Lecture 2

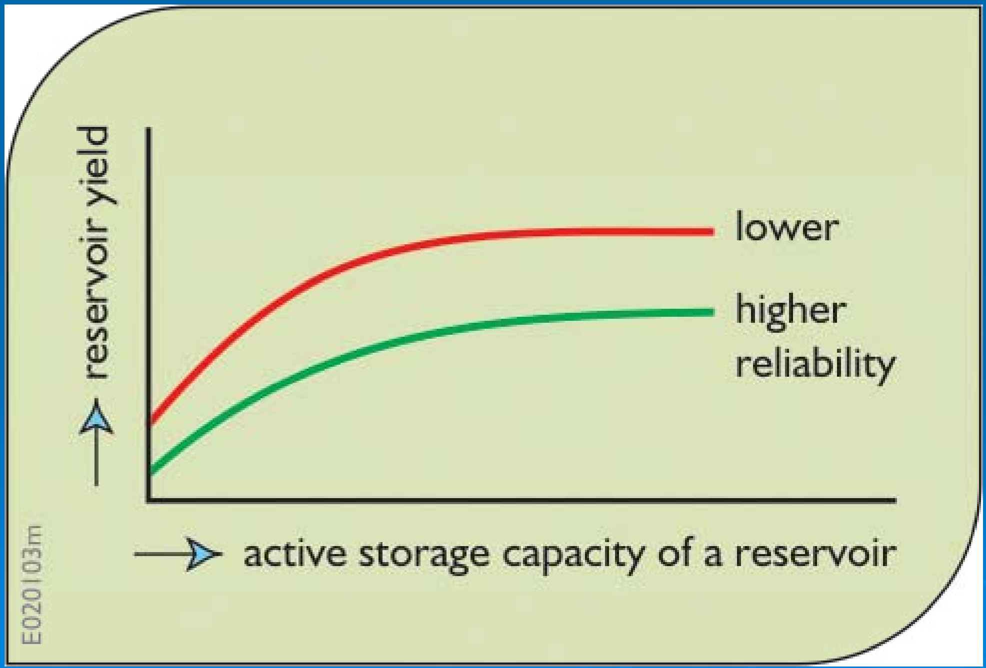
Reservoir Capacity Yield Analysis

(how to size a reservoir and measure its performance)

Reservoir Yield: Controlled Release from a reservoir (or system of reservoirs).

Often expressed as a ratio of % of mean annual flow. E.g., 70% yield means the reservoir can provide a regulated release of 70% of the mean annual flow.

The Yield depends on the active **storage capacity** of the reservoir



Reliability of Yield: probability that a reservoir will be able to meet the demand in any particular time interval (usually a year)

Reliability = Ns/N

Ns is number of intervals in which demand was met; N is the total number of intervals

Firm Yield: can be met 100% of time

Estimating Active Storage Capacity

Mass Balance Equation of Reservoirs

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

Where

S_{t-1} is storage at end of previous time interval
S_t is storage at end of current time interval
Q_t is inflows at current time interval
R_t is release at current time interval
L_t is loss (evap/seepage) at current time interval

