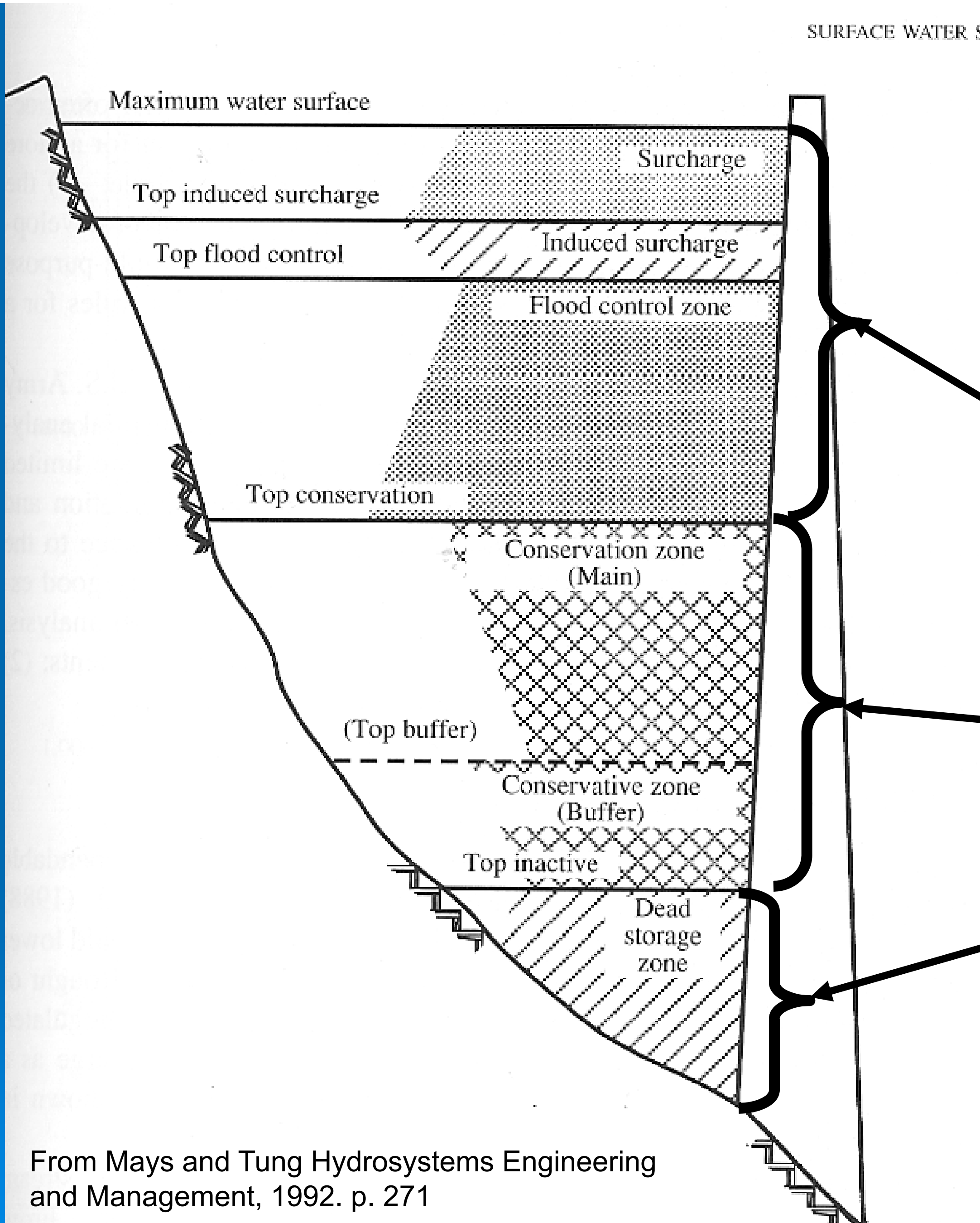
# Lecture 3
# Flood Control and Operating Criteria

# Purpose of a Reservoir

To smooth out the variability of surface water flow through control and regulation and make water available when and where it is needed. The dis-benefits of evaporation and seepage are offset by the benefits of water supply, hydropower, recreation and flood control.

# Two Main Operational Purposes:

1. **Conservation** – includes
   water supply (M&I and irrigation),
   low-flow augmentation for water quality and ecological habitat,
   recreation,
   navigation,
   hydropower
2. **Flood Control** – retention of water during flood events for the purpose of reducing downstream flooding.




From Mays and Tung Hydrosystems Engineering and Management, 1992. p. 271

# Reservoirs have 3 primary storage zones

## Flood Control Storage

**reserved for storing excessive flood volume to reduce potential downstream flood damage.**

## Active Storage

for conservation purposes

## Dead Storage

for sediment collection, hydropower head.

# Design of Dead Storage Capacity

Considers estimates of sediment load (a future topic)

# Design of Active Storage Capacity

Screening methods for yield as discussed last week

Multi-objective reservoirs designed with consideration of

- Reliability of hydrology (chance-constrained optimization models; transition probability matrix; DP)
- Hydropower firm energy commitments; B/C of power
- Buffer zone design for low flow augmentation in drought
- Trade-off among objectives based on economic or other criteria

# Multi-objective Tradeoff Analysis

An Example: A reservoir has 2 purposes – recreation (boating) and irrigation. These objectives conflict because boating requires high reservoir levels in the summer, whereas irrigation requires water to be released for downstream use. If X is total units of water delivered and Y is visitor-days in the season, the possible solution is:

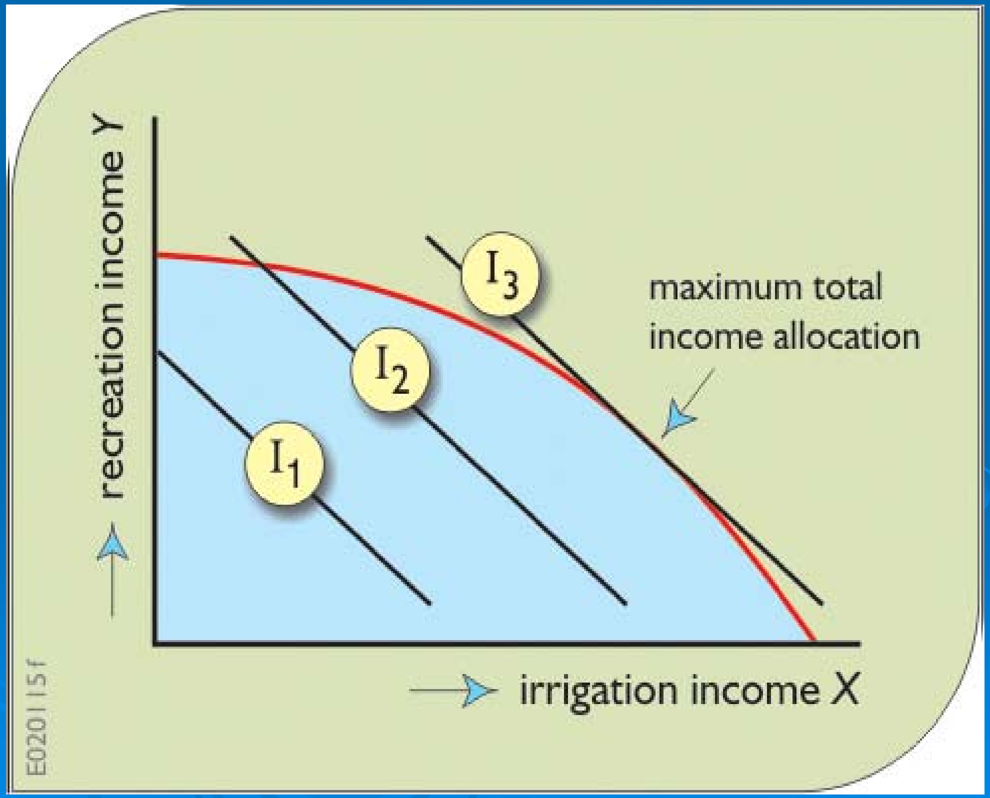
Best solution is on boundary where any improvement in one objective will result in harm to the other.

