

RESERVOIR OPERATION SIMULATION

INTRODUCTION

Reservoir simulation deals with the mathematical simulation of river network with reservoirs. The simulation models include the mass balance of reservoir inflows, outflows and storage fluctuations. These models provide an economic evaluation of damages due to floods, benefits from irrigation, hydropower generation or other such activities. Simulation models provide a realistic and detailed representation of reservoir operations. One of the most popularly used reservoir system simulation models is the HEC-5 model developed by Hydrologic Engineering Center. HEC-ResSim is the Next Generation (NexGen) model which eventually replaces HEC-5. In this lecture we will discuss the simulation of reservoir operation and the simulation models.

Components of a Reservoir simulation model

The main components of a reservoir simulation model are: Inputs, physical relationships and constraints, operating rules and outputs. In reservoir simulation, the inputs required are reservoir inflow, evaporation rate and irrigation water demand etc. Physical relationships and constraints defining the relationships among the physical variables of the system involve reservoir storage-elevation-area relationships, storage continuity relationships, and soil moisture balance etc. Operating rules such as release policies and rule curves define the operation of the system. The outputs are a measure of system response resulting from operating the system following known or specified rules and constraints (e.g. Quantum of reservoir release for irrigation, hydropower etc).

STEPS FOR SIMULATION OF RESERVOIR SYSTEM

The steps to perform a simulation study are:

- (i) Prepare the diagram of the reservoir system indicating their names, locations, diversions, length and directions of rivers and various tributaries
- (ii) Collect operational details such as control locations (reservoir, diversion weir, barrage etc) and time details.
- (iii) Assign numbers to all control points starting from upstream node.
- (iv) Collect details about each location such as maximum reservoir level, initial storage, elevation – area relationship, demands, evaporation rates etc for all the periods.

- (v) Calculate the flows from the catchment (local flow) to each control location for all periods. Identify the parameters of routing, if required.
- (vi) Simulate the operation of the system. Examine the performance statistics (like time and volume reliabilities, frequency of spill, largest spill, maximum storage, continuous periods of shortage etc) and plots of different variables such as release, storage and demand for various reservoirs and analyze the possible scope of improvement that can be made on the operation policy.
- (vii) Modify the input operation policy and simulate the model again. Repeat the model to get desired results.

RESERVOIR OPERATION FOR CONSERVATION PURPOSES

The general procedure for simulation of a reservoir for conservation purposes (such as hydropower, irrigation etc) involves:

- (i) Identifying the system
- (ii) Determining the objectives and the criteria for measuring the objectives
- (iii) The availability of data
- (iv) Formulation of model by mathematically and quantitatively representing the system's components, hydrology and operating criteria
- (v) Validation of model
- (vi) Organizing and solving the model
- (vii) Analyze and evaluate the results to check how much the objectives are achieved

Simulation of Reservoir Operation for Hydropower Generation

Preliminary Concepts

An average flow of q_t m^3/s , falling through a height of H_t meters continuously in a period t (e.g. a week or a month), will yield a power of $9.81 q_t H_t$ kilowatts (kw). Power expressed in kwh will be

$$P = 9.81 \times 10^6 R_t H_t / 3600 = 2725 R_t H_t \text{ Kwh}$$

where R_t is the total volume of flow in Mm^3 in period t .

Considering a overall efficiency, η , power generated

$$P = 2725 \eta R_t H_t \text{ Kwh}$$

Therefore, hydropower produced in MW for one month (approx. 30 days)

$$P = 2725 \eta R_t H_t / (1000 \times 30 \times 24) = 0.003785 \eta R_t H_t \text{ Mw}$$