Reservoirs have a fixed storage capacity, K, so

S_t <= K for each interval

Mass Diagram Analysis (Rippl) Method

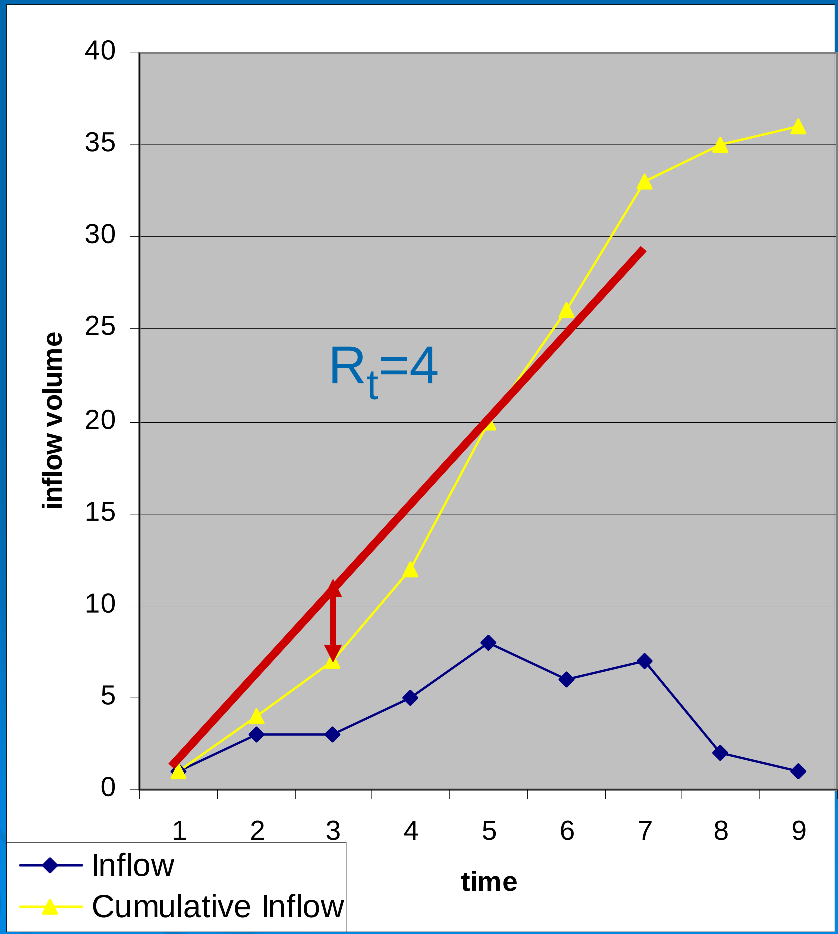
Find the maximum positive cumulative difference between a sequence of pre-specified (desired) reservoir releases R_t and known inflows Q_t.

Record of historical inflows is used, typically

Example: Nine period-of-record flows:

[1, 3, 3, 5, 8, 6, 7, 2, 1]

1. Plot cumulatives
2. Add demand line
3. Find max deficit



Mass Diagram Analysis (Rippl) Method

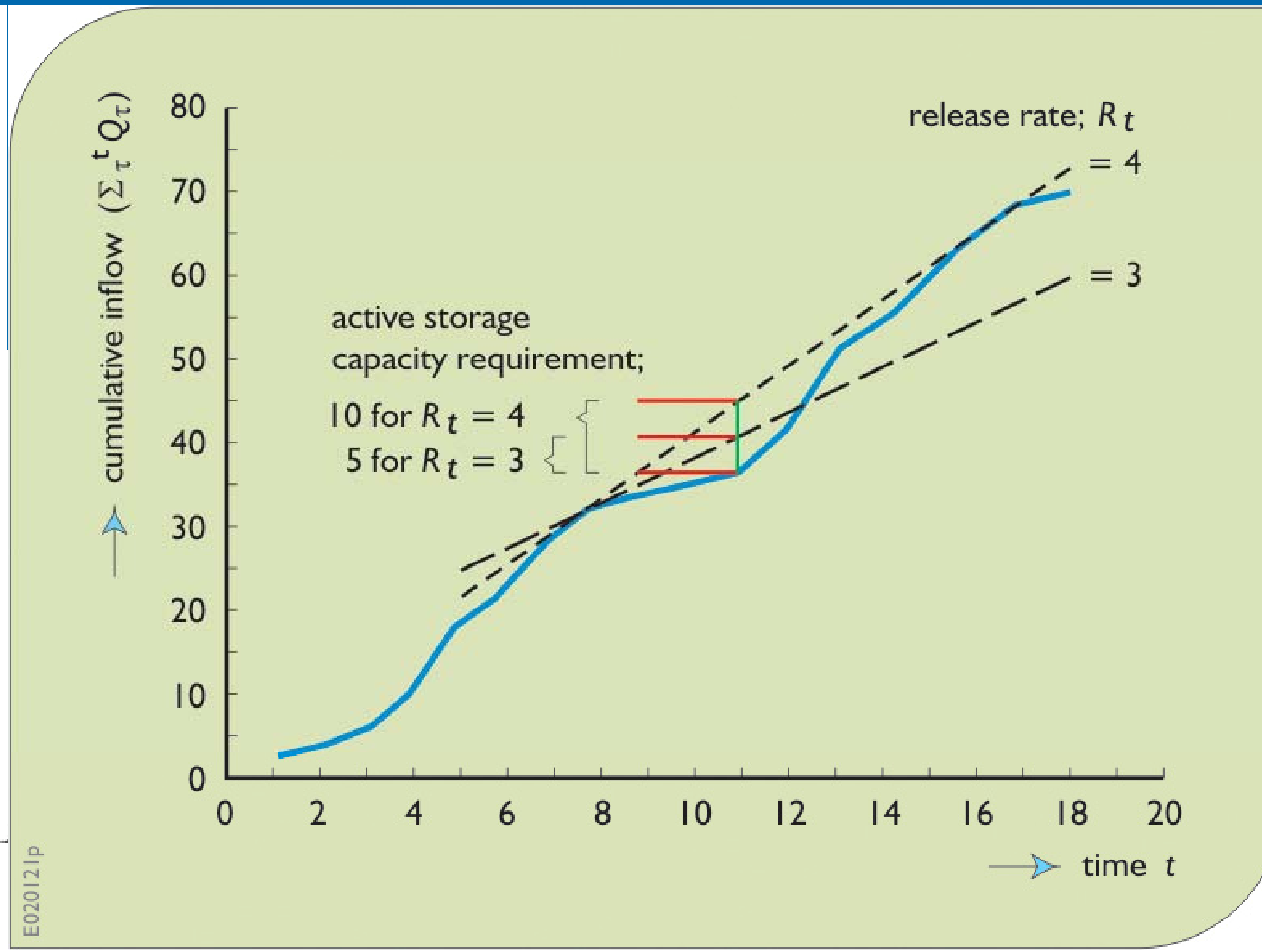
Repeat the hydrologic sequence in case critical period is at end

