Water Resources Engineering and Management

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

5 ETCS, Master course

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Platform of hydraulic constructions

Lecture 4-1 Water uses: consumptive vs non consumptive, traditional vs non-traditional, water engineering, reservoir design and operation

Complexity of river basin systems

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

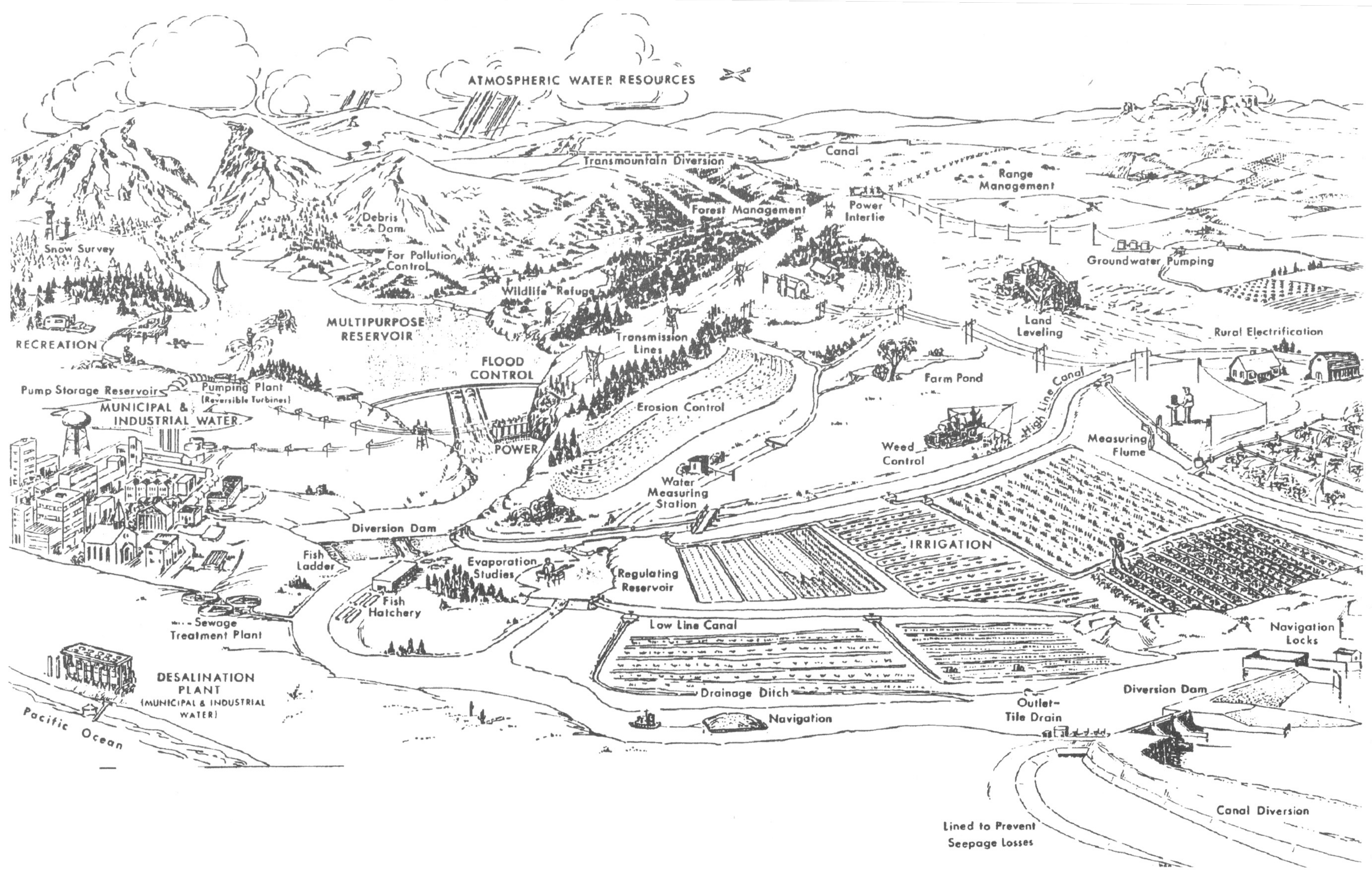

Figure 19.1 Comprehensive watershed diagram. (*Source: U.S. Bureau of Reclamation.*)

Water uses

Water-use purpose	Definition
Domestic use	Water for household needs such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens (also called residential water use).
Commercial use	Water for motels, hotels, restaurants, office buildings, and other commercial facilities and institutions.
Irrigation use	Artificial application of water on lands to assist in the growing of crops and pastures or to maintain vegetative growth in recreational lands such as parks and golf courses.
Industrial use	Water for industrial purposes such as fabrication, processing, washing, and cooling.
Livestock use	Water for livestock watering, feed lots, dairy operations, fish farming, and other on-farm needs.
Mining use	Water for the extraction of minerals occurring naturally and associated with quarrying, well operations, milling, and other preparations customarily done at the mine site or as part of a mining activity.
Public use	Water supplied from a public water supply and used for such purposes as firefighting, street washing, municipal parks, and swimming pools.
Rural use	Water for suburban or farm areas for domestic and livestock needs, which is generally self-supplied.
Thermoelectric power use	Water for the process of the generation of thermoelectric power.

Source: Solley et al. (1993).

Definition of water uses: consumptive and non-consumptive

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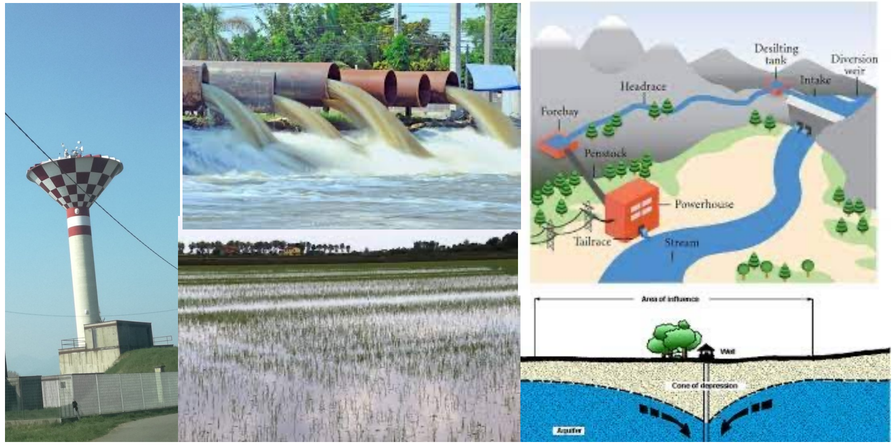
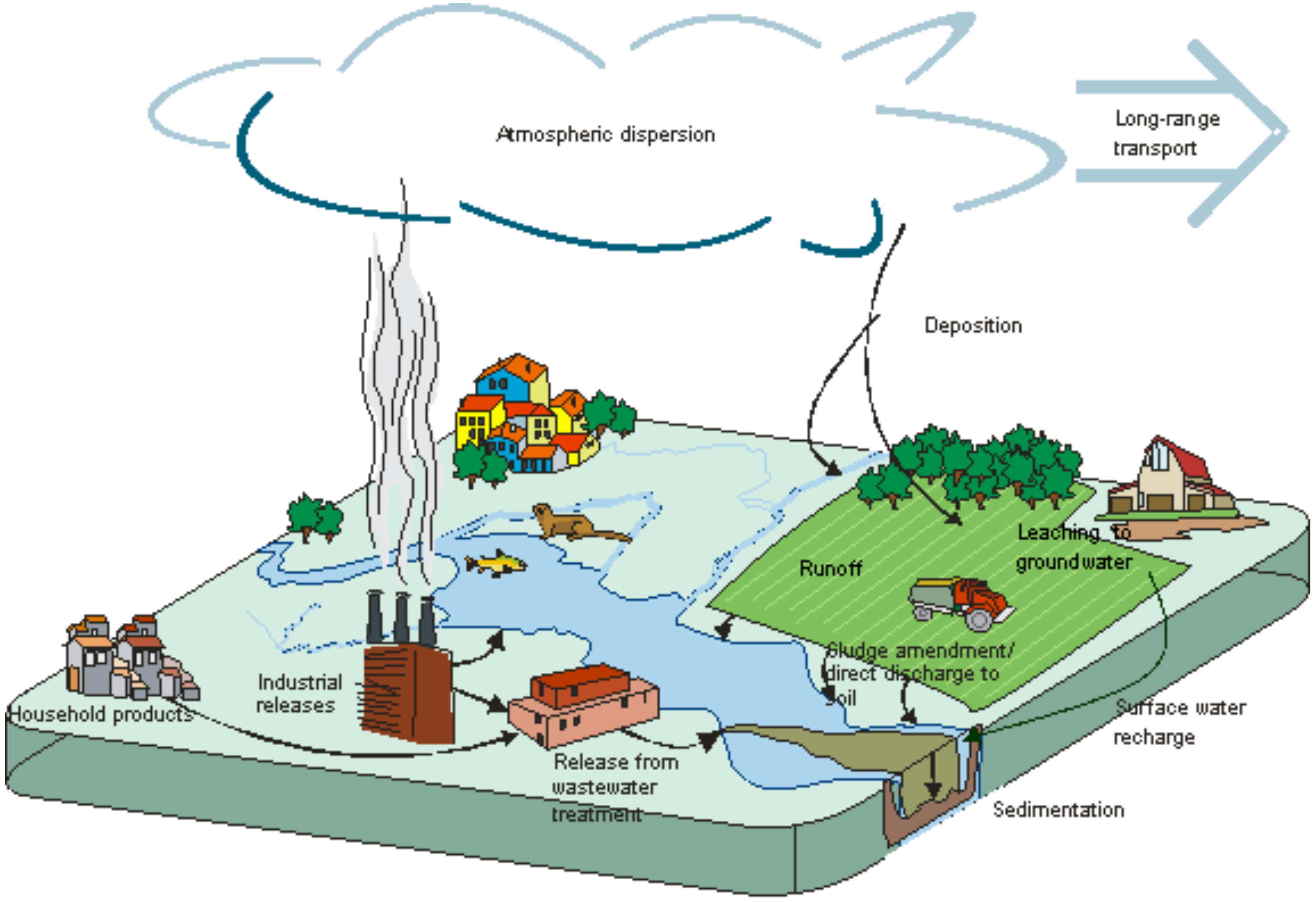
- Consumptive water use: any use of water which may change its quality or availability to next users, e.g. return flow coefficient <1 (e.g., urban water, industrial water, irrigation, hydropower with diversion*, etc.)



