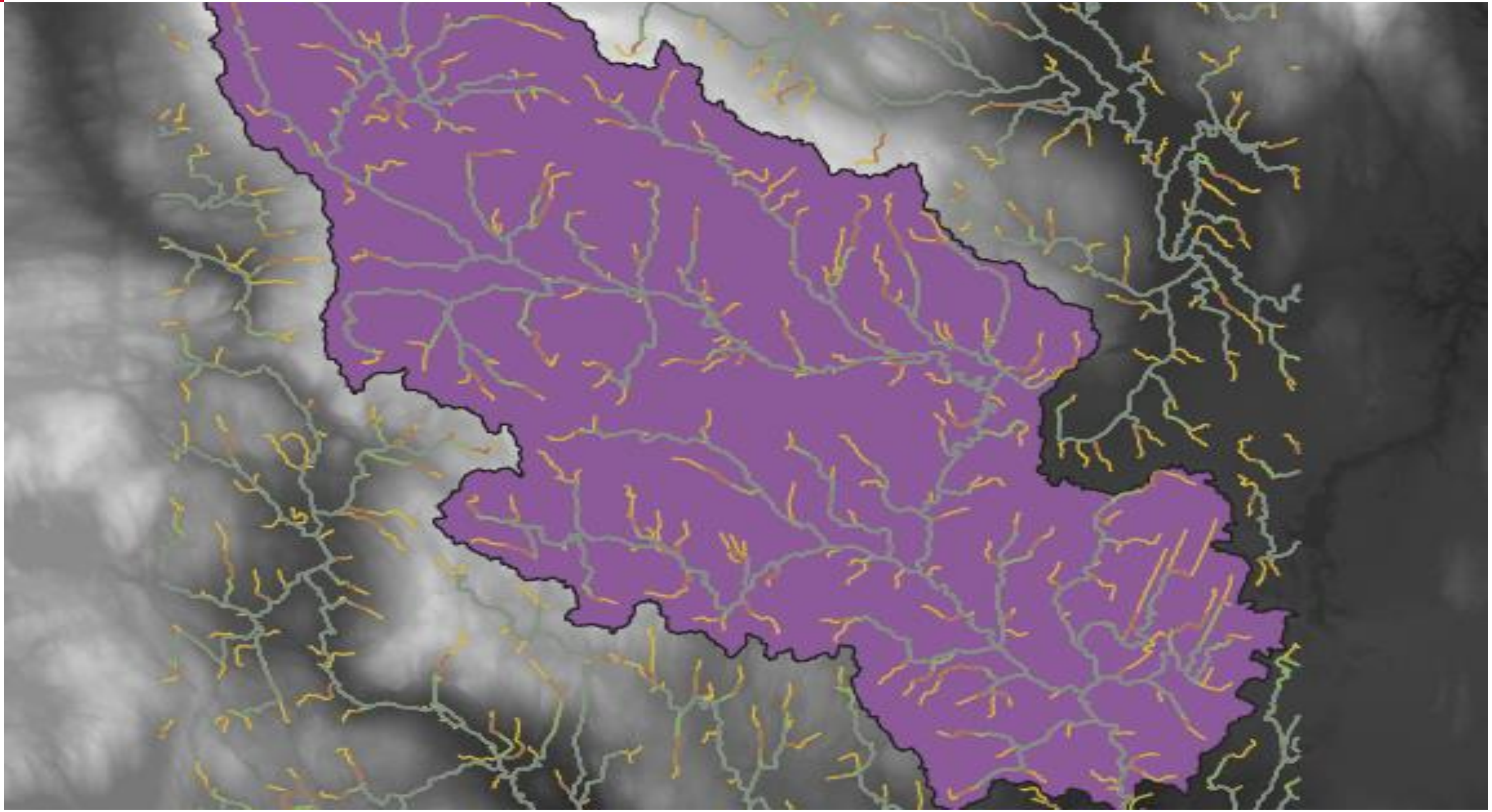
The DDD (Distance Distribution Dynamics) model- a parameter parsimonious rainfall runoff model.

Basic principles and ideas

Thomas Skaugen

Forsker, NVE



What determines runoff dynamics in a catchment?

- Meteorology/Climate-precipitation temperature, radiation, etc.
- Wetness in the catchment, what was the weather like yesterday
- Soils
- Wetlands
- Rivernetwork
- Topography
- Glaciers

More?

Many of these elements are dependent on each other, i.e. soils-rivernetworks glaciers-climate

Hydrological modelling is to:
1) Describe mathematically how these elements transport/store water/energy
2) Describe mathematically how these elements interact - soils/rivernetwork
3) Describe mathematically the order of these elements

What determines runoff dynamics in a catchment?

- Meteorology/Climate-precipitation temperature, radiation, etc.
- Wetness in the catchment, what was the weather like yesterday
- Soils
- Lakes
- Wetlands
- Rivernetwork
- Topography
- Permafrost
- Glaciers

More?

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Hydrological modelling is to:
1) Describe mathematically how these elements transport/store water/energy
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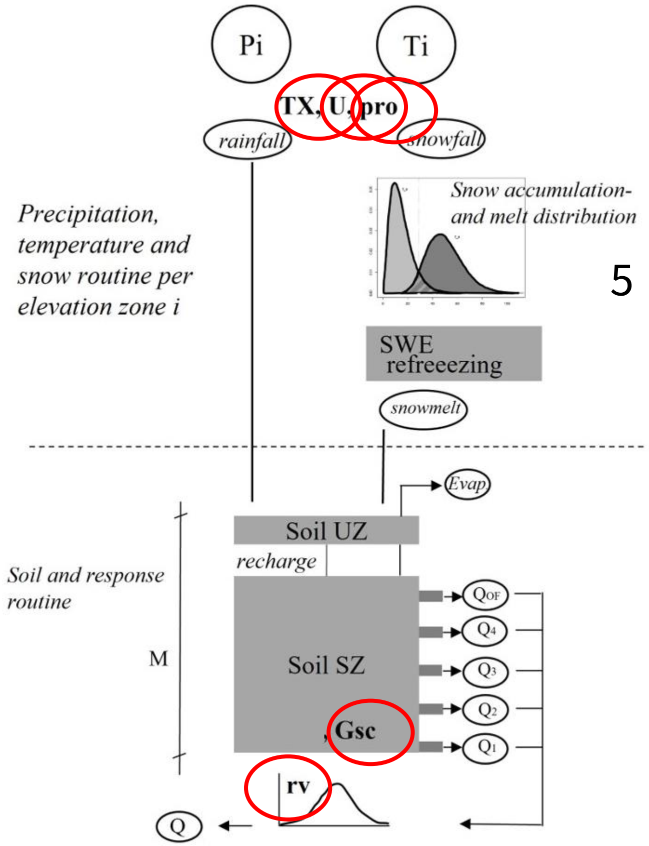
3) Describe mathematically the order of these elements

Model parameters
- quantifying nature or mathematical adjustement

The problem is that there is little information available for quantifying the parameters- only runoff
One parameter- no problem
More than one- problems

Compensating behaviour
of pairs/ triplets/quadruplets etc. of parameters
gives equifinality- many parameter constellations give acceptable results. The physical meaning of the parameter is lost ..



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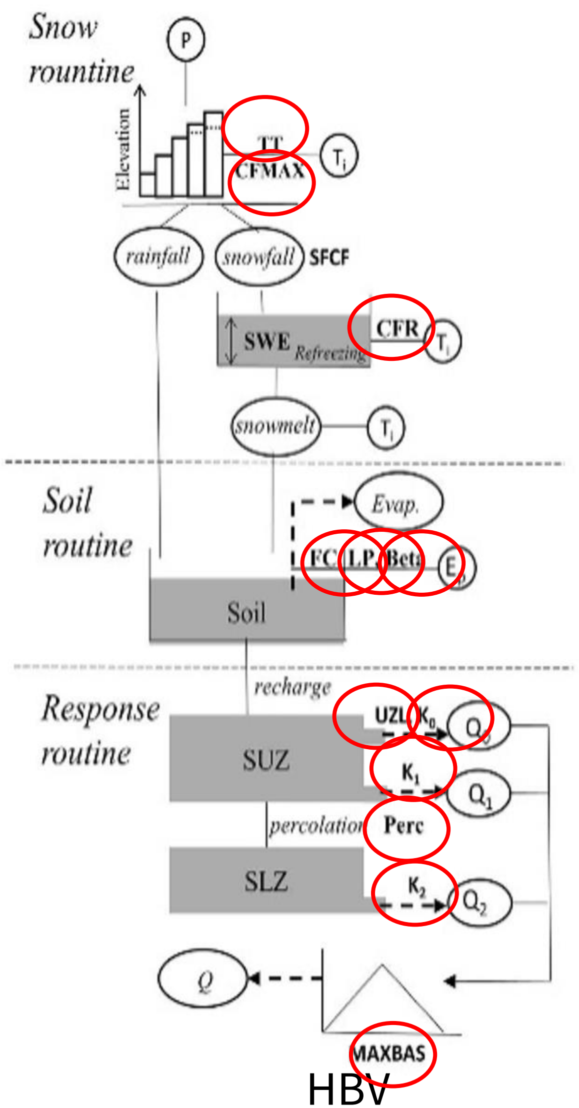
DDD



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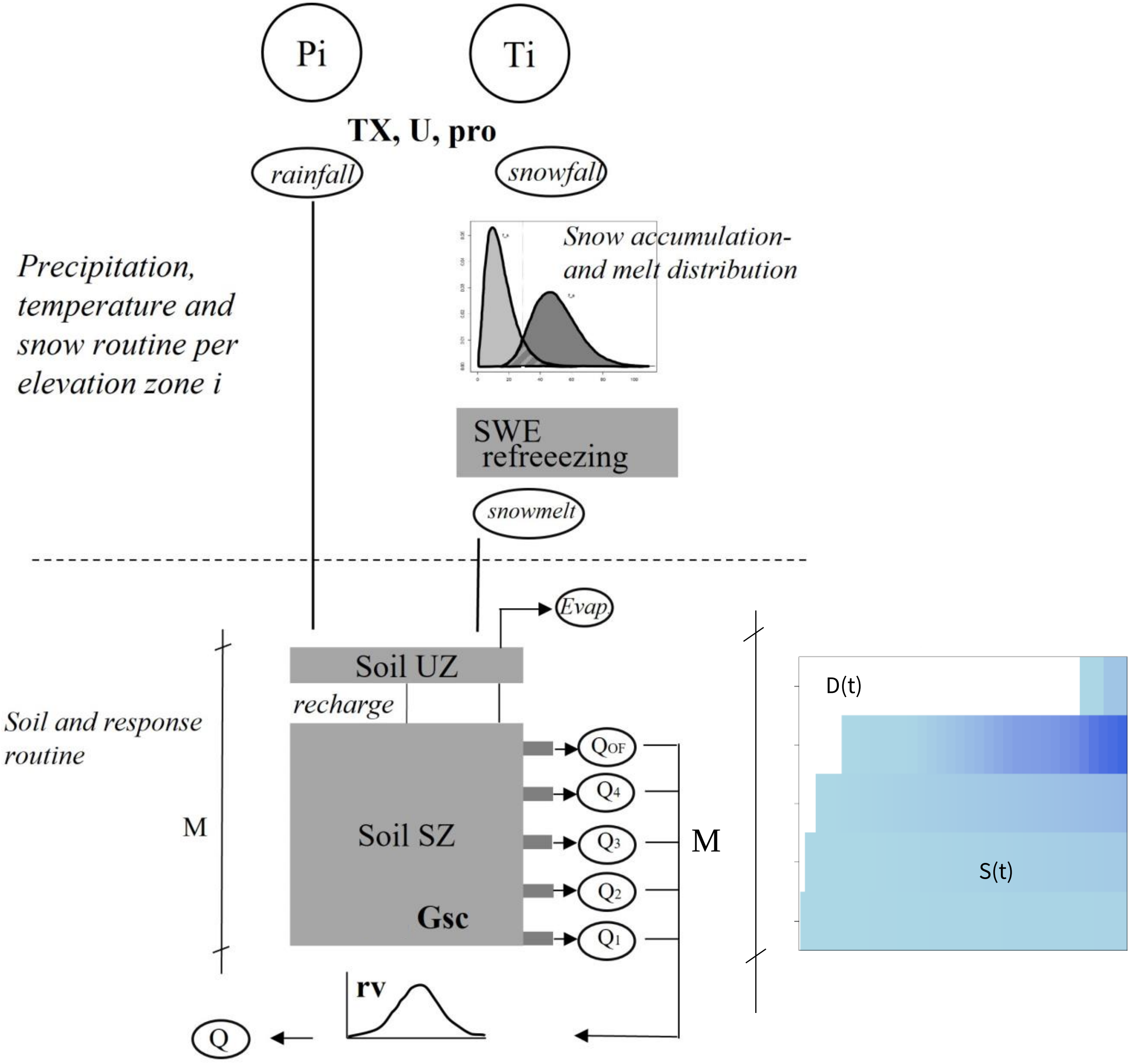
HBV

The Distance Distribution Dynamics (DDD) model



DDD model

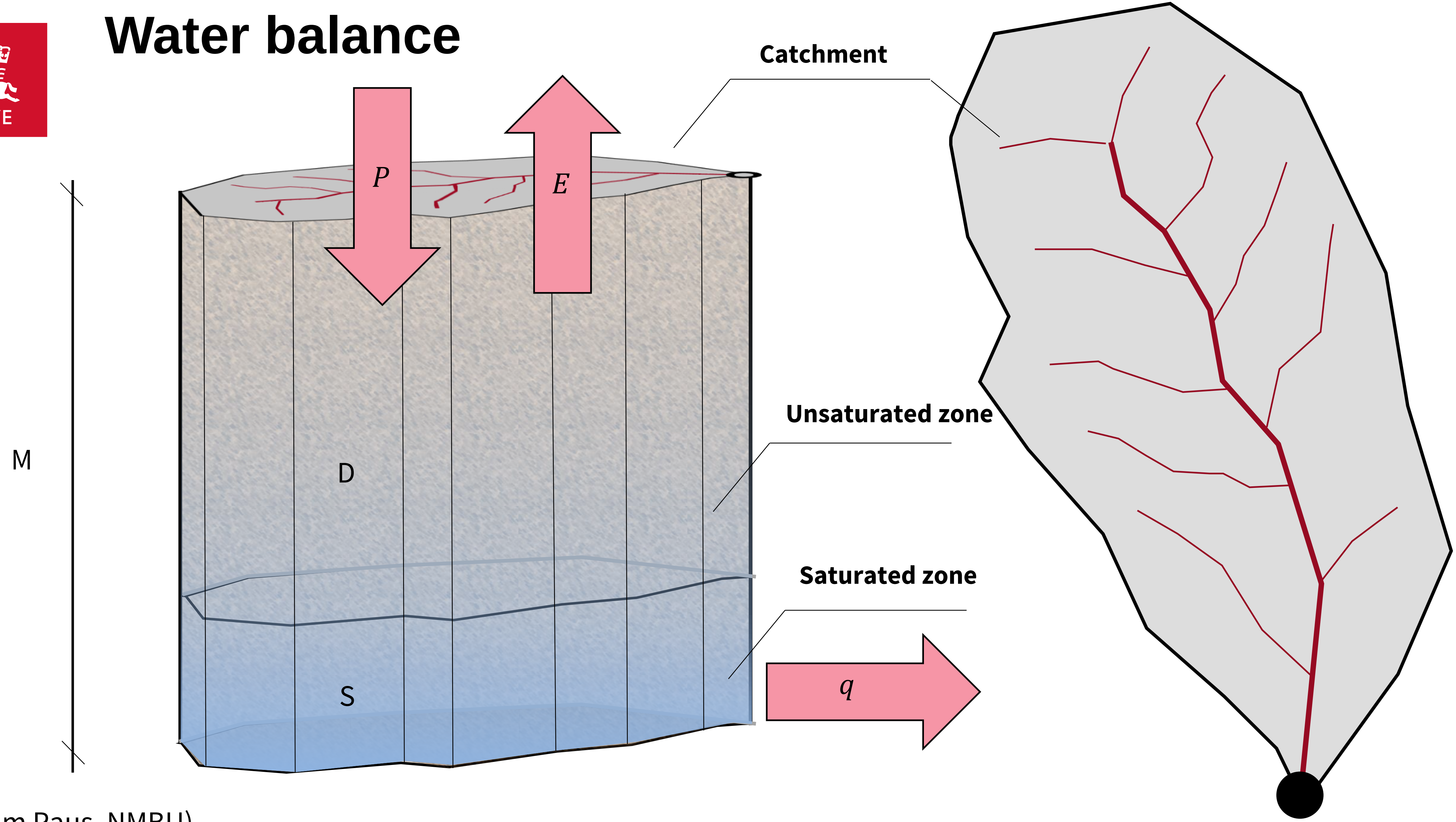
-a parameter parsimonius rainfall-runoff model using combinations of unit hydrographs (UHs).

