a pipe system. When this pressure become too much for the pipe, the system could collapse, resulting in damaged pipe or ruptured valves [21]. A study in water hammer is needed in order to understand the physics that form these pressure changes, and also to analyze maximum and minimum pressures that could happen in a pipe system.

The transient conditions that happen in the hydraulic system propagate as a flow with velocity that is quantified as elastic wave celerity value. This value depends on the elastic properties of the hydraulic circuit components and the type of fluids. For the pipe with thin wall, the elastic wave celerity value can be calculated using equation 2.20 [21].

$$c = \frac{1425}{\sqrt{1 + \frac{K}{E}\frac{D}{t}}} \tag{2.20}$$

where E is Young's modulus of elasticity of the pipe wall (250 GPa for steel), K is the fluid bulk modulus of elasticity ($2x10^3 MPa$ for water), D is the pipe diameter, and t is the pipe thickness.

One of the models that can show the example of water hammer is a model of a single pipe that leads to a turbine. In water hammer condition, the turbine is modelled as a valve. In the ideal conditions, with a instantaneous valve closing time, the pressure variation will change as the time goes as shown in Figure 2.13.

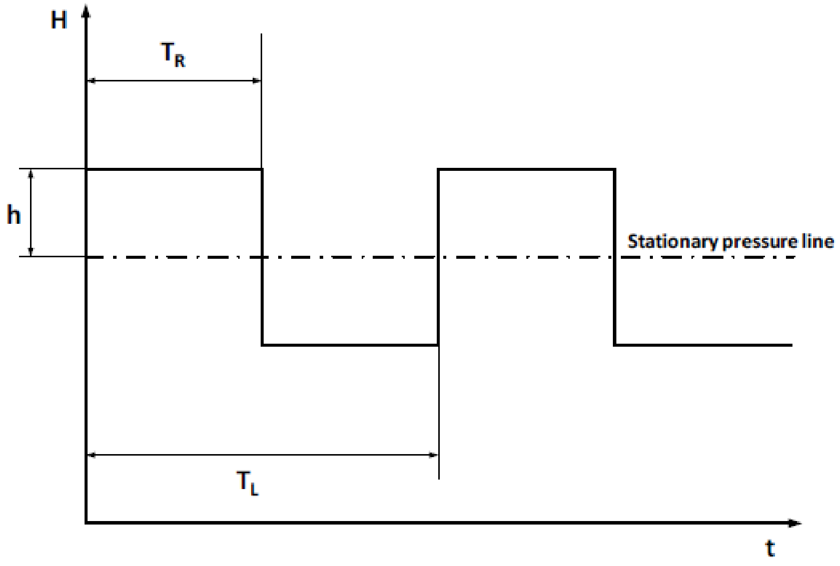


Figure 2.13: Pressure Variation in Idealized Condition

At the $t = 0$, shown with the dotted line, there are stationary pressure line, which is related to the elevation of the site. In the turbine, the pressure that happen is the addition of these stationary pressure and the dynamic pressure from water hammer.

The pressure variations are also related to the water flow direction. At the time of $t = 0$ and just as it go to $t = T_E$, the water is running in the normal velocity towards the valve. Since the valve is closed instantaneously at the time $t = 0$, the water flow is blocked and its velocity drops to zero suddenly. However, due to the gage pressure, the water will eventually returns the normal velocity, but with the direction that is going away from the valve. This inversion in water flow direction is shown by the step line in the Figure 2.13. The inverse flow then will propagate in the pipeline until the starting point of the pipe, where the pressure steps up again as shown in the end of $t = T_L$. From there, the process cycle is repeated.

Therefore, the time coefficient T_E is defined as the time that is needed for the first pressure wave to reach the opposite end of the turbine, defined as

$$T_E = \frac{2L}{c} \tag{2.21}$$

while the period of the wave (T_L) that occur in these process is formulated in equation (2.22)

$$T_L = \frac{4L}{c} \tag{2.22}$$

where L is the length from the valve to the closest free water surface (m), and c is the wave speed.

Moreover, the amount of pressure (h) that happen in idealized condition can be calculated by equation (2.23)

$$h = \frac{c\Delta v}{g} \tag{2.23}$$

where v is the water flow velocity. In order to reduce the amount of pressure in the pipe, the closing time T_e should be slower than T_e [27].

Method of Characteristics

The governing equations for the system dynamics in the unsteady flow is described by continuity equations, which are a hyperbolic differential equations. In order to solve these equations, a numerical method called the Method of Characteristics (MOC), which convert the partial differential equations of wave equations (equations 2.24 and 2.25)

$$\frac{\partial H}{\partial t} + \frac{c^2}{g}\frac{\partial v}{\partial x} = 0\,, \tag{2.24}$$

$$g\frac{\partial H}{\partial x} + \frac{\partial v}{\partial t} + \lambda\frac{v|v|}{2D} = 0\,, \tag{2.25}$$

into ordinary differential equations. The results of those transformations are as follows, with C^+ is the pressure wave when the flow is at normal direction, and C^- is the pressure wave when the flow is at inverse direction.

$$C^+ = \begin{cases} \frac{g}{a}\frac{dH}{dt} + \frac{dv}{dt} + \frac{\lambda v|v|}{2D} = 0 \\ \frac{dx}{dt} = c \end{cases} \tag{2.26}$$

$$C^- = \begin{cases} -\frac{g}{a}\frac{dH}{dt} + \frac{dv}{dt} + \frac{\lambda v|v|}{2D} = 0 \\ \frac{dx}{dt} = -c \end{cases} \tag{2.27}$$

After the continuity equations and equation of motion is set, the Method of Characteristics can be used by defining the boundary conditions such as turbines, shafts, etc [21]. A convenient way to solve these equations is by creating a graph that shows the discretized pipe line, as shown in figure 2.14.

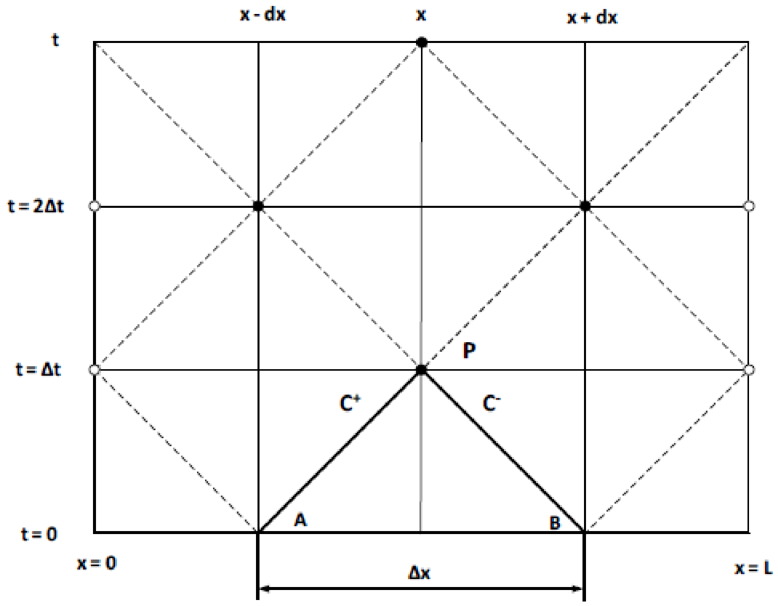


Figure 2.14: Diagram in xt-plane to Solve Single Pipe Problems [27]

In equations 2.26 and 2.27, the component $\frac{dx}{dt} = \pm c$ determines the characteristic lines, which shown by straight lines of from A to P and B to P.

In order to calculate the pressure propagation in a pipe, following steps are need to be taken:

- The pipe line is discretized, with each part is $\Delta x = c\Delta t$. The total length of the pipe is $n\Delta x$, where the n is integer value.
- Calculates the value for Q and H at $t = 0$
- The values for next time step uses the previous calculation results
- Procedures is repeated for the remaining time steps

2.2.2 Surge Oscillation

In addition of the relatively fast water hammer condition in the pipe, there are also a slower transient condition that is called surge oscillation. In order to accommodate this condition, the installation of a surge chamber between the intake and turbine may be necessary. In the case that the surge chamber is installed, the regulation of the system will get a benefit, since it can able to store water in the case of lower load. In addition, when the load increases, surge tank can also provide additional water [27].

Since the surge oscillation is relatively slower when compared to water hammer, the inertia of the water does not contribute significantly on the oscillation. In these conditions, and by assuming that the water and pipes are rigid, the equation (2.24) is rearranged to equation (2.28).

$$\frac{\partial v}{\partial x} = -\frac{g}{c^2}\frac{\partial H}{\partial t}\,, \tag{2.28}$$

by assuming that $c \to \infty$, equation (2.29) is obtained.

$$\frac{\partial v}{\partial x} = 0\,, \tag{2.29}$$

Using equations (2.25) and (2.29), and by taking note that $Q = vA$ and $\frac{\partial H}{\partial x} = \frac{H_2 - H_1}{\Delta x}$, following equation for surge oscillations are obtained

$$\frac{L}{gA}\frac{dQ}{dt} = H_1 - H_2 - cQ|Q| \tag{2.30}$$

where $c = \lambda \frac{L}{2gA^2D}$.

2.3 Hydrology

One of the most important factors in determining hydropower plant potential energy is the water discharge that runs on the site river. Eventhough a site have a very promising topographic condition, at the end of the day the energy that is harnessed from a river is dependent on the flow of water. To utilize the maximum available energy, it is important to know or estimate the water discharge discharge data through the year. Through a hydrology study, some data characterization are expected [16]:

- The operating discharge of a plant (design discharge) sizing, based on the runoff data at the river. This data will also include the water intake sizing, and diversion circuit sizing.
- The peak flow design, is based on the flood/peak flows. This data will determine the size of dam/weir, and the diversion channel on the plant.

To determine if a site has an adequate water supply for hydropower development, few approaches can be taken, which depend on the availability of the data. If the data is available through a gauging station (which is usually not the case), then this data can be used. However, it is important to make sure that the data is gauged regularly. On the other hand, the data also has to be sufficient in time. At least, the data of a period of 40 years is expected [11]. In the case there are no data or not enough data is available, the study of rainfall and streamflow based on catchment area, evapotranspiration, and geology are executed [18].

In the case that there is a gauging station that is located nearby the proposed sites, it is important to make sure that the station is located at the similiar watershed areas, or located close to the site so that the site value of mean precipitation and runoff can be represented with the gauging stations. Furthermore, another data, such as climate and geological data could also be represented through this way.

2.3.1 Watershed

Watershed shows a scope of area in land, where waters flow downstream to the common lowest point or basin [28]. This water flows through the river system, which consists of multiple and various streams of river and tributary. The river system has the lowest point compared to the surrounding areas, which serve as a conveyance system for the excess water or water runoff from a catchment area [29].

The watershed boundaries are determined by the topographical analysis that shows the hilltop with its own river channel. In practice, the boundaries are determined by drawing a line that separate the hilltop according to their landscape relief. These boundaries can be further divided into more boundaries in the form of sub-catchment areas. These areas will provide the tributaries with the water drain, which will end up in the main river channel. In Figure 2.15, example of few sub-catchment areas in watershed is shown with the purple line border. Each area that is within the border has their own tributaries that will supply the water discharge to the main river channel (shown by a thicker blue line).

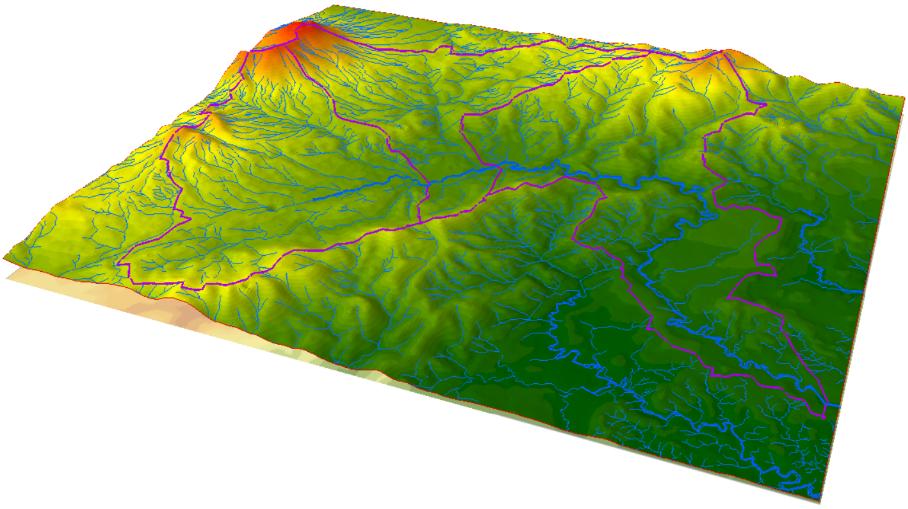


Figure 2.15: Watershed and Its Sub-Watersheds

2.3.2 Precipitation in a Catchment Area

The water that is precipitated within a catchment area determines the water supply that is flowing in to a river or reservoir. To measure the amount of precipitation, ideally a number of rain gauges is deployed within the catchment area to measure the timely quantity of data. However, since very often in the case of hydropower development the rain gauge is not placed at the catchment area, it is sometimes necessary to sample few station that is located close to the proposed site.

The sampling process inevitably produce an error, which is related to the number of rain gauges, catchment area size, the weather characteristics, and the terrain [30]. Consequently, to further reduce the errors, it is important to have more rain gauges in the area. However, in the case of Indonesia, very often it is found that the data that is provided by the rain gauge station location is very limited, thus providing the data from that station is unusable.

The amount of error can be estimated [31], in terms of rain gauge spacing between each others. The recommended spacing of rain gauges is by placing a gauge in every area of 600-900 km^2 for flat areas. For mountainous regions, more rain gauges are needed, with a gauge in every 100-250 km^2 [32].

Table 2.5: Errors related to the number of gauges within an area

	Area per gauge (km^2)					
	10	50	100	500	1000	5000
Number of gauges	Error: percent of mean (%)					
1	26	28	34	38	47	54
2	18	20	23	27	35	38
5	11	12	15	17	22	24
10	8	8	10	14	16	17
20	6	6	8	8	10	12
50	4	4	4	6	7	8
100	2	2	3	4	5	6

In the condition that there are no rain gauge in the watershed of interest, estimation of the precipitation can also be done in the location between gauges. One rough way to estimate the precipitation in area of interest is by using a rain gauge data that have a similar vegetation [30]. To gain a better data estimation, average value of few nearby rain gauge data can be calculated, after each rain gauge data is weighted by the distance of particular rain gauge to the area of interest.

2.3.3 Evapotranspiration

Evapotranspiration is the representation of total evaporation and transpiration that comes from the land to atmosphere. Evaporation defined as the water movement process from soil to the atmosphere, while transpiration is the water movement from plant to the atmosphere through stomata. Determining factor that affect evapotranspiration is the air temperature, relative humidity, wind speed, and sunshine duration during the day [33].

When the amount of water resource is available, the amount of evapotranspiration that occurs is called as potential evapotranspiration (PET). There are few methods that can be used to estimate evapotranspiration, depending on the available data [34]. For the application of watershed that is large, the method of crop coefficient-reference calculation with monthly time step could be sufficient. The crop coefficient-reference method is defined in equation (2.31).

$$PETc = K_c PET_o \tag{2.31}$$

PET_c is the crop potential evapotranspiration, PET_o is the reference crop potential evapotranspiration, and K_c is the crop coefficient. The value of K_c in humid climate is listed on Table 2.6 [35].

When the measurement of daily radiation data, daily temperature data, and wind speed data is available, Penman-Monteith approach is recommended to calculate the evapotranspiration value [34]. This approach uses more data, needs more detailed timestep, and also need accurate data.

Table 2.6: Crop Coefficient Values in Humid Regions

Crop	Humid Climate		
	Winter	Summer	Tropical
Wet Grass	0,9	1,0	1,0
Short Grass	0,7	0,8	0,8
High Vegetation	0,8	1,0	1,0
Rice Field	1,0	1,0	1,2

For some sites in Indonesia, where the data is not completely available or where the climate data in the site cannot be estimated accurately with available data, some empirical methods could be applied. The first method is by using temperature based evapotranspiration models, which are developed to estimate the evapotranspiration using data with low time resolution (for example, monthly temperature data) . One of the most used model is the Thornwaithe evapotranspiration model [36], which is described in equations (2.31) to (2.34).

$$PET = f16\Big(10\frac{T}{I}\Big)^a \tag{2.32}$$

$$I = \sum_{1}^{12} i \tag{2.33}$$

$$i = \Big(\frac{T}{5}\Big)^{1,514} \tag{2.34}$$

PET is the monthly potential evapotranspiration (mm), T is the mean montly temperature (^oC), I is the yearly thermal index, i is the monthly thermal index, a is the empirical factor ($a = 675\text{x}10^{-9}I^3 - 77,1\text{x}10^{-6}I^2 + 17,92\text{x}10^{-3}I + 492,39\text{x}10^{-3}$), and f is the correction factor which is described as:

$$f = \frac{D_m \bar{N_m}}{360} \tag{2.35}$$

where D_m is the number of days in the month, and N_m is the mean daily sunshine duration (hours).

The second method, is based on radiation models. For tropical countries, Turc method has been known to perform well [37]. The required data for this method is the average daily temperature, daily relative humidity data, and solar radiation measurement. For the climate with relative humidity more than 50%, the potential evapotranspiration can be calculated in equation (2.36) [37].

$$PET = 0,313\frac{T}{T+15}(S_n + 2,1) \tag{2.36}$$

$$Sn = S_o(1-\alpha)\Big(a_s + b_s\frac{n}{N}\Big) \tag{2.37}$$

S_n is the amount of solar radiation (mm/day), S_o is the extraterrestial radiation (mm/day), $\alpha = 0,23$ is the albedo value that is recommended in the absense of knowledge of land cover [37], $a_s = 0,25$ and

$b_s = 0,5$ is the Angstrom coefficient [38], $\frac{n}{N}$ is the percentage of bright sunshine hours compared to the total day length.

Extraterrestial radiation S_o is calculated as follow:

$$S_o = 15,392 d_r (\omega_s sin(\Phi) sin(\delta) + cos(\Phi) cos(\delta) sin(\omega_s)) \tag{2.38}$$

where d_r is the relative distance of sun-earth, ω_s is the sunset hour angle (rad), Φ is the latitude (rad), and δ is the solar declination angle (rad)

2.3.4 Water Balance Methods

Water balance method is an analysis of input and output of water in a specific area and specific time, in order to calculate water surplus or deficit. Therefore, with those information, water resources can be utilized properly. For hydropower development, the water balance methods serve as a way to calculate the water discharge in the site.

The Thornwaithe-Mather method provides a model to know the monthly water quantity in a year, including the monthly runoff. This method needs the air temperature data, water holding capacity data from soil, and also the correction factor based on site's latitude. Those data will produce the number of water used by plants for evapotranspiration, and knowledge about surplus or deficit of water in soil [33]. To estimate monthly actual evapotranspiration, this method uses a bookkeeping model with monthly precipitation values and potential evapotranspiration values.

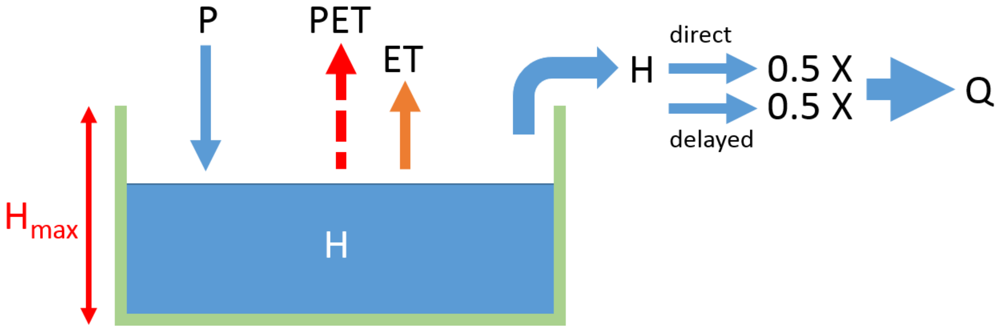


Figure 2.16: Thornwaithe-Mather Model [39]

Steps to calculate the water discharge using the Thornwaithe-Mather method is as follows:

- Determine the precipitation data and temperature data on the same time series and time step. In Indonesia, the precipitation and temperature data is gathered from Badan Meteorologi, Klimatologi dan Geofisika (BMKG) or the Biro Pusat Statistik (BPS).
- Calculate the potential evapotranspiration based on the same time series.
- Calculate the amount of water available in the soil at each time step. At the time t, amount of water

available in soil is:

$$H_t = \begin{cases} H^{max} & \text{if } P_t - ET_t \geq H^{max} - H_{t-1} \\ H_{t-1} + P_t - ET_t & \text{if } P_t - ET_t \leq H^{max} - H_{t-1} \end{cases} \tag{2.39}$$

the value of H_max, water holding capacity, is determined by the product of soil depth and soil porosity.

- Calculate the water available in soil for evapotranspiration

$$H_t^{disp} = \begin{cases} min\Big((PET_t - P_t)\frac{H_{t-1}}{H^{max}}; min(H_{t-1}, H^{max})\Big) & \text{if } P_t \leq PET_t \\ \text{No calculation is necessary} & \text{if } P_t \geq PET_t \end{cases} \tag{2.40}$$

- Calculate the real evapotranspiration during timestep t,

$$ET_t = \begin{cases} PET_t & \text{if } PET_t \leq P_t + H_t^{disp} \\ P_t + H_t^{disp} & \text{if } PET_t \geq P_t + H_t^{disp} \end{cases} \tag{2.41}$$

- calculate the water discharge Q_t

$$\begin{aligned} Q_t &= \alpha X_t + (1-\alpha)X_{t-1}; \alpha = 0,5 \\ X_t &= P_t - ET_t - (H_t - H_{t-1}) \end{aligned} \tag{2.42}$$

2.4 Financial

Investments in hydropower plants development is very site specific and can be different from site to site. However, as a mature technology, hydropower could provides cheap, clean, and reliable energy when compared to another source of energy [40]. One of the way to compare the cost of energy is by comparing the Levelised Cost of Energy (LCOE), which is measured by the amount of cost of project per amount of energy.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \text{[41]} \tag{2.43}$$

I is the investment expenditure, M is the operation and maintenance costs, F is the fuel cost (if any), and E is the electricity generated in current year. The average LCOE of hydropower plant project is around USD 0,05/kWh, while on some specific site the LCOE could be as low as USD 0,02/kWh [40].

The cost structure of hydropower project development consists of few components, which is classified as capital costs, operating and maintenance costs, and indirect costs. Hydropower plant project development is a very capital-intensive, with most of the capital costs goes into the civil engineering works and equipment costs. The civil works include any development that is needed to develop the site, from the road access to the dam development. The capital costs in a big hydropower plant could be as high as 75% to 90% of the total investment costs [40].

One of the advantage of hydropower plant in terms of costs is that it has a very low Operation and Maintenance (O&M) costs. The O&M costs is usually calculated as the percentage of yearly investment costs, with value averaged for about 2,5% [41].

In Indonesia, private companies are able to provide electriciy through Power Purchase Agreement (PPA) scheme. In this scheme, PLN granted rights to private companies to be able to produce electricity through a power plant that is managed by private companies. The electricity power generated then will be bought by PLN to be distributed to the grid.

In order to determine whether a project is feasible and profitable to be launched, the economic study is done. Generally, the study is based on components that are taken from cost structure of hydropower project, while also considering the potential revenue and the contingency cost from the project. These components subsequently accounted to a cashflow sheet, in order to determine whether the project is feasible.

The potential revenue gained on the project lifetime is based on the Indonesia's Feed-in-tariff Law No.12/2014 about the power purchase by PT.PLN. For the region of interest in Sumatera area, the electricity price is 1397 IDR/kWh for low voltage up to 250 kW of capacity, and 1182,5 IDR / kWh for medium voltage up to 10 MW. At the 9th year of the project, these price then will be adjusted to be 847 IDR/kWh for low voltage, and 825 IDR/kWh for medium voltage. The feed-in-tariff contract will last for 20 years, and it is possible to be extended.

In addition, due to the new law that is enacted by ministry of mineral and resource (No.19/2015), the power purchase price can increase dramatically if the majority of the investor is the local investors. According this law, the electricity price is set based on foreign currency, which is the US dollar. For Sumatera area, the electricity price for the run of river power plant is 0,132 USD/kWh for the first 8 years, and then reduced to 0,825 USD/kWh until the contract expired. It is important to note that eventhough the rate is in foreign currency, the payment is still made in local currency based on the corresponding national bank rate at the time.

Some policies are enacted to encourage the development of renewable energy sources, as stated in Indonesia's Ministry of Finance Law No.21/PMK011/2010. Due to this law, tax facilities are given to the renewable energy developers. They are tax discount and the tax income duty facility. The tax discount applies to the net income for six years, with annual tax discount of 5% from the capital costs. On the other hand, the tax income duty is free for the imported equipments.

To do the economic analysis, few concepts will be used. They are the time value of money, internal rate of return, net present value, and payback period [18]. These concepts will be calculated in a cashflow table.

Time Value of Money (TVM)

In the TVM concept, the money that is available today will be worth more than the money that will be received in the future, due to opportunity that is opened due to available money. Through this concept, the Future Value (FV) of money can be represented in the Present Value (PV) of money. To relation between FV and PV is determined by the discount rate (r), and also the number of years difference (n), shown in equation (2.44).

$$PV_0 = \frac{FV_n}{(1+r)^n} = \frac{1}{(1+r)^n} FV_n \tag{2.44}$$

Net Present Value (NPV)

The Net Present Value shows the sum of the present value of future return at corresponding discount rate that is reduced by present value of investment costs. In other words, NPV shows the value that a project produces in its lifetime, in terms of present value. If and only if the NPV is positive, a project should be considered for development. The formula to obtain NPV, for the yearly time periods and assuming that the cash flow occurs at the same time interval, is as follows:

$$NPV = \sum_{i=1}^{i=n} \frac{R_i - (I_i + O_i + M_i)}{(i+r)^i} \tag{2.45}$$

R is the return of the project, while I is the investment, M and O are the maintenance and operations costs.

Internal Rate of Return (IRR)

IRR shows the rate of interest that will produce the NPV of project that equals to zero. In order to determine whether a project is profitable or not, the IRR is compared to the bank loan rate. The project is feasible if the IRR is equal to the bank rate, and is profitable when it is bigger than bank rate. The IRR value is obtained through a trial and error process, where the discount rates varied to achieve zero NPV.

Payback Period (PBP)

PBP shows the required time for the project to offset the invested capital, which usually is measured by years. This method of analysis shows the liquidity of the project, with the most liquid project having the fastest PBP. For the small hydro project, the payback ratio should not exceed 7 years to be considered profitable [18].

$$PBP = \frac{InvestmentCost}{NetAnnualRevenue} \tag{2.46}$$

Benefit to Cost Ratio (BCR)

In BCR, the benefit that is adjusted to present value is compared to the capital investment. In order to be considered as a feasible project, the value of BCR usually have to be more than 1. Following is the calculation of BCR.

$$BCR = \frac{\sum_0^n \frac{R_n}{(1+r)^n}}{\sum_0^n \frac{I_n + M_n + O_n}{(1+r)^n}} \tag{2.47}$$

2.4.1 Sensitivity Analysis

Sensitivity analysis maps the risks that is associated with a hydropower project, and also shows risks that could potentially impact the project [42]. Since there are many assumptions made in a project, it is important to understand which assumptions that could most potentially changes the project outcomes. The sensitivity analysis is made by changing some of the assumptions in the project, while keeping other assumptions at their base (original) values. Therefore, the new project outcomes can be compared to the base outcomes, and then impact of a particular assumptions can be assessed.

