Water Resources Engineering
Exercise

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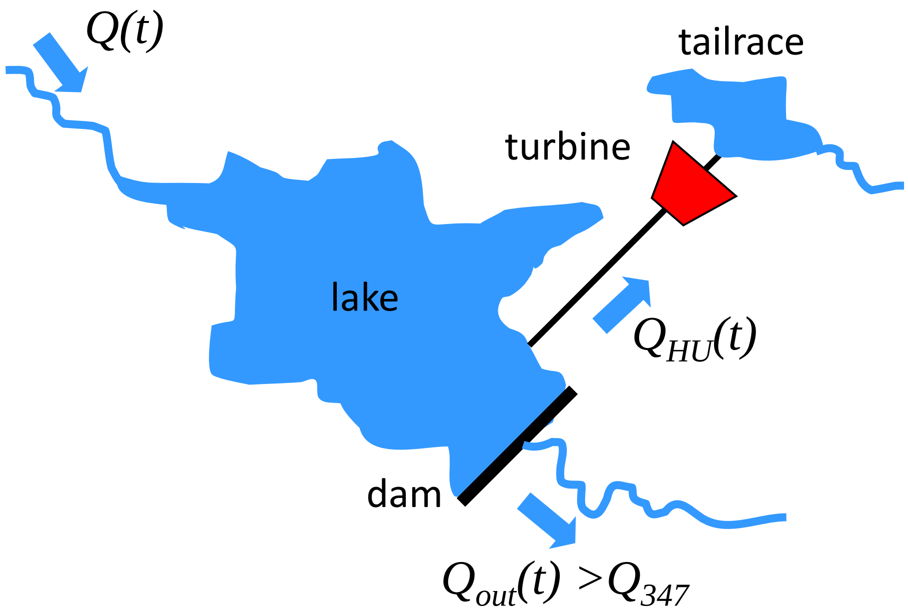
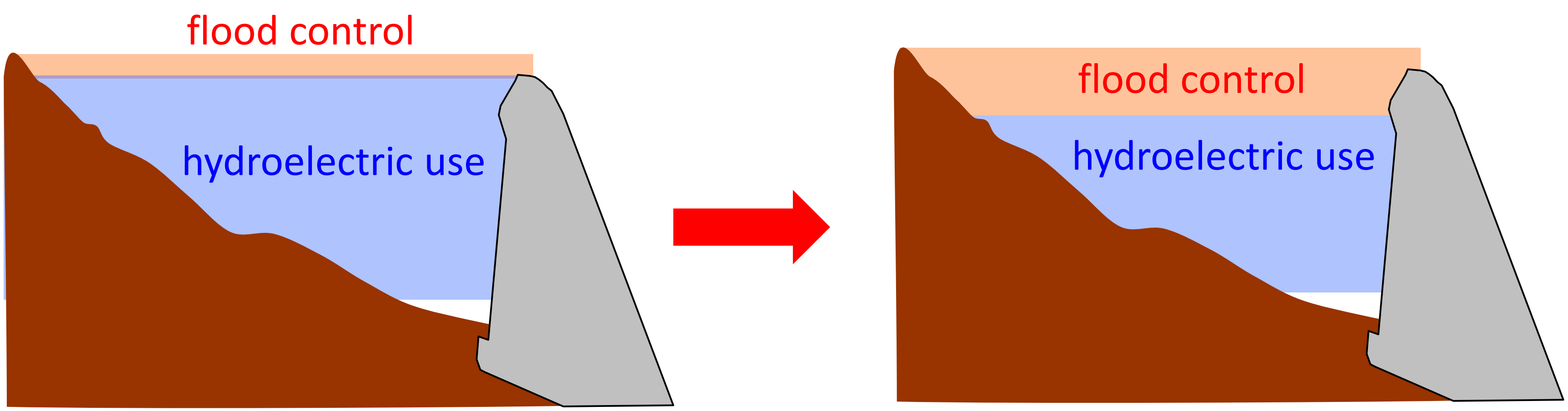
lecture: Tuesday 8.15-10 in room GR B3 30
exercise: Thursday 10.15-12 in room INF 3
office hours: Thursday 12-14 (GR C1 532 – GR C1 564)

