PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Water Resources Engineering and Management

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

5 ETCS, Master course

Lecture 5-3: Flood protection measures; non-traditional uses

Prof. P. Perona
Platform of hydraulic constructions

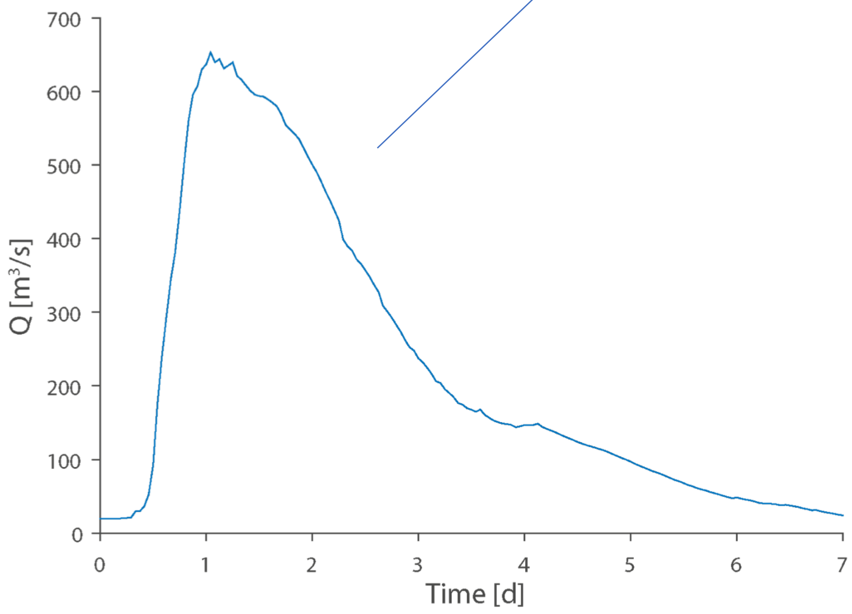
EPFL

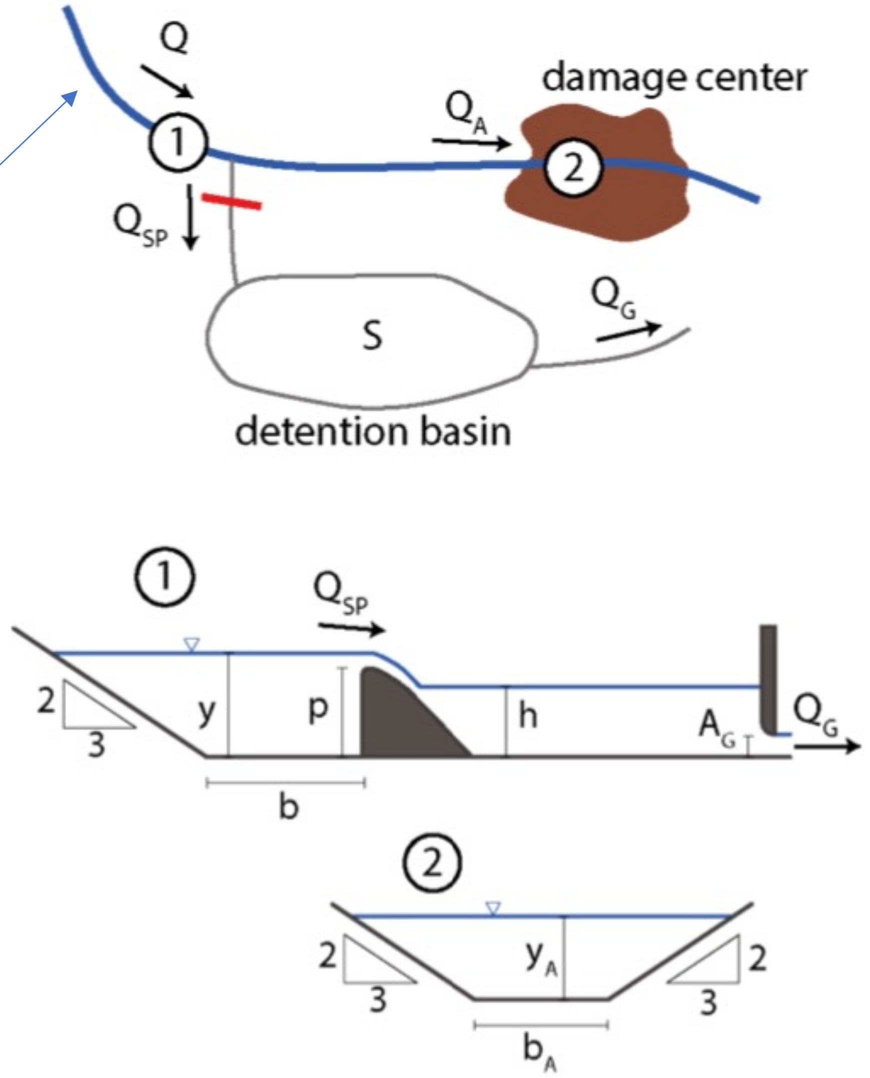
Design of a detention basin

Assumptions

- A realistic hydrograph is used.
- The spillway has finite length L.
- Trapezoidal river cross-sections.
- Uncontrolled sluice gate (area AG) that allows emptying of the basin. Water is delivered further downstream.
- Submerged flow conditions are taken into account.

Parameter	Value	Unit
b	25	m
b_A	20	m
s_0	0.001	-
K_s	35	$m^{1/3}s^{-1}$
L	20	m
S	800000	m^2
A_G	10	m^2
$C_{Q,SP}$	0.45	-
$C_{Q,G}$	0.4	-





Stage-discharge rating curve: it can be reconstructed from Manning-Strickler's formula:

$$Q = A K_s \sqrt{s_0} R_H^{2/3}$$

Discharge through the spillway:

- If $h < p$ (free flow):

$$Q_{SP} = C_{Q,SP} L \sqrt{2g} (y-p)^{1.5}$$

- If $p < h < y$ (submerged flow):

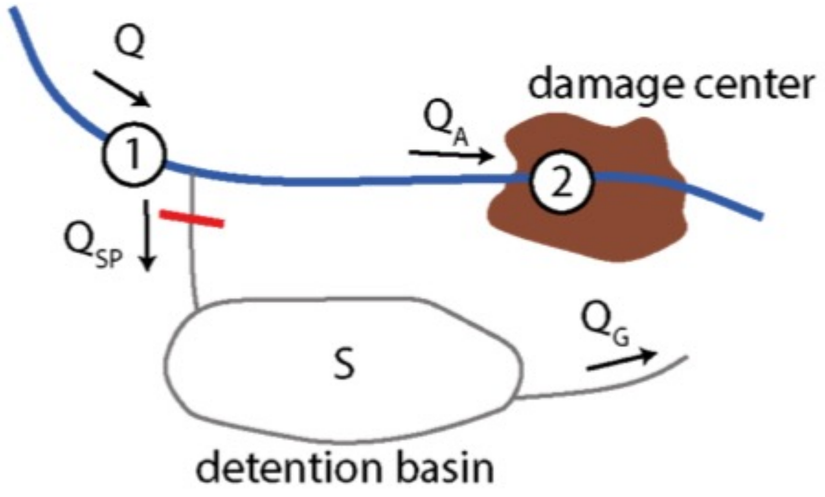
$$Q_{SP} = \left(1 - \frac{h-p}{y-p}\right) C_{Q,SP} L \sqrt{2g} (y-p)^{1.5}$$

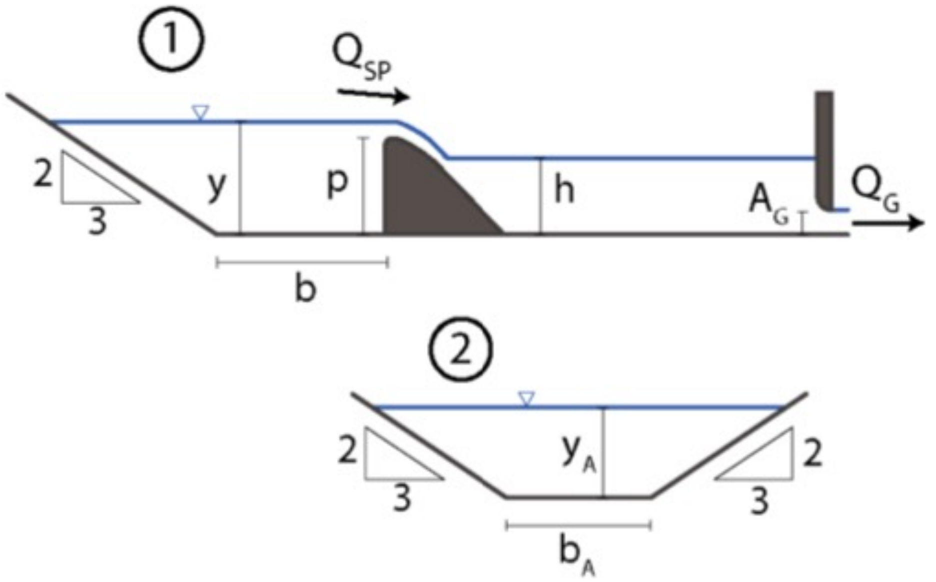
- If $y < h$ (water flows back to the river):

$$Q_{SP} = -\left(1 - \frac{y-p}{h-p}\right) \frac{C_{Q,SP}}{3} L \sqrt{2g} (y-p)^{1.5}$$