In the hydropower development, financial parameters and assumptions are very crucial to the project feasibility. Based on the common practices, few parameters options that usually varied in the preliminary study is the total installed costs and interest rate.

Chapter 3

Hydrology Study and Power Plant Design

In this chapter, the presentation of the hydropower potential site location, the preliminary lay out consideration, and the hydrology data processing are described. These processes provide the annual available energy in the river that serves as the basis for the power plant design and annual energy production calculations. The most optimum designs are selected by taking into account the financial analysis and characteristics of the sites.

3.1 Geographical Location

The location of the site is on the Manna River, Ulu Manna Region, Bengkulu, Indonesia. The site is located around:

- Longitude: 103° 1'55.22"E
- Latitude: 4° 8'22.41"S

The site is located about 230 km from the capital city of Sumatera Selatan, and around 94 km from capital city of Bengkulu. The Province Bengkulu itself is surrounded by land in the northern, eastern, and southern side, while it is facing Indian Ocean on the western side. On the other hand, the climate in the site is tropical, with two seasons, which is rainy season that usually occurs on December-March, and the dry season occurs on June-September. There are also transition month between rainy and dry season that happen at April-May and October-November. Based on the preliminary visit, this potential site is shown to be a feasible site, since the water discharge on the site is available all year long.

After assessing the potential site, two sites are proposed for the pre-prelimary study. The location of the proposed weirs, forebays, and the powerhouses of the first and second site of hydropower plant is shown in Figure 3.2, with their corresponding locations. The upper (upstream) site will be called the "Site 1", while the lower one will be called the "Site 2" in the following sections. The considerations of the

(a) Site Location Map

Figure 3.1: Site Geographical Location

preliminary location is only based on the topographical map that is provided from Indonesian Geospatial Portal, with the resolution of 1:50.000.

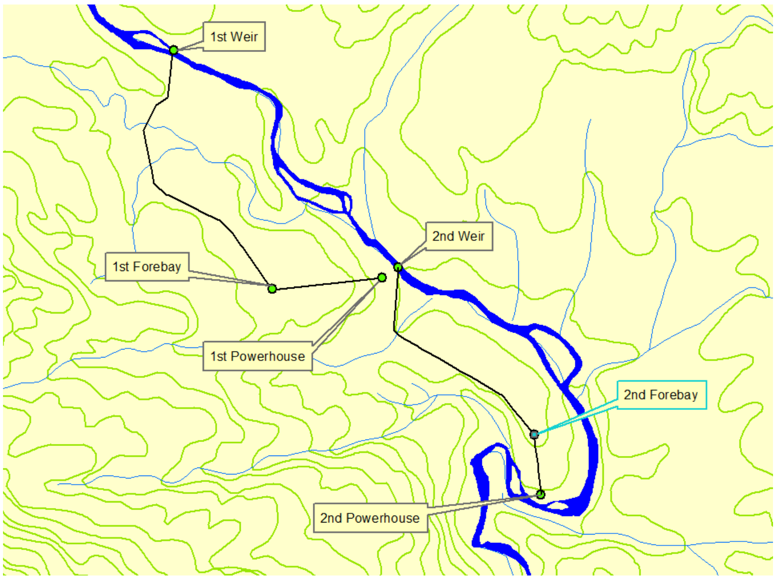


Figure 3.2: Site 1 and 2 Preliminary Location

The site characteristics are listed in Table 3.1. For the first site, canal is planned for about 2 km, before the water flow settle in the forebay at 591,87 m elevation and going through penstock for about 622,44 m long. The gross head for the site 1 is 49,175 m, and with the losses assumption of 5% [21], the net head is around 46,72 m.

The site 2 has a significantly shorter canal, which is 1,5 km long. The forebay is designed at elevation of 520,1 m, and then the water flows to the penstock that is 173,096 m long. The gross head for site 2 is 18,2 m, and with the losses assumption of 5%, the net head is around 17,29 m.

Based on the preliminary location selection, the elevation profile curve of hydraulic circuit in both sites are depicted in Figures 3.3 and 3.4.

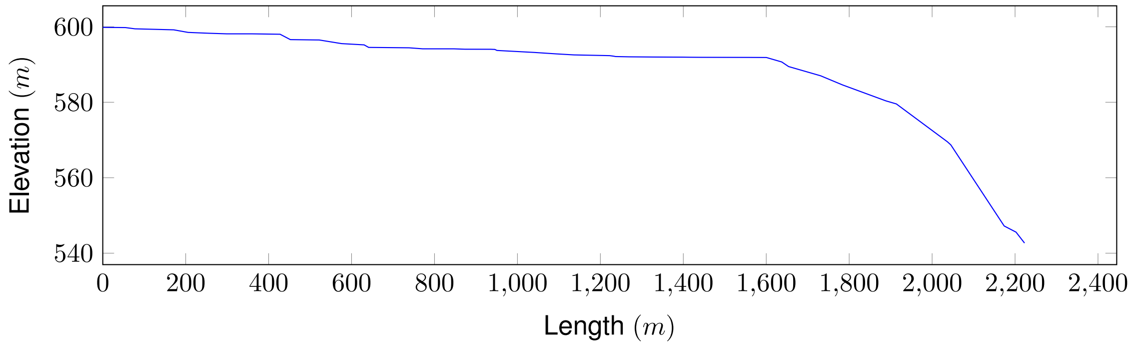


Figure 3.3: Elevation Profile Curve at Potential Site 1

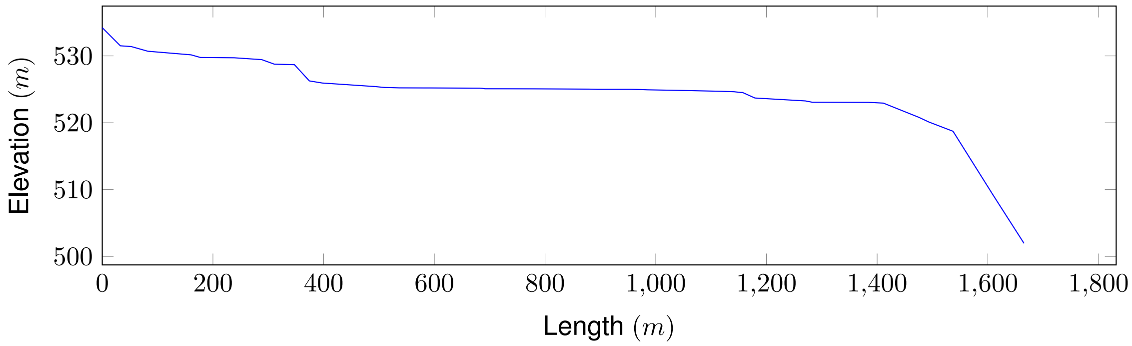


Figure 3.4: Elevation Profile Curve at Potential Site 2

Table 3.1: Sites Characteristics

Characteristics	Site 1	Site 2
Dam/Weir Elevation	599,8 m	534,2 m
Forebay Elevation	591,87 m	520,1 m
Powerhouse Elevation	542,68 m	501,9 m
Gross Head	49,175 m	18,2 m
Assumed Losses	5%	5%
Net Head	46,72 m	17,29 m
Penstock Length	625,181 m	173,096 m

3.2 Hydrology Data

3.2.1 Watershed

In the hydrology study of Manna site, the watershed areas are defined based on the data obtained from Directorate of Planning and Evaluation of Watershed of Indonesian Forest Ministry [43]. These data provide several watershed areas, which are used to determine the specific catchment areas for the Manna sites. In addition with the 1:50.000 hipsography map, the watershed areas for the Manna sites are traced as shown in Figure 3.5. There are three watersheds that is traced based on the catchment area of site 1 and site 2. The first watershed (orange line) represents the catchment areas of the site 1, while the second watershed (red line) shows the catchment area for the site 2. The third watershed (pink line) is needed for the data verification purpose that will be discussed in 3.2.4. Each watershed will have their own assumed evapotranspiration and precipitation data, and consequently their own calculated water discharge values.

The watersheds areas (in km^2) are tabulated at Table 3.2, with the total watershed area is 605.091 km^2.

Table 3.2: Watersheds Areas in km^2.

Watershed	Areas (km^2)
First Watershed (Orange Line)	192.920
Second Watershed (Red Line)	162.101
Third Watershed (Pink Line)	250.070
Total	605.091

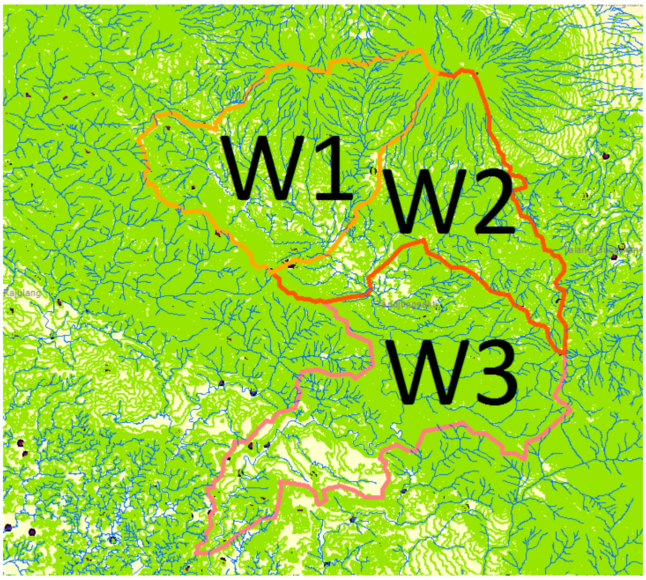


Figure 3.5: Watersheds in Manna Sites

3.2.2 Evapotranspiration

For the evapotranspiration calculation, Thornwaithe and Turc methods are used, since the data availability is scarce. The Thornwaithe method can provide quick and simple calculation, while Turc method has been proven as the method that worked well in humid climate [37]. For these methods, the temperature data and the sunshine duration data is needed. For preliminary study purpose, it is assumed that the adjusted temperature data from the closest climatology station can represent the temperature data for the measured watershed. The closest climate station that can provide reliable, long records of monthly values of climate data is the Pulau Baai (Bengkulu) climate station which is located about 100

km from the site (Figure 3.1(a)).

However, since the temperature data at the climate station are measured at the different elevation compared to the watershed areas, an adjustment has to be made. Approximate relationship between two location with different elevation is described in equation 3.1 [30].

$$T = T_c - 0.006h \tag{3.1}$$

where T is the measured temperature at the climate station at the height h, and T_c is the temperature equivalent at the sea level.

On the other hand, to ensure that the data is reliable, it is important to know whether the data on the climate station's location can be correlated with the site's location. In order to validate the data, one way to do it is by using the correlation factor [30]. If the correlation factor is greater than 0,7, then the site is reliable as a reference. Favourably, for the range of 100 km, the correlations factor for daily mean temperatures is 0,9. Thus, the data from the Baai climate station will be adjusted for calculations. Furthermore, for the daily sunshine duration data, the correlation value for climate space of 100 km is 0,75 [44]. A higher correlation factor is expected for a bigger time step [30].

The time step used for the calculation is the monthly average data, due to the data availability. Therefore, the data correlation is also expected to be higher for both cases.

Using the temperature data from Baai station (see Appendix A.2) [45], the adjusted monthly mean temperature data for watershed 1, 2, and 3 is shown in Figure 3.6. To calculate the adjusted temperature, the mean elevation values of these watersheds are obtained through digital elevation model. The mean elevation of watershed 1 is 1202,61 m, while the watershed 2 has similar elevation at 1201,607 m, and the watershed 3 elevation is 729,5205 m. It is worth to note that the equation (3.1) only depends on the elevation difference.Thus, due to the similarity of the elevation between watershed 1 and 2, it is shown that for those watersheds, the values of the adjusted temperature are very similiar. The temperature data will be then validated with the global area data from the last 30 years [46].

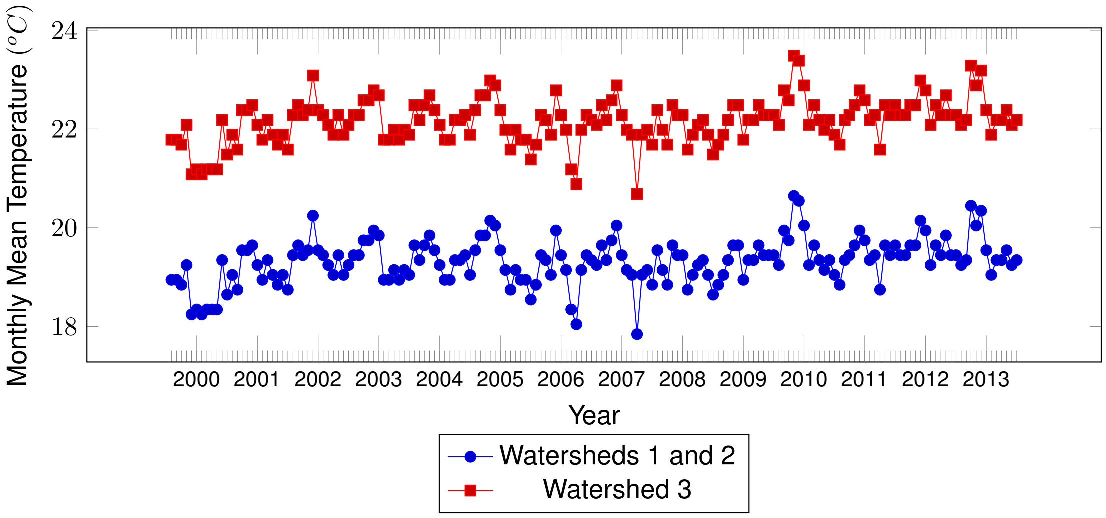


Figure 3.6: Monthly Mean Temperature in Watershed 2000-2013

For the radiation data, it is assumed that the monthly radiation data that are gathered from Baai station can represent the monthly radiation data in watershed 1, 2, and 3, with the correlation factor higher than 0,75.

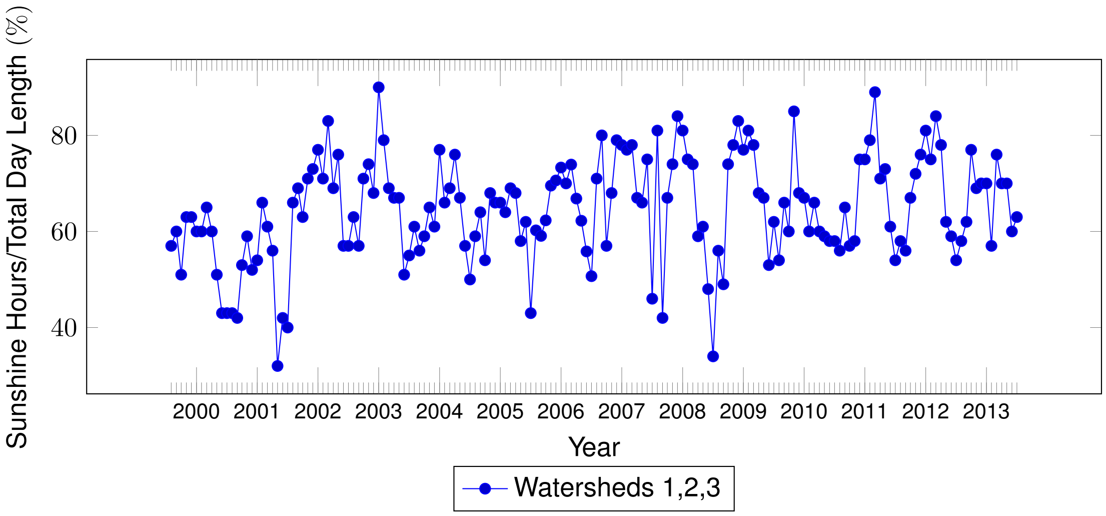


Figure 3.7: Monthly Mean Sunshine Duration 2000-2013

Based on the monhly mean temperature and the monthly mean sunshine duration data, the monthly potential evapotranspiration is calculated using Thornwaithe model (equation 2.32) and Turc model (equation 2.36). The result of these calculations are shown in figure 3.8.

In order to validate the data, the global yearly statistical data from NTSG, University of Montana are used [47]. The result of the validation is that both methods perform well in the area of interest by providing calculation results close to data from NTSG, which is 1200mm/year (Figure 3.8 shows monthly data).

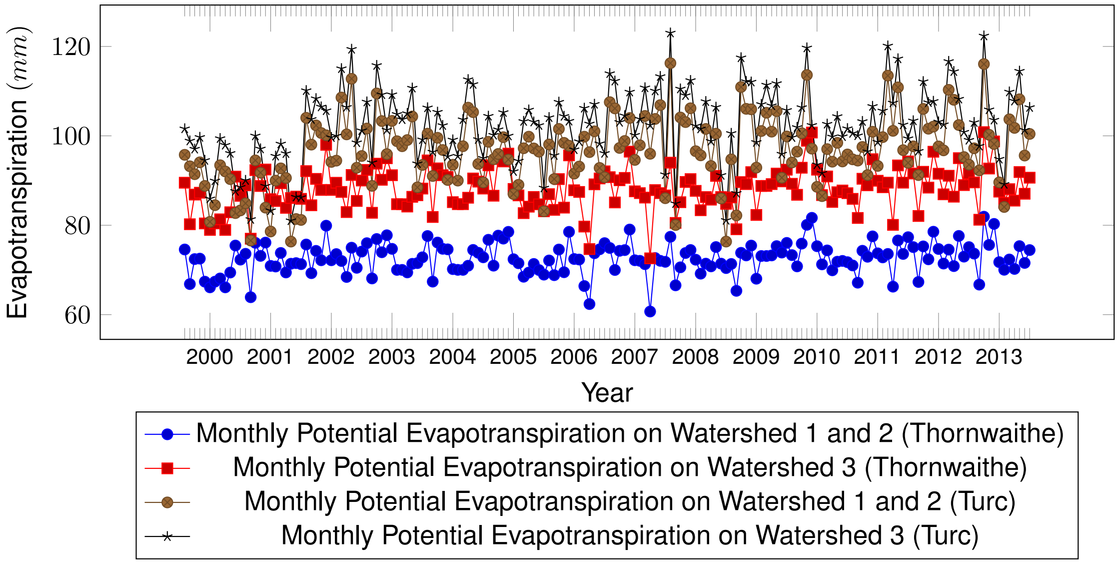


Figure 3.8: Monthly Evapotranspiration Calculation on Watershed 1,2,3

3.2.3 Precipitation

Monthly precipitation data are calculated from the daily precipitation data that are obtained from the various rain gauges that are close to the sites, or are considered that they can represent the sites due to its similarity regarding vegetation types or elevation characteristics. The available rain gauge is marked on the map on Figure 3.9, with gauge from South Sumatera province marked by blue dot, and gauge from Bengkulu Province marked by teal dot. The data availability on the recent years is shown at Table 3.3.

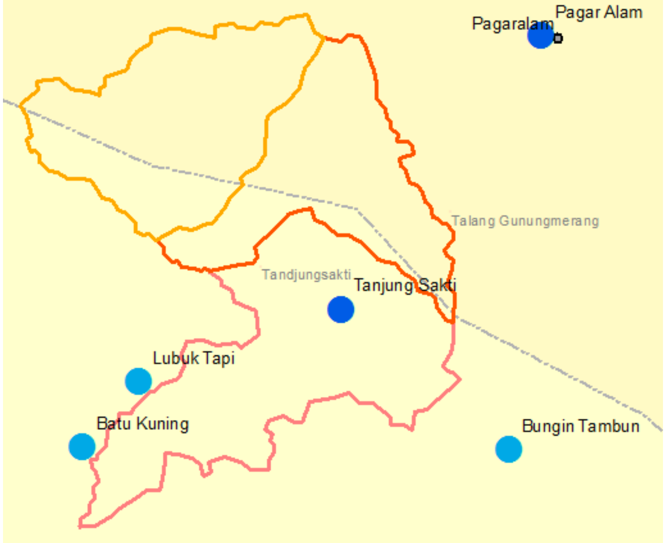


Figure 3.9: Climate Station Near the Watersheds

Table 3.3: Data Availability On The Rain Gauge Near Watershed

Rain Gauge	Data Available in Year
Pagar Alam	1985-1999, 2004-2008
Tanjung Sakti	1992-1996, 1998-2001
Lubuk Tapi	2000-2001, 2003-2006, 2008-2013
Batu Kuning	,2000-2001, 2003-2010, 2012-2013
Bungin Tambun	2000-2004, 2006-2013

Since three of the five references have data series mostly between year 2000-2013 (14 years), this range of time are used as the base time for the water discharge calculation. The missing data between year 2000-2013 are obtained by averaging the precipitation values over time. For the Lubuk Tapi (elevation 152m), Batu Kuning (elevation 183m), and Bungin Tambun(elevation 205m) rain gauge, the minimum data period that are needed to obtain an accurate long time precipitation average are 6 years [30].These long term precipitation forecast data then used to fill the missing data.

For the rain gauge with lack of data during these periods, Pagar Alam (elevation 725m) and Tanjung Sakti(730m), the missing data are also forecasted, using the same method as above. Therefore, for Pagar alam and Tanjung Sakti rain gauge, the average long-term precipitation data from the previous decade are used to forecast data for the year of 2000-2013.

Since the average long-term data are used, it is assumed that this data represents a stable climate, and any fluctuations in the precipitation data are represented in the average value of data.

To estimate the precipitation data in watershed 1 and 2, the data from Pagar Alam, Bungin Tambun, and Tanjung sakti are used due to the similarity of land cover and elevation between these stations and both watersheds. The arithmetic average of these rain gauge stations are calculated to determine the estimate precipitation value. The calculation result is presented in Figure 3.10.

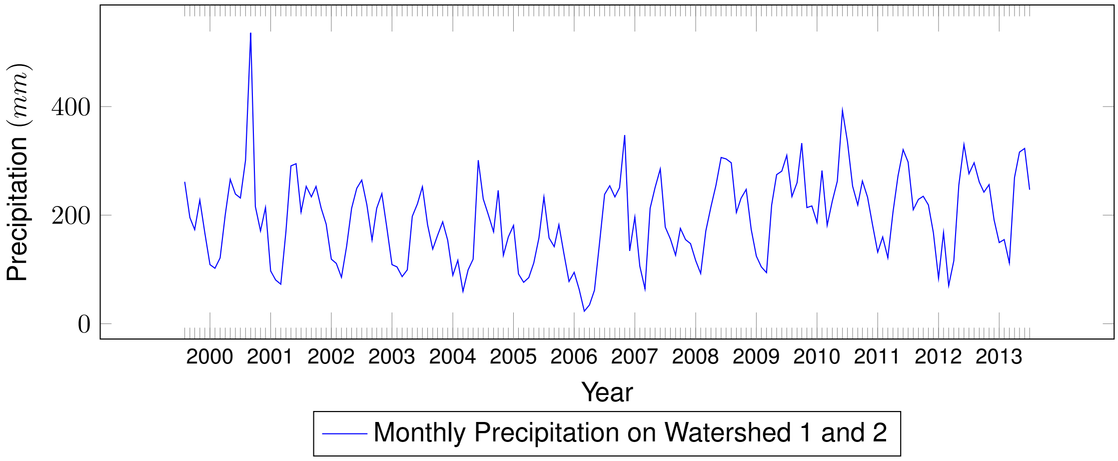


Figure 3.10: Estimated and Logged Monthly Precipitation Data in The Watershed 1&2

For the watershed 3 precipitation estimation, the data from Bungin Tambun, Batu Kuning, Lubuk Tapi, and Tanjung Sakti are used, by calculating the arithmetic average data from these stations. The averaged data are shown in Figure 3.11.

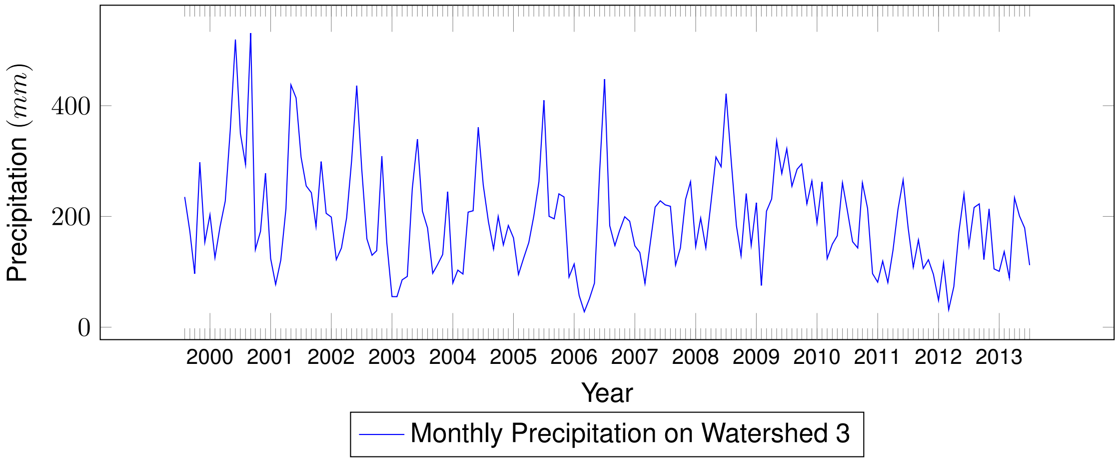


Figure 3.11: Estimated and Logged Monthly Precipitation Data in The Watershed 3

The monthly precipitation data is then checked with the annual precipitation data that is gathered from the National Statistic Bureau [45], which state that the range of the annual precipitation is at the range of 1000-4000 mm/year.

3.2.4 Water Discharge Calculation

By the means of Thornwaithe Mather water balance model, the water discharge value are calculated for the period 2000-2013. For comparison purposes, the water discharge calculation uses the results from two Potential Evapotransporation calculations from previous section. These values are calculated with two methods, which are Thornwaithe model and Turc model. Using the equation (2.42), the water discharge for these period is obtained as following, in Figures 3.12 and 3.13.

Since both sites have the same monthly precipitation and potential evapotranspiration per unit area (mm), the trends of the water discharge for both sites follow the same pattens over the years. Moreover, the similiarity of mean elevation between those sites made the adjusted mean temperature value for both sites also alike. For the site 1, the water discharge data is obtained from the watershed 1 water discharge calculation. On the other hand, for the site 2, the discharge data is obtained from the addition of watershed 1 and 2 calculations.

