# SCENARIO ANALYSIS OF RESERVOIR OPERATION : A CASE STUDY OF MUGU KARNALI STORAGE HYDROELECTRIC PROJECT, NEPAL

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## ABSTRACT

*Optimization of the reservoir consists of the interaction of different reservoir variables; inflow, turbine release, tailwater elevation, reservoir storage- elevation curve, generating head, evaporation losses etc. This paper presents a scenario analysis of the energy generation from Mugu Karnali Storage Hydroelectric Project, located in upper reach of Karnali River, Nepal. Wide range of the full supply levels, minimum drawdown levels, tailwater levels, turbine efficiency for the variable operating heads and minimum operation hours for dry season are considered. The inflow series are generated from the hydrologic analysis of the catchment based on the historical gauge data of the river. A simple algorithm and coded program in Python are developed for the scenario analysis. Outputs of the program are the design discharge, plant capacity, annual energy, seasonal energy, and spill water. The result obtained can be used to optimize the dam height, project capacity and reservoir operation to handle day to day service and extreme events.*

**Keywords:** *Dam, Reservoir, Reservoir Operation*

## 1. INTRODUCTION

Over the world, number of sources of energy are being used to fulfill the energy demand of households and industries. Conventional sources of energy include fossil fuels (Coal and Petroleum), fire-woods, cow dung cakes etc. which are being used from a long time. The conventional sources cannot cope with rapidly varying demand on electricity (Ilyinykh, 1982). The recently developed non-conventional energy sources include energy sources like Hydropower, Thermal Power, Geothermal Power, Solar and Wind Power etc. Nepal has a very large potential of hydropower development but very less have been tapped up to yet. Large effort is being put to use this untapped energy.

Broadly the hydropower development scheme can be divided into Run-of-River and Storage type. Run-of-River type project utilizes the available river flow without any regulation for instantaneous power generation. Storage hydropower plants include a dam and a reservoir to impound water, which is released when needed. Water stored in reservoir provides flexibility to generate electricity on demand and reduces dependence on the variability of inflow (Killingtveit, 2019). The Integrated Nepal Power System (INPS) consists mostly run-of- river hydropower plants and a few numbers of Peaking Run-of-River projects and only one storage project, Kulekhani HEP (92MW) [Figure 1] . The river flow in Nepalese river significantly reduce in dry season and consequently the energy production. This results severe power shortage during dry season. To reduce the power deficit during dry season numbers of peaking and numbers of reservoir projects with seasonal storage capacity have been studied for development.

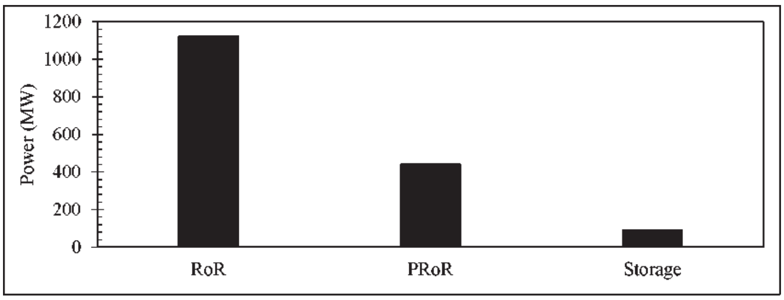


**Figure 1** : Distribution of power plants in Nepal (NEA, 2019)

### 1.1. Reservoir for Hydropower

Reservoirs store the water in wet season and make available to use in the dry seasons when the natural flow in the streams drops significantly. A typical reservoir includes a dam to retain the water and at least four different zones of water and sediments behind the dam as shown in

Figure 2. These four storage zones are defined by different water level. These storage zones and water level are defined in the following lines:

**Maximum Water Level (MWL):** This is water level which a reservoir attains during the passage of design flood from the spillway and sluices.

**Full Reservoir Level (FRL):** This is the maximum reservoir water level for normal operation. This is often known as Full Supply Level (FSL)

**Minimum Drawdown Level (MDDL):** This is the minimum reservoir level up to which the water level can be drawn down.

**Dead Storage Level (DSL):** Lowest level of the bottom most outlet structure withdrawing water from reservoir. In most of the cases it is the invert level of penstock.

**Live Storage:** Storage zone between FRL and DSL. The volume of water within this zone is used in for the power generation purpose.

