Chapter 2
Theoretical Principles Concern

2.1 Basic knowledge of hydropower plant

Hydropower plants are an energy source to produce electricity and they are very important for countries. Lao PDR has highly effective natural resource by building dam of close the river and storing water volume to make high water level for rotating the turbine and activate the generator which is installed at the area of the lower water level. The advantages of hydro energy are: do not lose fuel fee which decrease imports of oil prices which are high in the current economic conditions, low operation cost, impact on the environment less than thermal power plants. Also, hydropower plants do not cause high temperature of water and impair with the water for animals, not pollute air caused by the process of fire-burned fuel [14].

To classify the type of hydropower plants, generally they are divided according to the size of the production of the electricity and the characteristics of quarantine stored water to generate power. Separate categories for the size of the electric power can be:

- Large-Hydropower plant : installed capacity over 100MW
- Medium-Hydropower plant: installed capacity between 15 MW to 100 MW
- Small -Hydropower plant: installed capacity between 1 MW to 15 MW
- Mini-Hydropower plant : installed capacity between 0.1 MW to 1 MW
- Micro-Hydropower plant: installed capacity lees than 100 kW

On the basis of the characteristics of stored water to produce electricity, it can be separated into 4 types:

2.1.1 Run of river hydropower plant which has no reservoir power generation depends on water flow of river. Installed capacity is calculated from annual water rate at lowest duration time to generation over the year.

2.1.2 Regulating pond hydropower plant has small reservoir which can control the water flow in the short time. The power generation can be controlled in accordance with the requirements better than run of river.

2.1.3 Reservoir hydropower plant are large dams barricade across sections of river for sequestration of water in the rainy season and used in the dry season. This power plant can control the water usage to produce electrical energy to consumers in a system with high efficiency over the year.

2.1.4 Pumped storage hydropower plant is able to pump the water back to the reservoirs. The benefits of this type of power plant are it can change the energy remaining in the period with low demand as midnight to accumulate in the form of stored water in the reservoir. The water can be used to produce electrical energy in high demand.

2.2 The Component of hydropower plant

The general hydropower plant has the important components are show in Figure 2.1

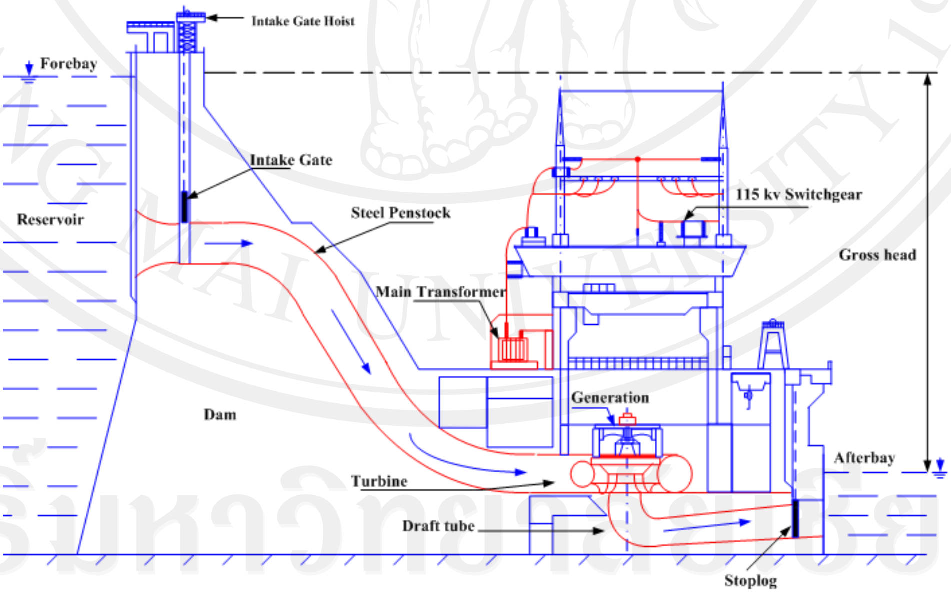

Figure 2.1 Components of a hydropower plant

2.2.1 Dam

Barrier dam is used for storing water volume and high water level for operation and it is divided into 5 types as: earth dam, stone dam, arch concrete dam, gravity concrete dam and grip dam.

2.2.2 Intake

Intake is the structures which is used for river system and control the water flow, it may be built near dam or may be separated, depending on topography.

2.2.3 Surge tank

The system is derived from the water flow by using tunnel or penstock. The length of water flow system depends on high water level demand for power generation.

2.2.4 Penstock

Penstock is to deliver water to turbine. Water systems building will be constructed.

2.2.5 Power house

Power house is a building which installs the turbine, generator, controlled equipment and transmission line which is located at higher level for preventing flooding in rainy season. The released water is delivered back into the original river through tailrace or release for other purposes.

2.2.6 Turbine

Turbine has two types as:

2.2.6.1 Impulse turbine

Impulse turbines change the direction of flow of a high velocity fluid or gas jet. The resulting impulse spins the turbine and leaves the fluid flow with diminished kinetic energy. There is no pressure change of the fluid or gas in the turbine blades (the moving blades), as in the case of a steam or gas turbine; the entire pressure drop takes place in the stationary blades (the nozzles). Before reaching the turbine, the fluid's pressure head is changed to velocity head by accelerating the fluid with a nozzle. Pelton wheels and de Laval turbines use this process exclusively. Impulse turbines do not require a pressure casement around the rotor since the fluid jet is created by the nozzle prior to reaching the blade on the rotor. Newton's second law describes the transfer of energy for impulse turbines.