Start demand line at full reservoir

Calculate Active Storage K_a as max accumulated storage over 2 successive periods of record

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

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



Mass Diagram Analysis (Rippl) Method

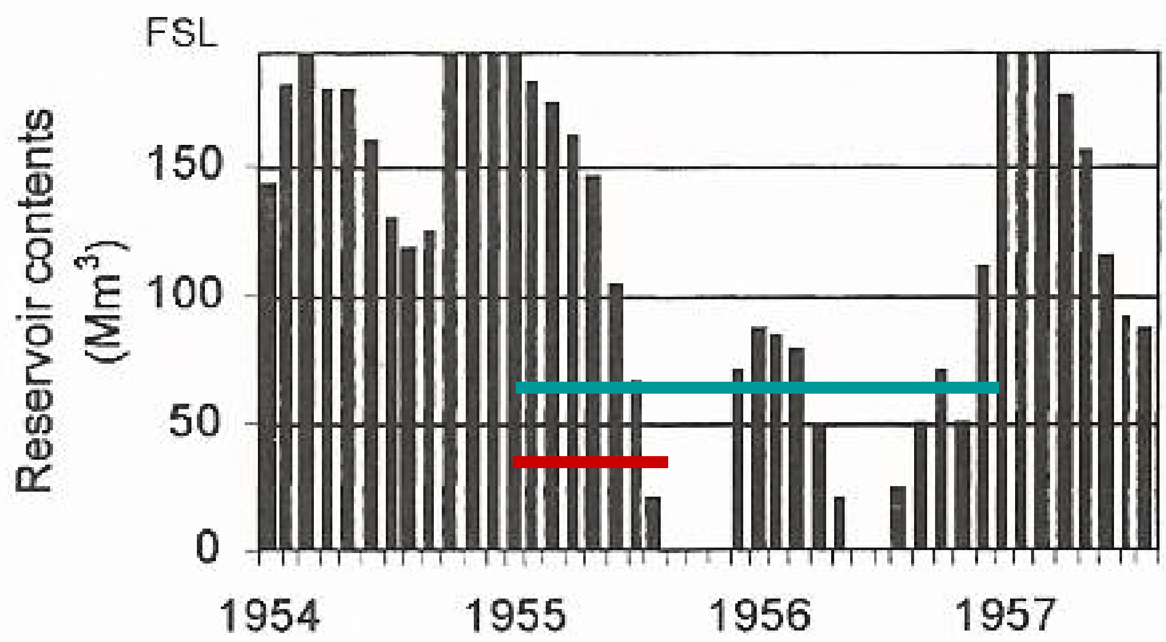
The maximum capacity is determined by the Critical Period