- A UH can be seen as a set of weights which distributes the input in time.

- runoff dynamics are modelled by UH arranged in parallell, turned on and off according to level of saturation

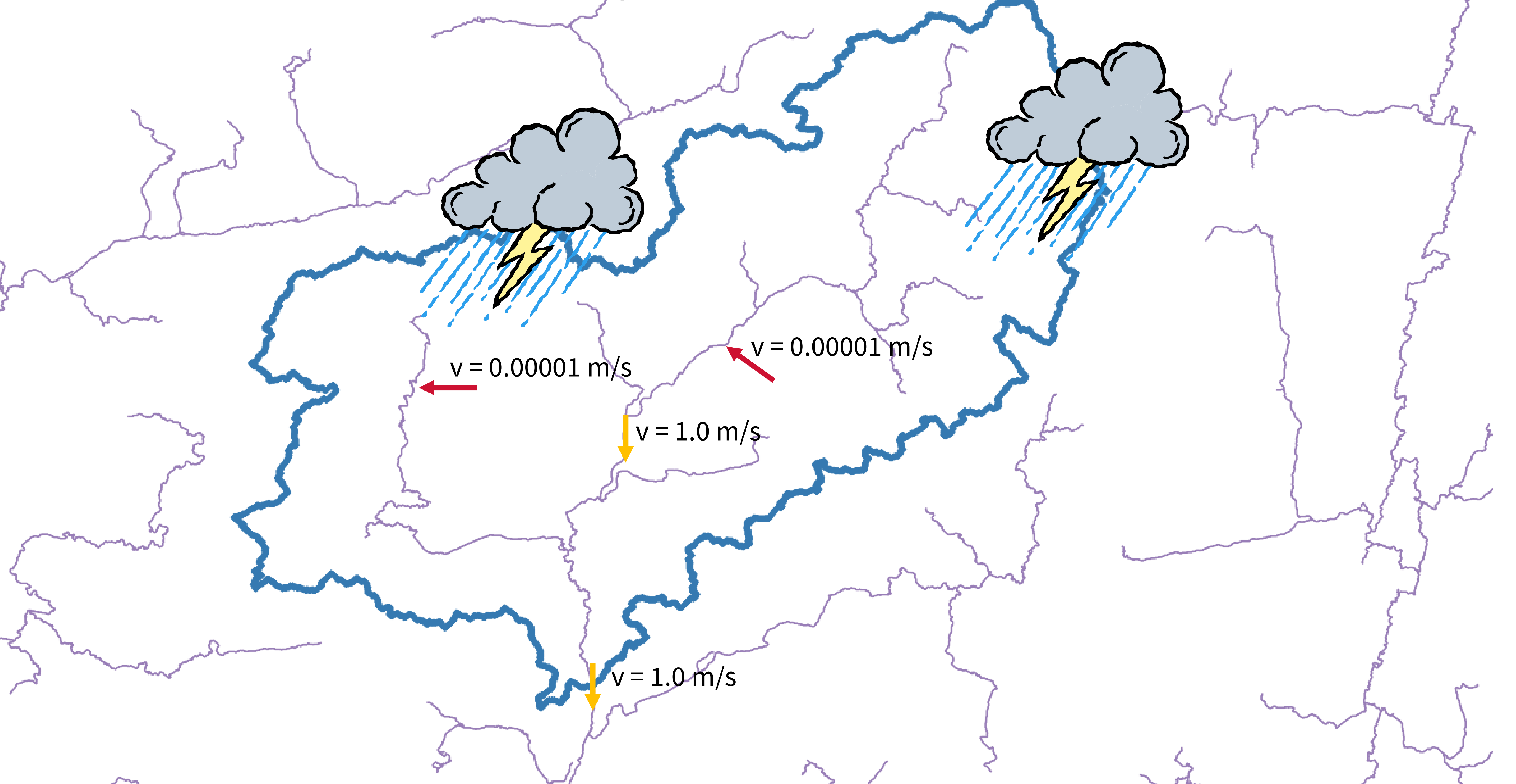
- The parameters of the UHs are, as far as possible, determined from observed data

Water balance



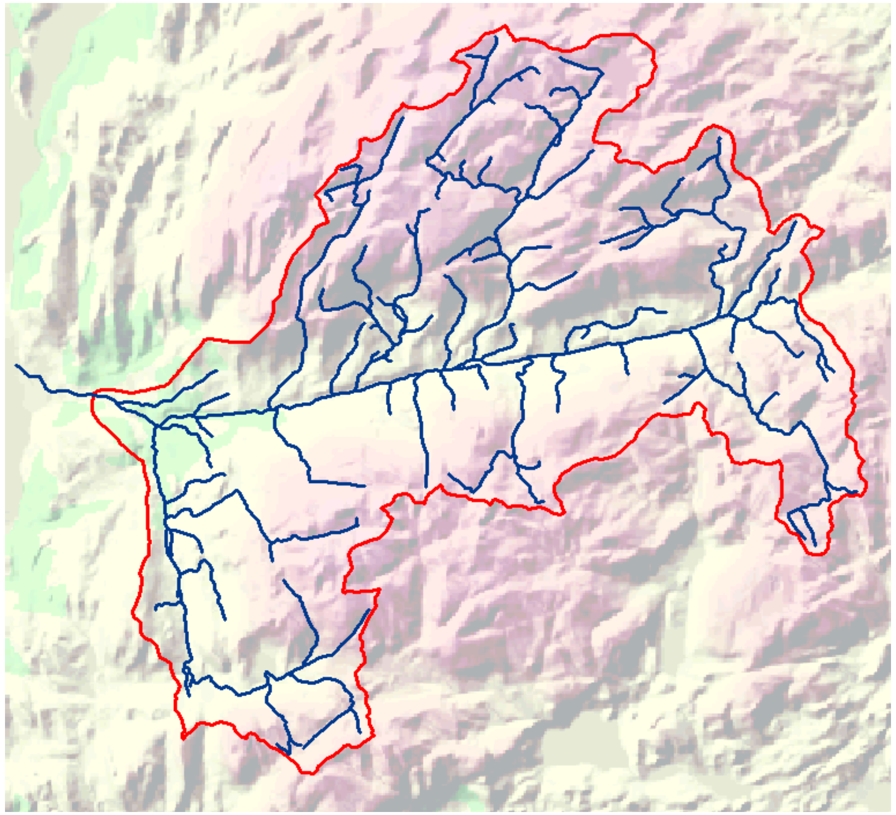
(Kim Paus, NMBU)

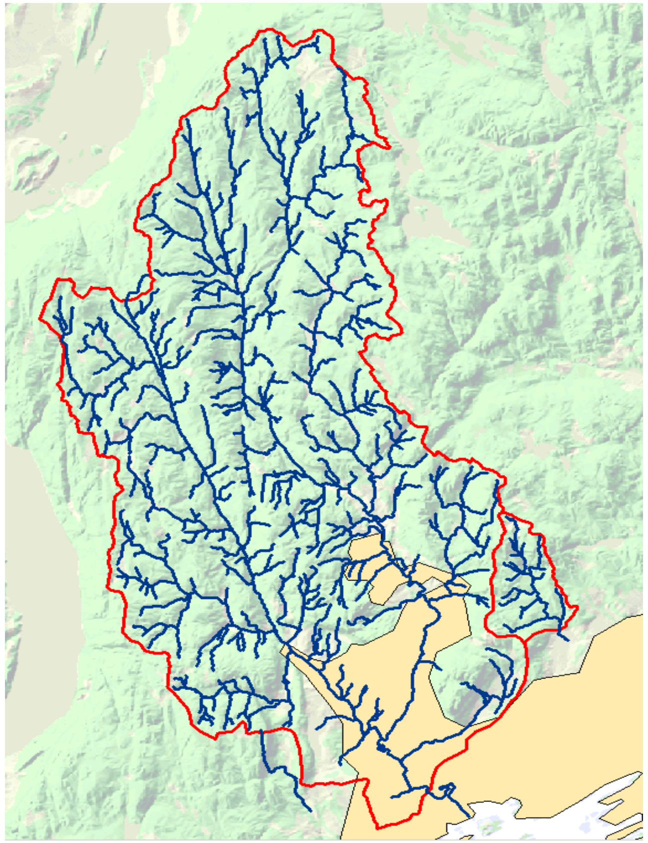
An intuitive rainfall-runoff concept

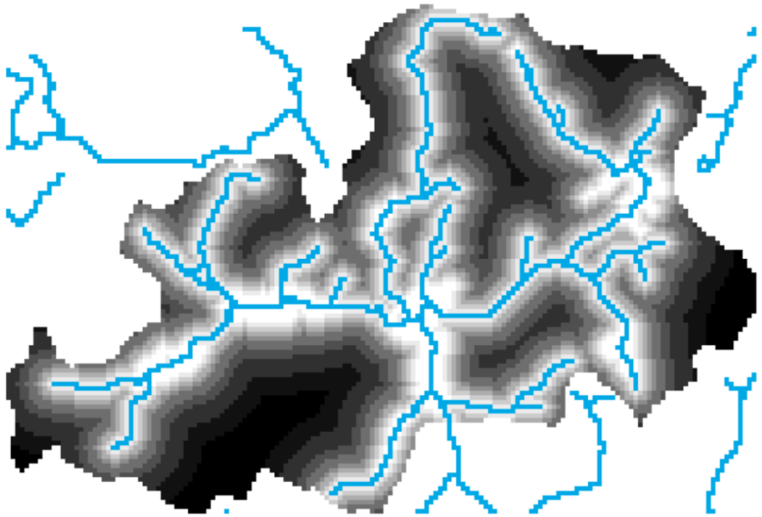


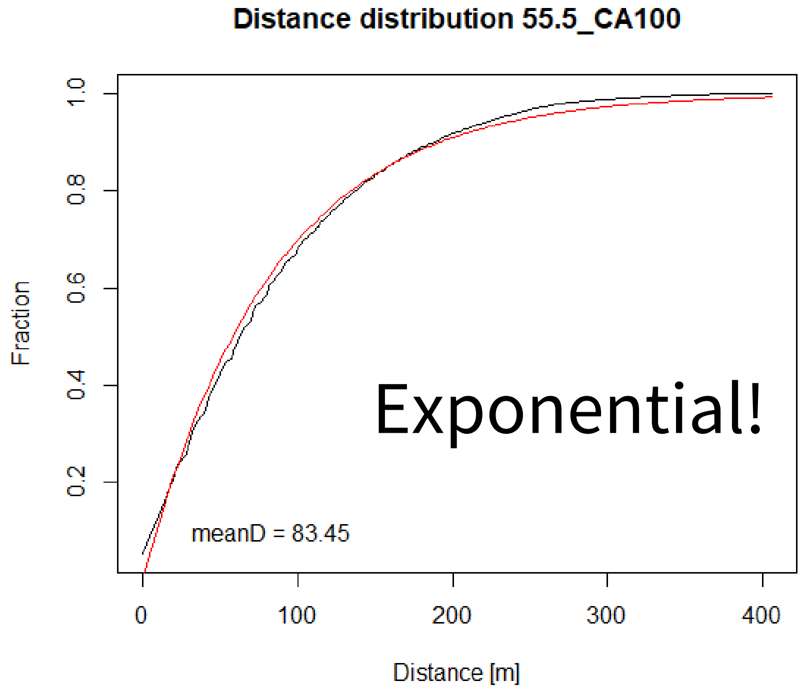
The DDD model: Distances and velocities/celerities

- The water travels from hillsopes (soils) to the rivernetwork: distances and velocities



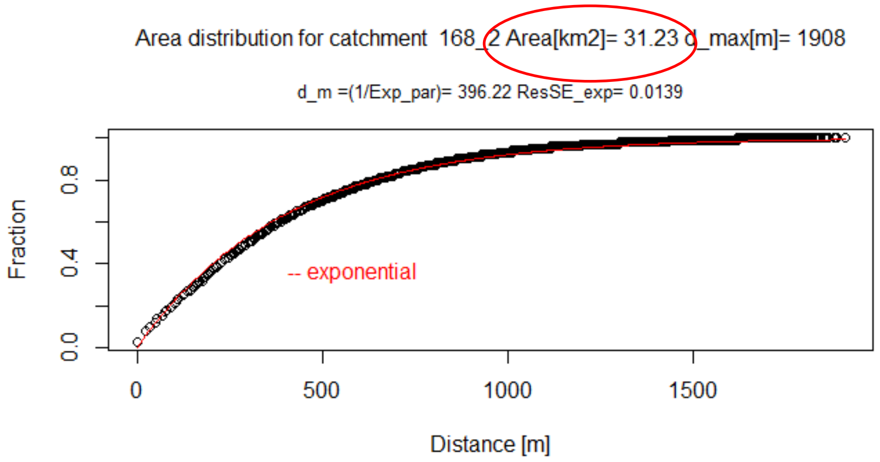


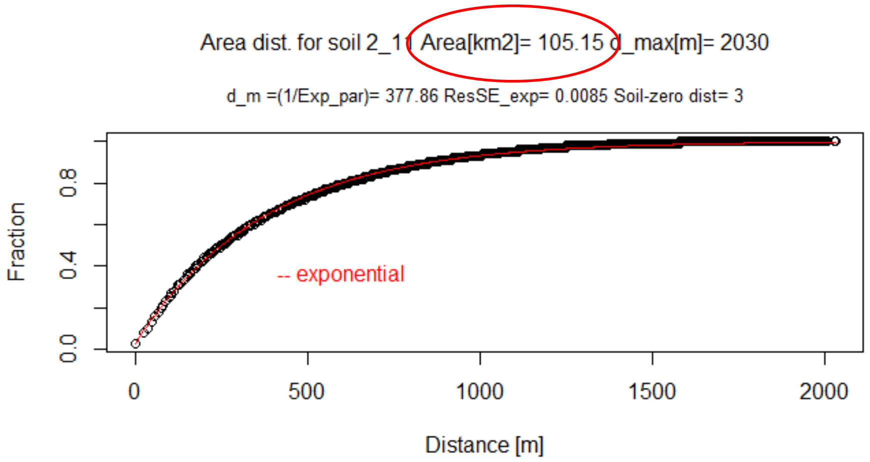


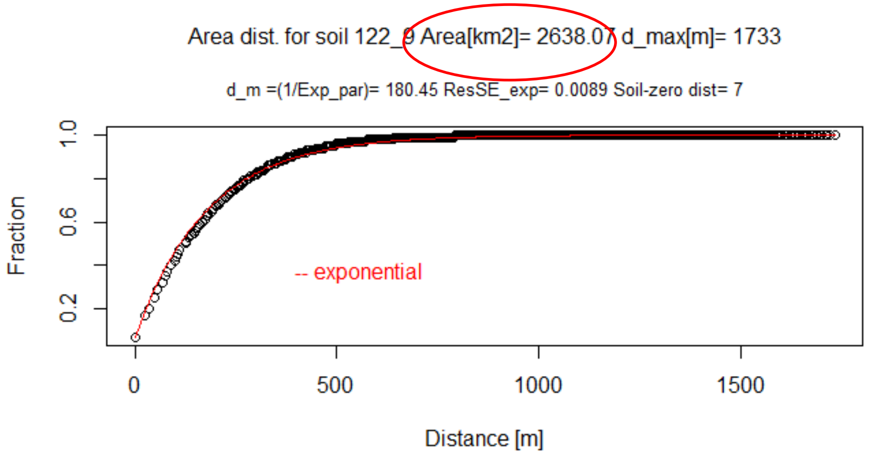


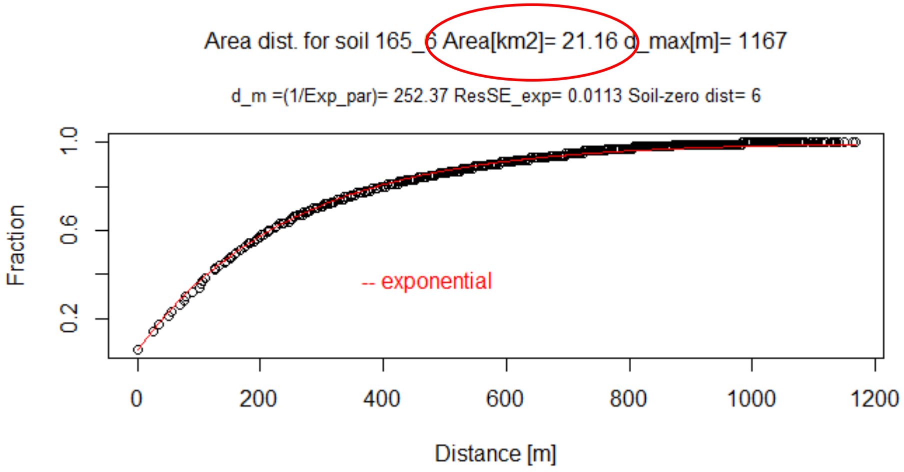
The distance distribution is exponential!