- Non Consumptive water use: any use of water which preserves quality and availability, e.g., return flow coefficient = 1 (e.g., hydropower run-of-river, flood protection, environmental uses, recreational uses, etc.)

*The case of hydropower is peculiar as it changes return flow coef only locally, i.e. within the impounded reach



Courtesy of Dr. A. Semiao, The University of Edinburgh

- Dams and reservoirs
- Irrigation diversions and drainage returns
- Potable water supply
- Wastewater treatment
- Changes in land use
- Flood mitigation
- Changes in climate conditions
- Domestic use (pollution)
- Agricultural use (use and pollution)
- Industrial (use and pollution)

Consumptive Non-consumptive

Definition of water uses: Traditional vs non-traditional

- Domestic and Urban (e.g., drinking,)
- Industrial (e.g., hydropower,)
- Agricultural (e.g., irrigation)
- Navigation (e.g., commercial, private, etc)
- Flood control

Traditional water uses

- Recreational (e.g., stream activities, boating, fishing, etc.)
- Ecological (e.g., riverine and riparian ecosystem, restoration, etc.)

Non- Traditional water uses

Traditional water uses: general aspects

- Use of water in classic civil engineering
- Water is seen as a resource mostly illimited
- Only financial aspects are considered (monetary flow)
- Old concept
- They are of course fundamental, but in order to increase economic (and environmental) efficiency also non-traditional uses must be considered

The state of water use in the world

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Table 1.1: Sectoral water withdrawals by region, rounded numbers (%).

Region	Residential	Industry	Agriculture
Africa	7	5	88
Europe	14	55	31
North America	13	47	49
Central America	6	8	86
South America	18	23	59
Asia	6	9	85
Oceania	64	2	34

Source: World Resources Institute (1998).

Compare the values above (25 ys old) with actual statistics and draft your conclusions

Water consumption per person per year has dramatically changed

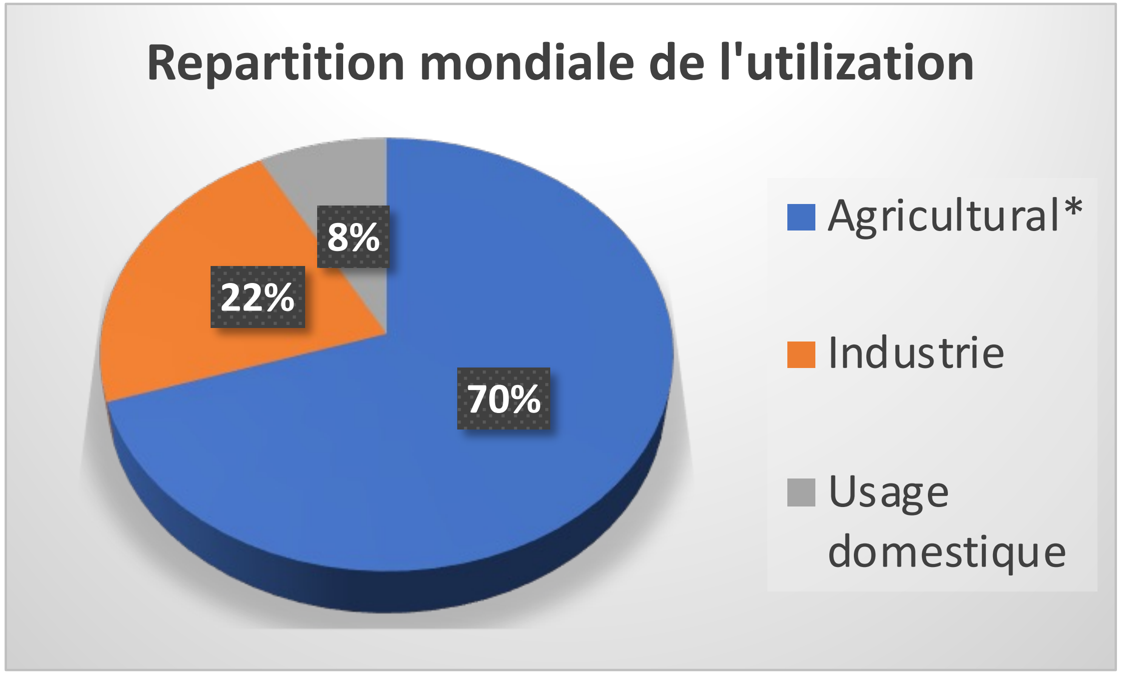
350 cm → 1900

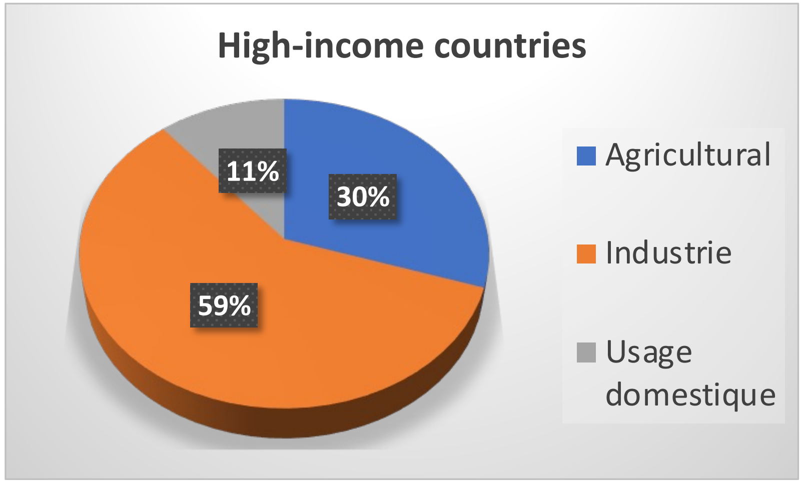
642 cm → 2000

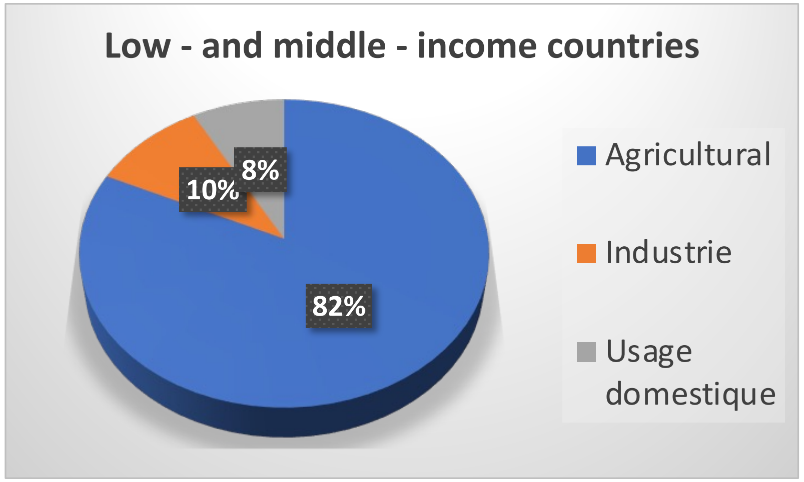
However, the amount of available water today is more or less the same as when Mesopotamian civilization prospered

Increased consumption led to increased water withdrawal!