Critical Drawdown Period:

Longest period from full reservoir condition to emptiness

Critical Period:

Longest period from full condition, through emptiness and to a full condition again



Problems with Mass Diagram Method

- Reservoir release needs to be constant (this is not accurate for monthly interval as demands are often seasonal)
- Assumes that future hydrology is like the past
- Cannot compute storage size for a given reliability
- Evaporation and other losses that depend on level in reservoir cannot be factored into analysis

Reservoir Planning by Simulation

- Simulation models are based on mass balance equations and take into account all time-varying processes as well as elevation-based processes (losses)
  Simulation based techniques are called **Behavior Analysis**
- Why is it difficult to use simulation for reservoir sizing?
- Another type of “simulation” is based on deficit instead of storage. This solves some of the simulation problems.
- Approach is called **Sequent Peak Algorithm**

Sequent Peak Analysis

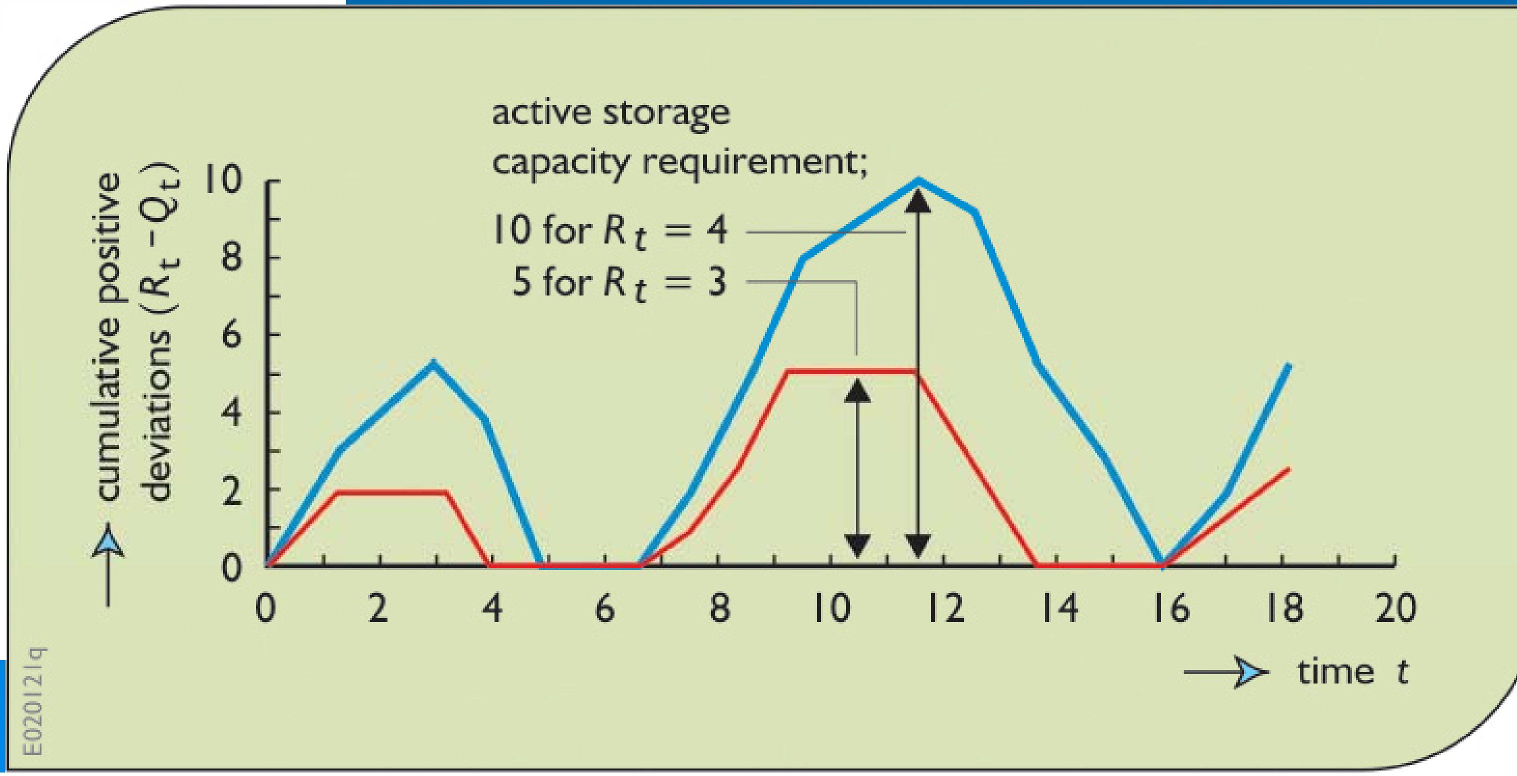
Let K_t be the maximum total storage requirements needed; Set $K_0 = 0$