2.2.6.2 Reaction turbines

Develop torque by reacting to the gas or fluid's pressure or mass. The pressure of the gas or fluid changes as it passes through the turbine rotor blades. A pressure casement is needed to contain the working fluid as it acts on the turbine stage(s) or the turbine must be fully immersed in the fluid flow (such as with wind turbines). The casing contains and directs the working fluid and, for water turbines, maintains the suction imparted by the draft tube. Francis turbines and most steam turbines use this concept. For compressible working fluids, multiple turbine stages are usually used to harness the expanding gas efficiently. Newton's third law describes the transfer of energy for reaction turbines.

- **Francis turbines** are the most common water turbine in use today. They operate in a water head from 10 to 650 meters (33 to 2,133 feet) and are primarily used for electrical power production, generally ranges from 10 to 750 Megawatts, though mini-hydro installations may be lower. Penstock (input pipes) diameters are between 1 and 10 meters (3 and 33 feet). The speed range of the turbine is from 83 to 1000 rpm. Guide vanes around the outside of the turbine's rotating runner adjust the water flow rate through the turbine for different water flow rates and power production rates. Francis turbines are almost always mounted with the shaft vertical to keep water away from the attached generator and to facilitate installation and maintenance access to it and the turbine.

- **The Kaplan turbine** is a propeller-type water turbine which has adjustable blades. It was developed in 1913 by the Austrian professor Viktor Kaplan, who combined automatically-adjusted propeller blades with automatically-adjusted wicket gates to achieve efficiency over a wide range of flow and water level.

The Kaplan turbine was an evolution of the Francis turbine. Its invention allowed efficient power production in low-head applications that was not possible with Francis turbines. The head ranges from 10–70 meters and the output from 5 to 120 MW. Runner diameters are between 2 and 8 meters. The range of the turbine is from 79 to 429 rpm. Kaplan turbines are now widely used throughout the world in high-flow, low-head power production.

2.2.7 Generator

In electricity generation, an electric generator is a device that converts mechanical energy to electrical energy. A generator forces electric charge (usually carried by electrons) to flow through an external electrical circuit. The source of mechanical energy may be a reciprocating or turbine steam engine, water falling through a turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, compressed air, or any other source of mechanical energy. Generators supply almost all of the power for the electric power grids which provide most of the world's electric power.

2.2.8 Transmission line

Electric-power transmission is the bulk transfer of electrical energy, from generating power plants to electrical substations located near demand centers. This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as electric power distribution.

2.3 Concepts of reservoir operation

The draw down refill cycle of a reservoir is usually 12 months long except when the reservoir capacity is large in relation to stream flows. The cycle may extend over many years in arid regions. In many regions of the world, the refill periods (when inflows are more than the demands and therefore extra water is stored in the reservoir for later use) and drawdown periods (when inflows are smaller than the demands and therefore water is withdrawn from storage to meet various demands) are distinctly separated. For example, in monsoon climate, high flows occur during certain calendar months only. Many reservoirs receive a significant portion of their annual flows through snowmelt. In addition, benefits from operation of reservoirs considerably improve when reliable weather and inflow forecasts are available.

A reservoir is operated according to a set of rules or guidelines to store and release water depending on the purposes it is required to serve. The decisions regarding releases in different time periods are made in accordance with the available water, inflows, demands, time of the year, etc. Many operation rules are based on intuition and common sense. For example, in a multi-reservoir operation, the consumptive demand may be met from the reservoir that is nearest to the demand point so as to minimize transit losses and wastage. Likewise, in irrigation operation, the manager may release water to save the standing crop from serious damage and take the risk of shortage of water for a future crop.

For reservoirs which are designed for multi-annual storage, the operation policy is based on long term targets. The estimates of water availability are made using long-term data. The requirements for conservation uses are worked out by projecting the demand data. The magnitudes of releases for the uses which are to be served from storage on a long-term basis are determined and the reservoir is operated accordingly. In periods of droughts, based on pre-specified priorities, the supply for some uses is curtailed keeping in view the minimum demands of each purpose. Consideration is given to the maintenance of essential services even if it is at the cost of agriculture and industrial production.

Many basins in cold countries experience floods when the snow melts. It is possible to fairly accurately predict the runoff volume during this period by using snow surveys data and storage may be allocated to ensure desired flood protection. One can be quite sure that this space will be filled by the time flood season is over. However, such a long-range forecasting with desired reliability is not possible for rain-fed rivers in monsoon climate, and a calculated risk is taken while allocating storage space for flood control pool, conservation pool and inactive pool. The schematic of a reservoir is shown in Figure 2.2 [15].

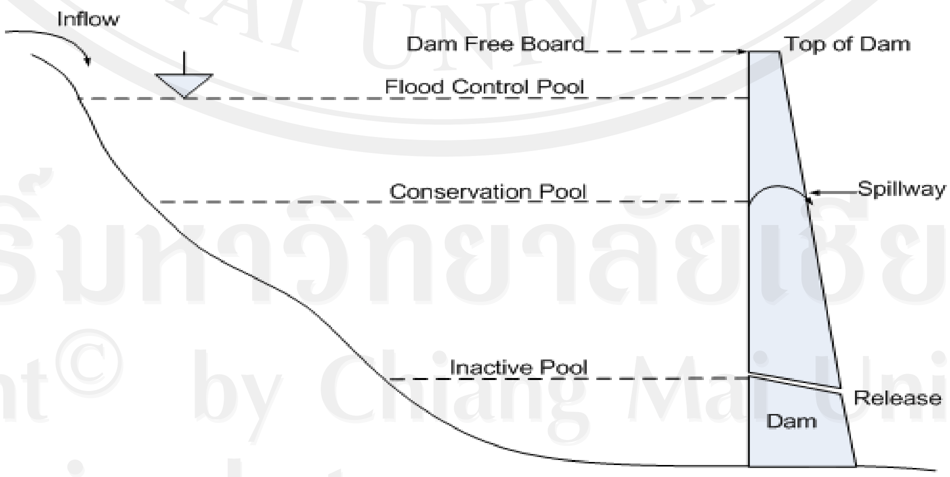

Figure 2.2 Schematic presentation of a reservoir

Inactive pool: also called dead storage, this level indicates the lower operation limit, water releases are normally not made below this level. The dead storage level may be fixed by the invert of the lowest outlet, or in the case of hydroelectric power, by conditions of operation efficiency for the turbine.