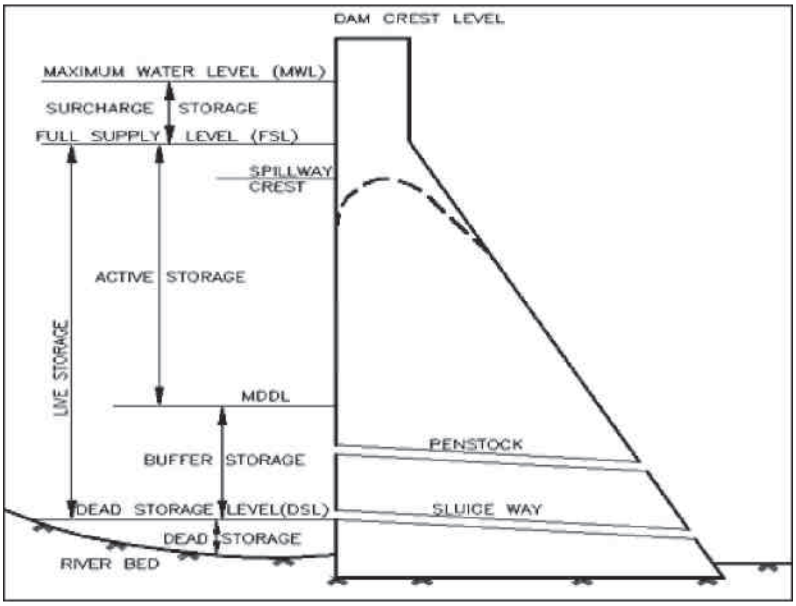


**Figure 2** : Water levels and storage zones of reservoir

**Dead Storage:** Storage volume below the invert dead storage level. This is used to pile up the sediment during the design life of reservoir.

**Surcharge Storage:** Reserve between FRL and MWL. This is responsible for attenuation of the flood peak.

**Buffer Storage:** Storage between levels MDDL and DSL. This neither can be used for power generation nor can be used for the sediment storage.

The reservoir operation involves the optimum planning and management of these different levels and storage zones for the optimization of power, energy and life of the reservoir.

## 2. OBJECTIVE OF THE STUDY

The main objective of this study is to present the different scenario of installed capacity, design discharge, total energy, fraction of dry energy and spillage volume for the operation of the reservoir. The output of the study is useful in optimization of the reservoir for the financial analysis.

## 3. STUDY AREA

The study is centered within the licensed area of Mugu Karnali Hydroelectric Project (MKHEP) located in the western Nepal. The study area is bounded within 81°39'14" E, 29°23'43" N in the south to 81°57'13" E, 29°41'22" N in the north. The location lies in the upper reach of Karnali River Ranging from Elevation 1350 masl to 1040 masl. Wide valley of the mainstream and tributaries are contributing for the storage volume for the dam. The proposed dam will be more than 200m high from the existing river bed level. The project is owned by Vidhyut Utpadan Company Limited, a company under Government of Nepal. The proposed dam locations are presented in plan and profile of Karnali River in Figure 3. Within the study area the mainstream of the river flows with average slope of 1:156. The catchment area of the river at proposed dam options 1 and 2 are 16,014 and 16,075 km$^2$ respectively. The catchment area delineated for option 1 has been presented in Figure 4.