Example: Nine period-of-record flows: [1, 3, 3, 5, 8, 6, 7, 2, 1]

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

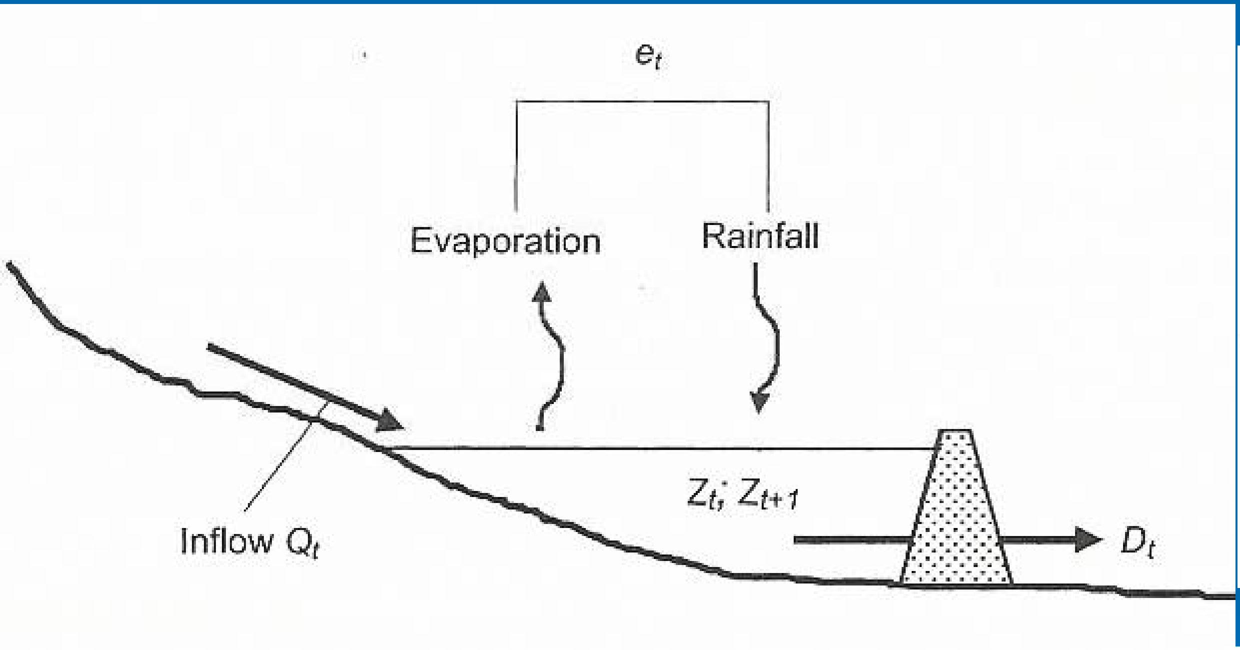
Apply the equation consecutively for up to 2x the total length of the record.