Conservation pool: This is defined as the storage zone between the flood control pool and the inactive pool, searching for the target level for maximum average energy generation, trying to obtain the optimum balance over time between creation of head and avoidance of spilling. This target level is not relevant if there is no hydropower plant.

Flood control pool: this zone serves for flood control purposes. It lies between the maximum reservoir level and the maximum level of the conservation pool. This storage space should be kept as empty as technically possible, so that by storing the water in the reservoir, incoming floods are attenuated and thus avoid downstream damage.

2.4 Classification of reservoirs

Various classifications of reservoirs are possible depending on the purpose, size, and the storage space available in it. These are briefly discussed as follows:

2.4.1Classification based on purposes

Depending on the number of purposes that a reservoir serves, a reservoir may be classified either as single purpose or multipurpose. A single purpose reservoir serves only one purpose. This purpose may be either a conservation purpose like water supply for domestic and industrial purposes, irrigation, navigation, generation of hydroelectric power, and recreation. The flood control purpose is non-conservation in nature. A multipurpose reservoir is designed and operated to serve a combination of these purposes.

2.4.2 Classification based on size

Depending on the size, reservoirs are classified as major, medium or minor. These norms, however, vary from country to country. In India, if the gross capacity and the hydraulic head of the reservoir exceed $60*10^{\wedge 6}$ m^3 and 30 m, respectively, the reservoir is classified as a major reservoir. If gross capacity lies between 10 and $60*10^{\wedge 6}$ m^3 and the hydraulic head lies between 12 and 30 m, a reservoir is classified as a medium reservoir. Minor reservoirs have a gross capacity of less than 10 million m^3 and a hydraulic head of less than 12 m.

2.4.3 Classifications based on storage

Based on the storage space provided, a reservoir may be classified as a seasonal storage or over-year storage. A seasonal storage reservoir is designed to serve conservation purposes for periods of low flows. These reservoirs fill and spill frequently and are constructed on small tributaries to serve relatively small areas. An over-year storage reservoir is designed to serve for periods exceeding more than a water year. The storage in an over-year storage reservoir at the end of a water year is carried over to the next year. These reservoirs may neither be completely full nor dry every year.

2.4.4 Characteristics and requirements of water uses

As a thumb rule, the bigger a reservoir is, the more are the purposes that it can serve. The major purposes for which a reservoir is used and the functional requirements for these are discussed below:

2.4.4.1 Irrigation

Irrigation demands are consumptive and only a small fraction of the water supplied is available to the system as return flow. These requirements have direct correlation with rainfall in the command area. Irrigation requirements are seasonal in nature and the variation largely depends on cropping patterns in the command area. In general, demands will be small during the wet season and large during winter and summer months. The average annual demands remain more or less steady unless there is an increase in the command area or large variation in the cropping pattern. The safety against droughts depends on the available water in the reservoir and hence it is desirable to keep as much water in storage as possible consistent with current demands.

2.4.4.2 Municipal and industrial water supply

Generally, water requirements for municipal and industrial purposes show less change through the year, more so when compared with irrigation and hydroelectric power. The water requirements increase with time due to growth and expansion. The seasonal peak of the demand is observed in summer. For the purpose of design, a target value is arrived at by projecting population and industrial growth. The supply system for such purposes is designed for a high level of reliability.

2.4.4.3 Hydroelectric power

Water is a renewable source of energy. The hydroelectric power generation is a non consumptive use of water because after passage through the power plant where its mechanical energy is converted to electric energy, the same water can again be utilized for other uses downstream. Due to this feature, hydroelectric projects are frequently multipurpose. As a result of research and development in turbine technology, efficient turbines with capacities varying from several hundreds of MW to a few MW have been developed. Therefore, one now comes across mega hydropower projects, providing power to a big region, to micro projects, catering to the needs of a small village. It is estimated that one quarter of the electrical energy generated in the world is from hydropower. Some advantages of hydropower generation are:

- This is a renewable source of energy, the sun being the prime mover of water cycle. As no payment is made for the input, the production is free from inflation.
- The hydropower plants do not require much outlay on account of operation and maintenance, and have a long life.
- The hydropower generation does not pollute the environment; no heat is produced and no harmful gases are released.
- The hydropower power plants work at a very high efficiency (say up to 90%), whereas the thermal power plants work at a comparatively low efficiency.
- The plant can be started or shutdown in a short time, with no wastage of water.

The electric power demands usually vary seasonally and to a lesser extent, daily and even hourly. The degree of fluctuation depends on the type of loads being served, viz., industrial, municipal and agricultural. For example, in case of municipal areas, the hydroelectric demands are at maximum during the peak summer months. Furthermore, during the course of a day, two demand peaks are observed, one in the morning and another in the evening. The hydroelectric power plants are usually part of a regional or national grid and their operation is governed by their role in the grid.

2.4.4.4 Flood control

Flood control reservoirs are designed and operated to moderate flood flows that enter into them. The flood moderation is achieved by storing a part of inflows in the reservoir and releasing the balance. The degree of flood attenuation or moderation depends on the empty storage space available in the reservoir when the flood impinges on it. The achievement of this purpose requires the availability of empty storage space in the reservoir. As far as possible, the releases from the storage are kept smaller than the safe capacity of the downstream channel.