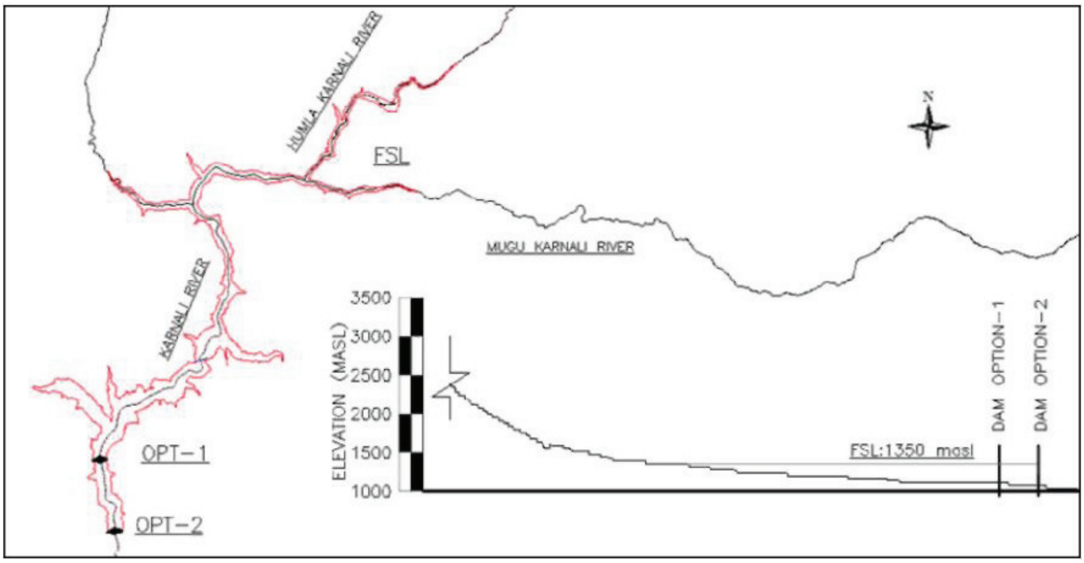


**Figure 3** : Study area showing the river network and profile of river

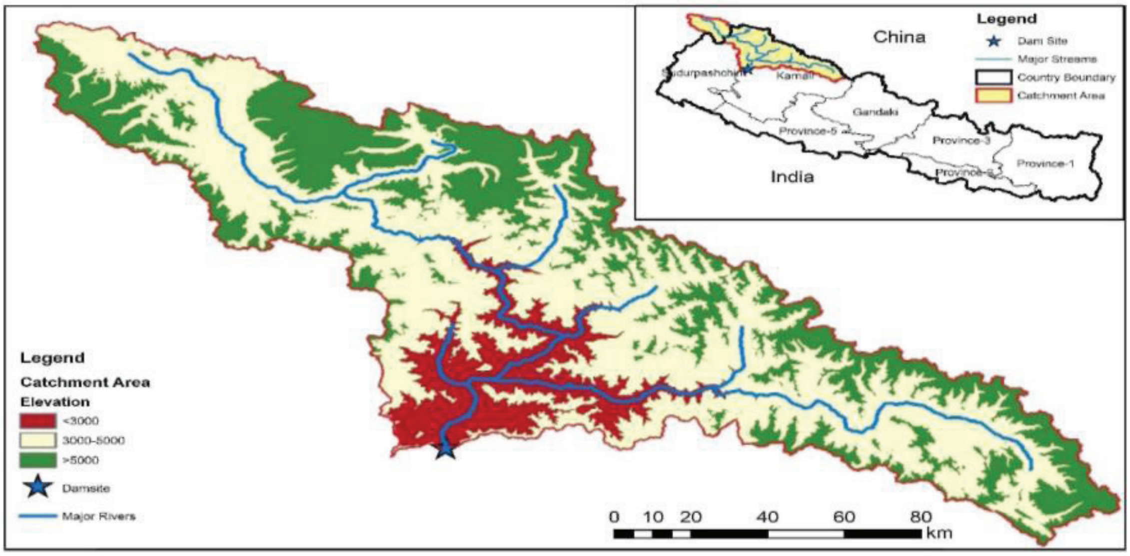


**Figure 4** : Catchment area at dam site (Option-1)

## 4. DATA ACQUISITION AND PREPARATION

Different data required during the study are listed below:

- River discharge gauging data
- Topographical data/digital elevation model
- Sediment data
- Evaporation data

Karnali River is a gauged river basin and includes four gauging stations along its mainstream. The nearest gauging station to the proposed area is Lalighat (Station No 215) which is about 40km downstream of the dam location. The catchment area of the river at this gauging station is about 16,995 km$^2$ while it is 16,014 km$^2$ at dam site (option 1). Being 94% catchment area common between gauging station and dam site, catchment area ratio method is used to generate the daily discharge data at project site. The annual flow hydrograph derived from the catchment area ratio method is presented in Figure 5. Based on the derived flow data, the total annual water volume available at the dam site is 9.88BCM and about 69% of this volume flows in the months of June to September.

