INDIAN INSTITUTE OF SCIENCE

Water Resources Systems:

Modeling Techniques and Analysis

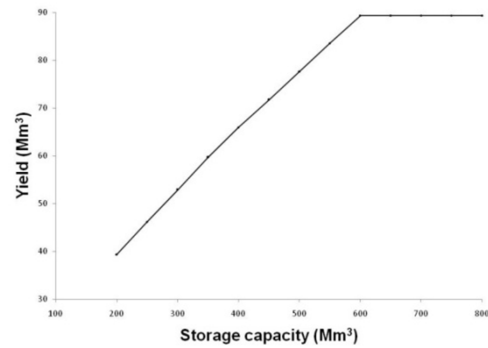
Lecture - 23

Course Instructor : Prof. P. P. MUJUMDAR

Department of Civil Engg., IISc.

Summary of the previous lecture

- Storage yield function



- Mixed integer LP formulation for maximizing yield

Maximize R

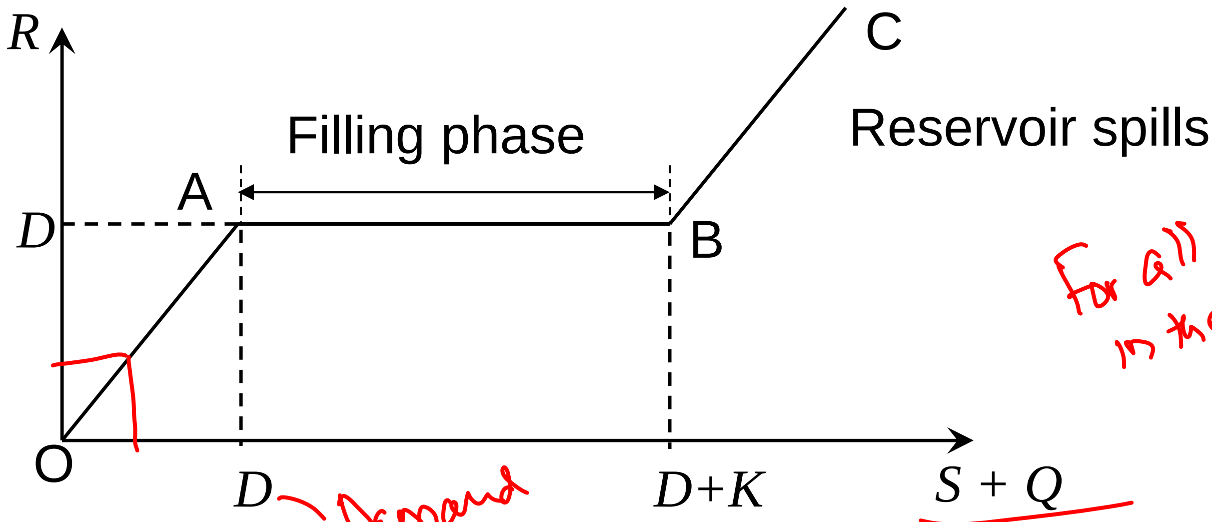
s.t.

$$\left.\begin{aligned} &(1 - a_t)\, S_t + Q_t - L_t - R - Spill_t = (1 + a_t)\, S_{t+1} \\ &Spill_t \le \beta_t\, M \\ &\beta_t \le \frac{S_{t+1}}{K} \\ &\beta_t \text{ is integer} \le 1 \\ &S_t \le K \end{aligned}\right\} \forall\, t$$

and $S_{T+1} = S_1$

- Introduction to reservoir operation

Standard Operating Policy



- Along OA : Release = water available.
- Along AB : Release = demand.
- Up to A : Reservoir is empty after release.
- At B and beyond : Reservoir is full after release.
- Along BC : Release = demand + excess water above capacity (spill).

Standard Operating Policy

- The release in any time period = S+Q or D whichever is less as long as availability does not exceed D+K.
- Once the availability exceeds D+K, release = demand + excess availability over capacity.
- Note that releases made as per SOP are not necessarily optimal releases.
- For highly stressed systems, SOP performs poor in terms of distributing deficits across the periods in a year.