Use unit cost or value to find solution:

Income = Px X + Py Y
where Px is unit price of water
and Py is unit price of visitor-day

Find X ,Y values for constant I
where $I_1 < I_2 < I_3$

$I_3$ will provide the highest income and will be feasible for a single X,Y solution



# Multi-objective Tradeoff Analysis

In reality, it is not easy to find a solution for multi-objective tradeoff problems because

- There may not be quantifiable and commensurate values for objectives (environmental, social objectives; also legally mandated objectives).
- The market values may not reflect social values

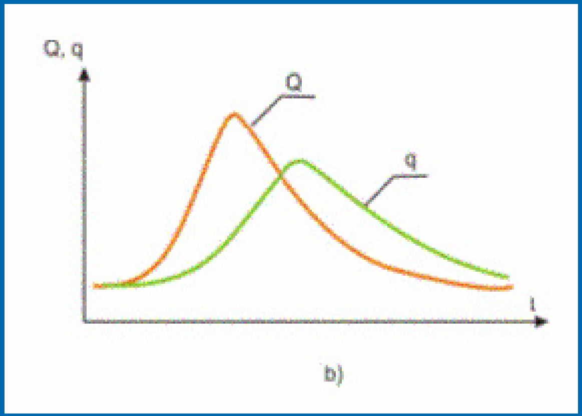
The results of rigorous benefit–cost analyses seldom dictate which of competing water resources projects and plans should be implemented. This is in part because of the multi-objective nature of the decisions. One must consider environmental impacts, income redistribution effects and a host of other local, regional and national goals, many of which may be non-quantifiable.

Other important considerations are the financial, technical and political feasibilities of alternative plans. Particularly important when a plan is undertaken by government agencies is the relative political and legal clout of those who support the plan and those who oppose it. Still, a plan's economic efficiency is an important measure of its value to society and often serves as an indicator of whether it should be considered at all.

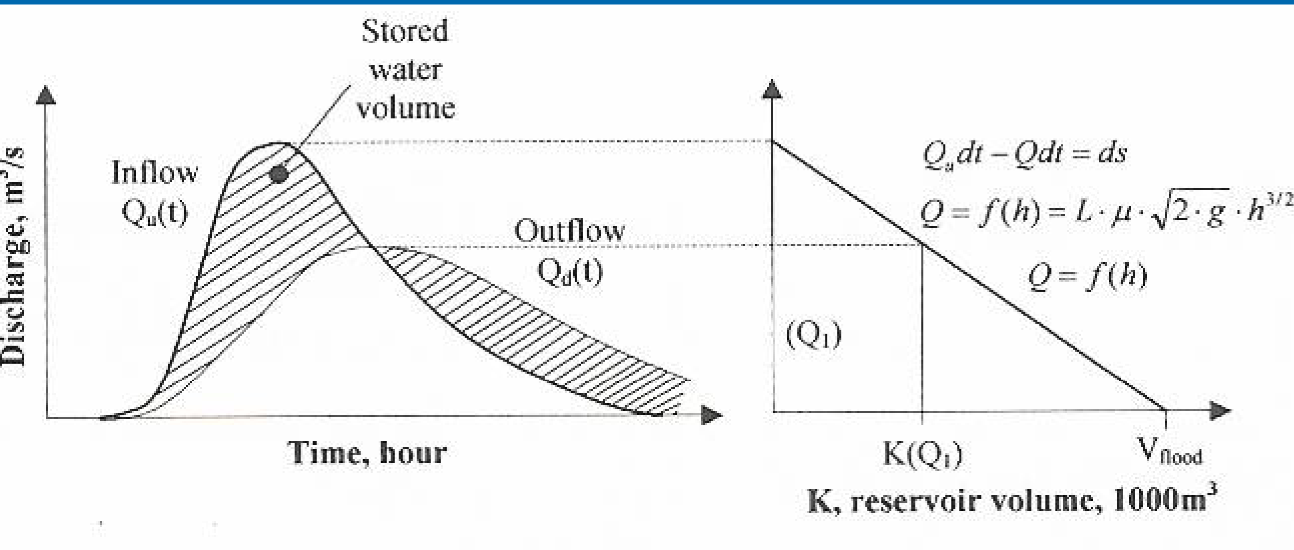
Loucks and van Beek, 2005

# Sizing of Flood Pool

A flood wave passing through a reservoir is delayed and attenuated in order to lessen damage downstream.

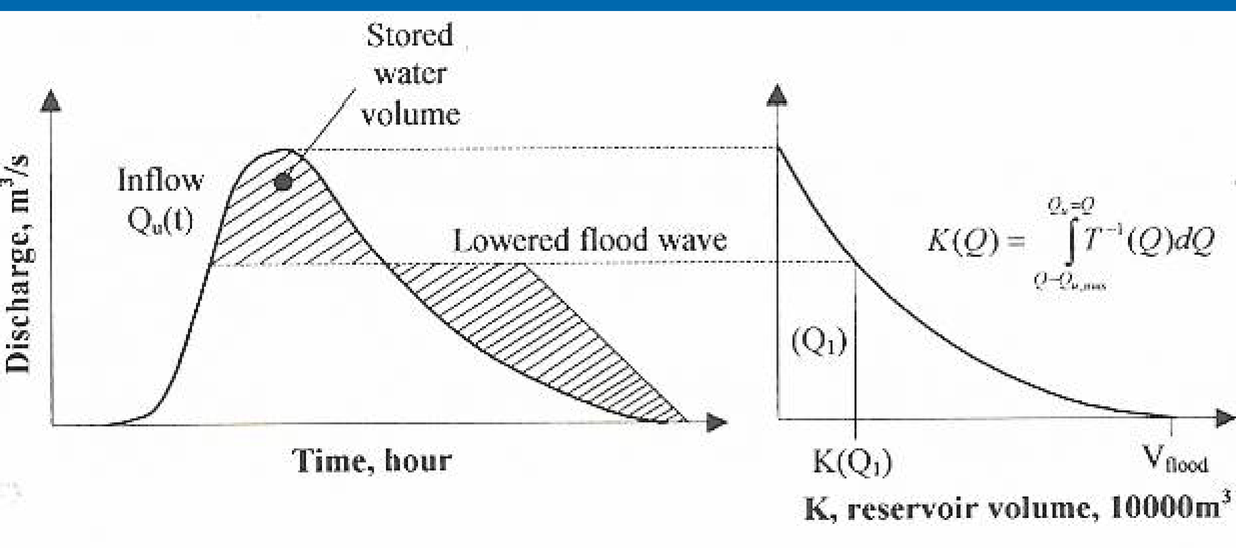



Translation of INFLOW hydrograph to OUTFLOW hydrograph depends on the geometric and hydraulic features of the pool and reservoir operation.