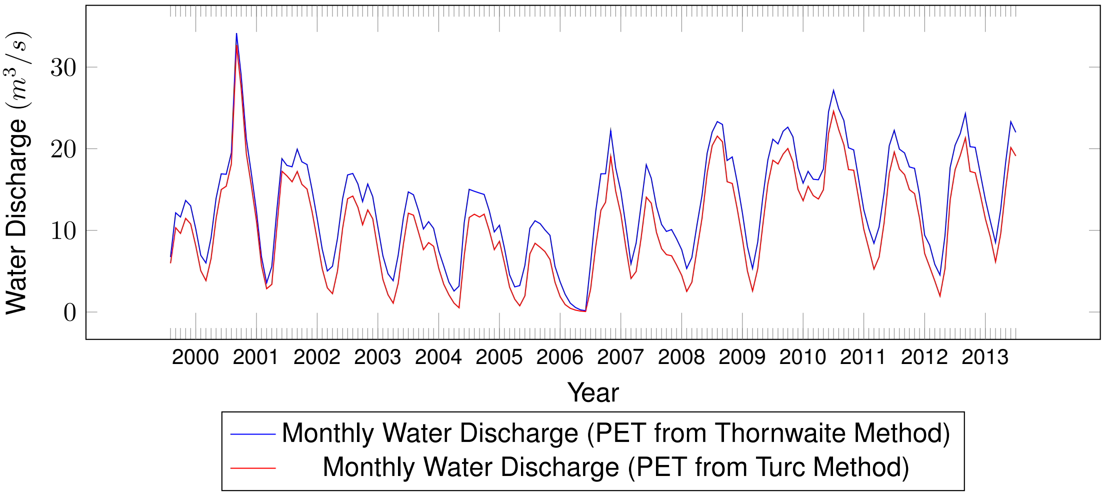


Figure 3.12: Monthly Water Discharge at Preliminary Site 1

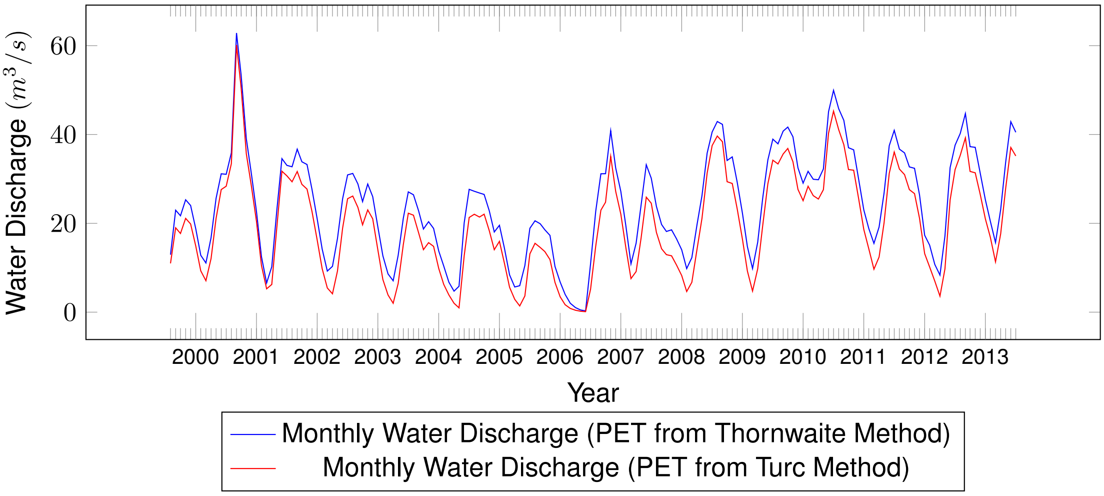


Figure 3.13: Monthly Water Discharge at Preliminary Site 2

In order to verify the water discharge calculations, these data are compared to one gaging station (Manna-Bandar Agung station) that is located in the southest end of watershed 3 (shown in Figure 3.5). Thus, the water discharges calculations from watershed 1, 2, and 3 are added and then compared to the gaging station, shown in Figure 3.14. However, since the measurement of the measuring station is only available for years 1984, 1992, 1996-1999, 2008-2009, the monthly mean value of these measurement period is used as the base of the comparison.

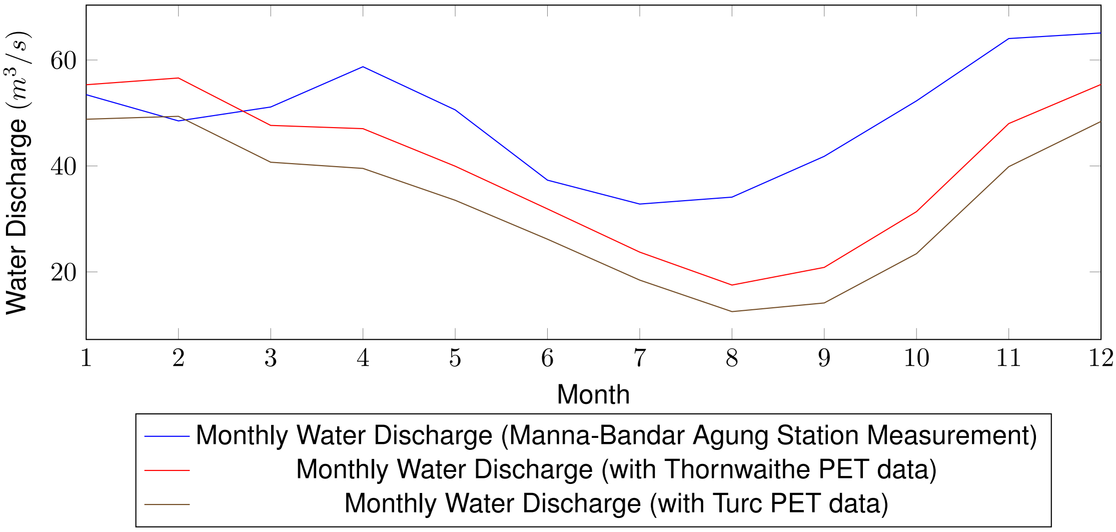


Figure 3.14: Comparison of The Discharge Calculation and Manna-Bandar Agung Data

It is shown that the total water discharge from watershed 1,2, and 3 did not match the data from the Manna-Bandar Agung station. The mean flow of the measurement station is 49,15 m^3/s, while the mean flow from Thornwaithe and Turc methods calculation results are 39,61 m^3/s and 32,91 m^3/s. The discrepancy between the calculation results and the measurement is quite often found in the study of mini hydropower in Indonesia. In the case of this study, the calculated data will be used as the basis of power plant sizing, since the data for the calculation are already verified with the other source of data. For the discharge measurement station, verification process has to be made in the next phase of the study in order to ensure that the discharge measurement device is properly calibrated.

3.3 Basic Power Plant Design

3.3.1 Turbine Design Discharge

Design discharge is calculated in order to find the optimum power plant design, that can provide the most beneficial outcome, both economically and design wise. In order to determine design discharge, a flow duration curve that uses water discharge data from previous section are arranged to understand the characteristics of the river flow. This curve shows the percent of time that a specified discharge is exceeded in a given period. Since there are two calculation results for the design discharge, the one that resembles closer to the Manna-Bandar Agung gaging station will be used. Therefore, the discharge value that uses Thornwaithe Potential Evapotransporation values are arranged as a flow duration curve.

Flow Duration Curve

The first step in creating the flow duration curve is to determine the data time step. Commonly, the daily time step is used when the data is available [48], that will give a steep curve. However, the available data at Manna site only provide mean monthly flow. Therefore, the monthly discharge data from years

2000-2013 are used, with total 168 data step (see Figure 3.12 and 3.13). By increasing the time step, the resulting curve is expected to be flatter, since the extreme low or high value are averaged out in these time periods.

Next, these data ranked from the highest to the lowest value, from the 1st data to the 168th data, with the 1st data is the highest discharge value. For each discharge data, the exceedance probability (P) is then calculated by the equation 3.2.

$$P = \frac{M}{n+1} 100\% \tag{3.2}$$

where P is the probability that given flow will be exceeded or equaled (% of time), M is the data rank, and n is the total of time steps.

Based on the numbers of data steps, then the exceedence probability is matched to the corresponding discharge data, with the highest discharge has the lowest probability and the lowest discharge with the highest probability. Lastly, these data is then arranged into a plot with percentage of exceedance is on x axis, while the discharge value is on y axis. The flow duration curve is shown in Figure 3.15.

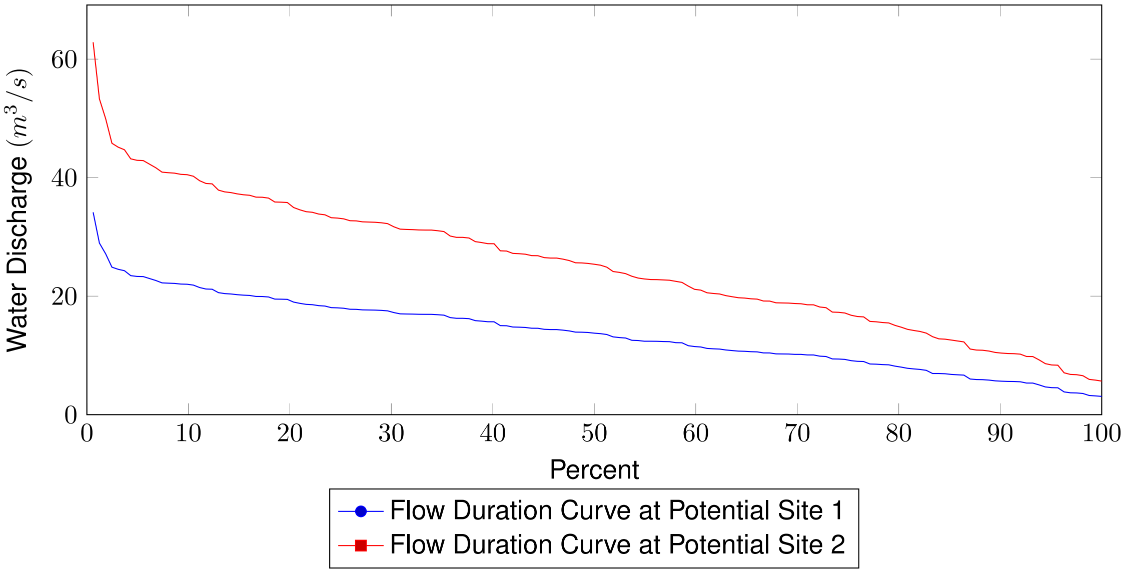


Figure 3.15: Flow Duration Curve in Potential Sites

Design Discharge

In order to determine the design discharge, an optimization process is conducted by comparing the economic parameters of few discharge values based on assumptions above. The optimization process done by taking into account the flow duration curve and the minimum technical turbine flow [18]. Since there are many possible alternatives of design discharge size, an optimum design flows need to be found through an optimization process. Based on the common practice, the design discharge flow is chosen at the maximum flow that happens at around 40% of time. This flow of water then divided into two flows, because of few reasons. First reason is that the water discharge varies heavily between dry season and wet season. In order to operate efficiently in dry season, one generator can be turned off. The other reason is in maintenance case, one generator can still be operating while the other is serviced.

The summary of calculation results is listed in Table 3.4, based on the assumption that Total Installed Cost is 15.000.000 IDR/kW. This assumptions based on the historical price of the power plant development by the company. The detailed calculation and assumptions are described in the financial analysis (section 5.2).

Table 3.4: Economic Parameters of Different Design Discharge

Parameters	Site 1 Alternative Flow			Site 2 Alternative Flow		
	9 m^3/s	13 m^3/s	16 m^3/s	15 m^3/s	20 m^3/s	25 m^3/s
Rated Power (kW)	2x1903	2x2754	2x2289	2x1178	2x1573	2x1968
Net Present Value (10^9 IDR)	187,014	218,356	210,343	131,913	150,813	149,656
Benefit/Cost Ratio	4,61	3,91	3,28	5,11	4,52	3,79
Internal Rate of Return	39,25%	33,65%	28,26%	41,66%	37,36%	32,58%
Payback Period	5 years	6 years	6 years	5 years	5 years	6 years

For the first site, the design discharge of 13 m^3/s looks to be the most attractive option, since it provides the highest NPV. It is worth to notice that the lower design discharge will provide higher BCR and IRR, but also lower rated power. Therefore, the 13 m^3/s design discharge is still selected as the design discharge. For the second site, the design discharge of 20 m^3/s is selected due to similar reasons.

3.3.2 Hydraulic Circuit

In the preliminary hydraulic circuit design, the water intake is located at the end of the canal. The main consideration of this water intake is the minimum submergence value, in order to avoid vortex formation. Based on rearranged equation 2.2, the minimum submergence height of the intake is calculated.

For the site 1,

$$S_1 = 2,09\,m$$

For the site 2,

$$S_2 = 2,62\,m$$

The value of the minimum submergence value is then adjusted to 3m for site 1 and 3,5m for site 2.

Furthermore, the optimum design of the penstock is very crucial. In addition to the penstock length, the penstock diameter have to be designed with regard to the system efficiency and economic benefits. The economic penstock diameter is calculated using following equations [21]:

$$D_{economic} = C_{EC}\,C_{MP}\,Q^{0.43}\,H^{-0.24} \tag{3.3}$$

where the $C_{EC} = 1,4$ is the coefficient of energy cost where the energy cost is moderate (it is assumed that in Sumatra the electricity price is moderate), $C_{MP} = 1,2$ is the steel pipe materials coefficient, H is the net head, and Q is the design discharge. In order to improve the power plant reliability in the dry season, the flow divided into two channels, through their own penstock, and then discharged into each of the outlet channel's turbine. In this case, if the water discharge is not enough for two turbine operations, one turbine can be turned off.

The next step after the design discharge value obtained is to calculate the penstock economic diameter. For the site 1, the economic diameter D_{ec1} is 1,49 m, while in the site 2 has an economic diameter of 2,28 m. These diameter values can be further optimized, by changing the penstock diameter. However, the water flows in penstock have to be maintained within certain velocity limits, which for mini hydro power plant is between 3-4 m/s [21]. If the discharge goes faster than that, the head losses will become higher. Based on trial and error calculation to find the water velocity in the penstock, the diameter of penstock 1 changed to 1,65 m, while penstock 2 diameter is reduced to 1,9 m.

In addition, the parameter of penstock pipe thickness is also calculated. The empirical equation for penstock thickness is [21]:

$$t = 0.0084\,D\, + 0.001 \tag{3.4}$$

which will give the penstock pipe thickness of 0.0195 m for penstock 1, and 0.0224 m for penstock 2.

The penstock parameter definition is needed in order to determine the head losses that happen in the penstock and the valve connected to the mini hydropower system. For the losses calculation in this study, the friction and singular losses from penstock are considered. On the other hand, the gross head is assumed relatively constant.

In order to measure the range of losses that happen in the hydraulic circuit, the losses in the condition of minimum discharge, rated discharge, and maximum discharge are calculated. On the Table 3.5, series of calculation results are shown in order to obtain the Reynolds number (Re), friction factor (f), and hydraulic gradient values (J). The value of Reynolds number is calculated with equation (2.7), based on water temperature of $32^o\,C$ from preliminary visit data. For that water temperature, the dynamic viscocity of water is $\mu = 0.798\,10^{-3}\,Ns/m^2$, and $\rho = 1000kg/m^3$.

Furthermore, the friction factor for the steel penstock is calculated with equation (2.6). The value of corresponding diameters and Reynold numbers are used in these equation. In addition, for the steel pipe, $k = 0,00010$ according to table 2.1. The hydraulic gradient value is calculated using equation 2.5. The calculated parameters and results are tabulated in Table 3.5, with the maximum flow is at 110% of the optimal flow, and the minimum flow is 40% of the optimal flow.

Table 3.5: Losses Parameters in Penstocks

Parameters	Penstock 1			Penstock 2		
	Optimum Flow	Maximum Flow	Minimum Flow	Optimum Flow	Maximum Flow	Minimum Flow
Q	6,5	7,15	2,6	10	11	4
v_{mean}	3,034	3,344	1,215	3,527	3,879	1,410
Re	6285454	3858976	2514182	6687885	7356673	2675154
f	0,0109	0,0109	0,108	0,0106	0,0106	0,0105
J	0,0031	0,0038	0,0005	0,0035	0,0043	0,0006

On the top of the friction losses, the singularity losses are also calculated, based on the bends that recorded on the elevation model. Since all of the bends angle have value less than 30^0, it is assumed that the epsilon values (Table 2.2 - 2.4) for these bends are represented by the next biggest epsilon value, which is 0,20. The result of these calculations are summarized in Tables 3.6 and 3.7.

Table 3.6: Losses in Site 1 Penstocks

Head Loss Type	Head Losses (m, Optimum Flow)	Losses %-age	Head Losses (m, Max Flow)	Losses %-age	Head Losses (m, Min Flow)	Losses %-age
Friction	1,934	3,934	2,342	4,762	0,306	0,622
Singular	0,057	0,116	0,069	0,140	0,009	0,019
Singular	0,057	0,116	0,069	0,140	0,009	0,019
Singular	0,057	0,116	0,069	0,140	0,009	0,019
Singular	0,057	0,116	0,069	0,140	0,009	0,019
Singular	0,057	0,116	0,069	0,140	0,009	0,019
Singular	0,057	0,116	0,069	0,140	0,009	0,019
Total	2,277	4,630	2,756	5,605	0,361	0,733

Table 3.7: Losses in Site 2 Penstocks

Head Loss Type	Head Losses (m, Optimum Flow)	Losses %-age	Head Losses (m, Max Flow)	Losses %-age	Head Losses (m, Min Flow)	Losses %-age
Friction	0,613	3,370	0,742	4,079	0,097	0,533
Singular	0,067	0,367	0,081	0,444	0,011	0,059
Singular	0,067	0,367	0,081	0,444	0,011	0,059
Singular	0,067	0,367	0,081	0,444	0,011	0,059
Total	0,814	4,470	0,985	5,411	0,129	0,709

Assuming that the most of the mini hydro power plant operation is happening at the optimum flow, the losses value of optimum flow is picked as the losses for the penstock 1 and the penstock 2. Compared to losses assumptions in the beginning (5%), the detailed calculation shows a similiar values, thus the losses percentage assumptions is kept at 5%. Therefore, the net head for the potential site 1 is 46.72m, and the net head for potential site 2 is 17.29 m, respectively.

3.3.3 Turbine Design

Based on turbine selection method on section 2.5, the Francis turbine is applied to the potential site 1, while Kaplan/propeller turbine is applied to the second site. After the turbine type is selected, there are various parameters that need to be designed in order to ensure that turbine would work efficiently. Those parameters are specific speed, rotational speed, range of discharges through the turbine, and suction head.

Turbine 1

The net head for the site 1 is 46,72m, and using the equation (2.13), the specific speed is

$$N_{s1} = \frac{1}{2}(\frac{1550+2330}{\sqrt{46,72}}) = 283,82rpm$$

Based on the specific speed, net head, and power plant capacity data, equation 2.11 is used to determine the rotational speed of the generator (N)

$$N_1 = 283,82\frac{46,72^{1.25}}{\sqrt{2754}} = 660rpm$$

Since the power produced by the turbine is more than 1000 kW, a synchronous electric generator is selected. This generator pole number can be calculated with equation (2.18):

$$n_{p1} = \frac{3000}{660} = 4,54$$

The number of pair poles has to be an integer. Therefore, the value is then changed to $n_{p1} = 5$. Based on this new pair poles value, using the equation (2.18), the new rotational value (N=600 rpm) is obtained. In addition, the value of the specific speed is also adjusted based on equation (2.11), resulting N_{s1} value of 257,78 rpm.

The runaway speed of the turbine is calculated using equation (2.14) as follow:

$$n_{rw1} = (0,63)(257,78)^{0,2}(600)\frac{49,175}{46,72} = 1177,23rpm$$

After the specific speed is obtained, the admissible suction head need to be defined in order to avoid cavitation. Using equation (2.16), the Thoma coefficient is obtained:

$$\sigma = 1,2715\left[\frac{1,924}{46,72^{0,512}}\right]^{1,41} + \frac{3,034^2}{2(9,8)(46,72)} = 0,196$$

The elevation of the powerhouse is 542,68 m, providing local barometric head of 9,72m [16]. and with the water temperature of 32^oC, the vapour pressure is 4,24 kPa. The specific weight of water is assumed at $9,8kN/m^3$. Thus, the admissible suction head is calculated:

$$h_{s1} = 9,72 - \frac{4,24}{9,8} - (0.196)(46,72) = 0,567m$$

The positive value means that the turbine is located above the tailwater.

Regarding the runner diameter, the outside diameter of the Francis turbine can be calculated using equation (2.9)

$$D = 84,5(0,31 + 2,5\,10^-3N_s)\frac{\sqrt{H_o}}{60\,N} = 0,918m$$

Turbine 2

For the Kaplan turbine, the specific speed is calculated using the equation 2.12

$$N_{s2} = \frac{1}{2}(\frac{2700}{\sqrt{17,29}}) = 639,33rpm$$

The rotational speed of the generator (N) is also calculated based on the specific speed, net head, and power plant capacity data using equation 2.11.

$$N_2 = 639,33\frac{17,29^{1.25}}{\sqrt{1573}} = 577rpm$$

The generator that coupled into the turbine will be a synchronous generator, since the power produced is more than 1000 kW. The number of pole pairs is calculated with equation (2.18):

$$n_{p2} = \frac{3000}{577} = 5,19$$

The number of pole pairs value is adjusted to 5, since it has to be an integer. Based on this new value, the new rotational value of 600 rpm is obtained. Furthermore, the value of specific speed is also calculated using equation (2.11), producing adjusted specific value of 674,95 rpm.

The runaway speed of the turbine is also calculated using equation (2.14) as follow:

$$n_{rw2} = (0,63)(674,95)^{0,2}(600)\frac{182,2}{17,29} = 1427,198rpm$$

The Thoma coefficient for the Site 2 turbine is calculated below:

$$\sigma = 1,5241\left[\frac{1,924}{17,29^{0,512}}\right]^{1,46} + \frac{3,527^2}{2(9,8)(17,29)} = 0,714$$

Thus, using these coefficient, the admissible suction head is

$$h_{s2} = 9,76 - \frac{4,24}{9,8} - (0.714)(17,29) = -2,38m$$

where the negative result shows that the turbine is located below the tailwater.

The outside diameter of the axial/propeller turbine can be calculated using equation (2.10)

$$D = 84,5(0,79 + 1,602\,10^{-}3N_s)\frac{\sqrt{H_o}}{60N} = 1,095m$$

The summary of those calculations is tabulated at Table 3.8.

Turbine Performance

The parameters for the both turbines are shown in Table 3.8, while both of the turbine efficiency curve are shown in the Figures 3.16 and 3.17. These turbines parameters are based on the typical parameters from TURBNPRO software, a software to simulate small scale hydropower system.

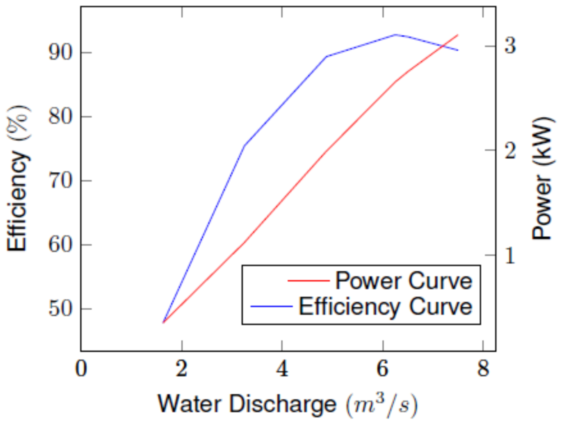


Figure 3.16: Turbine 1 Performance

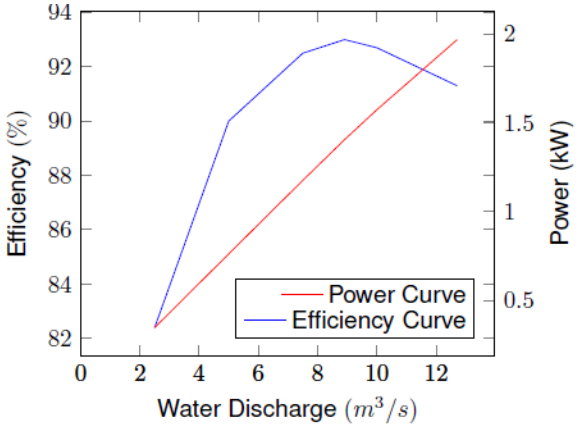


Figure 3.17: Turbine 2 Performance

As for the turbine 1 (Francis turbine), the efficiency drops almost half from the maximum efficiency to 47,8% at the minimum operating discharge. On the other hand, the maximum value of efficiency is obtained at 92,7% when operating at 6,25 m^3/s discharge. These drops in efficiency are typical for a Francis turbine [18]. Meanwhile, for the turbine 2 (Kaplan turbine), a wider range of discharge and a narrower range of efficiency is obtained. The minimum efficiency in turbine 2 is at 82,4%, while the maximum efficiency is at 93% when operating at 8,91 m^3/s discharge. Related to the power production, the Francis turbine could produce the maximum power of 3106 kW at the discharge of 7,5 m^3/s, while the axial/propeller turbine produce the maximum power of 1,967 kW at maximum discharge of 12,71 m^3/s.

Table 3.8: Turbine 1 & 2 Parameters

Parameters	Turbine 1	Turbine 2
D (Runner Diameter)	918 mm	1095 mm
N_o (Runner Speed)	600 rpm	600 rpm
N_s (Specific Speed) (100% Output)	258	675
N_{RW} (Max Runaway Speed)	1177 rpm	1427 rpm
P_{RATED} (Rated Power)	2754 kW	1573 kW

The relation between characteristics in different net heads and discharges are arranged in a hill curve which is shown in Figures 3.18 and 3.19. In those figures, the x axis is the net head and the y axis is the turbine discharge. Constant efficiency contours are shown from the lowest efficiency to the highest efficiency in the blue line. The maximum and minimum limit of the site's net head is also shown in the striped black line, while the red line shows the maximum flow limit due to hydraulic limitations or cavitation. The striped red line shows the turbine's head limitations. In those figure, the rated discharge and the peak efficiency point is marked with the green lines.

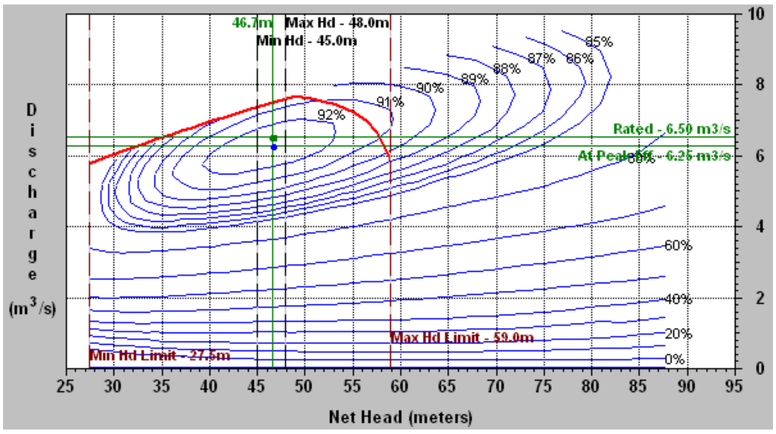


Figure 3.18: Turbine 1 Hill Curve

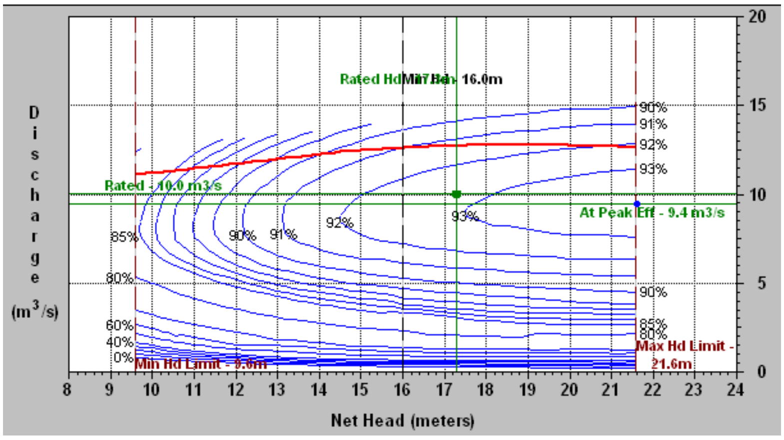


Figure 3.19: Turbine 2 Hill Curve

Chapter 4

System Dynamics

This section presents the water hammer calculations. The result of those calculations are the water discharge plot during the valve closure, pressure data tabulations in the penstocks, hydraulic head plot in the turbine, and head envelope profiles.