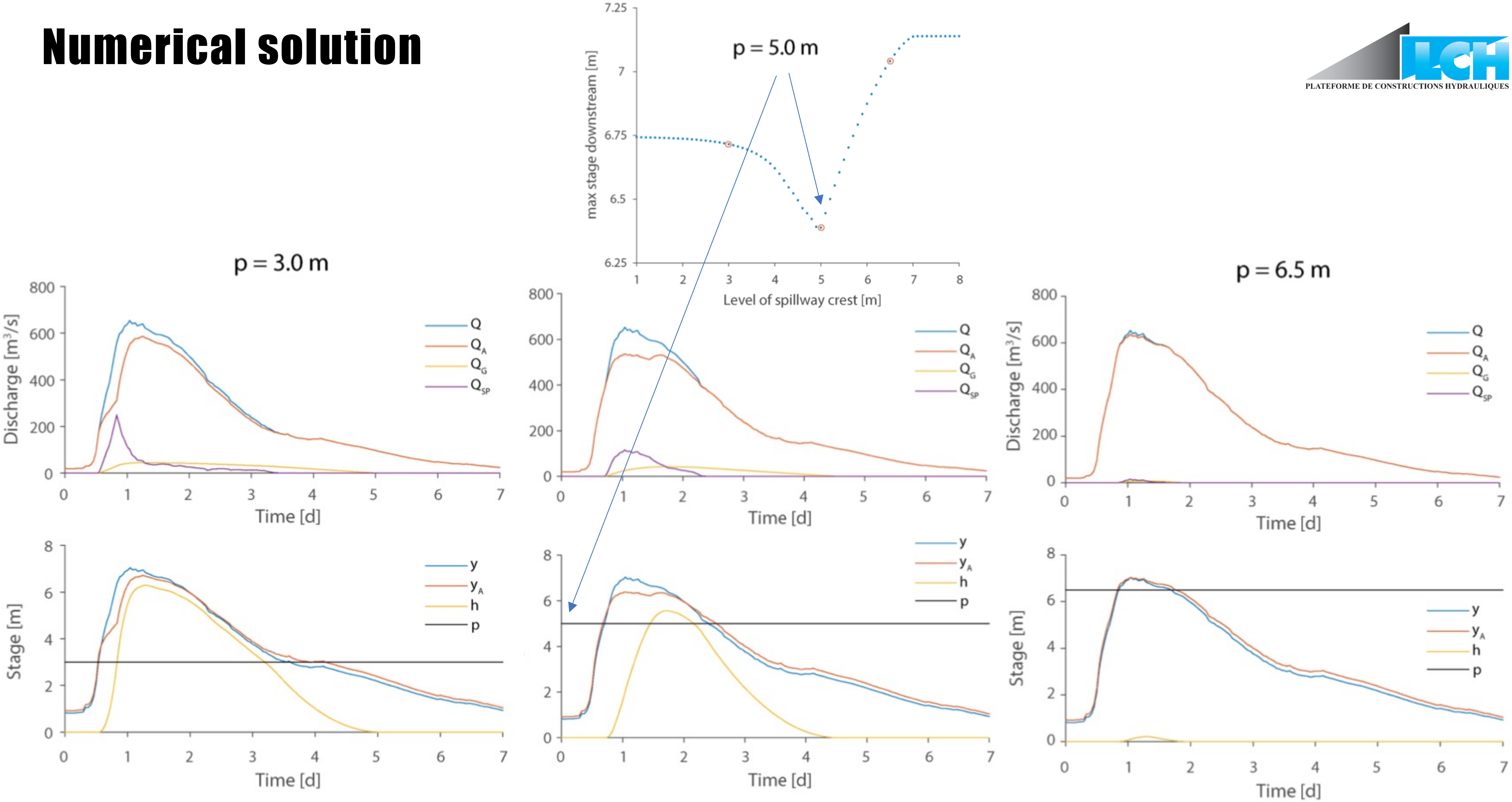
Discharge through the sluice gate: $$Q_G = C_{Q,G} A_G \sqrt{2gh}$$

Storage equation for the basin: $$S \frac{dh}{dt} = Q_{SP} - Q_G$$

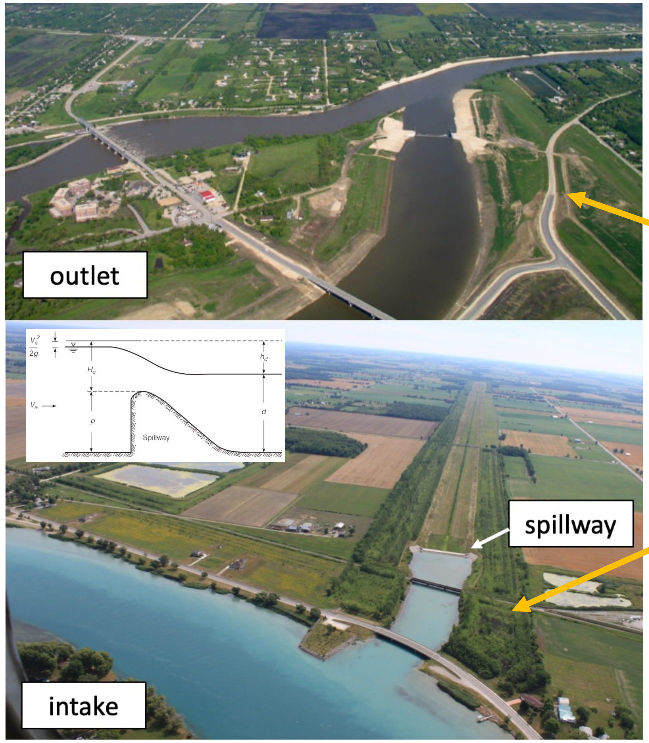




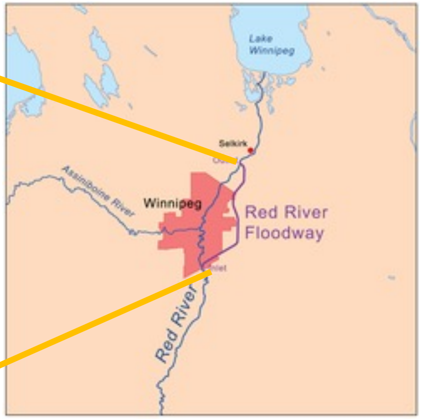
Numerical solution

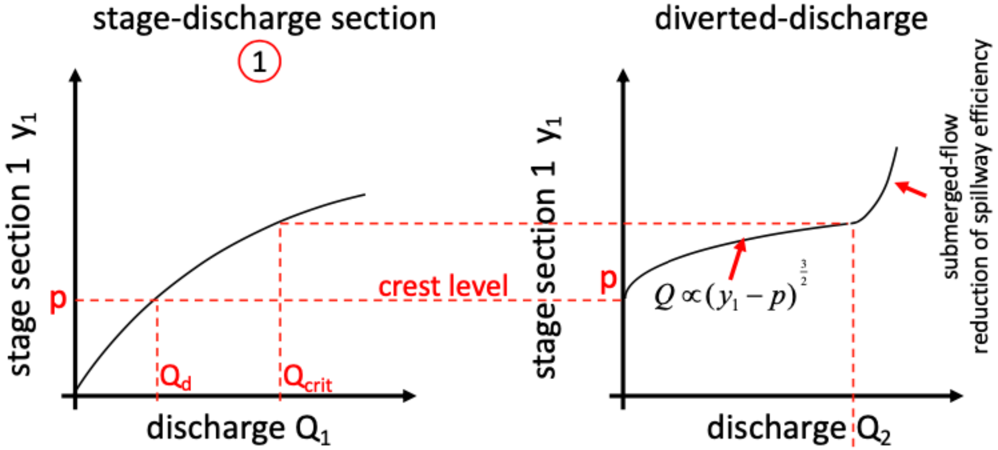


Structural measures: diversions

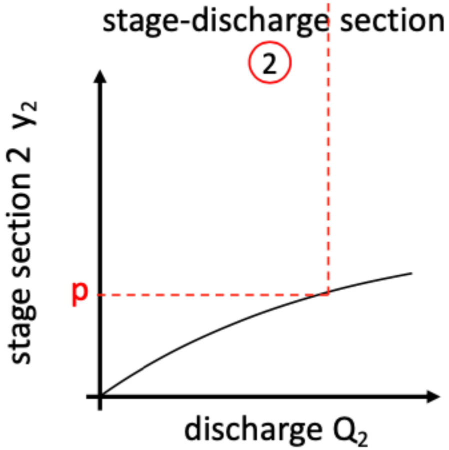


Diversion structures are used to reroute or bypass flood flows from damage centers in order to reduce the peak flows at the damage centers.