2. *Opened sluice*

A flood pool with an uncontrolled spillway stores water as it is released according to the weir flow equation. The hydrograph is delayed and attenuated. The outflow hydrograph depends on the area of the reservoir and the length of the spillway.




1. Regulated sluice

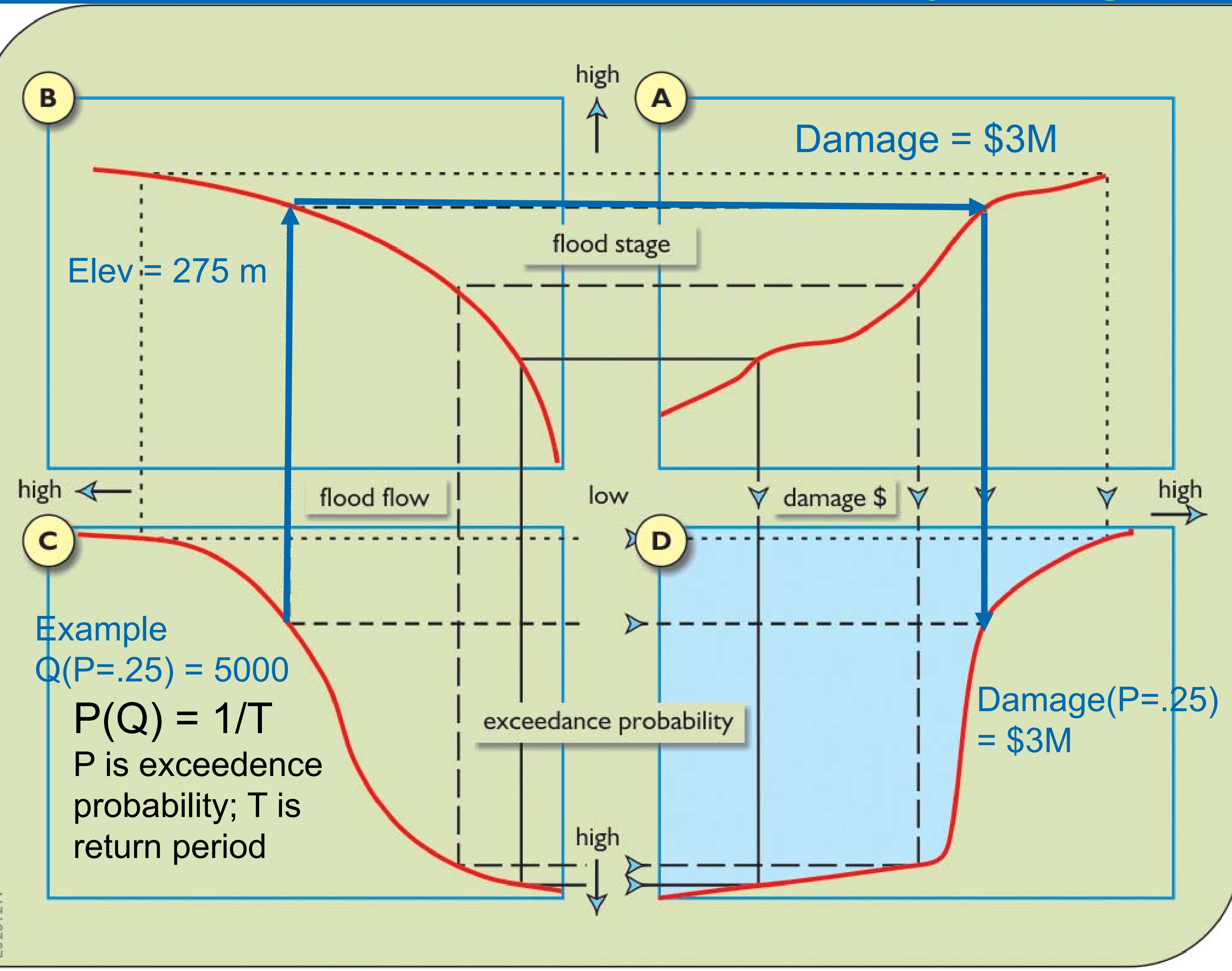
A gated structure can more efficiently control the release. Less storage space is needed for the same outflow peak Q. However, the gates add significant cost to the project.

# Flood Pool Sizing

To size the pool, need to know

1. Upstream hydrograph –
   based on analysis of record
2. Downstream hydrograph –
   based on flood damage analysis

# Flood Pool Sizing – determination of downstream hydrograph




Calculation of the expected annual flood damage *without the reservoir* is shown as the shaded area in quadrant (D) derived from:

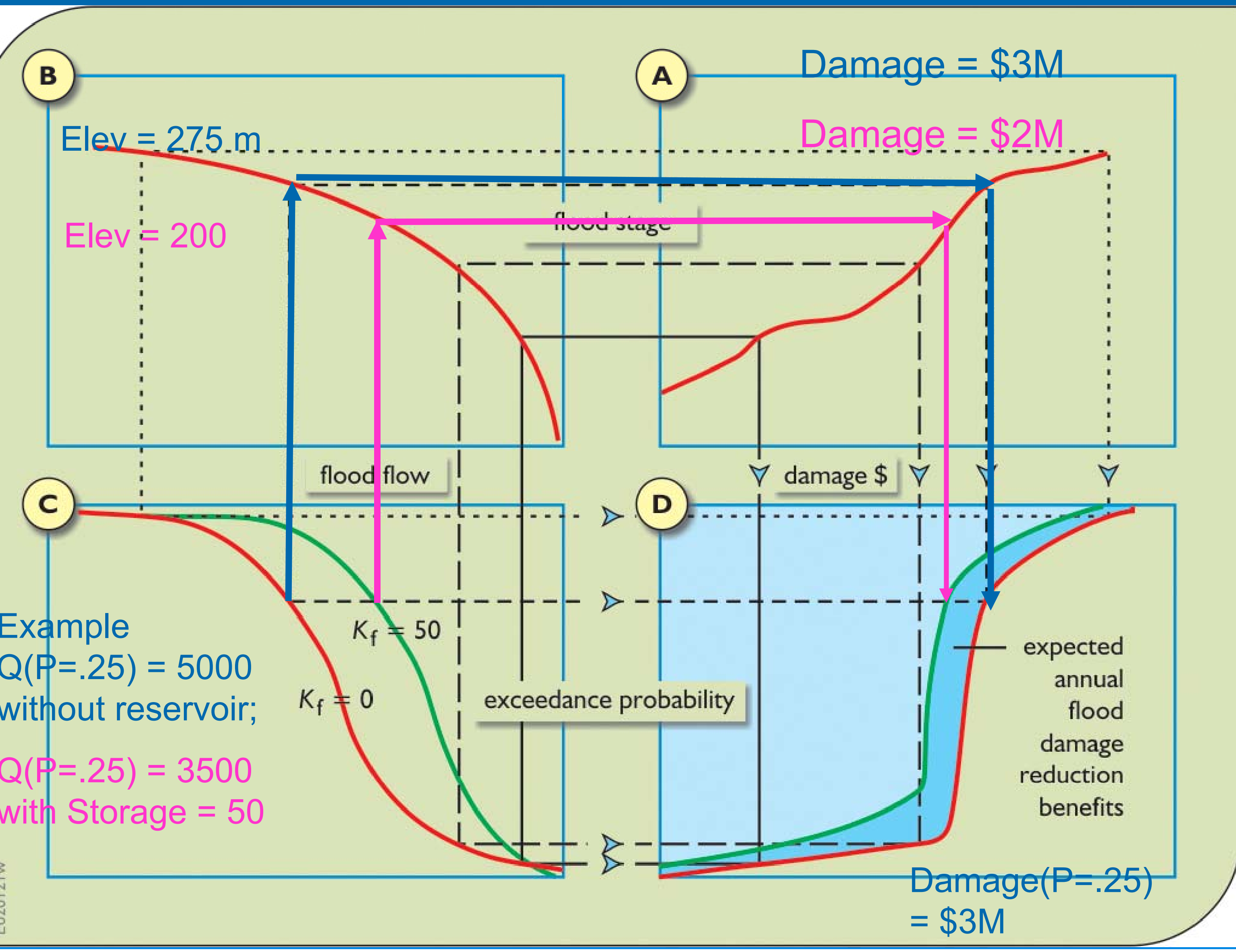
A - the expected stage-damage function,

B - the expected stage-flow relation, and

C - the expected probability of exceeding an annual peak flow

(Loucks and van Beek, 2005)

# Flood Pool Sizing – determination of downstream hydrograph

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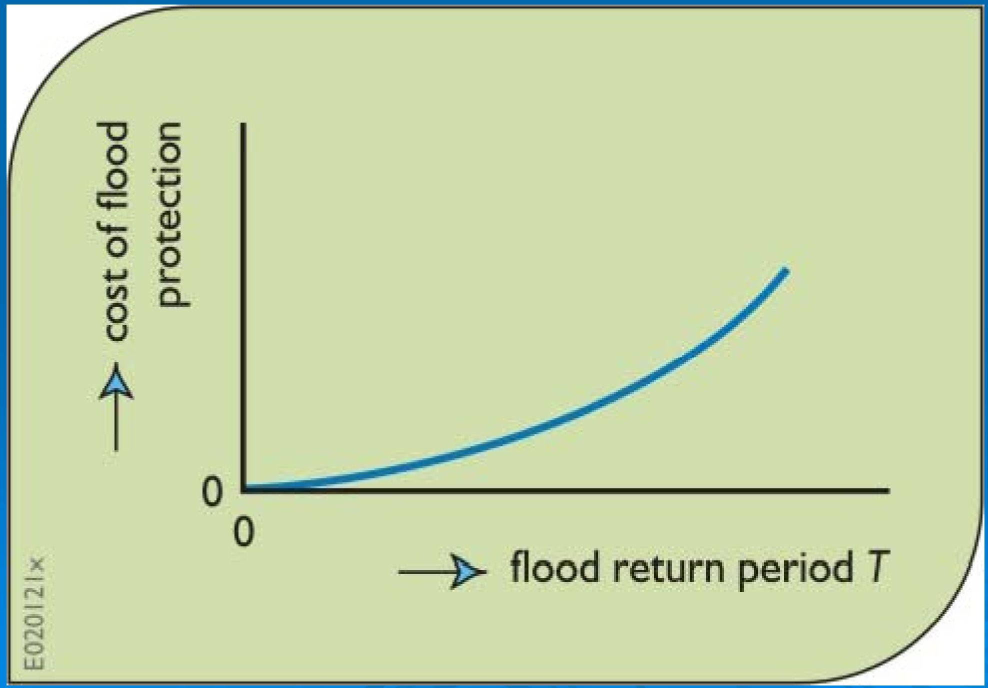
# Design Decisions are based on cost of protecting downstream. Cost of protection is based on storage (height of dam and area of reservoir) and operational capabilities (gates)