2.4.4.5 Navigation

Storage reservoirs may also be operated to maintain a stretch of downstream river navigable. The requisite depth of flow in the navigation section is maintained by releasing water from the dam. The demand for water for this purpose depends on the type and volume of traffic in the navigable waterways. The water requirements for navigation show a marked seasonal variation. There is seldom any demand during the wet period when sufficient depth of flow is available in the channel. The demands are at a maximum in the dry season when large releases are required to maintain the required depth.

2.4.4.6 Thermal power generation

Water is also an important input in thermal power generation where it is used for cooling purposes. The simplest arrangement, known as once-through cooling, consists of diverting the water from the source to the power plant where it is used to cool the condensers and the heated water is returned to the source. Although this method has many advantages, the main being the least cost of construction, it is being gradually discarded due to thermal pollution of the receiving waters. Most new power plants use evaporative cooling tower systems. In such systems, a tall cooling tower is constructed and the water, after cooling the condensers, is passed through an air stream, cooled and recycled to the condensers.

2.4.4.7 Recreation

The benefits from recreation are derived when the reservoir is used for swimming, boating, skiing and other water sports and picnic. Usually the recreation benefits are incidental to other uses of the reservoir and rarely a reservoir is constructed solely for recreation. The recreation activities are best supported by a reservoir which remains nearly full during the recreation season. Large and rapid fluctuations in the water level of a reservoir are harmful from a recreational point of view because they can create marshy land near the rim of the reservoir.

2.4.4.8 Minimum flow maintenance

Many times, it is necessary to release a certain minimum amount of water in the river below the reservoir from water quality (dilution of pollution) or environmental considerations. The release under this head vary seasonally and may get the highest priority.

2.5 Operation of a multi-reservoir system

The discussion so far was limited to operation procedures for a single reservoir. It is well known that the benefits from the joint operation of a system of reservoirs can be. Substantially larger than the sum of benefits obtained from the operation of individual reservoirs. A system may consist of reservoirs in series, in parallel, or a combination. Approaches to develop operation policies for a system of reservoirs are discussed in the following section. Some of these operational policies are developed by intuition and are anticipatory but this does not diminish their utility and effectiveness.

2.6 Reservoirs in series

Consider a system of two reservoirs in series as shown in Figure 2.3 a complex system can be decomposed into this simple configuration. The diversion demand D1 can be met only by reservoir 1 while demands D2 and D3 can be satisfied by both reservoirs. The rules for refill and drawdown of reservoirs in series for various purposes are given in Table 2.1 The reservoirs shown in Figure 2.3 can serve conservation demands by minimizing the uncontrolled outflow of water from the system. The spill from any reservoir, except the lowest, can be captured by a downstream reservoir. Thus, the most-upstream reservoir should be filled up first (subject to the availability of inflows), followed by the reservoir just downstream to it, and so on. This strategy permits capture of spills from the upstream reservoirs in the system itself. During the drawdown season when the natural stream flows are small in comparison with the demands, the most downstream reservoir should be drawn down first and so on. The demands at a location are met by the immediately-upstream reservoir before using any other upstream reservoir. This rule can be bypassed if due to various reasons, such as topography, system configuration; it is not possible to meet all the demands by all reservoirs. The relative magnitudes of water loss due to evaporation and seepage from various reservoirs should be considered while applying these rules [15]

Table 2.1 General rules for operation of reservoirs in series

Purpose	Refill period	Drawdown period
Water supply	Fill upstream reservoir first	Withdraw from downstream reservoir first
Flood control		
Energy storage		
Hydropower production	Maximize storage in reservoirs with greatest energy production per unit of water	
Recreation	Equalize marginal recreation improvement of additional storage among reservoirs	

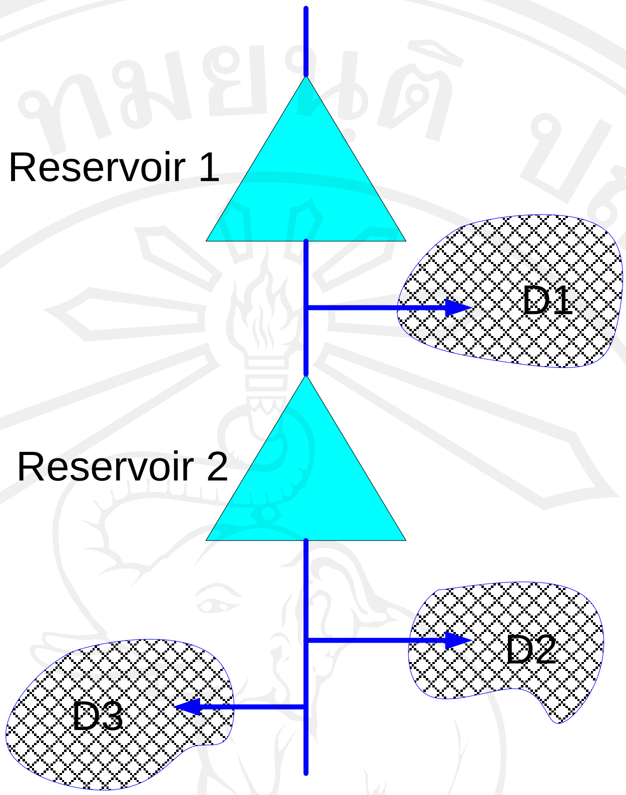

Figure 2.3 System of two reservoirs in series

If these rules are applied to the system shown in Figure 2.3, demand D1 is met from reservoir 1 (meeting this demand from reservoir 2 may involve pumping) and demands D2 and D3 are met from reservoir 2. When there is not enough water in reservoir 2, water from reservoir 1 is released (assuming that it has enough water) to meet demands D2 and D3. This rule ensures minimization of spills from reservoir 2. The spills of reservoir 1 can be captured by reservoir 2.