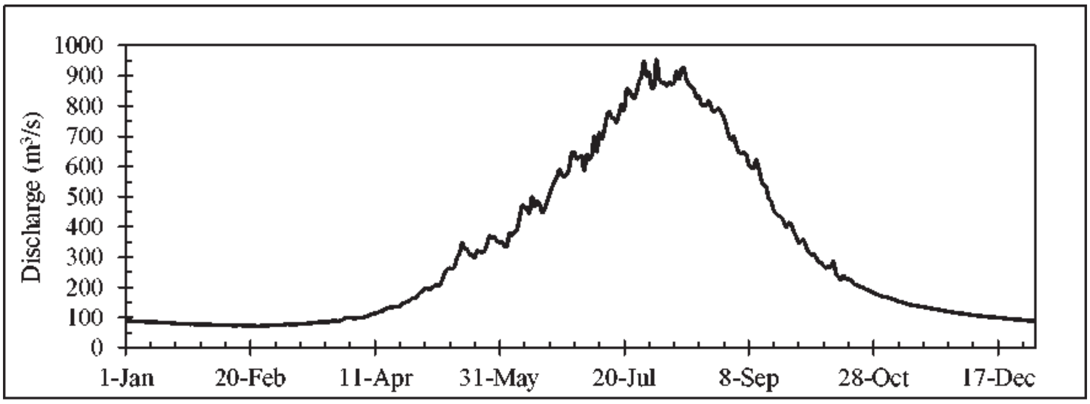


**Figure 5** : Annual hydrograph derived for dam site

The elevation-volume-area curve for the dam for different dam heights is prepared with the help of the freely available 90m x 90m digital elevation model (DEM) downloaded from Shuttle Radar Topography Mission (SRTM) website as an input raster in GIS. The derived elevation volume and elevation area relation is presented below in Figure 6.

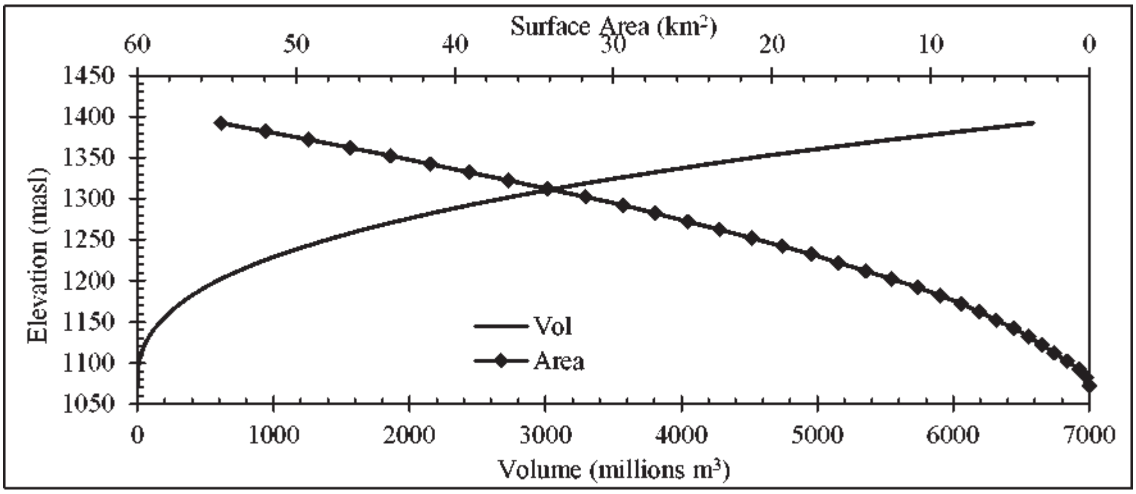


**Figure 6** : Elevation-volume-area curve for dam site (Option-1)

The long-term sediment measurement data is not available at the dam site. A new sediment station has recently been installed at the project site, but the station has not enough usable data. Thus the sediment yield into the reservoir is estimated based on the Himalayan Sediment Yield Technique (HSYT) developed for Nepalese Rivers. The sediment yield from respective physiographic region can be estimated as:

$$S_y = Z_{sy} \times A \tag{1}$$

where $S_y$ is the total sediment yield from a physiographic zone in tons/year, $Z_{sy}$ is zone specific sediment yield in tons/km$^2$/year, and $A$ is catchment area of the zone in km$^2$.(DoED 2006 & Galay, 1987).Using HSYT, the total annual sediment yield to the reservoir has been estimated to be about 47 MT per year which will be equivalent to 2,380 MT for design life of 50 years.

Evaporation from the reservoir surface is calculated based on the reference crop evapotranspiration (ET0) available at nearest meteorological station, Pusma Camp at an elevation of 950 masl. The evaporation from the reservoir surface is taken 25% more than reference crop evapotranspiration. (McDonald, 1990). The recorded evapotranspiration data from the Pusma station are presented in Table 1.