# What are storage/operations requirements for meeting Q(P) downstream?

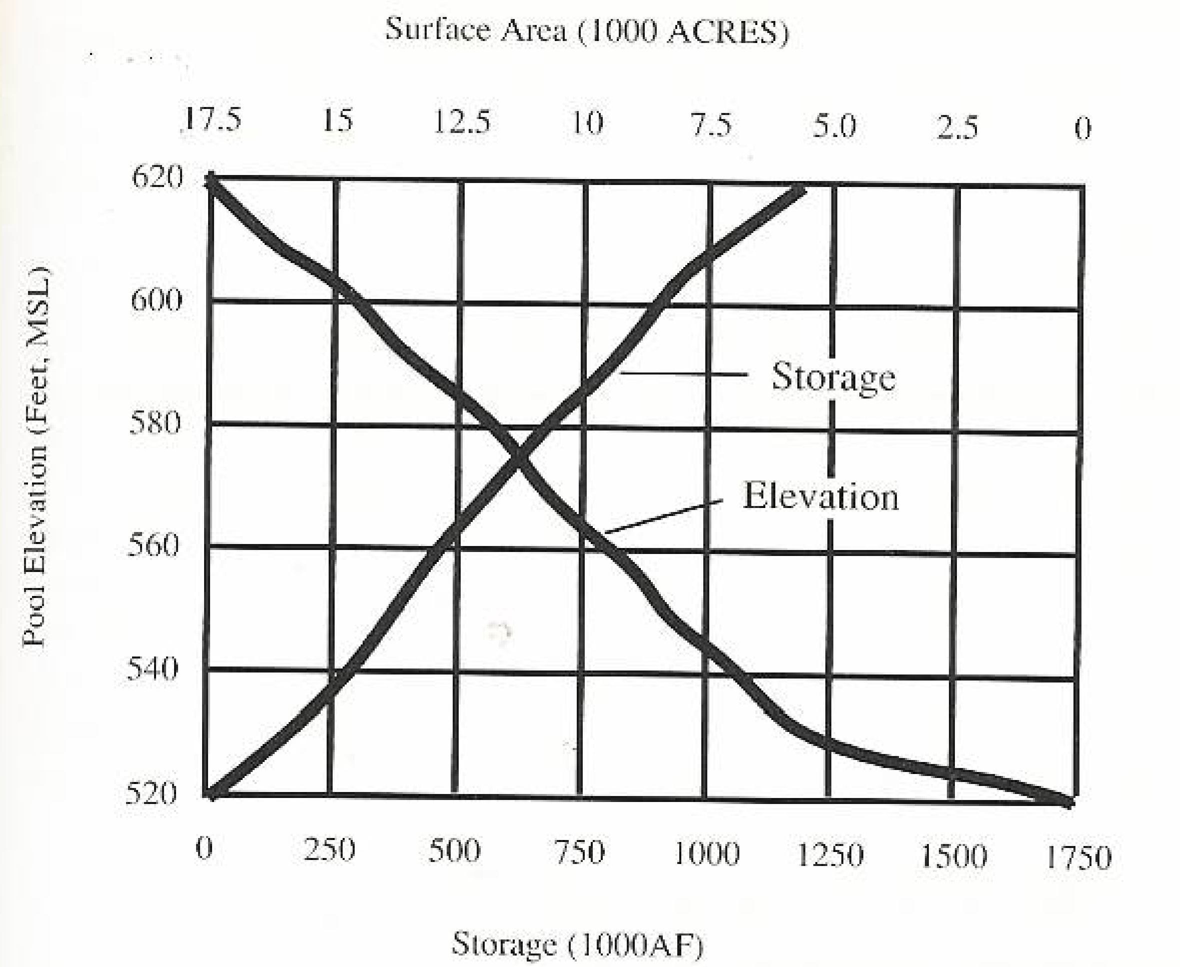
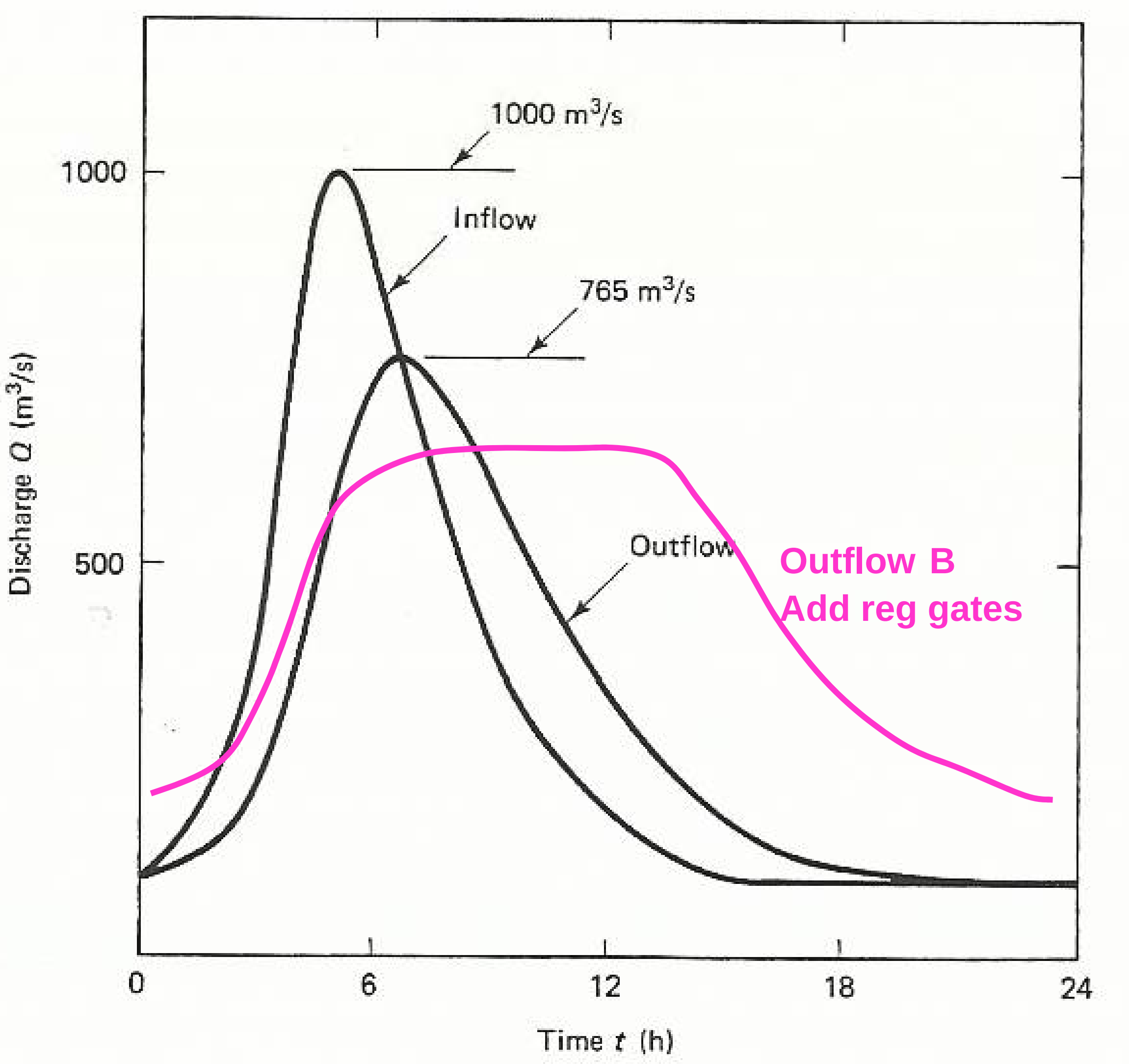



FIGURE 7.2.3 Mays and Tung, 1992 p.281

First: Develop the Elevation-Area-Storage relationships based on topography of the reservoir site

# What are storage/operations requirements for meeting Q(P) downstream?




Use storage routing to simulate the outflow hydrograph, given Q(P), using different outlet capabilities:

- Uncontrolled spillway length
- Regulated outflow (gates)

