MODELING AND SIMULATION OF HYDROELECTRIC POWER PROJECTS: A CASE STUDY ON MULLAPERIYAR RESERVOIR

Paul Pynadath
Department of Civil Engineering, Manipal Institute of Technology Manipal, Karnataka, India

K.V. Ramesh
CSIR - Fourth Paradigm Institute, NAL Belur, Bangalore, Karnataka, India

Mohandas Chadaga
Department of Civil Engineering, Manipal Institute of Technology Manipal, Karnataka, India

ABSTRACT

Water is one of the most precious resources available on Earth and it can be stored and used effectively. Large reservoirs are formed by building dams across flowing water, for storing water and allocating water for different purposes. Modeling of water storage in reservoirs will help us to plan effective usage of water allocation for different purposes like downstream irrigation, power production and domestic water requirement. Here we develop a mathematical model to estimate water storage. Digital Elevation Model (DEM) data from Bhuvan is processed in ArcMAP for delineation of watershed and reservoir region. Inflow to the reservoir is rainfall and outflow is for irrigation, power generation is included in the model. The study takes account of the reservoir capacity, flow rate of water and computation of water level at the reservoir. The simulations show that it successfully simulated the daily volume of water for the period 2005-2015. Predicting the available water in the reservoir is critical for planning and efficient use of water for different purposes.

Key words: Digital Elevation Model, Modelling, Reservoir, Watershed.


http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=4
1. INTRODUCTION

Hydroelectricity uses the energy stored in impounded water for the production of electricity. Dams are built across flowing water bodies which helps accumulate water forming a reservoir. This stored water can be diverted for different purposes such as irrigation, power production and domestic purposes.

The storage of water in the reservoir is dependent on the rainfall over the watershed region of the reservoir. The discharge of the water is related to the water demand on the benefited irrigation areas downstream of the reservoir. If the water requirement of the irrigation areas is less than the rainfall available on that day, the water supply to the irrigation land can be reduced and excess water can be stored in the reservoir. The stored water can be utilized when there is a higher water demand than the water available in the irrigation area. Evaporation from the reservoir area will also affect the water level by a small amount.

Catchment area is the area which is drained by the reservoir and the whole water which originates or precipitates in the catchment area flows into the reservoir.

The runoff from the reservoir is the source of supply of water to the reservoir.

ArcMAP software is utilized for the watershed and reservoir delineation. DEM (Digital Elevation Model) from Cartosat version 3 satellite is downloaded through Bhuvan having a resolution of 30m. The DEM is processed using hydrology tools in ArcMAP and watershed and reservoir region are identified. The rainfall and evaporation data is used from high resolution (4x4 km) downscaled weather data.

Another important factor which necessitates the modelling of the reservoir is the uneven topography of the reservoir area. At each point the depth of the reservoir will be uneven. Hence finding the capacity of the reservoir is not easy as can be done for conventional tanks. Capacity of reservoir is determined by integrating the volume which each pixel of the elevation raster of the reservoir area can hold.

2. LITERATURE REVIEW

Hydropower is the largest renewable energy source based on the stages of water cycle, which produces around 16% of the world’s electricity and over four-fifths of the world’s renewable electricity (IPCC, 2011; REN, 2011; and IHA, 2011). Hydropower is the most developed, reliable and cost-effective renewable power generation technology. [1]

In many countries, water for crop irrigation is often considered as a static asset. In these cases irrigation water is usually allocated as a prescribed volume of water, which remains to a large extent independent to the availability of water in the reservoir. This system where static volume of water is given for irrigation, the water provided maybe typically less than what farmers would expect. [2]

With the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using automated procedures. The processing of DEM to delineate watersheds is referred to as terrain pre-processing. There are several tools available online for terrain pre-processing. [3]

Geographic Information Systems (GIS) are widely used in hydrological studies. Digital Elevation Model (DEM) generated can be used to determine basin characteristics, stream network, and storage volume of reservoirs and surface area of the storage volume. [4]