**Table 1** : Reference Crop Evapotranspiration of Pusma Camp, mm/day (McDonalds, 1990)

| Stn Name | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pushma Camp (401) | 2.00 | 2.93 | 4.71 | 6.89 | 7.05 | 5.02 | 4.00 | 3.72 | 3.35 | 3.27 | 2.69 | 1.85 |

## 5. METHODOLOGY

The scenario analysis of the possible combinations of the Full Supply Levels, Minimum Operating Levels, and minimum dry season operating hours is done with the help of coded program in python. Several combinations of these factors are analyzed systematically making small module in Python. The methodological steps are presented in Figure 7 and briefly described in the following sections. Six months from December to May are considered as the dry season months and remaining months are considered as wet season.

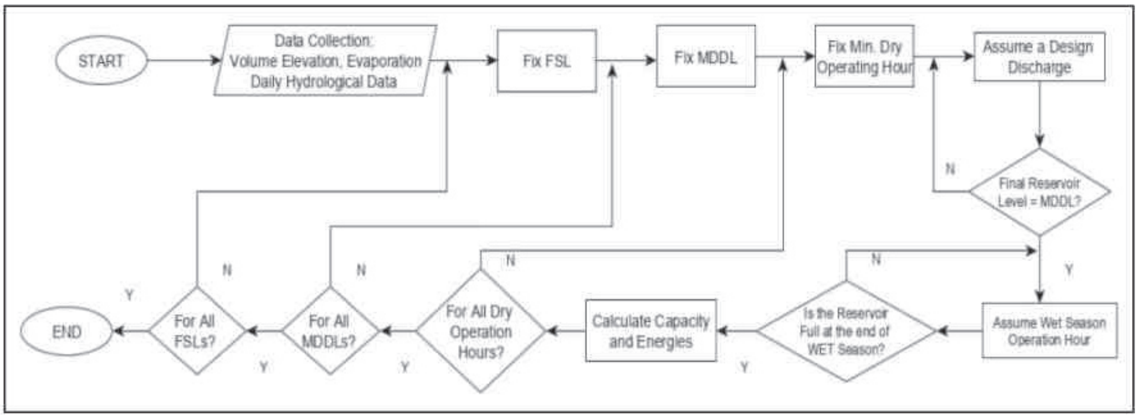


**Figure 7** : Methodology adopted for programming in Python

## 5.1 Check for Dead Storage

Total sediment yield calculated based on HSYT and reservoir storage elevation relationship are used for estimating design life DSL of the reservoir. While computing the scenarios, due considerations to the computed DSL was made and range of FSL and MDDL were chosen so as not to interfere the DSL.

## 5.2. Fixing Design Discharge

The design discharge is fixed based on the available volume above the MDDL and operation in dry season. It is chosen such that the plant will run at least for the stipulated minimum operation hours in dry season using the regular inflow of the river and the volume of water collected between the FSL and MDDL. The reservoir will depletes to the MDDL at the end of the dry season. The plant capacity is fixed based on the same design discharge operated when the reservoir is at the full supply level.

## 5.3. Fixing Wet Season Operation Hours

The reservoir is to be at the FSL level at the end of the wet season for the maximum utilization of reserved water in dry season.. During the wet season the plant should be operated mostly based on the river inflow. The main aim at this season will be to minimize the water volume spill from the dam without energy generation. Thus, the wet season operation hour is kept minimum and the filling of reservoir will continue. Near the end of the wet season when the reservoir is to its FSL , the plant operates for the potential operation hours based on the river inflow for the remaining days of the wet season. The reservoir may start filling and becomes full any days from June to November. After December 1 the plant will start to run for its full dry season hours utilizing the reserved water and consequently the water level will be decreasing at the reservoir.

## 5.4. Input and Output

The programming module accept the input data and in excel format and provide the output data in excel. The input data includes the long-term average daily discharge, stage-volume data and other data related to range of FSL, range of MDDL, range of dry season operation hours, tailwater level, efficiency of plant, and daily evaporation. The output of the program are the details of the annual energy produced, installed capacity, fraction of dry season energy, spill volume of water in different combination of FSL, MDDL and Operation hour.

# 6. RESULTS AND DISCUSSION

The result of the analysis is presented in Figure 8 to Figure 13. The results presented shows the scenario of plant capacity, and annual energy for several combination of FSL, MDDL and operation hours.

The plant capacity is the function of the rate of discharge and net head available at the plant. Combination of the FSL, MDDL and operation hour results different scenarios of discharge and head. The capacity of the plant increases with both increase in FSL and drawdown i.e. lowering the MDDL. [Figure 8 and Figure 9]. This is because higher FSL gives maximum possible head and , lower MDDL allows the higher design discharge because of the larger active storage volume between MDDL and FSL.