For more than 140 monitored catchments in Norway, the empirical DD is well aproximated by an exponential distribution, big and small



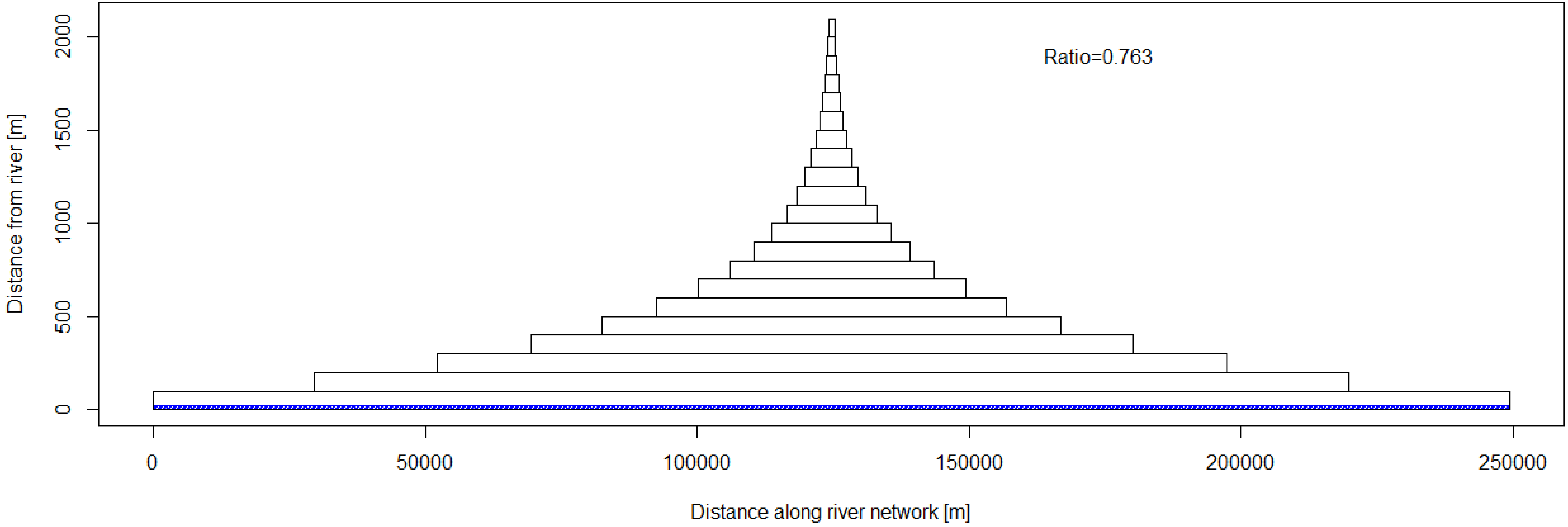






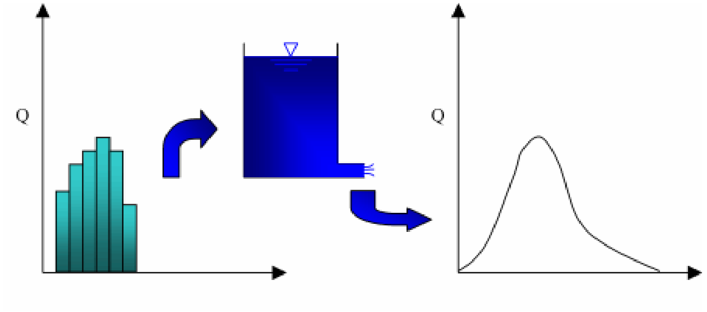
Another way to visualize the distance distribution.. From «a mess» to order

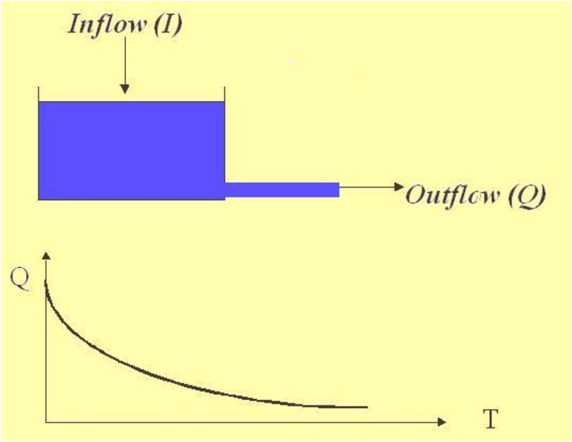
The exponential distance distribution tells us how big an area that drains into the river network per timestep

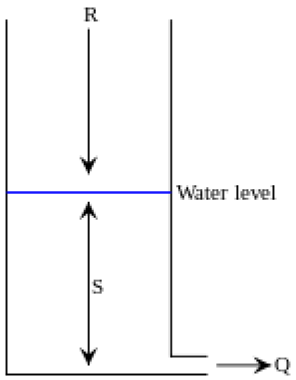


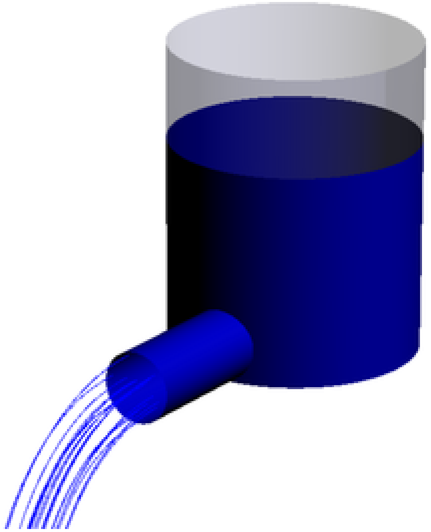
The linear reservoir

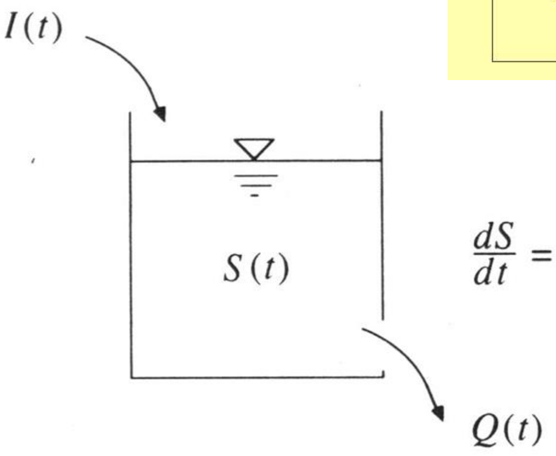
- building block of almost all conceptual hydrological models (since mid- 1930)
- characterised by exponential recession
- «The model to beat» (Keith Beven)







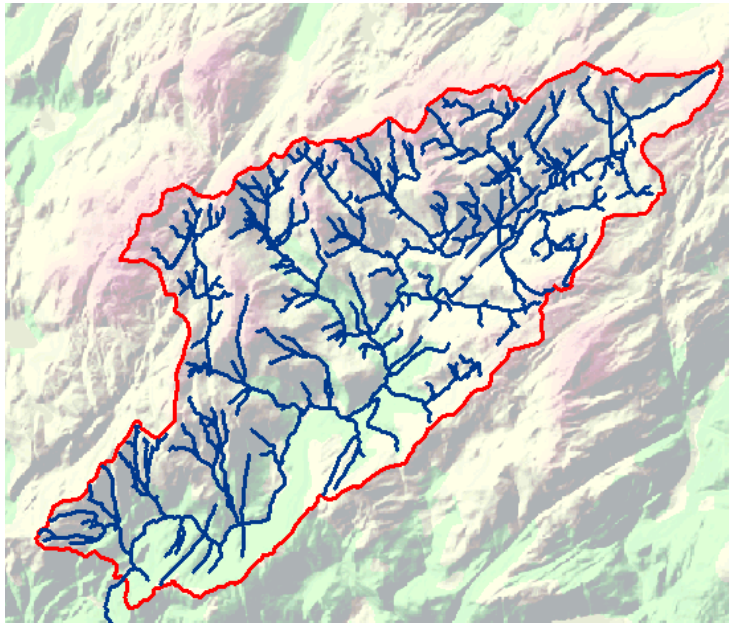




$$\frac{dS}{dt} = I(t) - Q(t)$$

What does a linear reservoir look like?

- How can we recognise a linear reservoir when we see one? Not many catchments formed like straight sided buckets with holes in the bottom…



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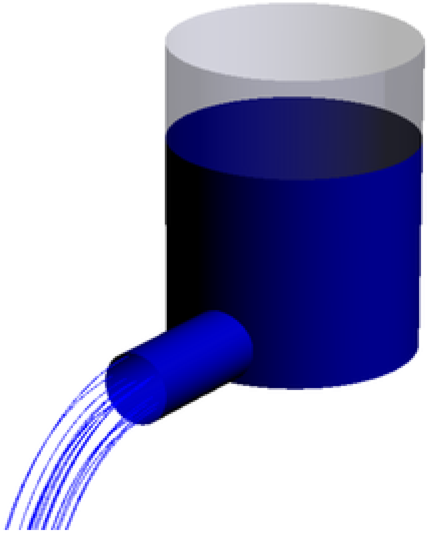
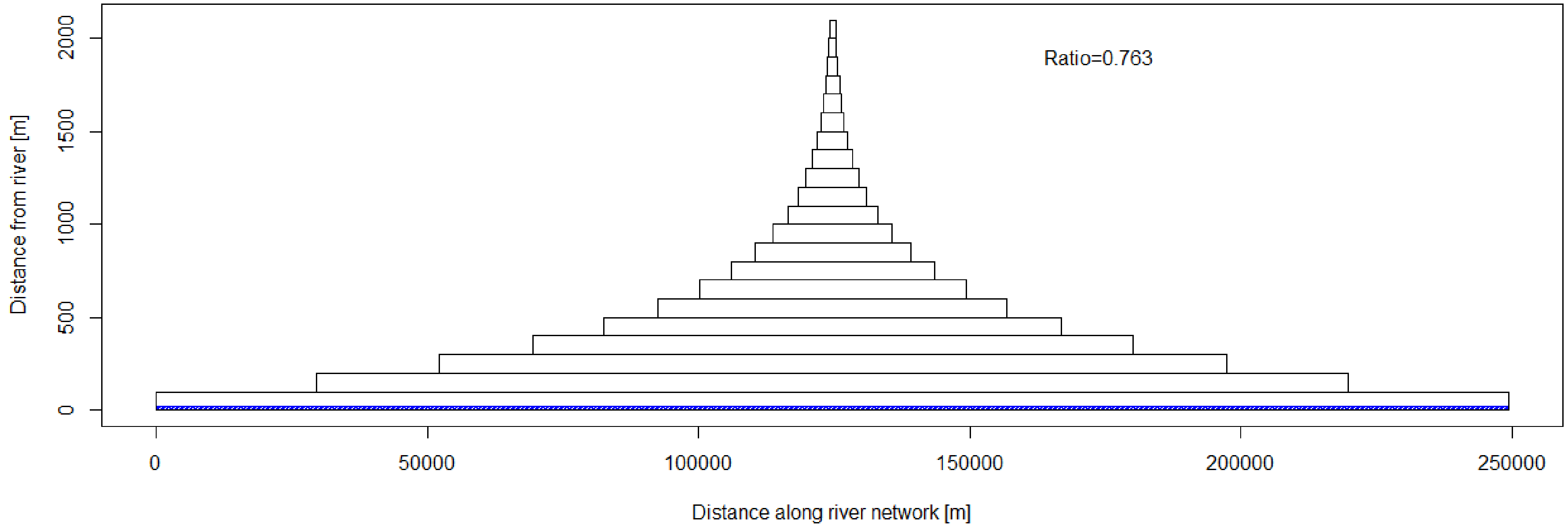


The simplest of experiments..

- Uniform rainfall over an area
- Uniform velocity of water transport in the hillslope to the river network

How do we get an exponential recession/response?