4.1 Water Hammer Numerical Equation Model

By discretizing equations (2.26) and (2.27), the numerical equation system is obtained and written as equations (4.1) and (4.2)

$$C^{+} : H_P = H_A - B(Q_P - Q_A) - RQ_P|Q_A| \tag{4.1}$$

$$C^{-} : H_P = H_B + B(Q_P - Q_A) + RQ_P|Q_B| \tag{4.2}$$

where P shows the value at current time step, A shows the value at $x - dx$ and B shows the value at $x + dx$. The pipeline characteristic impedance is also shown in B value, which can be calculated in equation (4.3)

$$B = \frac{c}{gA} \tag{4.3}$$

R value in equations (4.1) and (4.2) shows the resistance coefficient, and defined as

$$R = \frac{J\Delta x}{q_n^2} \tag{4.4}$$

In order to find the Q and H values, the equations (4.1) and (4.2) can be rearranged as shown in equations (4.5) and (4.6).

$$H(x,n) = \frac{1}{B}(C_A - BQ_R) + \frac{1}{B}C_B \tag{4.5}$$

$$Q(x,n) = \frac{1}{B}(H(x,n) - C_B) + Q(x+dx, n-1) \tag{4.6}$$

The values of C_A, C_B, and Q_R in equations (4.5) and (4.6) are known and written in equations (4.7), (4.8), and (4.9)

$$C_A = H(x-dx, n-1) - RQ(x-dx, n-1)|Q(x-dx, n-1)| \tag{4.7}$$

$$C_B = H(x+dx, n-1) + RQ(x+dx, n-1)|Q(x+dx, n-1)| \tag{4.8}$$

$$Q_R = Q(x+dx, n-1) - Q(x+dx, n-1) \tag{4.9}$$

4.1.1 Boundary Conditions Definition

As stated in 2.2.1, in the addition of characteristic equations, the boundary conditions are needed. One of the boundary is in the reservoir, which will be assumed as a constant head, as shown in equation (4.10) and Figure 4.1.

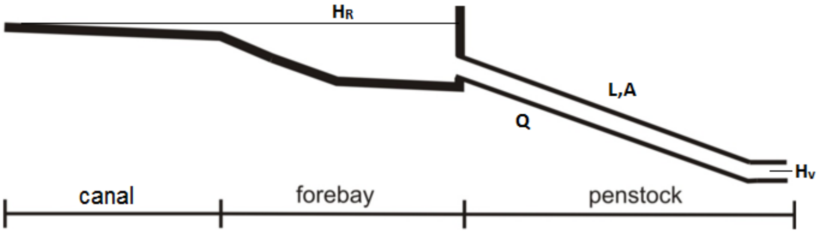


Figure 4.1: Intake Assumptions for Water Hammer Calculations

$$H(x_o, n) = Z_R \tag{4.10}$$

where Z_R is the hydraulic head in the reservoir.

The elevation of the turbine in the hydraulic system is also used as boundary conditions, since it affects the flow discharge that are going away from the turbine. Furthermore, the water flow that goes through the turbine is also defined in equation (4.11).

$$Q(L,n) = -0,5BC_V + 0,5\sqrt{(BC_V)^2 + 4C_VC_P} \tag{4.11}$$

where C_V is defined as

$$C_V = \frac{(kQ_n)^2}{H_n} \tag{4.12}$$

The pressure that happen in (x,n), is calculated in equation (4.13)

$$H(x,n) = \left(\frac{Q(x,t)}{kQ_n}\right)^2 H_n \tag{4.13}$$

4.2 Water Hammer Calculations

In order to understand the condition that happen in the transient phase, different conditions in few scenarios are set for the valve closure times. The valve closure time scenarios is listed in Table 4.1, calculated with the penstock values from each site.

Table 4.1: Valve Time Closure Scenarios

Scenario	1	2	3	4
Closure Time	L/c	3L/c	20L/c	50L/c
Site 1 Value (in sec)	0,60	1,79	11,92	29,81
Site 2 Value (in sec)	0,17	0,50	3,30	8,26

Those conditions includes the fast manoeuvre, with closure time less than 2L/c, and the slow closure with the closure time more than 2L/c.

4.2.1 Calculation Assumptions

The assumptions that are used in the calculations are based on the sites data obtained from previous sections. Those data are listed in Table 4.2, along with the constant that is used in the calculations.

Table 4.2: Data used in Calculations

Parameters	Site 1	Site 2
Q (m^3/s)	6,5	10
L (m)	625,181	173,096
D (m)	1,65	1,9
c (m/s)	1048,77	1048,18
t (sec)	0,0195	0,0224
R	0.00045	0,00007
Z_R (m)	591,87	520,1
Δx (m)	5	5
t_s (s)	25	25

The other assumptions is that the system is based on general scheme of reservoir hydropower plant, as shown in Figure 2.2.

4.2.2 Calculation Method

The numerical problem is solved using Matlab programs, which is written based on Brunes (2009) model [27], with some modifications to adjust with the assumptions on the both sites. In each of the sites, since there are couple of turbines that have identical parameters, the water hammer simulation is assumed to be the same for both turbines. Thus, the simulation is only executed for each turbine in both sites. The modified code is presented at the appendix.

4.3 Calculation Results

4.3.1 Site 1

During valve closure, the amount of water flow that can go through the turbine reduces as the time increases. In Figure 4.2, the relation between water flow and time is described, with the assumption that the valve closure type is linear.

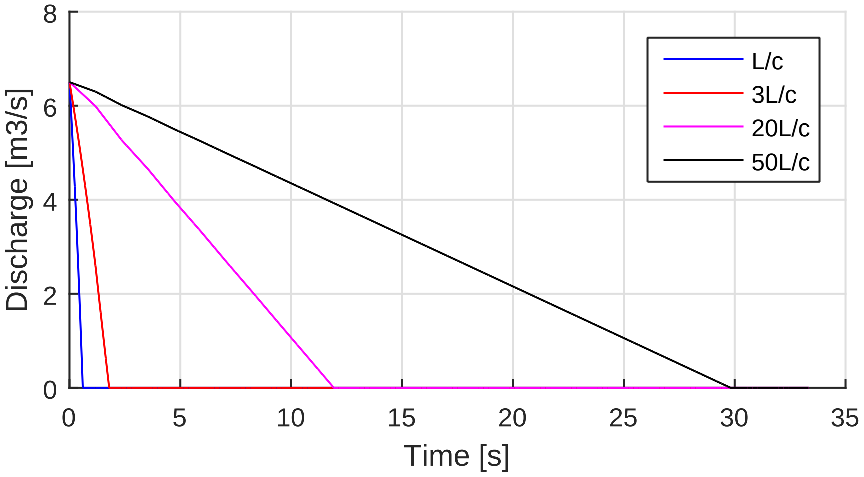


Figure 4.2: Effect of Different Closure Times to Water Flow in Site 1

Different closure times will affect the penstock with different set of pressures along the penstock. In the Table 4.3, the maximum and minimum pressure in penstock for different scenarios are listed. Representative values from 12 section of the penstock are listed in the table.

Table 4.3: Max and Min Pressure in Site 1 Penstock in Different Closure Times

Section	0.00	1.00	2.00	3.00	4.00	5.00	6.00	8.00	9.00	10.00	11.00
L/c											
Hmax (m)	49.00	124.39	192.50	254.73	311.47	363.13	375.39	375.50	375.62	375.73	375.88
Hmin (m)	49.00	-23.91	-91.64	-153.54	-209.95	-261.28	-273.45	-273.57	-273.68	-273.79	-273.94
3L/c											
Hmax (m)	49.00	72.01	93.34	114.02	134.04	153.44	172.22	190.39	207.98	224.98	247.47
Hmin (m)	49.00	28.04	6.74	-13.89	-33.88	-53.22	-61.40	-69.00	-75.82	-81.77	-88.20
20L/c											
Hmax (m)	49.00	52.38	54.74	57.08	59.40	61.71	64.00	66.27	68.52	70.76	73.81
Hmin (m)	49.00	48.38	46.92	45.41	43.90	42.39	40.90	39.42	37.95	36.43	34.38
50L/c											
Hmax (m)	49.00	50.79	51.57	52.35	53.12	53.89	54.65	55.41	56.17	56.92	57.96
Hmin (m)	49.00	49.37	48.74	48.11	47.48	46.85	46.22	45.58	44.95	44.32	43.48

The pressure head plots in the turbine area are shown on Figures 4.3 to 4.6.

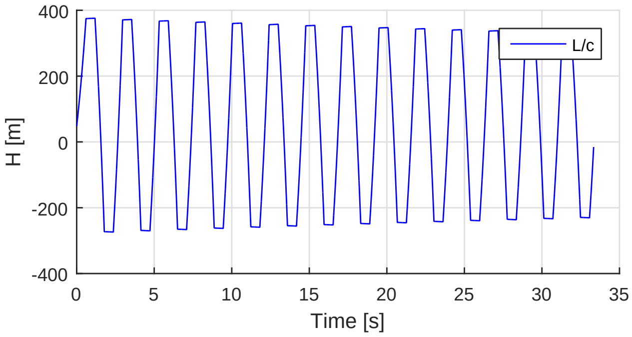


Figure 4.3: Hydraulic Head in front of Turbine at Site 1 (Closure Time: L/c)

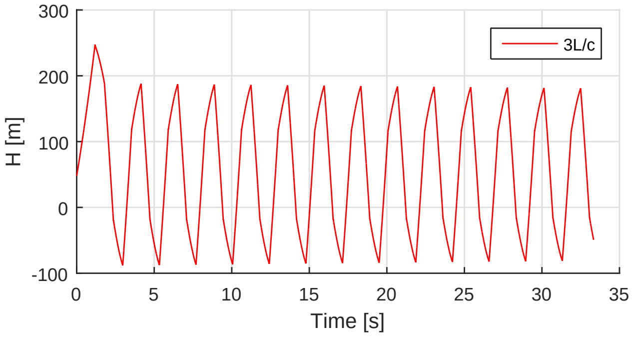


Figure 4.4: Hydraulic Head in front of Turbine at Site 1 (Closure Time: 3L/c)

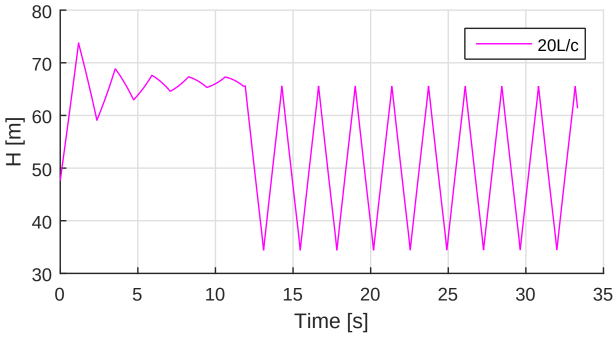


Figure 4.5: Hydraulic Head in front of Turbine at Site 1 (Closure Time: 20L/c)

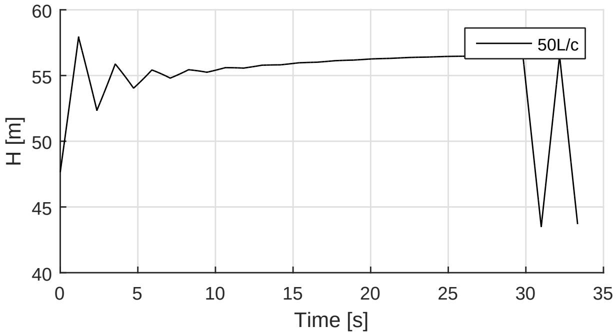


Figure 4.6: Hydraulic Head in front of Turbine at Site 1 (Closure Time: 50L/c)

The comparison between pressure envelops on the penstock and penstock profile for site 1 is described in Figures 4.7 to 4.10.

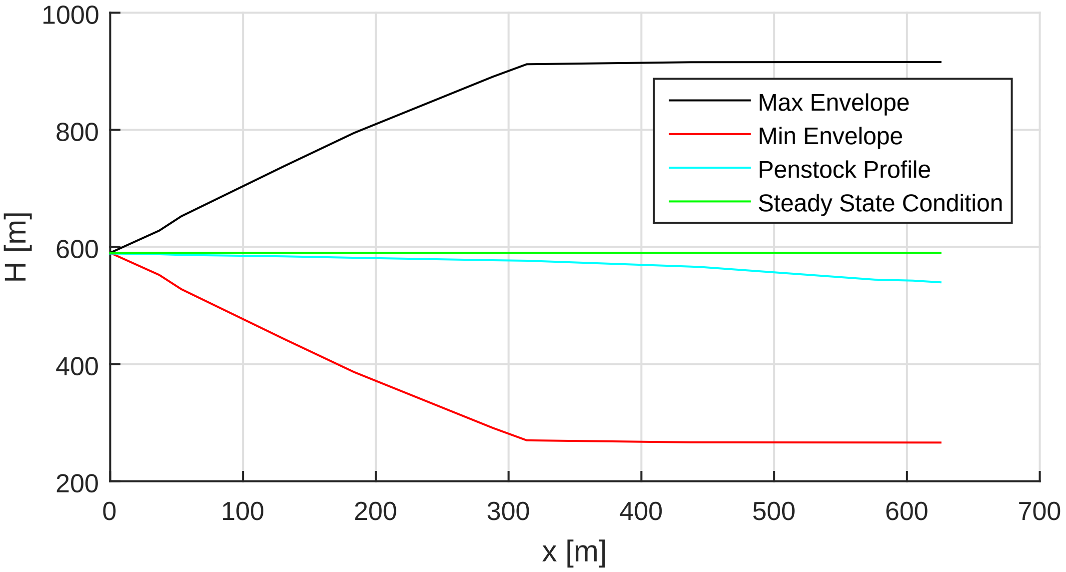


Figure 4.7: Head Envelope and Pipeline Profile in Site 1(L/c)

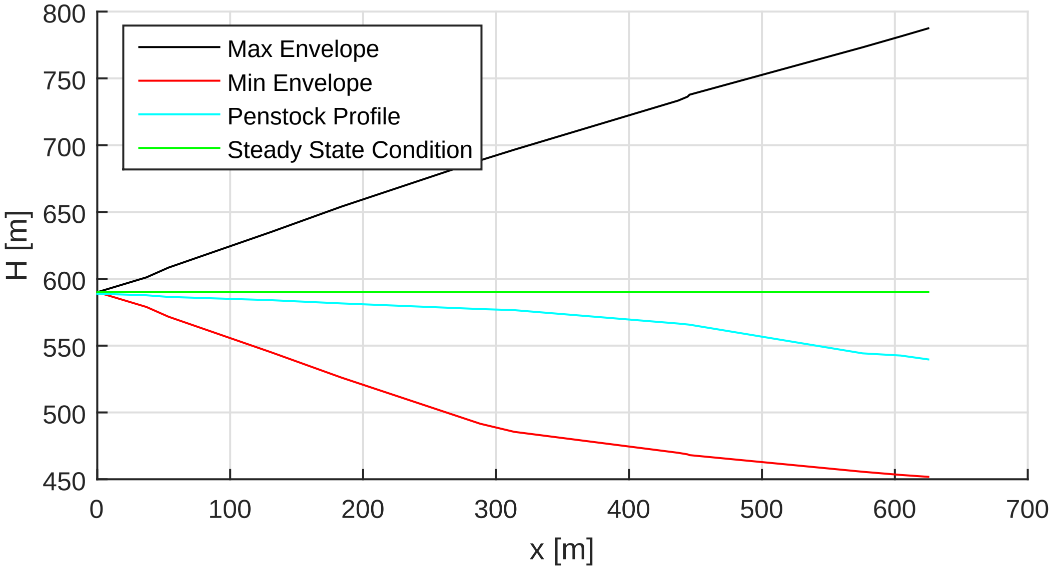


Figure 4.8: Head Envelope and Pipeline Profile in Site 1 (3L/c)

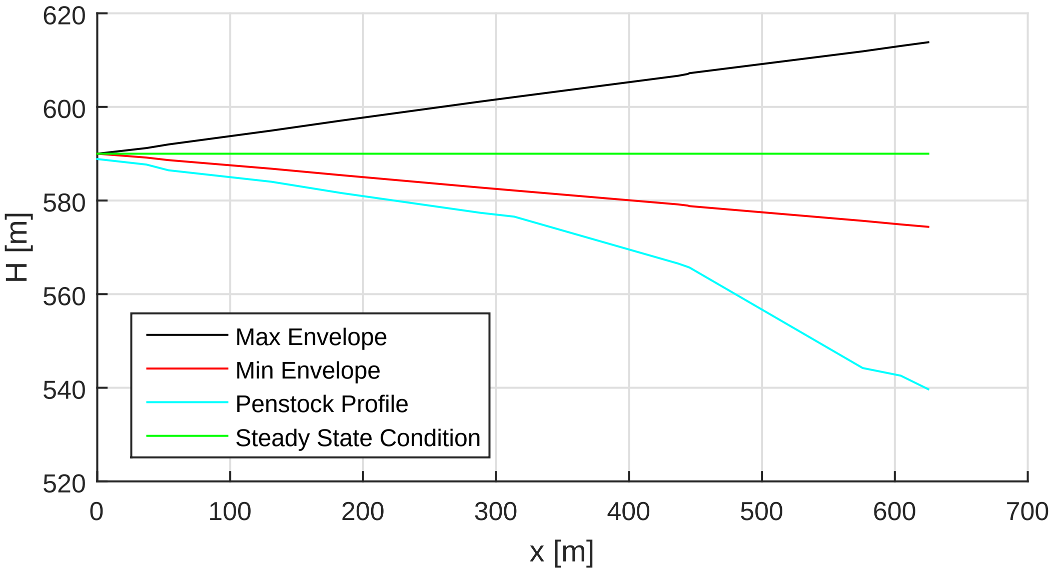


Figure 4.9: Head Envelope and Pipeline Profile in Site 1 (20L/c)

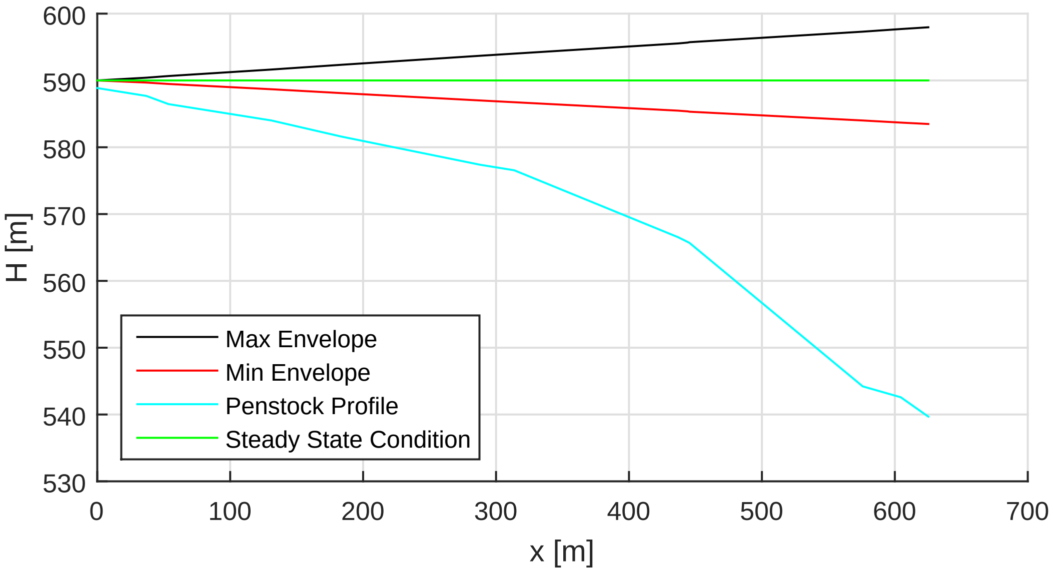


Figure 4.10: Head Envelope and Pipeline Profile in Site 1 (50L/c)

4.3.2 Site 2

The relation between water flow during valve closure and time in site 2 are described in figure 4.11. In this site, the valve closure type is also assumed to be linear.

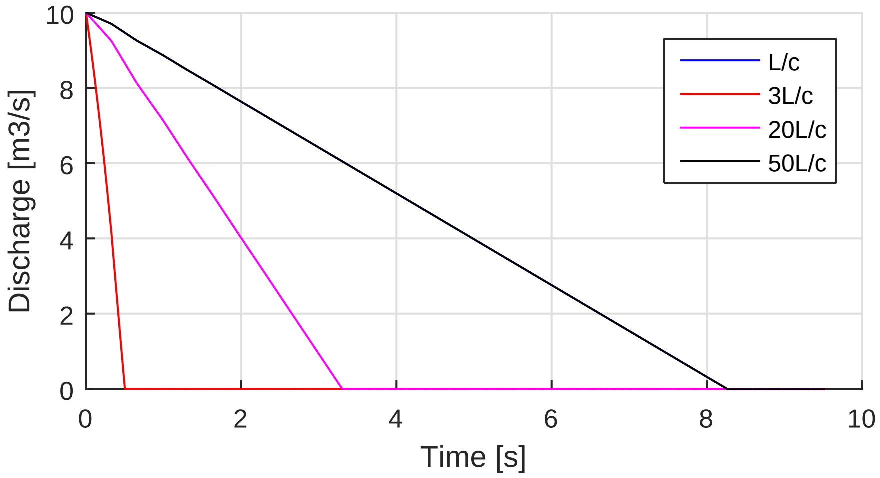


Figure 4.11: Effect of Different Closure Times to Water Flow in Site 2

In the Table 4.4, the maximum and minimum pressure thorough the penstock in Site 2 are listed.

Table 4.4: Max and Min Pressure in Site 2 Penstock in Different Closure Times

Section	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00
						L/c						
Hmax (m)	18.00	103.17	180.07	249.33	311.59	367.49	396.37	396.40	396.43	396.46	396.48	396.50
Hmin (m)	18.00	-67.05	-143.85	-213.03	-275.22	-331.04	-359.87	-359.90	-359.93	-359.96	-359.99	-360.01
						3L/c						
Hmax (m)	18.00	42.52	66.19	89.01	111.03	132.26	152.72	172.45	191.46	209.78	227.43	241.29
Hmin (m)	18.00	-6.51	-30.17	-52.98	-74.99	-96.20	-107.51	-117.71	-127.04	-135.40	-142.66	-147.31
						20L/c						
Hmax (m)	18.00	20.67	23.32	25.95	28.57	31.17	33.76	36.33	38.88	41.42	43.98	45.98
Hmin (m)	18.00	16.22	14.48	12.73	10.98	9.24	7.50	5.77	4.04	2.33	0.59	-0.73
						50L/c						
Hmax (m)	18.00	19.03	20.00	20.98	21.96	22.95	23.93	24.91	25.88	26.87	27.87	28.61
Hmin (m)	18.00	17.30	16.59	15.89	15.18	14.48	13.78	13.07	12.37	11.66	10.96	10.43

The pressure head plots in the turbine area are shown on Figures 4.12 to 4.15.

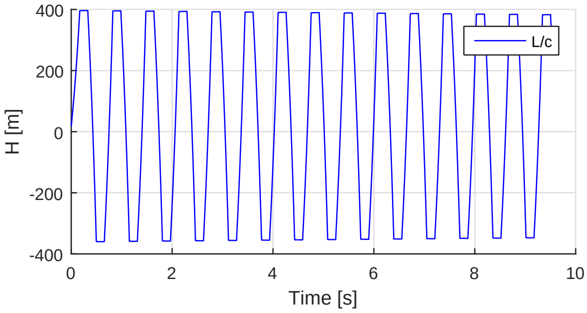


Figure 4.12: Hydraulic Head in front of Turbine at Site 2 (Closure Time: L/c)

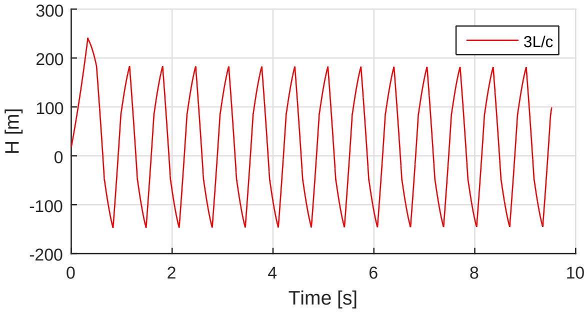


Figure 4.13: Hydraulic Head in front of Turbine at Site 2 (Closure Time: 3L/c)

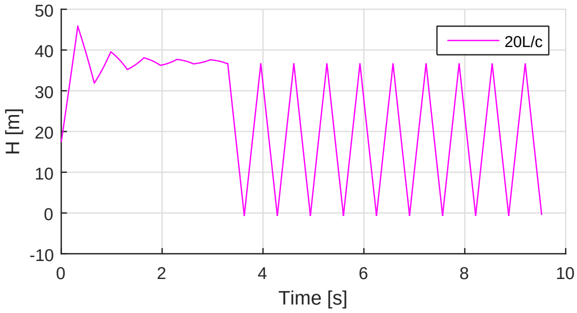


Figure 4.14: Hydraulic Head in front of Turbine at Site 2 (Closure Time: 20L/c)

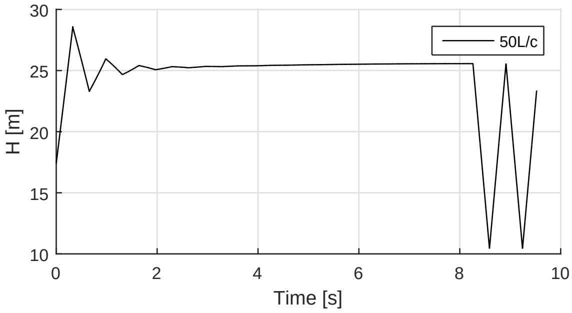


Figure 4.15: Hydraulic Head in front of Turbine at Site 2 (Closure Time: 50L/c)

The comparison between pressure envelops on the penstock and penstock profile for site 2 is described in Figures 4.16 to 4.19.

