INTRODUCTION AND RIVER BASIN SIMULATION

INTRODUCTION

As explained in Module 1, simulation is the process of duplicating a system's behavior. It essentially represents a what-if condition i.e., how the system will respond to any conditions it may face in the future. Simulation is preferred to model complex systems, in which instead of the entire system, only those factors relevant to the objective of the study are modeled. This reduces the complexity of the system. The main advantage of simulation models is their ability to reproduce the reality.

Simulation models can be deterministic or stochastic depending on the way the stochasticity of the variables involved is addressed. A deterministic model may be adequate if the measured value of the variable is available for a long period. On the other hand, if the process is stationary, then it may be reasonable to model a stochastic process. However, since the hydrological variables involved will not repeat exactly, the outputs from the model will not exactly represent the system values. Stochasticity is usually incorporated in the models either by inputting the synthetically generated flows or combining the simulation model with other models that account for the stochastic nature (eg. Chance constrained models as described in Module 6).

In this lecture, we will introduce the concept of Monte Carlo simulation and the basics of river basin simulation.

Simulation model

The main components of a simulation model are:

(i) Inputs which "drive" the model
(ii) Physical relationships and constraints
(iii) Operating rules and
(iv) Outputs

The first step in a simulation study is to decompose the system into subsystems, which are linked by physical relationships and constraints. Each subsystem and its linkages are formulated using computer programs taking care of the operating rules. The model is then verified with known inputs and outputs for each subsystem. The model is then run for different sets of inputs, which results in different outputs. The results from each of these simulation runs define a response surface. If the response surface is steep, then the system is highly sensitive to the variations of input.

MONTE CARLO SIMULATION

Most of the real world systems are designed based on the historical observations. These historical data may not be long enough to represent the entire range of values taken by the system variables. The performance of the system modeled critically depends on these rare, yet possible extreme values.

The randomness in the system can be from the input values or from any parameters or even from the initial conditions or may be from the boundary conditions. However, the probability distributions of these random conditions are known. In such cases, the simulations are done with a set of possible synthetically generated inputs. The statistical properties of the random variables are preserved during this artificial generation. These experiments with different inputs will result in a set of outputs, which are statistically analysed to understand or forecast the behavior of the system. This approach helps in determining the risk of possible failures by giving a better insight of the system's performance and is known as Monte Carlo simulation.

An important part of Monte Carlo simulation is random number generation. A number of techniques such as congruence method, midsquare method etc are available for generating uniformly distributed random numbers. Most simulation models have provision to generate uniformly distributed random numbers ranging between zero and one. Uniformly distributed random numbers can be defined by their CDF and PDF as:

PDF of random number u is

$$\begin{aligned} f_U(u) &= 1 \text{ if } 0 \leq u \leq 1 \text{ and} \\ &= 0 \text{ otherwise} \end{aligned}$$

Its CDF can be defined as

$$\begin{aligned} F_U(u) &= 0 \text{ for } u = 0, \\ &= u \text{ for } 0 \leq u \leq 1 \\ &= 1 \text{ for } u \geq 1 \end{aligned}$$

The input variables to the system may have a different probability distribution. Therefore, these uniformly distributed random numbers, u_t are to be converted. If $F_Q(q)$ is the desired distribution, then Q can be generated by taking the inverse, $Q = F_Q^{-1}(u)$. Figure 1 shows the CDF of Q.