2.7 Reservoirs in parallel

The simplest configuration of parallel reservoirs is shown in Figure 2.4 It consists of two reservoirs located on two different streams which join downstream of the reservoirs. The direct demands of reservoirs 1 and 2 are D1 and D2, respectively. Either or both of the reservoirs can meet demand of D3. An important difference in operation of series and parallel reservoirs is that the release from an upstream reservoir cannot be captured by a downstream reservoir. Therefore, balancing of the operation is important in such cases. Rules to operate parallel reservoirs are summarized in Table 2.2.

In this configuration, the commonly-followed procedure is to discharge water first from the reservoir with larger drainage area or potential inflows per unit storage capacity. To that end, the drainage areas to storage volume capacity ratios for two reservoirs are compared (assuming the runoff per unit of drainage area is the same). The reservoir with the larger ratio will supply water for demand D3 before the other reservoir is drawn down. Discharging water first from the reservoir having the largest drainage to the storage volume capacity ratio will usually result in a reasonable conservation of water [15].

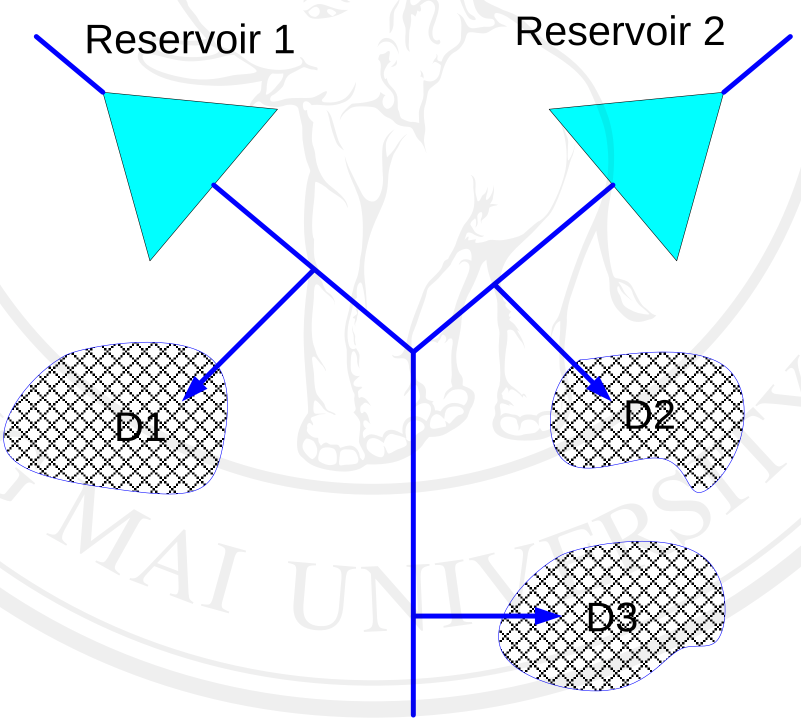

Figure 2.4 System of two parallel reservoirs

Several types of rules have been developed for conservation operation of parallel reservoirs during refill periods. A typical objective of such system is to minimize expected shortages. These rules prescribe ideal releases or storage levels for reservoirs in parallel to avoid the inefficient condition of having some reservoirs full and spilling whereas other reservoirs have unused storage capacity. The severity of shortages is reduced by minimizing uncontrolled spills from the system.

Table 2.2 General rules operation of reservoirs in parallel

Purpose	Refill period	Drawdown period
Water supply	Equalize probability of spill among reservoirs	Equalize probability of emptying among reservoirs
Flood control	Keep more vacant space in reservoirs likely to receive bigger floods	Not applicable
Energy storage	Equalize EV of energy spill among reservoirs	For the last time-step, equalize EV of seasonal energy spill among reservoirs
Water Quality	Equalize EV of marginal seasonal water quality spill among reservoirs	For last time-step, equalize EV of refill season water quality spill among reservoirs
Hydropower production	Maximize storage in reservoirs with greatest energy production per unit of water	
Recreation	Equalize marginal recreation improvement of additional storage among reservoirs	

2.8 Hydropower rules

For steady-state hydropower production at reservoirs in parallel, the storage effectiveness of parallel reservoir *j* can be defined as

$$V_j = a_i \eta_i I_j \qquad (2.1)$$

Where : Vj The increased power production per unit increase in the storage

a_i Unit change in hydropower head per unit change in storage

η_i The power generation efficiency, all for reservoir *i* and

Ij Direct inflows and releases into reservoir *j*

2.9 Rule curve

A rule curve or rule level specifies the desired storage to be maintained in a reservoir as closely as possible during different times of the year while trying to meet various demands. The rule curves are generally derived by operation studies using historic or generated flows. Here the implicit assumption is that a reservoir can best satisfy its purposes if the storage levels specified by the rule curve are maintained in the reservoir at different times. The rule curve as such does not give the amount of water to be released from the reservoir. This amount will depend on the inflows to the reservoir and the demands for various purposes. Different rule curves may be developed for different purposes such as municipal water supply, irrigation, hydropower generation and for flood control.