A more recent vision







* Asia: 82%; USA: 40%; Europe: 30%

Non-traditional water uses: general aspects

- 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

Reservoir design and operation

Some typical questions: reservoir design

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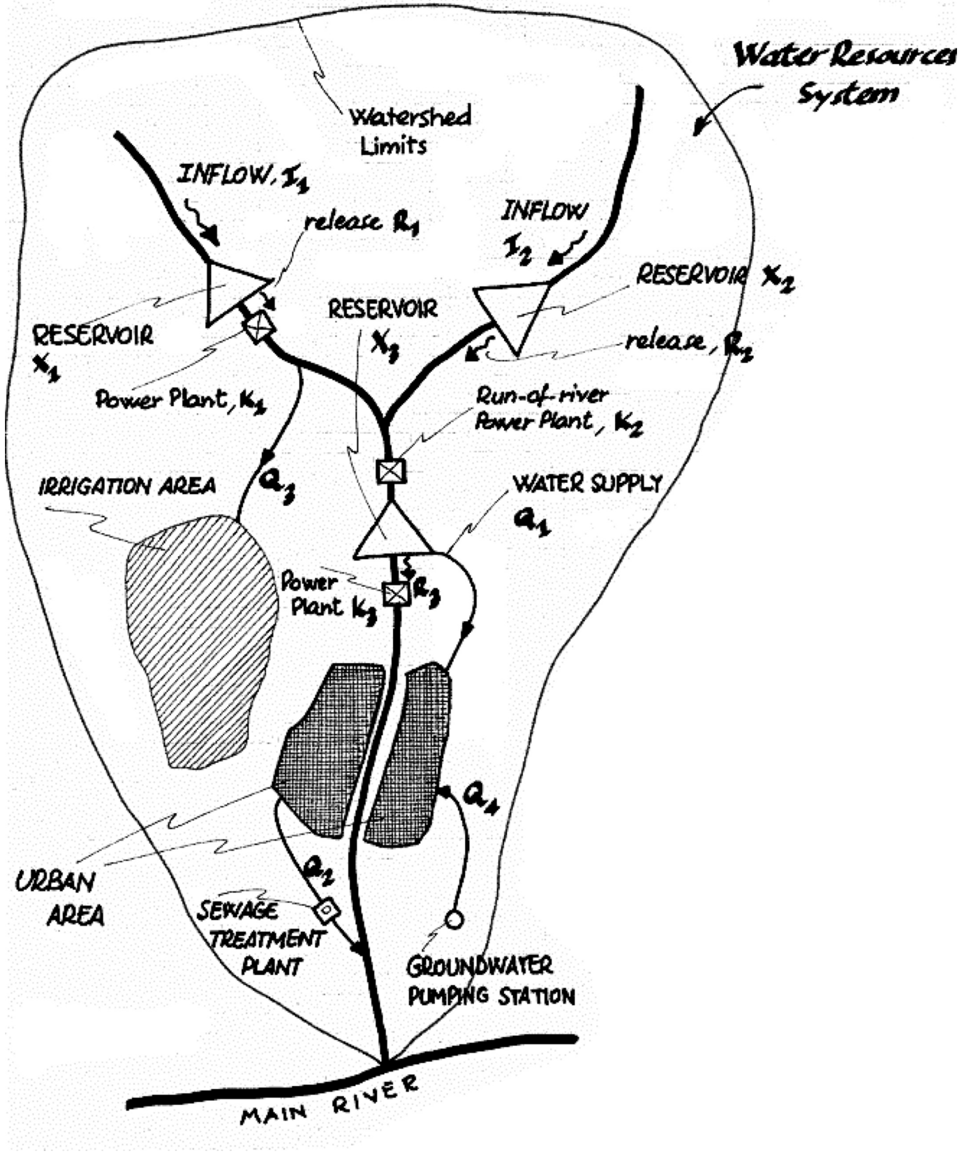
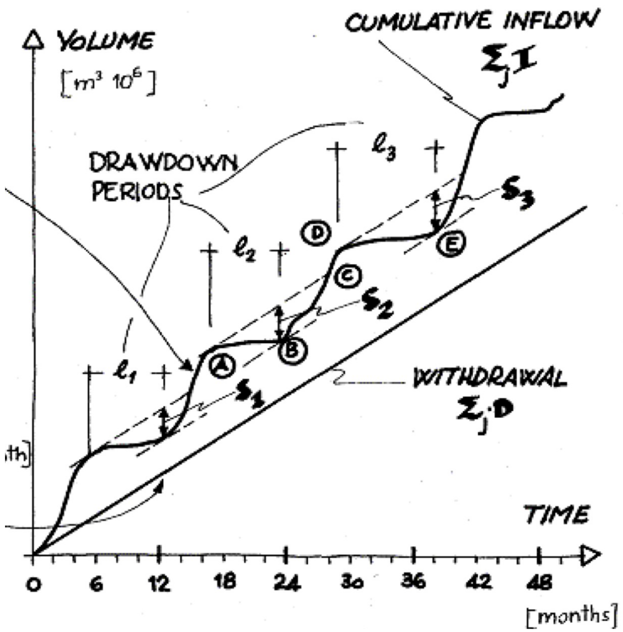
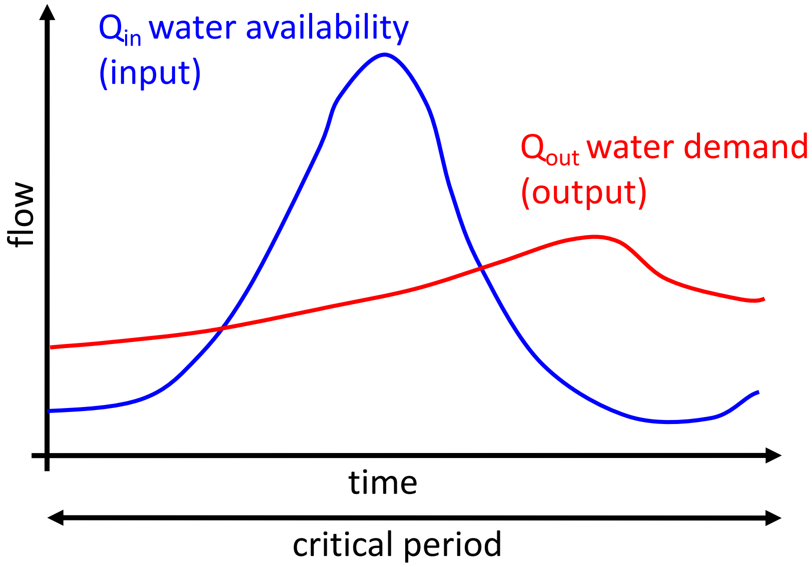


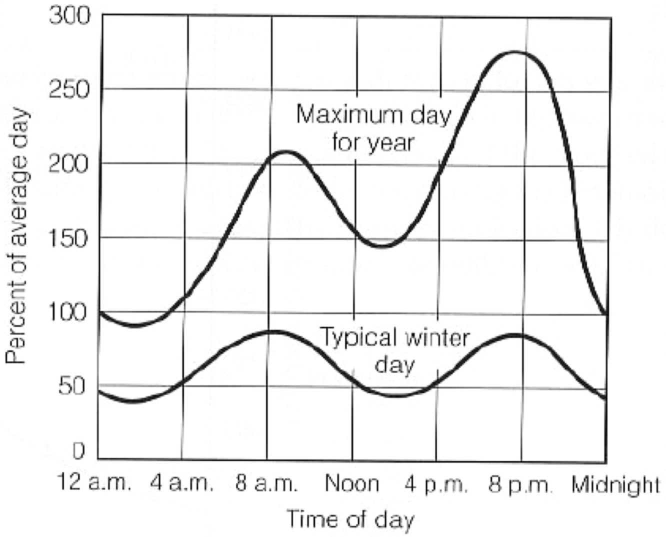
Given variable inflows and demand, what is the best size of the reservoir that allows to them at maximum reliability?