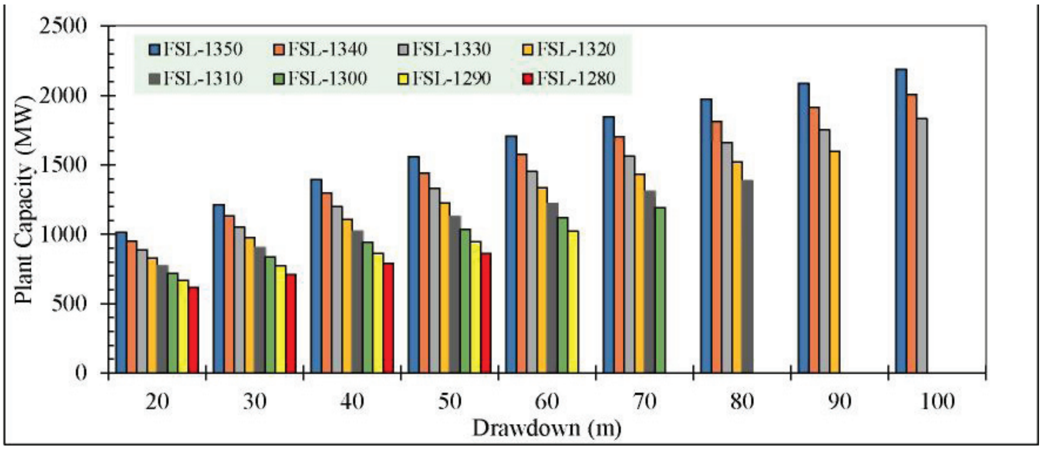


**Figure 8 :** Scenario of the plant capacity when running as a peaking plant (8 hours minimum operation)

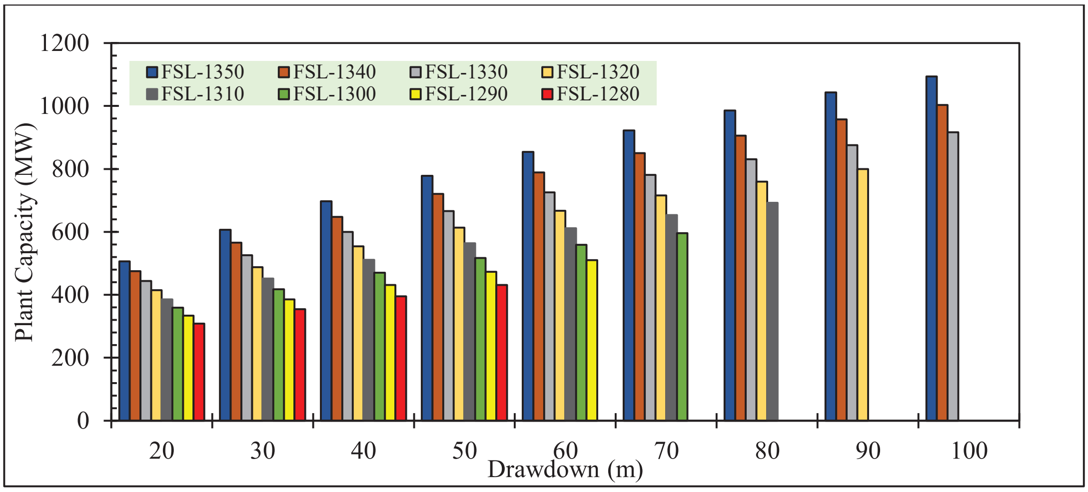


**Figure 9** : Scenario of the plant capacity when running as a base load plant (16 hours minimum operation)

The Total annual energy generation increases with the increase in FSL. However, for a given FSL, the annual energy first increases with increase in drawdown and decreases after achieving a maximum annual energy. For a given drawdown the increases in FSL increases the plant capacity and consequently the annual energy . For a given FSL, increasing the drawdown or lowering the MDDL increases the design discharge but decrease the available head as the water level approaches to MDDL. While lowering MDDL, the combination of design discharge and head (i.e. Q x H) increases up to certain MDDL and decreases thereafter, which illustrates the concave downward nature of the curves presented in Figure 10 and Figure 11. The optimum MDDL for given FSL is that which corresponds to maximum annual energy and it changes with respect to the minimum operation hours required. Higher operation hour corresponds to the lower optimum MDDL. As shown in Figure 10 and Figure 11 the optimum drawdown is in the range of 30m-40m when plant is operated as peak load plant while it ranges from 70m-80m if plant is run as base load plant.

