Simulation

Simulation of a System
Hydropower Generation
Performance Measures

Introduction

- Simulation is a modeling technique used to examine and evaluate the performance of complex water resource systems.
- 'What-If' analysis.
- In water resources modeling, knowledge of solutions around the optimum are just as useful as the optimum itself.
- Simulation is by far the most widely used method for evaluating alternate water resource systems and plans.
- Though it is not an optimization procedure, for a set of given design and policy parameters, it offers a rapid means in evaluating the expected performance of the system.
- Example 1: One can simulate the performance of a reservoir for 50 years, based on given operating rules, to determine the sequence of annual benefits from irrigation and hydropower.
- Example 2: For a given aquifer parameters, simulation can be used to determine the change in the ground water levels over a period of time for different pumping patterns.

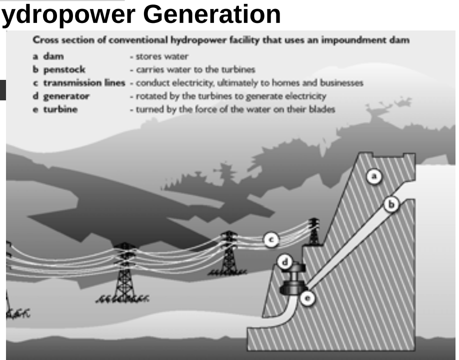
Components of a Simulation Model

- Inputs: Physical relationships, constraints, operating rules
- Outputs: Measure of system performance
- The model transforms the inputs into outputs according to a set of physical or governing relationships.
- For example, In reservoir simulation, reservoir inflow, evaporation rate and irrigation water demand are among the inputs required for simulation.
- Physical relationships and constraints define the relationships among the physical variables of the system: e.g. Reservoir storage-elevation-area relationships, storage continuity relationships, and soil moisture balance.
- Operating rules define how the system is operated: e.g. Reservoir release policies, rule curves.
- 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, low flow augmentation, etc.
- Time step in Simulation

Steps in Simulation

- First step in simulation is to decompose the system into components or subsystems, which are held together by linkages.
- Each subsystem and its linkages are tagged on with specific operating rules and constraints.
- Computer programs are formulated for each of the subsystems and for flow of information through the linkages.
- Important step is model verification. This is carried out with known inputs and outputs for each subsystem, to verify that simulation of the total system produces the known outputs from the given set of inputs.
- The model is then ready to consider additional or alternate sets of inputs and give the corresponding outputs resulting from simulation.
- Simulation runs

Simulation of Reservoir Operation for Hydropower Generation



Hydropower Generation Preliminary Concepts

- Kinetic energy produced by 1 m^3 of water falling through a height of 1 m is equal to $\rho g H$ = 1000 x 9.81 x 1 = 9810 Nm, where ρ is the density of water (1000 kg/m3), g is the acceleration due to gravity (9.81 m/s^2), and H is the height (head) in m over which the water falls.
- Power - the energy generated per second, is 9810 watts or 9.81 kw.
- 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 is expressed in kwh or Mwh.
- $Kwh_t = 9.81 \times 10^6 R_t H_t / 3600 = 2725 R_t H_t$
  where R_t is the total volume of flow in Mm^3 in period t.
- Considering a overall efficiency, η, power generated is
  $Kwh_t = 2725 \eta R_t H_t$
- Hydropower produced in MW for one month (approx. 30 days)
  Power in MW = $2725 \eta R_t H_t / (1000 \times 30 \times 24) = 0.003785 \eta R_t H_t$

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 20 Mm³. If a drop of 30 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 η R_t H_t = 2725x0.7x20x30 =1144500 Kwh = 1.1445 Gwh
- For determining the secondary power for a run-of-the-river plant, we must know the flow with 50% reliability (i.e. the flow which will be equaled or exceeded 50% of the time) and substitute it for R_t.