(See reading assignment: Engineering Hydrology, Principles and Practices, Chp 8,

# What range of Q(P) upstream need to be considered?

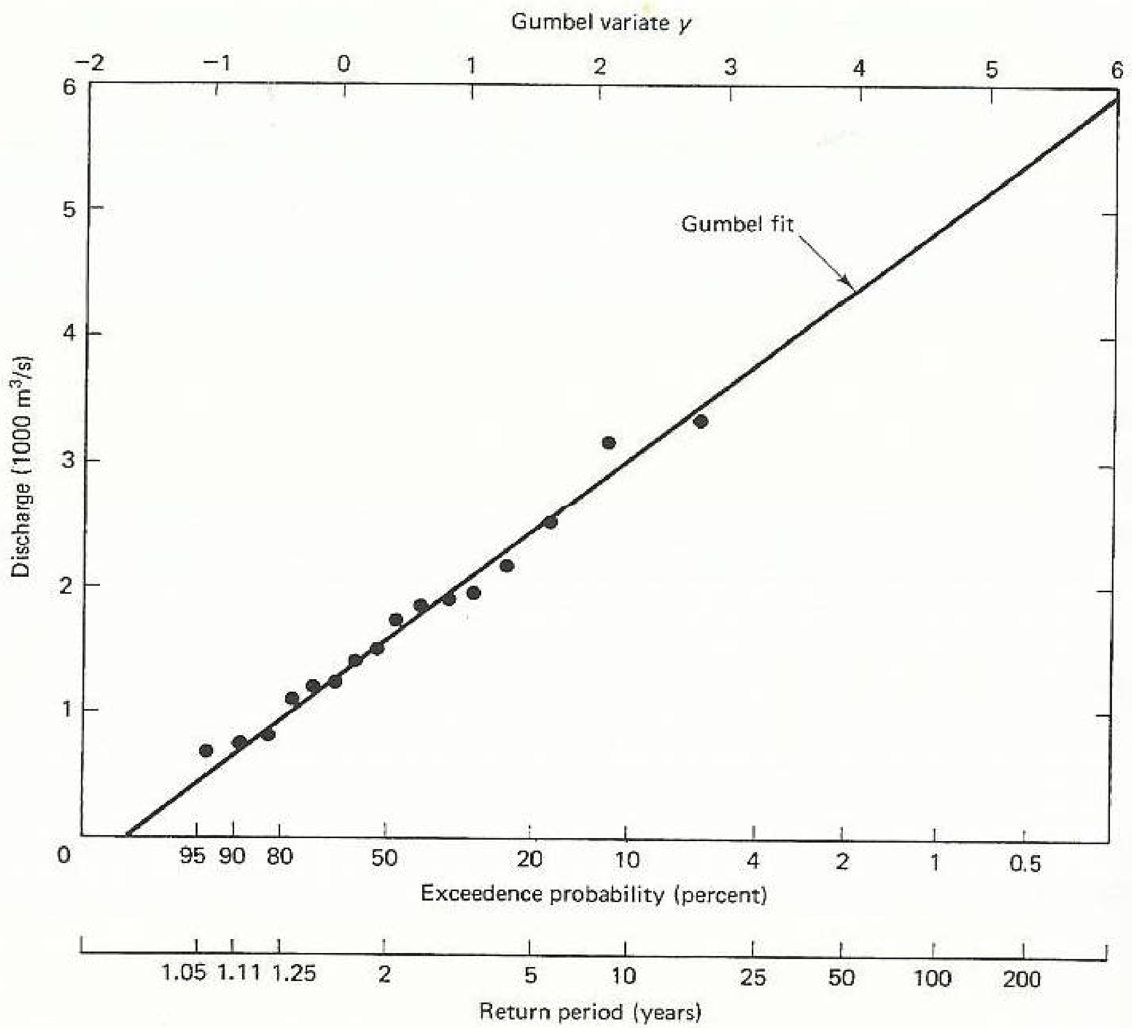
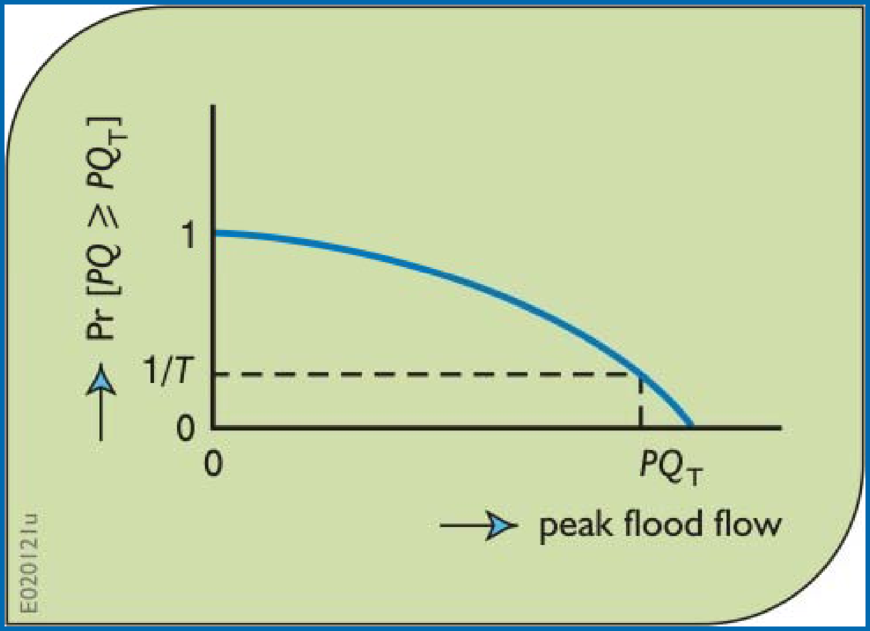


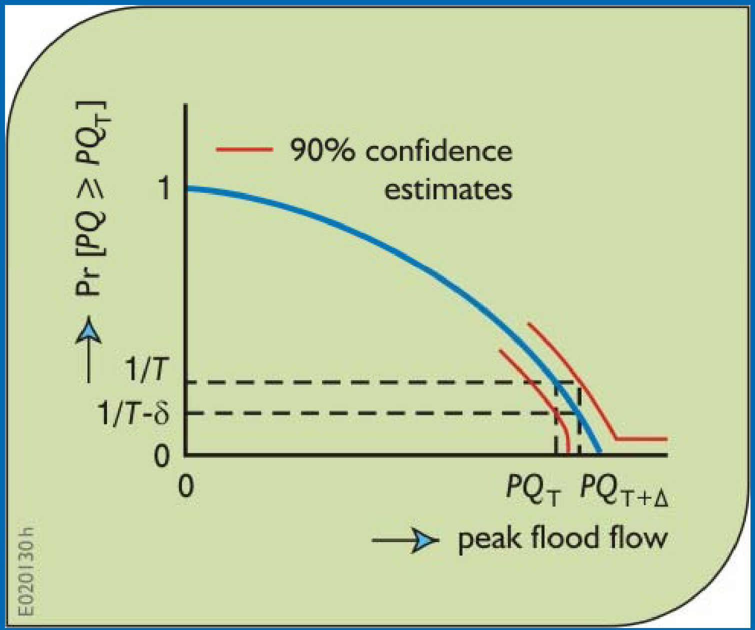

**Figure 6-6** Flood-frequency analysis by Gumbel method: Example 6-6.

Standard methods of fitting historical data to flood frequency curves provide a means of getting Q(P) for a range of return flows that have been obseved.

What about very large flows (T = 1000 or greater)?