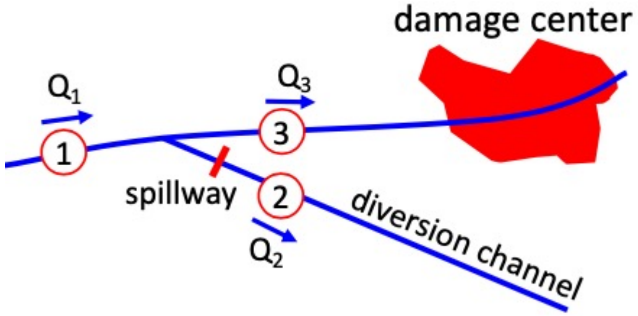




- The diversion channel is activated when $Q_1 > Q_d$ ($y_1 > p$).



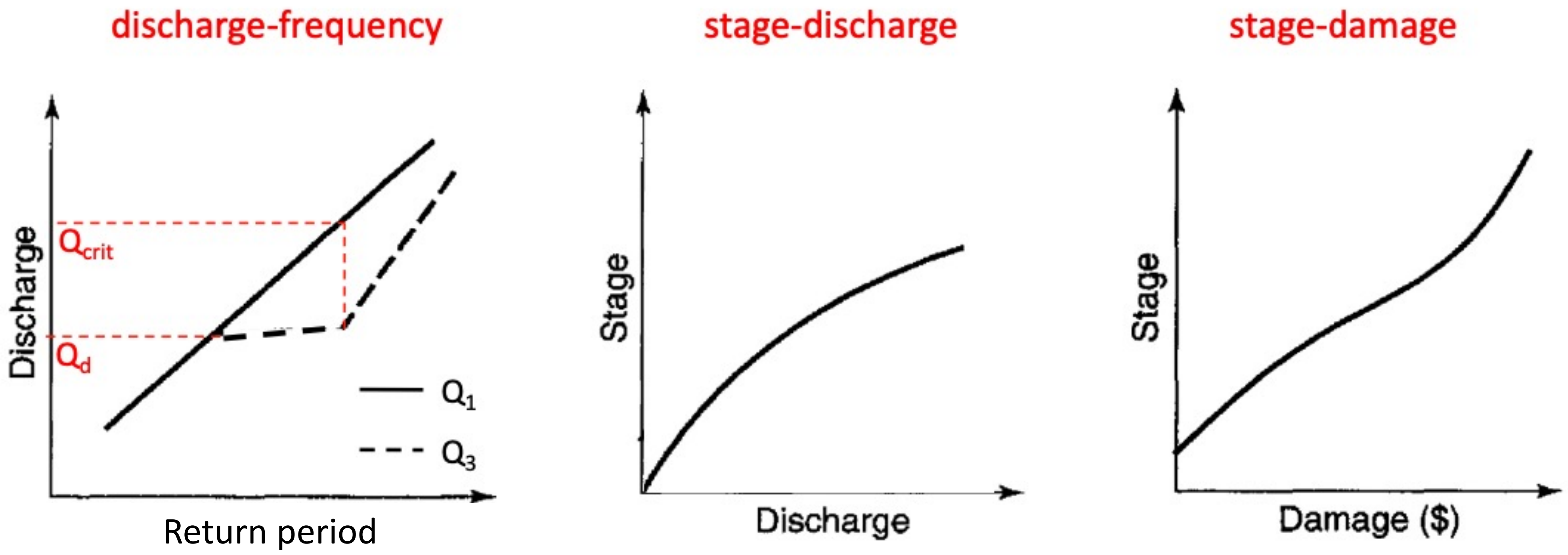
- When the diverted discharge Q_2 is such that the stage in section 2 (y_2) equals the spillway crest level ($y_2 = p$)



- The discharge in section 1 at which submerged-flow occurs is term critical (Q_{crit}) → reduced spillway efficiency

Courtesy of A. Rinaldo

Diversion structures are designed to modify (lower) the frequency curve so that the flow magnitude for a specific event is lowered. When floods exceeds the critical discharge Qcrit, floods are not efficiently attenuated.



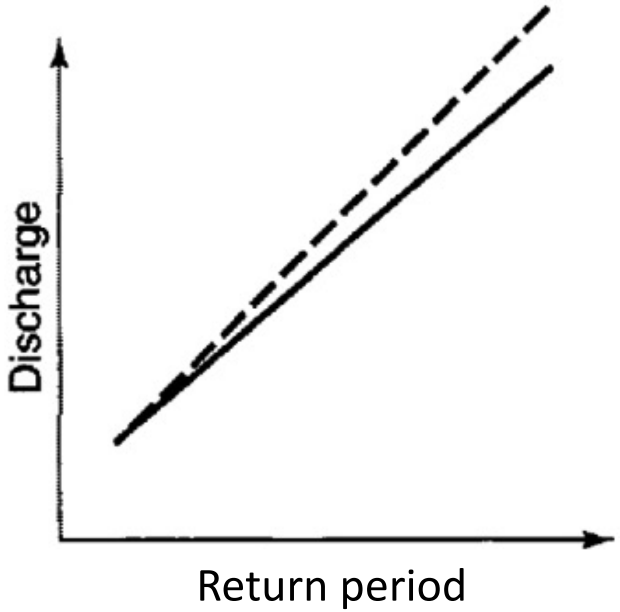
Courtesy of A. Rinaldo

Structural measures: levees or dikes

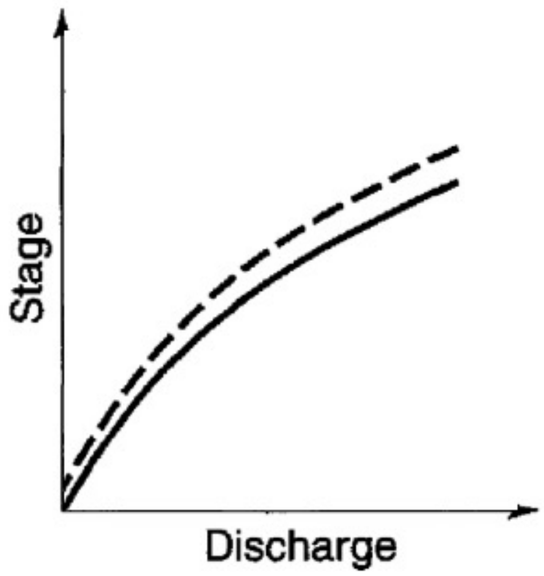
Levees essentially modify all three functional relationships. The effect of levees is to reduce the damage in protected areas.