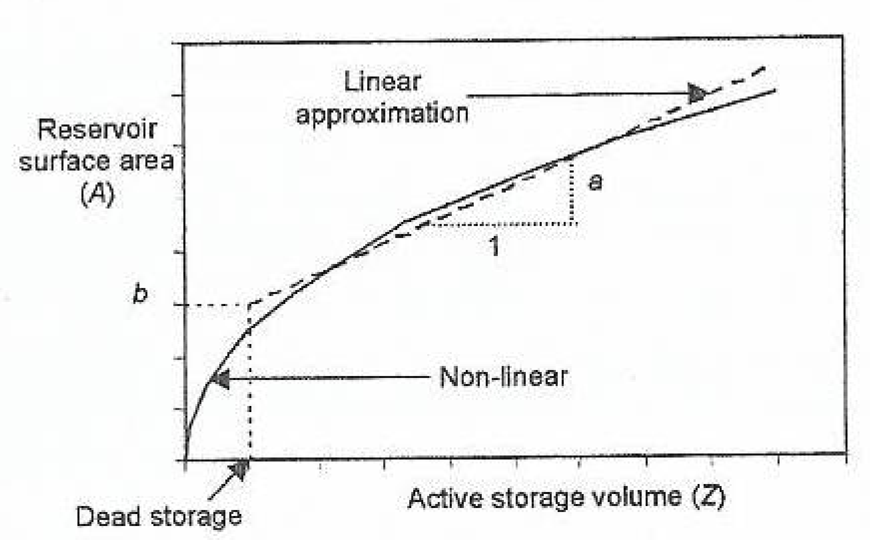
The maximum of all K_t is the required storage capacity for the specified releases R_t and inflows Q_t



Accounting for Losses

Evaporation and Rainfall (net losses) depend on Surface Area





Surface area depends on storage non linearly: $A_t = cZ_t^d$

But can be approximated linearly:

$$A_t = aZ_t + b \qquad (3.54)$$

where a, b, c and d are coefficients which can be obtained by least squares, A_t is the surface area at the beginning of period t and Z_t is the storage at the beginning of t.

Accounting for losses

- Losses can alter the critical period and change the storage capacity
- Net evap (equations) can be included in storage based simulations directly
- Lele and Montaseri developed methods for including evap in SPA in an interative approach
  (See McMahon et al., Sequent Peak Algorithm paper on class website)
- An alternative evap model can be used directly with SPA

Active storage (vol. units)	Evaporation (vol. units)
0 - 2	0.1
3 - 5	0.2

Reliability

Reliability (time-based) - Ns/N

Resiliance – Speed of recovery

Vulnerability – severity of failure (volumetric reliability)

