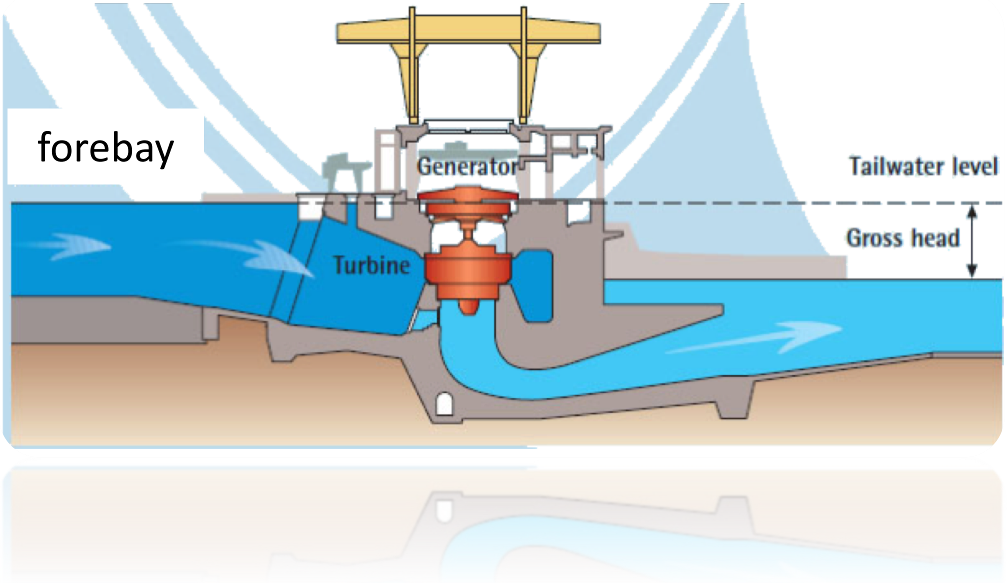
Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

5 ETCS, Master course



Lecture 5-2: Hydropower and energy production 2; other traditional uses

Prof. P. Perona
Platform of hydraulic constructions

How much energy can be extracted from an hydropower site?

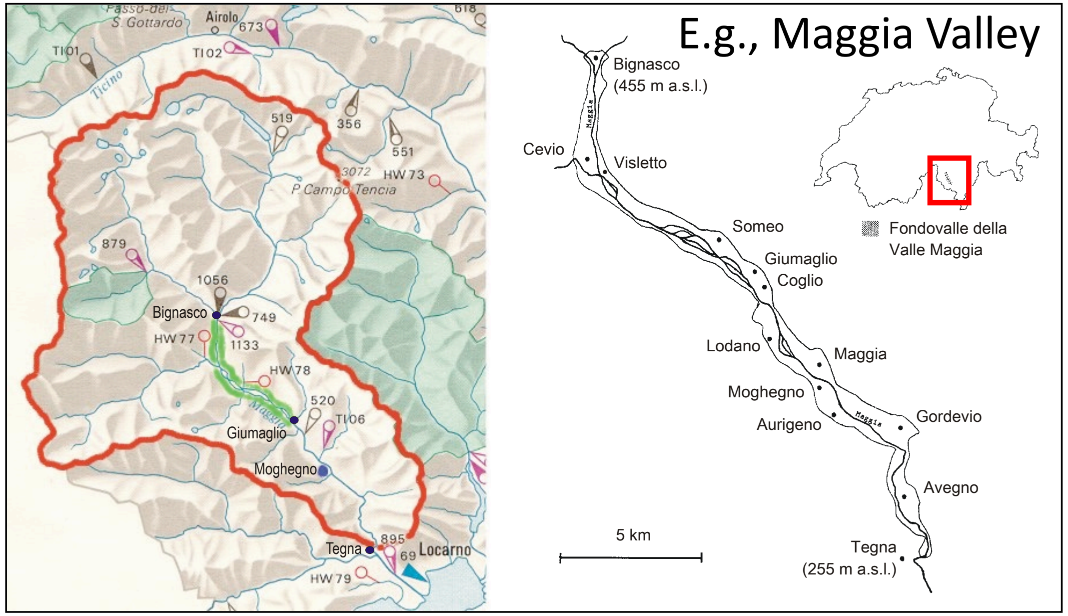
Discharge and head ranges for different turbines

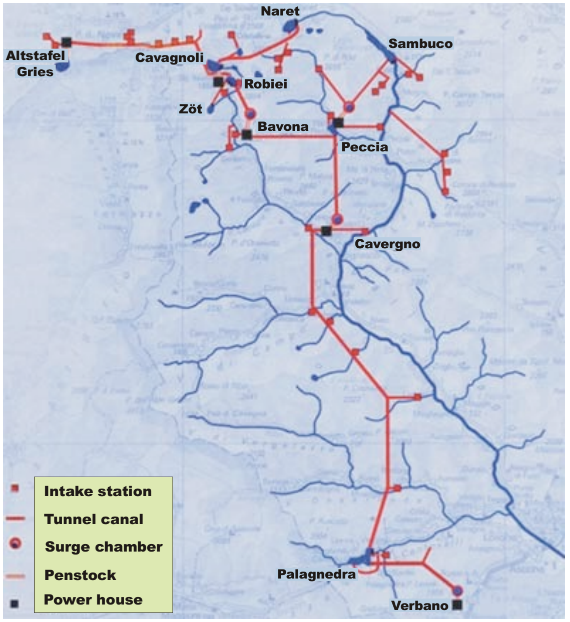
The amount of energy that can be extracted depends also on the type of turbine that will be adopted. There are mechanical limitations for the discharge and the head, which are the two main variables defining the power that can be extracted.

Exemplary data

Turbine type	Ratio of minimum discharge to rated discharge	Ratio of minimum head to maximum head
Francis	0.40	0.50
Vertical-shaft Kaplan	0.40	0.40
Horizontal-shaft Kaplan	0.35	0.33
Fixed-blade propeller	0.65	0.40
Fixed-gate adjustable blade propeller	0.50	0.40
Fixed geometry units (pumps as turbines)	—	0.80
Pelton (adjustable nozzles)	0.20	0.80