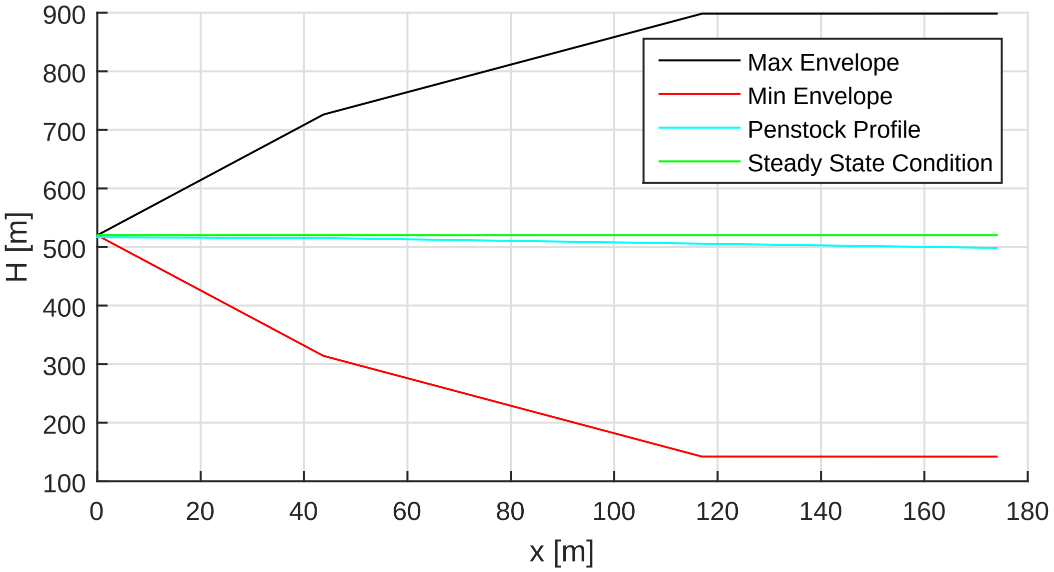


Figure 4.16: Head Envelope and Pipeline Profile in Site 2(L/c)

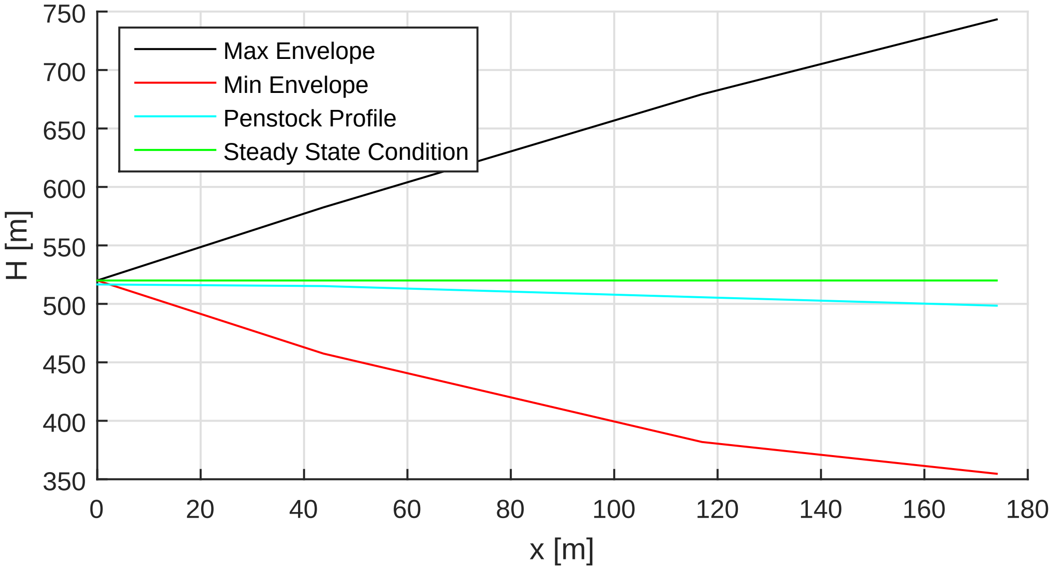


Figure 4.17: Head Envelope and Pipeline Profile in Site 2 (3L/c)

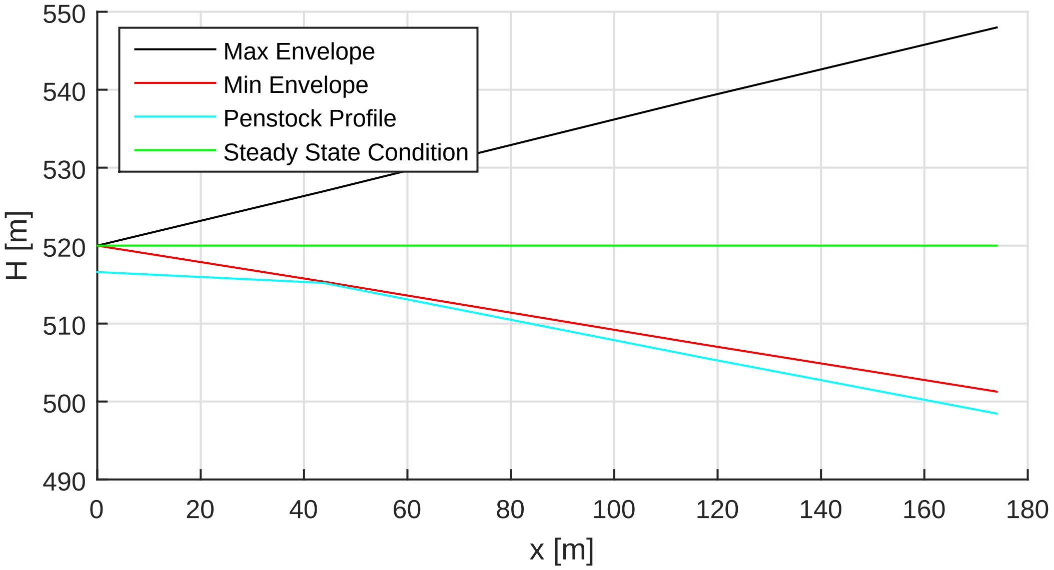


Figure 4.18: Head Envelope and Pipeline Profile in Site 2 (20L/c)

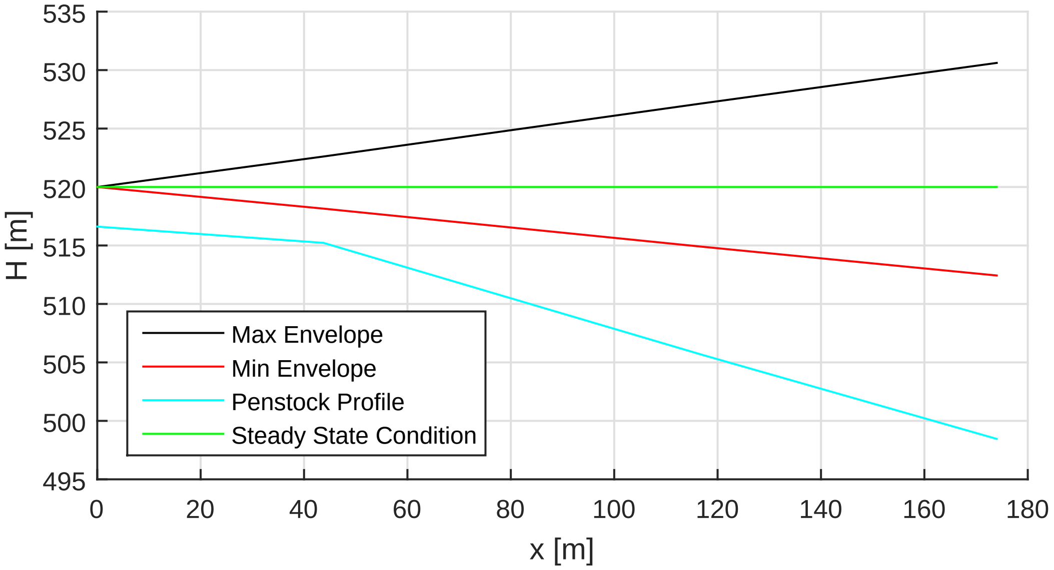


Figure 4.19: Head Envelope and Pipeline Profile in Site 2 (50L/c)

4.4 Water Hammer Analysis

Site 1

For site 1, the comparison of pressure variation in the turbine between four scenarios are shown in Figure 4.20. It is shown that at the fast manoeuvre of the valve, rapid pressure changes occur. In the case of closure time of L/c and 3L/c, very huge pressure spikes up to 375 m and 247 m occurs, which is much higher than the design head of the turbine at 46,72 m.

On the other hand, the slow manoeuvre scenario (with valve closure time of 20L/c and 50L/c) provides the hydraulic circuit with a reduced pressure spike during transient condition.

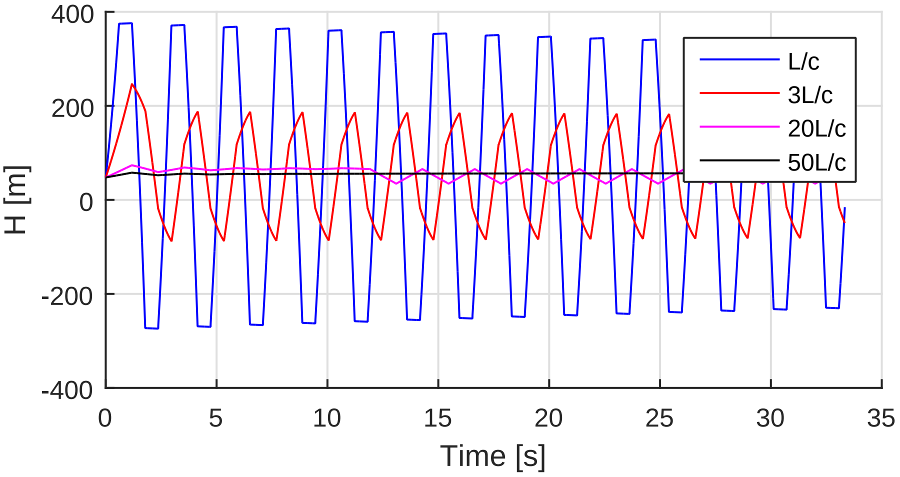


Figure 4.20: Comparison Between Different Valve Closure Time at Site 1

The maximum and minimum pressure are influenced by the valve closure time. The value of these pressures are listed in Table 4.5.

Table 4.5: Maximum and Minimum Head for Different Closure Times at Site 1

Parameter	L/c	3L/c	20L/c	50L/c
H_{max} (m)	375,87	247,46	73,81	57,95
H_{min} (m)	-273,94	-88,20	34,37	43,48

The typical value for allowable maximum transient head variations ($\Delta H/H_o$) is 0,5 for the head that is lower than 50 [16]. Abiding these criterion, the pressure can be maintained below the point that may break the pipe. In addition, by reducing the pressure spikes, the cavitation phenomena that was caused by over pressure can also be avoided. Looking at the Table 4.5, based on the net head of 46,72 m, it is shown that the closure times of 20L/c and 50L/c are able to fulfil these criterion, since the pressure variation are less than 50%. Therefore, in order to have a safe criteria of valve closure, the valve closure time has to be more than 20L/c, which is 12 seconds.

Site 2

For the site 2, the pressure spikes are also found in the simulation with the closure time of L/c and 3L/c, with the maximum values of 396,5 m and 241,29 m. Compared to the site1, the maximum value of the pressure spikes in site 2 is quite similiar in value. Those fact can be explained with the relation between maximum pressure variation and flow velocity as shown in equation (4.14) [49].

$$\Delta p_j = \pm \rho c \Delta V \tag{4.14}$$

Since the velocity range of the water flow in both sites are within the same range ($3 - 4\, m/s$), then the maximum pressure variation are roughly similar. Furthermore, the same case is also found in site 2, where the maximum pressure values are also way above the turbine head design values of 17,29 m. On the other hand, it is also observable that by using longer valve closure time, the pressure spikes are reduced.

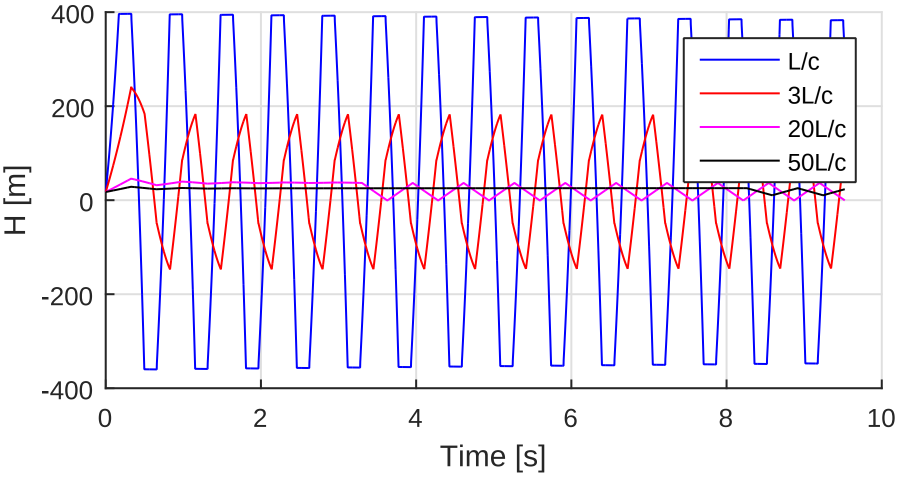


Figure 4.21: Comparison Between Different Valve Closure Time at Site 2

The value of maximum pressures during different valve closure scenarios are listed in Table 4.6.

Table 4.6: Maximum and Minimum Head for Different Closure Times at Site 2

Parameter	L/c	3L/c	20L/c	50L/c
H_{max} (m)	396,50	241,29	45,98	28,61
H_{min} (m)	-360,00	-147,31	-0,72	10,43

Since the net head of site 2 is also lower than 50 m, the same criterion is also used in order to determine the maximum allowable transient head variations. Based on Table 4.6, the valve closure time of 50L/c (8,26 sec) was able to fulfil the defined criteria, since the maximum variation of pressure is still below $0.5H_o$.

Chapter 5

Energy Production and Financial Sensitivity Analysis

In this chapter, the annual energy production is calculated based on the most optimum power plant design that is selected in the previous chapter. Furthermore, the financial sensitivity analysis was calculated in order the determine the economic feasibility of these optimum designs.

5.1 Annual Energy Productions

The yearly energy productions is simulated based on the sites characteristics and the turbine profiles. At the site 1, the turbine with design flow of 2x6,5 m^3/s is used, with the expected capacity factor (equation 2.19) of the first and second turbines are 75,3% and 90,4%. In other words, one turbine serves as the base load turbine and the other turbine serves as the additional turbine when enough water discharge is available. Since those turbines operate on a different discharge through a year, the turbines efficiency varies. At the optimum discharge, the turbines efficiency are 92,4%. For the first turbine, the efficiency can go as low as 75% at its lowest operating point. On the other hand, as the second turbine operates on a steady flow, its' lowest efficiency is higher, at 84%. Based on the tabulated energy production (Appendix A.3), the total annual energy produced by turbines are about 42,9 GWh. It is important to note that these annual energy value does not include the generator or transmission losses.

For the second site, with the design flow of 2x10 m^3/s, the total annual energy produced by turbines are 26,3 GWh. The maximum efficiency for both of the turbines are 92,57%. The first turbine work as the additional turbine with capacity factor of 83,6% and minimum operating turbine efficiency of 90,7%. For the second turbine, the capacity factor is at 95,8%, with the minimum operating turbine efficiency of 91,1%.

The available flows and the operating flows for both sites are depicted in Figures 5.1 and 5.2. The brown line shows the river discharge flow that based on the flow duration curve. Meanwhile, each of the turbine operating flow is marked with red and blue colour, with each colour describe each turbine. The detailed data on the produced energy on each percent flow is tabulated on Appendixes A.3 and A.4.

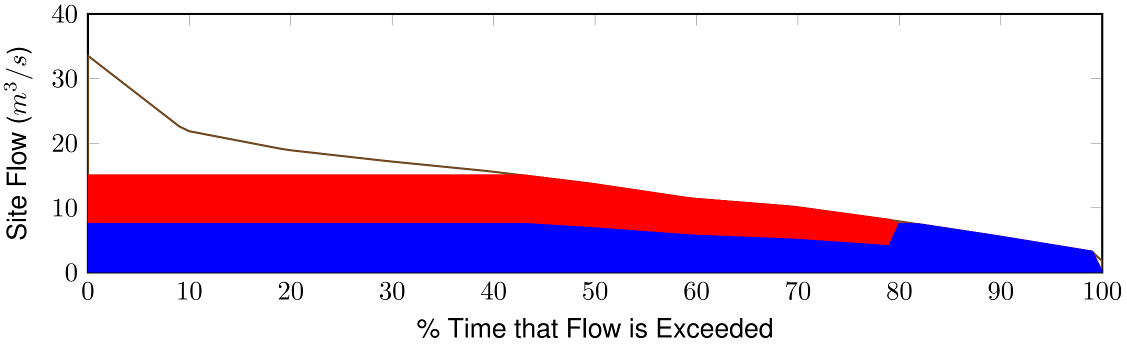


Figure 5.1: Potential Site 1 Available and Operating Flow

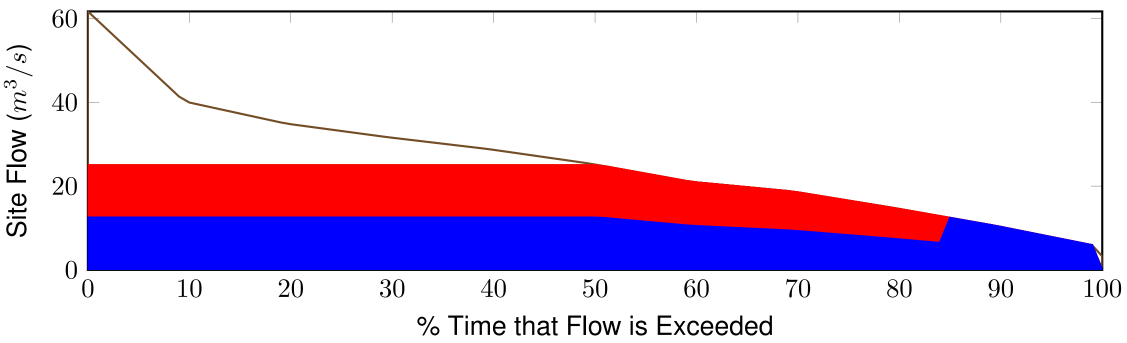


Figure 5.2: Potential Site 2 Available and Operating Flow

The actual annual energy produced has to consider the losses that occur in the electric power generation. The assumptions that applies to the actual annual energy production calculations are as follows:

- Generator efficiency is set to 95%
- The generators also use energy for its operations, and it is assumed 1% of the energy goes to generators
- The capacity factor decreases in the case of major overhaul, which is recommended after 10 years of operation [50]. The energy production is expected to decrease for about 20% from the normal production [51] during major overhaul.

Using assumptions above, the annual generated electricity for both sites are calculated. During normal operations, the annual electricity production of site 1 is 40,34 GWh, while site 2 can produce about 24,73 GWh anually. In the case of major overhaul, the energy production for site 1 drops to 32,27 GWh per year, while for site 2 the energy production drops to 18,91 GWh. These values are used for the detailed financial analysis.

5.2 Financial Sensitivity Analysis

The assumptions made for the financial analysis based on the best practice approach in the company and also literature study are listed below [51]:

- The annual Operation and Maintenance costs are assumed to be 2,5% from the investment costs.
- There are additional contingency costs for about 10% of the total capital costs.
- The feasibility study and the planning cost is already included in the capital cost. The feasibility study cost is assumed to be the same for all of the site, while the planning costs are assumed to be 2% of the capital cost.
- The Investment Loan from bank is scheduled to be paid in 8 years, with the annual interest of 15%. The common practice in Indonesia for the bank loan is that the annual interest is twice of the discount rate.
- The time that is required for the feasibility study and the development of the mini hydropower plant is three years (including time to arrange study and permit). Therefore the energy productions is started at the fourth year of the project.
- Payment, expenses, and the income of the plant is calculated at the end of the year.
- Lifetime of the project is the same as the lifetime of the power purchase agreement contract, which is 20 years.
- The interest rate is assumed to be constant through the lifetime of the project, at 7,5%
- The long term USD to IDR exchange rate is set at 11.963,33 IDR per 1 USD, considering the exchange rate projections at the lifetime of the project [52].
- The income tax is calculated according to the Indonesian Government Law No. 46 Year 2013 about income tax, which is calculated by $(25 - \frac{600000000}{EBIT})\%$ (EBIT=Earning Before Income Tax) if the income is more than 4.800.000.000 IDR. The income tax is 1% if the EBIT is equal or less than that.
- The tax discount is applied to the capital costs for the first six year of the project, with the amount of tax discount is equal to 5% of the total capital costs.
- The power purchase agreement energy price is as stated in chapter 2.4, with the assumption that local investor made the majority investment.

Using these assumptions, a sensitivity analysis for the optimum design choice was made by using two different values for the Total Installed Costs, which are low cost (base cost) and high cost assumptions. The low cost assumptions is made by assuming that the price of Total Installed cost is at IDR $15.000.000/kWh$, while for the high cost, the cost is assumed at IDR $30.000.000/kWh$. The calculated capital costs for both assumptions in both sites are tabulated in Table 5.1.

Table 5.1: Capital and O&M Costs

Costs Name	First Site (IDR, Low Cost)	First Site (IDR, High Cost)	Second Site (IDR, Low Cost)	Second Site (IDR, High Cost)
Capital Costs	82.620.000.000	165.240.000.000	47.190.000.000	94.930.000.000
Feasibility Study	1.096.000.000	1.096.000.000	1.096.000.000	1.096.000.000
Planning Costs	1.652.400.000	3.304.800.000	943.800.000	1.887.600.000
Operation and Maintenance Costs / year	2.065.500.000	4.131.000.000	1.179.750.000	2.359.500.000

Furthermore, these capital costs and Operation and Maintenance costs assumptions used as the basis to calculate the project financial parameters. The calculation results are tabulated in the Table 5.2. From the table, it is noticeable that those project is very attractive at the low cost assumption of capital costs, while positive NPVs are still maintained on the high cost assumption.

Table 5.2: Economic Parameters of Site 1 and Site 2

Parameters	Site 1 Alternative Flow		Site 2 Alternative Flow	
Price Assumption	Low Cost	High Cost	Low Cost	High Cost
Site Flow	13 m^3/s		20 m^3/s	
Rated Power (kW)	2x2754		2x1573	
Net Present Value (10^9 IDR)	218,356	64,955	150,813	63,039
Benefit/Cost Ratio	4,61	1,43	4,52	1,73
Internal Rate of Return	39,25%	11,30%	37,36%	14,03%
Payback Period	6 years	14 years	5 years	11 years

For the site 1, the low price assumptions giving a very high return to the investments, with Benefit/Cost Ratio of 4,61. In this assumptions, the payback period is also short, below 6 years, which is very attractive considering it will take three year to develop the plants (including the study and permit). In the case of high cost assumptions, the project still offers better return than interest rate, with IRR of 11,30%, compared to the interest rate of 7%. However, for the investor that wish a short term return on the investment, the site 1 project may not be that interesting, since the Payback Period of the high cost assumptions is 14 years.

Meanwhile, for the second site, the low price assumptions also returns the investment with a high Benefit/Cost Ratio of 4,52. This site offers a very short Payback Period of 5 years. At the high cost assumptions, this project can still double the value of interest rate, with IRR of 14,03%. This project could also attract investor who interested in short and medium investment project, since at the high price assumptions, this project could still return the investments in 11 years.

LCOE Sensitivity

The project Levelized Cost of Electricity is calculated using equation (2.43). Compared to the LCOE data from IRENA [40], the assumptions made on the projects result in the value of LCOE between the minimum and average value, which is between USD 0.02-0.05/kwh. Using the exchange rate of the project, for the site 1, the LCOE value is 0,021 USD/kWh for the low cost and 0,043 USD/kWh for the high cost assumption. On the other hand, for the site 2, the LCOE is 0,020 USD/kWh for the low cost and 0,040 USD/kWh for the high cost assumption.

The LCOE sensitivity can be further analysed by varying the interest rate. In the Table 5.3, three discount rate are used as comparison. The base value for the discount rate is 7%, while for the comparison lower (5%) and higher (9%) value of discount rates are used.

Table 5.3: Sensitivity of the LCOE of Site 1 and 2

Investment Cost (IDR/kW)	Discount Rate (%)	Site 1 LCOE (IDR/kWh)	LCOE (USD cent/kWh)	Site 2 LCOE (IDR/kWh)	LCOE (USD cent/kWh)
15.000.000	5	223,50	1,9	208,95	1,7
15.000.000	7	255,51	2,1	238,87	2,0
15.000.000	9	290,27	2,4	271,38	2,3
30.000.000	5	446,84	3,7	417,62	3,5
30.000.000	7	510,73	4,3	477,27	4,0
30.000.000	9	580,12	4,8	542,06	4,5

It appears that the project is sensitive to the interest rate assumption, due to huge capital investment in the beginning of the project. For the site 1, a 2% change of interest rate could impact the LCOE value to about 10% in the low cost assumption, while for the high cost assumption the same interest rate modification produces about 14% change in LCOE. On the other hand, in site 2, for the low cost assumption, about 15% change in LCOE happened at 2% shift of interest rate. For the high cost assumption, with the same modification in interest rate, the LCOE can decrease or increase for about 12,5%. Considering the increase in LCOE value in both sites and both assumptions, those two sites LCOE values are still within the lower and medium range of reference LCOE values [40].

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

Hydropower plant study in Manna Region shows that the sites are showing promising economic results, due to the recent Feed-in-Tariff that imposed by Indonesian government. However, there are still several steps needed in order to fully ensure that the project is feasible both economically and technically.

The preliminary hydrology study is based on the data that is available in that region. The 1:50.000 topology map is used as a base for selecting the preliminary location for the weir, forebay, and the powerhouse. Based on these maps and also the map from Indonesia's Ministry of Forestry, the watersheds that relates to the sites are traced. Based on the Thornwaithe-Mather water balance method, the mean discharge value is obtained.

The water discharge data arranged to create flow duration curve, which is used to determine the design discharge. The hydropower plant capacity is based on the design discharge value. Based on the economical analysis, the optimum design discharge value is obtained at 13 m^3/s for site 1 and 20 m^3/s for site 2. Therefore, the rated capacity for site 1 is 2x2754 kW, while for site 2 it is 2x1573kW.

A Hydraulic study was done in order to test the hydraulic circuit in the case of transient condition. Using the Method of Characteristics (MOC), a water hammer model is created and then simulated for few scenarios, based on different valve closure times. Those study shows that on both sites, the risk of water hammer can be mitigated by using the slow manoeuvre valve closure. In site 1, the closure time has to be more than 12 seconds, while on site 2 the closure time has to be more than 8,5 seconds.

The financial analysis was made in order to determine the economic parameters of the hydropower project. In this analysis, the revenue is heavily dependent on the annual energy generation. The site 1 is projected to be able to produce 40,34 GWh of energy in a year, while site 2 produces 24,73 GWh anually. With the low cost estimation of Total Installed Costs (IDR 15.000.000/kW), both of the projects are able to return the investments in less than 6 years. However, with the increase of the total investment costs (the high cost estimate of IDR 30.000.000/kW), site 1 PBP increases to 14 years, while the site 2 PBP increases to 11 years. Nevertheless, both of the sites are still producing positive Net Present

Value, thus is very attractive sites for development.

In terms of Levelised Cost of Electricity, the project cost is valued between the low cost and average value, if compared with the data from IRENA [40], which is between 0.02 to 0.05 USD/kWh.

6.2 Recommendations

Based on this study, the Manna Sites are shown to be promising sites that need to be advanced to further stage of developments. The future study has to include more detail, and also direct data measurement to the sites. These measurements are:

- Topography survey to provide a 1:500 map, which is used to produce x and y axis map of detailed weir/dam, forebay, powerhouse, and road plans.
- Hydrology and hydrometry study to provide river morphology and vegetation data, water sample, and also request of latest hydrology data to the closest climate station. In addition, the river discharge data also need to be directly measured for data comparison.
- Electro-Mechanical detailed design and analysis
- Geology and soil study to determine the feasibility of site development in the proposed sites.
- Detailed hydraulic studies, including the design of dam/weir, hydraulic circuits, and safety components. They also include surge analysis in transient conditions that happen in plant startup/shutdown, valve manoeuvres, pressure and discharge variation.
- Structure studies
- Detailed cost estimate based on detailed study data.

