Reservoir Sizing & Storage Yield

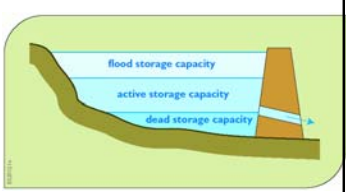
Mass Diagram
Sequent Peak Algorithm
Linear Programming

Reservoir Sizing

- Annual demand for water at a particular site may be less than the total inflow, but the time distribution of demand may not match the time distribution of inflows resulting in surplus in some periods and deficit in some other periods.
- A reservoir is a storage structure that stores water in periods of excess flow (over demand) in order to enable a regulation of the storage to best meet the specified demands.
- The problem of reservoir sizing involves determination of the required storage capacity of the reservoir when inflows and demands in a sequence of periods are given.

Reservoir Storage Capacity Components

- *Active storage* used for downstream flow regulation and for water supply, recreational development or hydropower production (for conservation purposes).
- *Dead storage* required for sediment collection
- *Flood storage* capacity reserved to reduce potential downstream flood damage during flood events.



Reservoir sizing studies are focused more on determination of Active Storage requirement.

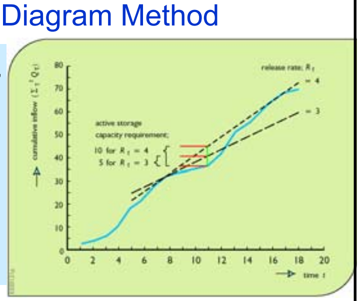
Inflows are assumed to be deterministic

Mass Diagram Method

- Developed by W. Rippl (1883).
- It involves finding the maximum positive cumulative difference between a sequence of pre-specified (desired) reservoir releases R_t and known inflows Q_t.
- One can visualize this as starting with a full reservoir, and going through a sequence of simulations in which the inflows and releases are added and subtracted from that initial storage volume value.
- Doing this over two cycles of the record of inflows will identify the maximum deficit volume associated with those inflows and releases.
- This is the required reservoir storage.

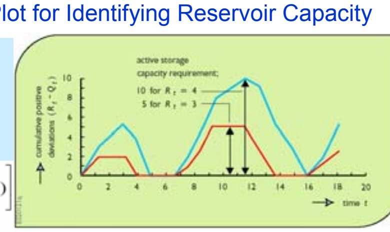
Rippl's Mass Diagram Method

- Inflows for a nine period sequence are 1, 3, 3, 5, 8, 6, 7, 2 and 1.
- Required reservoir storage for two different release rates are shown.
- Sum of all the desired releases should not exceed the sum of all the inflows over the same sequence of time periods.



Alternative Plot for Identifying Reservoir Capacity

- The active storage capacity, K_a, will equal the maximum accumulated storage deficit one can find over some interval of time within two successive record periods, T.



$$K_a = \text{maximum}\left[\sum_{t=i}^{j}(R_t - Q_t)\right]$$

where $1 \le i \le j \le 2T$.

- Above Equation is the analytical equivalent of graphical procedures proposed by Rippl for finding the active storage requirements.
- Mass diagram method does not account for losses.
- The equivalent method shown above is also called the sequent peak method

Sequent Peak Algorithm

- Let K_t be the maximum total storage requirement needed for periods 1 through period t. As before, let R_t be the required release in period t, and Q_t be the inflow in that period. Setting K_0 equal to 0, the procedure involves calculating K_t using equation below for upto twice the total length of record.

$$K_t = R_t - Q_t + K_{t-1} \quad \text{if positive,}$$
$$= 0 \text{ otherwise}$$

- The maximum of all K_t is the required storage capacity for the specified releases R_t and inflows, Q_t.