Powerplants with storage reservoirs





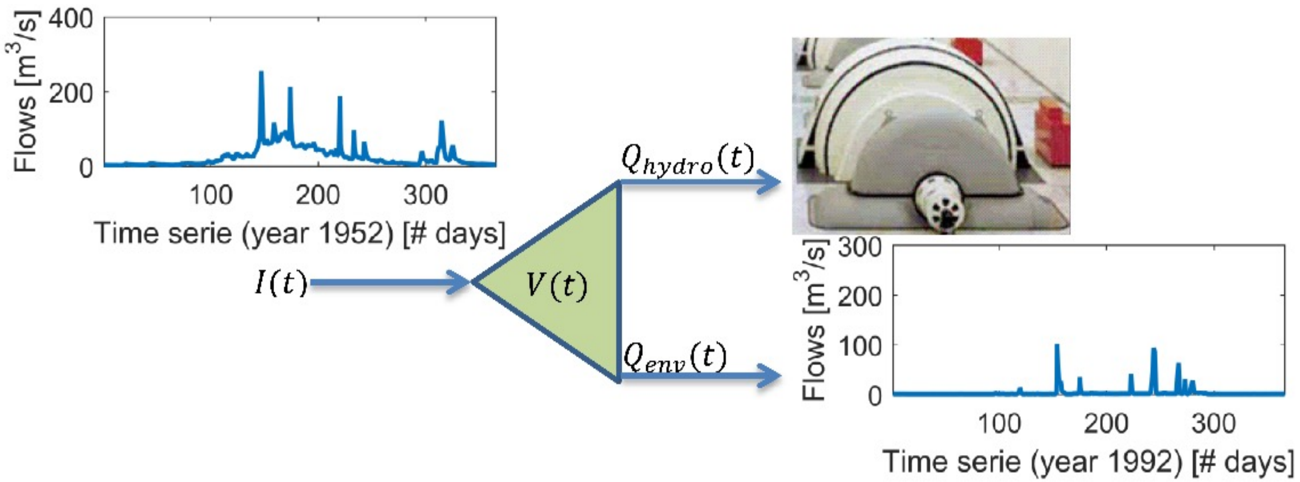
Sequential streamflow routing method

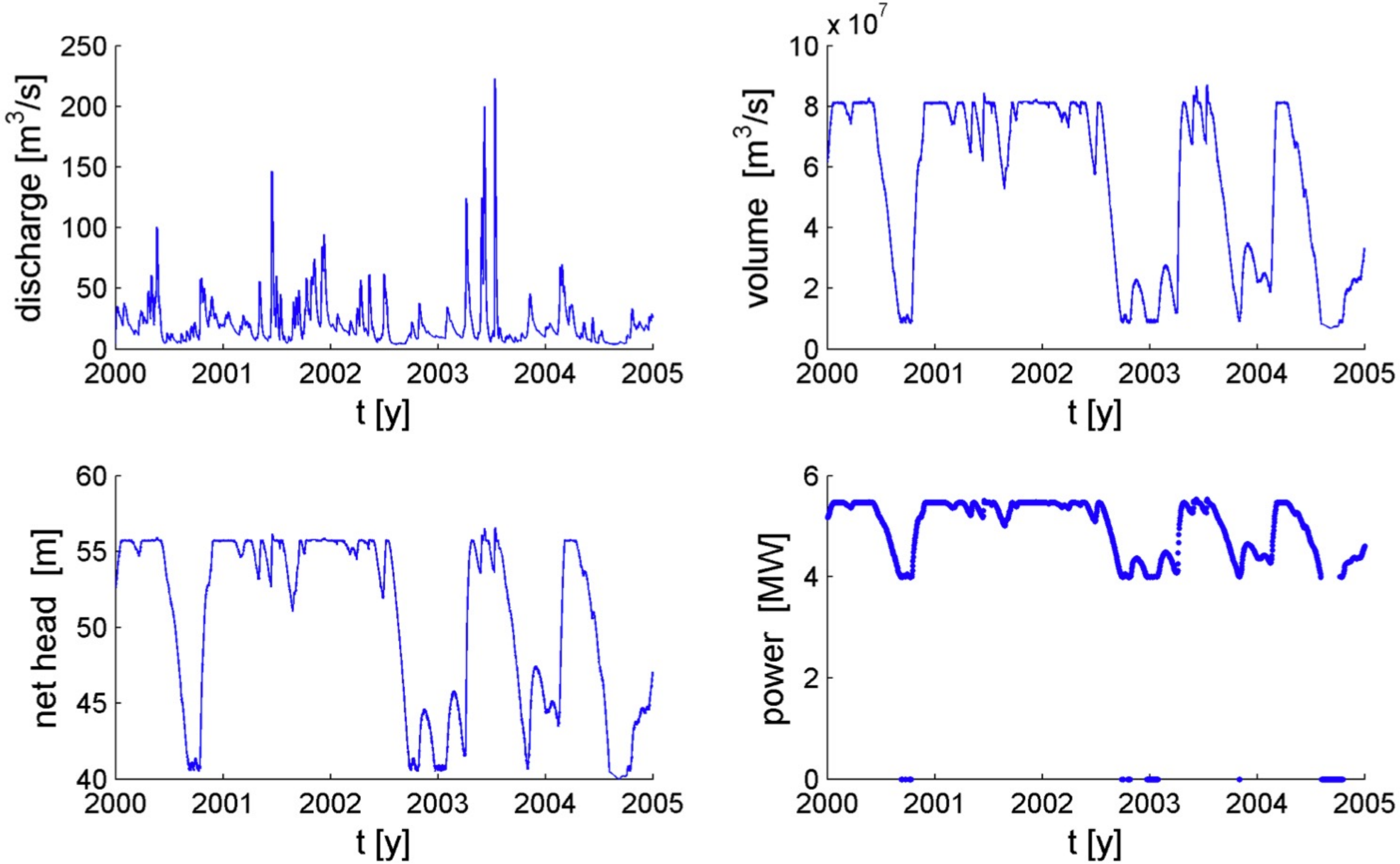
As we have seen, the storage allows for regulation and decisions about when water can or should be turbinated.

$$\frac{dV(t)}{dt} = \mathrm{I(t)} - \mathrm{Q_{env}(t)} - \mathrm{Q_{Hydro}(t)}$$

Storage equation (e.g. reservoir volumes)

How much should Q_{env} be?





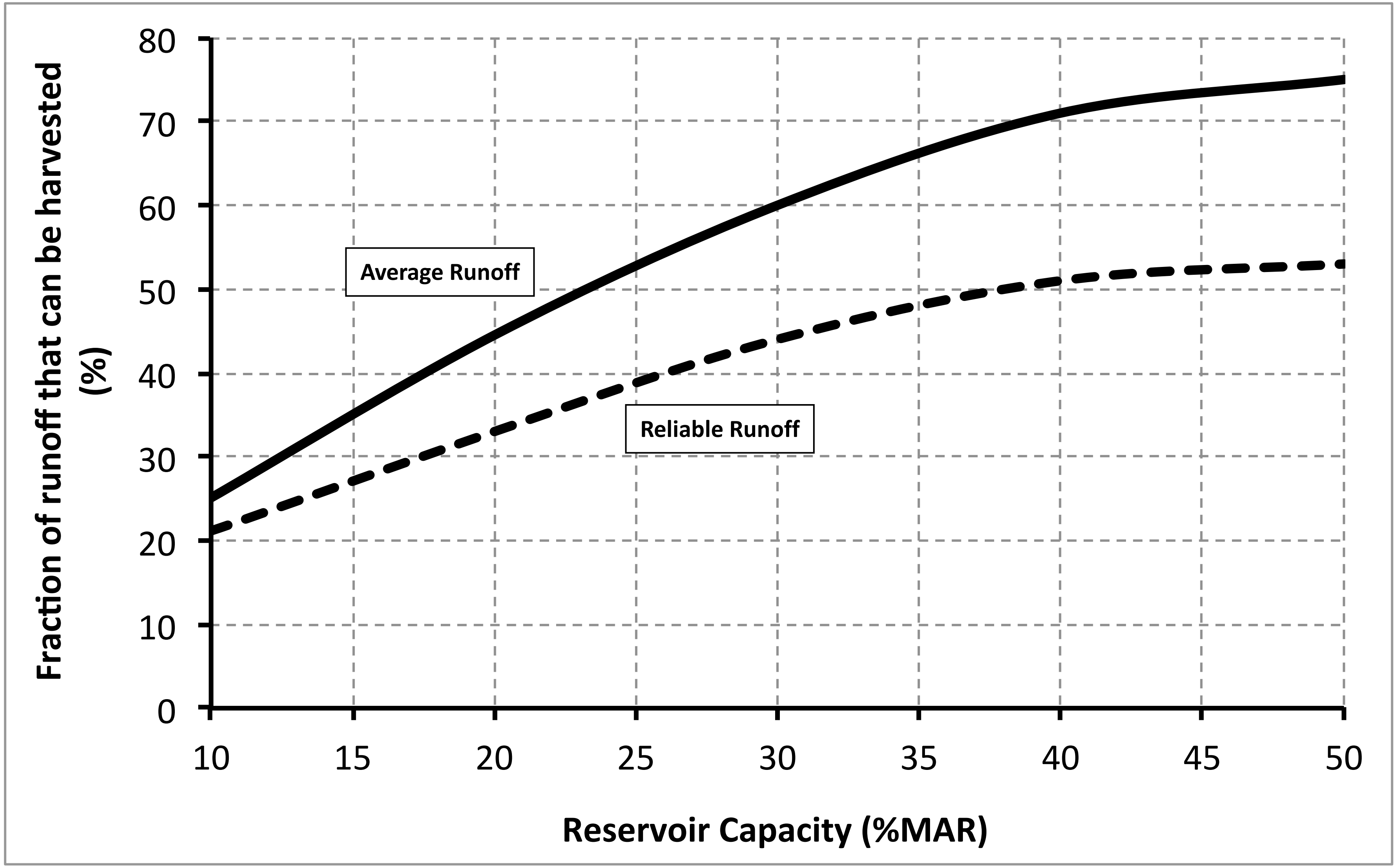
Sequential streamflow routing method: chronological simulation of the system to estimate available streamflow, available net head, energy demand and energy price. Typical numerical analysis for power plant with storage reservoir.

In later lectures we shall see optimisation techniques that serve tofind the best strategy to maximize the benefits

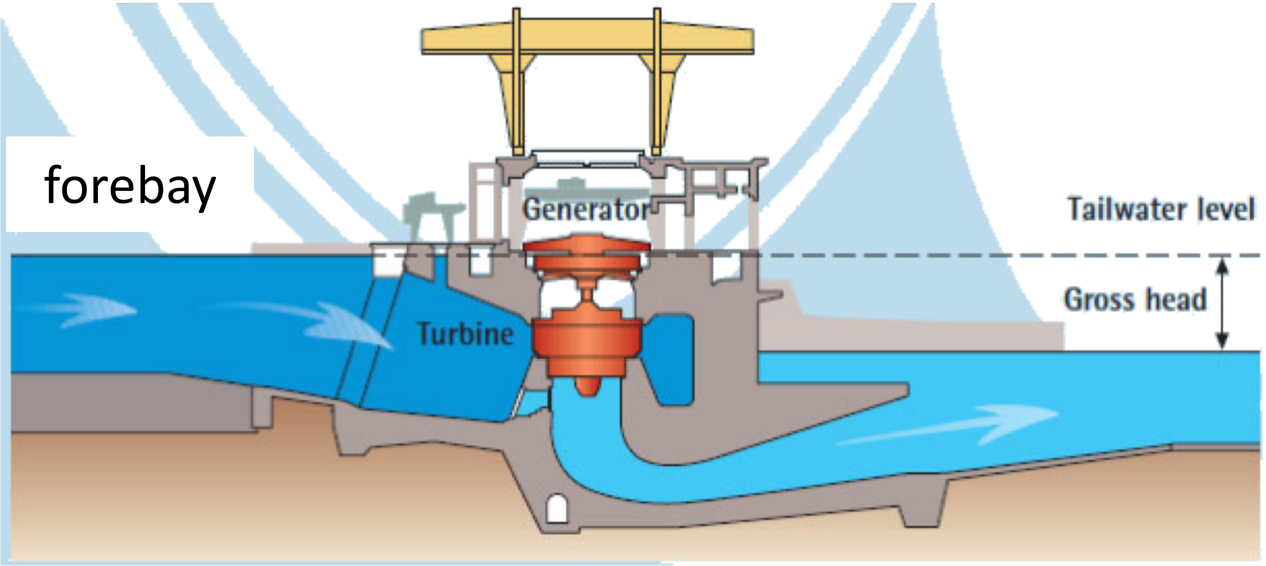
Courtesy of A. Rinaldo

Reservoir regulation curve method

- The amount of the mean annual runoff (MAR) that can be regulated depends upon the reservoir storage available, and is described by the reservoir regulation curves.
- Give an indication of the relationship between reservoir storage, mean annual runoff (MAR), and the proportion of the MAR that can be regulated
- Can be developed for a particular region from a number of simulation studies
- And be used in screening at pre-feasibility level studies