2.9.1 Derivation of rule curves

The derivation of rule curves depends on the type of the reservoir and the purposes to be served. A reservoir may be classified either as a seasonal reservoir or a multi-annual reservoir. The storage of a seasonal reservoir is utilized to carry water from the wet season to the dry season whereas multi-annual reservoir storage is used to carry water from a wet period to a subsequent dry period which could occur several years later. Consider the case of a reservoir with seasonal storage serving conservation needs, if this reservoir is able to meet the demands during the critical year, it will be able to do so in all other years. The Upper and Lower rule curve use for reservoirs operating management general is shown in Figure 2.5.

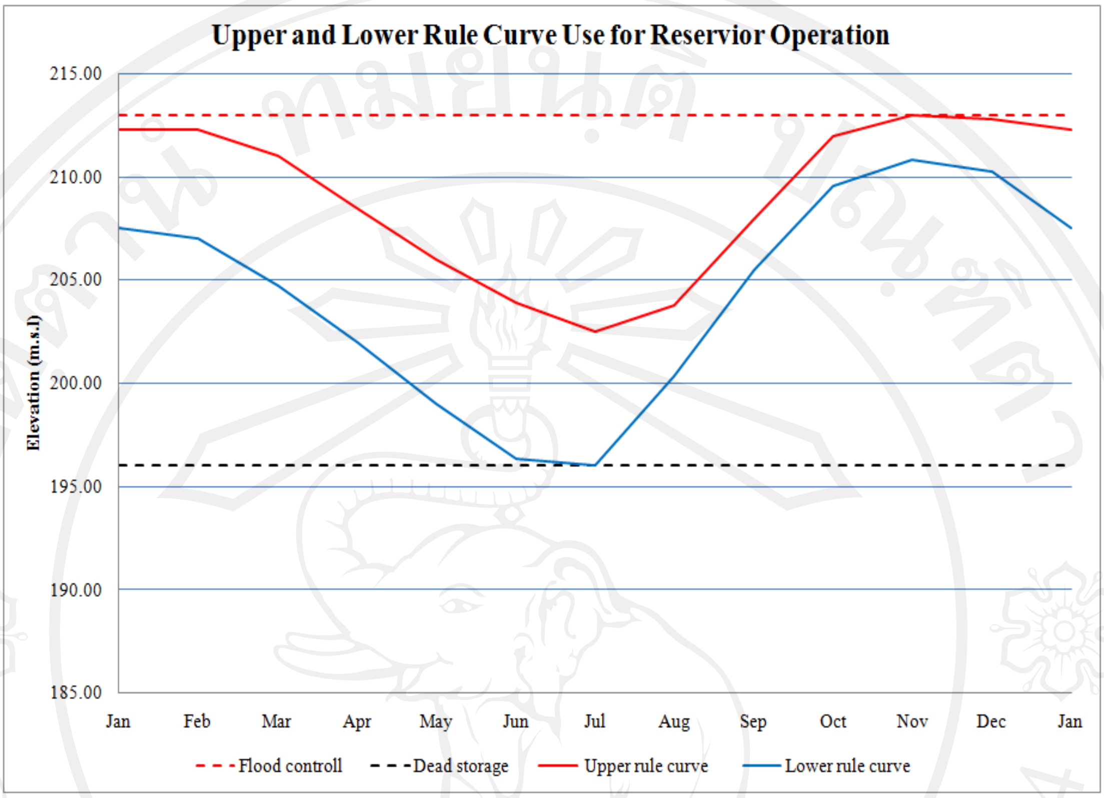

Figure 2.5 Upper and lower rule curve use for reservoirs general

2.9.2 Upper rule curve

To minimize the spill water, before starting of high inflow periods, the reservoir storage should be at lower level in order to capture the incoming water and provide spill water protection. After the high inflow, the reservoir should be ideally full for serving the demand. The inflow data that are used for creating this curve is the maximum inflow, the rule curve is the same concept of flood control rule curve and guarantee no spill water. Practically, if the maximum inflow in the past years is used to define the upper rule curve, the very high water will be released and may bring the reservoir to more shortage risk situation. Therefore, the inflow for the rule curve is selected which is acceptable and spill probability such as once in decade, once in five years, etc. Concern to the electricity generation reservoir and spill water protection, the water can be released pass turbines at the same time as high inflow coming, if assume that flood problem is not concerned. Normally, the reservoir will employ this rule curve as maximum limit, called upper rule curve, and can be determined by the following formula (2.2) [16].

$$URCi = Sf - \sum_{j=i+1}^{k-1} (It\ max - RRt\ max) \qquad (2.2)$$

Where:

URCi	Upper rule curve in the month *i*
S*f*	Full reservoir water volume
J	Month
i	The month that is calculating upper rule curve
k	The month that (It max - RRt max) ≤ 0
It max	Maximum inflow in the month *j*
RRt max	Maximum outflow through turbine in the month *j*

2.9.3 Lower rule curve

On the other hand, the system requires minimum generation from the hydro power plant which implies that the system requires minimum water storage for electricity generation. For protecting the water shortage, the minimum limit called lower rule curve must be calculated. The release water is easy to calculate from minimum generation but how to predict the inflow is not as easy. If the minimum inflow is used, it will guarantee no water shortage. But if the higher inflow is employed, the system will take higher risk. However, it will give more opportunities to produce the electricity at the most proper time. The proper inflow selected to create the minimum limit depends upon the acceptable water shortage probability, the consequential damage from water shortage and opportunities to relieve electricity shortage. If the reservoir is very large when compared with the inflow, with this situation, the minimum inflow should be selected because it guarantees that electricity shortage will not occur as the reservoir has large storage capability. The lower rule curve can be calculated by the following formula (2.3) [16].

$$LRCi = Sd + \sum_{j=i+1}^{k-1}(It\ min - RRt\ min) \quad (2.3)$$

Where:

LRCi	Lower rule curve in the month *i*
Sd	Reservoir water volume at dead storage
J	Month
i	The month that is calculating lower rule curve
K	The month that (I*t* min - RR*t* min) ≥ 0
It min	Minimum inflow in the month *j*
RR t min	Minimum outflow through turbine in the month *j*

2.10 Hydraulic power theory

The hydraulic turbine is a main piece of equipment that transforms the energy of the water into mechanical energy and rotates a water-wheel hydroelectric generator. The turbine runner and the rotor of the water-wheel generator are usually mounted on the same shaft. Modern hydraulic turbines are divided into two groups, an impulse turbine and reaction turbines. An impulse turbine(like Pelton turbine) is the one which driving energy is supplied by the water in kinetic form. A reaction turbine (like Francis propeller turbine, Kaplan and diagonal turbine) is the one which the driving energy is provided by the water partially in kinetic and partially in pressure form. The hydraulic power is a function of the effective water head and water discharge, the power source is given by equation [17].

$$P_m = \rho g Q h \quad (2.4)$$

Where:

P_m	Hydraulic power (W)
ρ	Water density (kg/m^3)
g	Gravitational acceleration (m/s^2)
Q	Water volumetric flow rate (m^3/s)
h	Gross head (m)

2.11 Efficiency theory

The power transfer to the runner is further exposed to additional losses before the resulting power *P* is transferred to the generator shaft. These losses are composed of mechanical friction in the bearing and stuffing boxes, viscous friction from the fluid between the outside of the runner and the covers of the reaction turbines and vibration or aim friction losses of the runner in impulse turbine. Through the space between the covers and the outside of the runner, a leakage flow also passes according to the clearance of labyrinth from the inlet rim to the suction side of the runner, some energy is also required for operation of the turbine governor, tapping water for sealing boxes, cooling of bearing and the governor oil account for all the losses of the turbine efficiency. Efficiency is the ratio of output of power to input of power both expressed in units of the same denomination, foot-pounds per second, horse-power, or kilowatts. Generator output is measured at the generator terminals. Turbine is not measured directly except when it is absorbed by a break or dynamometer, as it is in the laboratory. It is equal to the generator output and those losses of the generator and other loads which are supplied by the turbine. Turbine input is the power in the water flow at the turbine inlet. International code for the field acceptance tests of efficiency [17]:

$$\eta = \frac{P_e}{P_m} \qquad (2.5)$$

Where:

η	Power plant efficiency
Pe	Electrical power output of generator (kW)
P_m	Hydraulic Power, the input power to turbine (kW)

2.12 Reservoir water balance

The presentation can be considered, additional reservoir storage by the solution of equation as can be rewritten below [18].

$$St = St\text{-}1 + I\,t - (Rt + Ft) - Evt \qquad (2.6)$$

The St-1 Reservoir volume change of hours , days, weeks, months and years and can be computed by formula below.

Reservoir volume change is easily obtained and can be rewritten below.

$$I_t = R_t + F_t + S_{t-1} \qquad (2.7)$$

In case volume storage normally St-1 = 0 or Head Water Level HWL2 = HWL1 the water inflow solution is easily obtained and can be rewritten below.

$$I_t = R_t + F_t \qquad (2.8)$$

In case volume storage decreases, head water level HWL2 < HWL1, the water inflow solution minus by end of month reservoir storage

Reservoir volume change is easily obtained and can be rewritten below.

$$I_t = R_t + F_t - S_{t-1} \qquad (2.9)$$

The St at end of month reservoir storage smaller than Smax t in case water level increase during rain season of the year can be rewritten or mean maximum reservoir storage.

$$S_t < S_{max\,t}$$

The St end of month reservoir storage greater than Smin t in case water level decrease during dry season of the year can be rewritten or mean minimum reservoir storage.

$$S_t > S_{min\,t}$$

The Rt release made power generation of month smaller than Rmax t maximum release made power generation of month that means power plant capacity.

$$R_t < R_{max\,t}$$

Where:

S*t*	Reservoir storage at end of *t*
S*t-1*	Reservoir storage at end of *t-1*
I*t*	Natural water inflow during *t*
RR*t*	Required releases during *t*
EV*t*	Net evaporation during *t* (losses)
R*t*	Water release to generate power during *t*
F*t*	Spill way discharge during *t*
t ,T	Time step, Time interval (month)
HWL*1*	Head water level first time
HWL*2*	Head water level second time

2.13 Strategy for improved operation

The energy generation from general reservoir can be computed as:
Energy generation equation used for calculating energy output of hydroelectricity power according to (2.10) [2].

$$E = T\eta gQH \tag{2.10}$$

Where:

E	Energy production (KWh)
T	Hours per year (t = 8.760)
g	Gravity (m/s^2) (g = 9.81)
η	Efficiency (0.88)
Q	Turbine discharge(m^3/s)
H	Gross head (m)

The Power generation from hydroelectricity power can be computed as:

$$P = \eta gQH \tag{2.11}$$

Where:

P	Power production (KW)
g	Gravity (m/s^2) (g = 9.81)
η	Efficiency (0.88)
Q	Turbine discharge (m^3/s)
H	Gross head (m)

Tail water equation used for calculating gross head of hydroelectricity power can be computed as:

$$H = HR - HL - HT \tag{2.12}$$

Where:

H	Gross head (m)
HR	Reservoir level (m.a.s.l)
HL	Head losses in power conduits (m)
HT	Tail water level (m.a.s.l)

2.14 Reservoir operation models

Numerous researchers have developed computer models for the operation of reservoirs and river systems. Nowadays, the majority of the reservoirs planning and operations are undertaken, using simulation and optimization models. Different types of reservoir operation techniques have been applied to dam operation.