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Appendix A

Appendix

A.1 Tables

Table A.1: Projects Assumptions on Site 1 and Site 2

Total Installed Costs/kW LOW	IDR 15,000,000.00
Total Installed Costs/kW HIGH	IDR 30,000,000.00
Feasibility Study Cost	IDR 1,096,040,000.00
Project Assumption	
Feed In Tariff (Year 1-8)	1579,16 IDR (13,2 cent USD)
Feed In Tariff (Year 9-20)	986,975 IDR (8,25 cent USD)
Interest Rate	0,07
Bank Loan Rate	0,14
Power Plant Project Year	Costs Incurred
1st year	All FS Cost & 1/2 Planning Costs
2nd year	1/2 Planning Costs + 1/2 Construction Costs
3rd year	Remaining Capital Costs
4rd year	Start Energy Production

Table A.2: Monthly Temperature Mean Data from Baai Weather Station

	Mean Monthly Temperature in Year (^0C)													
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Jan	26.1	26.2	26.6	26.6	26.8	26.7	26	26.4	26.7	26	26.4	26	26.6	26.4
Feb	26.1	25.9	26.8	26.6	26.5	27	26.6	26.8	26.3	26.2	27.1	26.5	26.6	26.5
Mar	26	26.7	26.6	26.9	26.8	27	26.5	26.5	26	26.5	26.9	26.6	26.8	27.6
Apr	26.4	26.7	26.7	26.9	27	27.3	26.2	26.9	26.8	26.8	27.8	26.8	26.8	27.2
May	25.4	26.8	27.4	27.1	26.7	27.2	27.1	27.2	26.6	26.8	27.7	27.1	27.3	27.5
Jun	25.5	26.4	26.7	27	26.4	26.7	26.6	26.6	26.6	26.1	27.2	26.9	27.1	26.7
Jul	25.4	26.1	26.6	26.1	26.1	26.3	26.3	26.3	25.9	26.5	26.4	26.5	26.4	26.2
Aug	25.5	26.5	26.4	26.1	26.1	25.9	25.5	26.2	26.2	26.5	26.8	26.6	26.8	26.5
Sep	25.5	26.2	26.2	26.3	26.5	26.3	25.2	25	26.4	26.8	26.5	25.9	26.6	26.5
Oct	25.5	26	26.6	26.1	26.5	26.1	26.3	26.2	26.5	26.6	26.3	26.8	27	26.7
Nov	26.5	26.2	26.2	26.3	26.6	26.1	26.6	26.3	26.2	26.6	26.5	26.6	26.6	26.4
Dec	25.8	25.9	26.4	26.2	26.2	25.7	26.5	26	25.8	26.6	26.2	26.8	26.6	26.5

Table A.3: Site 1 Annual Energy Production ($13m^3/s$ flow)

% Time Step	Avg Flow	Flow of Turbine1	Eff of Turbine1	of Turbine1 (kW)	Flow of Turbine2	Eff of Turbine2	Capacity of Turbine2 (kW)	MWHr Produced	Accum MWHr Produced
1	33.5425	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	544.1196
2	32.3275	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	1088.239
3	31.1125	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	1632.359
4	29.8975	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	2176.478
5	28.6825	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	2720.598
6	27.4675	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	3264.718
7	26.2525	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	3808.837
8	25.0375	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	4352.957
9	23.8225	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	4897.076
10	22.6075	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	5441.196
11	21.8495	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	5985.315
12	21.5485	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	6529.435
13	21.2475	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	7073.555
14	20.9465	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	7617.674
15	20.6455	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	8161.794
16	20.3445	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	8705.913
17	20.0435	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	9250.033
18	19.7425	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	9794.153
19	19.4415	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	10338.27
20	19.1405	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	10882.39
21	18.902	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	11426.51
22	18.726	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	11970.63
23	18.55	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	12514.75
24	18.374	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	13058.87
25	18.198	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	13602.99
26	18.022	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	14147.11
27	17.846	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	14691.23
28	17.67	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	15235.35
29	17.494	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	15779.47
30	17.318	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	16323.59
31	17.152	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	16867.71
32	16.996	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	17411.83
33	16.84	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	17955.95
34	16.684	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	18500.07
35	16.528	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	19044.19
36	16.372	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	19588.31
37	16.216	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	20132.42
38	16.06	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	20676.54
39	15.904	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	21220.66
40	15.748	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	21764.78
41	15.574	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	22308.9
42	15.382	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	22853.02
43	15.19	7.50267143	90.31762	3105.7054	7.502671	90.31762	3105.7054	544.1196	23397.14
44	14.998	7.499	90.32835	3104.5545	7.499	90.32835	3104.55448	543.9179	23941.06
45	14.806	7.403	90.60897	3074.3322	7.403	90.60897	3074.33219	538.623	24479.68
46	14.614	7.307	90.88959	3043.863	7.307	90.88959	3043.86297	533.2848	25012.97
47	14.422	7.211	91.17021	3013.1468	7.211	91.17021	3013.14684	527.9033	25540.87
48	14.23	7.115	91.44308	2981.9311	7.115	91.44308	2981.9311	522.4343	26063.31
49	14.038	7.019	91.66437	2948.8159	7.019	91.66437	2948.81587	516.6325	26579.94
50	13.846	6.923	91.88566	2915.5059	6.923	91.88566	2915.5059	510.7966	27090.73
51	13.6335	6.81675	92.06306	2876.3027	6.81675	92.06306	2876.30275	503.9282	27594.66
52	13.4005	6.70025	92.202	2831.4128	6.70025	92.202	2831.41284	496.0635	28090.73
53	13.1675	6.58375	92.34095	2786.3745	6.58375	92.34095	2786.37455	488.1728	28578.9
54	12.9345	6.46725	92.47989	2741.1879	6.46725	92.47989	2741.18789	480.2561	29059.16
55	12.7015	6.35075	92.61884	2695.8528	6.35075	92.61884	2695.85285	472.3134	29531.47
56	12.4685	6.23425	92.71606	2649.1773	6.23425	92.71606	2649.17733	464.1359	29995.6
57	12.2355	6.11775	92.58462	2595.9863	6.11775	92.58462	2595.98632	454.8168	30450.42
58	12.0025	6.00125	92.45317	2542.9357	6.00125	92.45317	2542.93569	445.5223	30895.94
59	11.7695	5.88475	92.32173	2490.0254	5.88475	92.32173	2490.02543	436.2525	31332.2
60	11.5365	5.76825	92.19028	2437.2555	5.76825	92.19028	2437.25553	427.0072	31759.2
61	11.3575	5.67875	92.01655	2394.9174	5.67875	92.01655	2394.91741	419.5895	32178.79
62	11.2325	5.61625	91.83787	2363.9597	5.61625	91.83787	2363.95967	414.1657	32592.96
63	11.1075	5.55375	91.65918	2333.1043	5.55375	91.65918	2333.10429	408.7599	33001.72
64	10.9825	5.49125	91.4805	2302.3513	5.49125	91.4805	2302.35129	403.3719	33405.09
65	10.8575	5.42875	91.30182	2271.7007	5.42875	91.30182	2271.70066	398.002	33803.09
66	10.7325	5.36625	91.12313	2241.1524	5.36625	91.12313	2241.15239	392.6499	34195.74
67	10.6075	5.30375	90.94445	2210.7065	5.30375	90.94445	2210.70649	387.3158	34583.06
68	10.4825	5.24125	90.76577	2180.363	5.24125	90.76577	2180.36296	381.9996	34965.06
69	10.3575	5.17875	90.58708	2150.1218	5.17875	90.58708	2150.1218	376.7013	35341.76
70	10.2325	5.11625	90.4084	2119.983	5.11625	90.4084	2119.98301	371.421	35713.18
71	10.0625	5.03125	90.09321	2077.494	5.03125	90.09321	2077.49401	363.977	36077.16
72	9.8475	4.92375	89.5511	2020.8718	4.92375	89.5511	2020.87183	354.0567	36431.21
73	9.6325	4.81625	89.009	1964.7838	4.81625	89.009	1964.78383	344.2301	36775.44
74	9.4175	4.70875	88.46689	1909.23	4.70875	88.46689	1909.23002	334.4971	37109.94
75	9.2025	4.60125	87.92479	1854.2104	4.60125	87.92479	1854.2104	324.8577	37434.8
76	8.9875	4.49375	87.21088	1796.1866	4.49375	87.21088	1796.18655	314.6919	37749.49
77	8.7725	4.38625	86.40635	1737.0442	4.38625	86.40635	1737.04421	304.3301	38053.82
78	8.5575	4.27875	85.60181	1678.6947	4.27875	85.60181	1678.69466	294.1073	38347.93
79	8.3425	4.17125	84.79727	1621.1379	4.17125	84.79727	1621.13789	284.0234	38631.95
80	8.1275	4.06375	83.99274	1564.3739	4.06375	83.99274	1564.37391	274.0783	38906.03
81	7.901	7.50267143	90.31762	3105.7054	0	0	0	272.0598	39178.09
82	7.663	7.50267143	90.31762	3105.7054	0	0	0	272.0598	39450.15
83	7.425	7.425	90.54466	3081.2799	0	0	0	269.9201	39720.07
84	7.187	7.187	91.24037	3005.4292	0	0	0	263.2756	39983.35
85	6.949	6.949	91.82573	2924.5466	0	0	0	256.1903	40239.54
86	6.711	6.711	92.18918	2835.5613	0	0	0	248.3952	40487.93
87	6.473	6.473	92.47303	2743.4216	0	0	0	240.3237	40728.25
88	6.235	6.235	92.71691	2649.5202	0	0	0	232.098	40960.35
89	5.997	5.997	92.44838	2541.003	0	0	0	222.5919	41182.94
90	5.759	5.759	92.17985	2433.0717	0	0	0	213.1371	41396.08
91	5.512	5.512	91.53982	2312.5499	0	0	0	202.5794	41598.66
92	5.256	5.256	90.80794	2187.5148	0	0	0	191.6263	41790.29
93	5	5	89.93562	2060.979	0	0	0	180.5418	41970.83
94	4.744	4.744	88.64465	1927.3876	0	0	0	168.8392	42139.67
95	4.488	4.488	87.16785	1793.0031	0	0	0	157.0671	42296.73
96	4.232	4.232	85.25193	1653.5667	0	0	0	144.8524	42441.59
97	3.976	3.976	83.33601	1518.6263	0	0	0	133.0317	42574.62
98	3.72	3.72	80.82058	1377.9604	0	0	0	120.7093	42695.33
99	3.464	3.464	78.06368	1239.3637	0	0	0	108.5683	42803.9
100	3.208	3.208	74.91633	1101.4954	0	0	0	96.491	42900.39

Table A.4: Site 2 Annual Energy Production ($20m^3/s$ flow)

% Time Step	Avg Flow	Flow of Turbine1	Eff of Turbine1	of Turbine1 (kW)	Flow of Turbine2	Eff of Turbine2	Capacity of Turbine2 (kW)	MWHr Produced	Accum MWHr Produced
1	61.719	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	318.6159
2	59.457	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	637.2319
3	57.195	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	955.8478
4	54.933	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	1274.464
5	52.671	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	1593.08
6	50.409	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	1911.696
7	48.147	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	2230.312
8	45.885	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	2548.927
9	43.623	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	2867.543
10	41.361	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	3186.159
11	39.966	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	3504.775
12	39.438	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	3823.391
13	38.91	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	4142.007
14	38.382	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	4460.623
15	37.854	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	4779.239
16	37.326	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	5097.855
17	36.798	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	5416.471
18	36.27	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	5735.087
19	35.742	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	6053.703
20	35.214	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	6372.319
21	34.7875	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	6690.935
22	34.4625	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	7009.551
23	34.1375	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	7328.167
24	33.8125	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	7646.782
25	33.4875	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	7965.398
26	33.1625	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	8284.014
27	32.8375	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	8602.63
28	32.5125	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	8921.246
29	32.1875	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	9239.862
30	31.8625	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	9558.478
31	31.557	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	9877.094
32	31.271	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	10195.71
33	30.985	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	10514.33
34	30.699	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	10832.94
35	30.413	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	11151.56
36	30.127	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	11470.17
37	29.841	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	11788.79
38	29.555	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	12107.41
39	29.269	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	12426.02
40	28.983	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	12744.64
41	28.667	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	13063.25
42	28.321	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	13381.87
43	27.975	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	13700.49
44	27.629	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	14019.1
45	27.283	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	14337.72
46	26.937	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	14656.33
47	26.591	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	14974.95
48	26.245	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	15293.56
49	25.899	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	15612.18
50	25.553	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	15930.8
51	25.1615	12.4945256	91.08011	1818.5841	12.49453	91.08011	1818.58411	318.6159	16249.41
52	24.7245	12.36225	91.17397	1801.1857	12.36225	91.17397	1801.18571	315.5677	16564.98
53	24.2875	12.14375	91.32903	1772.3592	12.14375	91.32903	1772.35917	310.5173	16875.5
54	23.8505	11.92525	91.46271	1743.0171	11.92525	91.46271	1743.01712	305.3766	17180.87
55	23.4135	11.70675	91.59205	1713.5004	11.70675	91.59205	1713.50044	300.2053	17481.08
56	22.9765	11.48825	91.72139	1683.8934	11.48825	91.72139	1683.89342	295.0181	17776.1
57	22.5395	11.26975	91.82115	1653.6634	11.26975	91.82115	1653.66337	289.7218	18065.82
58	22.1025	11.05125	91.91816	1623.315	11.05125	91.91816	1623.31499	284.4048	18350.22
59	21.6655	10.83275	92.01516	1592.8989	10.83275	92.01516	1592.89886	279.0759	18629.3
60	21.2285	10.61425	92.11178	1562.4085	10.61425	92.11178	1562.4085	273.734	18903.03
61	20.895	10.4475	92.17476	1538.9144	10.4475	92.17476	1538.91443	269.6178	19172.65
62	20.665	10.3325	92.21819	1522.6921	10.3325	92.21819	1522.69207	266.7757	19439.43
63	20.435	10.2175	92.26162	1506.4538	10.2175	92.26162	1506.45375	263.9307	19703.36
64	20.205	10.1025	92.30505	1490.1995	10.1025	92.30505	1490.19947	261.0829	19964.44
65	19.975	9.9875	92.34848	1473.9292	9.9875	92.34848	1473.92922	258.2324	20222.67
66	19.745	9.8725	92.39191	1457.643	9.8725	92.39191	1457.64301	255.3791	20478.05
67	19.515	9.7575	92.43534	1441.3408	9.7575	92.43534	1441.34084	252.5229	20730.58
68	19.285	9.6425	92.4678	1424.8537	9.6425	92.4678	1424.85366	249.6344	20980.21
69	19.055	9.5275	92.49878	1408.3321	9.5275	92.49878	1408.33209	246.7398	21226.95
70	18.825	9.4125	92.52977	1391.7991	9.4125	92.52977	1391.79914	243.8432	21470.79
71	18.5125	9.25625	92.56344	1369.1929	9.25625	92.56344	1369.19288	239.8826	21710.68
72	18.1175	9.05875	92.57073	1340.084	9.05875	92.57073	1340.08404	234.7827	21945.46
73	17.7225	8.86125	92.57802	1310.9706	8.86125	92.57802	1310.9706	229.682	22175.14
74	17.3275	8.66375	92.5726	1281.6766	8.66375	92.5726	1281.67658	224.5497	22399.69
75	16.9325	8.46625	92.54395	1252.0717	8.46625	92.54395	1252.07171	219.363	22619.05
76	16.5375	8.26875	92.50656	1222.3695	8.26875	92.50656	1222.3695	214.1591	22833.21
77	16.1425	8.07125	92.46918	1192.6909	8.07125	92.46918	1192.6909	208.9594	23042.17
78	15.7475	7.87375	92.36815	1162.2351	7.87375	92.36815	1162.23508	203.6236	23245.8
79	15.3525	7.67625	92.26712	1131.8429	7.67625	92.26712	1131.84291	198.2989	23444.09
80	14.9575	7.47875	92.16608	1101.5145	7.47875	92.16608	1101.51453	192.9853	23637.08
81	14.547	7.2735	92.06108	1070.0636	7.2735	92.06108	1070.06362	187.4751	23824.55
82	14.121	7.0605	91.93909	1037.351	7.0605	91.93909	1037.35104	181.7439	24006.3
83	13.695	6.8475	91.73233	1003.7939	6.8475	91.73233	1003.79395	175.8647	24182.16
84	13.269	6.6345	91.52558	970.37761	6.6345	91.52558	970.377607	170.0102	24352.17
85	12.843	6.4215	91.31882	937.10202	6.4215	91.31882	937.10202	164.1803	24516.35
86	12.417	12.417	91.13512	1808.3919	0	0	0	158.4151	24674.77
87	11.991	11.991	91.42379	1751.8815	0	0	0	153.4648	24828.23
88	11.565	11.565	91.67596	1694.3034	0	0	0	148.421	24976.65
89	11.139	11.139	91.8792	1635.5111	0	0	0	143.2708	25119.93
90	10.713	10.713	92.06832	1576.2004	0	0	0	138.0752	25258
91	10.258	10.258	92.24632	1512.1743	0	0	0	132.4665	25390.47
92	9.774	9.774	92.42911	1443.6808	0	0	0	126.4664	25516.93
93	9.29	9.29	92.56219	1374.1667	0	0	0	120.377	25637.31
94	8.806	8.806	92.57933	1302.8152	0	0	0	114.1266	25751.44
95	8.322	8.322	92.51664	1230.3755	0	0	0	107.7809	25859.22
96	7.838	7.838	92.34987	1156.729	0	0	0	101.3295	25960.55
97	7.354	7.354	92.10226	1082.3906	0	0	0	94.81742	26055.36
98	6.87	6.87	91.75417	1007.3321	0	0	0	88.24229	26143.61
99	6.386	6.386	91.28436	931.56977	0	0	0	81.60551	26225.21
100	5.902	5.902	90.7824	856.231	0	0	0	75.00584	26300.22

Site 1

Low Price Estimate

Design Discharge 2x4,5m^3/s

Year	Sales	Net Sales	Investment	Cummulative Investment Loan	Expenditure			Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
					O&M	Installment Payment	Bank Interest							
0			IDR 1,666,940,000.00	-IDR 1,666,940,000.00								-IDR 1,666,940,000.00	-IDR 1,666,940,000.00	-IDR 1,666,940,000.00
1			IDR 27,996,980,000.00	-IDR 29,663,920,000.00								-IDR 27,996,980,000.00	-IDR 26,165,401,869.16	-IDR 27,832,341,869.16
2			IDR 27,426,080,000.00	-IDR 57,090,000,000.00								-IDR 27,426,080,000.00	-IDR 23,955,000,436.72	-IDR 51,787,342,305.88
3	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 49,953,750,000.00	-IDR 1,427,250,000.00	-IDR 7,136,250,000.00	-IDR 7,992,600,000.00	IDR 33,476,737,698.25	0.23	IDR 2,854,500,000.00	IDR 7,106,720,323.67	IDR 26,370,017,374.57	IDR 21,525,789,196.44	-IDR 30,261,553,109.44
4	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 42,817,500,000.00	-IDR 1,427,250,000.00	-IDR 7,136,250,000.00	-IDR 6,993,525,000.00	IDR 34,475,812,698.25	0.23	IDR 2,854,500,000.00	IDR 7,355,006,481.35	IDR 27,120,806,216.90	IDR 20,690,333,209.74	-IDR 9,571,219,899.70
5	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 35,681,250,000.00	-IDR 1,427,250,000.00	-IDR 7,136,250,000.00	-IDR 5,994,450,000.00	IDR 35,474,887,698.25	0.23	IDR 2,854,500,000.00	IDR 7,603,376,147.16	IDR 27,871,511,551.08	IDR 19,872,002,537.24	IDR 10,300,782,637.54
6	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 28,545,000,000.00	-IDR 1,427,250,000.00	-IDR 7,136,250,000.00	-IDR 4,995,375,000.00	IDR 36,473,962,698.25	0.23	IDR 2,854,500,000.00	IDR 7,851,822,458.89	IDR 28,622,140,239.36	IDR 19,072,140,577.48	IDR 29,372,923,215.02
7	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 21,408,750,000.00	-IDR 1,427,250,000.00	-IDR 7,136,250,000.00	-IDR 3,996,300,000.00	IDR 37,473,037,698.25	0.23	IDR 2,854,500,000.00	IDR 8,100,339,286.12	IDR 29,372,698,412.13	IDR 18,291,840,354.61	IDR 47,664,763,569.63
8	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 14,272,500,000.00	-IDR 1,427,250,000.00	-IDR 7,136,250,000.00	-IDR 2,997,225,000.00	IDR 38,472,112,698.25	0.23	IDR 2,854,500,000.00	IDR 8,348,921,135.23	IDR 30,123,191,563.02	IDR 17,531,971,748.23	IDR 65,196,735,317.87
9	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 7,136,250,000.00	-IDR 1,427,250,000.00	-IDR 7,136,250,000.00	-IDR 1,998,150,000.00	IDR 39,471,187,698.25	0.23		IDR 9,267,796,924.56	IDR 30,203,390,773.69	IDR 16,428,643,382.26	IDR 81,625,378,700.13
10	IDR 50,032,837,698.25	IDR 50,032,837,698.25		IDR -	-IDR 1,427,250,000.00	-IDR 7,136,250,000.00	-IDR 999,075,000.00	IDR 40,470,262,698.25	0.24		IDR 9,517,565,674.56	IDR 30,952,697,023.69	IDR 15,734,781,621.65	IDR 97,360,160,321.78
11	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 10,918,798,895.07	IDR 108,278,959,216.85
12	IDR 25,016,418,849.12	IDR 25,016,418,849.12			-IDR 1,427,250,000.00		IDR -	IDR 23,589,168,849.12	0.22		IDR 5,297,292,212.28	IDR 18,291,876,636.84	IDR 8,121,811,983.71	IDR 116,400,771,200.56
13	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 9,536,901,821.18	IDR 125,937,673,021.74
14	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 8,912,992,356.24	IDR 134,850,665,377.98
15	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 8,329,899,398.36	IDR 143,180,564,776.34
16	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 7,784,952,708.75	IDR 150,965,517,485.09
17	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 7,275,656,737.15	IDR 158,241,174,222.23
18	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 6,799,679,193.59	IDR 165,040,853,415.82
19	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 6,354,840,367.84	IDR 171,395,693,783.67
20	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 5,939,103,147.52	IDR 177,334,796,931.19
21	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 1,427,250,000.00		IDR -	IDR 29,843,273,561.40	0.23		IDR 6,860,818,390.35	IDR 22,982,455,171.05	IDR 5,550,563,689.27	IDR 182,885,360,620.46
22	IDR 25,016,418,849.12	IDR 25,016,418,849.12			-IDR 1,427,250,000.00		IDR -	IDR 23,589,168,849.12	0.22		IDR 5,297,292,212.28	IDR 18,291,876,636.84	IDR 4,128,717,372.77	IDR 187,014,077,993.23

Design Discharge 2x6,5 m^3/s

Year	Sales	Net Sales	Investment	Cummulative Investment Loan	Expenditure			Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
					O&M	Installment Payment	Bank Interest							
0			IDR 1,922,240,000.00	-IDR 1,922,240,000.00								-IDR 1,922,240,000.00	-IDR 1,922,240,000.00	-IDR 1,922,240,000.00
1			IDR 40,761,980,000.00	-IDR 42,684,220,000.00								-IDR 40,761,980,000.00	-IDR 38,095,308,411.22	-IDR 40,017,548,411.22
2			IDR 39,935,780,000.00	-IDR 82,620,000,000.00								-IDR 39,935,780,000.00	-IDR 34,881,456,895.80	-IDR 74,899,005,307.01
3	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 72,292,500,000.00	-IDR 2,065,500,000.00	-IDR 10,327,500,000.00	-IDR 11,566,800,000.00	IDR 39,755,858,369.99	0.23	IDR 4,131,000,000.00	IDR 8,368,560,120.97	IDR 31,387,298,249.02	IDR 25,621,384,922.02	-IDR 49,277,620,385.00
4	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 61,965,000,000.00	-IDR 2,065,500,000.00	-IDR 10,327,500,000.00	-IDR 10,120,950,000.00	IDR 41,201,708,369.99	0.24	IDR 4,131,000,000.00	IDR 8,727,834,792.22	IDR 32,473,873,577.78	IDR 24,774,162,669.12	-IDR 24,503,457,715.88
5	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 51,637,500,000.00	-IDR 2,065,500,000.00	-IDR 10,327,500,000.00	-IDR 8,675,100,000.00	IDR 42,647,558,369.99	0.24	IDR 4,131,000,000.00	IDR 9,087,257,808.28	IDR 33,560,300,561.71	IDR 23,928,030,479.82	-IDR 575,427,236.06
6	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 41,310,000,000.00	-IDR 2,065,500,000.00	-IDR 10,327,500,000.00	-IDR 7,229,250,000.00	IDR 44,093,408,369.99	0.24	IDR 4,131,000,000.00	IDR 9,446,814,576.21	IDR 34,646,593,793.78	IDR 23,086,488,356.21	IDR 22,511,061,120.15
7	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 30,982,500,000.00	-IDR 2,065,500,000.00	-IDR 10,327,500,000.00	-IDR 5,783,400,000.00	IDR 45,539,258,369.99	0.24	IDR 4,131,000,000.00	IDR 9,806,492,356.34	IDR 35,732,766,013.65	IDR 22,252,570,811.83	IDR 44,763,631,931.98
8	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 20,655,000,000.00	-IDR 2,065,500,000.00	-IDR 10,327,500,000.00	-IDR 4,337,550,000.00	IDR 46,985,108,369.99	0.24	IDR 4,131,000,000.00	IDR 10,166,279,977.10	IDR 36,818,828,392.89	IDR 21,428,893,344.08	IDR 66,192,525,276.06
9	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 10,327,500,000.00	-IDR 2,065,500,000.00	-IDR 10,327,500,000.00	-IDR 2,891,700,000.00	IDR 48,430,958,369.99	0.24		IDR 11,507,739,592.50	IDR 36,923,218,777.49	IDR 20,083,784,577.90	IDR 86,276,309,853.95
10	IDR 63,715,658,369.99	IDR 63,715,658,369.99		IDR -	-IDR 2,065,500,000.00	-IDR 10,327,500,000.00	-IDR 1,445,850,000.00	IDR 49,876,808,369.99	0.24		IDR 11,869,202,092.50	IDR 38,007,606,277.49	IDR 19,321,139,746.90	IDR 105,597,449,600.85
11	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 13,738,538,631.82	IDR 119,335,988,232.68
12	IDR 31,857,829,185.00	IDR 31,857,829,185.00			-IDR 2,065,500,000.00		IDR -	IDR 29,792,329,185.00	0.23		IDR 6,848,082,296.25	IDR 22,944,246,888.75	IDR 10,187,520,014.38	IDR 129,523,508,247.05
13	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 11,999,771,710.91	IDR 141,523,279,957.96
14	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 11,214,739,916.74	IDR 152,738,019,874.70
15	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 10,481,065,342.75	IDR 163,219,085,217.44
16	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 9,795,388,170.79	IDR 173,014,473,388.23
17	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 9,154,568,383.92	IDR 182,169,041,772.15
18	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 8,555,671,386.84	IDR 190,724,713,158.99
19	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 7,995,954,567.14	IDR 198,720,667,726.13
20	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 7,472,854,735.64	IDR 206,193,522,461.77
21	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 2,065,500,000.00		IDR -	IDR 37,756,786,481.25	0.23		IDR 8,839,196,620.31	IDR 28,917,589,860.93	IDR 6,983,976,388.45	IDR 213,177,498,850.22
22	IDR 31,857,829,185.00	IDR 31,857,829,185.00			-IDR 2,065,500,000.00		IDR -	IDR 29,792,329,185.00	0.23		IDR 6,848,082,296.25	IDR 22,944,246,888.75	IDR 5,178,818,587.92	IDR 218,356,317,438.14