Powerplant without storage reservoir



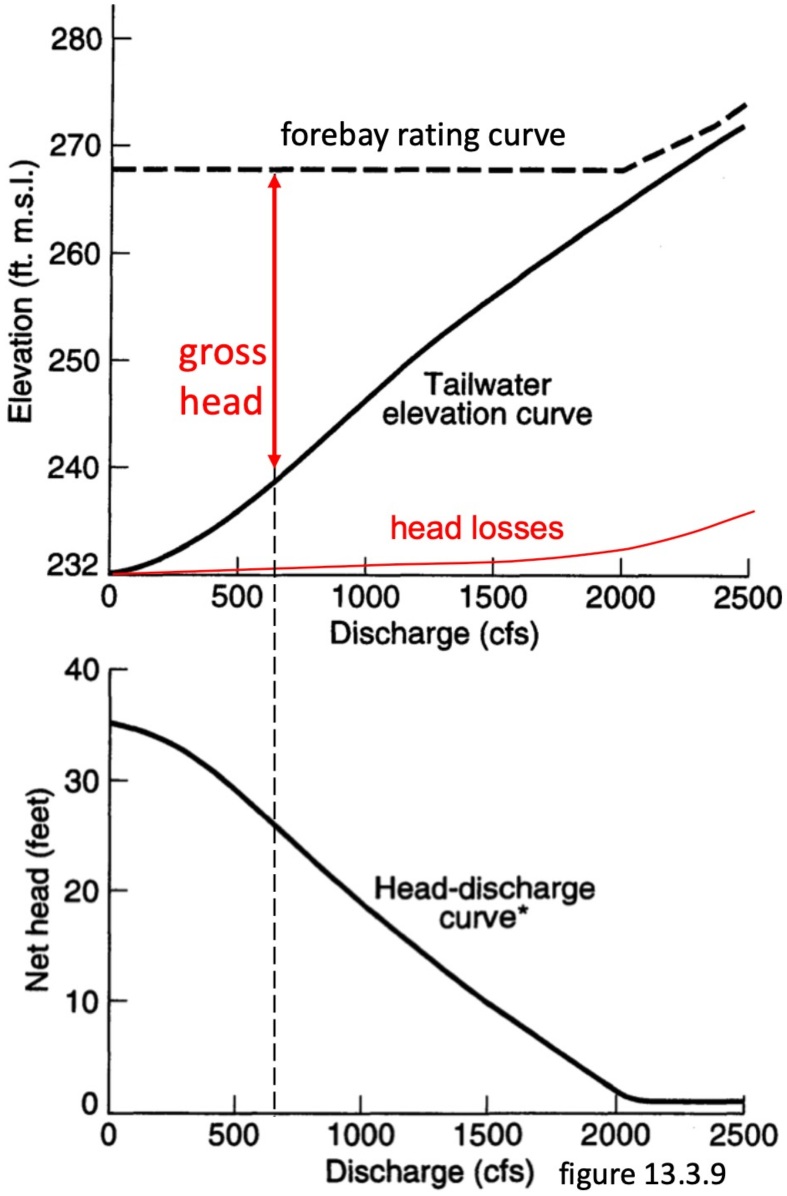


figure 13.3.9

The tailwater rating curve (elevation-discharge) depends on the geometry and on the roughness of the tailwater channel (e.g. open channel uniform flow equation).

The forebay rating curve is constant for a wide range of discharge (hydraulic profile MILD 1) and it increases only when the spillway of the dam is activated.

Head = forebay el. - tailwater el. - head losses

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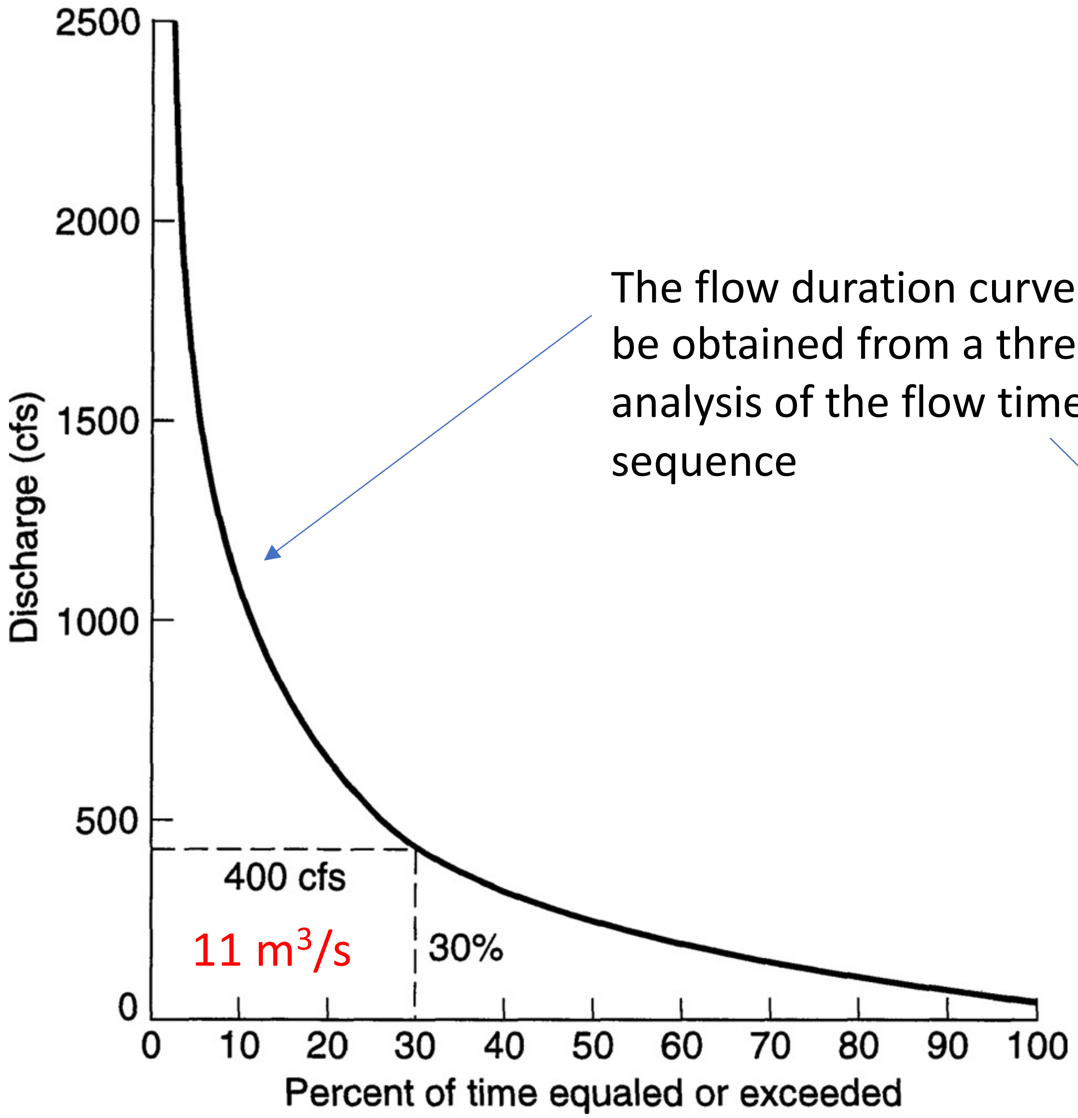
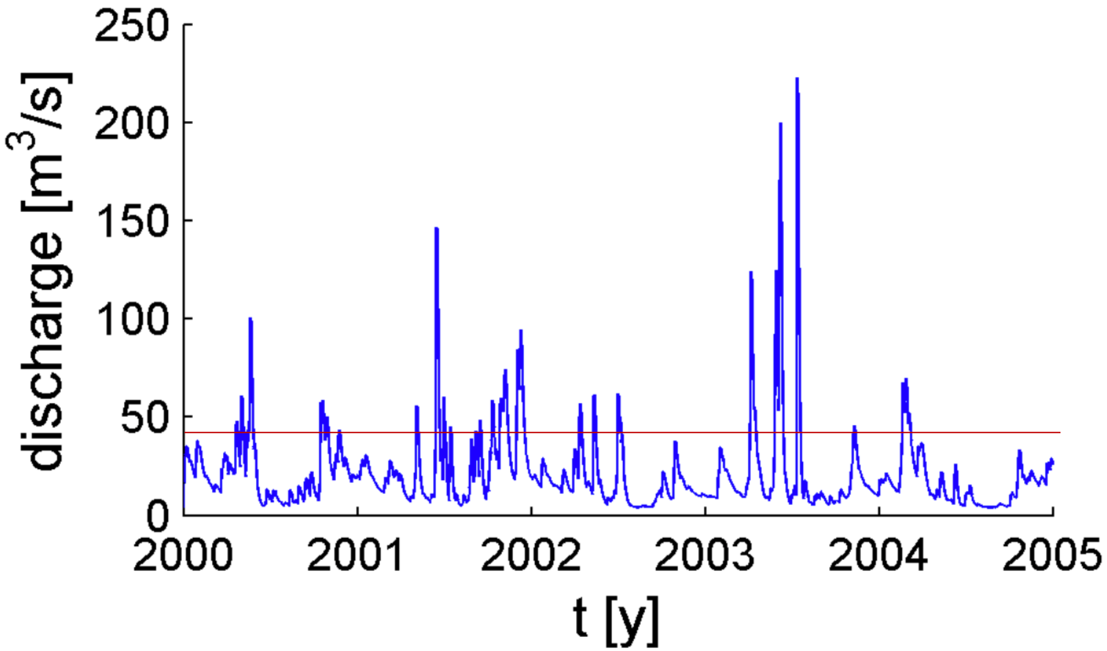
Flow-duration curve method



The flow duration curve can be obtained from a threshold analysis of the flow time sequence

Flow-Duration curve method: uses streamflow data as in duration curve. Typical analysis for run of river and mini-hydropower plants (no appreciable storage)



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Flow-duration curve method: rated discharge for turbines

Selection of hydraulic capacity (i.e. maximum discharge that can be passed through the turbine). In this example the selected hydraulic capacity is 400 cfs (11 m^3/s) which is exceeded 30% of the time.