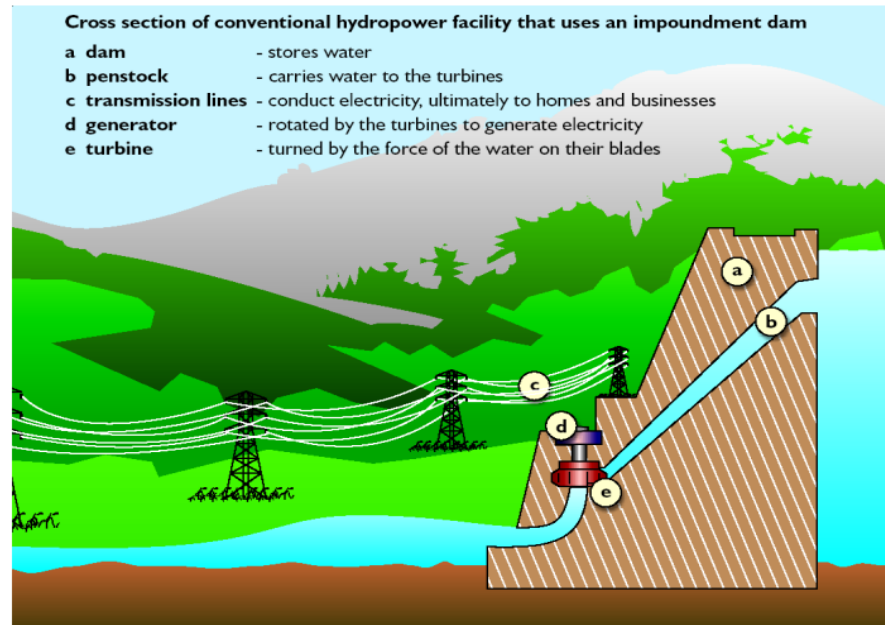


Fig. 1 Components of a hydropower system

Firm Power and Secondary Power

The amount of power that can be generated with certainty without interruption at a site, is called the firm power. i.e., at no time the power produced will be less than the firm power. The power that can be generated more than 50% of time is called the secondary power.

Example:

Consider a river with a minimum monthly flow of 40 Mm^3 . If a drop of 50 m is available at a site on the river, the firm power that can be produced at the site in a month, with an efficiency of 0.7, is

$$2725 \eta R_t H_t = 2725 \times 0.7 \times 40 \times 50 = 3815000 \text{ Kwh} = 3.815 \text{ Gwh}$$

If the flow with 50% reliability i.e., the flow which will be equalled or exceeded 50% of the time is 70 Mm^3 , then the secondary power is

$$2725 \eta R_t H_t = 2725 \times 0.7 \times 70 \times 50 = 6676250 \text{ Kwh} = 6.676 \text{ Gwh}$$

Reservoir Operation for Hydropower Generation

The procedure involves, essentially, applying the reservoir storage continuity and simulating the power generation. The data required for simulation to decide the firm power are:

- (i) The inflow series at the reservoir
- (ii) The storage-elevation-area relationships for the reservoir, and

- (iii) The power plant efficiency
- (iv) Specified Power
- (v) Average storage
- (vi) Head causing the flow
- (vii) Evaporation loss

The storage continuity equation can be expressed as

$$S_{t+1} = S_t + I_t - R_t - E_t - O_t$$

where S_t is the storage at the beginning of a period t , I_t is the reservoir inflow during the period t , R_t is the release required for the specified power generation for the period t , E_t is the evaporation during the period t and O_t is the spill from the reservoir during the period t . The head for power generation and the evaporation depend on the average storage $(S_{t+1}+S_t)/2$ during the period t . Hence, these values are calculated through an iterative procedure starting with an assumed average storage value and adopting a iterative procedure till convergence. The procedure is given below.