levee

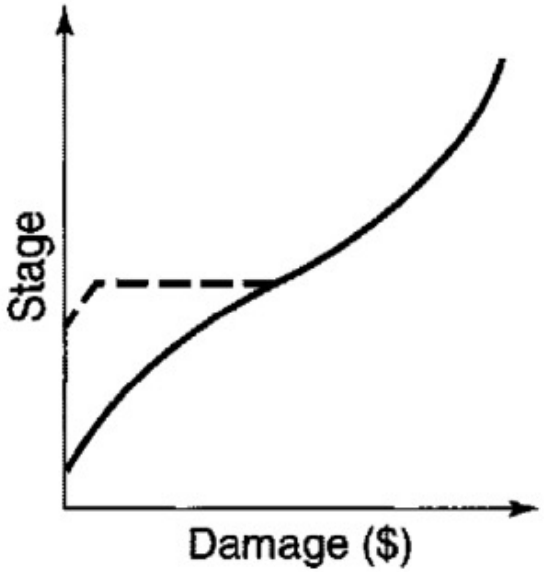
discharge-frequency



stage-discharge



stage-damage

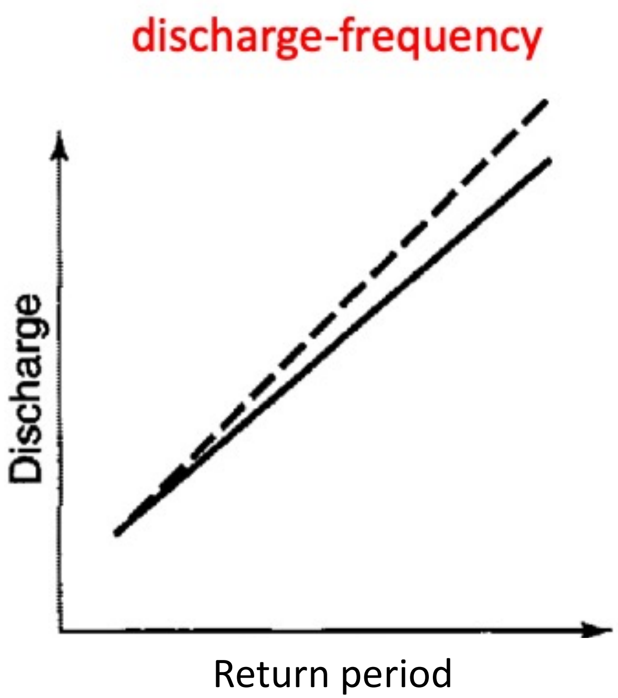


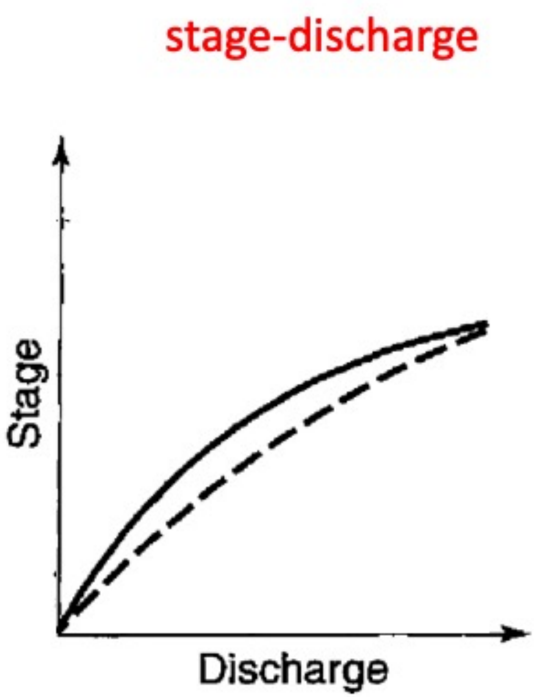
Courtesy of A. Rinaldo

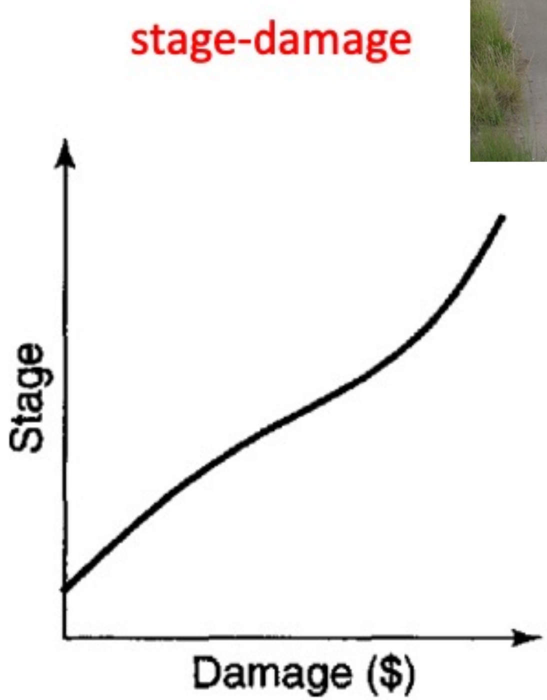
Non-structural measures: channel modification

Channel modifications (channel improvements) are performed to improve the conveyance characteristics of a stream channel (e.g. reducing roughness). This effect results in higher peak discharges downstream than would occur without the channel modifications, causing an upward shift of the discharge-frequency curve.

channel improvements







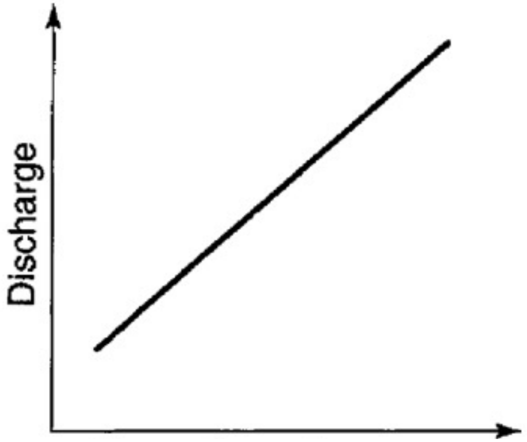
Courtesy of A. Rinaldo

Non structural measures: flood proofing

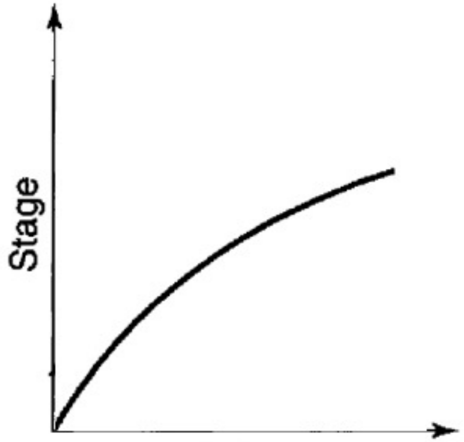
Flood proofing consists of a range of non-structural measures designed to modify the damage potential of individual structures susceptible to flood damage.