Selection of turbine. Rated discharge of turbine = Hydraulic capacity. Rated head of turbine = head corresponding to hydraulic capacity. With this quantities, one can select a specific turbine. Hydraulic limits of the turbine (minimum discharge and minimum head) impose limits on the range of river discharge at which the plant can work.

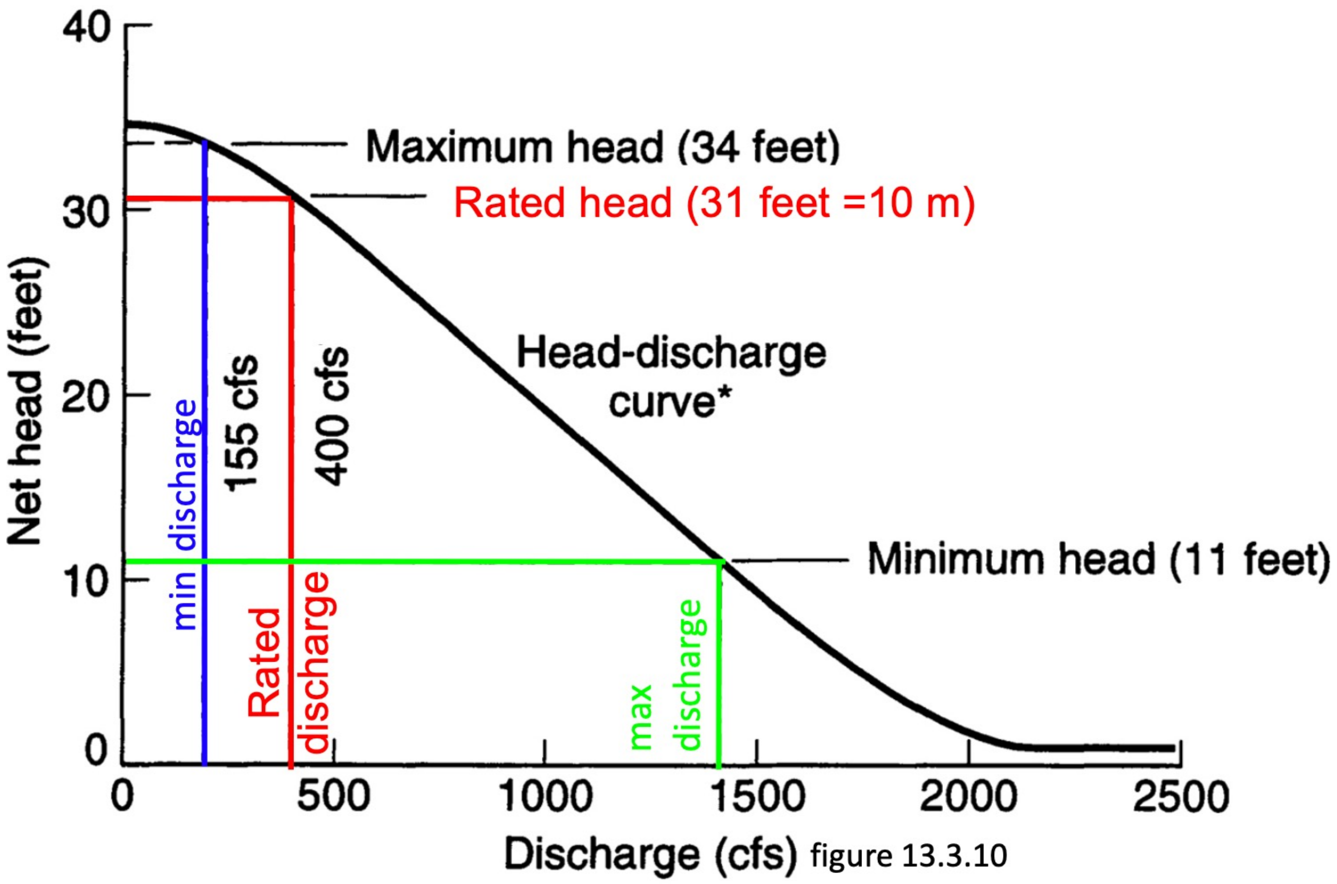

figure 13.3.10

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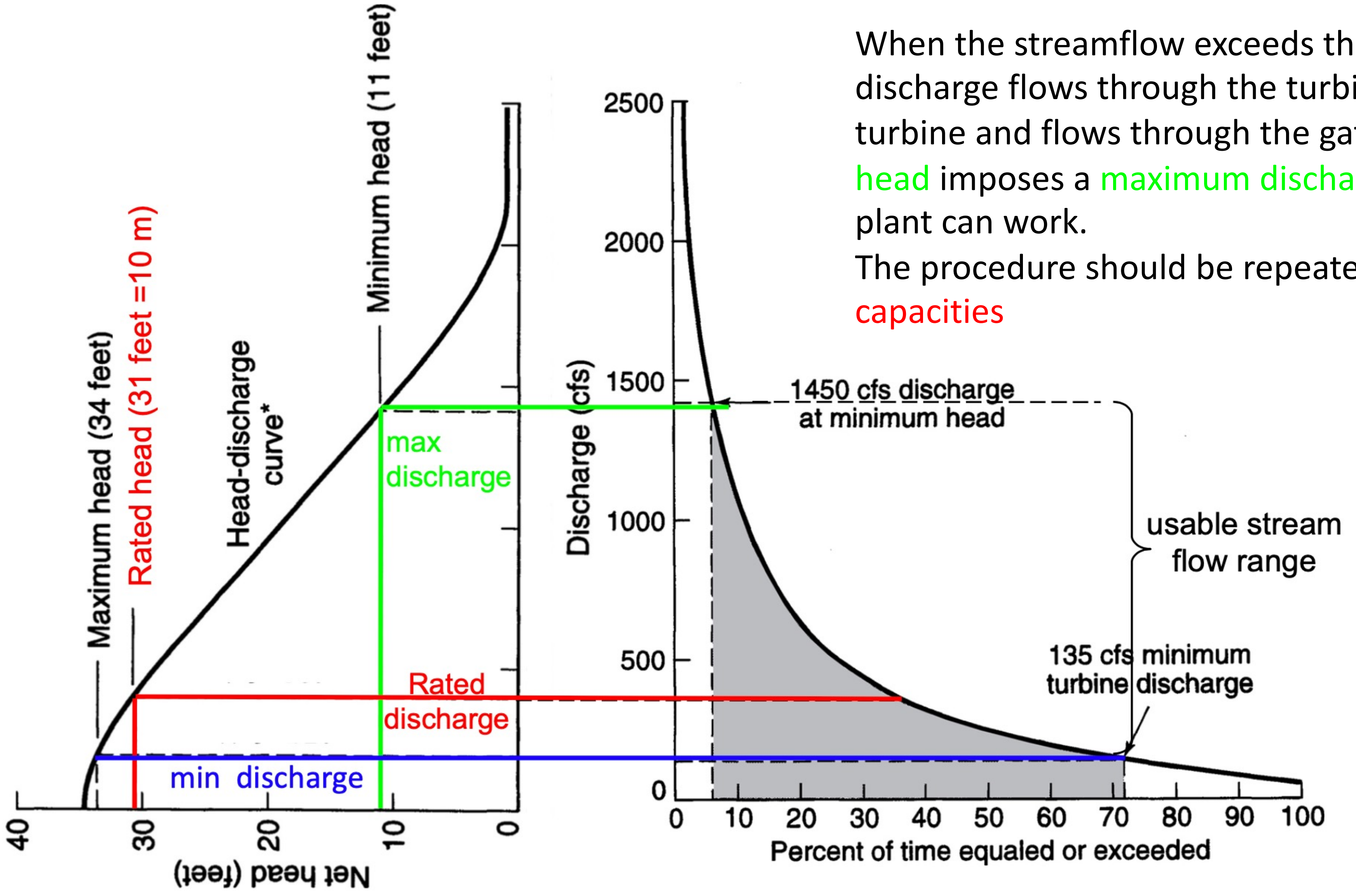
Flow-duration curve method: maximum capacity

When the streamflow exceeds the rated discharge, only the rated discharge flows through the turbine, the remaining flow bypass the turbine and flows through the gate or over the spillway. The minimum head imposes a maximum discharge in the river at which the power plant can work.