Only if:



There is a dircet link between the linear reservoir model and exponential distance distributions

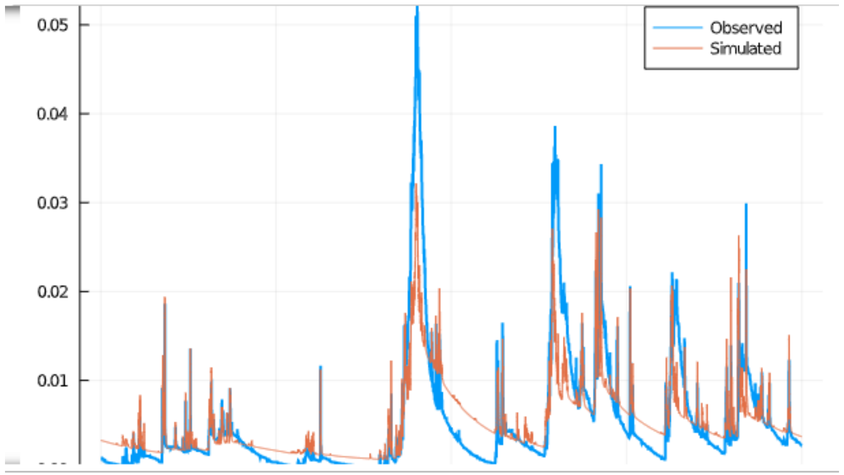
What about velocities (or celerities)? needed to calculate UHs

The DD gives the shape of the UHs- now we need the velocity/celerity to make calculate the scale of the UHs

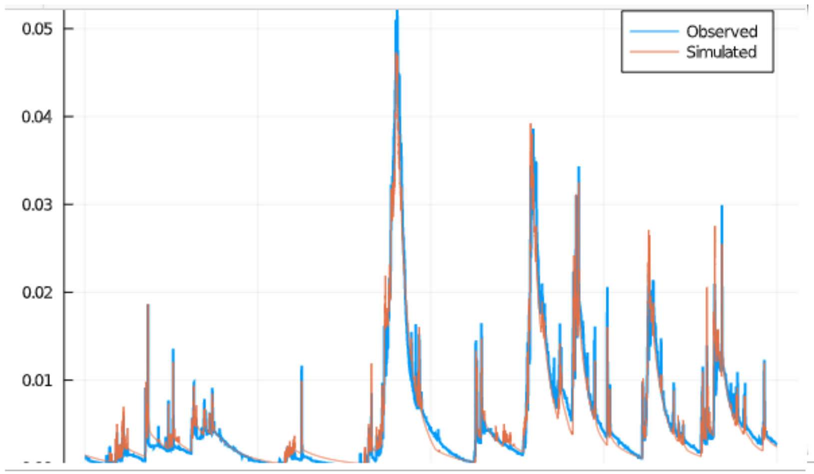
Many methods have been tried:

- calculating recession charateristic, $\Lambda = log(Q(t)) - log(Q(t + \Delta t))$ -very noisy statistic
- calibrating parameters of subsurface velocity distribution - parameters for velocity and snow compensate for each other
- matching simulated recession behaviour with observed -best so far

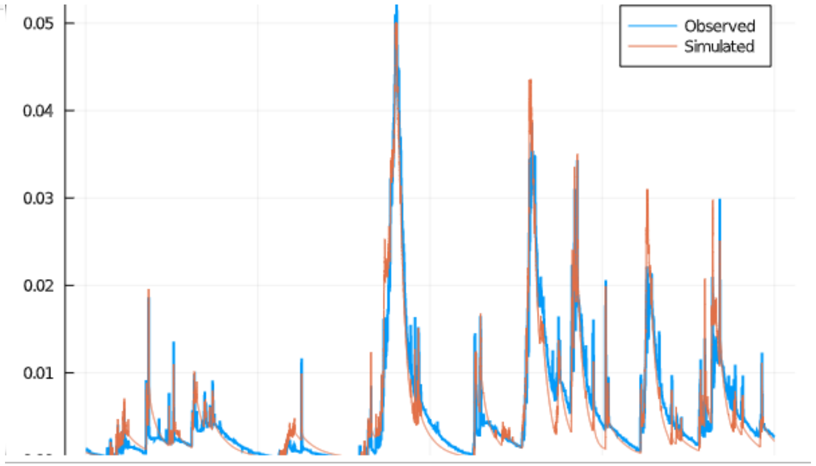
Too slow



OK



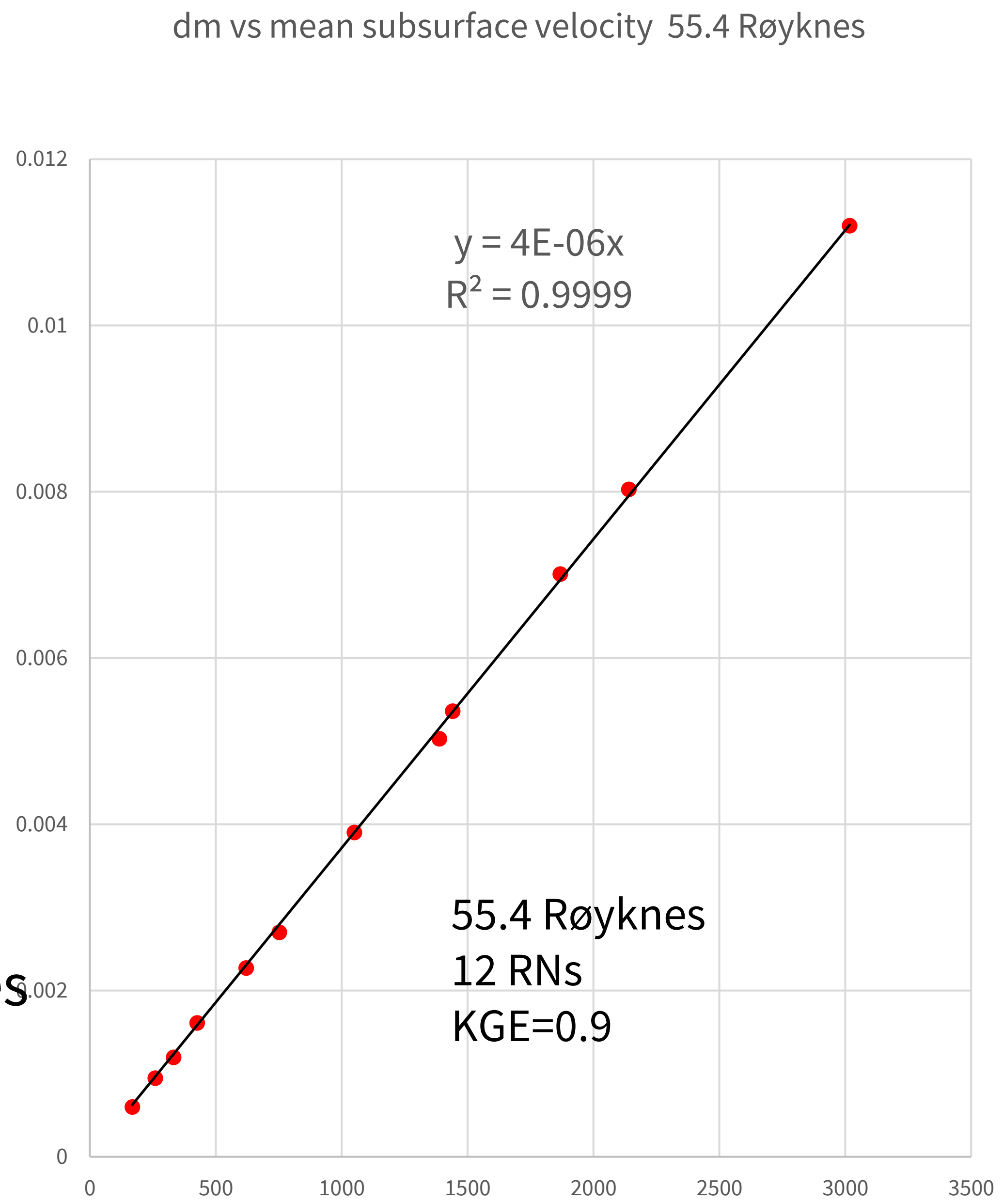
Too fast



Time to reflect…

- The celerity, v_h is estimated as $v_h = \Lambda \bar{d} / \Delta t$ where $\bar{d}$ is the mean of the **distance distribution**
- Can we trust $\bar{d}$ to be a catchment characteristic, really something unique for the catchment?

No- celerity and distances are relative measures

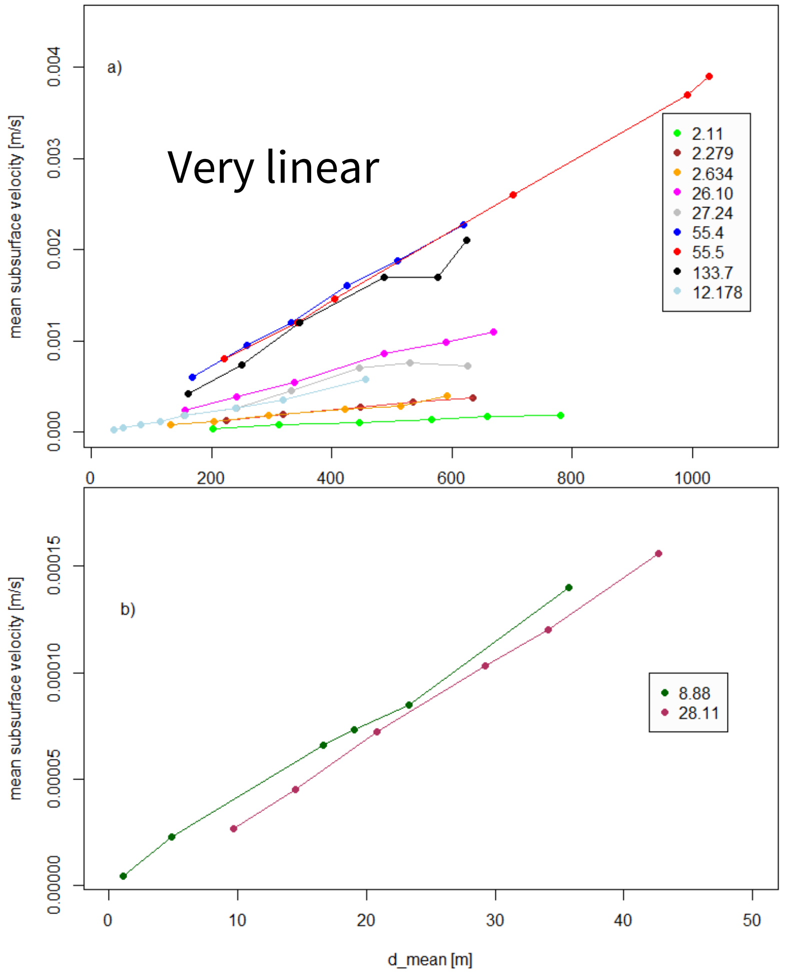


This is the case for all tested catchments

However, a new catchment characteristic- Mean Response Time:

$$MRT = \frac{\bar{d}}{\bar{v}} = \frac{\Delta t}{\Lambda}$$

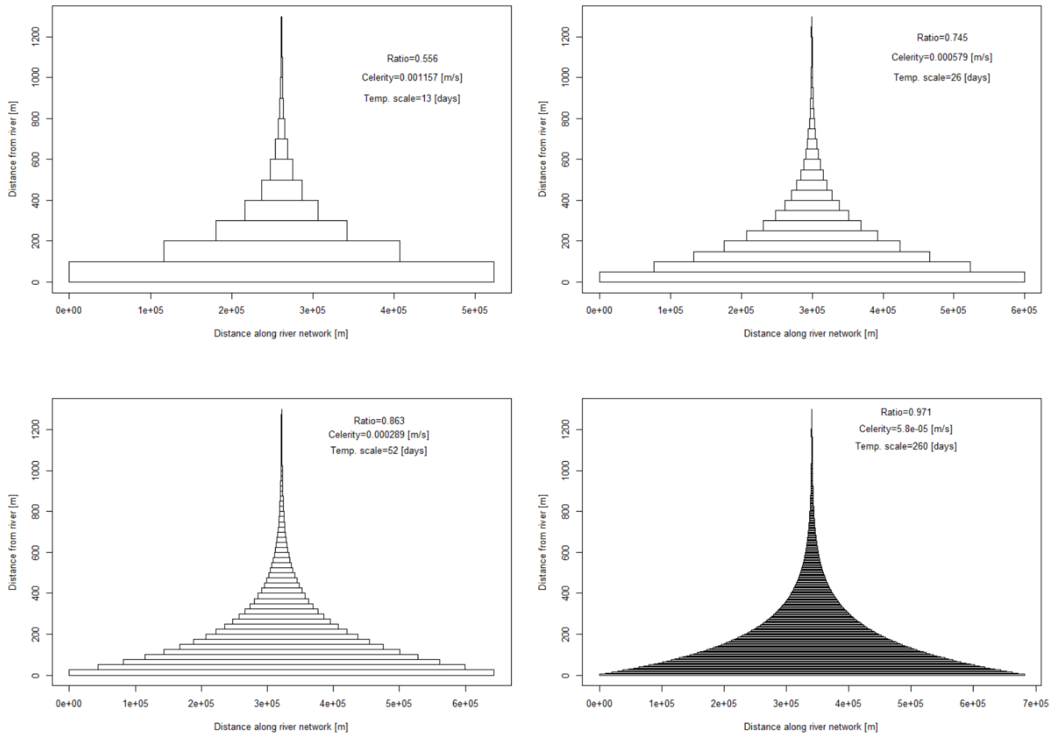
is independent of river networks and subsurface celerity, i.e unique for the catchment

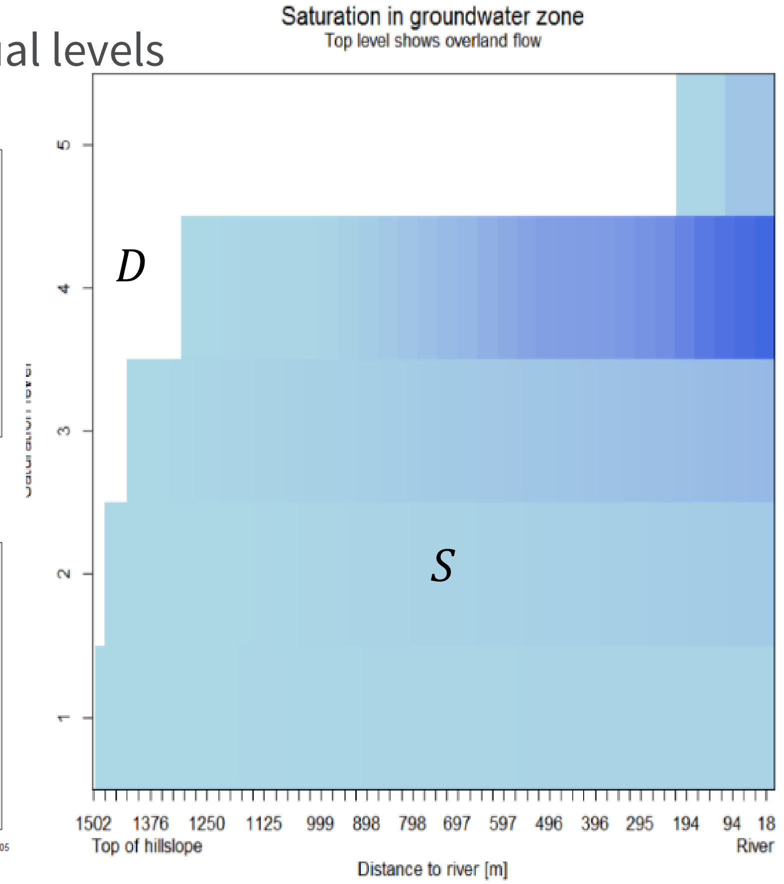


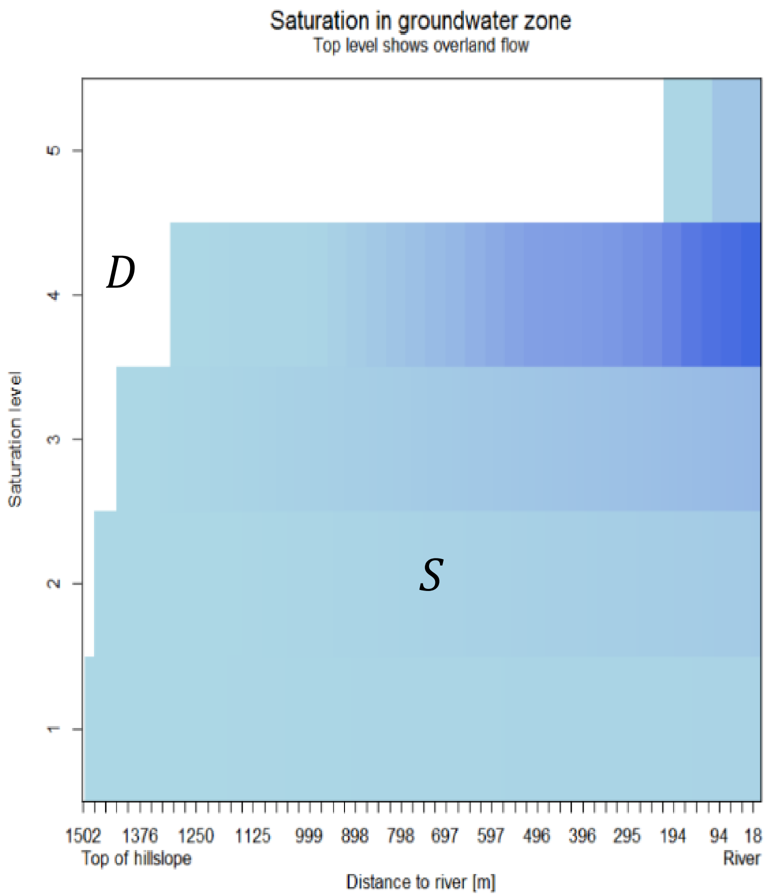
Station	MRT RN [days]	MRT HS [days]	$\frac{MRT_{RN}}{MRT_{HS}} * 100$ [%]	Catch. Area[km^2]
8.88	0.04	2.9	1.4	0.0075
28.11	0.008	3.35	0.2	1.9
5.55	0.007	3.3	0.2	3.3
55.4	0.09	3.17	2.8	50.0
26.20	0.06	7.0	0.9	77.2
2.11	0.06	42.1	0.14	119.0
2.634	0.07	19.2	0.4	182.6
27.74	0.12	8.4	1.4	184.7
133.7	0.07	3.7	1.9	206.6
12.178	0.17	10.2	1.7	310.8
2.279	0.19	19.0	1.0	432.0

