Module 7:

1. In a river basin there are four reservoirs. Reservoirs 1, 2 and 4 are in series. Reservoirs 3 and 4 are also in series with reservoir 3 in upstream. Reservoirs 1, 2 and 3 have power houses. Release made into the power houses subsequently reaches the immediate downstream reservoir. Each unit of power generated brings benefit of B_t in period t. The power generated at reservoir i is restricted by the plant capacity p_i. The storage elevation relationship for the reservoir i (i=1,2,3) may be assumed to be linear (known). Each unit of release made from reservoir 4 serves an irrigation area and fetches a benefit of W_t in period t. Assuming the inflows and capacities of reservoirs to be known, formulate an optimization model to maximize the benefits from the system. Identify the decision variables in the problem.

   For a 12 period problem, how many constraints and how many decision variables will result from the optimization model.

2. Average monthly inflows into a reservoir (Q_t), demands (D_t) and evaporation losses (E_t) are given in million cubic meters (MCM) in the Table below. Reservoir Capacity is K=350 MCM. To accommodate incoming floods, a storage (KF_t) of 60, 80, 70 and 50 MCM are to be kept empty in the reservoir during the months t=2, 3, 4 and 5 respectively. Perform the following tasks in Excel.
   a. Assuming the initial storage, S_1=20 MCM, using standard operating policy, compute the reservoir release and overflow (if any) for each month. Identify the months in which demands could not be met. Estimate the total amount of deficit in releases for the year.
   b. Perform task 1, if the flood storage is not required in months t=2 and 5 i.e., KF_2=0 & KF_5=0
   c. Perform task 1, if the flood storage is not required in any month i.e., KF_t=0 for all months.
   d. Perform tasks 1, 2, and 3 if S_1=200 MCM.
   e. Compare and comment on the total amount of annual deficit obtained for each task.

t	Q_t	D_t	E_t
1	86.52	55.69	10
2	425.75	139.68	8
3	360.6	138.76	8
4	159.39	71.26	8
5	122.85	39.59	6
6	56.08	220.15	6
7	22.65	220.15	5
8	17.38	191.3	5
9	12.99	90.19	6
10	9.58	0	8
11	10.81	0	10
12	21.22	0	10

Hint for Standard Operating Policy:

$$R_t = D_t \quad if \quad S_t + Q_t - E_t \geq D_t$$
$$= S_t + Q_t - E_t, \quad \text{otherwise}$$
$$O_t = (S_t + Q_t - E_t - D_t) - (K - cF_t) \quad \text{if positive}$$
$$= 0 \quad \text{otherwise}$$
$$S_t = (S_t + Q_t - E_t - R_t - O_t) \quad \text{with } R_t \text{ and } O_t \text{ determined as above}$$

3. Monthly reservoir inflow data for 5 years are given below. Demands and evaporation losses are same as those given for Question 1. Reservoir capacity is 350 MCM. Initial storage in the reservoir is S_1=10 MCM. Optimal storage targets at the end of each month (S_{t+1}) identified from reservoir operation rule curve (derived using Linear Programming) are also given in the Table below. This rule curve considers allowance for anticipated floods in 3rd and 4th months. Simulate the reservoir operation in Excel for the 60 months (5 years). Optimal storage targets should be adhered to the extent possible. Identify the number of months during which demand could not be met.

(i) Estimate Reliability of the rule curve which is given by the ratio of number of months in which demands are met and the total number of months (60 in this case).

(ii) Estimate the total amount of deficit in releases for each year.

(iii) Estimate the reliability of the operation policy assuming the reservoir capacity to be 200, 250, 300, 400 and 500 MCM (restrict the optimal storage to the reservoir capacity). Also estimate the annual deficits for each case and comment on the results.

(iv) Estimate the reliability of the operation policy assuming the monthly demands from the reservoir to 60%, 80%. 120%, 150% and 200% of the monthly demands given in Q1 with a reservoir capacity of 350 MCM. Also estimate the annual deficits for each case and comment on the results.

Monthly Reservoir Inflows (Million Cubic Meters)

Month	Year 1	Year 2	Year 3	Year 4	Year 5
1	70.61	63.55	76.26	53.38	48.04
2	412.75	371.48	445.77	312.04	280.84
3	348.40	313.56	376.27	263.39	237.05
4	142.29	128.06	153.67	107.57	96.81
5	103.78	93.40	112.08	78.46	70.61
6	45.00	40.50	48.60	34.02	30.62
7	19.06	17.15	20.58	14.41	12.97
8	14.27	12.84	15.41	10.79	9.71
9	10.77	9.69	11.63	8.14	7.33
10	8.69	7.82	9.39	6.57	5.91
11	9.48	8.53	10.24	7.17	6.45
12	18.19	16.37	19.65	13.75	12.38

Optimal Storage*
20.00
196.00
350.00
330.00
320.00
350.00
255.00
85.00
0.00
0.00
2.00
10.00

* at the end of the month in MCM