The procedure should be repeated for different maximum hydraulic capacities



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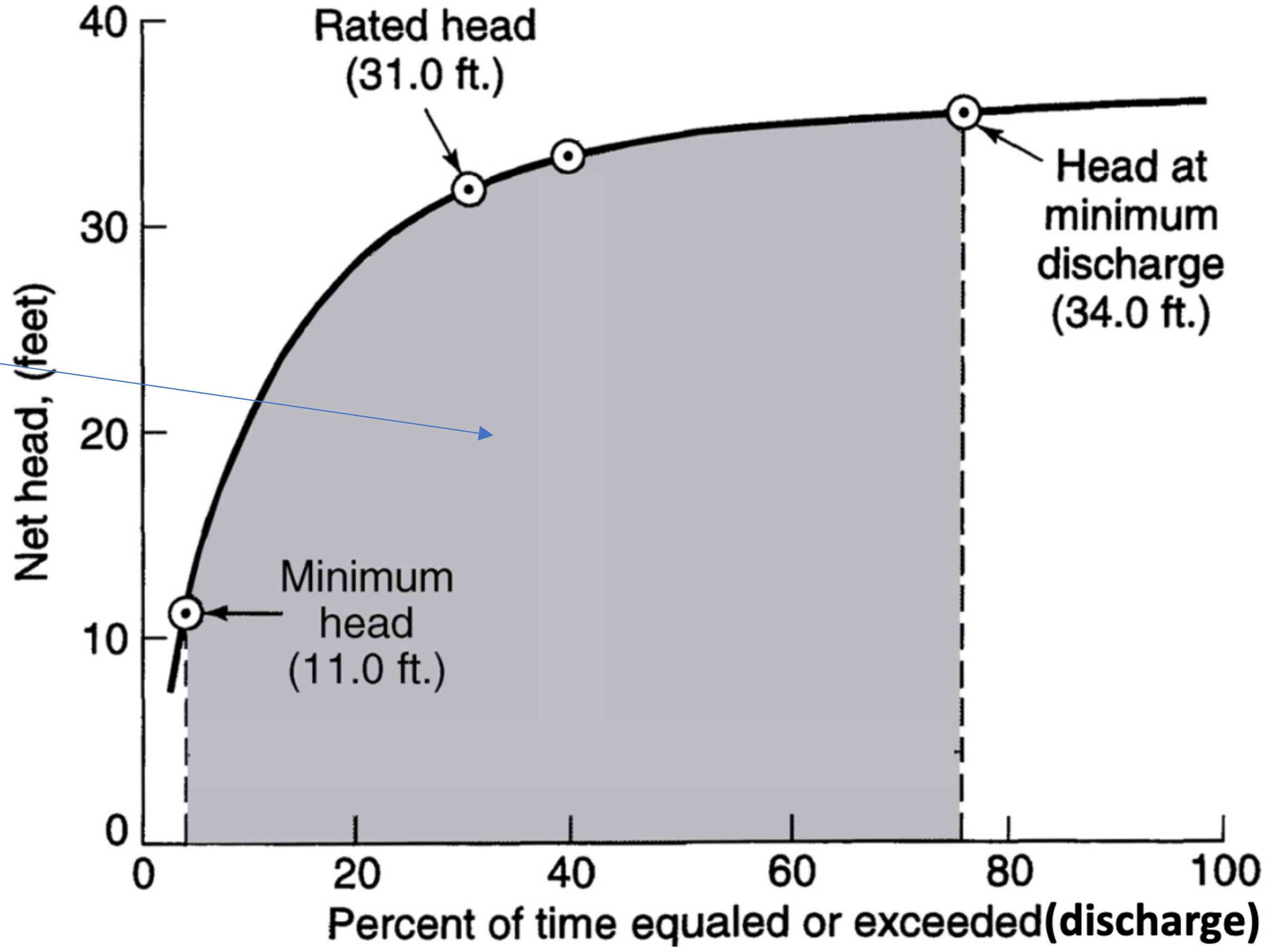
Flow-duration curve method: Head curve

Using the flow-duration curve and the head-discharge curve (plots of the previous slide) it is possible to derive the head curve

shaded area: head range where energy is produced



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Flow-duration curve method: generation curve

Using the flow-duration and the head- duration curves, it is possible to derive the generation curve.

potential generation: potential energy that can be extracted from the site without accounting for the limitations imposed by the turbine:

potential power = $\eta * \gamma *$streamflow*head

usable generation: generation that can be achieved by a specific turbine

actual power = $\eta * \gamma$ *turbine discharge*head

where the turbine discharge is the minimum between the stream and the rated discharge. In preliminary study, a constant efficiency h can be assumed. In the path ABC, the turbine discharge is equal to the rated one and the generation is limited by the head. In the path CD the turbine discharge matches the stream discharge and the generation is limited by insufficient streamflow.
This figure is not a power-duration curve because the x-axis refers to the streamflow (not to the power) exceedance probability.

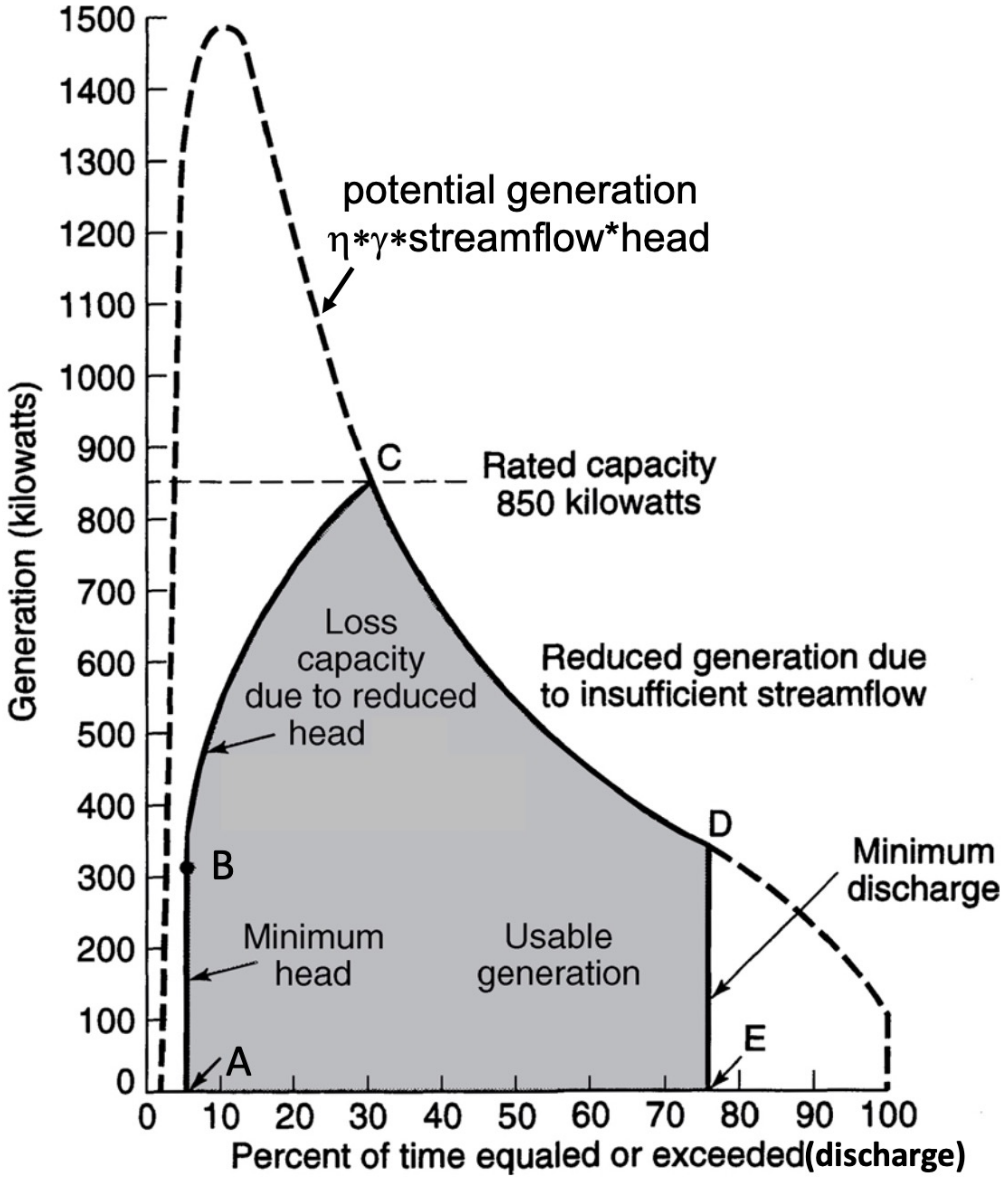
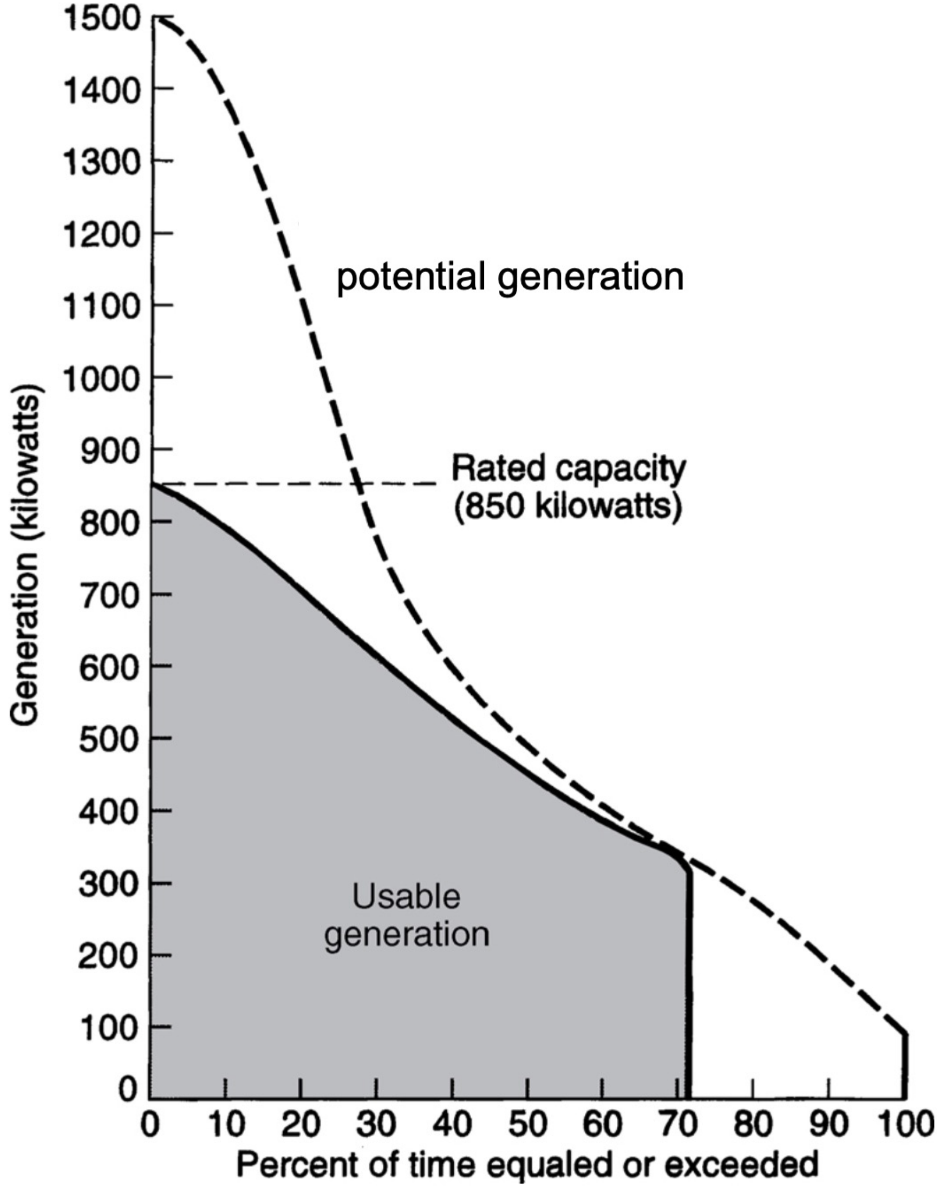