- (i) Start with an average storage $S_{avt} = S_t$
- (ii) From the storage - area - elevation relationship, obtain the net head H_t and water spread area A_t .
- (iii) Then the release for the specified power P Mw is

$$R_t = P / (0.003785 \eta H_t)$$

- (iv) Total evaporation loss, $E_t = A_t e_t$ where e_t is the evaporation rate
- (v) Then, the final storage for period t is

$$S_{t+1} = S_t + I_t - R_t - E_t \quad \text{if } S_{t+1} < \text{reservoir capacity, } K$$

$$= K \quad \text{otherwise}$$

- (vi) Find the average storage $S_{avt}^* = (S_{t+1}+S_t)/2$
- (vii) Set $S_{avt} = S_{avt}^*$ and repeat steps (ii) to (vi) until S_{avt}^* and S_{avt} are nearly equal. When S_{avt}^* and S_{avt} are nearly equal, then the computed values of S_t , R_t , E_t and H_t are acceptable.

RESERVOIR SIMULATION MODELS

HEC-5 SIMULATION MODEL

HEC-5 was developed by Hydrologic Engineering Center to simulate the operation of multi-purpose multi reservoir systems. This can be used to simulate the operation of a system of

reservoirs in a river network for flood control, water supply, hydropower and water quality. HEC-5 can be used for computing both storage requirements and operation rules for flood control and conservation purposes. The major capabilities of HEC-5 are:

- Determination of firm yield of a reservoir
- Hydropower simulation
- Flood control operation
- Multi-purpose multiple reservoir operation
- Simulation of on-line and off-line pumped storage project

The operational priorities in HEC-5 are given in Table 1.

Table 1. Reservoir operation priority (U.S. Army Corps of Engineers, 1998)

Condition	Normal Priority	Optional Priority
During flooding at downstream location: If primary power releases can be made without increasing flooding downstream:	No release for power requirements Release down to top of buffered pool	Release for primary power Release down to top of inactive pool (level 1)
During flooding at downstream location: If minimum desired flows can be made without increasing flooding downstream: If minimum required flows can be made without increasing flooding downstream:	No releases for minimum flow Release minimum flow between top of conservation and top of buffered pool Release minimum flow between top of conservation and top of inactive pool	Release minimum desired flow Same as normal Same as normal
Diversions from reservoirs (except when diversion is a function of storage):	Divert down to top of buffered pool	Divert down to top of inactive pool (level 1)

HEC-RESSIM (www.hec.usace.army.mil/software/hec-ressim/)

HEC-RESSIM has been developed by the Hydrologic Engineering Center of the US Army Corps of Engineers. It helps in predicting the behavior of reservoir systems in water management studies and aids in planning releases in real time during day-to-day and emergency operations.

ResSim has three sets of functions called modules that provide access to specific types of data within a watershed as shown in figure 2. These modules are watershed setup, reservoir

network, and simulation. The **watershed setup module** provides a common framework for watershed creation and definition among different modeling applications. The **reservoir network module** allows the user to construct a river schematic, describe the physical and operational elements of the reservoir system, and develop alternatives to be analyzed. The **simulation module** is used to configure and perform a simulation and review the results.