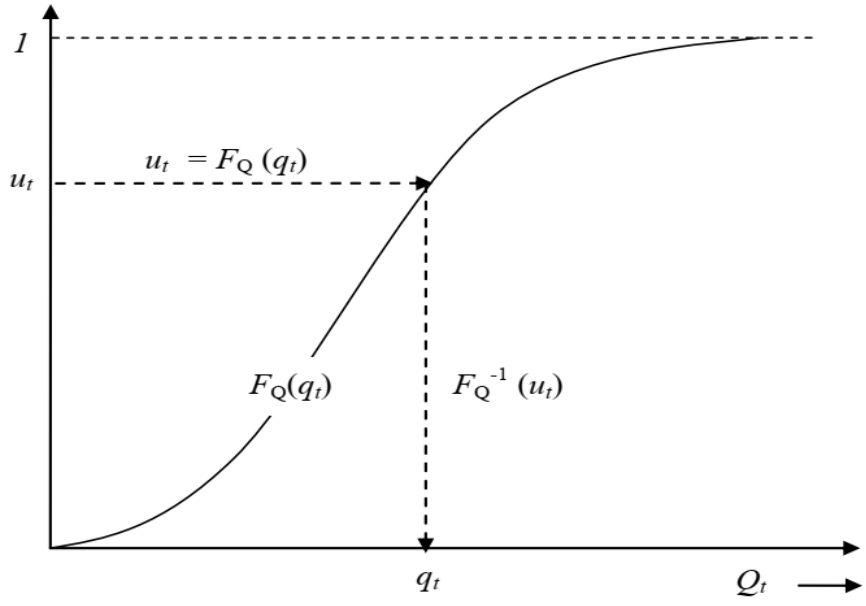

Fig. 1

Example:

The inflow, Q follows an exponential distribution with parameter, $\lambda = 0.6$. Let the first uniformly distributed random number be 0.46. Determine the corresponding inflow.

Solution:

The CDF of exponential distribution is

$$F_Q(q) = 1 - e^{-\lambda q}$$

The inverse is

$$q = F_Q^{-1}(u) = ln\ (1-u) / \lambda$$

This is equivalent to $q = ln\ (-u) / \lambda$, since $(1-u)$ will also be uniformly distributed.

Now,

$$q = -\ ln\ (u) / \lambda$$

$$= -\ ln\ (0.46) / 0.6 = 1.2942.$$

RIVER BASIN SIMULATION

According to Central Water Commission (CWC), river basins of India can be divided into three groups. (i) Major river basins with catchment area greater than 20,000 sq. km (ii) Medium river basins with catchment area between 20,000 sq. km and 2000 sq. km and (iii) Minor river basins with catchment area below 2000 sq. km. River basin simulation mainly deals with the simulation of all reservoirs in the basin together to meet the individual and combined demands. An example is given by illustrating the simulation of Narmada basin shown in figure 2. The major and medium reservoirs considered for the simulation study is shown in figure 3. The simulation should be done according to the stipulations of Narmada Waters Disputes Tribunal (NWDT). The simulation procedures are explained in flowchart in figure 4.

Narmada System Simulation Model

The simulation model is developed for the system of 8 major reservoirs. Simulation should consider the integrated operation of the eight major reservoirs (viz., Matiyari, Bargi, Barna, Tawa, Indira Sagar, Omkareshwar, Maheshwar and Sardar Sarvovar), along with the operation of the medium projects in the Narmada basin. Narmada Waters Disputes Tribunal (NWDT) Stipulations are considered. The simulation model developed is used to specify operating policies (Rule Curves) for the reservoirs. A number of operating scenarios were thus simulated. The following points are considered while simulation.

1. Possible flooding at specified locations
2. Meeting irrigation, drinking water and industrial demands from the reservoirs
3. Hydro-power production, and
4. Limitations on the utilisations within the year