Reservoir Operation for Hydropower Generation

- The procedure involves, essentially, applying the reservoir storage continuity and simulating the power generation.
- Data required for simulation to decide the firm power.
  - The inflow series at the reservoir,
  - The storage-elevation-area relationships for the reservoir, and
  - The power plant efficiency
  - Specified Power
- Average storage
  - Head causing the flow
  - Evaporation loss

Reservoir Operation for Hydropower Generation

1. Assume average storage $\bar{S}_t = S_t$
2. Obtain net head, H_t, and water spread area, A_t, corresponding to $\bar{S}_t$. These are got from the storage–area–elevation relationships for the reservoir.
3. Determine the release, R_t, required for generating the specified power, P (in MW), from:

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

4. The evaporation loss is got from $E_t = A_t e_t$ where e_t is the rate of evaporation (depth) in period t, and A_t corresponds to the storage S_t.
5. Get the end of period storage,

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

6. Get the average storage, $\bar{S}_t^* = (S_t + S_{t+1})/2$
7. If $\bar{S}_t^*$ is nearly equal to $\bar{S}_t$, the computed values of H_t, R_t, E_t, and S_{t+1} are acceptable. Else, set $\bar{S}_t = \bar{S}_t^*$ and go to step 2; repeat steps 2 to 7 until the computed values of H_t, R_t, E_t, and S_{t+1} are acceptable.

This procedure converges quickly, and is very useful in simulation of reservoir operation for hydropower generation.

Example

Simulate the reservoir operation for hydropower generation with the following data

Reservoir capacity = 1226 Mm³; minimum power desired in a month = 73.5 MW. The storage-elevation data for the site is as given in Table ☐ with an allowance of 47 m (R.L) for the tail race water level. Inflows are as shown in the Table☐. Rate of evaporation for the 12 months starting June are: 11, 9, 8, 9, 8, 7, 8, 8, 10, 13, 14, and 11 cms. The plant efficiency is 81.54%. Initial storage = 824.63 Mm³. The spill produces additional power with the head equal to maximum head.

Elevation–Capacity–Area Values

Elevation (m) (R.L)	*Capacity (Mm³)*	*Area (Mm²)*
280.00	204.50	8.40
285.00	248.82	10.00
290.00	302.82	11.60
294.00	351.62	12.80
297.50	398.52	14.00
300.00	434.77	15.00
304.25	500.94	15.00
309.00	582.02	16.14
314.50	686.36	19.94
323.00	868.85	23.00
329.00	1013.03	25.06
335.75	1189.68	27.28
338.00	1226.00	28.00

Solution

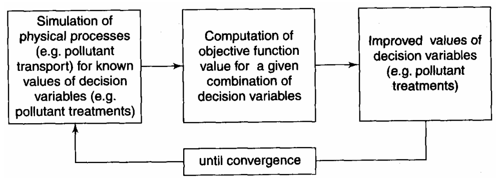
Month	*Storage M.m³*	*Inflow M.m³*	*Evap M.m³*	*Release M.m³*	*Net Head m*	*Spill M.m³*	*End-Stor. M.m³*	*Power MW*	*Additional power* MW*
JUN	824.63	190.76	2.17	86.10	276.57	0.00	927.12	73.5	0.00
JUL	927.12	433.76	2.22	82.23	289.60	50.43	1226.00	73.5	46.59
AUG	1226.00	212.97	2.74	79.57	299.30	130.67	1226.00	73.5	120.71
SEP	1226.00	146.89	2.43	79.57	299.30	64.89	1226.00	73.5	59.94
OCT	1226.00	209.72	2.13	79.57	299.30	128.03	1226.00	73.5	118.27
NOV	1226.00	42.92	2.40	79.91	298.02	0.00	1186.61	73.5	0.00
DEC	1186.61	28.02	2.34	80.74	294.95	0.00	1131.56	73.5	0.00
JAN	1131.56	11.95	2.80	81.89	290.81	0.00	1058.81	73.5	0.00
FEB	1058.81	7.07	3.47	83.31	285.86	0.00	979.11	73.5	0.00
MAR	979.11	9.25	3.54	84.84	280.71	0.00	899.99	73.5	0.00
APR	899.99	9.89	2.62	86.42	275.57	0.00	820.84	73.5	0.00
MAY	820.84	65.16	2.52	87.49	272.20	0.00	795.99	73.5	0.00

*Additional power is produced only when spill occurs.

Combination of Simulation and Optimization

- Often, use of a single algorithm may not be sufficient to model large and complex water resource systems.
- Combination of Simulation and Optimization (S-O models) is quite often used.
- A major advantage of the S-O methodology in most situations is that the physical processes such as the mass, energy, and temperature balance are accounted through simulation outside the optimization model, thus reducing the size and complexity of the optimization model itself.
- Such modeling situations arise especially in management of water quality where the transport of pollutants across a stream is modeled by a simulation model reproducing the physical processes, and the result from such a simulation model is used in the optimization model to evaluate the objective function value.