flood proofing

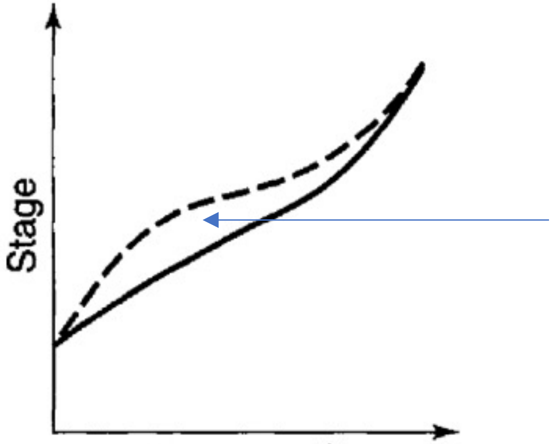
discharge-frequency



stage-discharge

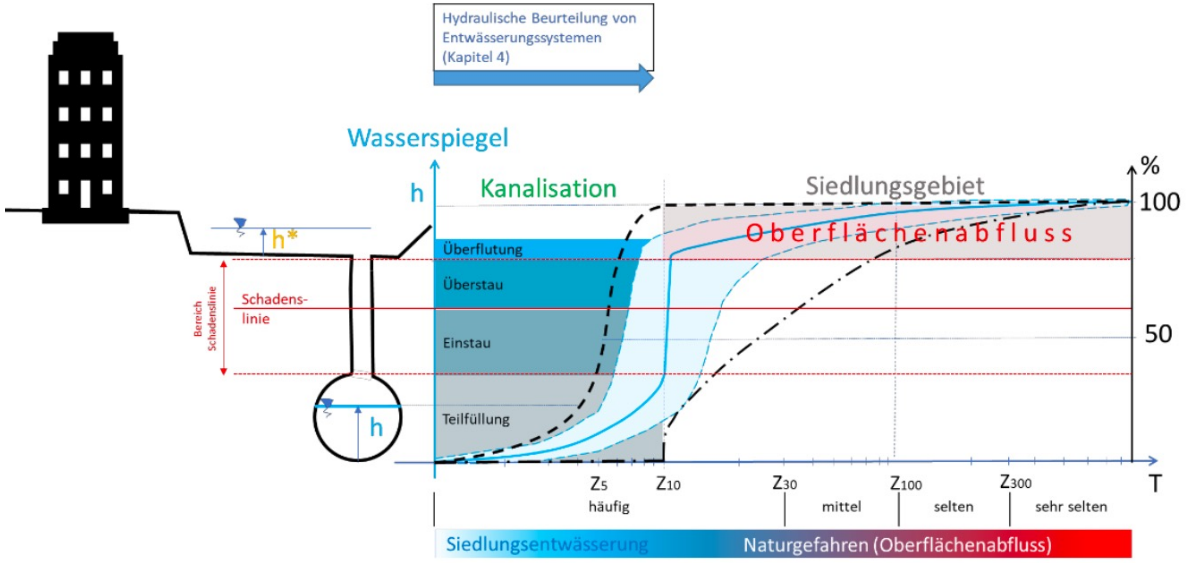


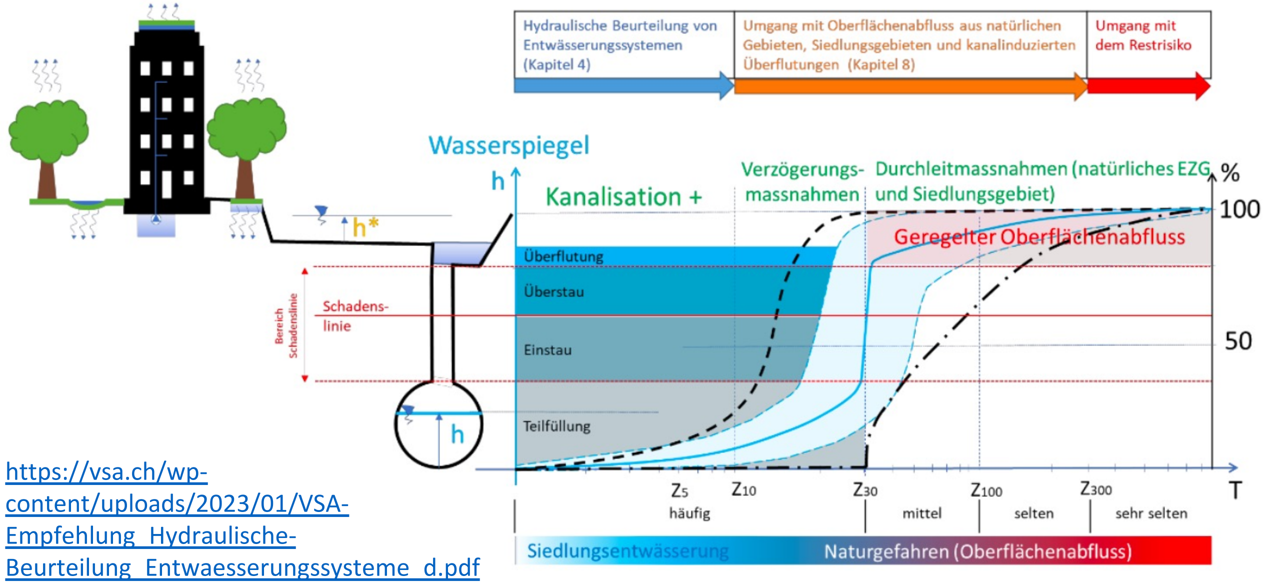
stage-damage



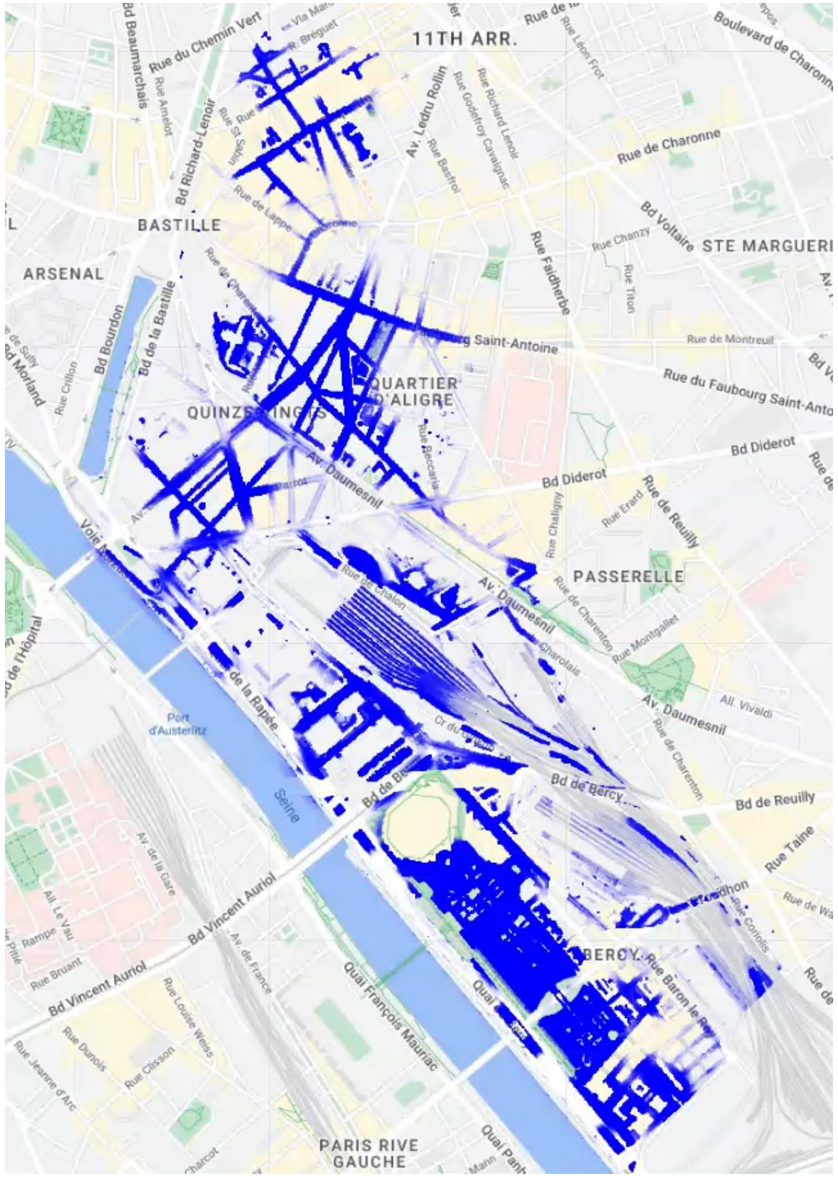
Flood proofing is most desirable on new facilities, and changes only the stage-damage relation shifting the relationship leftwards (less damage for a fixed stage).

Example: non-structural measures in urban stormwater (VSA)





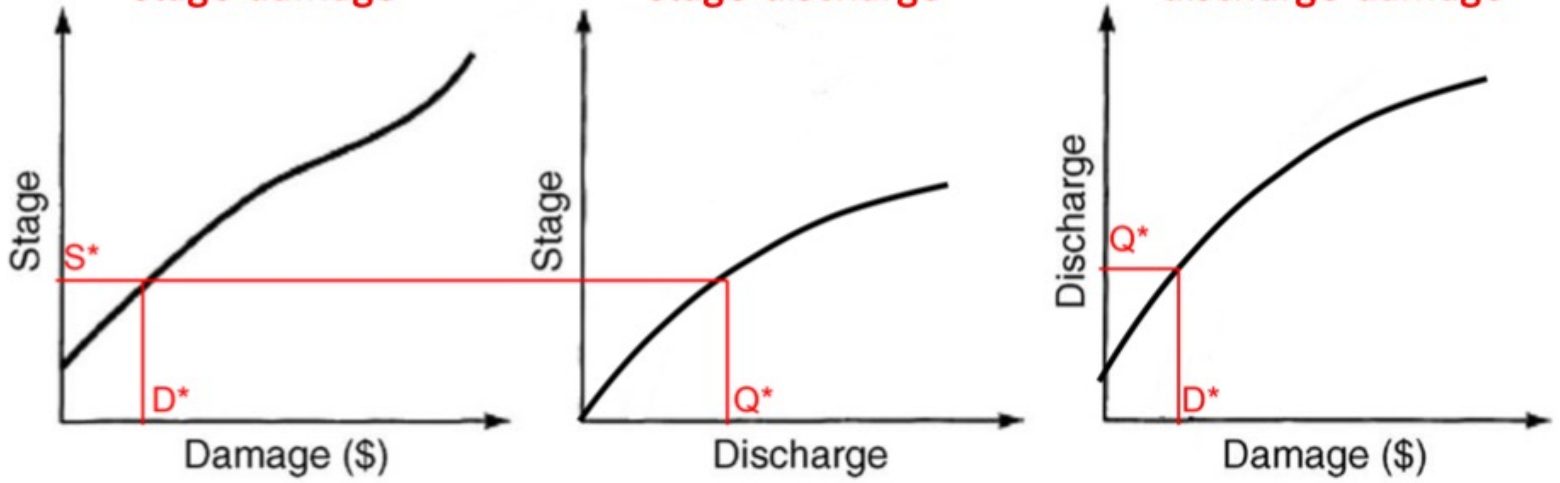
Example of the effect of different urban reservoir detention capacity for the city of Paris (Gare de Lyon)



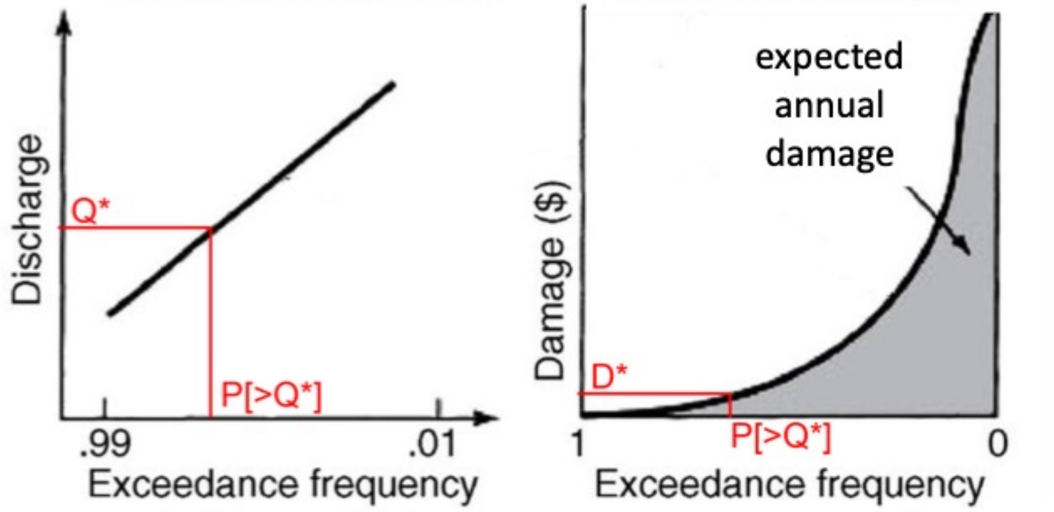
https://vsa.ch/wp-content/uploads/2023/01/VSA-Empfehlung_Hydraulische-Beurteilung_Entwaesserungssysteme_d.pdf

Quantification of expected damage

stage-damage | stage-discharge | discharge-damage



discharge-frequency | damage-frequency



expected annual damage $E[D]$

$$E[D] = \int_0^\infty D\, f(D)\, dD = \int_0^\infty F(D)\, dD$$

where D is the damage, f is the pdf of damage and $F(D)=P[>D]$ is the exceedance cumulative distribution. $E[D]$ is equal to the area under the damage-frequency curve