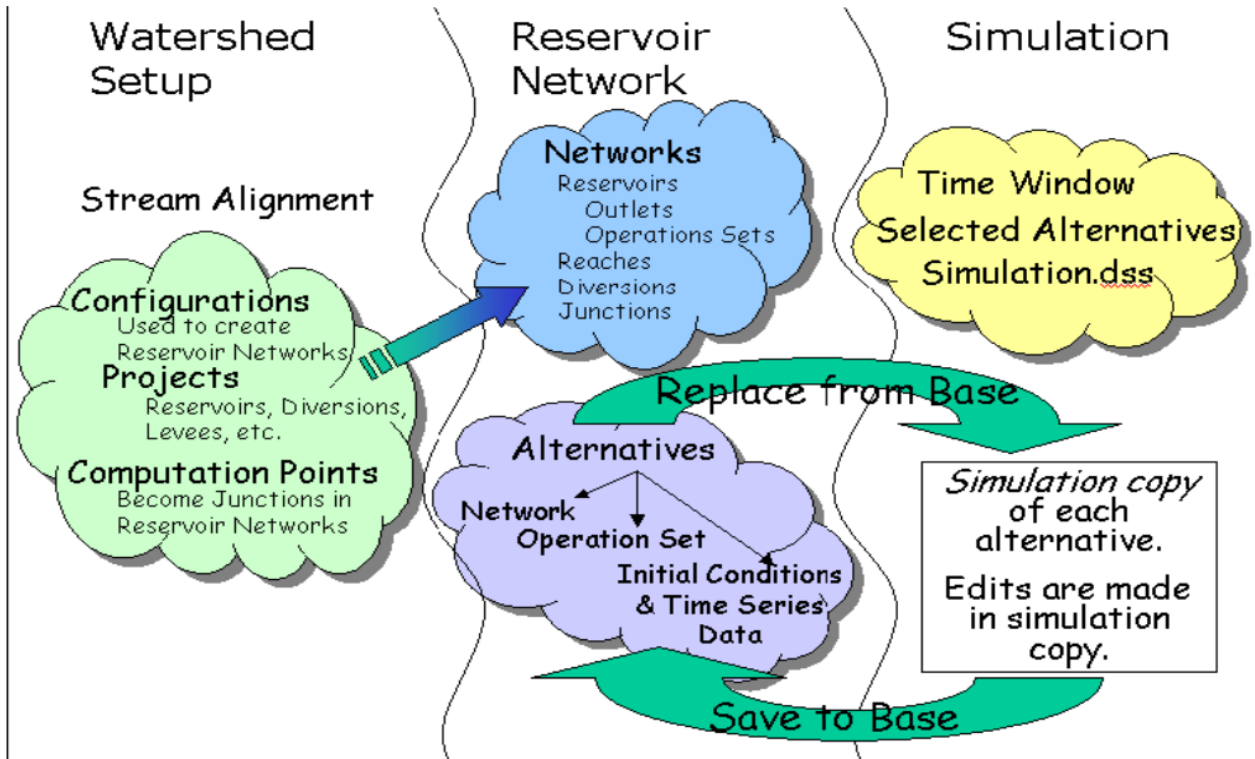


Fig. 2 Modules in HEC ResSim (Source: http://www.hec.usace.army.mil/software/hecrsim/documentation/HEC-ResSim_20_QuickStartGuide.pdf)

ResSim is comprised of a graphical user interface which allows construction of a reservoir/river system schematic by point-and-click selecting and connecting of icons. Watershed, reservoir network, and simulation data can be represented visually. ResSim is also aided with ad hoc algorithms to simulate multipurpose multiple reservoir systems. The user can select the time-step, which may vary from 15 minutes to one day. in a geo-reference context with interactions with associated data.

HEC-ResSim represents a system of reservoirs as a network composed of four types of elements: junctions, routing reaches, diversions, and reservoirs as shown in figure 3. HEC-ResSim user can build a network ranging from a single reservoir on a single stream to a highly developed and interconnected system by combining reservoirs, reaches, junctions, and diversions.