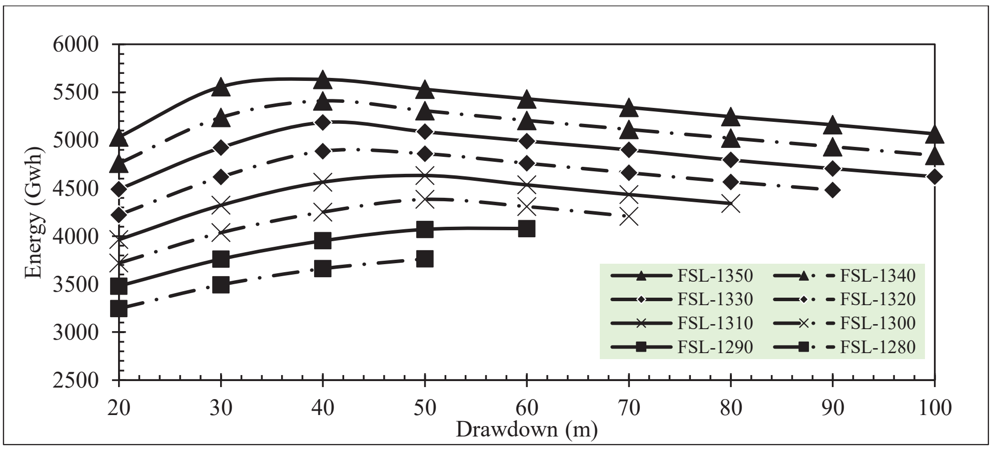


**Figure 10** : Scenario of annual energy when running as a peaking plant (8 hours minimum operation)

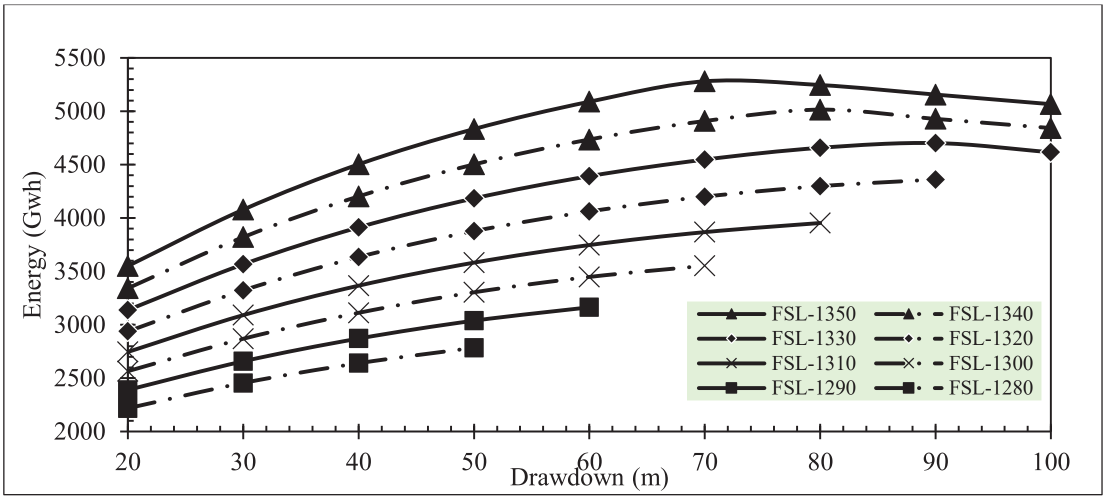


**Figure 11** : Scenario of annual energy when running as a base load plant (16 hours minimum operation)

For a defined FSL, the annual energy decreases with drawdown if the plant is operated as the peak load plant [Figure 12]. The decrease in annual energy with the increase in operating hours for small drawdown is due to the smaller design discharge and larger spill energy. The spill energy decreases with the increase in drawdown as the higher drawdown allows to draw higher design discharge and consequently the high annual energy will be achieved. However, the decrease in head due to higher drawdown plays the main role in the case the plant runs for higher operating hours.