Sequent Peak Analyses

- Inflows for a nine period sequence are 1, 3, 3, 5, 8, 6, 7, 2 and 1.
- Constant release required, R_t=3.5
- This method does not require all the releases to be same.
- Stopping Criteria
  - K_t value repeats for the corresponding period OR
  - Twice the number of periods

time t	$(R_t - Q_t + K_{t-1})^+ = K_t$	
1	3.5 – 1.0 + 0.0 = 2.5	
2	3.5 – 3.0 + 2.5 = 3.0	
3	3.5 – 3.0 + 3.0 = 3.5	
4	3.5 – 5.0 + 3.5 = 2.0	
5	3.5 – 8.0 + 2.0 = 0.0	
6	3.5 – 6.0 + 0.0 = 0.0	
7	3.5 – 7.0 + 0.0 = 0.0	
8	3.5 – 2.0 + 0.0 = 1.5	
9	3.5 – 1.0 + 1.5 = 4.0	
1	3.5 – 1.0 + 4.0 = 6.5	
2	3.5 – 3.0 + 6.5 = 7.0	
3	3.5 – 3.0 + 7.0 = 7.5	K_a
4	3.5 – 5.0 + 7.5 = 6.0	
5	3.5 – 8.0 + 6.0 = 1.5	
6	3.5 – 6.0 + 1.5 = 0.0	repetition begins
7	3.5 – 7.0 + 0.0 = 0.0	
8	3.5 – 2.0 + 0.0 = 1.5	
9	3.5 – 1.0 + 1.5 = 4.0	

Reservoir Capacity Considering Evaporation Losses

Reservoir Storage vs Area Relationship

Evaporation loss in volume units

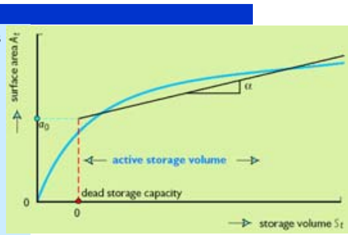
$L_t = [a_0 + \alpha(S_t + S_{t+1})/2]e_t$

- Let $a_t=\alpha e_t/2$
- Storage Continuity

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

- Substituting L_t and a_t

$(1-a_t)S_t+Q_t-R_t-a_0e_t=(1+a_t)S_{t+1}$



Sequent Peak Algorithm Considering Evaporation Losses (Lele, 1987)

Capacity estimated by considering evap loss will be more than that estimated by neglecting them

Reservoir Capacity Estimation using LP

- Linear Programming can be used more elegantly to obtain reservoir capacity by considering variable demands and evaporation rates.

Minimize K		Active storage capacity
subject to $(1-a_t)S_t+Q_t-R_t-a_0e_t = (1+a_t)S_{t+1}$	$\forall$ t	Storage continuity
$S_t \le K$	$\forall$ t	Storage capacity
$R_t \ge D_t$	$\forall$ t	Demands + Spill
$S_{T+1} = S_1$	where T is the last period	

Large LP problems can be solved very efficiently using LINGO - Language for INteractive General Optimization, LINDO Systems Inc, USA

Storage Yield or Maximum Yield

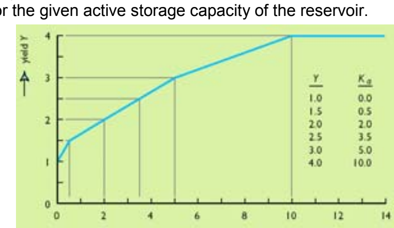
- A complementary problem to reservoir capacity estimation.
- Determine maximum yield (a constant amount of water that can be released per period) from a reservoir of given capacity.
- Earlier approach is useful in planning and design while the later is useful in evaluating what best can be expected from an existing reservoir.
- Linear Programming can be used for this purpose.
- Let the objective be to maximize the yield, R (per period) from a reservoir of given capacity, K.

Maximize R		Storage yield
subject to $(1-a_t)S_t+Q_t-R-a_0e_t = (1+a_t)S_{t+1}$	$\forall$ t	Storage continuity
$S_t \le K$	$\forall$ t	Storage capacity
$S_{T+1} = S_1$	where T is the last period	

Storage–yield function

Reservoir Storage vs Yield Relationship

Storage–yield function for the sequence of inflows: 1, 3, 3, 5, 8, 6, 7, 2 and 1 for the given active storage capacity of the reservoir.



Thank You