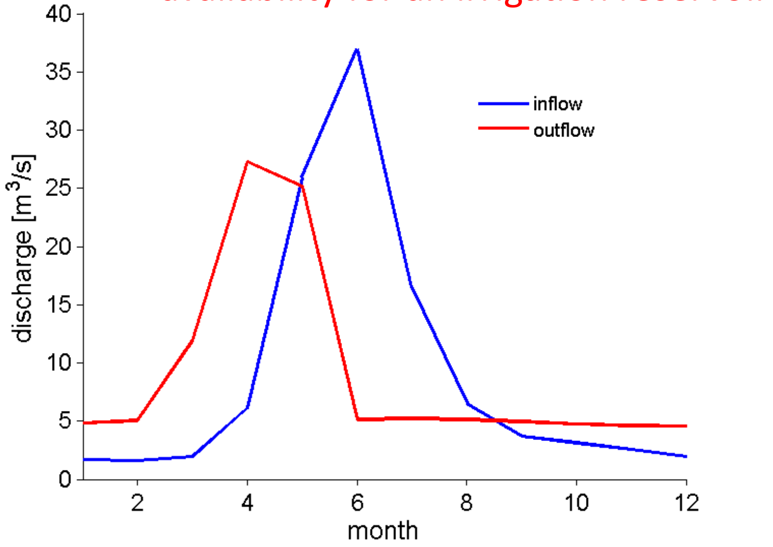
Why and how do we design the size of a reservoir?



daily public water demand



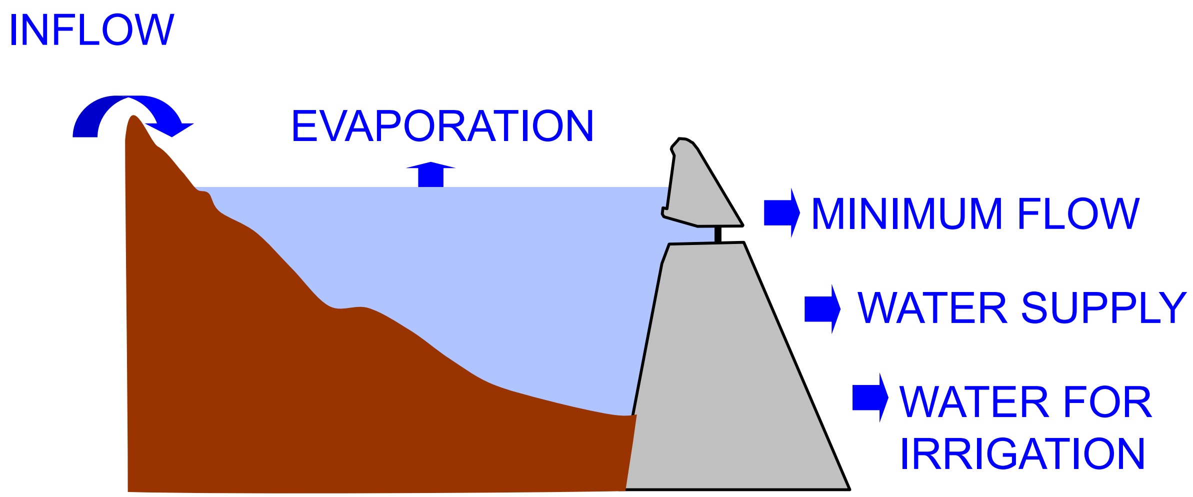
example of water demand and availability for an irrigation reservoir



Inflows and outflows are not synchronous → Need of a reservoir to temporarily store water

Designing the size of a reservoir requires to identify the statistical cycle with which inflow and outflow repeats (e.g., daily, weekly, monthly, yearly)

Reservoir mass-balance equation



reservoir equation

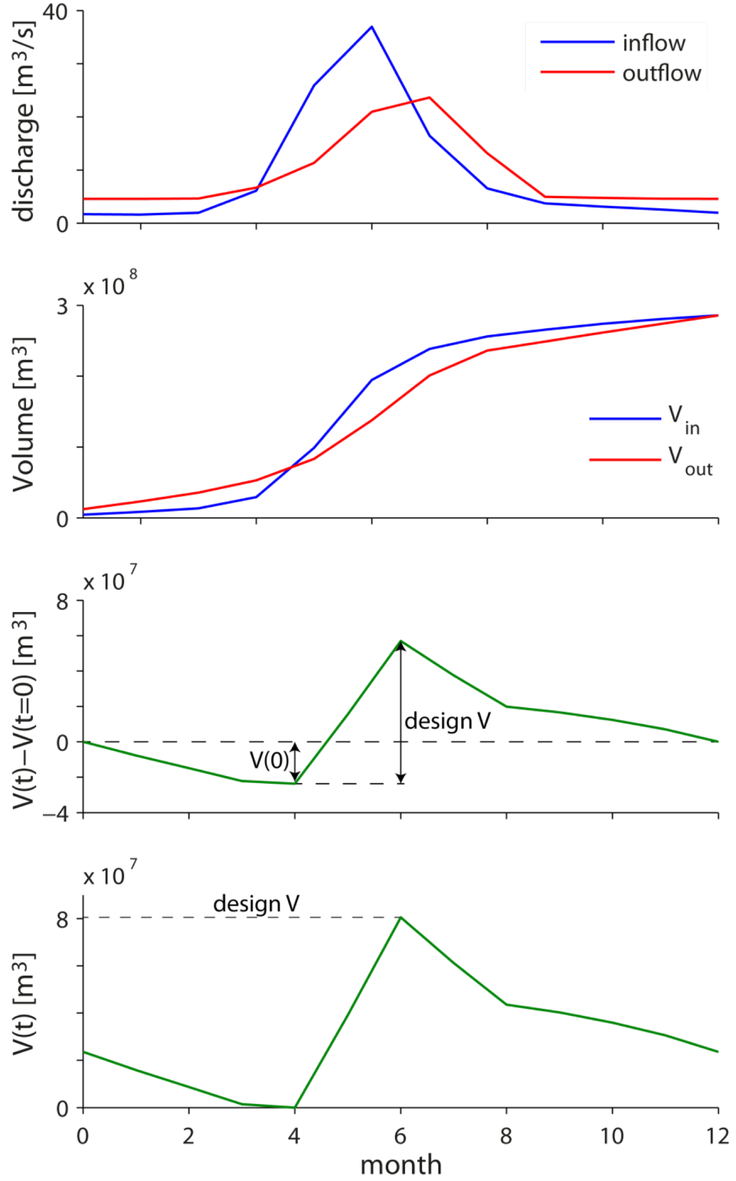
$$\frac{dV(t)}{dt} = Q_{in}(t) - Q_{out}(t)$$

$V(t)$ volume stored in the reservoir

$Q_{in}(t)$ inflow discharge

$Q_{out}(t)$ sum of outflow discharges

1st Problem: Reservoir design



1st problem: find the volume of the reservoir knowing the sequence of input and output flows. Reservoir equation

Reservoir equation

$$\frac{dV(t)}{dt} = Q_{in}(t) - Q_{out}(t)$$

integration between 0 and t

$$\int_0^t \frac{dV(t')}{dt} dt' = \int_0^t Q_{in}(t')\,dt' - \int_0^t Q_{out}(t')\,dt'$$

$$V(t) - V(t=0) = V_{in}(t) - V_{out}(t)$$

Determine the design storage (design V) as the maximum range of volume fluctuations and the initial volume as V(0)=-min[V(t)-V(0)].
The initial volume is the volume that should be stored in the reservoir at the beginning of the period.