Standard Operating Policy

- The SOP is expressed as

$$R_t = D_t \quad \text{if} \quad S_t + Q_t - E_t \geq D_t$$

$$= S_t + Q_t - E_t \quad \text{otherwise}$$

$$O_t = \left(S_t + Q_t - E_t - D_t\right) - K \quad \text{if positive}$$

$$= 0 \quad \text{otherwise}$$

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

$$S_{t+1} = K \quad \text{if} \quad O_t > 0$$

evaporation

capacity

S_t is the storage at the beginning of the period t
Q_t is the inflow during the period t
D_t is the demand during the period t
E_t is the evaporation loss during the period t
R_t is the release during the period t
O_t is the spill (overflow) during the period t

Example – 1

The monthly inflows (Q_t) and demands (D_t) and evaporation (E_t) in Mm^3 for a reservoir with a capacity of 350 Mm^3 are given below

	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Q_t	70.61	412.75	348.40	142.29	103.78	45.00	19.06
D_t	51.68	127.85	127.85	65.27	27.18	203.99	203.99
E_t	10	8	8	8	6	6	5

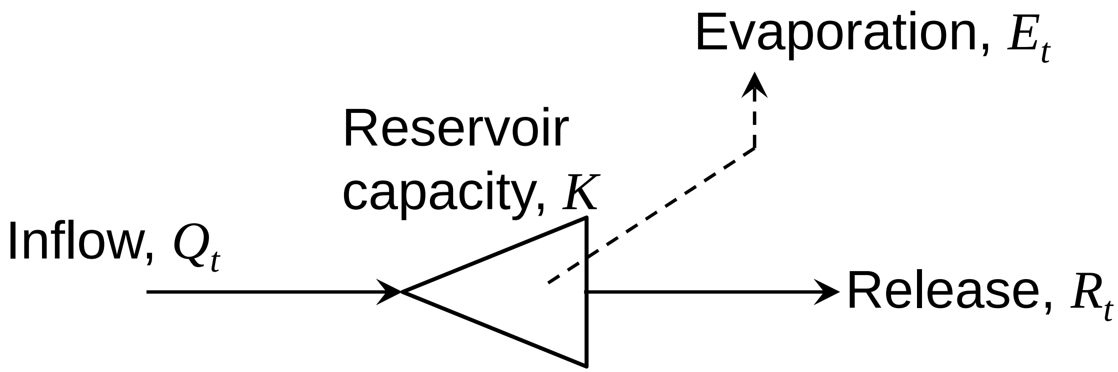
	Jan.	Feb.	Mar.	Apr.	May
Q_t	14.27	10.77	8.69	9.48	18.19
D_t	179.47	89.76	0	0	0
E_t	5	6	8	8	10

Initial storage, S_1 = 200 Mm^3

Example – 1 (Contd.)

Q_t	D_t	E_t	S_t	$S_t+Q_t-E_t$	R_t	O_t	S_{t+1}
70.61	51.68	10	200	260.61	51.68	0	208.93
412.75	127.85	8	208.93	613.68	127.85	135.83	350
348.4	127.85	8	350	690.4	127.85	212.55	350
142.29	65.27	8	350	484.29	65.27	69.02	350
103.78	27.18	6	350	447.78	27.18	70.6	350
45	203.99	6	350	389	203.99	0	185.01
19.06	203.99	5	185.01	199.07	199.07	0	0
14.27	179.47	5	0	9.27	9.27	0	0
10.77	89.76	6	0	4.77	4.77	0	0
8.69	0	8	0	0.69	0	0	0.69
9.48	0	8	0.69	2.17	0	0	2.17
18.19	0	10	2.17	10.36	0	0	10.36

Optimal Operating Policy Using LP



- Given a reservoir of known capacity K, and sequence of inflows, determine the sequence of releases R_t, that optimize an OF.
- OF may be function of storage volume or the release.

Optimal Operating Policy Using LP

LP formulation:

Max $\sum_t R_t$

$R_1 + R_2 + R_3 + \cdots + R_{12}$

s.t. $S_{t+1} = S_t + Q_t - E_t - R_t - O_t \quad \forall\, t$

overflows

$R_t \le D_t \quad \forall\, t$

$S_t \le K \quad \forall\, t$

known

$R_t \ge 0 \quad \forall\, t$

$S_t \ge 0 \quad \forall\, t$

$S_1 = S_0$ known

$S_{T+1} = S_1$

Optimal Operating Policy Using LP

- $S_t \leq K \;\; \forall \, t$ …. restricts the release during a period to the corresponding demand, while the OF maximizes the sum of releases.
- Thus the model aims to make the release as close to demand as possible over the period.
- $S_{T+1} = S_1$ …. makes the end of year storage equal to beginning of the next year's storage, steady state solution achieved.
- If the initial storage at beginning of first period is known, an additional constraint $S_1 = S_0$ may be included.