# What range of Q(P) upstream need to be considered?



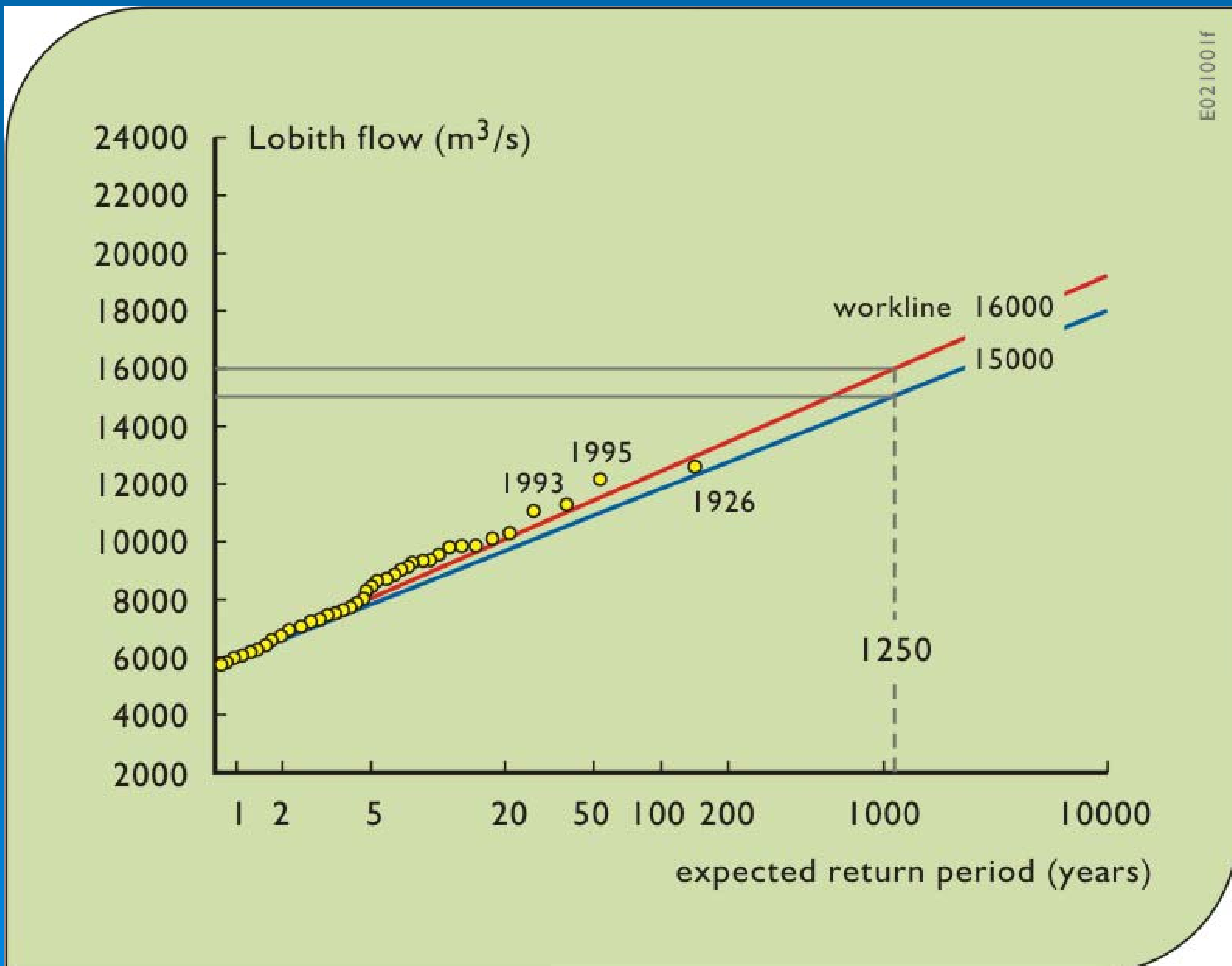




Portion of peak flow probability of exceedence function showing contours containing 90% of the uncertainty associated with this distribution. To be 90% certain of protection from a peak flow of PQT, protection is needed from the higher peak flow, PQTΔ expected once every T Δ years, i.e. with an annual probability of 1/(T *δ*) or (1/T) *δ* of being equalled or exceeded.

# What range of Q(P) upstream need to be considered?


As the return period increases, the value becomes more uncertain.

# What range of Q(P) upstream need to be considered?




This revision of the T=1250 flow was based on two new values in the period of record.

# Why are low exceedance values so difficult to determine?

- Hydrologic record is not long enough
- Many factors determine Q: rainfall volume, intensity, spatial pattern of precip, rain on snow, antecedent moisture conditions, temperature, changing runoff characteristics,
- Low-probability combinations of conditions are numerous

# Probable Maximum Flood

PMF is variously defined as T=1000, T=10,000

It can be derived statistically or by physical process modeling using an estimate of the Probable Maximum Precipitation (PMP)

Dam design policies require that the dam can pass the PMF, i.e., that the *dam does not fail*.

# Example: Canyon Lake Dam, SD June 9, 1972

Forecast *"partly cloudy, scattered t-storms, some possibly reaching severe proportions"*

*That evening,10 in. fell in a small, steep watershed that averages 14 in. annually; 6 in fell in 2 hours.*

Rapid creek delivered 31,000cfs into Canyon Lake, a 40 ac-ft reservoir behind a 20-ft high earthen dam. The previous record flow in 20 years was 2600cfs

The dam washed out, destroyed over half of Rapid City (pop 43,000). 237 fatalities, 5000 homeless. Pactola, 15 miles u.s. of Canyon Lake was unaffected.

The small spillway (background) on Canyon Lake dam became clogged with debris, and the dam was over-topped. Rapid Creek flows through the dam in a large cut where the dam failed.