$$V(t) = V(t=0) + V_{in}(t) - V_{out}(t)$$

Some typical questions: reservoir management

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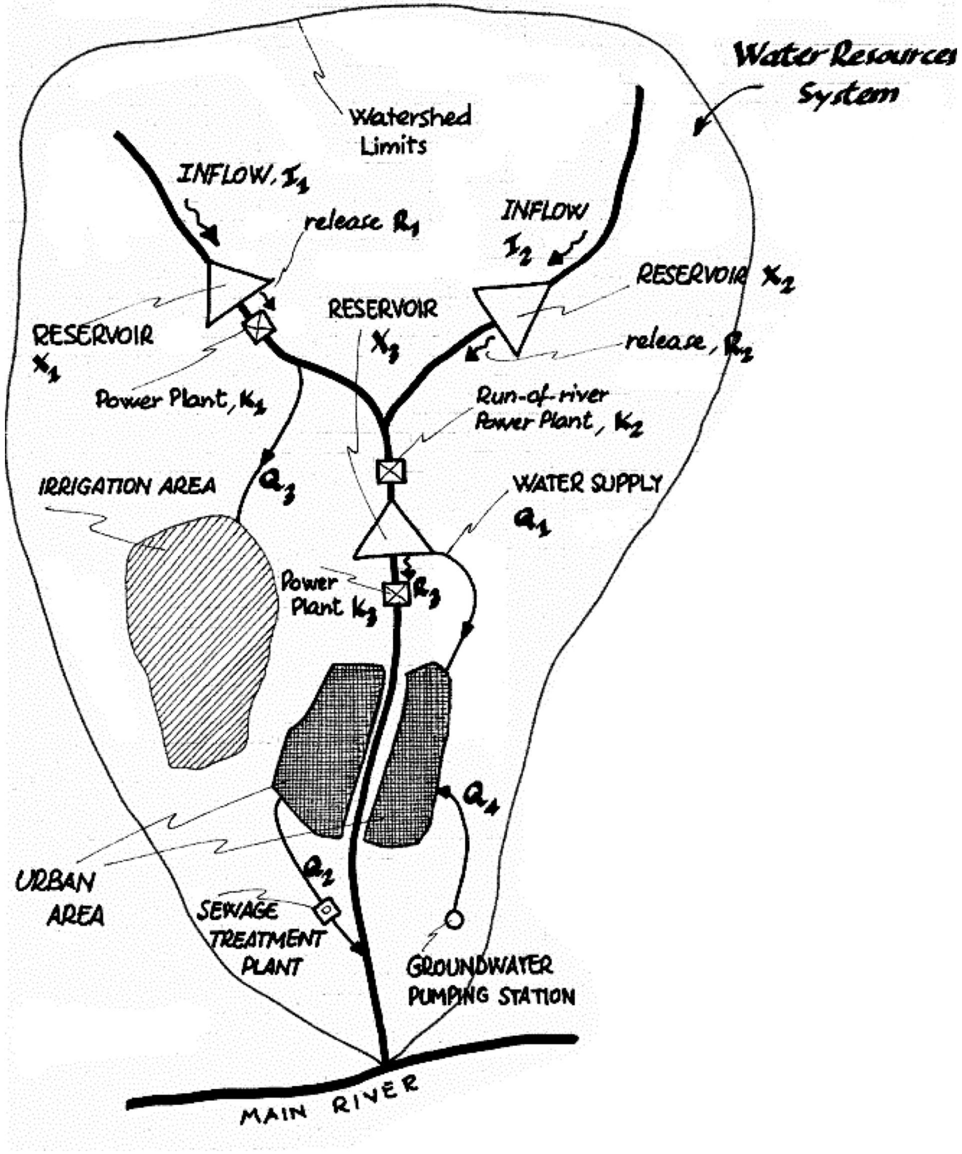
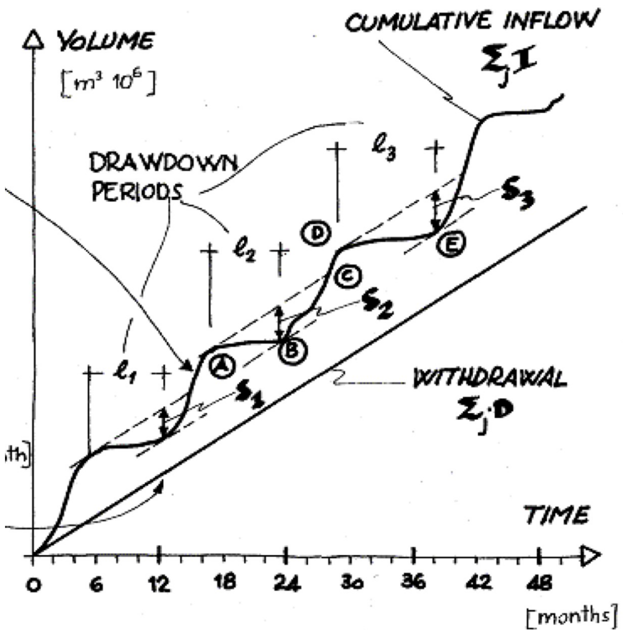


Given a reservoir size (cfr. water resources engineering for design), what is the best allocation that meets irrigation and water supply demand?

How reliable is the reservoir dynamics?



EPFL

2nd problem: reservoir management

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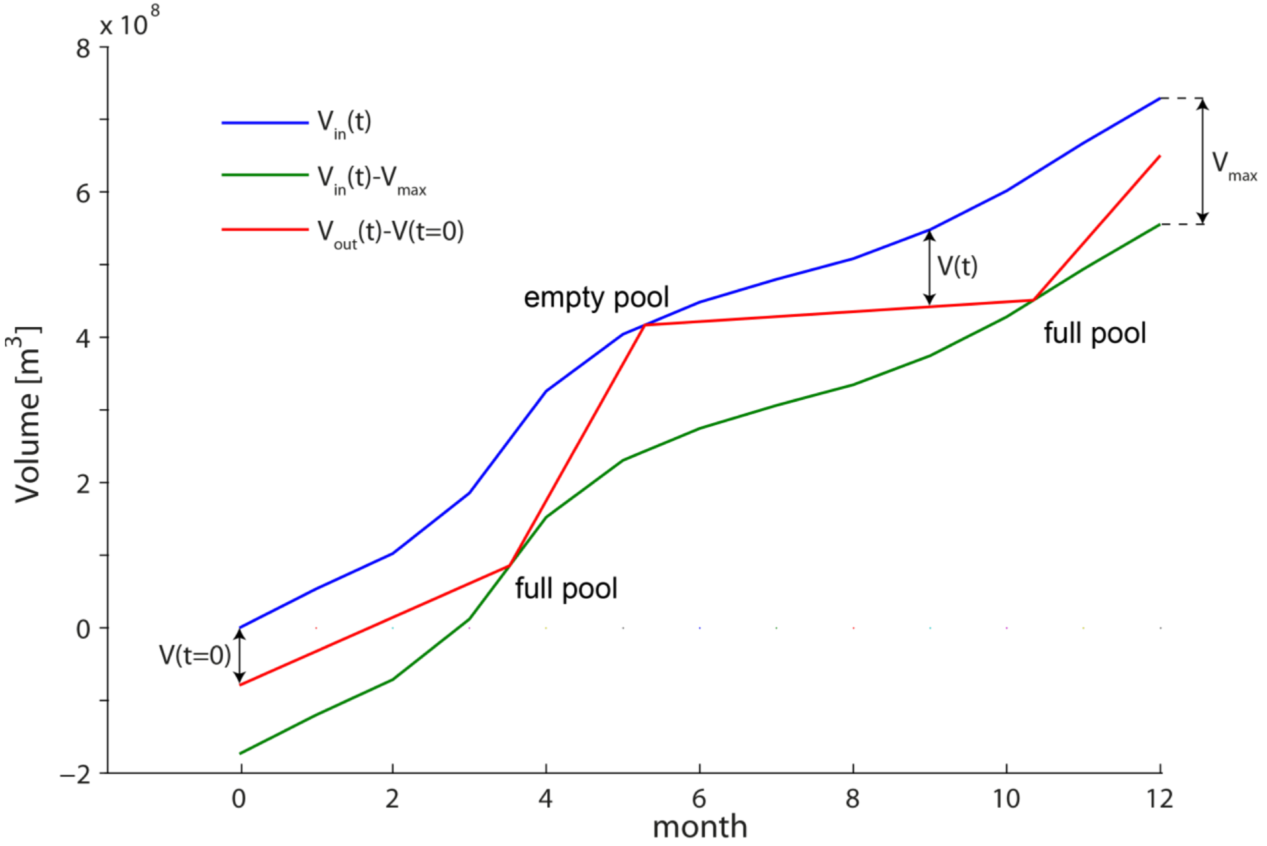
2nd problem: given the maximum volume of a reservoir (V_{max}) and the sequence of inflows ($Q_{in}(t)$), determine if a certain sequence of output is feasible.
The sequence of $V(t)$ (determined as before) must always be larger than 0 and smaller than V_{max}