figure 13.3.13

Flow-duration curve method: power generation curve

Sorting the values of the previous plot for both the potential and the usable generation, one finally gets the power- duration curve. The ratio between the usable energy and the potential energy represents the fraction of energy that the turbine can extract form the site.

The procedure should be repeated for different rated capacities and different turbines to determine which combination is able to maximize the usable energy.



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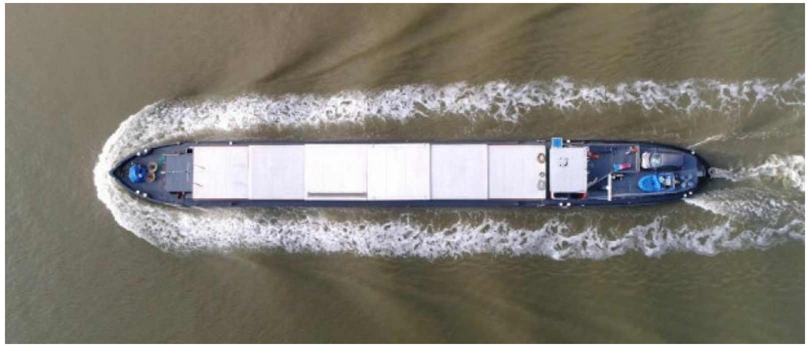
Other traditional uses: Navigation and flood protection (control)

Navigation

- Rivers (e.g., Main, Rheine,)
- Lakes (e.g., Thun, Zurich, Boden, Lemann)



Impose constraints on minimum streamflow, water level, maximum streamflow

Constraints may cause environmental problems, their values must be compromised

Flood protection and control

- Typically this condition plays the role of a constraint (maximum flow) for the river system at a certain location in order to protect downstream vulnerable points
- E.g., see the Murgenthal condition on the Aare maximum discharge ca. 800 m^3/s

Imposing a limit on river discharge, often means to accumulate the water in an upstream reservoir or lake

Flood protection and regulation are planned on a risk analysis basis

Risk = Occurrence probability x Losses

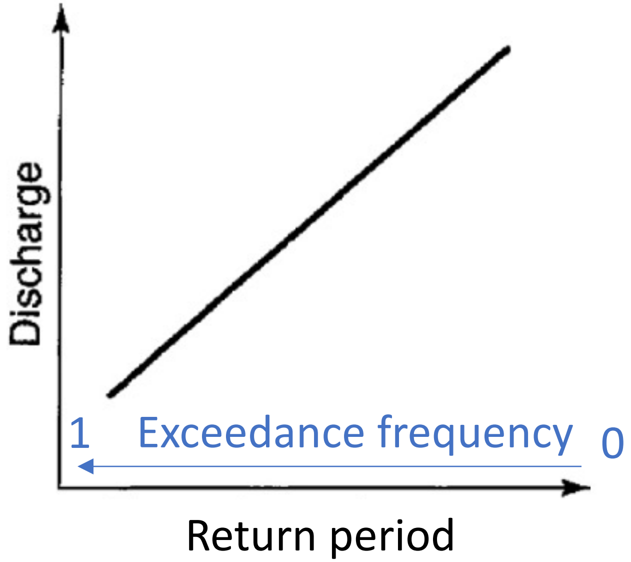
		Impact (1-5)				
		Very Low (1)	Low (2)	Medium (3)	High (4)	Very High (5)
Likelihood (1-5)	Very High (5)					
	High (4)					
	Medium (3)					
	Low (2)					
	Very Low (1)					

Flood control

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

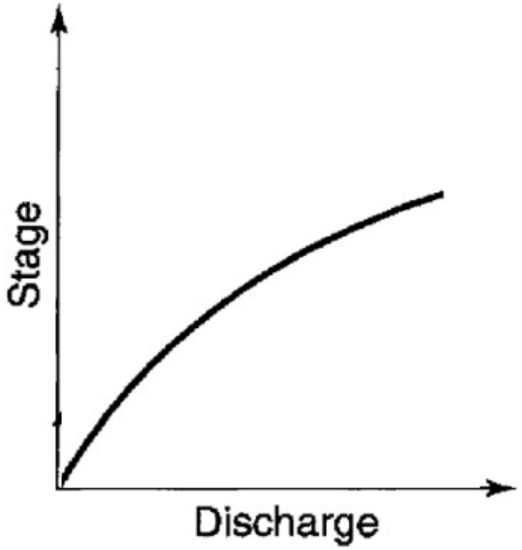
flood control analysis

hydrologic analysis



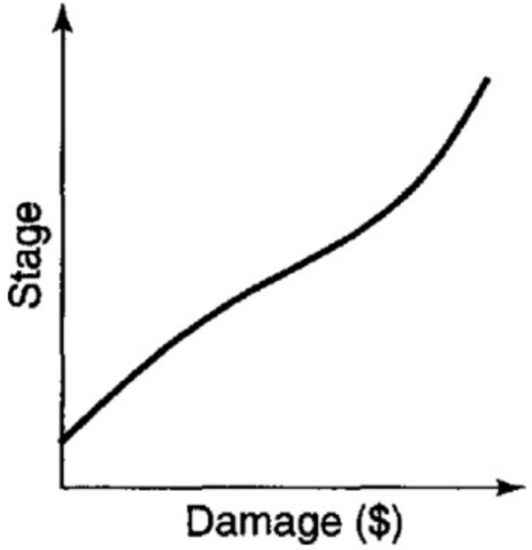
determination of the probability of a certain discharge

hydraulic analysis



determination of the water stage corresponding to a certain discharge

damage analysis



determination of damage caused by a certain water stage

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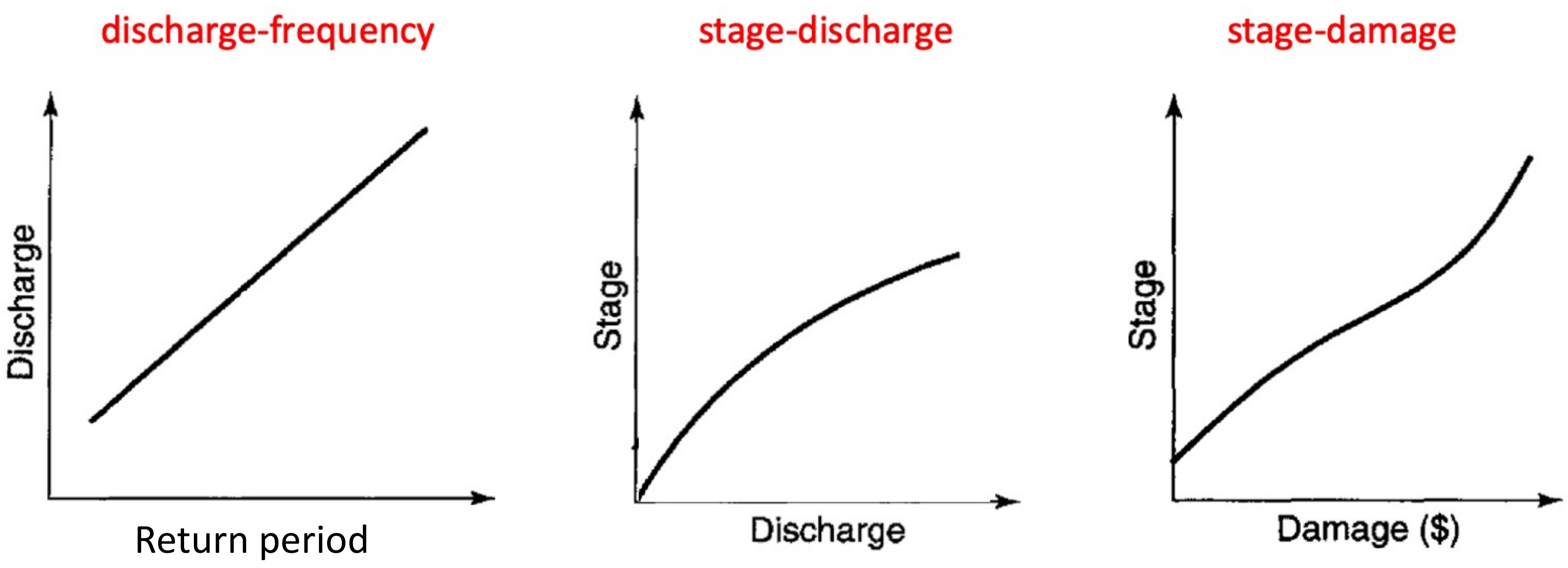
Flood control measures

Flood control facilities or interventions are aimed to reduce or manage damage and losses due to flooding. These interventions modify one or more of the three relationships reported below.