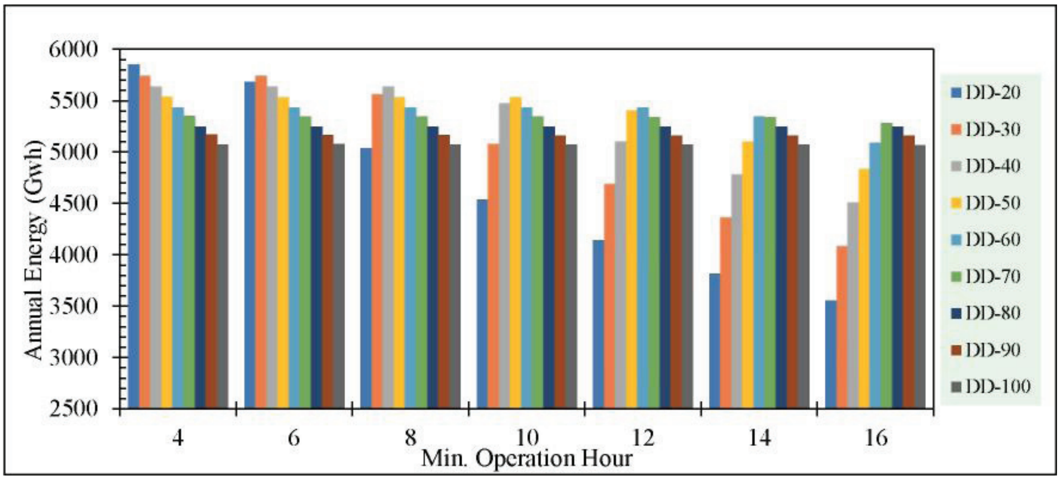


**Figure 12** : Scenario of annual energy for an FSL (1350 masl)

Scenario analysis for a particular drawdown is presented in Figure 13. The result shows that the annual energy generation remains constant for smaller operating hours and decreases thereafter. The decrease in energy for higher operating hour is due to the increase in the spill energy as the design discharge is small when during the time of maximum flow.

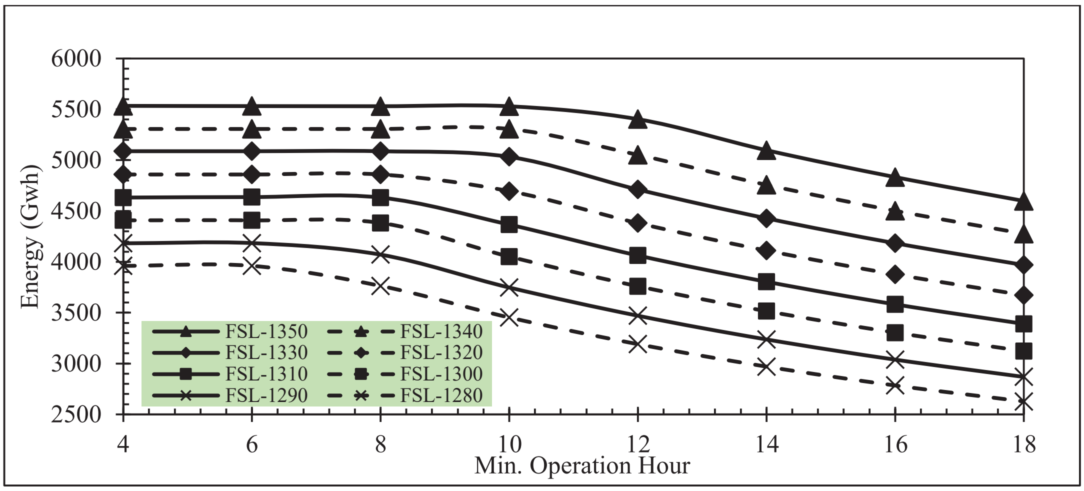


**Figure 13** : Scenario of annual energy generation for equal drawdown of 50m

## 7. CONCLUSION

A simple program is built for the analysis of multiple scenario of power and energy generation from a reservoir of MKHEP in the western Nepal. The FSL, MDDL, and minimum operating hours required in the dry season are found to be the main factors which governs the variation of the power and energy generation. These three have effects oriented in the multiple direction. The program built is found capable to handle these several hundred scenarios and the reservoir operation can be optimized accordingly. The main use of this program will be to optimize the project development concept during the feasibility study of reservoir project. This scenario analysis can be quickly performed for all the possible project development options including dam and reservoir. Combining this scenario analysis with benefit cost analysis for each layout, selection of the best project development alternative can be carried out .

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