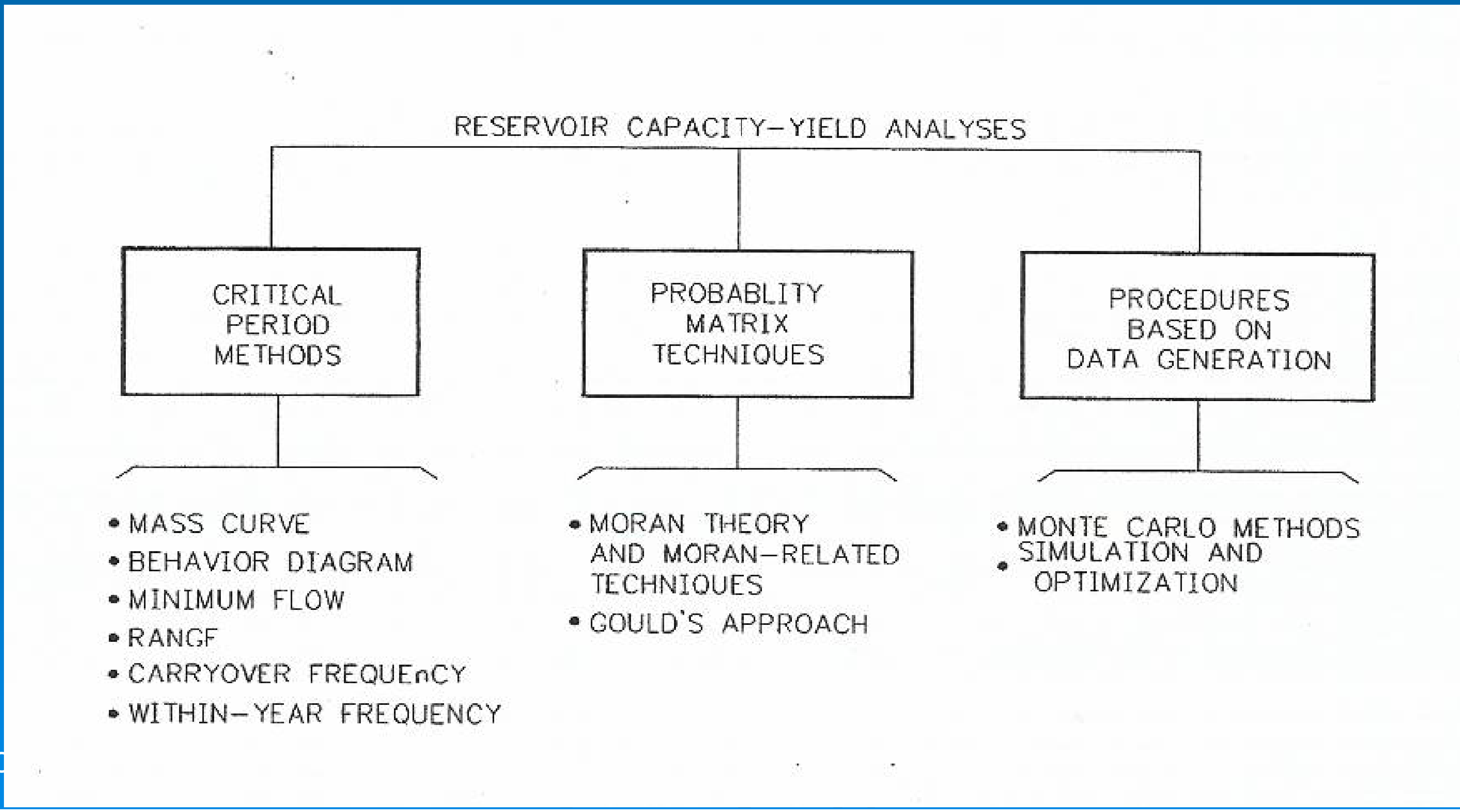
(Tradeoffs on these 3 lead to very tricky design; several authors have developed indices that attempt to combine these (Loucks, 1997; Zongxue, 1998)

Reliability and Vulnerability can be integrated into SPA:

- Determine number of failure periods permitted (from reliability)
- Determine reduced maximum reduced capacity permitted (from vulnerability)
- See example in McMahon

Classification of S-Y-P Procedures

(Storage – Yield – Performance)



Behavior Analysis – storage based simulation (detailed simulations of processes)

Case 1: Estimate System Performance
- Active capacity of reservoir is known.
- Series of demands is given (could be stochastic).
- Starting condition is known or assumed.
- Historical or synthetic inflows are used
  - (could be many traces) (index sequential or monte carlo)

Case 2: Find size of reservoir under consideration
- Series of demands is known (could be stochastic)
- series of inflows is given (historical or generated stochastic)
- Performance criterion is specified
- Estimate reservoir capacity; do simulations; adjust until get performance desired

Case 3: Estimate Yield of an existing reservoir
- Specify performance criteria (reliability, vulnerability, maybe resiliance)
- Use historic or stochastic hydrology
- Estimate demand (yield) and iterate until meet performance criteria
- Need to know and model detailed operating procedures

Additional important topics

- Optimization techniques
  simple ones can give identical results to SPA
  more complex methods can include cost functions
- Multiple reservoir systems
  single-reservoir techniques can be extended to multi-reservoir systems
  determine size at each site
  specify operating policies for releases and demands (heuristic policies have been developed)
  typical objective is to keep reservoirs balanced