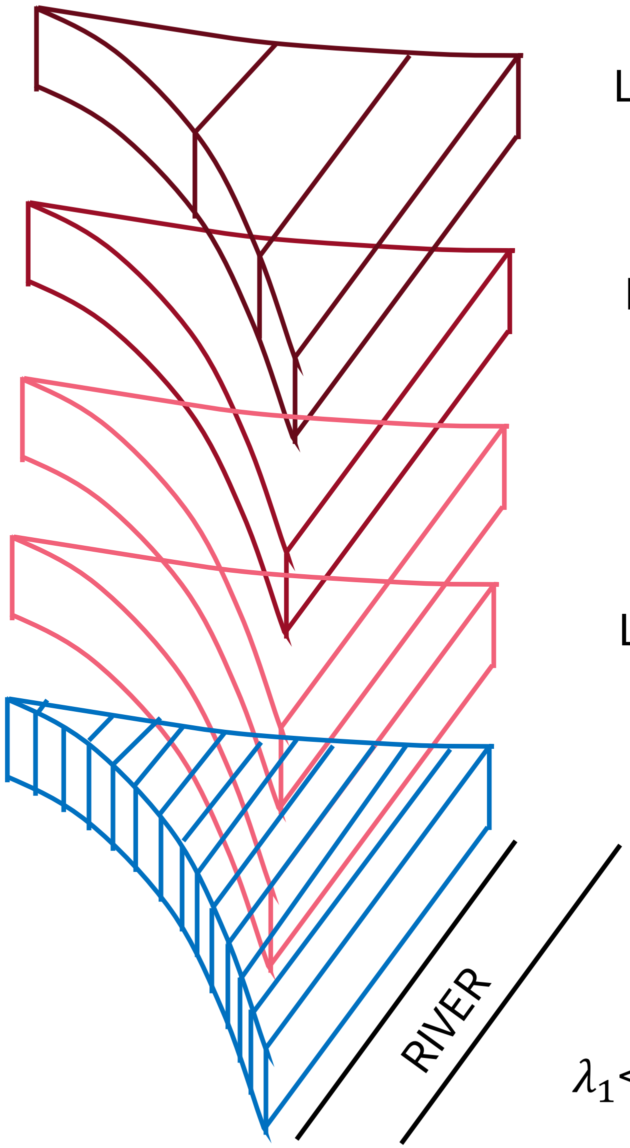
Saturation levels in the subsurface

- In DDD moisture input is distributed to saturation levels under the principle «filling up from below»
- Each saturation level is associated with a travel-time distribution and a celerity
- We need to estimate the velocities for the individual levels









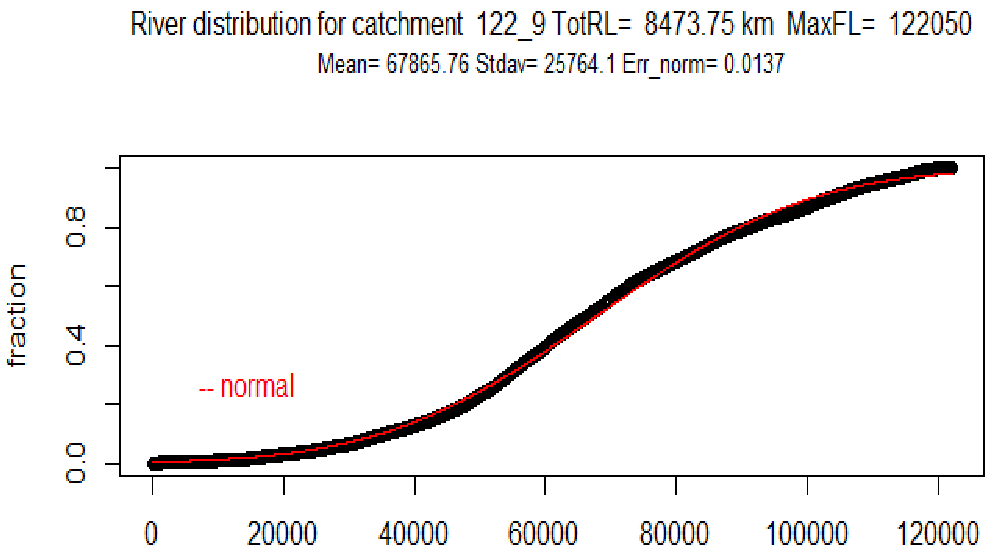
$\lambda_1 < \lambda_2 < \lambda_3 < \lambda_4 < \lambda_5$

Transport of water in the river network

- How does water transport in the river network itself affect the hydrograph?

- We apply the same reasoning as above and derive unit hydrographs from the estimated (GIS) distance distribution of the river network and assume (or calibrate) a river wave velocity.

It turns out that at a temporal resolution of one day, and river wave velocities higher than 0.2 m/s (which is very slow!), the catchments need to be quite large (> 100 km2) for the transport in the river network to play a role.



A normal distribution is often a quite good fit to the empirical distributions

Station	MTT_{RN} [days]	MTT_{HS} [days]	$\frac{MTT_{RN}}{MTT_{HS}} * 100$ [%]	Catch. Area[km^2]
8.88	0.04	2.9	1.4	0.0075
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26.20	0.06	7.0	0.9	77.2
2.11	0.07	48.9	0.14	119.0
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"The subsurface is where hydrological action is"

- M[mm] is the volume of a sub-surface water reservoir,
- M is **shared** by a **saturated volume** (S) and an **unsaturated volume** (D) of which relative sizes vary according to the total water content in the reservoir (M=D+ S).
- If actual soil moisture Z exceeds 30% of D (approx. field capacity), the excess moisture input X (precipitation/snowmelt) goes to S and we have an impulse. If not, input is retained in D and Z increases

EA(t)- evapotranspiration
G(t)- input rain/snowmelt
Z(t)- actual soilmoisture
D(t)- volume unsaturated zone (soilwater)
S(t)- volume saturated zone (groundwater)
X(T)- water released to S(t) and runoff

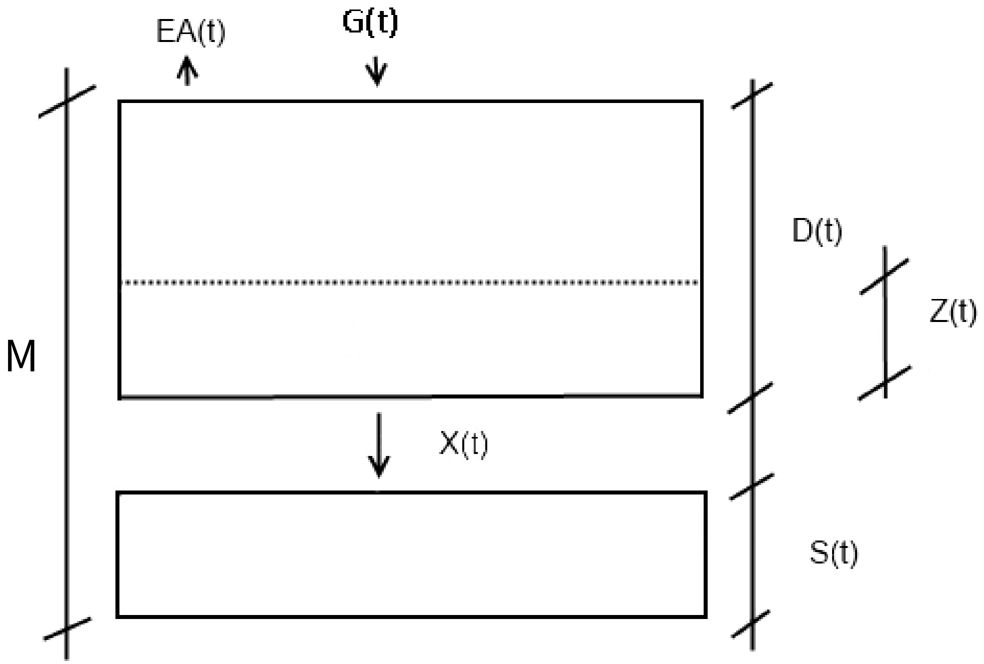
Excess water: $X(t) = Max\left\{\frac{G(t)+Z(t)}{D(t)} - R, 0\right\} D(t).$

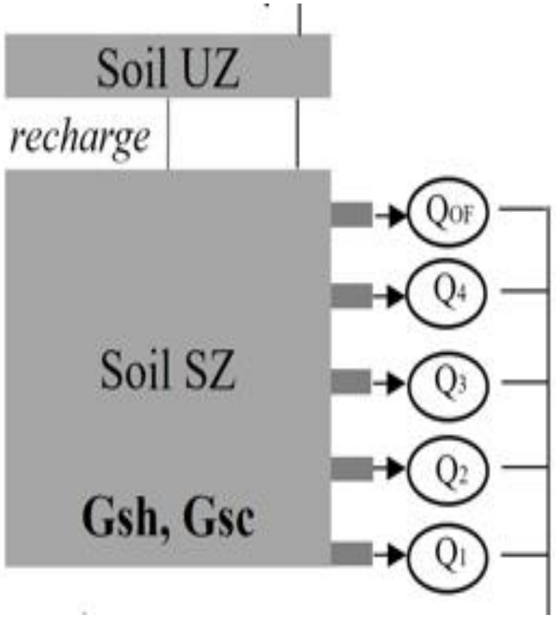
Groundwater: $\frac{dS}{dt} = X(t) - Q(\mathrm{t}).$

Soil water content: $\frac{dZ}{dt} = G(t) - X(t) - Ea(t).$

Soil water zone: $\frac{dD}{dt} = -\frac{dS}{dt},$

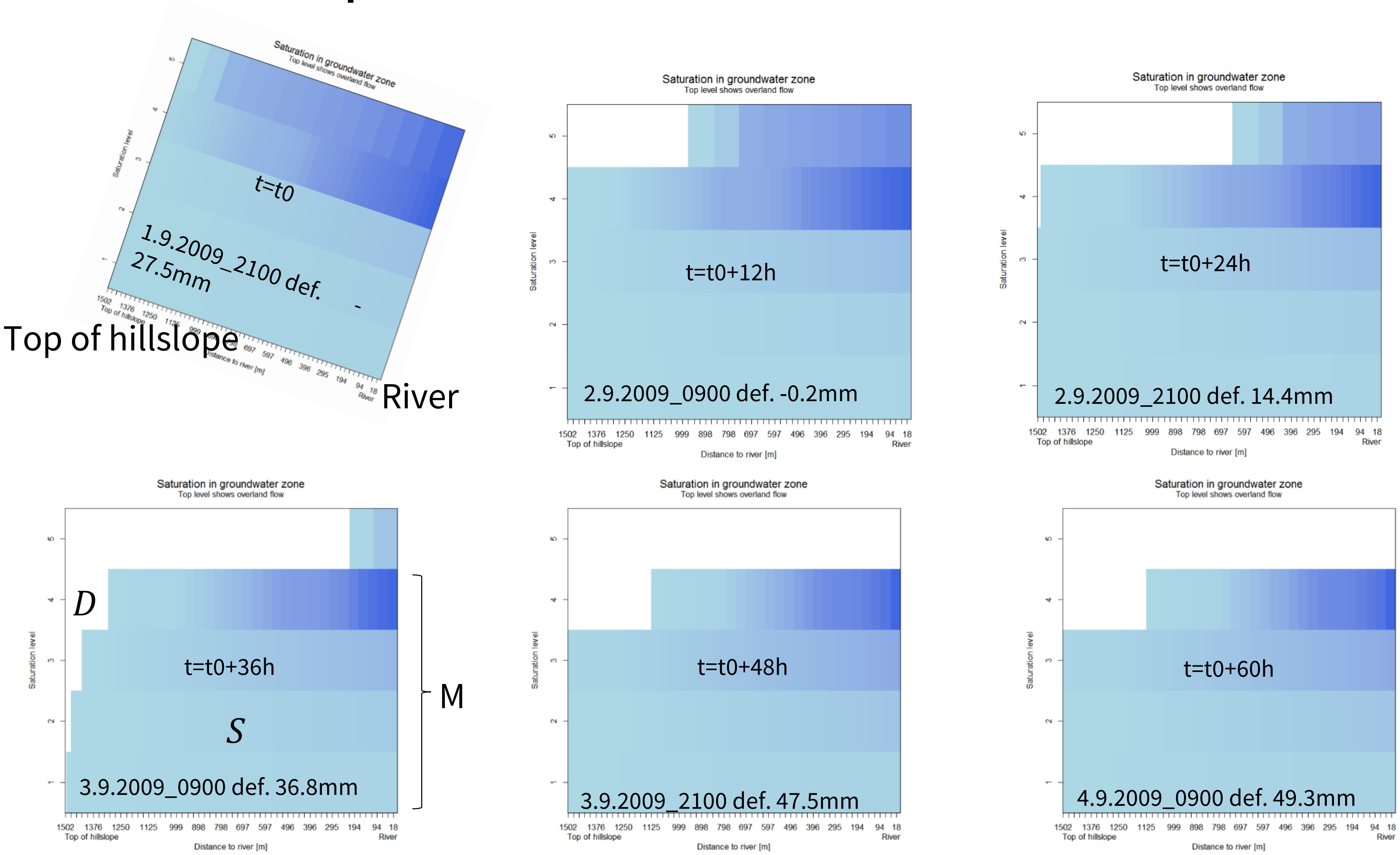
Q(t)- runoff
R - (field capacity: 30% of D)