A wide range of studies have found that river flows and consequently hydropower production are sensitive to changes in precipitation and temperature. Declining hydropower production potential will be detrimental to the economic viability of schemes, reducing
financial returns, raising unit prices and, ultimately, making investment in hydropower less likely. [5]

Evaporation of water from the reservoir also affects the loss of water from the reservoir. The relative humidity (RH) and the dew point temperature (td) are two widely used indicators of the amount of moisture in air. Rate of evaporation can be calculated from RH and td using the formula

\[ E_0 = \frac{700 \text{ Tm}/(100-A)+15(T-td)}{(80-T)} \text{(mm/day)} \]

Where, Tm = T + 0.006h

Mean dew point temperature 'Td' is given by

\[ Td = T * \left[ 1 - \frac{1}{L/Rw} \frac{T - \ln(RH/100)}{(L/Rw)} \right] \]

The exact conversion from Relative Humidity to dew point temperature, as well as highly accurate approximations, is too complex to be done. Dew point temperature decreases by about 1°C for every 5% decrease in Relative Humidity. [6]

3. WATERSHED DELINEATION AND RESERVOIR IDENTIFICATION

Hydrology tool in ArcMAP is utilized for watershed delineation.

Figure 1 Delineated (a) watershed and (b) reservoir region of Mullaperiyar basin
4. MODEL DEVELOPMENT

The different data required for the development of the model are:

- Full reservoir level (FRL).
- Minimum draw down level.
- Diameter of the tunnel outlet.
- Daily rainfall over the watershed area and the benefited irrigation area.
- Temperature and relative humidity data over the reservoir region.
- Area of watershed.
- Area of reservoir.
4.1. Finding the Water Level in the Reservoir
Let \( L(t) \) be the water level at any time \( t \) then,
\[
L(t) = L_{t-1} + \frac{dL}{dt}
\]  \( (1) \)
Where \( L_{t-1} \) is the water level of the previous day and \( \frac{dL}{dt} \) the change in water level for the day. The water level obtained is multiplied by the area of the reservoir to get the change in volume of water.

Let the change in volume of water level \( \frac{dV}{dt} \), then
\[
\frac{dV}{dt} = R(t) - E(t) - Q(t)
\]  \( (2) \)
Where \( R(t) \) is the volume of rainfall at any time \( t \), \( E(t) \) is the volume of evaporation at any time \( t \) and \( Q(t) \) is the calculated discharge volume at any time \( t \).

In turn change in volume of water \( \frac{dV}{dt} \) is then divided by area of reservoir to get change in water level \( \frac{dL}{dt} \).

4.2. Finding Volume of Water discharge from the Reservoir [7]
The discharge is calculated using Bernoulli’s equation
\[
Q(t) = \frac{d^2}{4} \sqrt{2g(L(t) - h)}
\]  \( (3) \)
Here, ‘\( v(t) \)’ is the velocity of flow of water through the tunnel in m/sec, ‘\( d \)’ is the diameter of the tunnel in m and ‘\( Q(t) \)’ is the rate of flow in m\(^3\)/sec.

Velocity of flow of water at any time ‘\( t \)’, ‘\( v(t) \)’ can be calculated using the equation
\[
v(t) = \sqrt{2g(L(t) - h)}
\]  \( (4) \)
Here, ‘\( g \)’ is the acceleration due to gravity in m/s\(^2\), ‘\( h \)’ is the height of sill level of tunnel outlet.

4.3. Finding Volume of Evaporation Water from the Reservoir [6]
\[
E_0 = \frac{700Tm/(100-A)+15(T-Td)}{(80-T)} (mm/day)
\]  \( (5) \)
Where, \( Tm = T + 0.006h \)
Here, ‘\( E_0 \)’ is the rate of evaporation in mm/day, ‘\( h \)’ is reservoir elevation in m, ‘\( T \)’ is mean temperature in Degree Celsius, ‘\( A \)’ is the latitude of reservoir in degrees, and ‘\( Td \)’ is the mean dew point temperature.

Mean dew point temperature ‘\( Td \)’ is given by
\[
Td = T \ast [1 - \frac{T \ast \ln(RH/100)}{(L/R_w)}]
\]  \( (6) \)
Where \( Td \) is dew point temperature in Kelvin, \( L \) is enthalpy of vaporization, RH is the relative humidity and \( L/R_w = 5423K \).