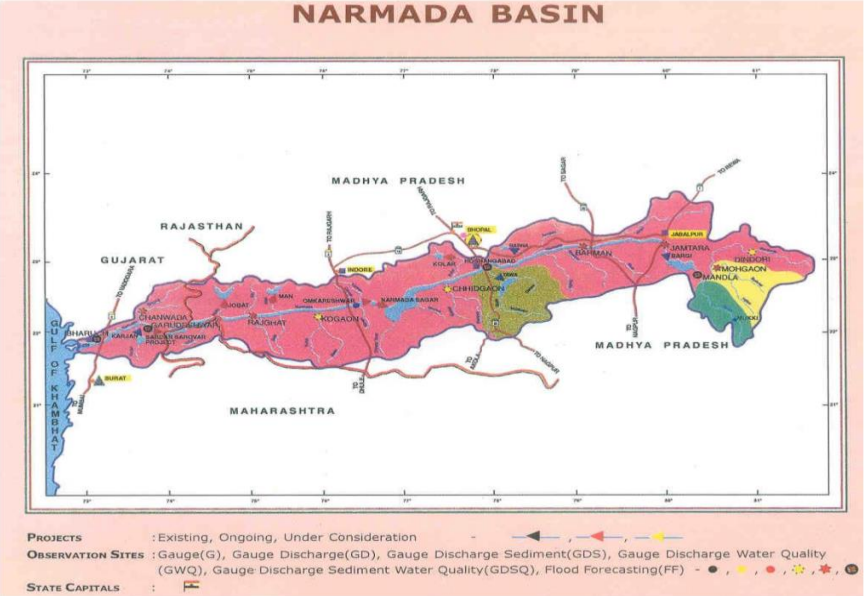

Fig. 2

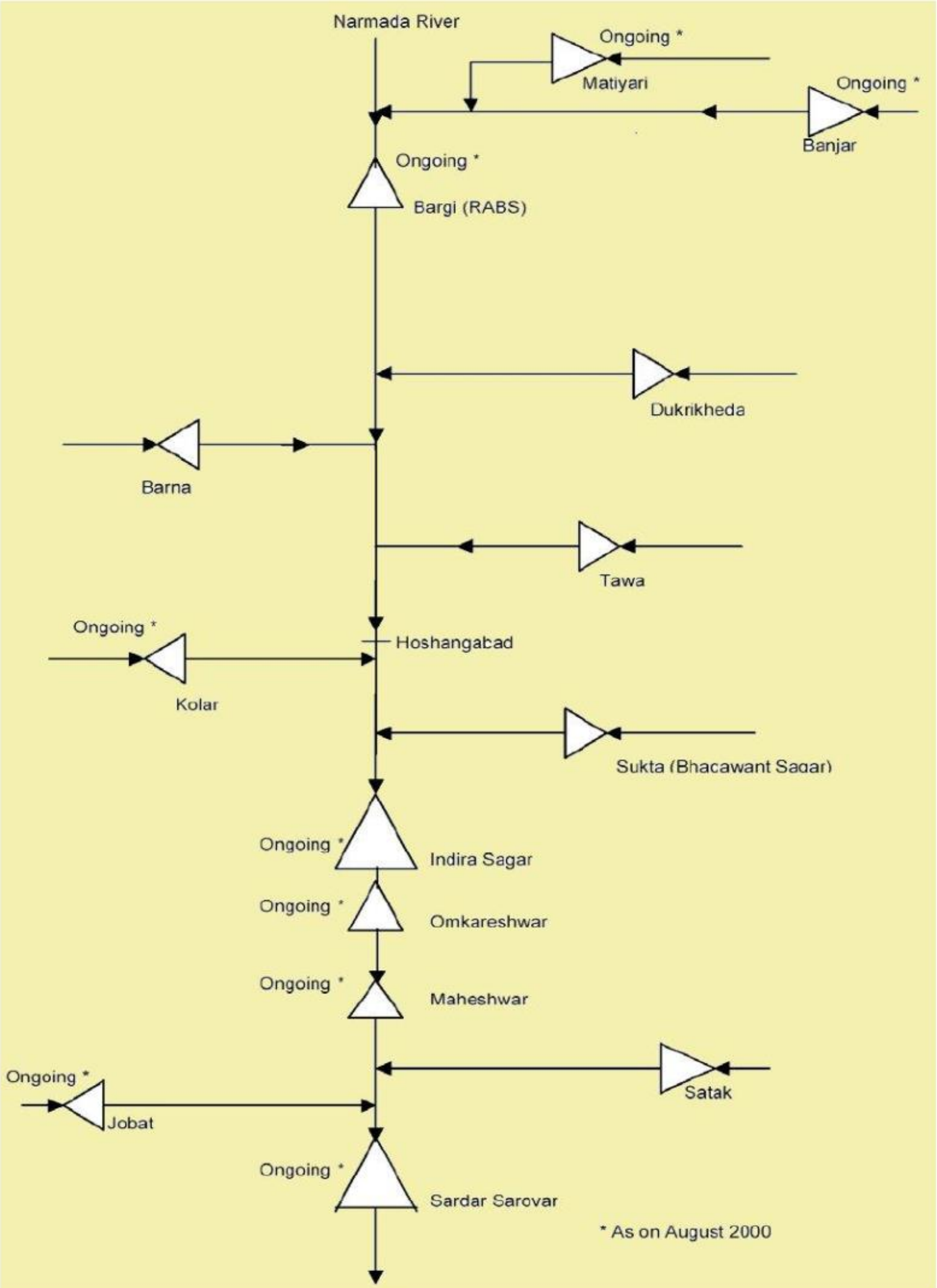

Fig. 3 System of Major and Medium Reservoir Projects Considered in the Simulation Study