Assignment: management of a multipurpose reservoir

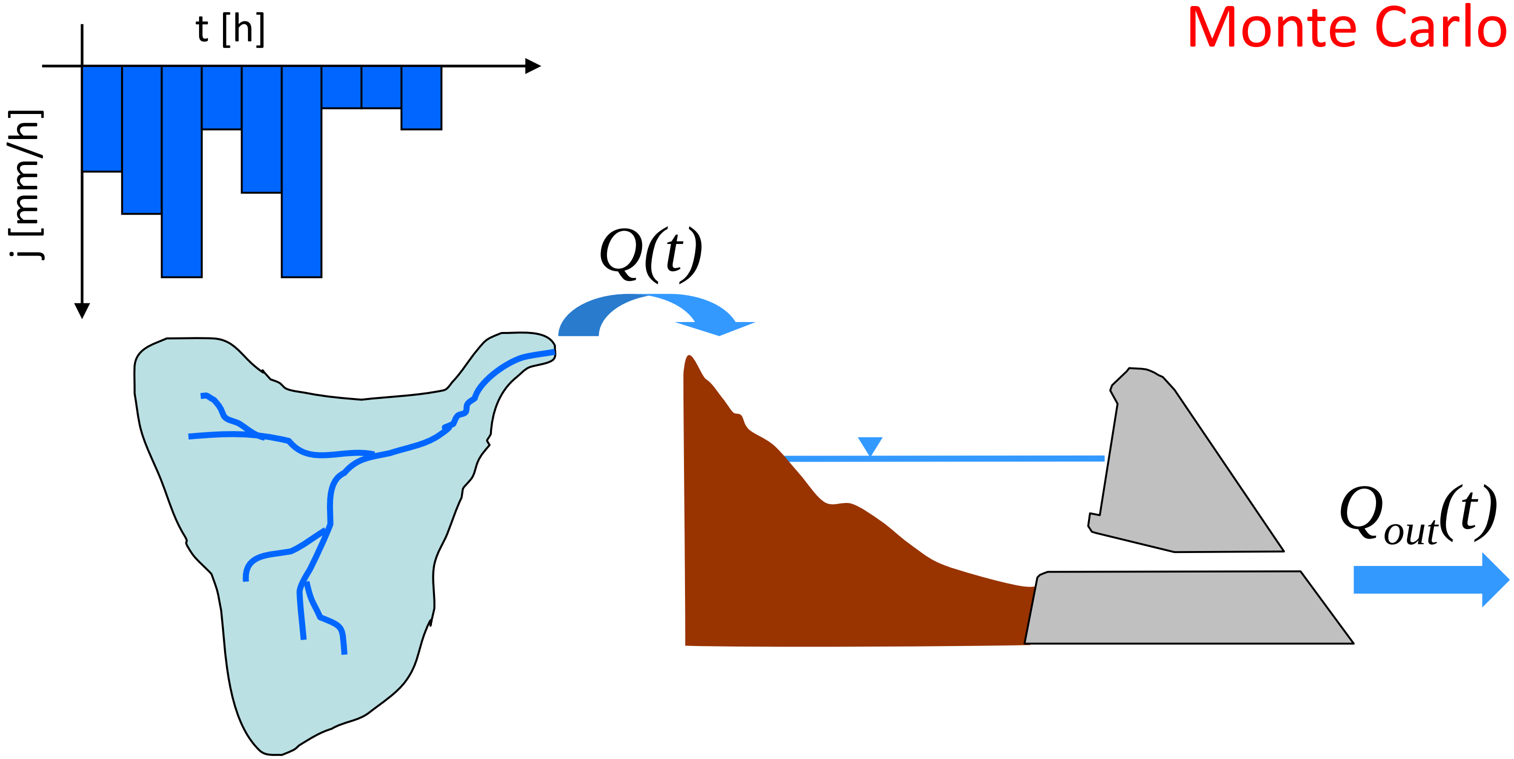


Evaluate the feasability of improving the flood control operations of an exixting reservoir of a hydropower plant.

A larger fraction of the storage needs to be reserved for flood control and cannot be used for hydroelectric purpose