They can be subdivided into:
structural measures. They modify the flood characteristics: e.g. reservoirs, diversions, levees, channel modifications;
non-structural measures. They modify the damage susceptibility of floodplains: e.g. flood proofing, flood warning and land-use controls.



Flood control measure typically modify the relationships above, thus addressing the problem from conceptually different point of views

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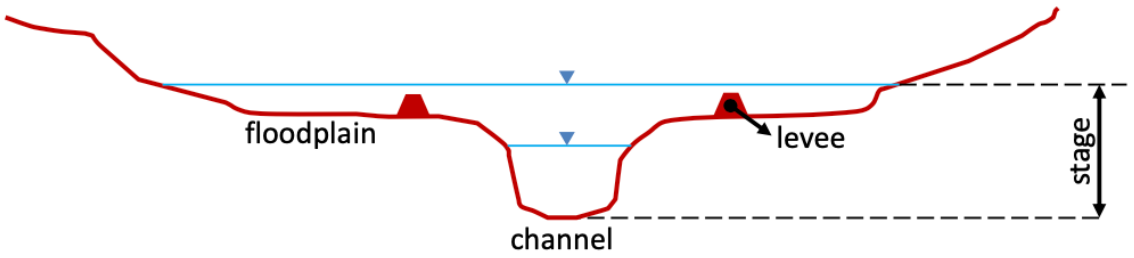
Flood control measures

The aim of flood control measures is to reduce damage through:

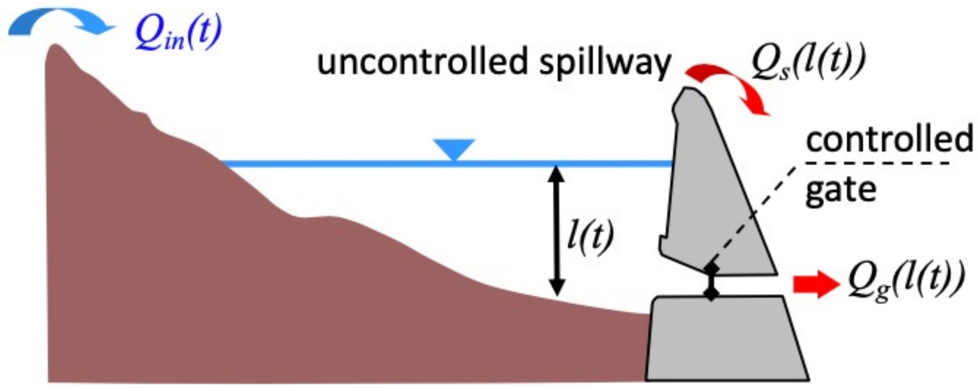
- actions that modify the flood;
- actions that reduce the susceptibility to floods;
- actions that assist individuals and communities in responding to floods.

Floodplains

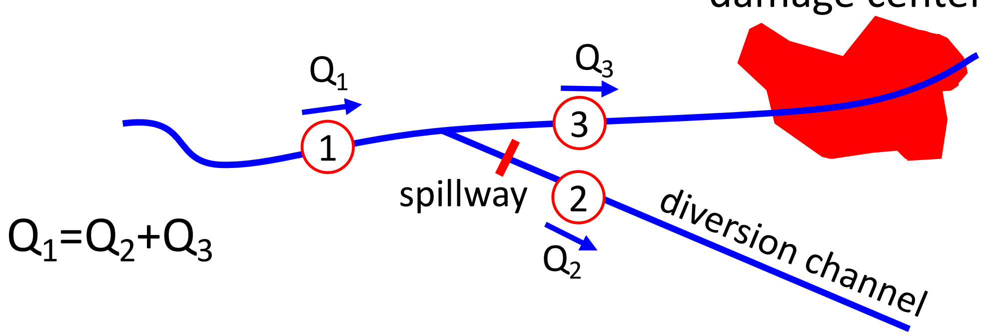


During large floods, the floodplain acts both as a conveyance and as a temporary storage for flood flows

Reservoirs (multipurpose or detention) :
Part of the volume of a reservoir can be used for flood control



Diversions: intermittent functioning to by-pass critical areas during potentially dangerous flood events



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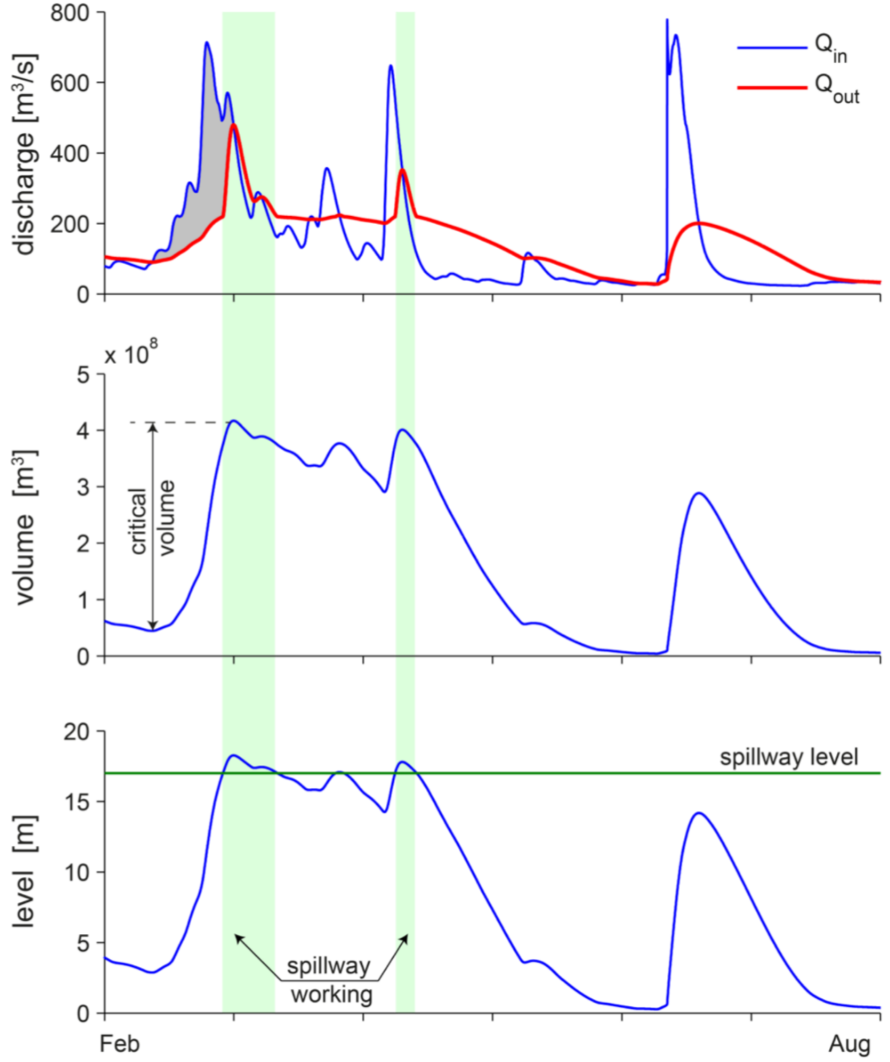
Impact of flood-damage-reduction measures