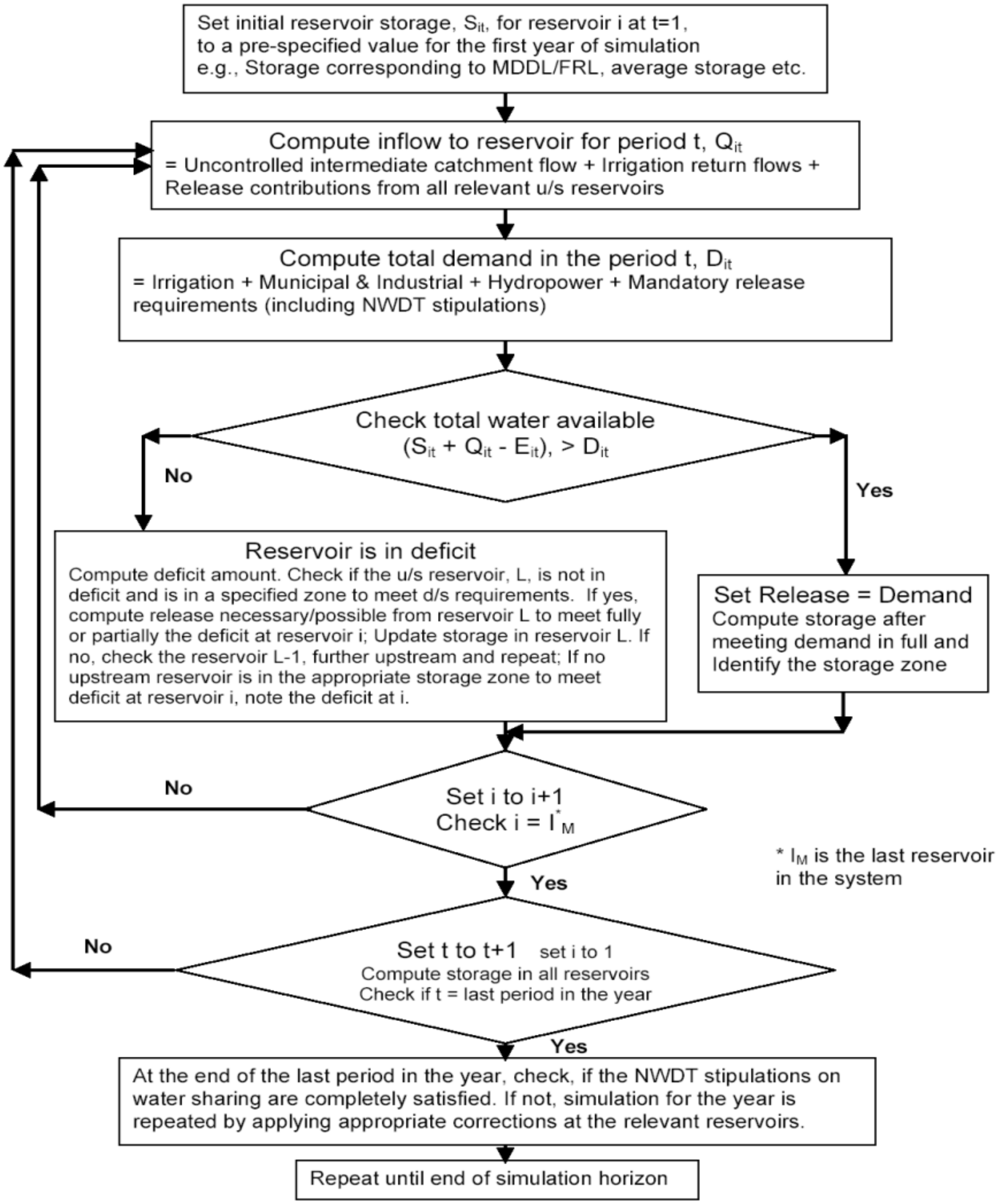

Fig. 4 Flow chart for Simulation

The system is simulated for a normal operation as well as for operation during flood season, with appropriate time intervals. The technical and hydrologic details considered in the Simulation model include

1. Storage zones to provide operation guidelines
2. Flood routing through reservoirs

3. Intermediate catchment flows
4. Storage dependent evaporation losses
5. Hydropower constraints
6. Reservoir inflows
7. Time of flow from one reservoir to the next
8. Physical constraints
9. NWDT stipulations