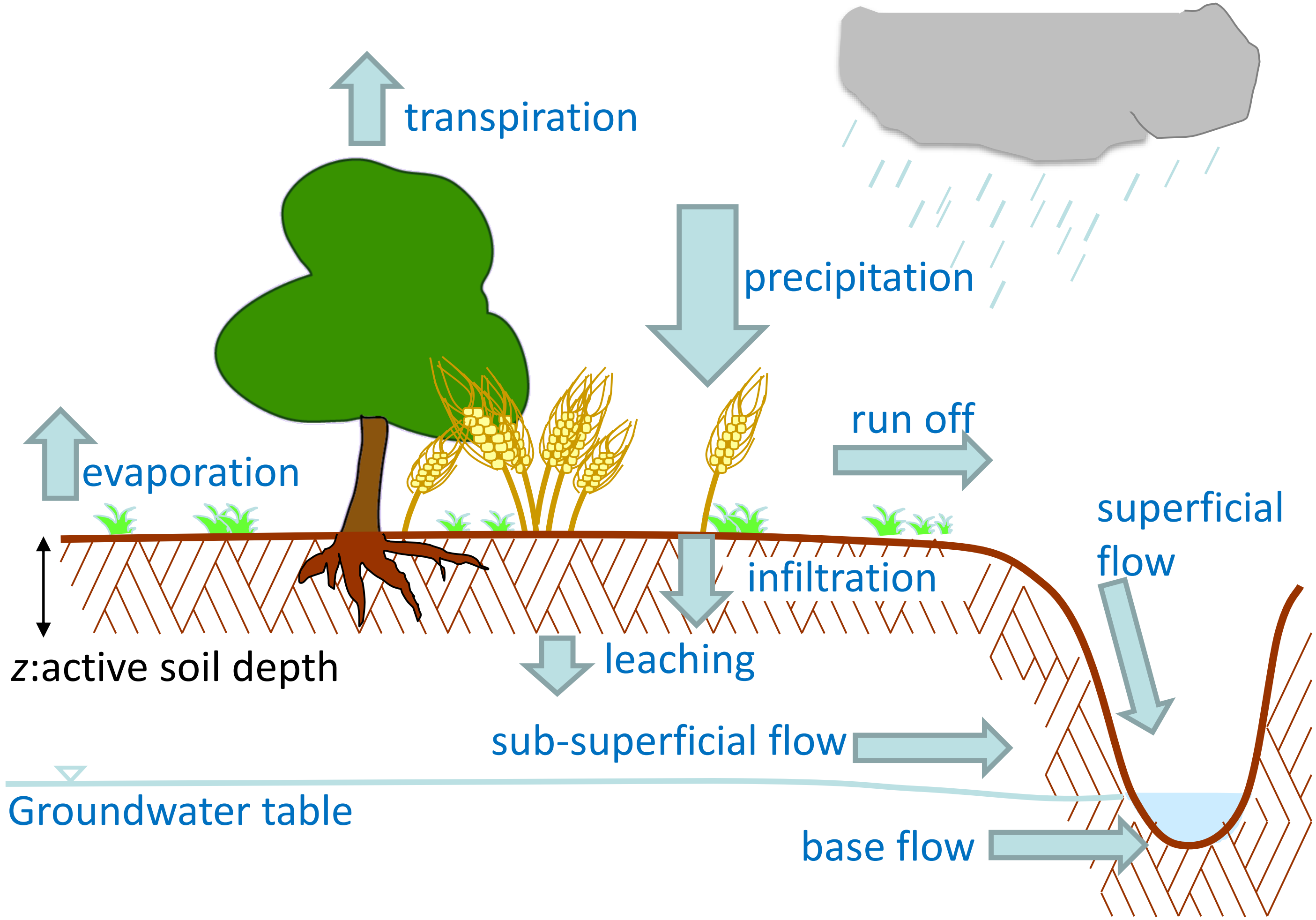
Monte Carlo approach



Step

- Develop and calibrate a lumped continuous hydrological model to transform rainfall into discharge. The model is fitted based on the available dataset.
- Generate rainfall time series with the same statistical properties of the observed ones.
- Transform generated rainfall into a generated time-series of input discharge.
- Simulate the reservoir routing and the flood control operations for different maximum level for hydroelectric use.
- Measure the energy produced and the flooding probability

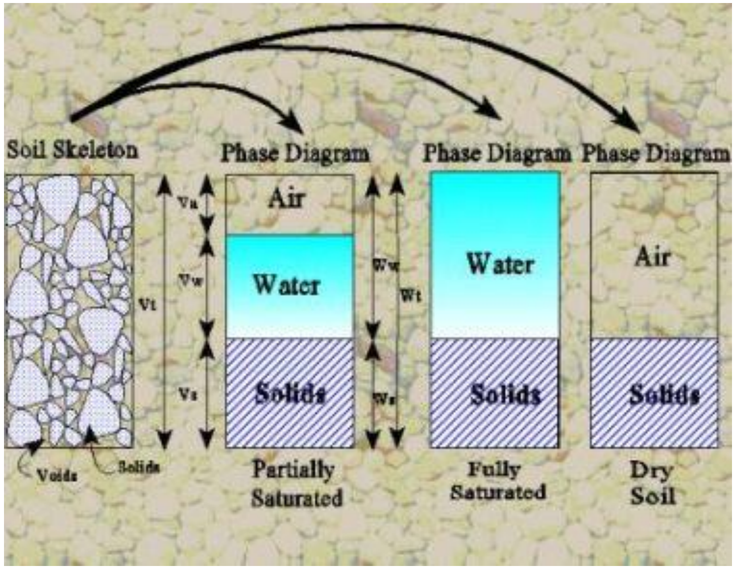
assigment, part 1: continuous lumped hydrological model



Lumped hydrological model does not consider explicitly the spatial distribution of soil properties and precipitation. The model is lumped in a representative soil column. The geometry of the basin is accounted for in the routing scheme that transforms run-off into superficial flow and leaching into sub-superficial flow. Continuous as it accounts for evapotranspiration and can thus be simulated for long time windows.