Figure 2.6 shows step sequence for preparing data to make model of HEC-ResSim3.0 for reservoir management to produce electrical energy. The input data consist of three groups as hydropower data as height of hydropower plant, length of hydropower plant, geography data as river data, reservoir location into Arc-GIS Shape files and hydrological data as elevation, water inflow, and water outflow. They are made to files .dss by using HEC-DssVeu2.0 and evaporation. The all data will be input to software to make model in data configuration or HEC-Ressim3.0 module setup and it divides processing cases in Alternative and Cases. This model consists of wet case, drought case and normal case. After finishing this step, the data will be simulated for three cases and then the result will be compared with the actual data for optimum value and that will be concluded and that result will be considered for making reservoir management planning of Nam Ngum-1 Hydropower Plant. The details are illustrated in flow chart of Figure 2.6.

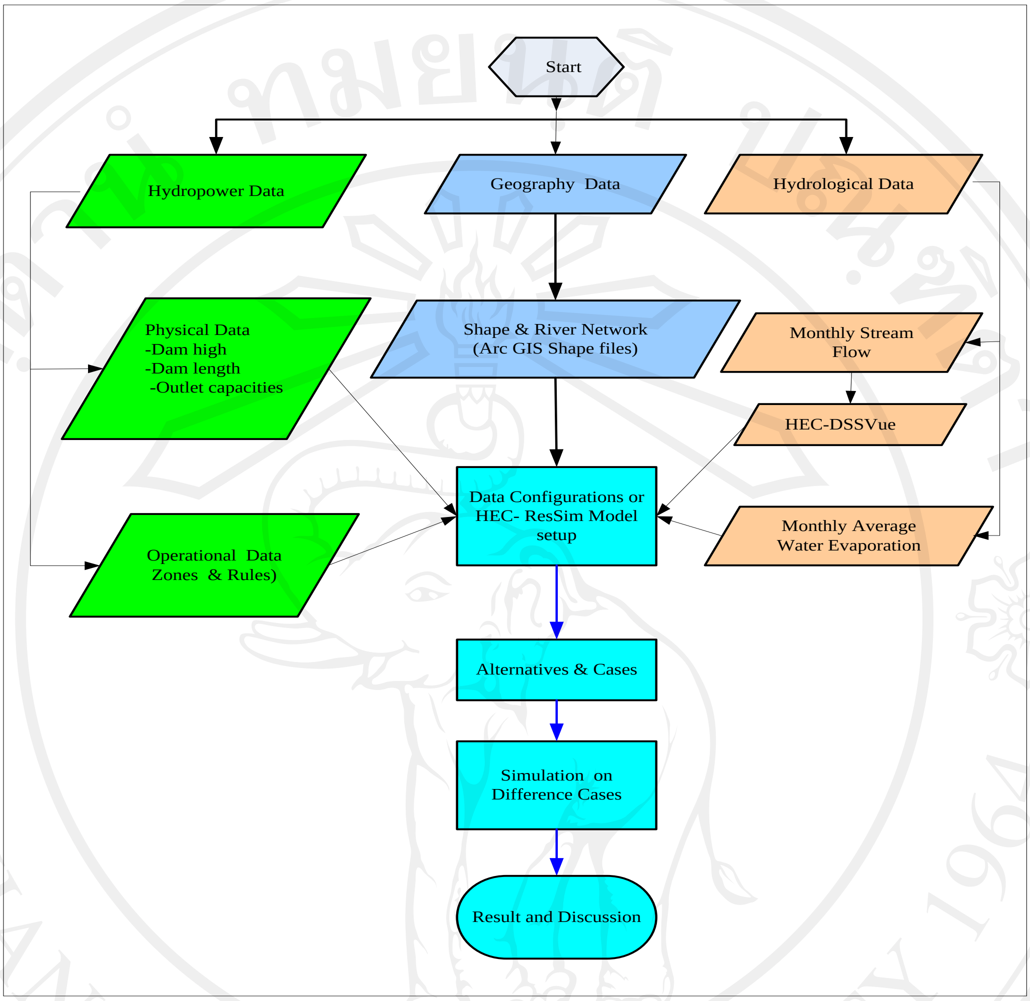

Figure 2.6 Flow chart of reservoir operation concept

2.14.1 Optimization techniques

Simulation model can accurately represent system operation and are useful in examining long-term reliability of the operation. In all mathematical optimization techniques, the problem of reservoir operation is formulated as a problem the objective of which is to maximize or minimize a set of benefits over time, subjected to a set of constraints. The most widely used techniques are linear programming, dynamic programming, non-linear programming, optimal control theory, fuzzy logic and artificial neutral network. Simulation models for the operation of reservoirs have been applied for many years. Many models are customized for particular system. However, more recently, the trend has been to develop general simulation models that can be applied to any basin or reservoir system [19].

2.14.2 Simulation techniques

Simulation model still remains the primary tool for reservoir operation studies. It is an abstraction of reality and replicates the physical behavior of the system on a computer. The key characteristics of the system (i.e., the main system process and variability) are reproduced by mathematical or algebraic descriptions.

Simulation is different from the mathematical programming techniques, which finds an “optimal solution” for the system operation meeting all system constraints while maximizing and minimizing some objective (Yeh, 1985). In contrast, simulation models provide the response of the system to specified input under a given condition or constraints. Hence, the simulation model enables the analysts to test the alternative sceneries (for instance, different operation rules) and examines the consistency before actually implementing them. The main drawback of simulation is that it requires prior specification of the system operation policy. In consequence, the only way to locate optimal policy is through subsequent trials. Many researchers have employed optimization method within simulation models. These techniques do not result in an optimal solution but rather facilitate compliance with the predefined operating rules [19].