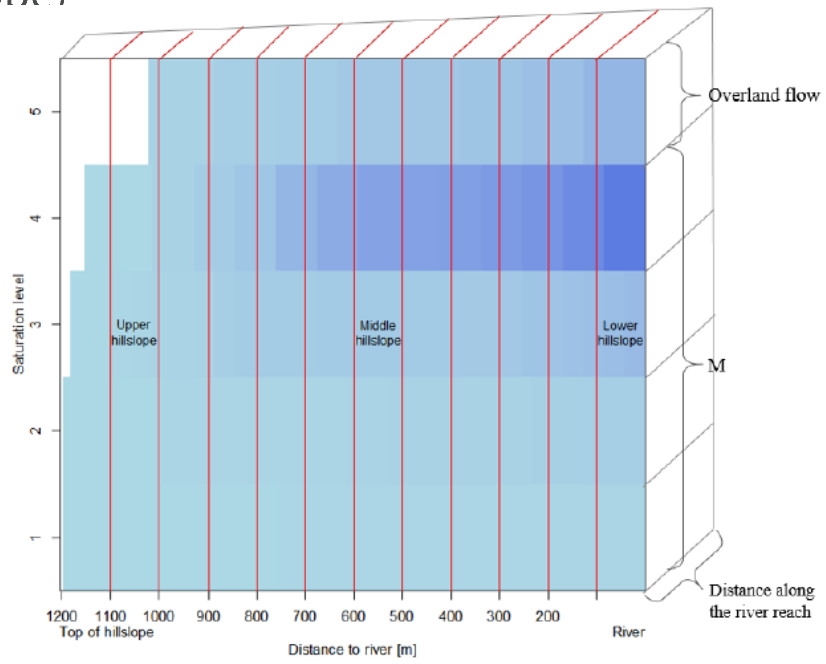
NVE

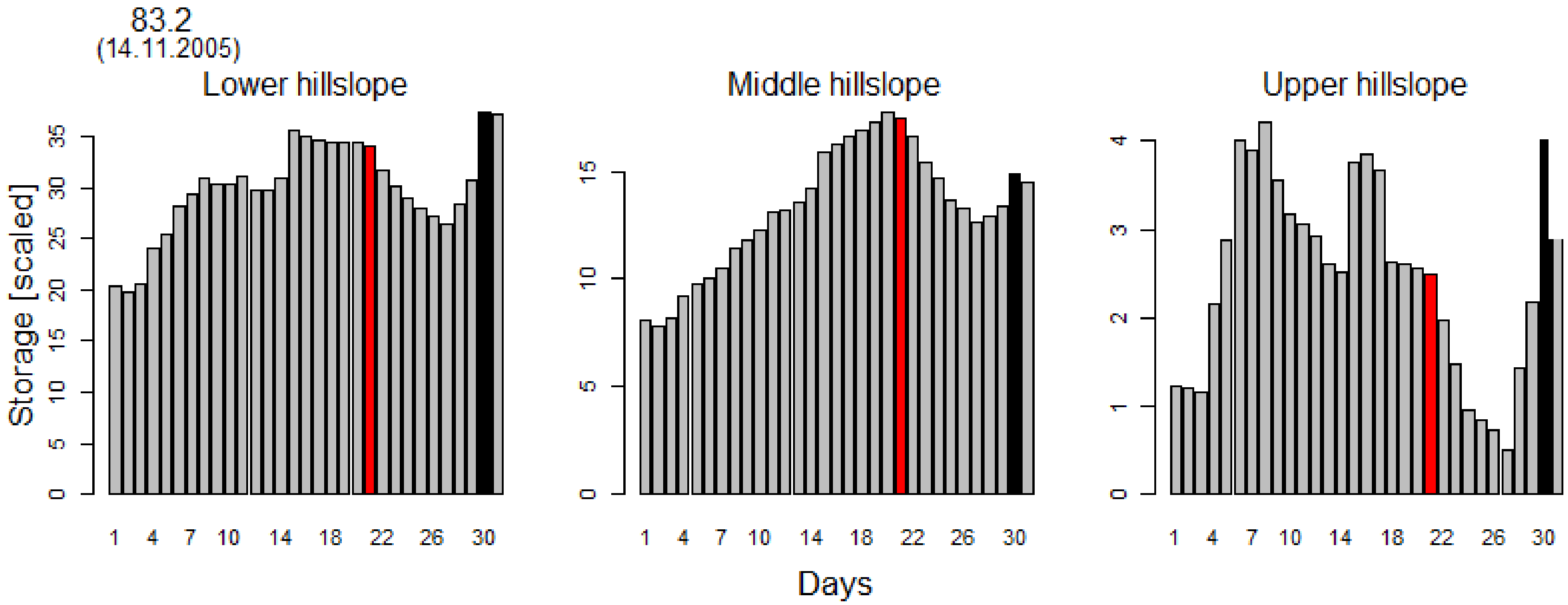
Development in S. Overland flow at t0



Subsurface in DDD has a 2-D representation:

x: length of hillslope (entire catchment is represented as a hillslope)
z: moisture varying with (relative) depth





Figures: Eline Kråbøl

Energy Balance (EB) (proxy) modelling for snowmelt and glacial melt

- Input is precipitation and temperature. Empirical relations and educated guessing is applied for estimating the energybalance elements

Cl is related to precipitation rate P (mm/Δt), in the following manner:

$$
\begin{aligned}
&if\ P > 1\ , \quad Cl = 1.0, \\
&if\ 0 < P \leq 1\ , \quad Cl = U(0.7, 1) \qquad (4) \\
&if\ P = 0\ , \quad Cl = U(0.1, 0.7)
\end{aligned}
$$

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In search of operational snow model structures for the future – comparing four snow models for 17 catchments in Norway

Thomas Skaugen, Hanneke Luijting, Tuomo Saloranta, Dagrun Vikhamar-Schuler and Karsten Müller

$$\lambda_F \rho_w \Delta SWE = S + L_a - L_t + H + LE + G + R - CC$$

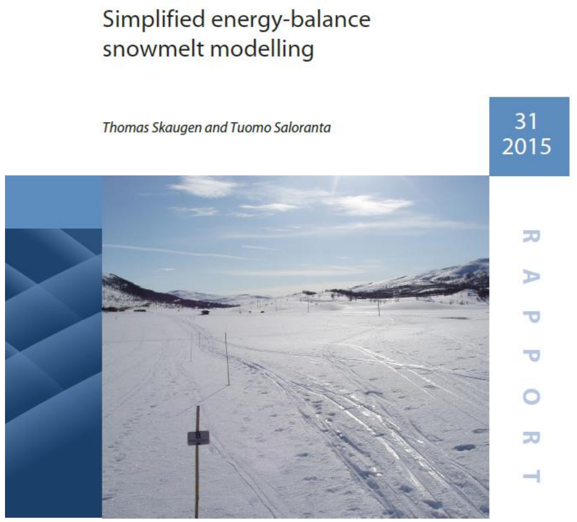
S- net shortwave radiation (Liston, 1995; Dingman, 2002; Tarboton and Luce, 1996 (Albedo);)

L – net longwave radiation (Walter et al., 2005; homemade (insp.Tvedalen, 2015))

H and LE- turbulent fluxes (Dingman, 2002, Walter et al. 2005; homemade insp.by Tvedalen, 2015 (RH))

G and R- Ground- and precipitation heat (Walter et al. 2005)

CC- cold content (Dingman, 2002, Walter et al. 2005, homemade with the help of Dingman, 2002)



EB (proxy) modelling for Evapotranspiration

- Instead of degree-day modelling of potential evapotranspiration, we make use of the already estimated net radiation,

  $R_n = SW_{net} + L_A - L_T$ from the snowmelt routine.

- Potental evapotranspiration (Ep) by Priestly-Taylor:

$$E_p = \alpha \left(\frac{\Delta}{\Delta+\gamma}\right)(R_n)\frac{1000}{\lambda_V \rho_W} \qquad \left[\frac{mm}{\Delta t}\right]$$

- The parameter α lumpes the effect of turbulent fluxes

- Actual evapotranspiration Ea, takes into account the level of saturation and becomes

  Ea = Ep x (M-def +SM + Isoil)/M

Nature based solutions-wetlands

Vi bruker informasjonskapsler for å forbedre brukeropp

Ny

Vi bruker informasjonskapsler

Nyheter

get Meny

– Ansvarsfraskrivelse

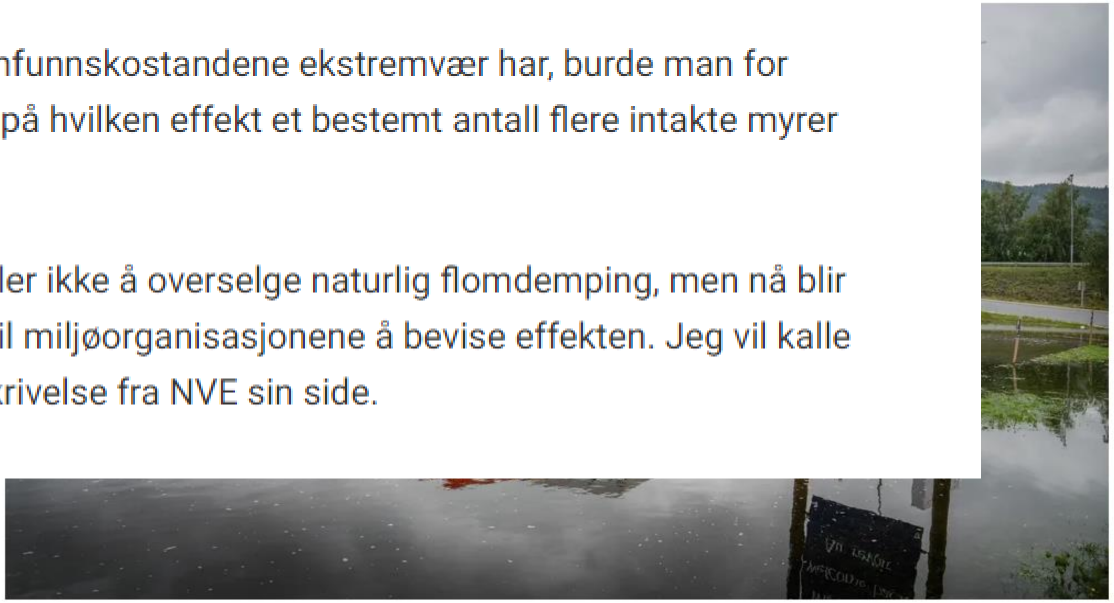
Steel er kritisk til det han opplever som liten interesse fra NVEs side for å se nærmere på naturens flomdempingspotensial.

– Jeg synes det er rart at de som er myndighet for vassdrag og flomarbeid virker avslappet til at de ikke vet om naturbaserte løsninger virker. De har faktisk ansvar for å ha sikrere kunnskap om dette, sier Steel.

Gitt de store samfunnskostandene ekstremvær har, burde man for eksempel regne på hvilken effekt et bestemt antall flere intakte myrer kan ha, sier han.

– Jeg mener heller ikke å overselge naturlig flomdemping, men nå blir det nesten opp til miljøorganisasjonene å bevise effekten. Jeg vil kalle det ansvarsfraskrivelse fra NVE sin side.

Ved storflom vil blan
beredskap være vikti
en av slusene ble ød
FOTO: CORNELIUS PO

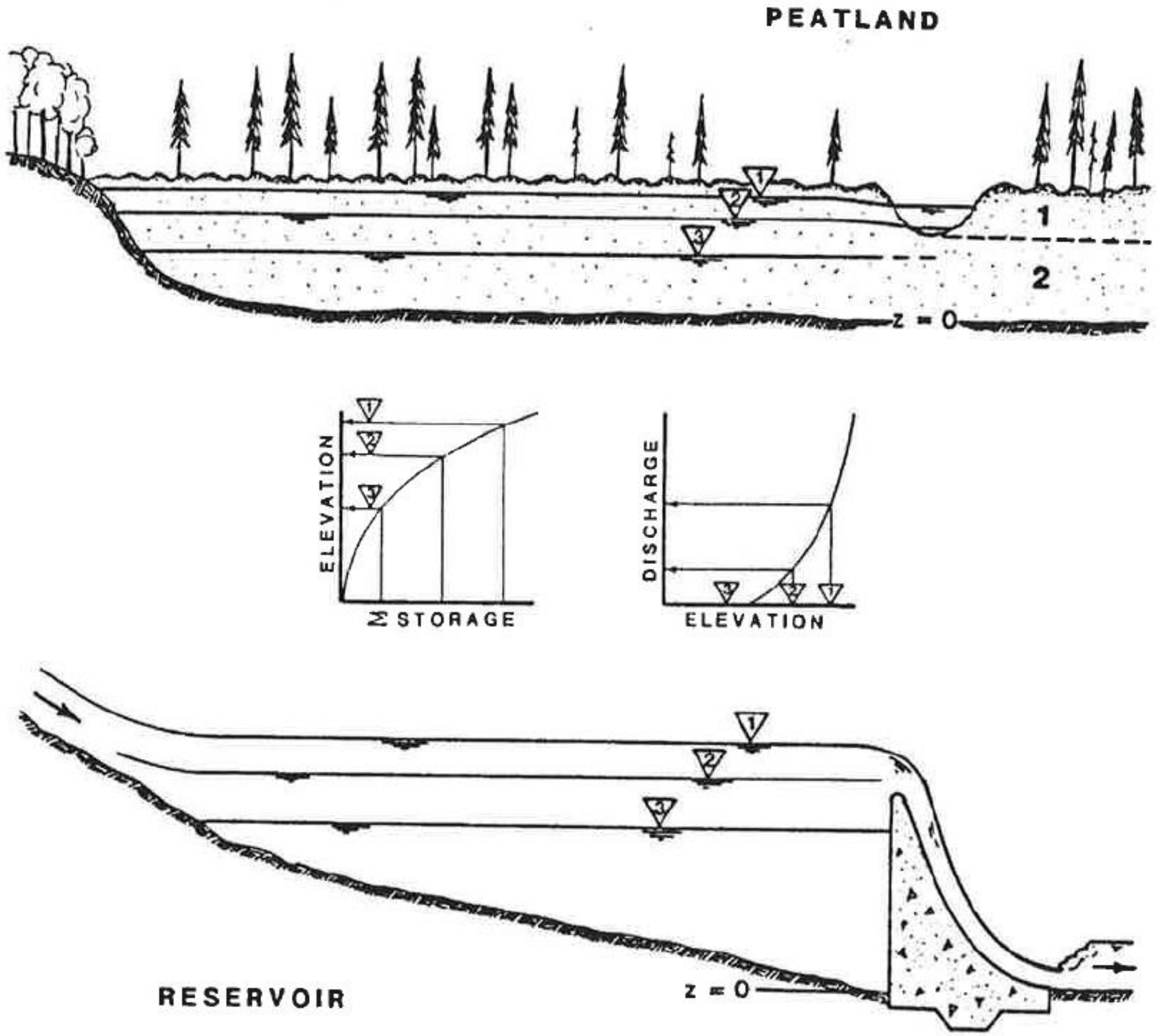


Kunne mer myr og gammelskog gitt mindre av dette? Her et oversvømt Strandtorg i Lillehammer i etter uværet Hans. *Foto: Eirik Helland Urke*

Wetlands in DDD

According to Guertin et al. (1987, Nordic Hydrology) wetlands is considered as an unregulated reservoir. When wetlands are saturated we have overland flow.

The wetlands are also constantly drained by evapotranspiration and no flow occurs for unsaturated conditions.



- Wetlands-good or bad for the mitigation of floods?
- Why are there wetlands? Apparently there are several types
- Take 5 minutes and discuss with your neighbour

Andy Bullock and Mike Acreman

Table 1. Categorisation of wetland type by hydrological features

Type	*Wetland type*	*Code*	*Features*
HEADWATER	Surface water depression	SW/D	No hydraulic connectivity with groundwater. Outlet has no direct connectivity with river system
	Surface water slope	SW/S	No hydraulic connectivity with groundwater. Outlet has direct connectivity with river system
	Groundwater depression	GW/D	Hydraulic connectivity (permanent or periodic) with groundwater. Outlet has no direct connectivity with river system
	Groundwater slope	GW/S	Hydraulic connectivity (permanent or periodic) with groundwater. Outlet has direct connectivity with river system
FLOODPLAIN	Floodplain	FP	Inputs are dominantly upstream river flows
GENERAL			Wetland type, or one element of the type, cannot be specified

Applications: SURF : Urban groundwater (case Grefsen-Kjelsås)

- DDD is further developed for urban hydrology (DDDUrban). Principles of waterbalance, physical realism, an parsimony of calibration parameters are followed:

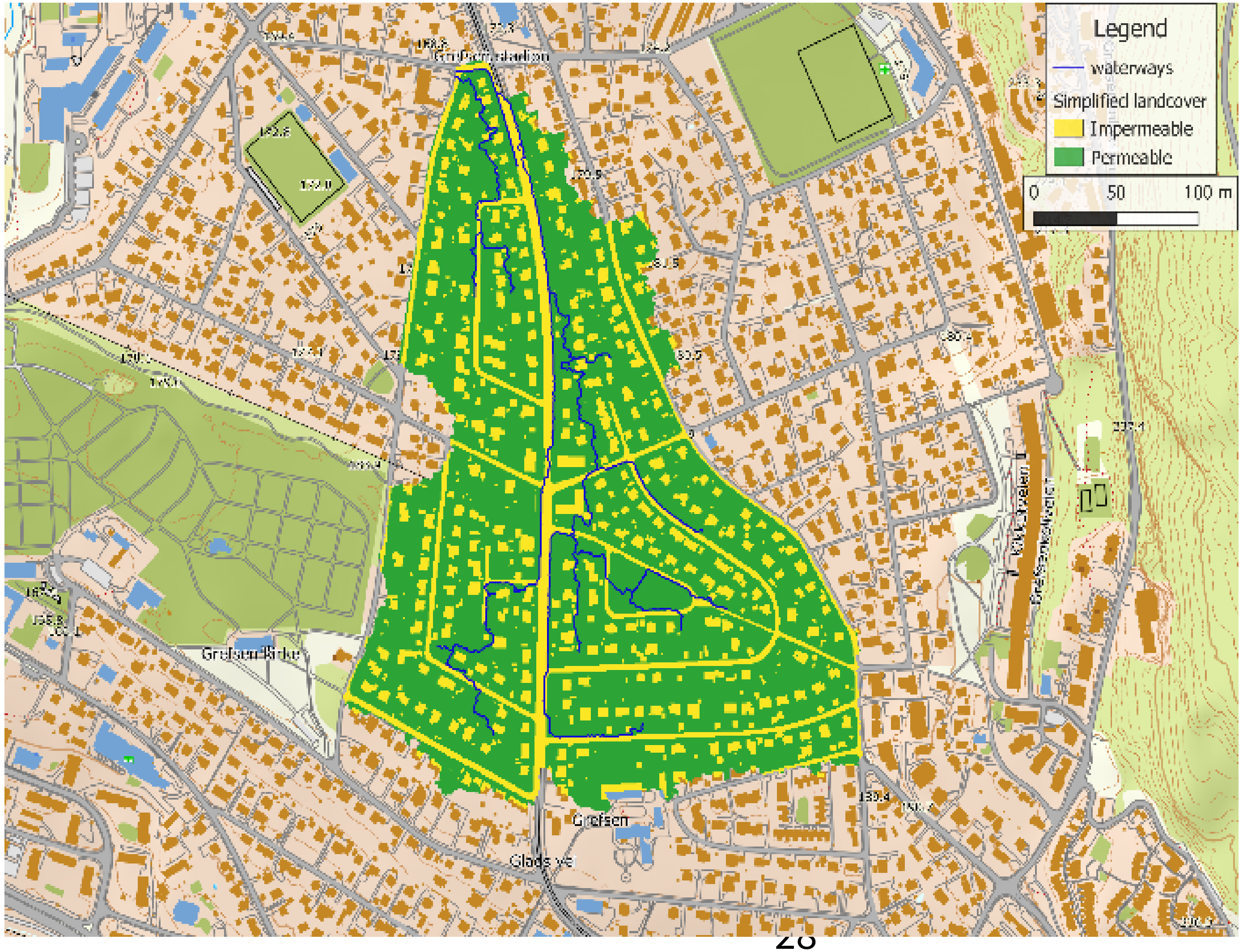
-Energybalance governs snowmelt and evapotranspiration,

-Rivernetwork determined from GIS

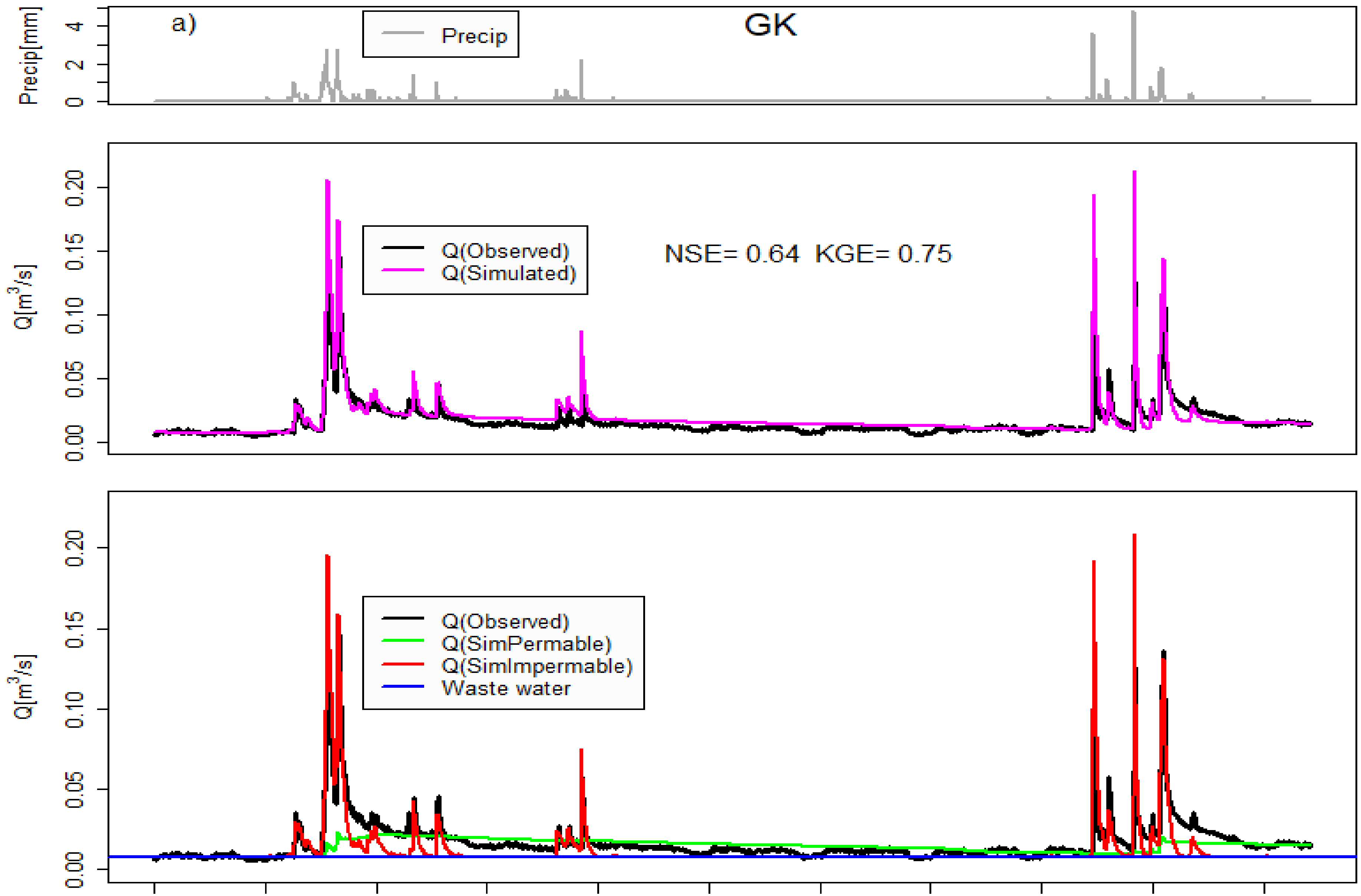
-Fraction of Impermeable (IP) and Permable (P, roofs and roads) surfaces from GIS

-Velocities (subsurface and surface) from infiltration measurements and litterature.

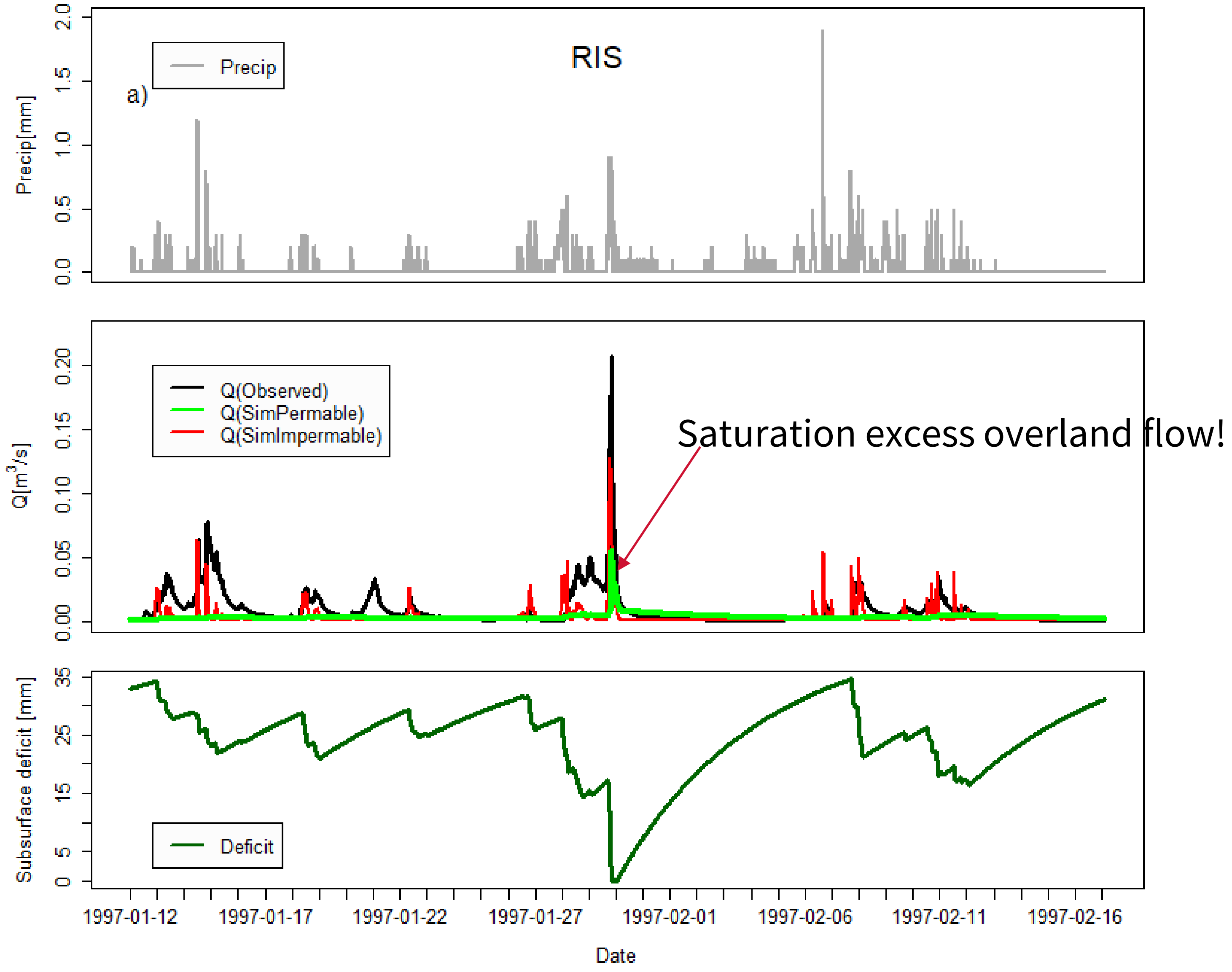
-As few calibration parameters as possible



Grefsen-Kjelsås 0.3 km² P: 0.70, IP: 0.30



Peak flow from permeable surfaces (Risvollan Trondheim)

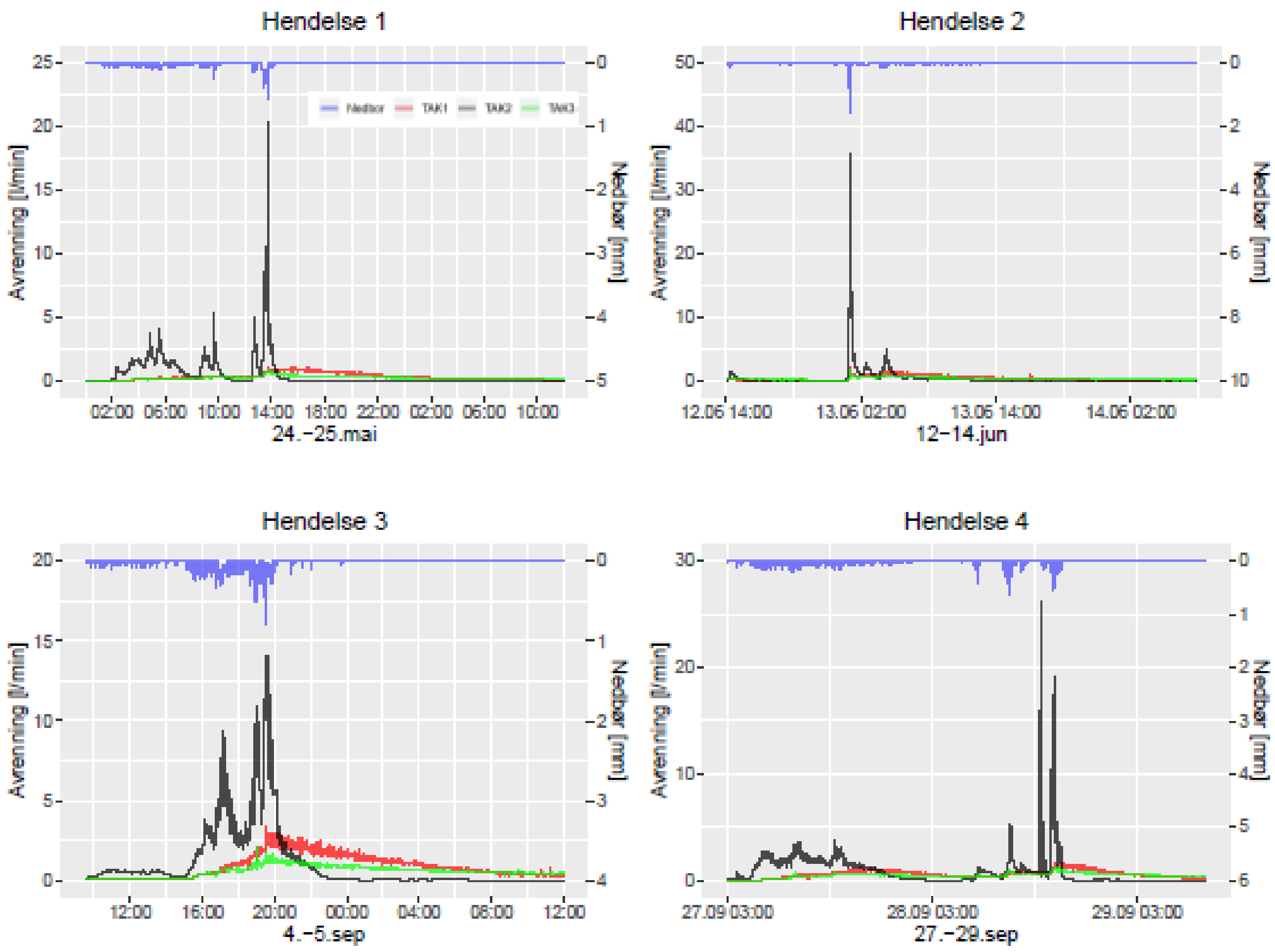


Applications: Green roofs at Ås Campus modelled using the DDD model (Viker-Walsøe og Valle, Msc, NMBU 2020)

- 10 X 5 meters 150 mm leca
- Two «identical» green roofs and a black roof
- for references
- 1-minute temporal resolution

Do the roofs work?