Design Discharge 2x8 m^3/s

Year	Sales	Net Sales	Investment	Cummulative Investment Loan	Expenditure			Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
					O&M	Installment Payment	Bank Interest							
0			IDR 2,112,740,000.00	-IDR 2,112,740,000.00								-IDR 2,112,740,000.00	-IDR 2,112,740,000.00	-IDR 2,112,740,000.00
1			IDR 50,286,980,000.00	-IDR 52,399,720,000.00								-IDR 50,286,980,000.00	-IDR 46,997,177,570.09	-IDR 49,109,917,570.09
2			IDR 49,270,280,000.00	-IDR 101,670,000,000.00								-IDR 49,270,280,000.00	-IDR 43,034,570,704.87	-IDR 92,144,488,274.96
3	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 88,961,250,000.00	-IDR 2,541,750,000.00	-IDR 12,708,750,000.00	-IDR 14,233,800,000.00	IDR 38,976,735,678.09	0.23	IDR 5,083,500,000.00	IDR 7,951,563,292.21	IDR 31,025,172,385.88	IDR 25,325,782,348.76	-IDR 66,818,705,926.19
4	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 76,252,500,000.00	-IDR 2,541,750,000.00	-IDR 12,708,750,000.00	-IDR 12,454,575,000.00	IDR 40,755,960,678.09	0.24	IDR 5,083,500,000.00	IDR 8,392,953,302.38	IDR 32,363,007,375.71	IDR 24,689,583,374.39	-IDR 42,129,122,551.81
5	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 63,543,750,000.00	-IDR 2,541,750,000.00	-IDR 12,708,750,000.00	-IDR 10,675,350,000.00	IDR 42,535,185,678.09	0.24	IDR 5,083,500,000.00	IDR 8,834,629,111.67	IDR 33,700,556,566.42	IDR 24,028,031,072.77	-IDR 18,101,091,479.04
6	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 50,835,000,000.00	-IDR 2,541,750,000.00	-IDR 12,708,750,000.00	-IDR 8,896,125,000.00	IDR 44,314,410,678.09	0.24	IDR 5,083,500,000.00	IDR 9,276,556,295.55	IDR 35,037,854,382.54	IDR 23,347,201,807.02	IDR 5,246,110,327.98
7	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 38,126,250,000.00	-IDR 2,541,750,000.00	-IDR 12,708,750,000.00	-IDR 7,116,900,000.00	IDR 46,093,635,678.09	0.24	IDR 5,083,500,000.00	IDR 9,718,705,744.66	IDR 36,374,929,933.43	IDR 22,652,478,227.11	IDR 27,898,588,555.10
8	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 25,417,500,000.00	-IDR 2,541,750,000.00	-IDR 12,708,750,000.00	-IDR 5,337,675,000.00	IDR 47,872,860,678.09	0.24	IDR 5,083,500,000.00	IDR 10,161,052,677.13	IDR 37,711,808,000.96	IDR 21,948,615,606.17	IDR 49,847,204,161.27
9	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 12,708,750,000.00	-IDR 2,541,750,000.00	-IDR 12,708,750,000.00	-IDR 3,558,450,000.00	IDR 49,652,085,678.09	0.24		IDR 11,813,021,419.52	IDR 37,839,064,258.57	IDR 20,581,943,838.04	IDR 70,429,147,999.31
10	IDR 68,461,035,678.09	IDR 68,461,035,678.09		IDR -	-IDR 2,541,750,000.00	-IDR 12,708,750,000.00	-IDR 1,779,225,000.00	IDR 51,431,310,678.09	0.24		IDR 12,257,827,669.52	IDR 39,173,483,008.57	IDR 19,913,812,357.86	IDR 90,342,960,357.17
11	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 14,625,635,755.74	IDR 104,968,596,112.91
12	IDR 34,230,517,839.05	IDR 34,230,517,839.05			-IDR 2,541,750,000.00		IDR -	IDR 31,688,767,839.05	0.23		IDR 7,322,191,959.76	IDR 24,366,575,879.28	IDR 10,819,051,096.15	IDR 115,787,647,209.06
13	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 12,774,596,694.68	IDR 128,562,243,903.75
14	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 11,938,875,415.59	IDR 140,501,119,319.34
15	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 11,157,827,491.21	IDR 151,658,946,810.55
16	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 10,427,876,160.01	IDR 162,086,822,970.55
17	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 9,745,678,654.21	IDR 171,832,501,624.77
18	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 9,108,110,891.79	IDR 180,940,612,516.56
19	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 8,512,253,169.90	IDR 189,452,865,686.45
20	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 7,955,376,794.29	IDR 197,408,242,480.75
21	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 2,541,750,000.00		IDR -	IDR 40,246,397,298.81	0.24		IDR 9,461,599,324.70	IDR 30,784,797,974.10	IDR 7,434,931,583.45	IDR 204,843,174,064.20
22	IDR 34,230,517,839.05	IDR 34,230,517,839.05			-IDR 2,541,750,000.00		IDR -	IDR 31,688,767,839.05	0.23		IDR 7,322,191,959.76	IDR 24,366,575,879.28	IDR 5,499,856,966.30	IDR 210,343,031,030.49

High Price Estimate

Design Discharge 2x4,5 m^3/s

Year	Sales	Net Sales	Investment	Cummulative Investment Loan	Expenditure			Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
					O&M	Installment Payment	Bank Interest							
0			IDR 2,237,840,000.00	-IDR 2,237,840,000.00								-IDR 2,237,840,000.00	-IDR 2,237,840,000.00	-IDR 2,237,840,000.00
1			IDR 56,541,980,000.00	-IDR 58,779,820,000.00								-IDR 56,541,980,000.00	-IDR 52,842,971,962.62	-IDR 55,080,811,962.62
2			IDR 55,400,180,000.00	-IDR 114,180,000,000.00								-IDR 55,400,180,000.00	-IDR 48,388,662,765.31	-IDR 103,469,474,727.92
3	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 99,907,500,000.00	-IDR 2,854,500,000.00	-IDR 14,272,500,000.00	-IDR 15,985,200,000.00	IDR 16,920,637,698.25	0.21	IDR 5,709,000,000.00	IDR 2,405,348,603.34	IDR 14,515,289,094.91	IDR 11,848,799,670.63	-IDR 91,620,675,057.29
4	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 85,635,000,000.00	-IDR 2,854,500,000.00	-IDR 14,272,500,000.00	-IDR 13,987,050,000.00	IDR 18,918,787,698.25	0.22	IDR 5,709,000,000.00	IDR 2,883,505,037.51	IDR 16,035,282,660.73	IDR 12,233,240,365.70	-IDR 79,387,434,691.59
5	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 71,362,500,000.00	-IDR 2,854,500,000.00	-IDR 14,272,500,000.00	-IDR 11,988,900,000.00	IDR 20,916,937,698.25	0.22	IDR 5,709,000,000.00	IDR 3,365,746,446.01	IDR 17,551,191,252.24	IDR 12,513,756,796.32	-IDR 66,873,677,895.27
6	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 57,090,000,000.00	-IDR 2,854,500,000.00	-IDR 14,272,500,000.00	-IDR 9,990,750,000.00	IDR 22,915,087,698.25	0.22	IDR 5,709,000,000.00	IDR 3,851,004,223.96	IDR 19,064,083,474.29	IDR 12,703,203,777.28	-IDR 54,170,474,117.99
7	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 42,817,500,000.00	-IDR 2,854,500,000.00	-IDR 14,272,500,000.00	-IDR 7,992,600,000.00	IDR 24,913,237,698.25	0.23	IDR 5,709,000,000.00	IDR 4,338,552,593.51	IDR 20,574,685,104.73	IDR 12,812,879,838.33	-IDR 41,357,594,279.66
8	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 28,545,000,000.00	-IDR 2,854,500,000.00	-IDR 14,272,500,000.00	-IDR 5,994,450,000.00	IDR 26,911,387,698.25	0.23	IDR 5,709,000,000.00	IDR 4,827,881,330.64	IDR 22,083,506,367.60	IDR 12,852,801,766.67	-IDR 28,504,792,512.99
9	IDR 50,032,837,698.25	IDR 50,032,837,698.25		-IDR 14,272,500,000.00	-IDR 2,854,500,000.00	-IDR 14,272,500,000.00	-IDR 3,996,300,000.00	IDR 28,909,537,698.25	0.23		IDR 6,627,384,424.56	IDR 22,282,153,273.69	IDR 12,120,015,022.99	-IDR 16,384,777,490.00
10	IDR 50,032,837,698.25	IDR 50,032,837,698.25		IDR -	-IDR 2,854,500,000.00	-IDR 14,272,500,000.00	-IDR 1,998,150,000.00	IDR 30,907,687,698.25	0.23		IDR 7,126,921,924.56	IDR 23,780,765,773.69	IDR 12,088,935,447.47	-IDR 4,295,842,042.53
11	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 10,410,241,749.84	IDR 6,114,399,707.31
12	IDR 25,016,418,849.12	IDR 25,016,418,849.12			-IDR 2,854,500,000.00		IDR -	IDR 22,161,918,849.12	0.22		IDR 4,940,479,712.28	IDR 17,221,439,136.84	IDR 7,646,524,932.09	IDR 13,760,924,639.40
13	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 9,092,708,314.99	IDR 22,853,632,954.39
14	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 8,497,858,238.31	IDR 31,351,491,192.70
15	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 7,941,923,587.21	IDR 39,293,414,779.91
16	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 7,422,358,492.72	IDR 46,715,773,272.63
17	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 6,936,783,638.05	IDR 53,652,556,910.68
18	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 6,482,975,362.67	IDR 60,135,532,273.35
19	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 6,058,855,479.13	IDR 66,194,387,752.47
20	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 5,662,481,756.19	IDR 71,856,869,508.67
21	IDR 31,270,523,561.40	IDR 31,270,523,561.40			-IDR 2,854,500,000.00		IDR -	IDR 28,416,023,561.40	0.23		IDR 6,504,005,890.35	IDR 21,912,017,671.05	IDR 5,292,039,024.48	IDR 77,148,908,533.15
22	IDR 25,016,418,849.12	IDR 25,016,418,849.12			-IDR 2,854,500,000.00		IDR -	IDR 22,161,918,849.12	0.22		IDR 4,940,479,712.28	IDR 17,221,439,136.84	IDR 3,887,105,536.52	IDR 81,036,014,069.67

Design Discharge 2x6,5 m^3/s

					Expenditure									
Year	Sales	Net Sales	Investment	Cummulative Investment Loan	O&M	Installment Payment	Bank Interest	Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
0			IDR 2,748,440,000.00	-IDR 2,748,440,000.00								-IDR 2,748,440,000.00	-IDR 2,748,440,000.00	-IDR 2,748,440,000.00
1			IDR 82,071,980,000.00	-IDR 84,820,420,000.00								-IDR 82,071,980,000.00	-IDR 76,702,785,046.73	-IDR 79,451,225,046.73
2			IDR 80,419,580,000.00	-IDR 165,240,000,000.00								-IDR 80,419,580,000.00	-IDR 70,241,575,683.47	-IDR 149,692,800,730.20
3	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 144,585,000,000.00	-IDR 4,131,000,000.00	-IDR 20,655,000,000.00	-IDR 23,133,600,000.00	IDR 15,796,058,369.99	0.21	IDR 8,262,000,000.00	IDR 1,597,339,717.97	IDR 14,198,718,652.02	IDR 11,590,383,890.21	-IDR 138,102,416,839.98
4	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 123,930,000,000.00	-IDR 4,131,000,000.00	-IDR 20,655,000,000.00	-IDR 20,241,900,000.00	IDR 18,687,758,369.99	0.22	IDR 8,262,000,000.00	IDR 2,271,704,152.42	IDR 16,416,054,217.57	IDR 12,523,729,163.30	-IDR 125,578,687,676.69
5	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 103,275,000,000.00	-IDR 4,131,000,000.00	-IDR 20,655,000,000.00	-IDR 17,350,200,000.00	IDR 21,579,458,369.99	0.22	IDR 8,262,000,000.00	IDR 2,959,083,055.08	IDR 18,620,375,314.92	IDR 13,276,070,256.33	-IDR 112,302,617,420.35
6	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 82,620,000,000.00	-IDR 4,131,000,000.00	-IDR 20,655,000,000.00	-IDR 14,458,500,000.00	IDR 24,471,158,369.99	0.23	IDR 8,262,000,000.00	IDR 3,654,862,757.41	IDR 20,816,295,612.59	IDR 13,870,776,710.11	-IDR 98,431,840,710.24
7	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 61,965,000,000.00	-IDR 4,131,000,000.00	-IDR 20,655,000,000.00	-IDR 11,566,800,000.00	IDR 27,362,858,369.99	0.23	IDR 8,262,000,000.00	IDR 4,356,379,876.22	IDR 23,006,478,493.77	IDR 14,327,278,543.67	-IDR 84,104,562,166.57
8	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 41,310,000,000.00	-IDR 4,131,000,000.00	-IDR 20,655,000,000.00	-IDR 8,675,100,000.00	IDR 30,254,558,369.99	0.23	IDR 8,262,000,000.00	IDR 5,061,989,282.17	IDR 25,192,569,087.83	IDR 14,662,304,576.50	-IDR 69,442,257,590.07
9	IDR 63,715,658,369.99	IDR 63,715,658,369.99		-IDR 20,655,000,000.00	-IDR 4,131,000,000.00	-IDR 20,655,000,000.00	-IDR 5,783,400,000.00	IDR 33,146,258,369.99	0.23		IDR 7,686,564,592.50	IDR 25,459,693,777.49	IDR 13,848,386,521.44	-IDR 55,593,871,068.63
10	IDR 63,715,658,369.99	IDR 63,715,658,369.99		IDR -	-IDR 4,131,000,000.00	-IDR 20,655,000,000.00	-IDR 2,891,700,000.00	IDR 36,037,958,369.99	0.23		IDR 8,409,489,592.50	IDR 27,628,468,777.49	IDR 14,044,912,545.81	-IDR 41,548,958,522.83
11	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 13,002,560,503.62	-IDR 28,546,398,019.21
12	IDR 31,857,829,185.00	IDR 31,857,829,185.00			-IDR 4,131,000,000.00		IDR -	IDR 27,726,829,185.00	0.23		IDR 6,331,707,296.25	IDR 21,395,121,888.75	IDR 9,499,689,988.02	-IDR 19,046,708,031.19
13	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 11,356,939,910.57	-IDR 7,689,768,120.62
14	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 10,613,962,533.25	IDR 2,924,194,412.63
15	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 9,919,591,152.57	IDR 12,843,785,565.20
16	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 9,270,645,936.98	IDR 22,114,431,502.17
17	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 8,664,155,081.29	IDR 30,778,586,583.46
18	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 8,097,341,197.47	IDR 38,875,927,780.93
19	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 7,567,608,595.76	IDR 46,443,536,376.69
20	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 7,072,531,397.91	IDR 53,516,067,774.60
21	IDR 39,822,286,481.25	IDR 39,822,286,481.25			-IDR 4,131,000,000.00		IDR -	IDR 35,691,286,481.25	0.23		IDR 8,322,821,620.31	IDR 27,368,464,860.93	IDR 6,609,842,427.95	IDR 60,125,910,202.55
22	IDR 31,857,829,185.00	IDR 31,857,829,185.00			-IDR 4,131,000,000.00		IDR -	IDR 27,726,829,185.00	0.23		IDR 6,331,707,296.25	IDR 21,395,121,888.75	IDR 4,829,160,680.91	IDR 64,955,070,883.46

Design Discharge 2x8 m^3/s

					Expenditure									
Year	Sales	Net Sales	Investment	Cummulative Investment Loan	O&M	Installment Payment	Bank Interest	Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
0			IDR 3,129,440,000.00	-IDR 3,129,440,000.00								-IDR 3,129,440,000.00	-IDR 3,129,440,000.00	-IDR 3,129,440,000.00
1			IDR 101,121,980,000.00	-IDR 104,251,420,000.00								-IDR 101,121,980,000.00	-IDR 94,506,523,364.49	-IDR 97,635,963,364.49
2			IDR 99,088,580,000.00	-IDR 203,340,000,000.00								-IDR 99,088,580,000.00	-IDR 86,547,803,301.60	-IDR 184,183,766,666.08
3	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 177,922,500,000.00	-IDR 5,083,500,000.00	-IDR 25,417,500,000.00	-IDR 28,467,600,000.00	IDR 9,492,435,678.09	0.19	IDR 10,167,000,000.00	IDR -	IDR 9,492,435,678.09	IDR 7,748,655,090.55	-IDR 176,435,111,575.54
4	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 152,505,000,000.00	-IDR 5,083,500,000.00	-IDR 25,417,500,000.00	-IDR 24,909,150,000.00	IDR 13,050,885,678.09	0.20	IDR 10,167,000,000.00	IDR 588,387,972.73	IDR 12,462,497,705.36	IDR 9,507,579,829.57	-IDR 166,927,531,745.97
5	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 127,087,500,000.00	-IDR 5,083,500,000.00	-IDR 25,417,500,000.00	-IDR 21,350,700,000.00	IDR 16,609,335,678.09	0.21	IDR 10,167,000,000.00	IDR 1,377,859,295.14	IDR 15,231,476,382.95	IDR 10,859,832,154.17	-IDR 156,067,699,591.79
6	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 101,670,000,000.00	-IDR 5,083,500,000.00	-IDR 25,417,500,000.00	-IDR 17,792,250,000.00	IDR 20,167,785,678.09	0.22	IDR 10,167,000,000.00	IDR 2,202,668,892.08	IDR 17,965,116,786.01	IDR 11,970,915,870.32	-IDR 144,096,783,721.48
7	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 76,252,500,000.00	-IDR 5,083,500,000.00	-IDR 25,417,500,000.00	-IDR 14,233,800,000.00	IDR 23,726,235,678.09	0.22	IDR 10,167,000,000.00	IDR 3,046,916,708.67	IDR 20,679,318,969.42	IDR 12,878,040,550.56	-IDR 131,218,743,170.92
8	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 50,835,000,000.00	-IDR 5,083,500,000.00	-IDR 25,417,500,000.00	-IDR 10,675,350,000.00	IDR 27,284,685,678.09	0.23	IDR 10,167,000,000.00	IDR 3,902,997,387.08	IDR 23,381,688,291.01	IDR 13,608,355,465.47	-IDR 117,610,387,705.46
9	IDR 68,461,035,678.09	IDR 68,461,035,678.09		-IDR 25,417,500,000.00	-IDR 5,083,500,000.00	-IDR 25,417,500,000.00	-IDR 7,116,900,000.00	IDR 30,843,135,678.09	0.23		IDR 7,110,783,919.52	IDR 23,732,351,758.57	IDR 12,908,826,912.36	-IDR 104,701,560,793.09
10	IDR 68,461,035,678.09	IDR 68,461,035,678.09		IDR -	-IDR 5,083,500,000.00	-IDR 25,417,500,000.00	-IDR 3,558,450,000.00	IDR 34,401,585,678.09	0.23		IDR 8,000,396,419.52	IDR 26,401,189,258.57	IDR 13,421,025,871.11	-IDR 91,280,534,921.99
11	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 13,719,960,419.33	-IDR 77,560,574,502.66
12	IDR 34,230,517,839.05	IDR 34,230,517,839.05			-IDR 5,083,500,000.00		IDR -	IDR 29,147,017,839.05	0.23		IDR 6,686,754,459.76	IDR 22,460,263,379.28	IDR 9,972,625,548.10	-IDR 67,587,948,954.56
13	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 11,983,544,780.62	-IDR 55,604,404,173.94
14	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 11,199,574,561.33	-IDR 44,404,829,612.61
15	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 10,466,892,113.39	-IDR 33,937,937,499.22
16	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 9,782,142,162.05	-IDR 24,155,795,337.18
17	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 9,142,188,936.49	-IDR 15,013,606,400.69
18	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 8,544,101,809.81	-IDR 6,469,504,590.88
19	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 7,985,141,878.32	IDR 1,515,637,287.44
20	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 7,462,749,418.99	IDR 8,978,386,706.43
21	IDR 42,788,147,298.81	IDR 42,788,147,298.81			-IDR 5,083,500,000.00		IDR -	IDR 37,704,647,298.81	0.23		IDR 8,826,161,824.70	IDR 28,878,485,474.10	IDR 6,974,532,167.28	IDR 15,952,918,873.72
22	IDR 34,230,517,839.05	IDR 34,230,517,839.05			-IDR 5,083,500,000.00		IDR -	IDR 29,147,017,839.05	0.23		IDR 6,686,754,459.76	IDR 22,460,263,379.28	IDR 5,069,577,138.10	IDR 21,022,496,011.82

Site 2

Low Price Estimate

Design Discharge 2x7,5 m^3/s

					Expenditure									
Year	Sales	Net Sales	Investment	Cummulative Investment Loan	O&M	Installment Payment	Bank Interest	Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
0			IDR 1,449,440,000.00	-IDR 1,449,440,000.00								-IDR 1,449,440,000.00	-IDR 1,449,440,000.00	-IDR 1,449,440,000.00
1			IDR 17,121,980,000.00	-IDR 18,571,420,000.00								-IDR 17,121,980,000.00	-IDR 16,001,850,467.29	-IDR 17,451,290,467.29
2			IDR 16,768,580,000.00	-IDR 35,340,000,000.00								-IDR 16,768,580,000.00	-IDR 14,646,327,190.15	-IDR 32,097,617,657.44
3	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 30,922,500,000.00	-IDR 883,500,000.00	-IDR 4,417,500,000.00	-IDR 4,947,600,000.00	IDR 21,962,001,310.25	0.22	IDR 1,767,000,000.00	IDR 4,497,024,616.64	IDR 17,464,976,693.61	IDR 14,256,623,394.94	-IDR 17,840,994,262.50
4	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 26,505,000,000.00	-IDR 883,500,000.00	-IDR 4,417,500,000.00	-IDR 4,329,150,000.00	IDR 22,580,451,310.25	0.22	IDR 1,767,000,000.00	IDR 4,650,314,944.92	IDR 17,930,136,365.32	IDR 13,678,815,184.46	-IDR 4,162,179,078.04
5	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 22,087,500,000.00	-IDR 883,500,000.00	-IDR 4,417,500,000.00	-IDR 3,710,700,000.00	IDR 23,198,901,310.25	0.22	IDR 1,767,000,000.00	IDR 4,803,675,767.67	IDR 18,395,225,542.57	IDR 13,115,541,580.34	IDR 8,953,362,502.30
6	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 17,670,000,000.00	-IDR 883,500,000.00	-IDR 4,417,500,000.00	-IDR 3,092,250,000.00	IDR 23,817,351,310.25	0.22	IDR 1,767,000,000.00	IDR 4,957,101,593.44	IDR 18,860,249,716.81	IDR 12,567,380,738.03	IDR 21,520,743,240.34
7	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 13,252,500,000.00	-IDR 883,500,000.00	-IDR 4,417,500,000.00	-IDR 2,473,800,000.00	IDR 24,435,801,310.25	0.23	IDR 1,767,000,000.00	IDR 5,110,587,486.69	IDR 19,325,213,823.55	IDR 12,034,771,920.48	IDR 33,555,515,160.82
8	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 8,835,000,000.00	-IDR 883,500,000.00	-IDR 4,417,500,000.00	-IDR 1,855,350,000.00	IDR 25,054,251,310.25	0.23	IDR 1,767,000,000.00	IDR 5,264,128,999.25	IDR 19,790,122,310.99	IDR 11,518,031,365.45	IDR 45,073,546,526.27
9	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 4,417,500,000.00	-IDR 883,500,000.00	-IDR 4,417,500,000.00	-IDR 1,236,900,000.00	IDR 25,672,701,310.25	0.23		IDR 5,818,175,327.56	IDR 19,854,525,982.68	IDR 10,799,546,625.00	IDR 55,873,093,151.27
10	IDR 32,210,601,310.25	IDR 32,210,601,310.25		IDR -	-IDR 883,500,000.00	-IDR 4,417,500,000.00	-IDR 618,450,000.00	IDR 26,291,151,310.25	0.23		IDR 5,972,787,827.56	IDR 20,318,363,482.68	IDR 10,328,825,693.76	IDR 66,201,918,845.03
11	IDR 32,210,601,310.25	IDR 32,210,601,310.25			-IDR 883,500,000.00		IDR -	IDR 31,327,101,310.25	0.23		IDR 7,231,775,327.56	IDR 24,095,325,982.68	IDR 11,447,515,800.98	IDR 77,649,434,646.01
12	IDR 24,631,636,296.07	IDR 24,631,636,296.07			-IDR 883,500,000.00		IDR -	IDR 23,748,136,296.07	0.22		IDR 5,337,034,074.02	IDR 18,411,102,222.05	IDR 8,174,749,569.40	IDR 85,824,184,215.40
13	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 6,239,444,596.23	IDR 92,063,628,811.64
14	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 5,831,256,631.99	IDR 97,894,885,443.63
15	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 5,449,772,553.26	IDR 103,344,657,996.89
16	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 5,093,245,376.88	IDR 108,437,903,373.77
17	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 4,760,042,408.30	IDR 113,197,945,782.07
18	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 4,448,637,764.77	IDR 117,646,583,546.84
19	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 4,157,605,387.63	IDR 121,804,188,934.47
20	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 3,885,612,511.81	IDR 125,689,801,446.28
21	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 883,500,000.00		IDR -	IDR 19,248,125,818.90	0.22		IDR 4,212,031,454.73	IDR 15,036,094,364.18	IDR 3,631,413,562.44	IDR 129,321,215,008.71
22	IDR 15,394,772,685.04	IDR 15,394,772,685.04			-IDR 883,500,000.00		IDR -	IDR 14,511,272,685.04	0.21		IDR 3,027,818,171.26	IDR 11,483,454,513.78	IDR 2,591,966,865.50	IDR 131,913,181,874.21