Courtesy of A. Rinaldo

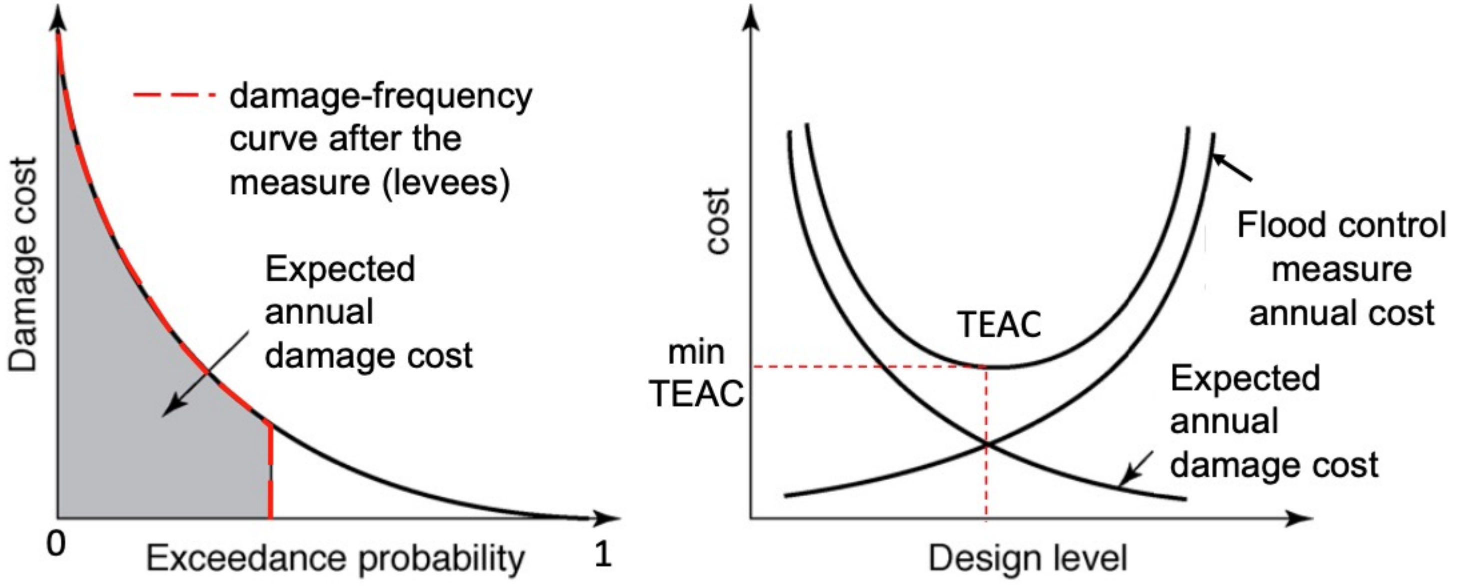
Risk-based analysis

Risk-based design approaches considers the economic trade-offs between project costs and expected damage costs through the risk relationships.
Goal: to determine the optimal structural sizes/capacities associated with the least total expected annual cost (TEAC).

$$\min_{x} TEAC = FC(x)CRF + E[D|x]$$

where FC is the total installation cost (first cost) of the structure, CRF is the capital recovery factor for conversion of cost to annual basis. CRF depends on the expected lifetime of the measure (e.g. 50-100 years) and on the discount rate. x is the design level, and $E[D|x]$ is the associated expected annual damage cost.

Example: design level can be thought as the level of the levees or the capacity of a diversion channel. The higher the design level, the lower the expected damage but the higher the cost of the infrastructure. The analysis should be repeated for different design levels to find the minimum TEAC



Courtesy of A. Rinaldo

Non-traditional uses: recreational activites, instream flow protection, environmental flows

Non-traditional water uses: general aspects

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

- Relatively new concept (mid 1990)
- Initiated a new era of water resources management (ecosystem wealth)
- Accounts also for those uses that may not directly produce a financial return in spite of invaluable environmental benefits (e.g. ecosystem and ecological functions)
- Very important for sustainability
- Very sensible for developing countries (primary water use?) EDUCATION

Non-traditional uses: recreational activities

- Boating
- Fishing
- Canyoning
- Windsurfing
- Diving
- Fun in the riparian environment (e.g., picnicking, jogging, walking, etc.)



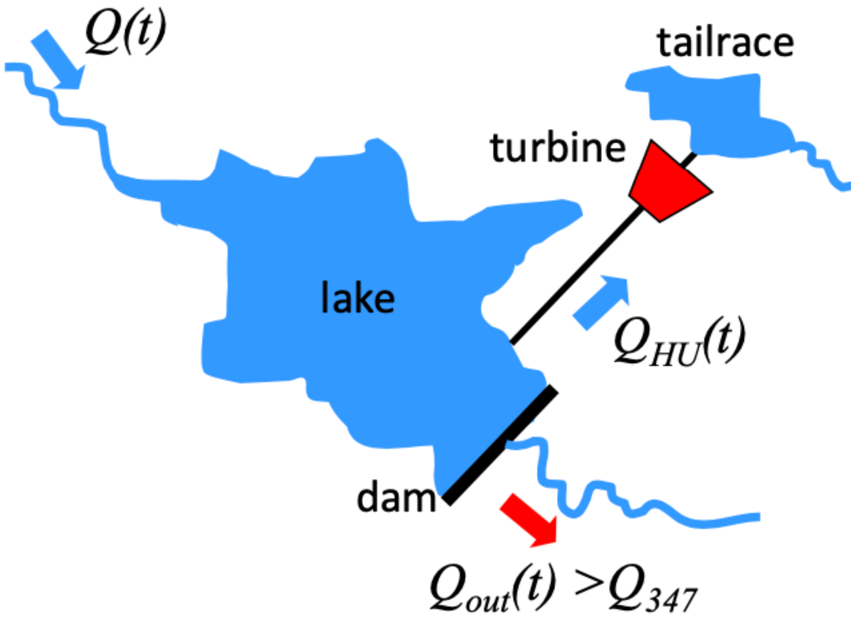


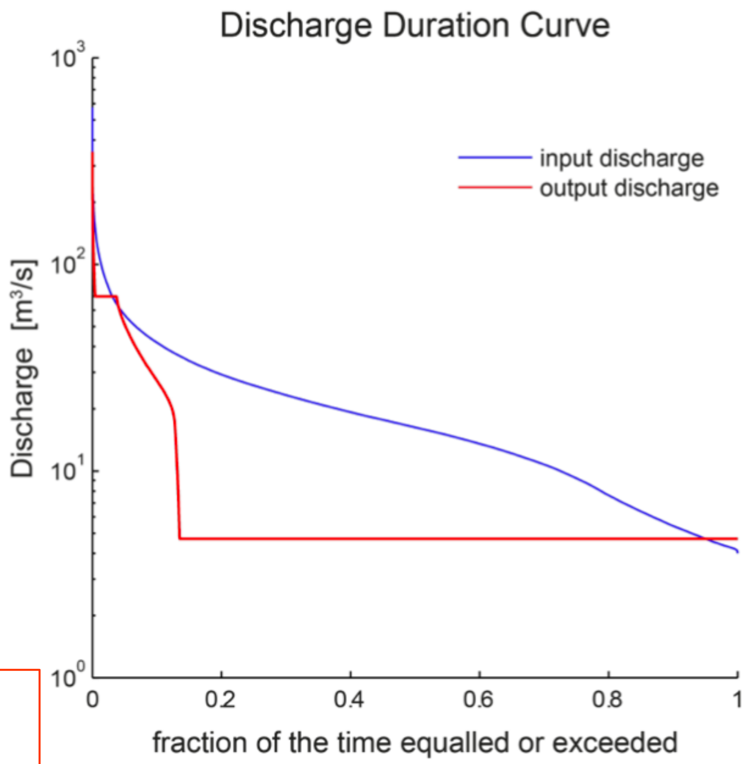

These impose conditions on:

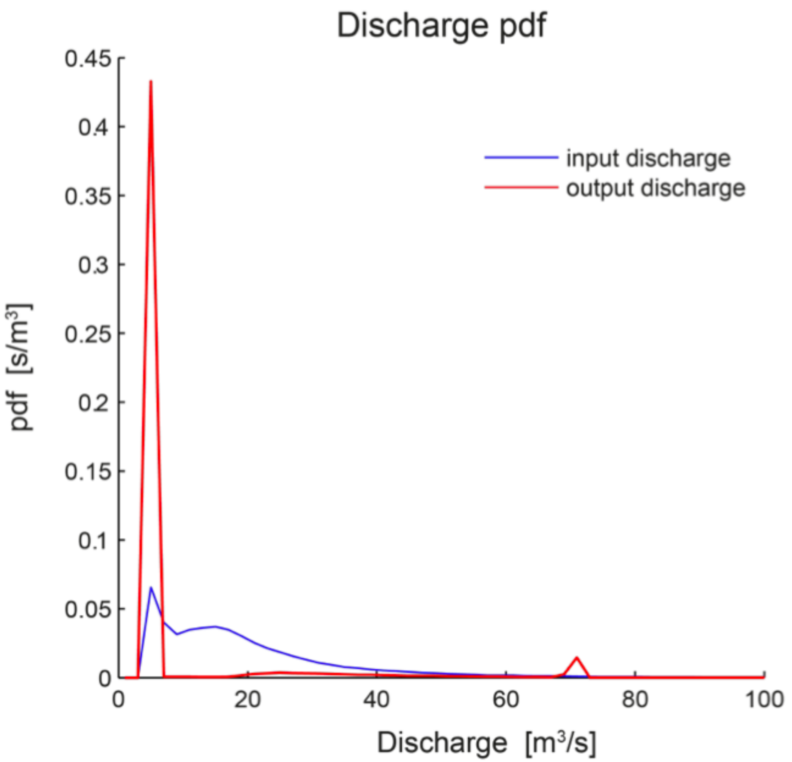
- Minimum discharge;
- Maximum discharge;
- Physical quality (discharge);
- Chemical quality;
- Etc.