The utility of the simulation model consists of the following

1. Rule Curves for Operation – Long Term Normal Operation, with NWDT Award in Place
2. Reliability of Meeting Demands at All Nodes in the System
3. Sensitivity to Storage Changes
4. Large Number of Operating Scenarios
5. Optimal Power Generation
6. Performance Evaluation
7. System Resilience; Deficit Indices.
8. Failure Indices for Storage Levels

SIMULATION MODELS FOR RIVER BASIN

River Basin Simulation Model (RIBASIM)

http://www.wldelft.nl/soft/ribasim/int/index.html

RIBASIM (River Basin Simulation Model) by Delft Hydraulics in the Netherlands, is a generic model package for analyzing the behavior of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin. RIBASIM enables the user to evaluate a variety of measures related to infrastructure, operational and demand management and the results in terms of water quantity and water quality. RIBASIM generates water distribution patterns and provides a basis for more detailed water quality and sedimentation analyses in river reaches and reservoirs. It provides a source analysis, giving insight into the water's origin at any location of the basin.

The performance of the basin is evaluated in terms of: Water allocation, water shortages, firm and secondary hydropower production, overall river basin water balance, flow composition, crop production, flood control, water supply reliability, groundwater use etc. The representation of a basin in RIBASIM and the typical results are demonstrated below