Graphical method

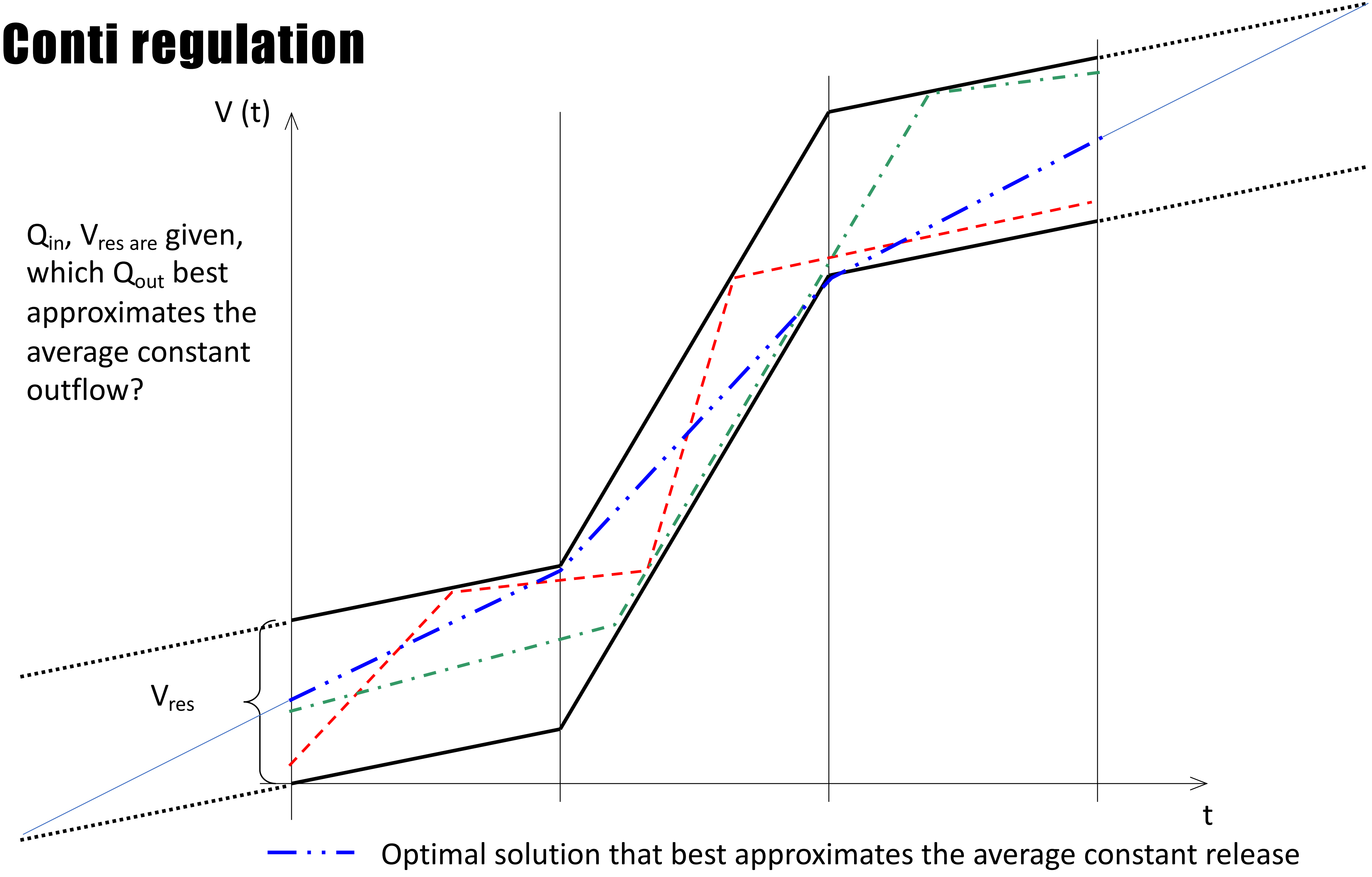


any sequence of outflow $Q_{out}(t)$ whose corresponding cumulative outflow volume $V_{out}(t)$ minus the initial volume $V(t=0)$ lies between the green and the blue curves is feasible.

Interesting question: Which regulation better approximate a constant average outflow? → graphical method

Conti regulation

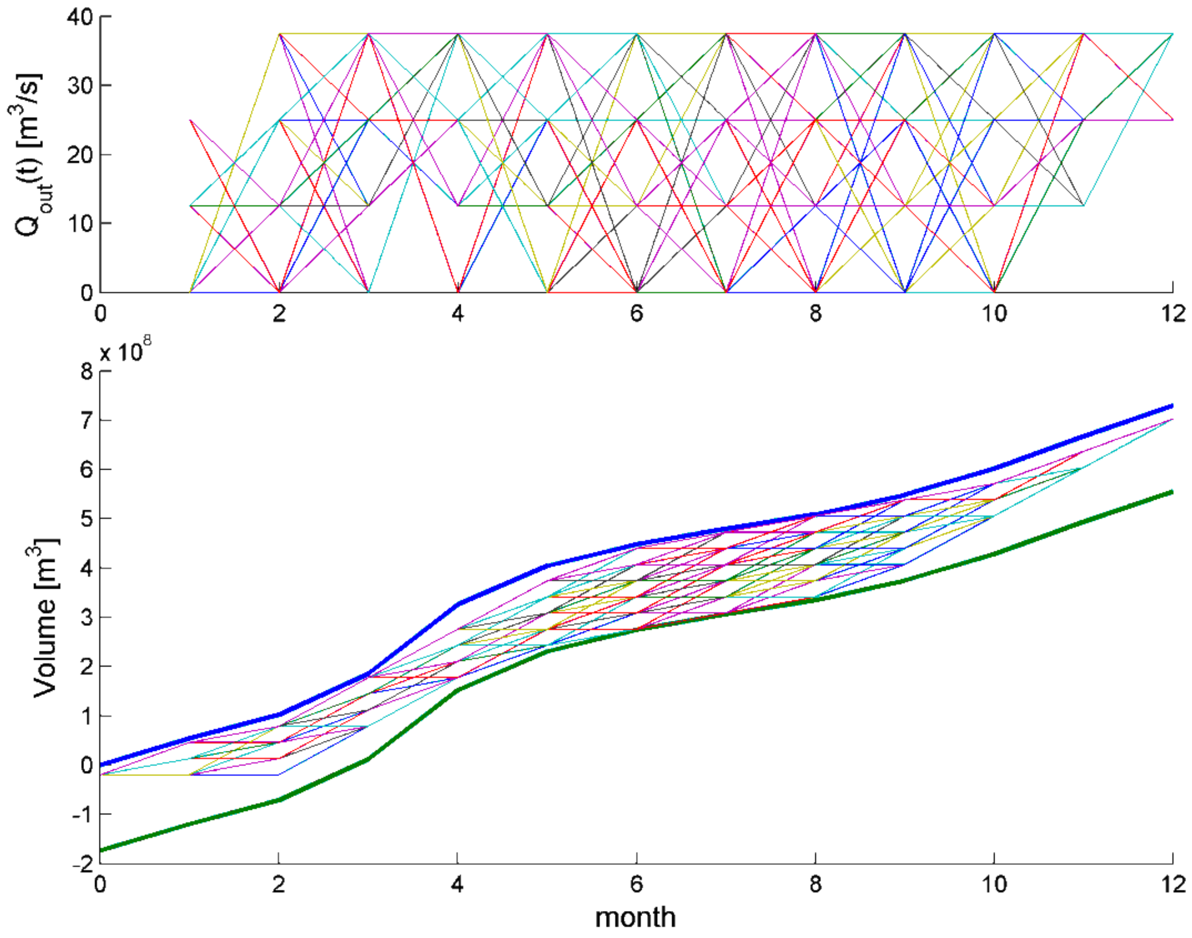
Q_{in}, V_{res} are given, which Q_{out} best approximates the average constant outflow?



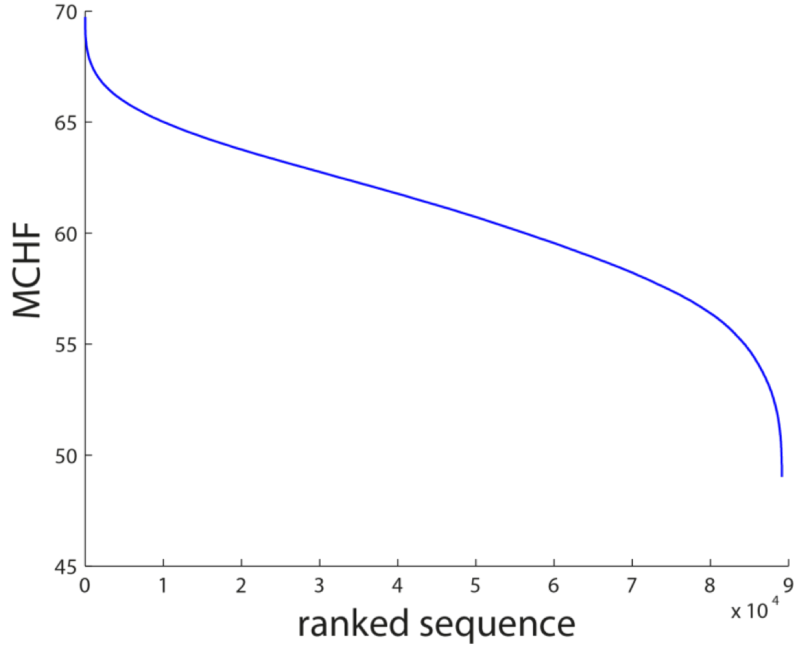
Why management is important?