Non-traditional uses: Instream flow protection

The requirement of releasing a minimum flow equal to the discharge exceeded 95% of the time is focused on the preservation of the instream ecosystem. However, this can result in a profound modification of the natural flow regime and in the alteration of the riparian and floodplain ecosystems, and in turn, on a profound deterioration of their ecological services.



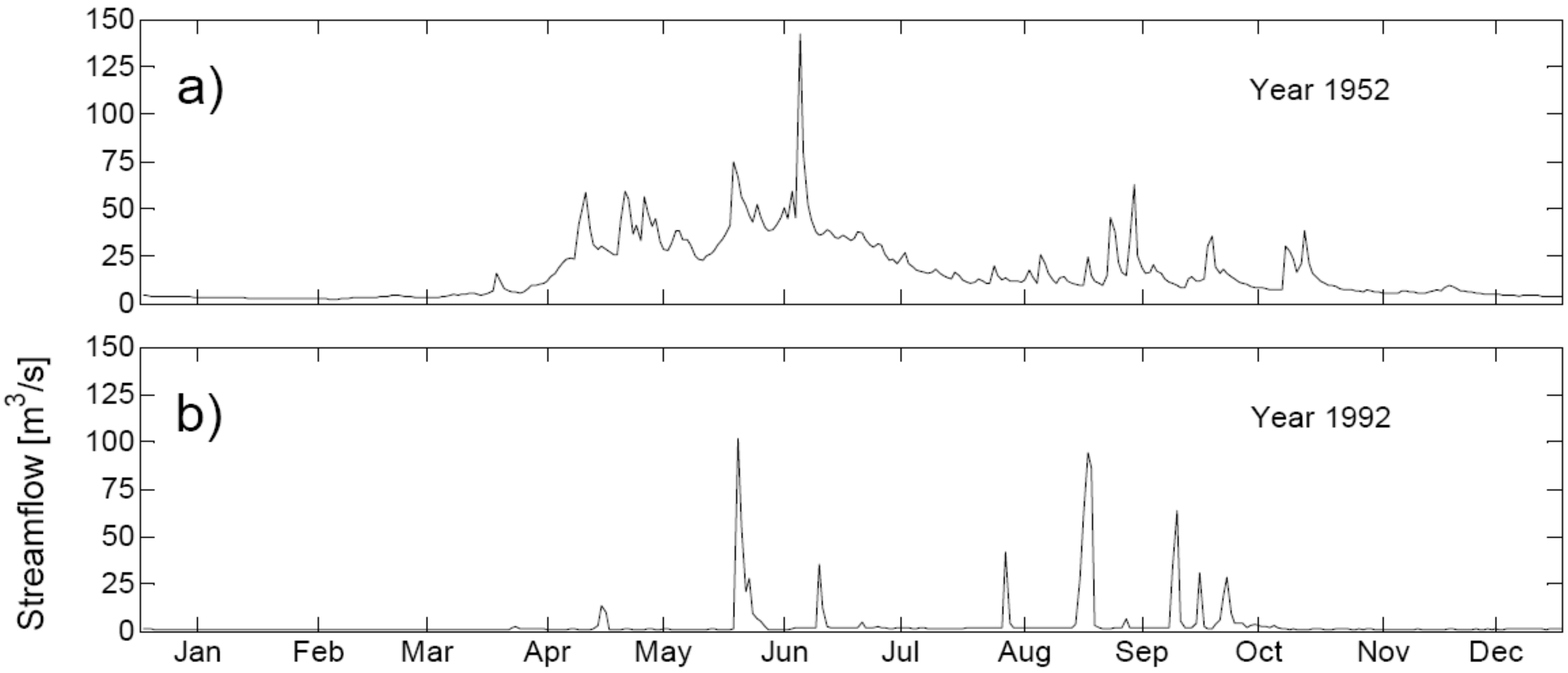




E.g., in Switzerland the basis for determining the Minimum Flow is the Q_{347} threshold, which is enforced by the law at the renewal of concessions (comments)

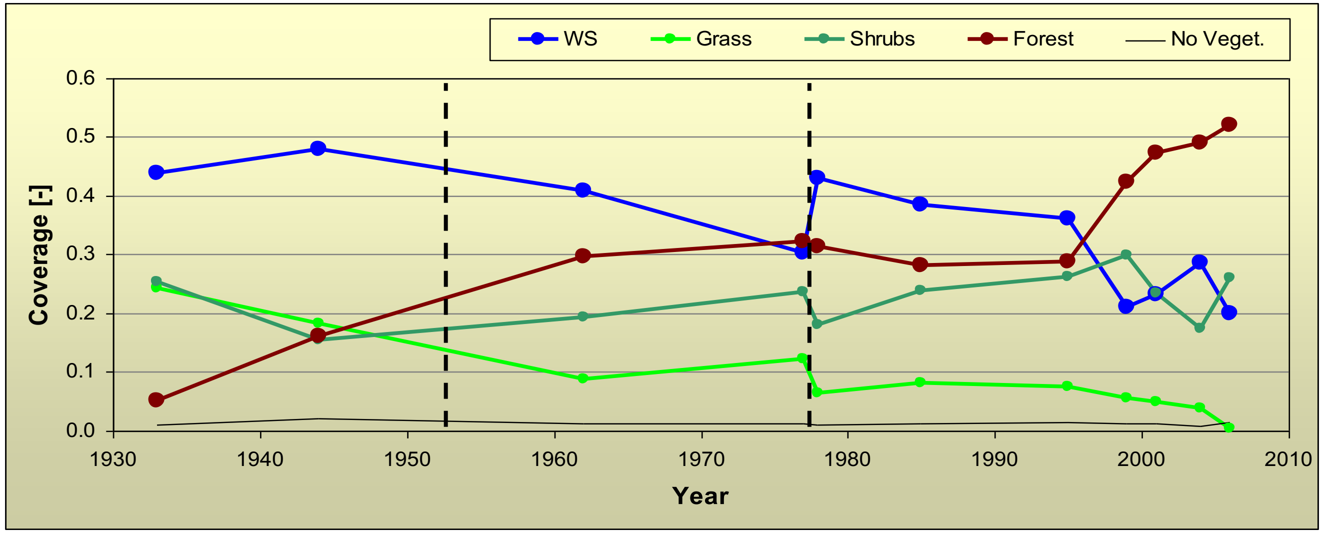
Is that a good policy that preserves ecosystem biodiversity?