Opposite of lumped: distributed. Opposite of continuous: event based

soil properties



V_s volume of solids

V_w volume of water

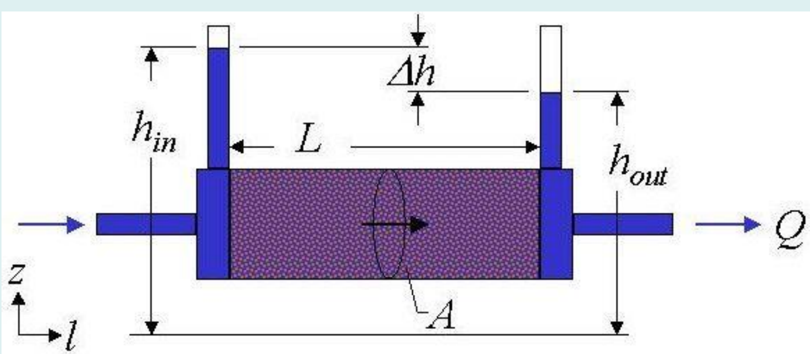
V_a volume of air

$V = V_a + V_w + V_s$ total volume

$n = \dfrac{V_a + V_w}{V}$ porosity

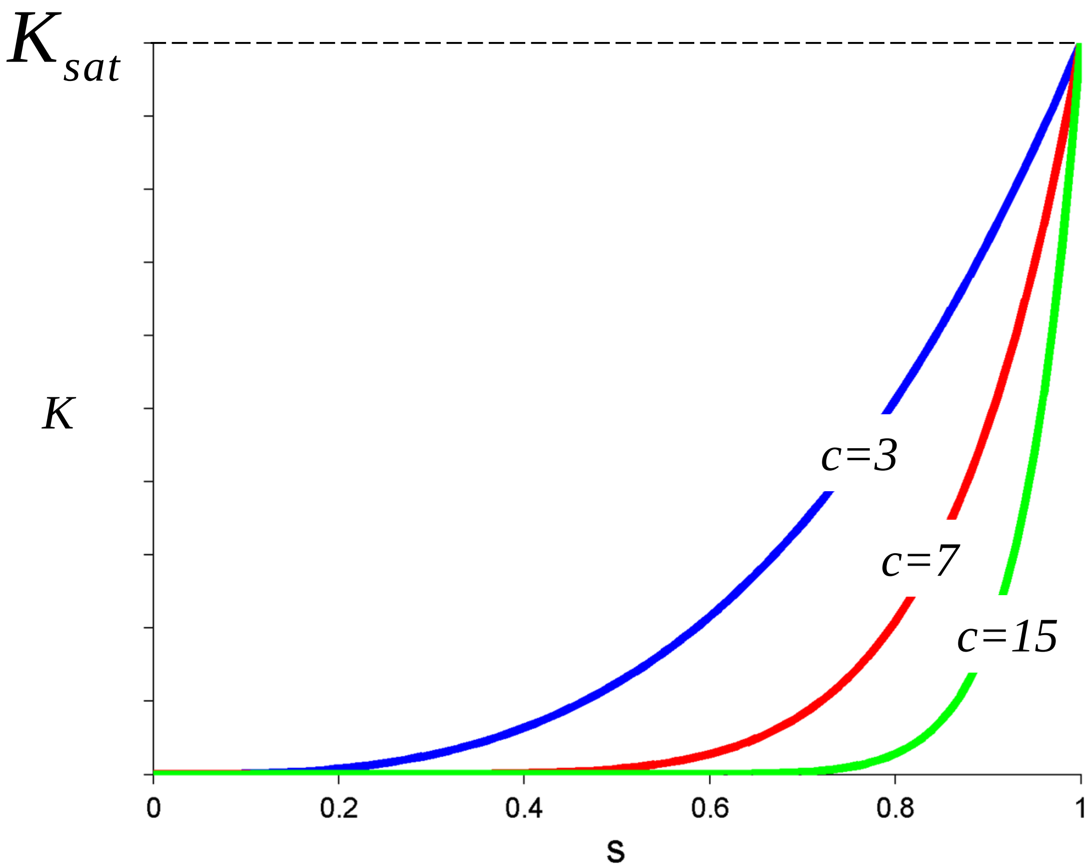
soil moisture $s = \dfrac{V_w}{V_a + V_w}$ dry $0 < s < 1$ saturation

Hydraulic conductivity at saturation K_{sat} [LT^{-1}]



Darcy Law

$$\frac{Q}{A} = K_{sat} \frac{\Delta h}{L}$$



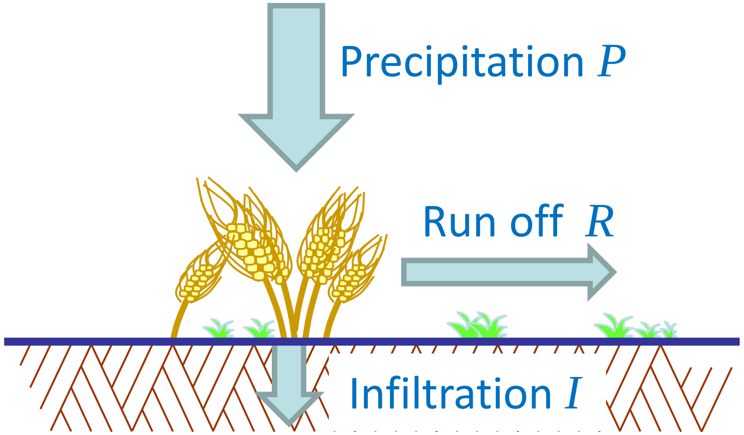
unsaturated hydraulic conductivity K [LT^{-1}]