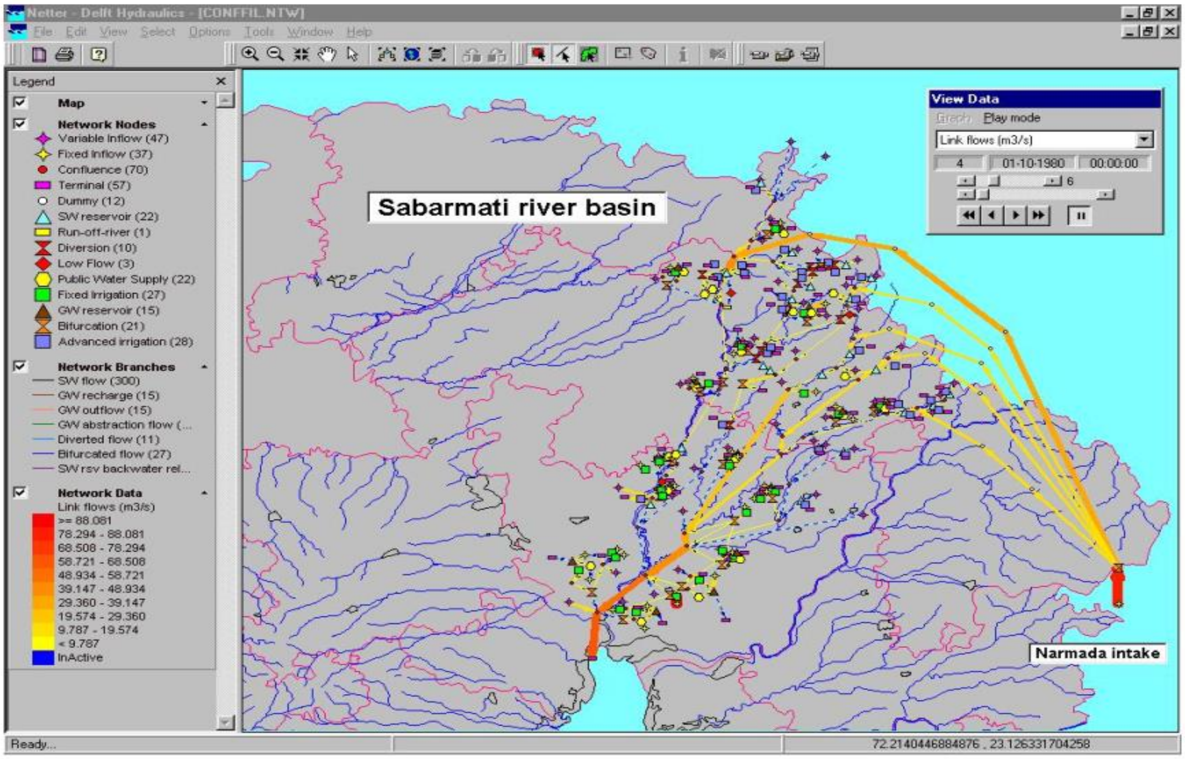

Fig. 5 Flow in Sabarmati basin indicating the diversions and reservoirs

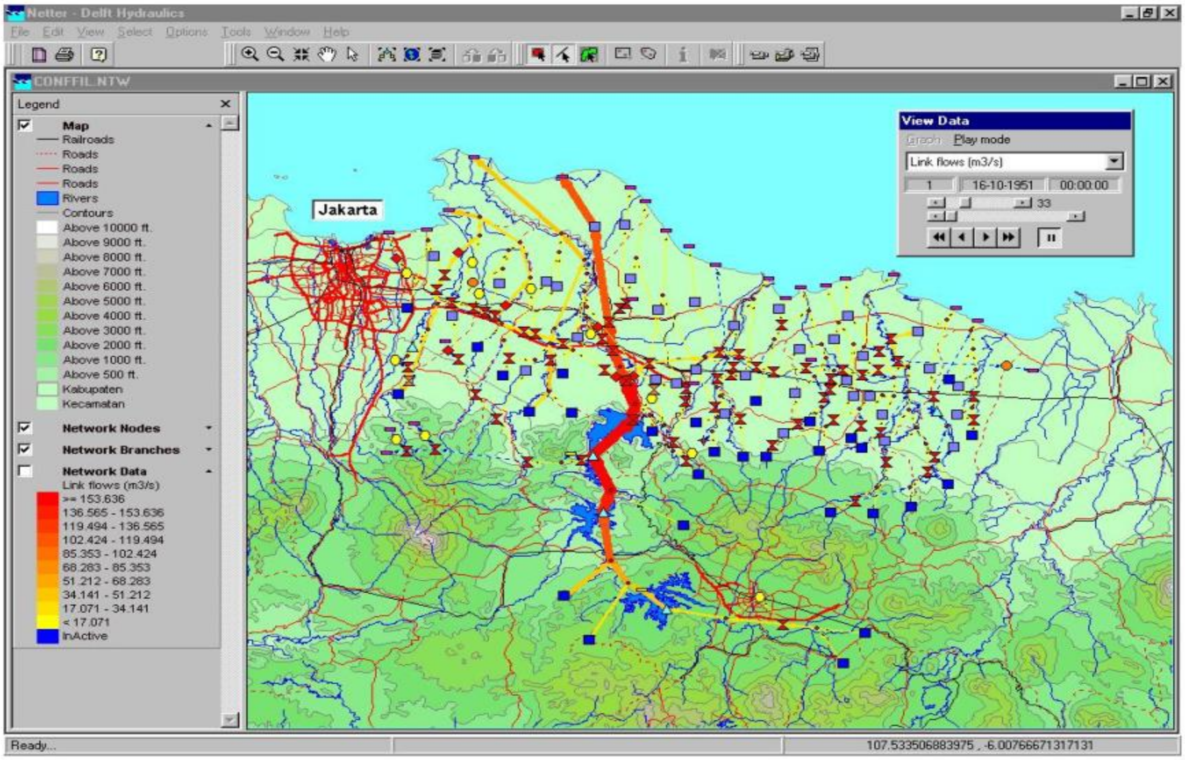

Fig. 6 Flow animation in basin