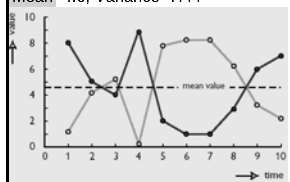
Simulation-Optimization in Water Quality Management



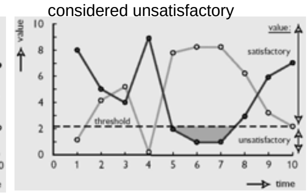
Need for Performance Criteria

Performance of two different policies having same mean and variance

Mean=4.6; Variance=7.44



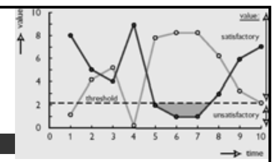
Threshold value distinguishing values considered satisfactory, and those considered unsatisfactory



Performance Criteria

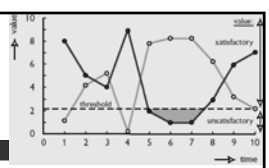
- Performance Criteria are used to evaluate the system performance in simulation.
- They will also be useful to evaluate and rank different alternative plans or policies using simulation
- Performance measures
  - Reliability
  - Resiliency
  - Vulnerability

Reliability



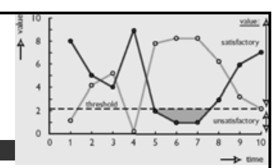
- The reliability can be defined as the number of data/periods in a satisfactory state divided by the total number of data/ periods in the Simulation (n).
  Reliability[X] = [number of time periods t such that $X_t \geq X^T$]/n
- The reliability of the original time series shown in red is 0.7. It failed three times in ten.
- The reliability of the rotated time series shown in blue is also 0.7, failing three times in ten.

Reliability



- Is a more reliable system better than a less reliable system?
- Not necessarily. Reliability measures tell nothing about how quickly a system recovers and returns to a satisfactory value, nor does it indicate how bad an unsatisfactory value might be should one occur.
- It may well be that a system that fails relatively often, but by insignificant amounts and for short durations, will be much preferable to one whose reliability is much higher but where, when a failure does occur, it is likely to be much more severe.
- Resilience and vulnerability measures can quantify these system characteristics.

Resiliency

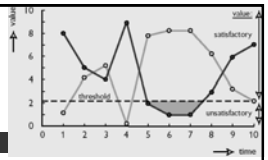


- Resiliency can be expressed as the probability that if a system is in an unsatisfactory state, the next state will be satisfactory.
- Resilience is an indicator of '**How quickly a system recovers from failure**'.
- It is the probability of having a satisfactory value in time period t+1, given an unsatisfactory value in any time period t. It can be calculated as

Resiliency [X] = [number of times a satisfactory value follows an unsatisfactory value]/ [number of times an unsatisfactory value occurred]

- Resilience is not defined if there are no unsatisfactory values.
- For the original time series shown in red, the resilience is 1/3, again assuming the value of 2 or less is considered a failure.
- For the rotated time series shown in blue, the resilience is 2/2=1.
- We cannot judge the resilience of the blue time series on the basis of the last failure in period 10 because we do not have an observation in period 11.

Vulnerability



- Vulnerability is a measure of the extent of the differences between the threshold value and the unsatisfactory time series values. Clearly, this is a probabilistic measure.
- Vulnerability is an indicator of '**How serious is the failure**'.
- Some use expected values, some use maximum observed values, and others may assign a probability of exceedance to their vulnerability measures.
- Assuming an expected value measure of vulnerability is to be used:
  Vulnerability [X] = [sum of positive values of $(X^T - X_t)$]/
  [number of times an unsatisfactory value occurred]

- The expected vulnerability of the red line is [(2-2) + (2-1) + (2-1)]/3 = 0.67.
- The expected vulnerability of the blue line is [(2-1.2) + (2-0.2)]/2 = 1.3.
- So, depending on whether a threshold value is considered a failure or not in this example, the reliability and resilience of original (red) time series is equal or less than the rotated (blue) time series.
- However, the expected vulnerability of the original red time series is less than that of the rotated blue line.
- This shows the typical tradeoffs one can define using these three measures of system performance

Exercise Problem

- For the reservoir simulation problem solved in this PPT file, estimate the performance measure of Reliability, Resiliency and Vulnerability if the firm power committed is (i) 80 MW, (ii) 90 MW and (iii)100 MW. Compare and comment on the system performance measures for the three firm power commitments.

Thank You