$$K(s) = K_{sat} \cdot s^{c}$$

K : unsaturated hydraulic conductivity

K_{sat} : saturated hydraulic conductivity

Precipitation/Infiltration/Runoff



$$P(t) = R(t) + I(t)$$

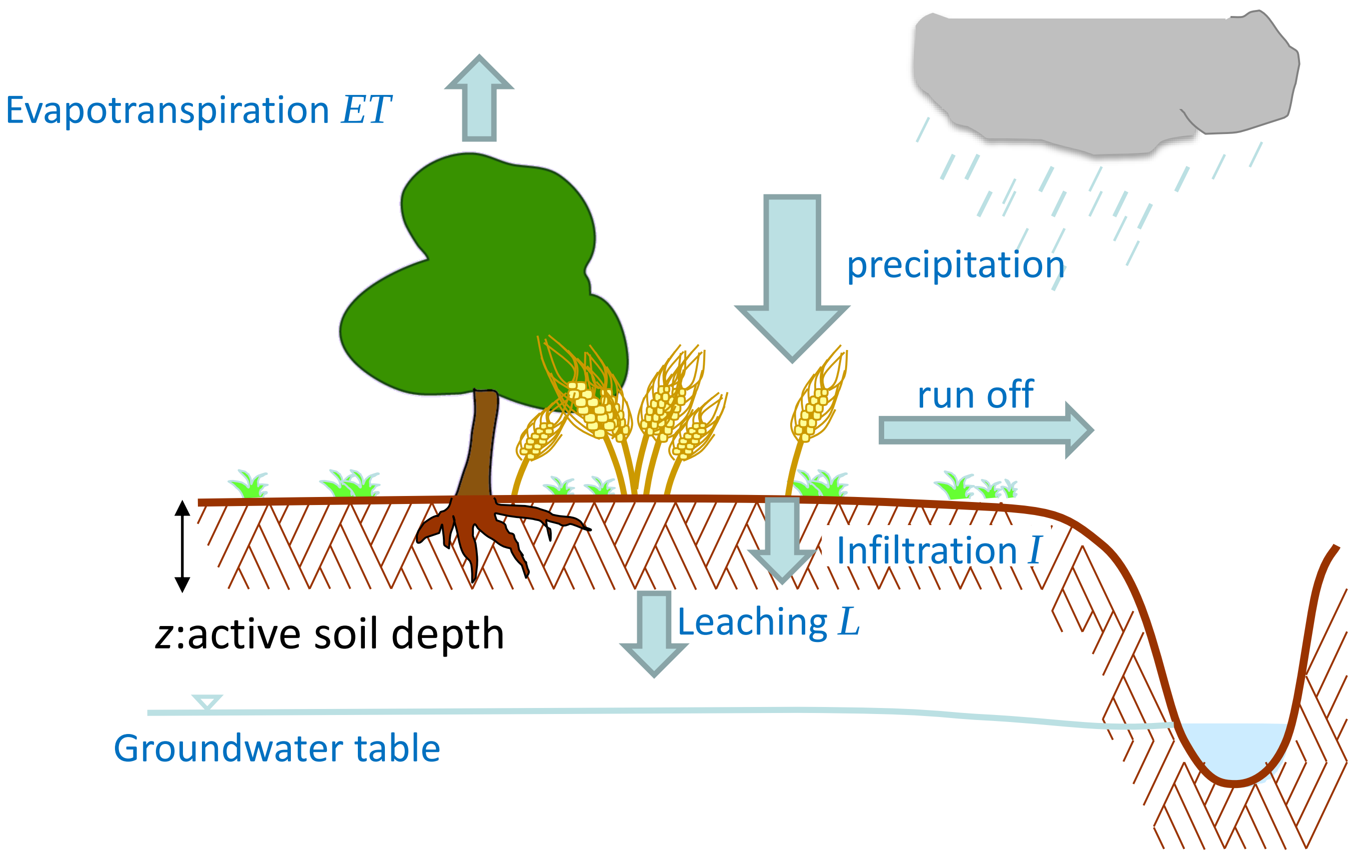
RUNOFF PRODUCTION MECHANISM

•Infiltration Excess (saturation from above, Horton mechanism): rate of rainfall exceeds the rate at which water can infiltrate into the ground. The maximum infiltration rate is equal to the saturate hydraulic conductivity

$$I(t) = \min(P(t), K_{sat})$$

$$R(t) = P(t) - I(t)$$

Soil moisture dynamic in the root zone



$$nz\frac{ds}{dt} = I(t) - ET(s,t) - L(s,t)$$

$$L(s,t) = K(s) = K_{sat} \cdot s(t)^{c}$$

n: porosity [-]

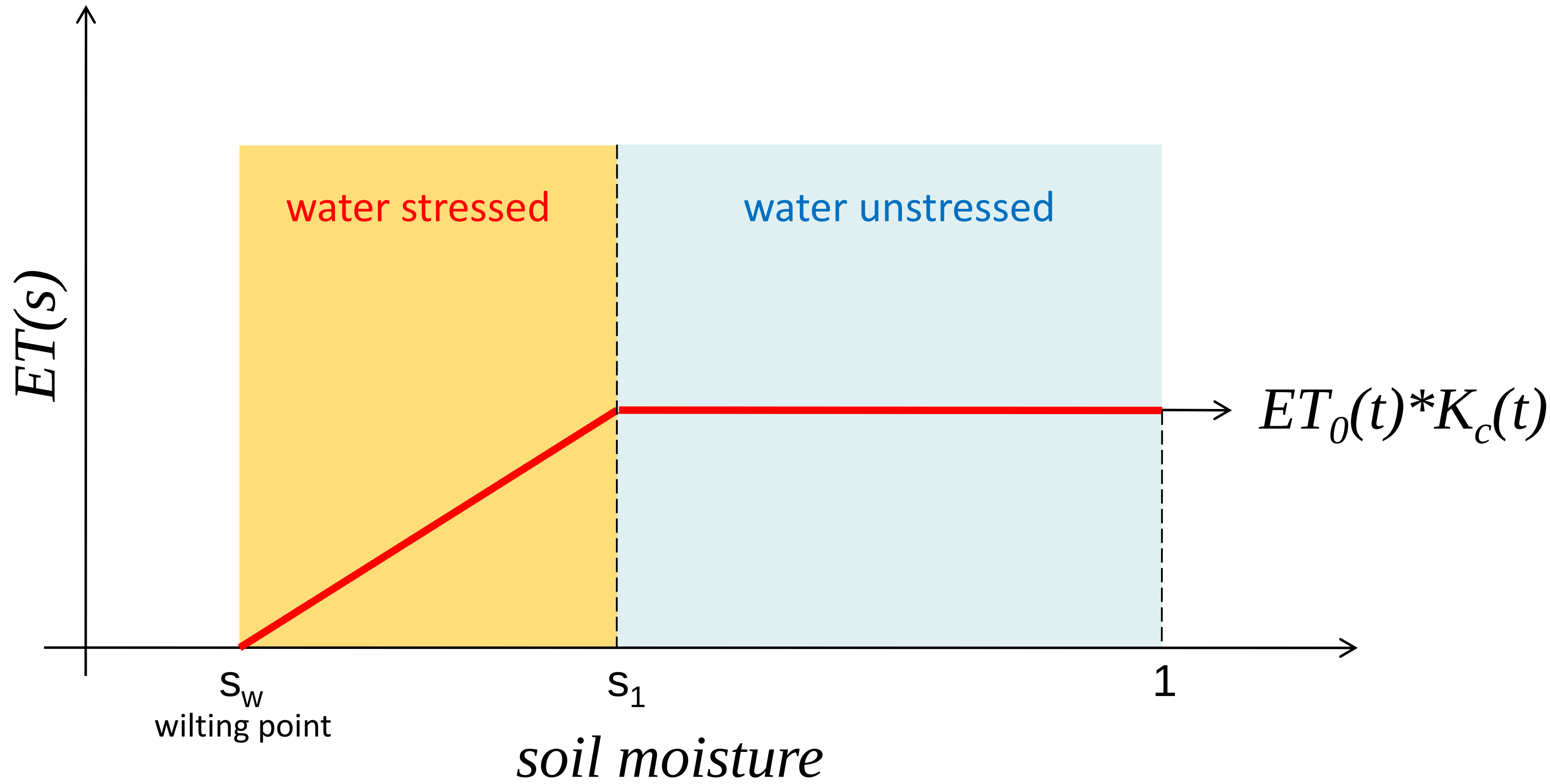
s: soil moisture 0< s <1 [-]