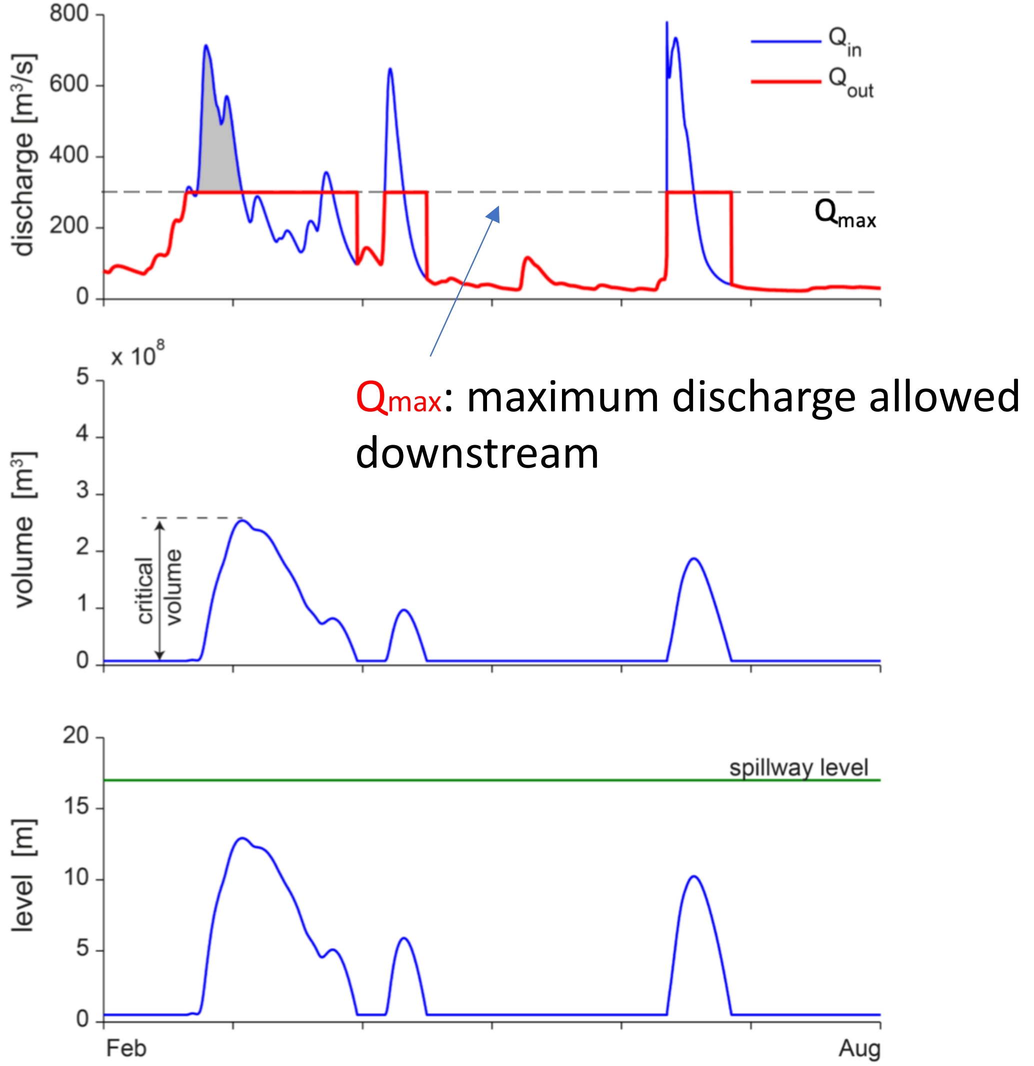
Measures	Impact of measure		
	Modifies discharge-frequency function	Modifies stage-discharge function	Modifies stage-damage function
Reservoir	Yes	Maybe, if stream and downstream channel erosion and deposition due to change in discharge	Maybe, if increased development in floodplain
Diversion	Yes	Maybe, if channel erosion and deposition due to change in discharge	Maybe, if increased development in floodplain
Channel improvement	Maybe, if channel affects timing and storage altered significantly	Yes	Not likely
Levee or floodwall	Maybe, if floodplain storage no longer available for flood flow	Yes	Yes
Floodproofing	Not likely	Not likely	Yes
Relocation	Not likely	Maybe, if flow obstructions removed	Yes
FWP plan	Not likely	Not likely	Yes
Land-use and construction regulation	Not likely	Maybe, if flow obstructions removed	Yes
Acquisition	Not likely	Maybe, if flow obstructions removed	Yes

Flood control through reservoirs

Example of flood attenuation through a reservoir with a fixed gate (fixed opening) and an uncontrolled spillway.



Optimization of the critical volume for flood control through varying gate opening.



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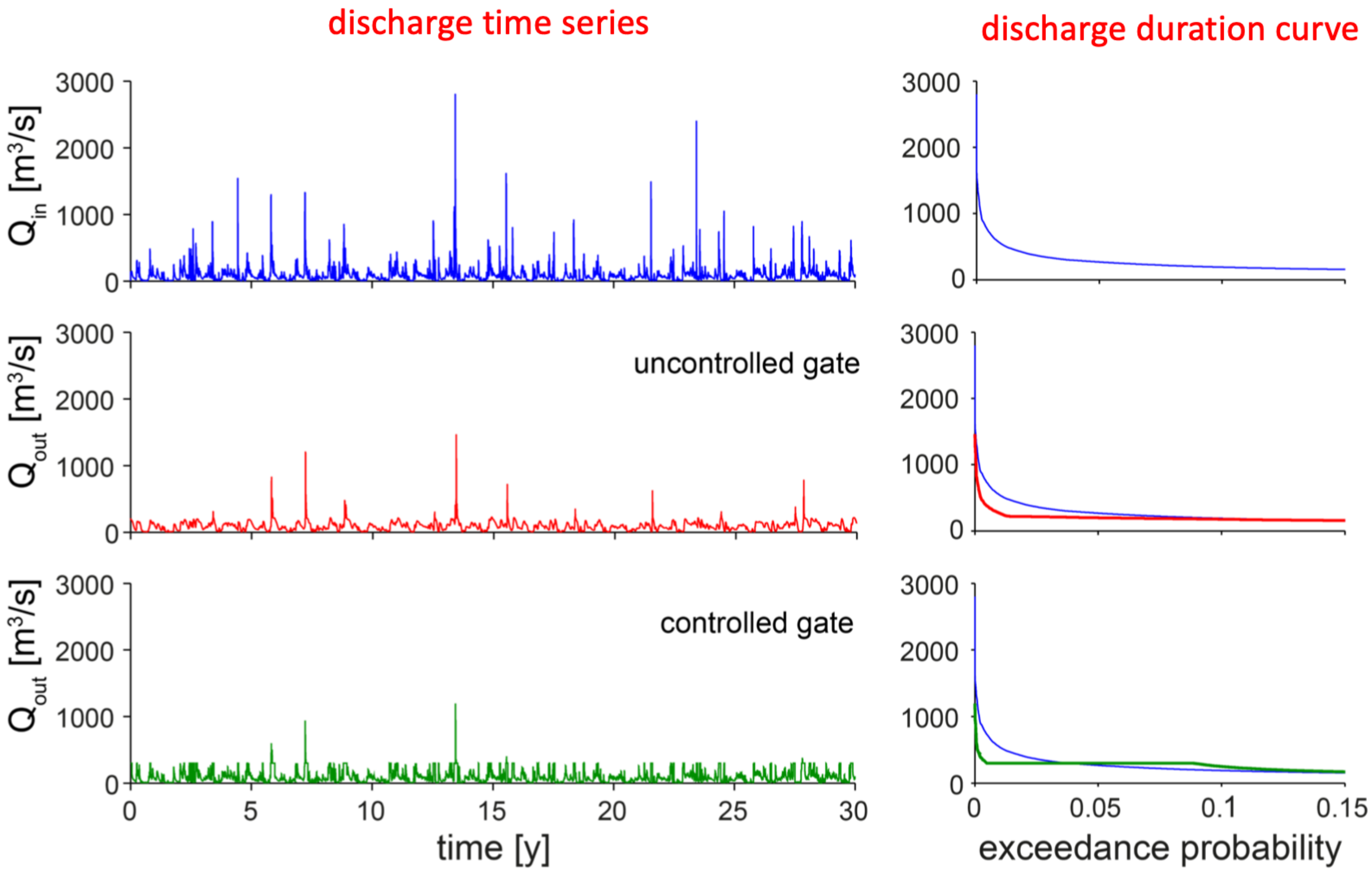
Flood control through reservoirs



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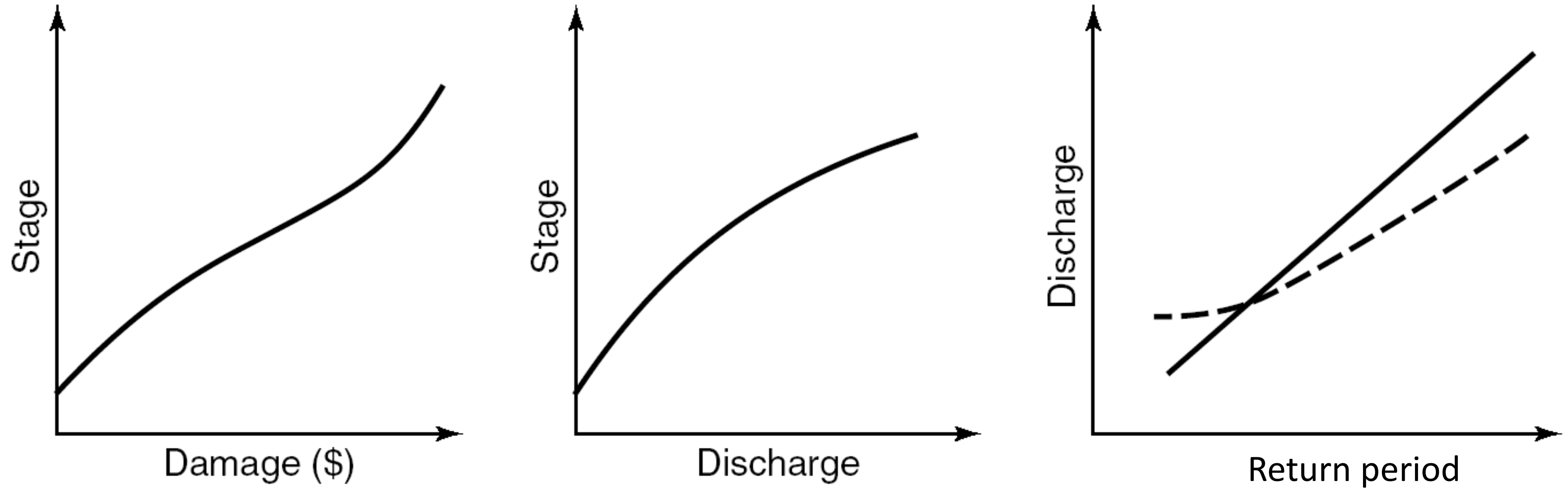
Flood control through reservoirs



As the reservoir controls the output flow, as a measure is acting on modifying the exceedance frequency rather than the stage vs discharge or the stage versus damage curves