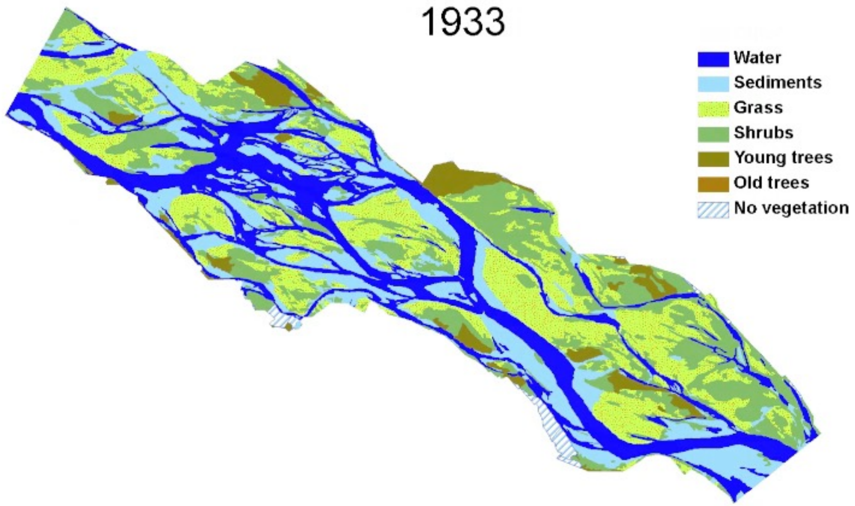
Example: the Maggia River case

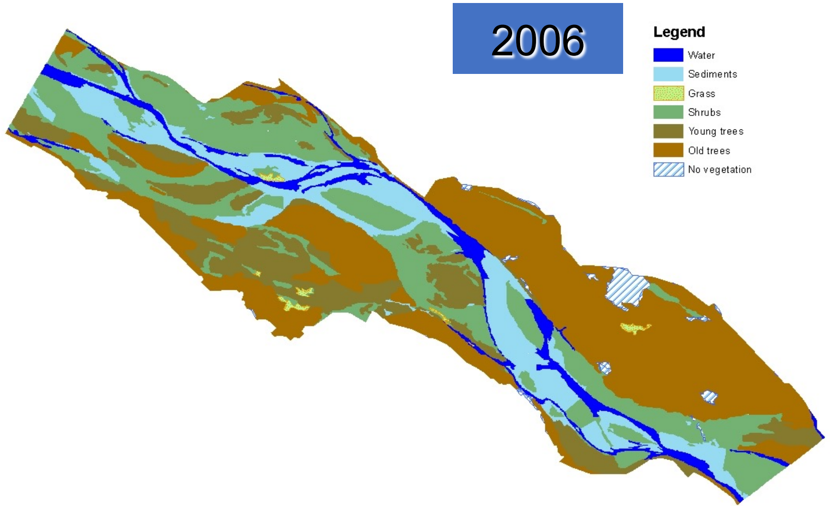


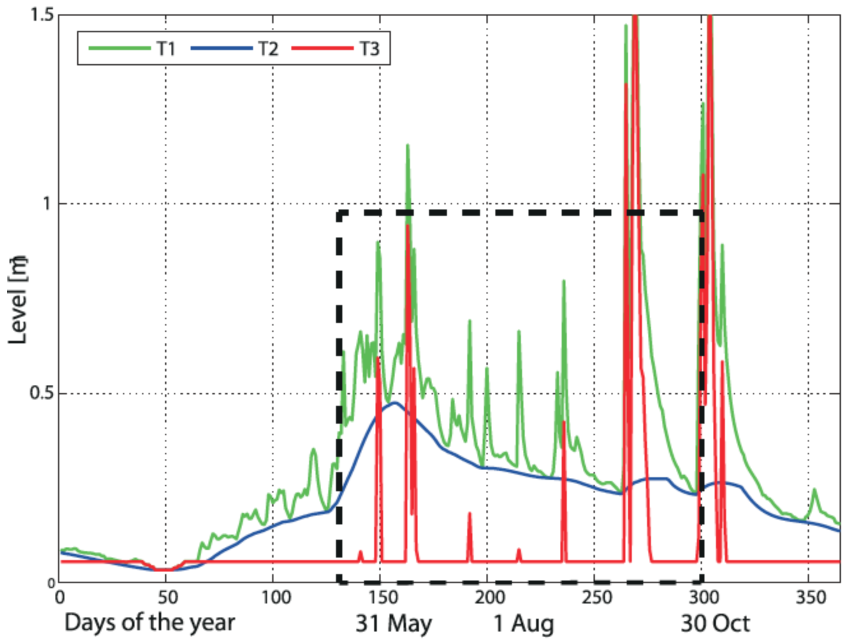
The amount of water is only one aspect among timing, duration, flood frequency, etc. properties of the Natural Flow Regime

Example: the Maggia river case





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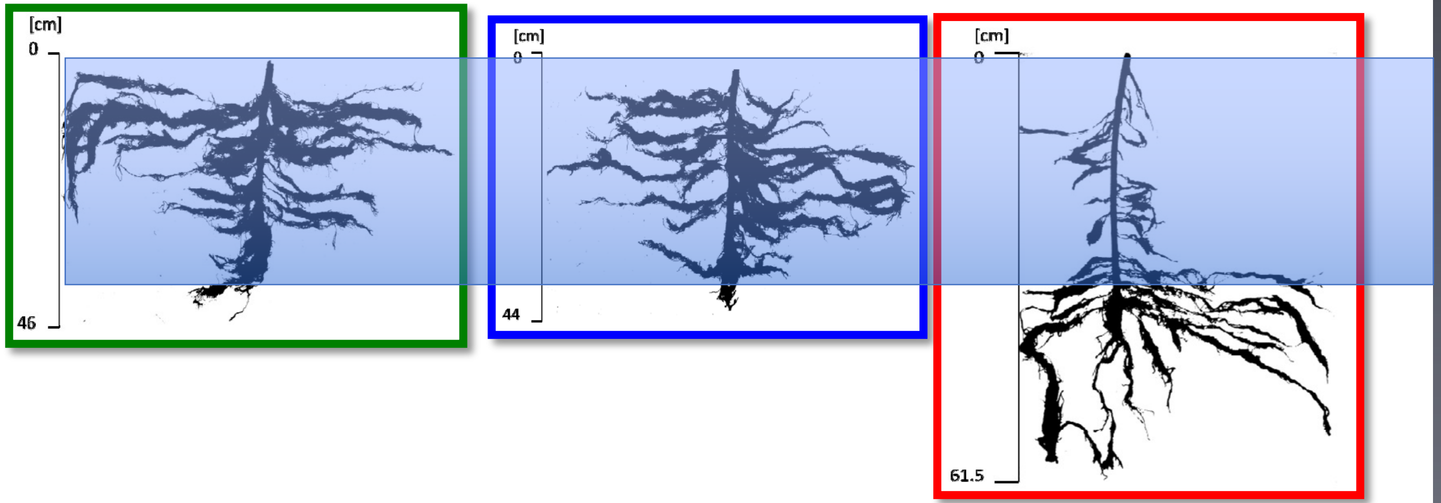
30 Oct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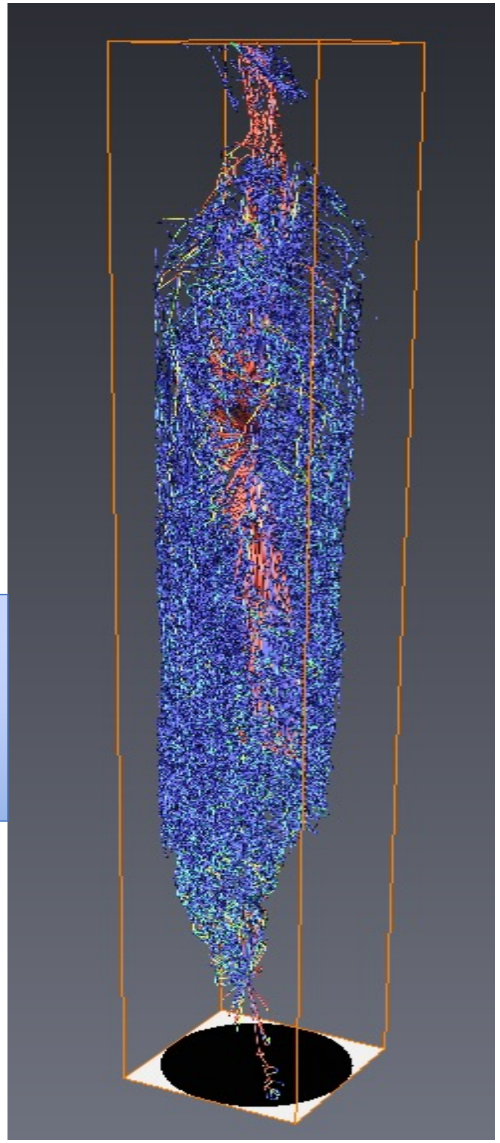

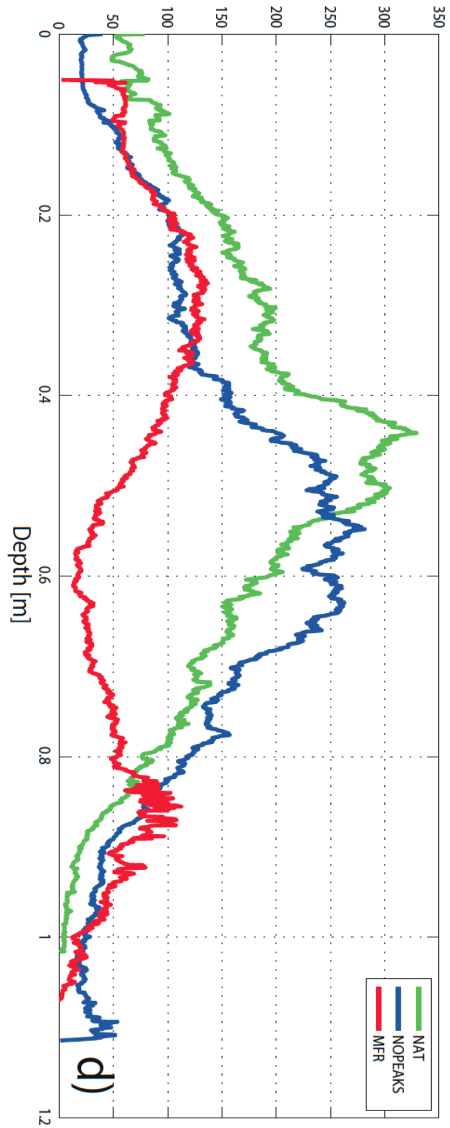
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Take home messages from these three lectures

- L5.1 I can explain why hydropower generation is used to cover Peak energy demand and the role of pumping
- L5.1 I understand the different types of hydropower plants and their functioning principle
- L5.1 I remember and can calculate the power that can be generated from a turbine
- L5.1 I can explain the functioning principle of mini-hydropower

- L5.2 I understand how hydropower with storage is designed via direct numerical simulations
- L5.2 I understand run-of-river power plant principles and the flow duration method
- L5.2 I can explain all steps of the flow duration method and how to select the hydraulic capacity and the turbine
- L5.2 I can explain the relationship between max capacity, head curve and generation curve
- L5.2 I recognize the principle of all flood control methods and the stage, discharge, damage interrelationships

- L5.3 I understand how to design the size of detention basins
- L5.3 I can explain and sketch how structural measures work (diversions, levees, channel modification)
- L5.3 I know how to calculate the expected damage from the damage frequency curve
- L5.3 I know and remember how to calculate the total expected damage cost (TEAC) and how this relates to Risk-based analysis
- L5.3 I can explain non-traditional water uses and illustrate related ecological, environmental and social relevance