z: root zone thickness [L]

nsz: root zone water storage [L]

L: leaching [LT^{-1}]

Evapotranspiration



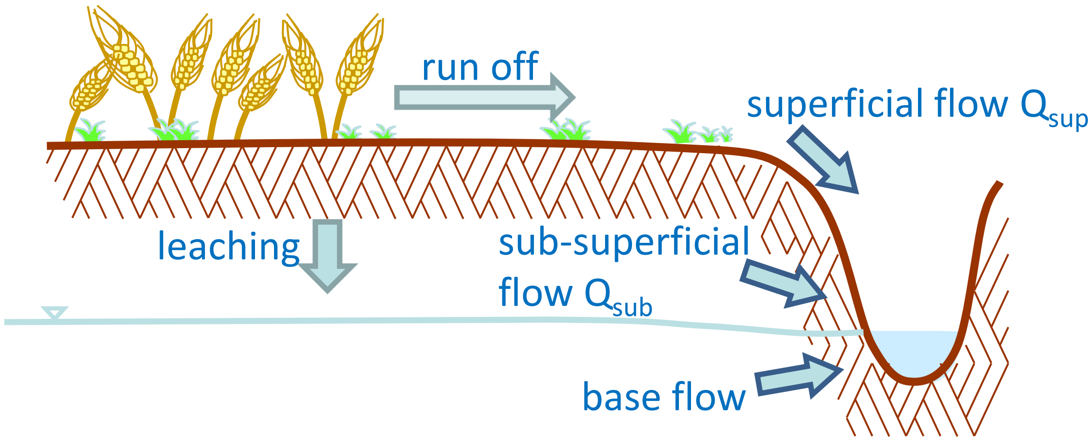
$ET_0(t)$: reference crop evapotranspiration (computed with the Thornthwaite method)

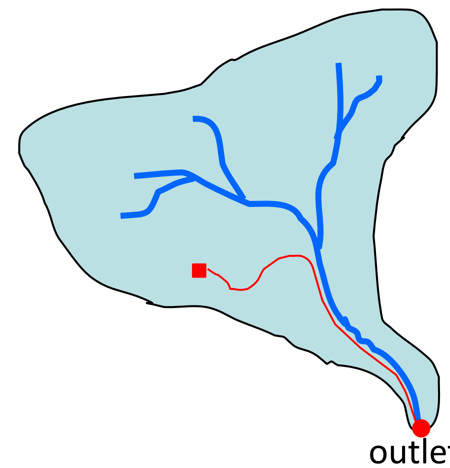
$K_c(t)$: crop coefficient representative of the whole catchment

s_w: wilting point, soil moisture content at which plants stop transpiring

s_1: soil moisture above which plants transpire at the maximum rate

routing





routing model accounts for the delay imposed by the drainage path of water (inside the hillslope and in the channel) from where it is produced to the outlet

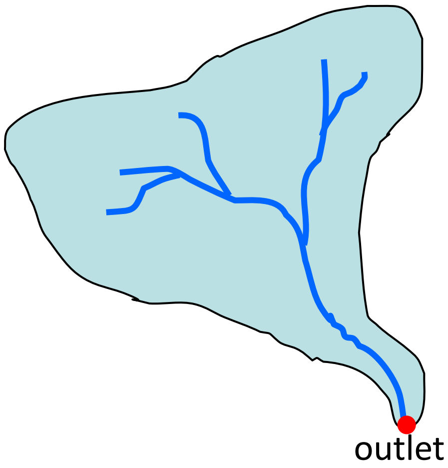
runoff $R(t)$ $\xrightarrow{\text{produces}}$ superficial flow $Q_{sup}(t)$

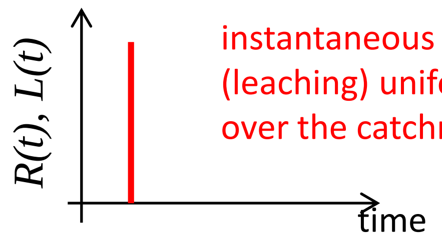
leaching $L(t)$ $\rightarrow$ sub-superficial flow $Q_{sub}(t)$

baseflow $Q_b(t)$ $\rightarrow$ long term drainage of groundwater (not directly coming from precipitation)

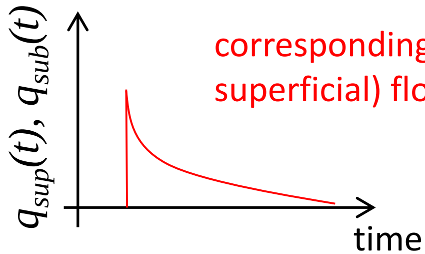
Total discharge at the outlet $Q(t) = Q_{sup}(t)+Q_{sub}(t)+Q_b(t)$