Design Discharge 2x10 m^3/s

					Expenditure									
Year	Sales	Net Sales	Investment	Cummulative Investment Loan	O&M	Installment Payment	Bank Interest	Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
0			IDR 1,567,940,000.00	-IDR 1,567,940,000.00								-IDR 1,567,940,000.00	-IDR 1,567,940,000.00	-IDR 1,567,940,000.00
1			IDR 23,046,980,000.00	-IDR 24,614,920,000.00								-IDR 23,046,980,000.00	-IDR 21,539,233,644.86	-IDR 23,107,173,644.86
2			IDR 22,575,080,000.00	-IDR 47,190,000,000.00								-IDR 22,575,080,000.00	-IDR 19,717,949,165.87	-IDR 42,825,122,810.73
3	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 41,291,250,000.00	-IDR 1,179,750,000.00	-IDR 5,898,750,000.00	-IDR 6,606,600,000.00	IDR 25,375,986,218.00	0.23	IDR 2,359,500,000.00	IDR 5,209,910,519.22	IDR 20,166,075,698.77	IDR 16,461,524,778.13	-IDR 26,363,598,032.60
4	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 35,392,500,000.00	-IDR 1,179,750,000.00	-IDR 5,898,750,000.00	-IDR 5,780,775,000.00	IDR 26,201,811,218.00	0.23	IDR 2,359,500,000.00	IDR 5,414,608,420.48	IDR 20,787,202,797.51	IDR 15,858,457,486.08	-IDR 10,505,140,546.52
5	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 29,493,750,000.00	-IDR 1,179,750,000.00	-IDR 5,898,750,000.00	-IDR 4,954,950,000.00	IDR 27,027,636,218.00	0.23	IDR 2,359,500,000.00	IDR 5,619,413,773.86	IDR 21,408,222,444.14	IDR 15,263,766,729.98	IDR 4,758,626,183.47
6	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 23,595,000,000.00	-IDR 1,179,750,000.00	-IDR 5,898,750,000.00	-IDR 4,129,125,000.00	IDR 27,853,461,218.00	0.23	IDR 2,359,500,000.00	IDR 5,824,317,021.83	IDR 22,029,144,196.17	IDR 14,678,948,932.45	IDR 19,437,575,115.92
7	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 17,696,250,000.00	-IDR 1,179,750,000.00	-IDR 5,898,750,000.00	-IDR 3,303,300,000.00	IDR 28,679,286,218.00	0.23	IDR 2,359,500,000.00	IDR 6,029,309,707.73	IDR 22,649,976,510.27	IDR 14,105,267,025.46	IDR 33,542,842,141.38
8	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 11,797,500,000.00	-IDR 1,179,750,000.00	-IDR 5,898,750,000.00	-IDR 2,477,475,000.00	IDR 29,505,111,218.00	0.23	IDR 2,359,500,000.00	IDR 6,234,384,321.65	IDR 23,270,726,896.34	IDR 13,543,774,923.52	IDR 47,086,617,064.90
9	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 5,898,750,000.00	-IDR 1,179,750,000.00	-IDR 5,898,750,000.00	-IDR 1,651,650,000.00	IDR 30,330,936,218.00	0.23		IDR 6,982,734,054.50	IDR 23,348,202,163.50	IDR 12,699,874,985.40	IDR 59,786,492,050.30
10	IDR 39,061,086,218.00	IDR 39,061,086,218.00		IDR -	-IDR 1,179,750,000.00	-IDR 5,898,750,000.00	-IDR 825,825,000.00	IDR 31,156,761,218.00	0.23		IDR 7,189,190,304.50	IDR 23,967,570,913.50	IDR 12,183,897,708.06	IDR 71,970,389,758.36
11	IDR 39,061,086,218.00	IDR 39,061,086,218.00			-IDR 1,179,750,000.00		IDR -	IDR 37,881,336,218.00	0.23		IDR 8,870,334,054.50	IDR 29,011,002,163.50	IDR 13,782,918,143.86	IDR 85,753,307,902.23
12	IDR 29,870,242,402.00	IDR 29,870,242,402.00			-IDR 1,179,750,000.00		IDR -	IDR 28,690,492,402.00	0.23		IDR 6,572,623,100.50	IDR 22,117,869,301.50	IDR 9,820,598,482.79	IDR 95,573,906,385.01
13	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 7,479,763,911.49	IDR 103,053,670,296.50
14	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 6,990,433,562.14	IDR 110,044,103,858.64
15	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 6,533,115,478.63	IDR 116,577,219,337.27
16	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 6,105,715,400.59	IDR 122,682,934,737.87
17	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 5,706,276,075.32	IDR 128,389,210,813.19
18	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 5,332,968,294.69	IDR 133,722,179,107.88
19	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 4,984,082,518.40	IDR 138,706,261,626.28
20	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 4,658,021,045.24	IDR 143,364,282,671.52
21	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 1,179,750,000.00		IDR -	IDR 23,233,428,886.25	0.22		IDR 5,208,357,221.56	IDR 18,025,071,664.69	IDR 4,353,290,696.48	IDR 147,717,573,368.00
22	IDR 18,668,901,501.25	IDR 18,668,901,501.25			-IDR 1,179,750,000.00		IDR -	IDR 17,489,151,501.25	0.22		IDR 3,772,287,875.31	IDR 13,716,863,625.94	IDR 3,096,076,705.34	IDR 150,813,650,073.34

Design Discharge 2x12,5 m^3/s

Year	Sales	Net Sales	Investment	Cummulative Investment Loan	Expenditure			Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
					O&M	Installment Payment	Bank Interest							
0			IDR 1,686,440,000.00	-IDR 1,686,440,000.00								-IDR 1,686,440,000.00	-IDR 1,686,440,000.00	-IDR 1,686,440,000.00
1			IDR 28,971,980,000.00	-IDR 30,658,420,000.00								-IDR 28,971,980,000.00	-IDR 27,076,616,822.43	-IDR 28,763,056,822.43
2			IDR 28,381,580,000.00	-IDR 59,040,000,000.00								-IDR 28,381,580,000.00	-IDR 24,789,571,141.58	-IDR 53,552,627,964.01
3	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 51,660,000,000.00	-IDR 1,476,000,000.00	-IDR 7,380,000,000.00	-IDR 8,265,600,000.00	IDR 27,126,606,556.14	0.23	IDR 2,952,000,000.00	IDR 5,508,945,467.67	IDR 21,617,661,088.47	IDR 17,646,450,849.86	-IDR 35,906,177,114.15
4	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 44,280,000,000.00	-IDR 1,476,000,000.00	-IDR 7,380,000,000.00	-IDR 7,232,400,000.00	IDR 28,159,806,556.14	0.23	IDR 2,952,000,000.00	IDR 5,764,849,798.39	IDR 22,394,956,757.76	IDR 17,085,005,284.51	-IDR 18,821,171,829.64
5	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 36,900,000,000.00	-IDR 1,476,000,000.00	-IDR 7,380,000,000.00	-IDR 6,199,200,000.00	IDR 29,193,006,556.14	0.23	IDR 2,952,000,000.00	IDR 6,020,923,704.33	IDR 23,172,082,851.81	IDR 16,521,374,823.19	-IDR 2,299,797,006.45
6	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 29,520,000,000.00	-IDR 1,476,000,000.00	-IDR 7,380,000,000.00	-IDR 5,166,000,000.00	IDR 30,226,206,556.14	0.23	IDR 2,952,000,000.00	IDR 6,277,149,796.13	IDR 23,949,056,760.02	IDR 15,958,267,739.78	IDR 13,658,470,733.33
7	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 22,140,000,000.00	-IDR 1,476,000,000.00	-IDR 7,380,000,000.00	-IDR 4,132,800,000.00	IDR 31,259,406,556.14	0.23	IDR 2,952,000,000.00	IDR 6,533,512,983.42	IDR 24,725,893,572.73	IDR 15,398,043,840.28	IDR 29,056,514,573.61
8	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 14,760,000,000.00	-IDR 1,476,000,000.00	-IDR 7,380,000,000.00	-IDR 3,099,600,000.00	IDR 32,292,606,556.14	0.23	IDR 2,952,000,000.00	IDR 6,790,000,107.12	IDR 25,502,606,449.03	IDR 14,842,749,143.47	IDR 43,899,263,717.08
9	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 7,380,000,000.00	-IDR 1,476,000,000.00	-IDR 7,380,000,000.00	-IDR 2,066,400,000.00	IDR 33,325,806,556.14	0.23		IDR 7,731,451,639.04	IDR 25,594,354,917.11	IDR 13,921,633,259.09	IDR 57,820,896,976.17
10	IDR 44,248,206,556.14	IDR 44,248,206,556.14		IDR -	-IDR 1,476,000,000.00	-IDR 7,380,000,000.00	-IDR 1,033,200,000.00	IDR 34,359,006,556.14	0.23		IDR 7,989,751,639.04	IDR 26,369,254,917.11	IDR 13,404,792,071.23	IDR 71,225,689,047.40
11	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 9,613,192,415.31	IDR 80,838,881,462.71
12	IDR 21,148,039,898.16	IDR 21,148,039,898.16			-IDR 1,476,000,000.00		IDR -	IDR 19,672,039,898.16	0.22		IDR 4,318,009,974.54	IDR 15,354,029,923.62	IDR 6,817,372,908.63	IDR 87,656,254,371.34
13	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 8,396,534,557.87	IDR 96,052,788,929.21
14	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 7,847,228,558.76	IDR 103,900,017,487.97
15	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 7,333,858,466.13	IDR 111,233,875,954.10
16	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 6,854,073,332.83	IDR 118,087,949,286.93
17	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 6,405,676,011.99	IDR 124,493,625,298.92
18	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 5,986,613,095.32	IDR 130,480,238,394.24
19	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 5,594,965,509.64	IDR 136,075,203,903.88
20	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 5,228,939,728.64	IDR 141,304,143,632.52
21	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 1,476,000,000.00		IDR -	IDR 26,179,129,097.59	0.23		IDR 5,944,782,274.40	IDR 20,234,346,823.19	IDR 4,886,859,559.48	IDR 146,191,003,192.00
22	IDR 21,148,039,898.16	IDR 21,148,039,898.16			-IDR 1,476,000,000.00		IDR -	IDR 19,672,039,898.16	0.22		IDR 4,318,009,974.54	IDR 15,354,029,923.62	IDR 3,465,606,692.32	IDR 149,656,609,884.32

High Price Estimate

Design Discharge 2x7,5 m^3/s

Year	Sales	Net Sales	Investment	Cummulative Investment Loan	Expenditure			Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
					O&M	Installment Payment	Bank Interest							
0			IDR 1,802,840,000.00	-IDR 1,802,840,000.00								-IDR 1,802,840,000.00	-IDR 1,802,840,000.00	-IDR 1,802,840,000.00
1			IDR 34,791,980,000.00	-IDR 36,594,820,000.00								-IDR 34,791,980,000.00	-IDR 32,515,869,158.88	-IDR 34,318,709,158.88
2			IDR 34,085,180,000.00	-IDR 70,680,000,000.00								-IDR 34,085,180,000.00	-IDR 29,771,316,272.16	-IDR 64,090,025,431.04
3	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 61,845,000,000.00	-IDR 1,767,000,000.00	-IDR 8,835,000,000.00	-IDR 9,895,200,000.00	IDR 11,713,401,310.25	0.20	IDR 3,534,000,000.00	IDR 1,625,873,750.55	IDR 10,087,527,559.70	IDR 8,234,427,330.06	-IDR 55,855,598,100.98
4	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 53,010,000,000.00	-IDR 1,767,000,000.00	-IDR 8,835,000,000.00	-IDR 8,658,300,000.00	IDR 12,950,301,310.25	0.20	IDR 3,534,000,000.00	IDR 1,917,808,969.68	IDR 11,032,492,340.57	IDR 8,416,635,583.57	-IDR 47,438,962,517.41
5	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 44,175,000,000.00	-IDR 1,767,000,000.00	-IDR 8,835,000,000.00	-IDR 7,421,400,000.00	IDR 14,187,201,310.25	0.21	IDR 3,534,000,000.00	IDR 2,212,758,980.73	IDR 11,974,442,329.52	IDR 8,537,611,887.97	-IDR 38,901,350,629.44
6	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 35,340,000,000.00	-IDR 1,767,000,000.00	-IDR 8,835,000,000.00	-IDR 6,184,500,000.00	IDR 15,424,101,310.25	0.21	IDR 3,534,000,000.00	IDR 2,509,998,490.98	IDR 12,914,102,819.27	IDR 8,605,211,991.18	-IDR 30,296,138,638.25
7	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 26,505,000,000.00	-IDR 1,767,000,000.00	-IDR 8,835,000,000.00	-IDR 4,947,600,000.00	IDR 16,661,001,310.25	0.21	IDR 3,534,000,000.00	IDR 2,809,017,588.43	IDR 13,851,983,721.82	IDR 8,626,319,287.35	-IDR 21,669,819,350.90
8	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 17,670,000,000.00	-IDR 1,767,000,000.00	-IDR 8,835,000,000.00	-IDR 3,710,700,000.00	IDR 17,897,901,310.25	0.22	IDR 3,534,000,000.00	IDR 3,109,447,318.40	IDR 14,788,453,991.85	IDR 8,607,014,865.70	-IDR 13,062,804,485.20
9	IDR 32,210,601,310.25	IDR 32,210,601,310.25		-IDR 8,835,000,000.00	-IDR 1,767,000,000.00	-IDR 8,835,000,000.00	-IDR 2,473,800,000.00	IDR 19,134,801,310.25	0.22		IDR 4,183,700,327.56	IDR 14,951,100,982.68	IDR 8,132,408,313.26	-IDR 4,930,396,171.94
10	IDR 32,210,601,310.25	IDR 32,210,601,310.25		IDR -	-IDR 1,767,000,000.00	-IDR 8,835,000,000.00	-IDR 1,236,900,000.00	IDR 20,371,701,310.25	0.22		IDR 4,492,925,327.56	IDR 15,878,775,982.68	IDR 8,071,964,530.76	IDR 3,141,568,358.82
11	IDR 32,210,601,310.25	IDR 32,210,601,310.25			-IDR 1,767,000,000.00		IDR -	IDR 30,443,601,310.25	0.23		IDR 7,010,900,327.56	IDR 23,432,700,982.68	IDR 11,132,707,436.78	IDR 14,274,275,795.60
12	IDR 24,631,636,296.07	IDR 24,631,636,296.07			-IDR 1,767,000,000.00		IDR -	IDR 22,864,636,296.07	0.22		IDR 5,116,159,074.02	IDR 17,748,477,222.05	IDR 7,880,536,144.90	IDR 22,154,811,940.51
13	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 5,964,478,778.95	IDR 28,119,290,719.45
14	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 5,574,279,232.66	IDR 33,693,569,952.12
15	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 5,209,606,759.50	IDR 38,903,176,711.61
16	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 4,868,791,364.02	IDR 43,771,968,075.63
17	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 4,550,272,302.82	IDR 48,322,240,378.45
18	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 4,252,590,937.21	IDR 52,574,831,315.66
19	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 3,974,384,053.47	IDR 56,549,215,369.13
20	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 3,714,377,620.07	IDR 60,263,592,989.20
21	IDR 20,131,625,818.90	IDR 20,131,625,818.90			-IDR 1,767,000,000.00		IDR -	IDR 18,364,625,818.90	0.22		IDR 3,991,156,454.73	IDR 14,373,469,364.18	IDR 3,471,380,953.33	IDR 63,734,973,942.53
22	IDR 15,394,772,685.04	IDR 15,394,772,685.04			-IDR 1,767,000,000.00		IDR -	IDR 13,627,772,685.04	0.21		IDR 2,806,943,171.26	IDR 10,820,829,513.78	IDR 2,442,403,679.42	IDR 66,177,377,621.96

Design Discharge 2x10 m^3/s

Year	Sales	Net Sales	Investment	Cummulative Investment Loan	Expenditure			Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
					O&M	Installment Payment	Bank Interest							
0			IDR 2,039,840,000.00	-IDR 2,039,840,000.00								-IDR 2,039,840,000.00	-IDR 2,039,840,000.00	-IDR 2,039,840,000.00
1			IDR 46,641,980,000.00	-IDR 48,681,820,000.00								-IDR 46,641,980,000.00	-IDR 43,590,635,514.02	-IDR 45,630,475,514.02
2			IDR 45,698,180,000.00	-IDR 94,380,000,000.00								-IDR 45,698,180,000.00	-IDR 39,914,560,223.60	-IDR 85,545,035,737.62
3	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 82,582,500,000.00	-IDR 2,359,500,000.00	-IDR 11,797,500,000.00	-IDR 13,213,200,000.00	IDR 11,690,886,218.00	0.20	IDR 4,719,000,000.00	IDR 1,385,160,208.74	IDR 10,305,726,009.26	IDR 8,412,542,261.18	-IDR 77,132,493,476.44
4	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 70,785,000,000.00	-IDR 2,359,500,000.00	-IDR 11,797,500,000.00	-IDR 11,561,550,000.00	IDR 13,342,536,218.00	0.21	IDR 4,719,000,000.00	IDR 1,768,092,584.70	IDR 11,574,443,633.29	IDR 8,830,087,629.95	-IDR 68,302,405,846.49
5	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 58,987,500,000.00	-IDR 2,359,500,000.00	-IDR 11,797,500,000.00	-IDR 9,909,900,000.00	IDR 14,994,186,218.00	0.21	IDR 4,719,000,000.00	IDR 2,157,629,743.50	IDR 12,836,556,474.50	IDR 9,152,287,358.48	-IDR 59,150,118,488.01
6	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 47,190,000,000.00	-IDR 2,359,500,000.00	-IDR 11,797,500,000.00	-IDR 8,258,250,000.00	IDR 16,645,836,218.00	0.21	IDR 4,719,000,000.00	IDR 2,551,805,645.80	IDR 14,094,030,572.20	IDR 9,391,447,674.02	-IDR 49,758,670,814.00
7	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 35,392,500,000.00	-IDR 2,359,500,000.00	-IDR 11,797,500,000.00	-IDR 6,606,600,000.00	IDR 18,297,486,218.00	0.22	IDR 4,719,000,000.00	IDR 2,949,364,122.21	IDR 15,348,122,095.79	IDR 9,558,039,073.56	-IDR 40,200,631,740.43
8	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 23,595,000,000.00	-IDR 2,359,500,000.00	-IDR 11,797,500,000.00	-IDR 4,954,950,000.00	IDR 19,949,136,218.00	0.22	IDR 4,719,000,000.00	IDR 3,349,465,011.76	IDR 16,599,671,206.23	IDR 9,661,159,774.81	-IDR 30,539,471,965.62
9	IDR 39,061,086,218.00	IDR 39,061,086,218.00		-IDR 11,797,500,000.00	-IDR 2,359,500,000.00	-IDR 11,797,500,000.00	-IDR 3,303,300,000.00	IDR 21,600,786,218.00	0.22		IDR 4,800,196,554.50	IDR 16,800,589,663.50	IDR 9,138,407,613.29	-IDR 21,401,064,352.33
10	IDR 39,061,086,218.00	IDR 39,061,086,218.00		IDR -	-IDR 2,359,500,000.00	-IDR 11,797,500,000.00	-IDR 1,651,650,000.00	IDR 23,252,436,218.00	0.22		IDR 5,213,109,054.50	IDR 18,039,327,163.50	IDR 9,170,279,194.15	-IDR 12,230,785,158.18
11	IDR 39,061,086,218.00	IDR 39,061,086,218.00			-IDR 2,359,500,000.00		IDR -	IDR 36,701,586,218.00	0.23		IDR 8,575,396,554.50	IDR 28,126,189,663.50	IDR 13,362,550,098.96	IDR 1,131,764,940.78
12	IDR 29,870,242,402.00	IDR 29,870,242,402.00			-IDR 2,359,500,000.00		IDR -	IDR 27,510,742,402.00	0.23		IDR 6,277,685,600.50	IDR 21,233,056,801.50	IDR 9,427,731,151.10	IDR 10,559,496,091.88
13	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 7,112,598,180.94	IDR 17,672,094,272.82
14	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 6,647,288,019.57	IDR 24,319,382,292.39
15	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 6,212,418,709.88	IDR 30,531,801,002.27
16	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 5,805,998,794.28	IDR 36,337,799,796.55
17	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 5,426,167,097.46	IDR 41,763,966,894.01
18	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 5,071,184,203.23	IDR 46,835,151,097.24
19	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 4,739,424,489.00	IDR 51,574,575,586.24
20	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 4,429,368,681.31	IDR 56,003,944,267.55
21	IDR 24,413,178,886.25	IDR 24,413,178,886.25			-IDR 2,359,500,000.00		IDR -	IDR 22,053,678,886.25	0.22		IDR 4,913,419,721.56	IDR 17,140,259,164.69	IDR 4,139,596,898.42	IDR 60,143,541,165.97
22	IDR 18,668,901,501.25	IDR 18,668,901,501.25			-IDR 2,359,500,000.00		IDR -	IDR 16,309,401,501.25	0.21		IDR 3,477,350,375.31	IDR 12,832,051,125.94	IDR 2,896,362,875.38	IDR 63,039,904,041.35

Design Discharge 2x12,5 m^3/s

Year	Sales	Net Sales	Investment	Cummulative Investment Loan	Expenditure			Profit	Percent Income Tax	Tax Discount	Income Tax	Cash Flow	PV	NPV
					O&M	Installment Payment	Bank Interest							
0			IDR 2,276,840,000.00	-IDR 2,276,840,000.00								-IDR 2,276,840,000.00	-IDR 2,276,840,000.00	-IDR 2,276,840,000.00
1			IDR 58,491,980,000.00	-IDR 60,768,820,000.00								-IDR 58,491,980,000.00	-IDR 54,665,401,869.16	-IDR 56,942,241,869.16
2			IDR 57,311,180,000.00	-IDR 118,080,000,000.00								-IDR 57,311,180,000.00	-IDR 50,057,804,175.04	-IDR 107,000,046,044.20
3	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 103,320,000,000.00	-IDR 2,952,000,000.00	-IDR 14,760,000,000.00	-IDR 16,531,200,000.00	IDR 10,005,006,556.14	0.19	IDR 5,904,000,000.00	IDR 779,314,375.54	IDR 9,225,692,180.61	IDR 7,530,912,939.88	-IDR 99,469,133,104.32
4	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 88,560,000,000.00	-IDR 2,952,000,000.00	-IDR 14,760,000,000.00	-IDR 14,464,800,000.00	IDR 12,071,406,556.14	0.20	IDR 5,904,000,000.00	IDR 1,235,305,428.66	IDR 10,836,101,127.48	IDR 8,266,809,667.42	-IDR 91,202,323,436.90
5	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 73,800,000,000.00	-IDR 2,952,000,000.00	-IDR 14,760,000,000.00	-IDR 12,398,400,000.00	IDR 14,137,806,556.14	0.21	IDR 5,904,000,000.00	IDR 1,709,013,845.13	IDR 12,428,792,711.02	IDR 8,861,557,430.62	-IDR 82,340,766,006.28
6	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 59,040,000,000.00	-IDR 2,952,000,000.00	-IDR 14,760,000,000.00	-IDR 10,332,000,000.00	IDR 16,204,206,556.14	0.21	IDR 5,904,000,000.00	IDR 2,193,661,540.59	IDR 14,010,545,015.55	IDR 9,335,817,722.55	-IDR 73,004,948,283.73
7	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 44,280,000,000.00	-IDR 2,952,000,000.00	-IDR 14,760,000,000.00	-IDR 8,265,600,000.00	IDR 18,270,606,556.14	0.22	IDR 5,904,000,000.00	IDR 2,685,536,827.75	IDR 15,585,069,728.40	IDR 9,705,598,150.61	-IDR 63,299,350,133.12
8	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 29,520,000,000.00	-IDR 2,952,000,000.00	-IDR 14,760,000,000.00	-IDR 6,199,200,000.00	IDR 20,337,006,556.14	0.22	IDR 5,904,000,000.00	IDR 3,182,436,565.92	IDR 17,154,569,990.23	IDR 9,984,115,919.21	-IDR 53,315,234,213.91
9	IDR 44,248,206,556.14	IDR 44,248,206,556.14		-IDR 14,760,000,000.00	-IDR 2,952,000,000.00	-IDR 14,760,000,000.00	-IDR 4,132,800,000.00	IDR 22,403,406,556.14	0.22		IDR 5,000,851,639.04	IDR 17,402,554,917.11	IDR 9,465,836,826.59	-IDR 43,849,397,387.32
10	IDR 44,248,206,556.14	IDR 44,248,206,556.14		IDR -	-IDR 2,952,000,000.00	-IDR 14,760,000,000.00	-IDR 2,066,400,000.00	IDR 24,469,806,556.14	0.23		IDR 5,517,451,639.04	IDR 18,952,354,917.11	IDR 9,634,416,206.40	-IDR 34,214,981,180.92
11	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 9,087,264,689.71	-IDR 25,127,716,491.21
12	IDR 21,148,039,898.16	IDR 21,148,039,898.16			-IDR 2,952,000,000.00		IDR -	IDR 18,196,039,898.16	0.22		IDR 3,949,009,974.54	IDR 14,247,029,923.62	IDR 6,325,851,669.75	-IDR 18,801,864,821.47
13	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 7,937,168,914.06	-IDR 10,864,695,907.41
14	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 7,417,914,872.95	-IDR 3,446,781,034.46
15	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 6,932,630,722.39	IDR 3,485,849,687.93
16	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 6,479,094,133.07	IDR 9,964,943,821.00
17	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 6,055,228,161.75	IDR 16,020,171,982.75
18	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 5,659,091,739.95	IDR 21,679,263,722.70
19	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 5,288,870,785.00	IDR 26,968,134,507.70
20	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 4,942,869,892.52	IDR 31,911,004,400.22
21	IDR 27,655,129,097.59	IDR 27,655,129,097.59			-IDR 2,952,000,000.00		IDR -	IDR 24,703,129,097.59	0.23		IDR 5,575,782,274.40	IDR 19,127,346,823.19	IDR 4,619,504,572.45	IDR 36,530,508,972.68
22	IDR 21,148,039,898.16	IDR 21,148,039,898.16			-IDR 2,952,000,000.00		IDR -	IDR 18,196,039,898.16	0.22		IDR 3,949,009,974.54	IDR 14,247,029,923.62	IDR 3,215,742,218.47	IDR 39,746,251,191.14

A.2 Matlab Code

```
clear all
clc
tic
disp('calculating');

%---------------- PARAMETERS --------------

Hv = 540;             % Elevation of turbine, reference
g   = 9.781 ;           % Gravity [m/s^2]

% Penstock
tunnel.L = 625 ;                % penstock length
tunnel.D = 1.65 ;                % penstock diameter
tunnel.A = (pi/4)*tunnel.D^2;   % penstock cross-section area
tunnel.np  = 1;                 % number of penstock
tunnel.c = 0.00045;         % pipeline resistance coefficient (J*deltaX/(q^2))

%-----------------------------------------------------------------------

L = tunnel.L;   % penstock length

a  = 1050;      % accoustic speed
dx = 5;
dt = dx/a;

x0 = dx;
Q0  = 6.5;
tmax = 7000;
x = x0;
l = 1;
y = 1;
Qn = Q0;

Z(1)  = 590;                % Maximum surge level in Surge Headbay.
B = a/(g*tunnel.A);         % pipeline characteristic impedance
R = tunnel.c;               % pipeline resistance coefficient

Tl= round(0.60/dt);           % Closing time turbine (dx/dt rounded into nth step)
k = (1-1e-7)/Tl;
%---------------------------

for t = 1:1:tmax

 for x = x0:dx:L    % Storing inital values at t=0
    Q(x,t) = Q0;
```

```
    H(x,t) = Z(1);

 end
end

%%
kappa = 1;

for n = 1:1:tmax
    if n <Tl              % shows time before turbine closure
       kappa = kappa - k;
    else
       kappa = 1e-7;
    end
    K(n,1) = kappa;

    for x = x0:dx:L
       if n == 1          %Inital values at t = 1
            Q(x,n) = Q0;
            if x == x0;
                H(x,n) = Z(1);
            else
                H(x,n) = H(x-dx,n) - R*Q(x-dx,n)*abs(Q(x-dx,n));
            end

            Hn   = H(L,1);

        elseif x == x0

            Z(n)   = Z(1);
            H(x,n) = Z(n);
            Cb     = H(x+dx,n-1) + R*Q(x+dx,n-1)*abs(Q(x+dx,n-1));
            Q(x,n) = (1/B)*(H(x,n) - Cb) + Q(x+dx,n-1);

         elseif x>x0 && x<L
            Ca     = H(x-dx,n-1) - R*Q(x-dx,n-1)*abs(Q(x-dx,n-1));
            Cb     = H(x+dx,n-1) + R*Q(x+dx,n-1)*abs(Q(x+dx,n-1));
            Qr     = Q(x+dx,n-1) - Q(x-dx,n-1);
            H(x,n) = 0.5*(Ca + Cb - B*Qr);
            Q(x,n) = (1/B)*(H(x,n) - Cb) + Q(x+dx,n-1);

         elseif x == L

            Cv = ((kappa*Qn)^2)/Hn;
            Ca = H(x-dx,n-1) + B*Q(x-dx,n-1) - ...
                R*Q(x-dx,n-1)*abs(Q(x-dx,n-1));
            Q(x,n) = -B*Cv*0.5 + 0.5*sqrt((B*Cv)^2 + 4*Cv*Ca);
            H(x,n) = (Q(x,n)/(kappa*Qn))^2*Hn;
         end
```

```
    end
end

%%


Hplot = H(L,:)-Hv;
Kplot = K;
Qplot = Q(L,:);

t1 = 1:1:tmax;
tplot = t1*dt;
figure(1)
clf
hold on
grid on

hl1 = line(tplot,Hplot);
ax1 = gca;
ylabel('Head at valve [m]')
xlabel('Time [s]')
legend('Pressure ')

hold off

figure(2);
clf
hold on
grid on
ql1 = line(tplot,Qplot);
ax3 = gca;
ylabel('Discharge [m3/s]')
xlabel('Time [s]')
legend('Water Flow ')
hold off

toc
```