The volume of water can be found out by multiplying evaporation rate by area of the reservoir.

4.4. Calculating Capacity of the Reservoir
The elevation raster of reservoir area can be utilized for finding the capacity of the reservoir. Each pixel of the reservoir area elevation raster will be having different elevation values. The volume of water which each pixel can hold is found out separately and then is added up together to get the capacity of the reservoir.
Modeling and Simulation of Hydroelectric Power Projects: A Case Study on Mullaperiyar Reservoir

\[ C = dx \times dy \times [(FRL - a) + (FRL - b) + \ldots] \quad (7) \]

Here, 'C' is the capacity of reservoir in \( m^3 \), 'dx' and 'dy' are the resolution of elevation raster in the x and y direction, 'FRL' is the full reservoir level in m and 'a', 'b', ... are the elevation values of different pixels in the elevation raster.

5. CASE STUDY: MULLAPERIYAR RESERVOIR

Mullaperiyar Dam situated in the state of Tamil Nadu, India. It is built across river Mullaperiyar, when the river passes through a narrow gorge 11km downstream from where river Periyar and Mullayar joins to form river Mullaperiyar. The dam diverts west flowing Periyar River so that the rain shadow regions of Cumbum and Theni district get enough water for irrigation.

5.1. Dam Technical Details [8]

The Mullaperiyar dam has a catchment area of 572.29 square km and a water submergence area of 42.7788 square km. The dam has a FRL of 47.43m (elevation from MSL=873m) from the foundation and the sill level of the tunnel inlet at a height of 31.69m from the foundation. The tunnel carries water from the reservoir to the fore bay dam. The water is then diverted from the fore-bay dam through an irrigation sluice to Cumbum valley for irrigation and also 4 penstocks from fore bay dam carry water for power generation.

![Pie Chart showing the percentage area of cultivation of different crops in Cumbum and Theni district.](http://www.iaeme.com/IJCIET/index.asp)

The daily irrigation water requirement of the benefited irrigation land is simulated. If the water demand of the irrigation land is more than the rainfall received, then excess demand is balanced by the water supplied from the reservoir.

For finding the water requirement, growth season and water requirement at different stages of growth for each crop per hectare is identified. Then the total area in hectare in which each crop is grown over the benefited irrigation land is identified. The area in hectare is then multiplied by water demand per hectare per day.

5.2. Calculating Water Level of the Reservoir

The model developed is applied to Mullaperiyar reservoir. The daily water level of the reservoir from 2005 to 2015 is simulated using the model. The results obtained are validated by comparing with the daily water level recorded by Central Electricity Authority (CEA). [9]
6. RESULTS AND DISCUSSION

Figure 4 Comparison between simulated daily water level and the actual daily water level

Figure 4 shows the graph plotted between the simulated daily water level and the actual daily water level. The two data showed a correlation of 0.64. The trend of simulated water level is comparable with that of the actual water level.

Whenever there is an increase in rainfall over the reservoir region, the water level in the reservoir rises. The water demand on the benefited irrigation land also depends on the rainfall over the irrigation area. If the volume of water discharged from the reservoir to meet different purposes remains the same for every day, it can happen that, the water supplied is more than the demand or is not sufficient to meet the demand. If excess water is supplied, it can lead to wastage of stored water. The water stored when the water demand is less can be used during times of scarcity.

Modeling helps incorporate water requirement into different activities of a hydroelectric power plant and hence optimize water balance.

7. CONCLUSION

Water is one of the most precious resources on Earth. Means to store and reduce wastage of water are important for the sustenance of the resource. Modeling of hydroelectric power plants helps optimize the water usage for different purposes, which is explained through this paper. ArcMAP is used for the processing of DEM data of Cartosat from Bhuvan. ArcMAP helped in the watershed delineation and reservoir identification. The model developed can be put to use for different hydroelectric power plants for its efficient operation.

REFERENCES


[9] Central Electricity Authority(CEA)