Hydropower production depends on reservoir levels and costs → max revenue for given inflows and reservoir size (optimization problem, see L10). E.g. assume electricity price also varies seasonally and simulate the process

feasible sequences



corresponding revenue



Reservoir characteristic volumes

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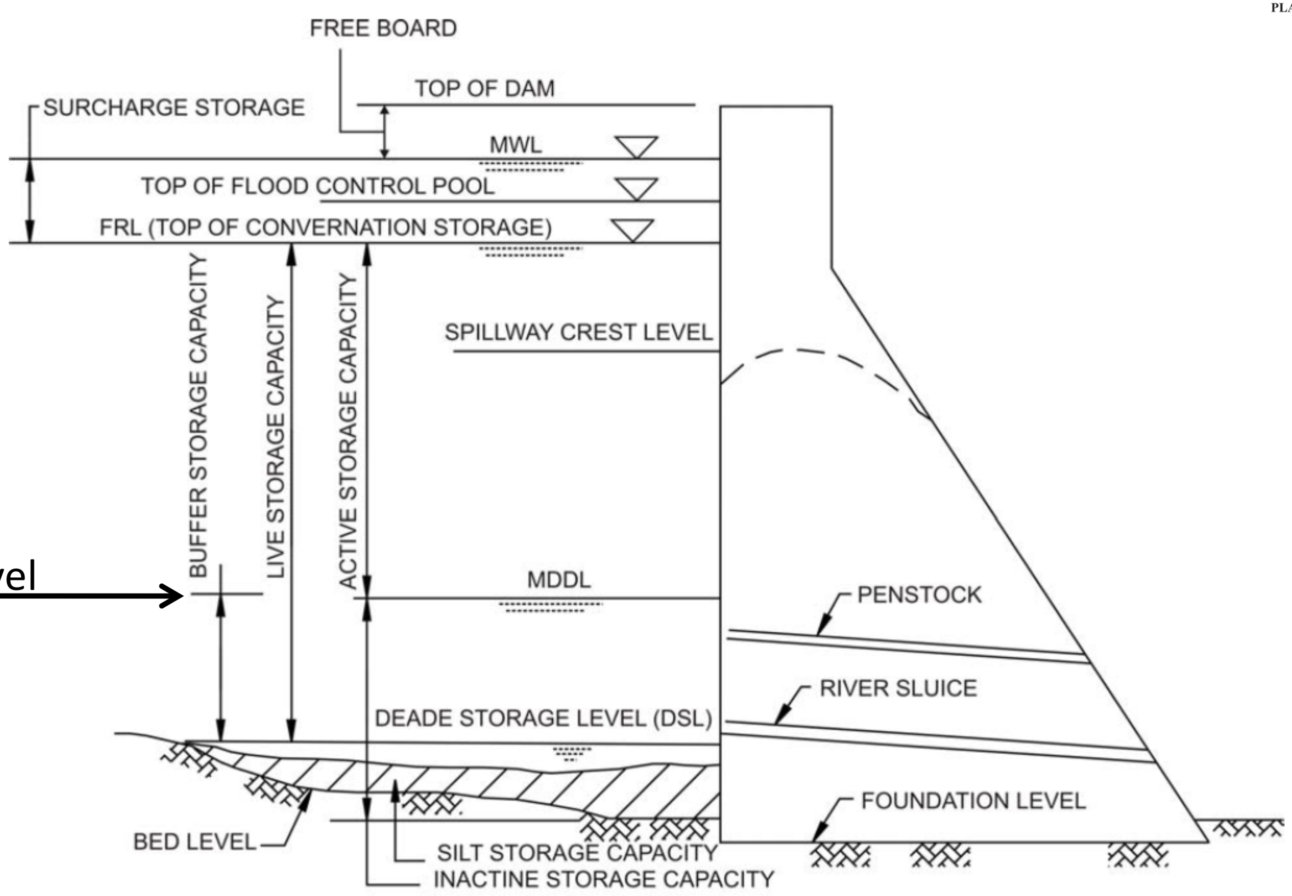
MWL: maximum water level

FRL: full reservoir level
maximum level that can be controlled

MDDL: minimum drawdown level
for hydropower use



Conservation storage: water is stored for many purposes: irrigation, water supply, recreation, maintenance of minimum flow, navigation, hydropower production, etc.

Flood control storage: retention of water during flood events for the purpose of reducing downstream flooding.

Dead storage for sediment collection.

Long-term reservoir size design

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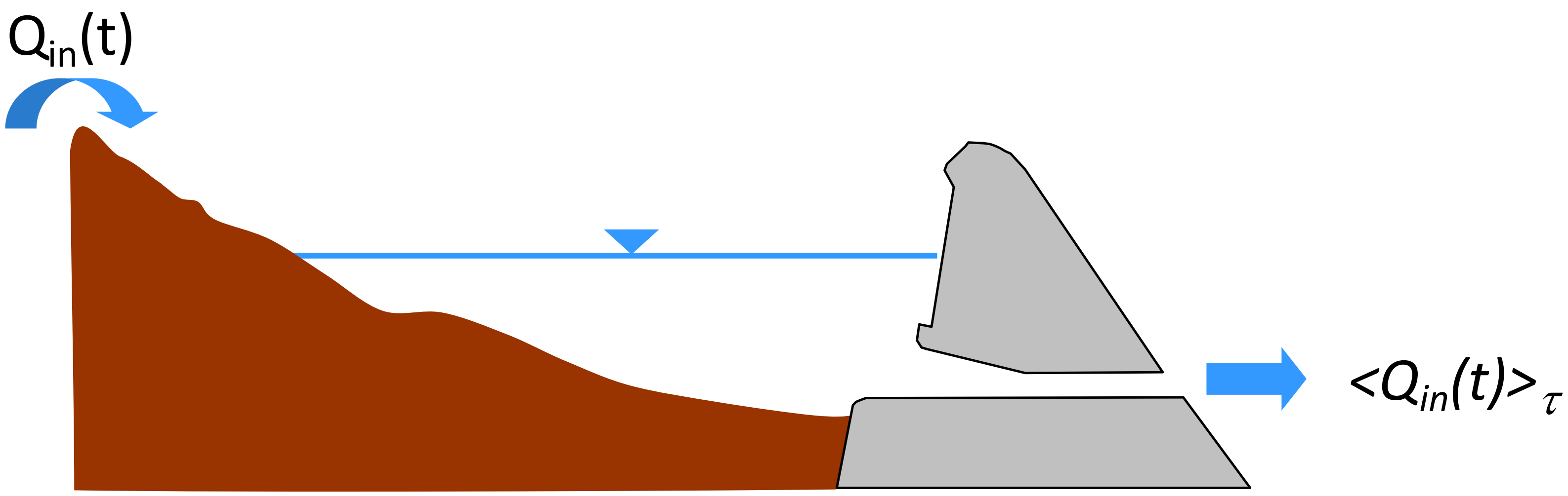
Problem: design of an ideal reservoir that never overflows or empties for a given period of analysis



One see this from the reservoir equation, i.e. imposing steady state conditions ⟨dV/dT⟩=0 for the reference period

$Q_{in}(t)$: record of input discharge $t=1,2,..,\tau$

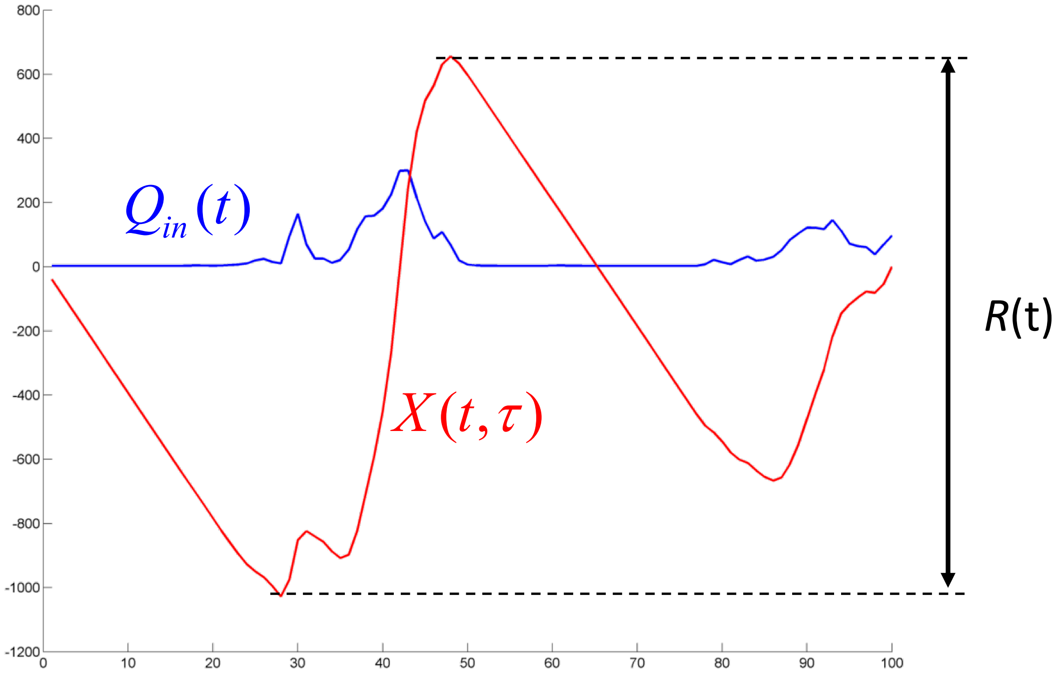
$$\langle Q_{in}(t) \rangle_\tau = \frac{1}{\tau}\sum_{t=1}^{\tau} Q_{in}(t)$$ outflow discharge equal to the mean inflow

Then, the integral storage equation

$$V(t) = V(0) + dt\sum_{t=1}^{\tau}[Q_{in}(t) - \langle Q_{in}(t)\rangle_{\tau}]$$