Linear reservoir scheme equivalent to assuming an exponential instantaneous unit hydrograph (IUH) often used when the time spent in the channel is negligible with respect to that spent in the hillslope





instantaneous pulse of runoff (leaching) uniformly distributed over the catchment



corresponding superficial (sub-superficial) flow at the outlet

$$\frac{dV_{sup}}{dt} = R(t) - q_{sup}(t)$$

$$q_{sup}(t) = V_{sup}(t) / t_{sup}$$

$$\frac{dV_{sub}}{dt} = L(t) - q_{sub}(t)$$

$$q_{sub}(t) = V_{sub}(t) / t_{sub}$$

V_{sup}: water stored in the superficial layer [L]

V_{sub}: water stored in the sub-superficial layer [L]

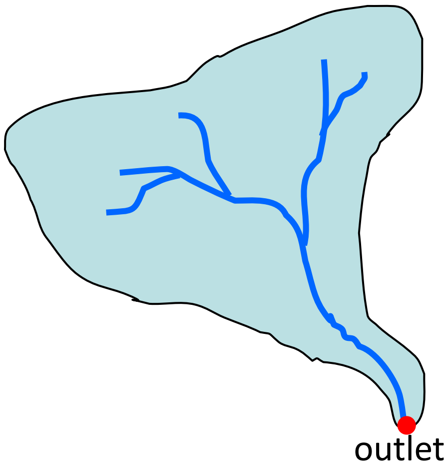
t_{sup}: mean superficial residence time [T]

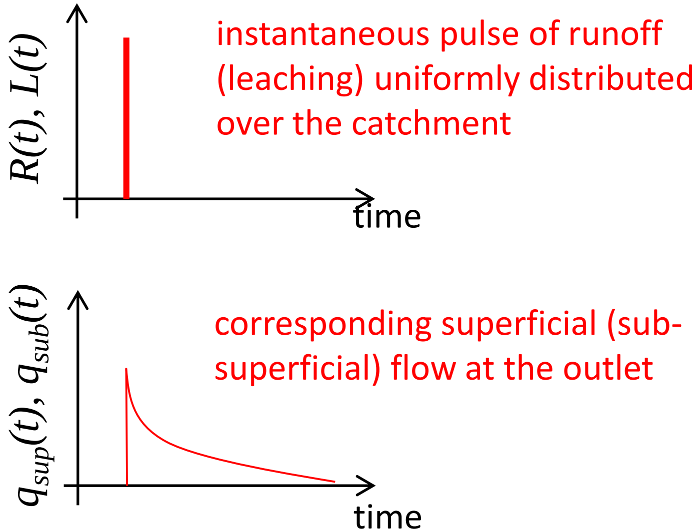
t_{sub}: mean sub-superficial residence time [T]

q_{sup}: superficial specific discharge (discharge per unit of area) [LT^{-1}]

q_{sub}: sub-superficial specific discharge (discharge per unit of area) [LT^{-1}]

Linear reservoir scheme equivalent to assuming an exponential instantaneous unit hydrograph (IUH) often used when the time spent in the channel is negligible with respect to that spent in the hillslope