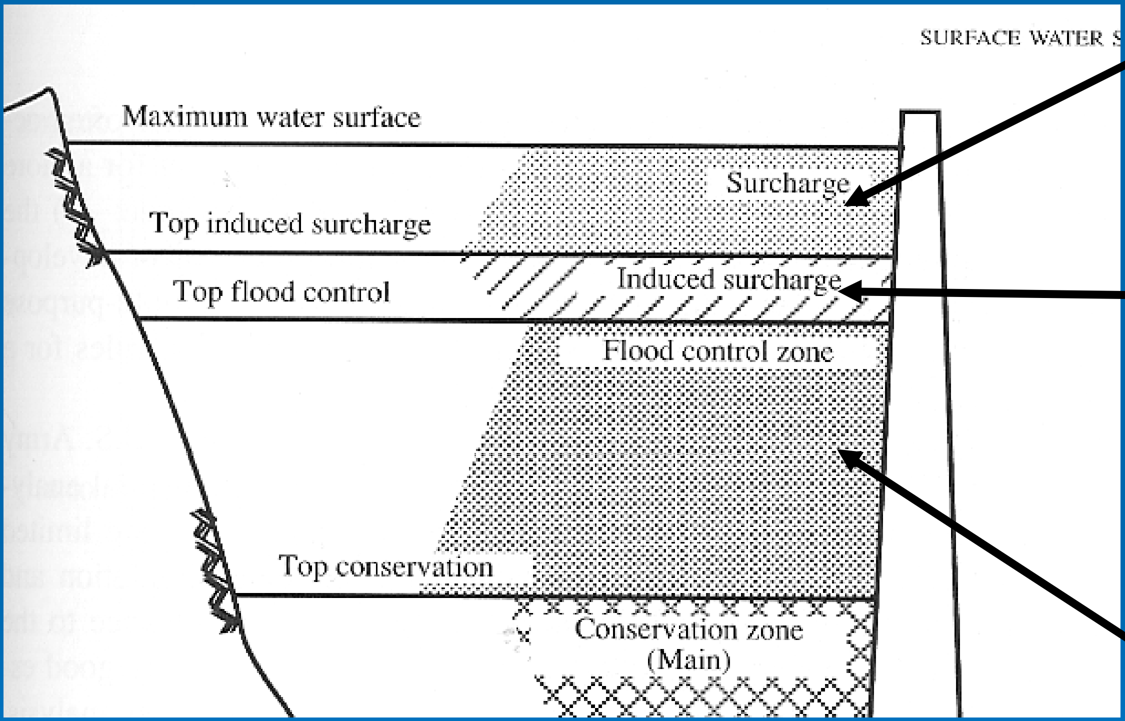
Erosion on the downstream face of Canyon Lake dam ultimately lead to its failure.

Close-up view of destroyed houses. The concrete silo houses a U.S. Geological Survey gage which had recorded a maximum of 2600 cubic feet per second in its 20 year history. On June 9, 1972, the discharge at this point was 31,200 cubic feet per second.


Flood-swept cars, pointing upstream (except for the Volkswagon bug), would stack on top of one another

People were moving into these new houses in western Rapid City the night of the flood.

# Flood Release Policies



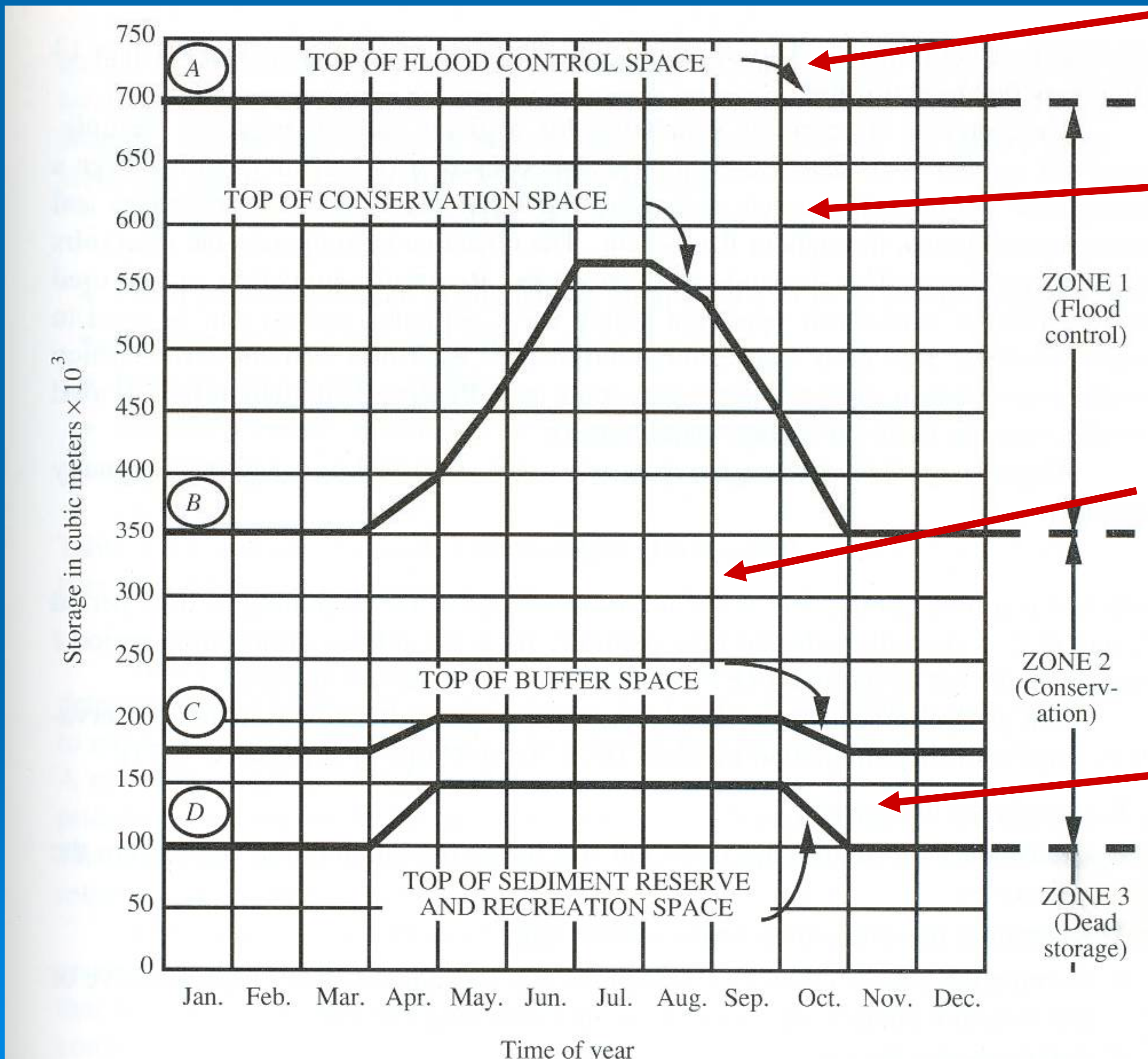

- In the Surcharge pool, all water is released as quickly as possible, without regard to d.s. damage.
- In the Induced Surcharge pool, release as quickly as possible without regard to d.s. damage, but regulation has the opportunity to take flatten the peak.
- In the Flood Pool, regulated discharges evacuate the flood pool as quickly as possible, but constrained by d.s. maximum allowable channel flows and rate of change constraints.

# Operating Policies (Rules)

Rules to achieve demands, flood control policies, low flow requirements and other objectives by specifying:

- Rule curves (reservoir storage over time)
- Release rules – how to release water when the storage is in specified pools.
- The rules are developed to vary seasonally and to account for uncertainties in inflow and demands.

# Rule Curves




Release as quickly as possible, without regard to d.s. damage.

Release down to bottom of flood pool as quickly as possible, but constrained by d.s. maximum allowable channel flows and rate of change constraints.

Meet demands and other objectives, but conserve water as possbile to keep level as close as possible to top of conservation pool.

No water for other objectives, but release as needed and as possible for d.s. low flow augmentation

Design of Outlet works must accomodate the operating policies, release requirements and storage requirements