Example – 2

Solve the problem in Example-1 using LP

Max $\sum_t R_t$ t = 1,2,.. 12

s.t. $S_{t+1} = S_t + Q_t - E_t - R_t - O_t \quad \forall\, t$

$R_t \le D_t \quad \forall\, t$

$S_t \le K \quad \forall\, t$

$R_t \ge 0 \quad \forall\, t$

$S_t \ge 0 \quad \forall\, t$

$S_{13} = S_1$

Example – 2 (Contd.)

Solution:

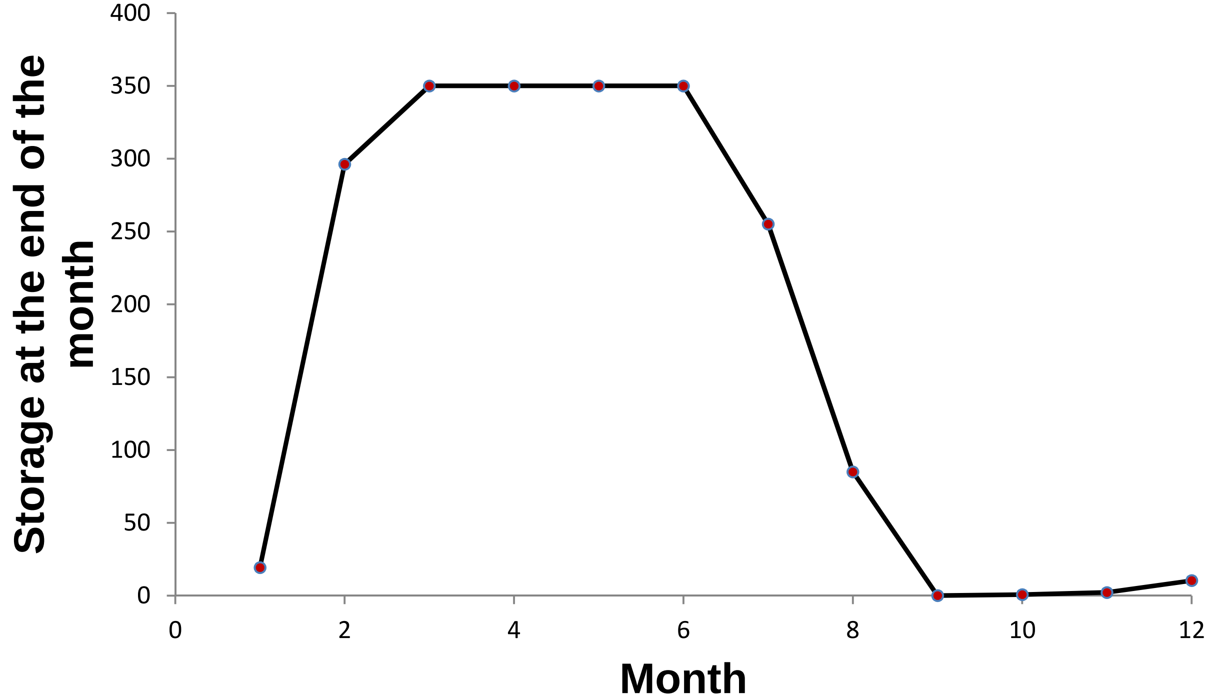
t	Q_t	D_t	E_t	S_t	R_t	O_t	S_{t+1}
1	70.61	51.68	10	10.36	51.68	0	19.29
2	412.75	127.85	8	19.29	127.85	0	296.19
3	348.4	127.85	8	296.19	127.85	158.74	350
4	142.29	65.27	8	350	65.27	69.02	350
5	103.78	27.18	6	350	27.18	70.6	350
6	45	203.99	6	350	39.00	0	350
7	19.06	203.99	5	350	108.87	0	255.19
8	14.27	179.47	5	255.19	179.47	0	84.99
9	10.77	89.76	6	84.99	89.76	0	0
10	8.69	0	8	0	0	0	0.69
11	9.48	0	8	0.69	0	0	2.17
12	18.19	0	10	2.17	0	0	10.36

Soln.: from optimization model.