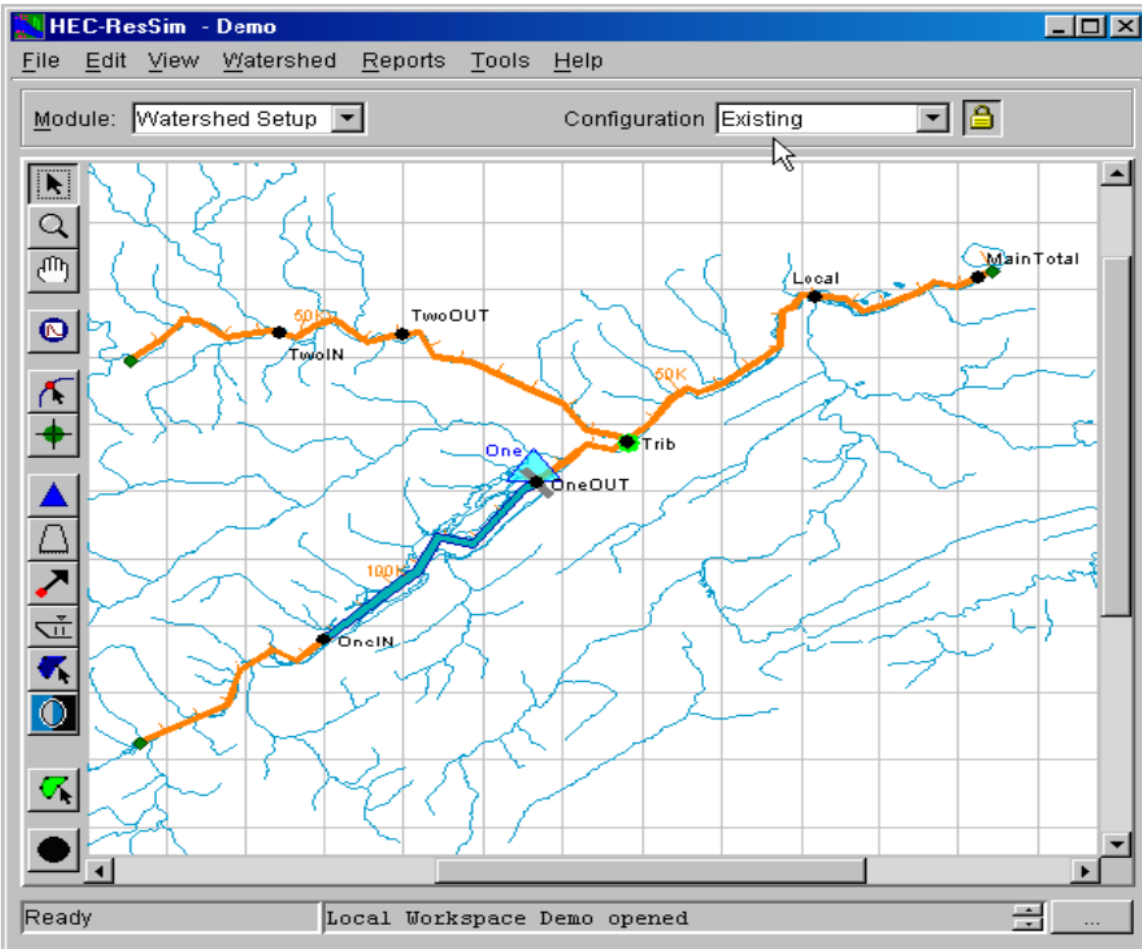


Fig. 3 Input Demo Screen (Source: http://www.hec.usace.army.mil/software/hecressim/documentation/HEC-ResSim_20_QuickStartGuide.pdf)

The features of ResSim 3.0 include: (<http://www.waterengr.com/HecResSim/hecressim.html>)

- A map based schematic development environment.
- A complex reservoir element that can include multiple dams and outlets.
- An operations scheme that can define the reservoir's operating goals and constraints in terms of pool zones and zone dependent rules.
- A set of operation rule types that include:
 - Release Requirements and Constraints
 - Downstream Control Requirements and Constraints
 - Pool Elevation or Inflow Rate-of-Change Limits
 - Hydropower Requirements
 - Induced Surcharge (Emergency Gate Operation)

- Operation of multiple reservoirs for a common downstream control, including storage balancing.
- Powerful alternative builder to allow for a wide range of “what if” analysis.
- Computation timesteps from 15min to 1day.
- Release Overrides of the reservoir’s release decisions timestep by timestep.
- Configurable plots.
- Summary Reports and a Release Decision Report.
- HEC-DSS for storage of input and output data.
- HEC-DSSVue for access to all computed results.
- Familiar Windows look and feel.