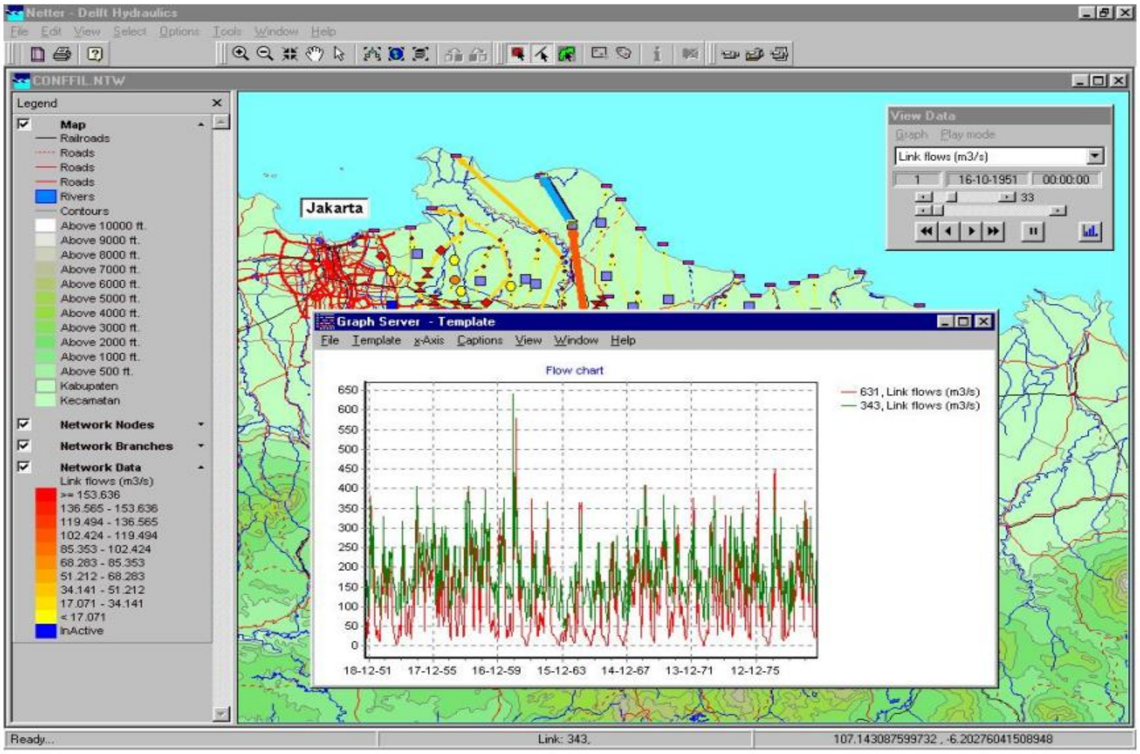

Fig. 7 Graphical display of flow variation

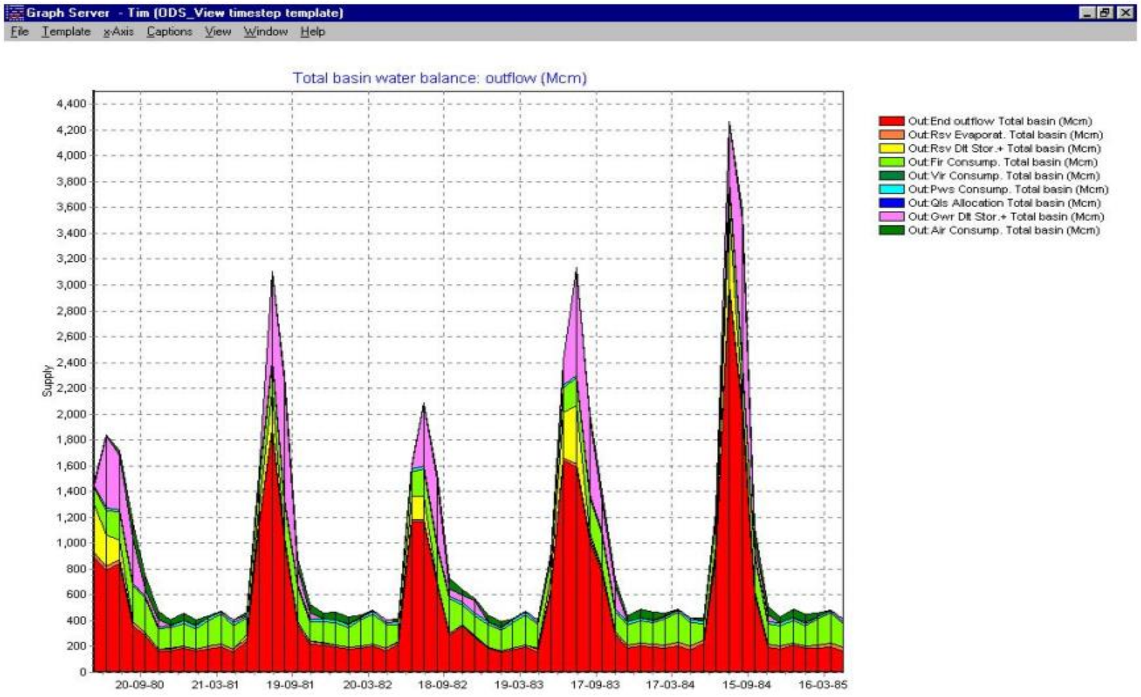

Fig. 8 Water balance plots for the basin