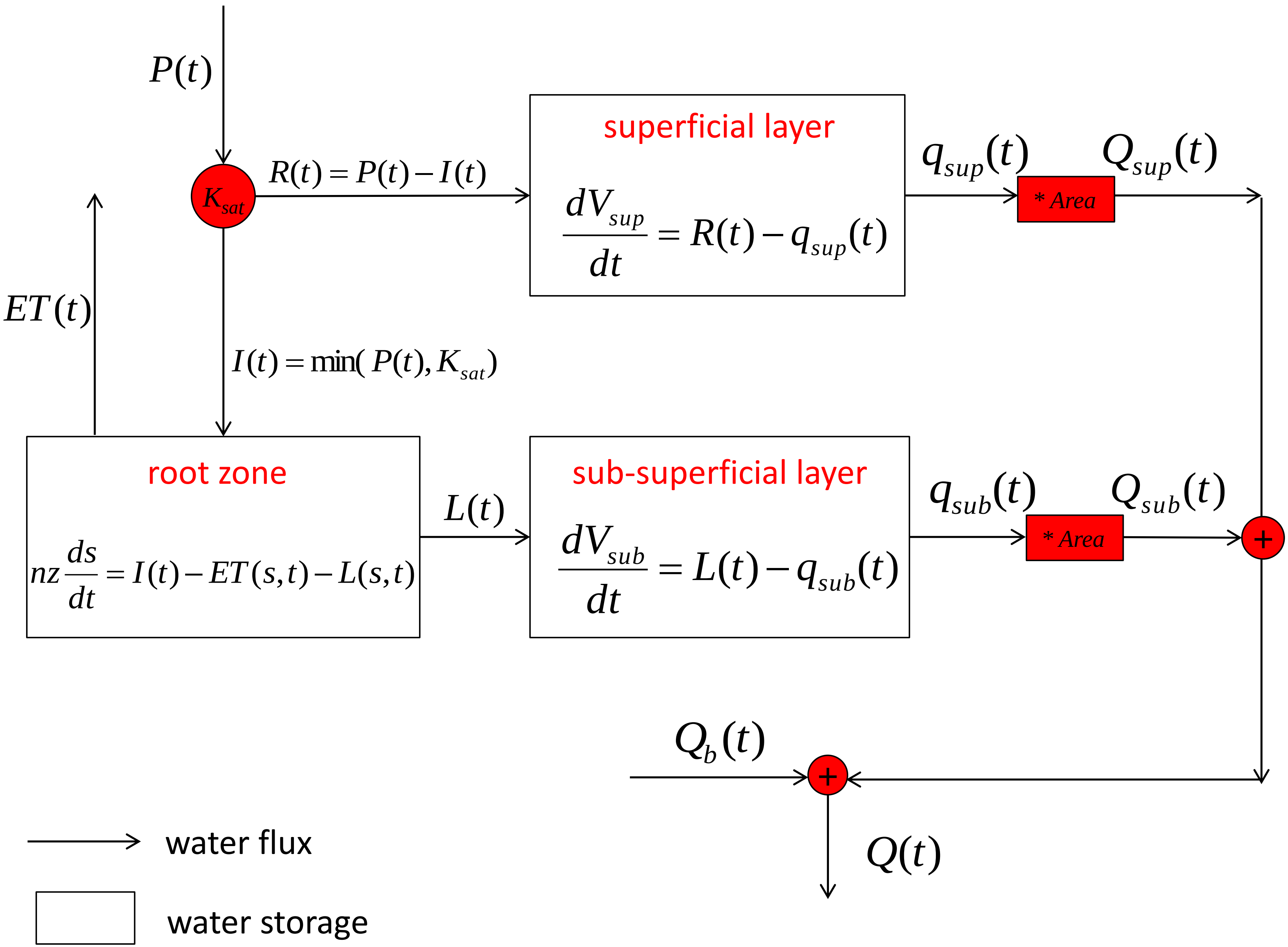


$$Q_{sup}(t) = Area * q_{sup}(t)$$

$$Q_{sub}(t) = Area * q_{sub}(t)$$

$Area$: Area of the catchment

model


$P(t)$
K_{sat}
$R(t) = P(t) - I(t)$
superficial layer
$\frac{dV_{sup}}{dt} = R(t) - q_{sup}(t)$
$q_{sup}(t)$
* Area
$Q_{sup}(t)$
$ET(t)$
$I(t) = \min(P(t), K_{sat})$
root zone
$nz \frac{ds}{dt} = I(t) - ET(s,t) - L(s,t)$
$L(t)$
sub-superficial layer
$\frac{dV_{sub}}{dt} = L(t) - q_{sub}(t)$
$q_{sub}(t)$
* Area
$Q_{sub}(t)$
+
$Q_b(t)$
+
$Q(t)$
water flux
water storage

numerical integration: Euler explicit method

The dynamics of each storage (root zone, superficial and subsuperficial storage) can be generically written as:

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

where F_{in} and F_{out} represent input and output fluxes, respectively.

Numerical integration

$$V(\bar{t} + \Delta t) \overset{\text{Taylor}}{=} V(\bar{t}) + \Delta t \left.\frac{dV}{dt}\right|_{t=\bar{t}} + \cancel{o(\Delta t^2)}$$

$$V(\bar{t} + \Delta t) \approx V(\bar{t}) + F_{in}(\bar{t})\Delta t - F_{out}(\bar{t})\Delta t$$

Time step of integration Δt=1 hour

model input and parameters

model inputs

```
% load input files (see detailed description of the headers of the txt files)
load P.txt               %precipitation data
load Q_obs.txt           %discharge data
load temperature.txt     %mean montly temperature
load kc.txt              %mean monthly crop coefficient
```

some parameters can be estimated from literature values and analysis of the discharge time series

s_w	0.25	Wilting point [-]
s_1	0.4	Soil moisture above which plants transpire at k_c*ET_0 [-]
n	0.3	Porosity [-]
Q_b	7	Baseflow [m^3/s]
t_{sup}	22	Superficial residence time [h]
$\mathcal{A}$	4000	Area of the basin [km^2]
φ	38	Latitude of the basin [degrees]

the remaining parameters (k_{sat}, c, t_{sub}, z) need to be calibrated

Goodness of fit: Nash-Sutcliffe

$$NS = 1 - \frac{\sum_t \left(Q_o(t) - Q(t)\right)^2}{\sum_t \left(Q_o(t) - \overline{Q_o(t)}\right)^2}$$

Q : modelled discharge

Q_o: observed discharge

$\overline{Q_o}$: average observed discharge

Nash-Sutcliffe index ranges from –∞ to 1:

$NS = 0$: the model is as predictive as the mean of the observed values

$NS = 1$: perfect fit (Q=Q_o for every t)

Free parameters for calibration: k_{sat}, c, t_{sub}, z

A (meta-heuristic) calibration algorithm must be implemented (next week!)

this week's task

Build function `Lastname_HydroModel.m` that, given the time series of precipitation and a parameter set, computes the time series of discharge that results from the implementation of the hydrological model.

Function `Lastname_HydroModel.m` is called by the main script `Lastname_CalibrateHM.m`, in which:

- Inputs and known parameters are read;
- Potential evapotranspiration is computed;
- The hydrological model is tested (check on water balance);
- The algorithm for calibration is implemented (next week!).

For this week, attribute arbitrary values to the parameters that require calibration in order to test the model.

Possible ranges: $10^{-7} \leq K_{sat} \leq 10^{-5}$ [m/s] $\quad 1 \leq c \leq 20$ [–]

$1 \leq t_{sub} \leq 400$ [h] $\quad 1 \leq z \leq 2000$ [mm]