Optimal Operating Policy Using LP

Rule curves for reservoir operation:

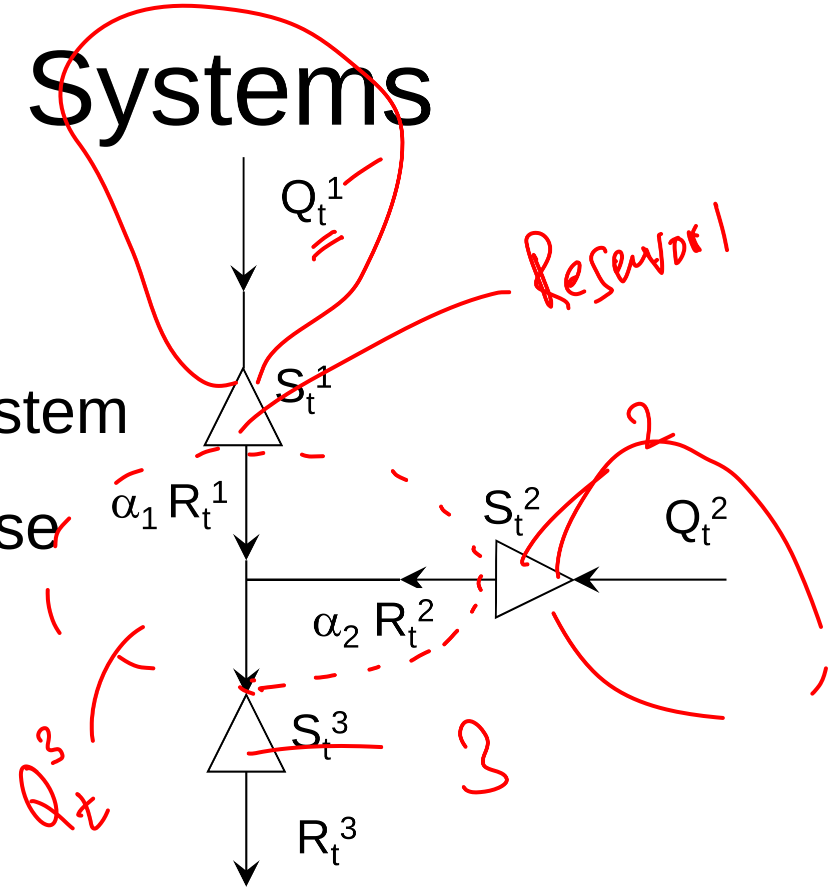
- Rule curve indicates the desired reservoir release or storage volume at a given time of a year.



Multi-reservoir Systems

Multi-reservoir operation:

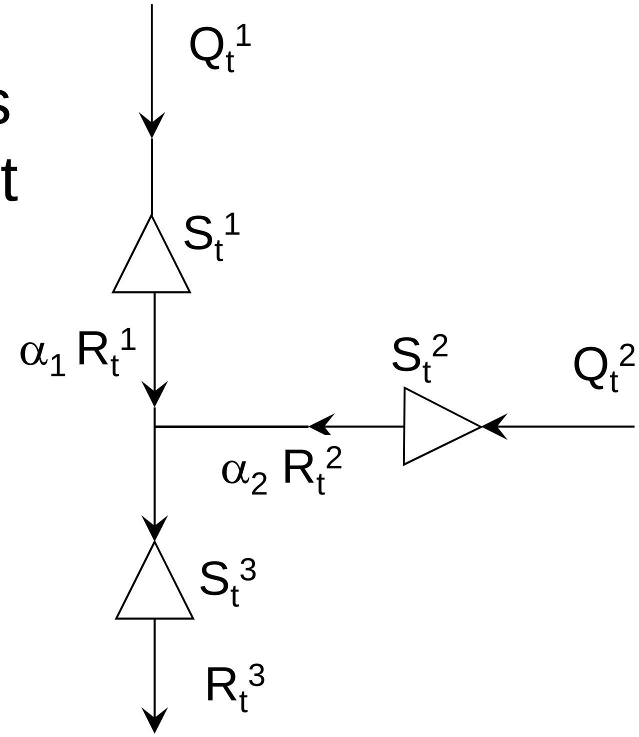
- Consider a three reservoir system
- The system serves the purpose of water supply, flood control and hydro power generation.
- Release for water supply is passed through powerhouse



- Losses in powerhouse are negligible
- Benefits from powerhouse are expressed as a function of storage alone

Multi-reservoir Systems

- B_{1t}^{i}, B_{2t}^{i} and B_{3t}^{i} are net benefits associated with unit release, unit available flood freeboard and unit storage for reservoir i in period t.
- A portion of release from reservoir 1 and 2 flows to reservoir 3.



- A minimum storage $F_{\min}^{i}$, needs to ensure flood control in flood season at the reservoir i.
- Maximum release at reservoir i is $R_{\max}^{i}$