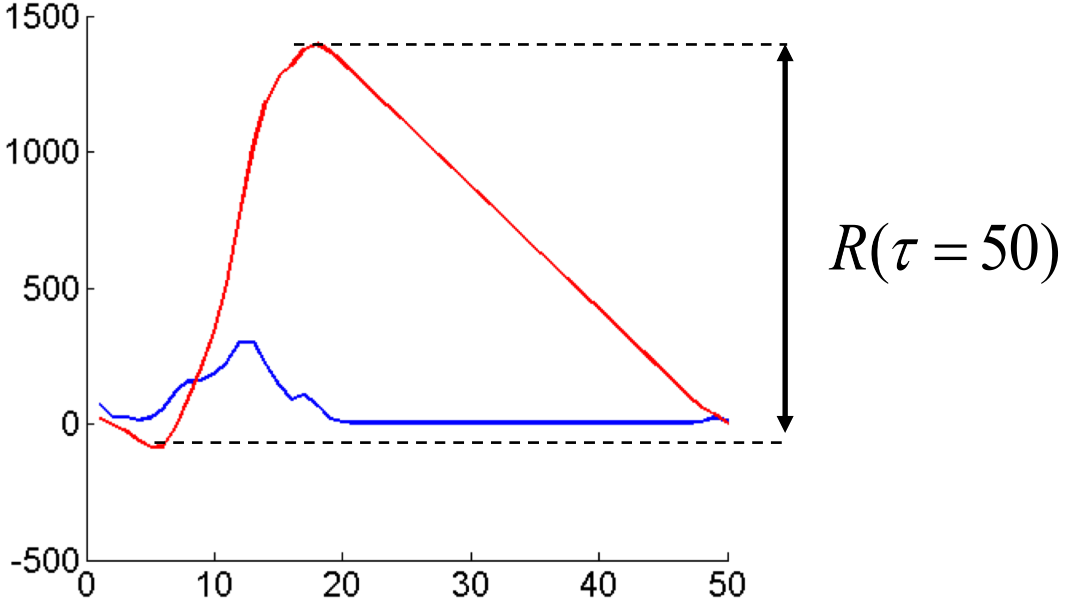
Shows that *V(t)*, except for a constant, it is proportional to the accumulated departure from the mean *X*

$$X(t,\tau) = \sum_{i=1}^{t}[Q_{in}(i) - \langle Q_{in}(i)\rangle_{\tau}]$$

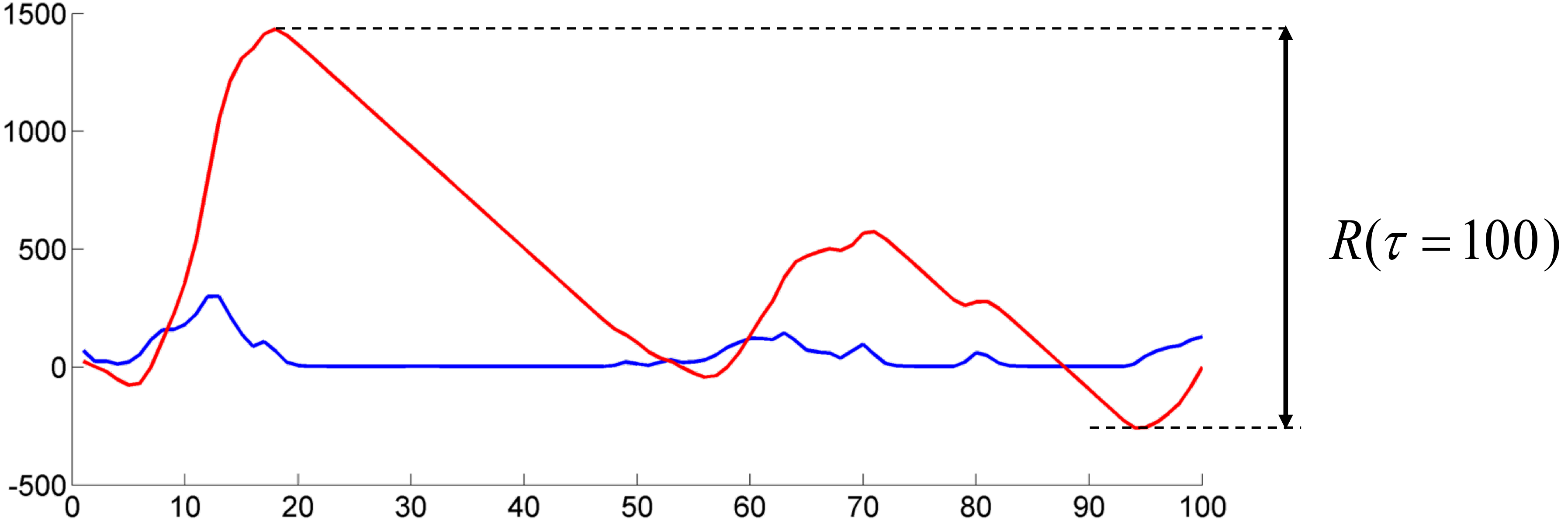


Hence, the required volume is proportional to the range *R*

$R(\tau)=\max X(t,\tau)-\min X(t,\tau)$



Because of uncertainty of the input flow, *R*(t) is expected to increase with the period τ



Hurst effect

Interestingly, R and the standard deviation of the inflows S over the period τ show an interesting relationship

$R(\tau)$=max $X(t,\tau)$-min $X(t,\tau)$

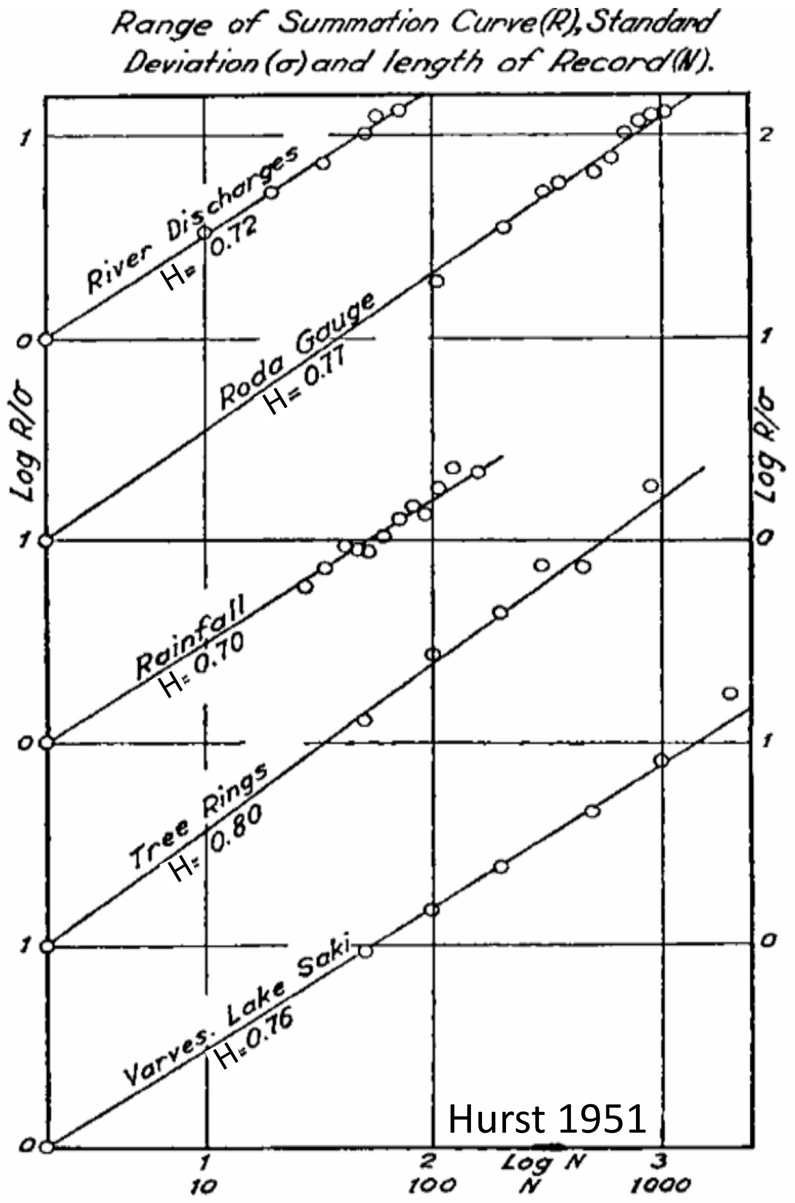
$$S(\tau)=\sqrt{\frac{1}{\tau}\sum_{t=1}^{\tau}[Q_{in}(t)-\langle Q_{in}(t)\rangle_{\tau}]^2}$$

$$\frac{R(\tau)}{S(\tau)} \propto \tau^H$$

H:Hurst exponent

For river discharge (and many other geophysical time series) H>0.5

H is a measure of the fractal dimension of a time series*.



*We shall return to this concept in L6 and L7