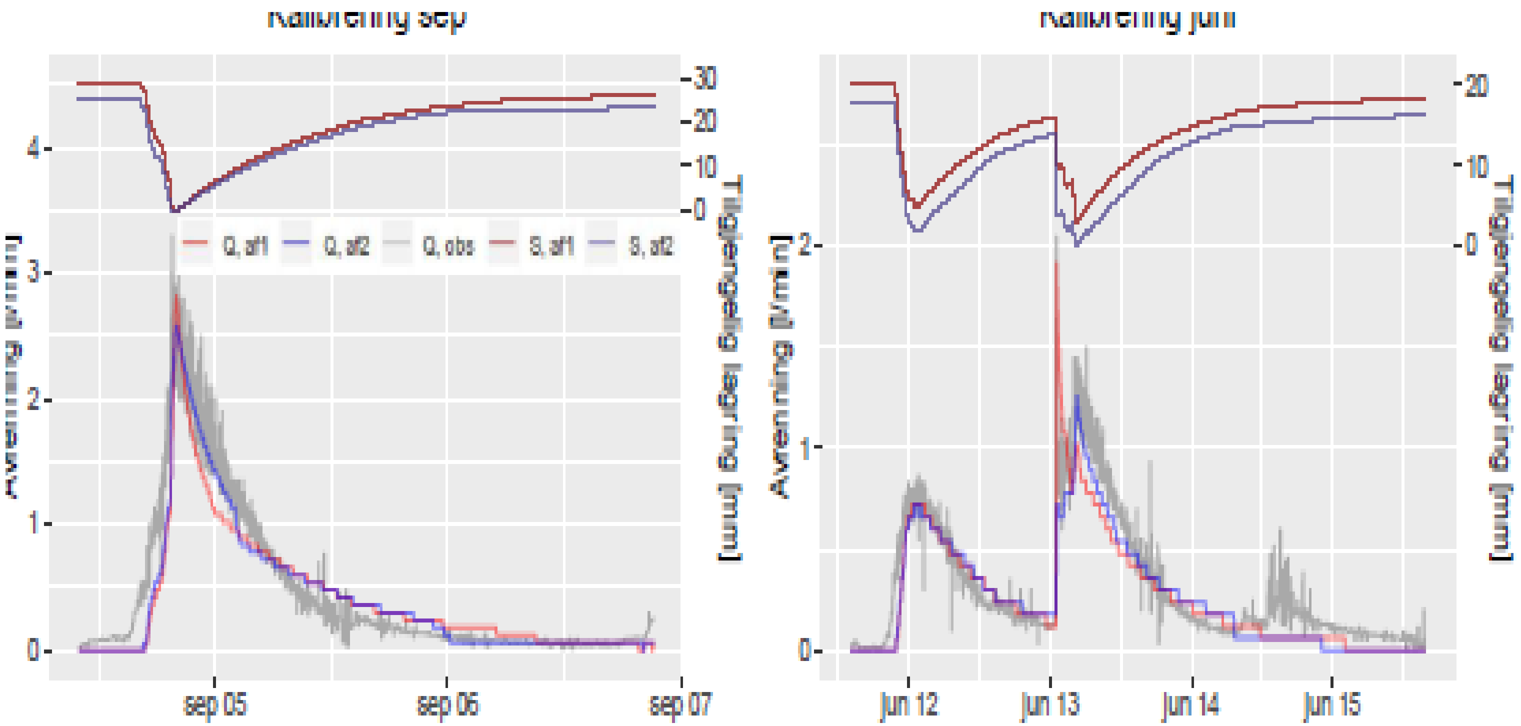
- Yup!
- 95% (median) reduction in peak flow
- Initial moisture conditions important for reduction in peak flow
- Reduced runoff due to evapotranspiration by approx. 30 %



Black line: black roof, Red line GR-1, Green line GR-2

Can the roofs be modelled?

- Yup!
- Well validated



Tabell 4.8: Validering for tak 1, sep-hendelsen

Kalibrering	Fordeling	Validering	KGE	NSE
sep	Af1	mai	0.83	0.88
		jun	0.70	0.68
		okt	0.88	0.92
	Af2	mai	0.79	0.84
		jun	0.80	0.77
		okt	0.88	0.89

Grey line: observed runoff
Red/Blue line: simulated runoff for different model configurations
Top panel: simulated subsurface deficit

Applications of the DDD model

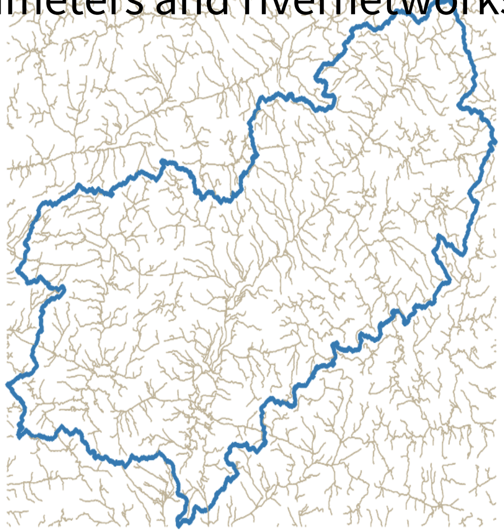
- Flood-drought forecasting
- Urban hydrology
- Effects of Climate Change
- Describe hydrological conditions for birds and fish
- Partitioning sources of runoff in (very) remote areas
- ….

All good , but are we confined to locations with runoff measurements?

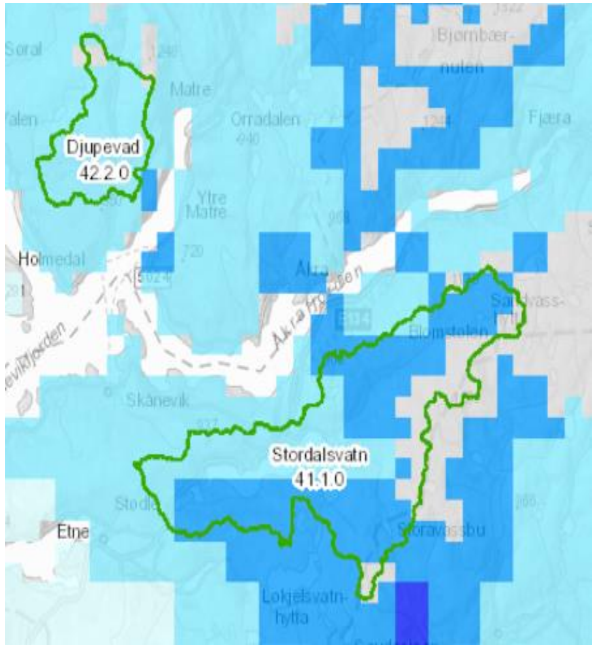
The number of locations without runoff measurements is infinite, but hydrological information is still needed

Today we can provide a reasonable description of hydrological conditions for everywhere (in Norway) because:

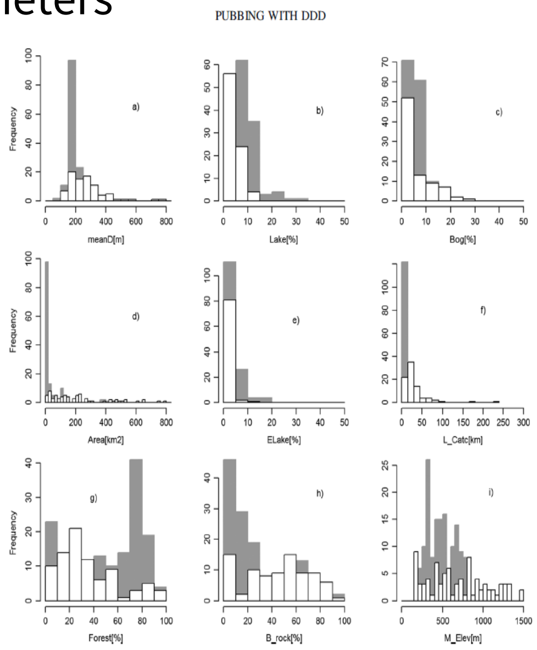
DTM- provides catchments model parameters and rivernetworks



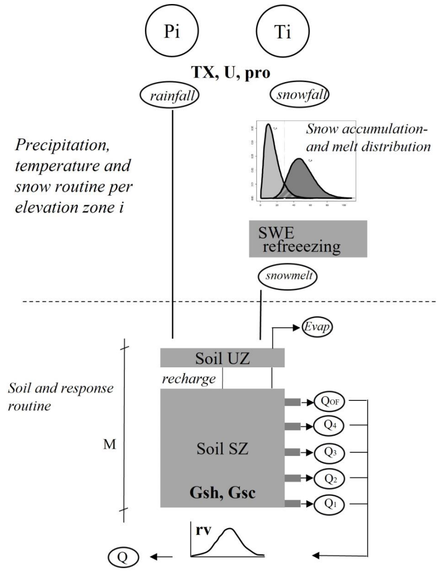
Meteorology- precipitation and temperature for everywhere



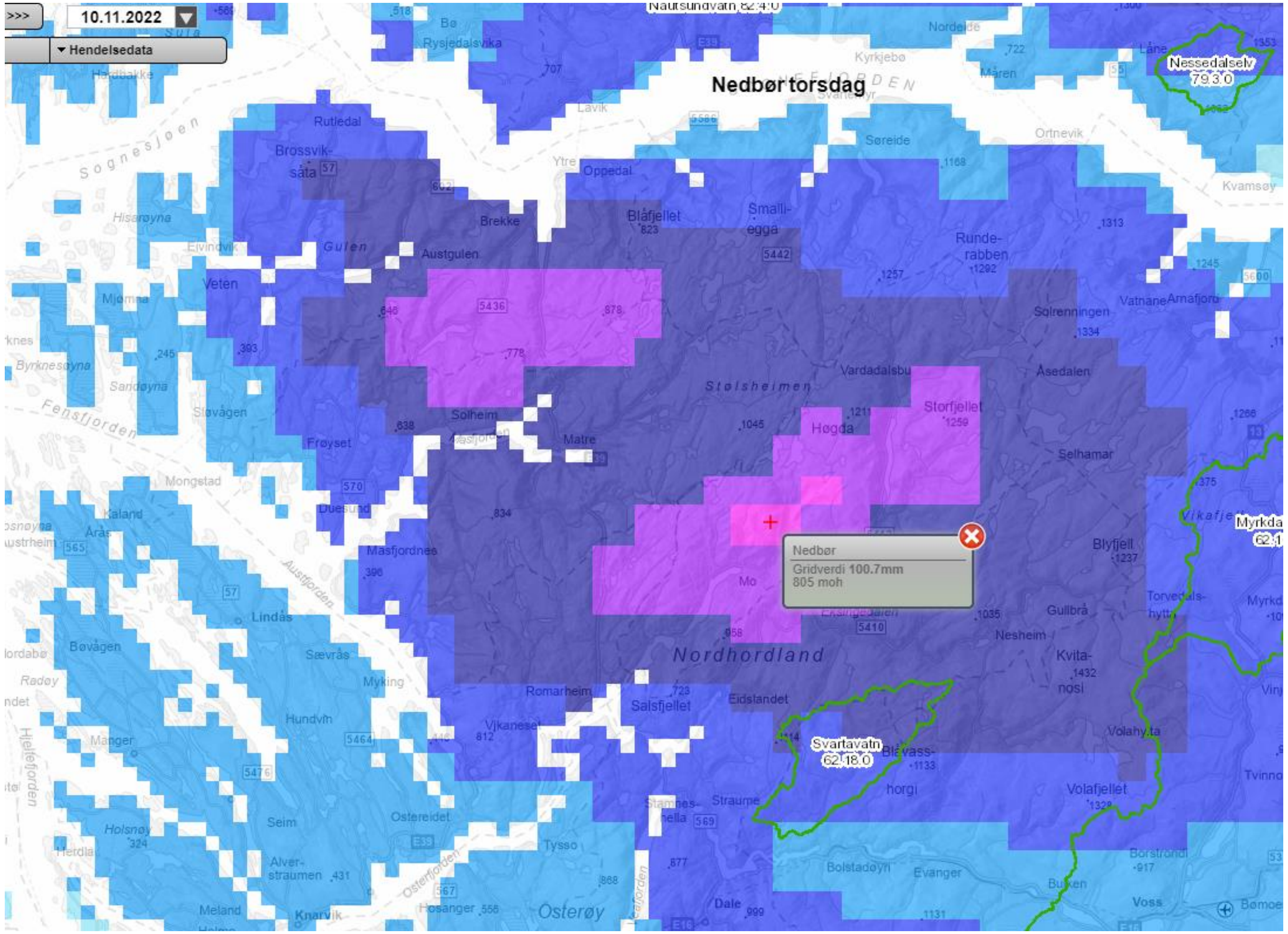
Digitized catchment characteristics for everywhere helps us to estimate model parameters



Suitable hydrological models with few and physically meaningful model parameters

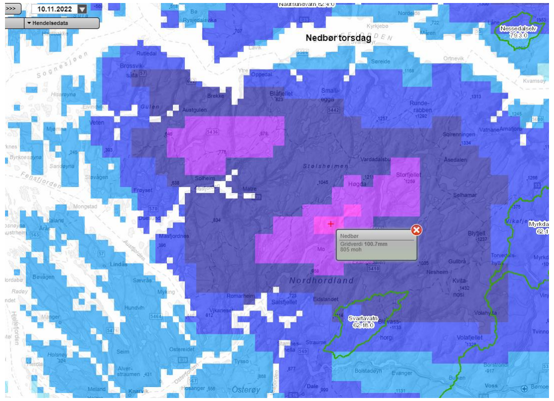


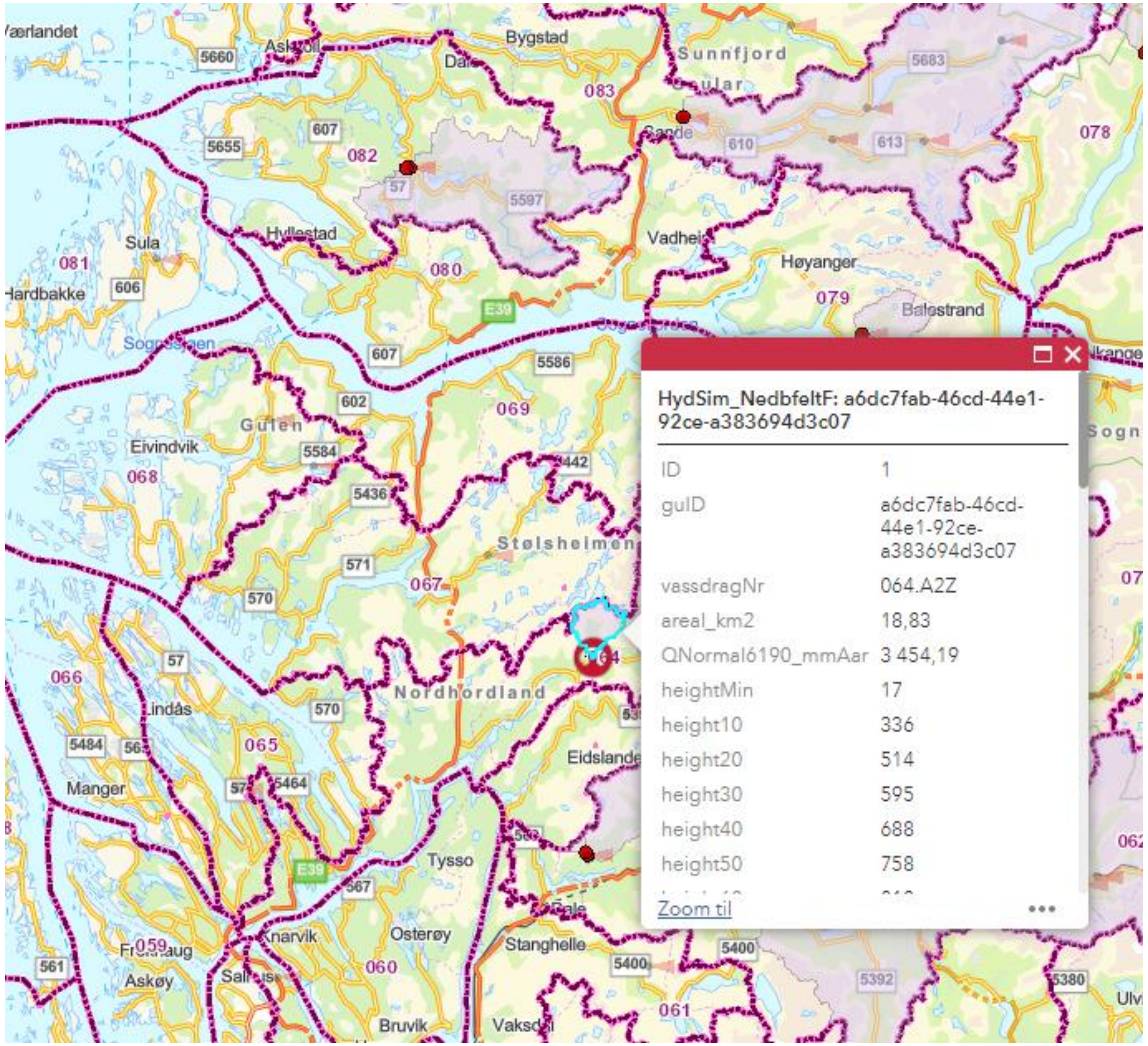
A pilotversion o a new service at NVE- HydSimOveralt (Hydrologiske simuleringer overalt)



A precipitation forecasts of 100 + mm at a location for which we have no runoff and no calibrated model

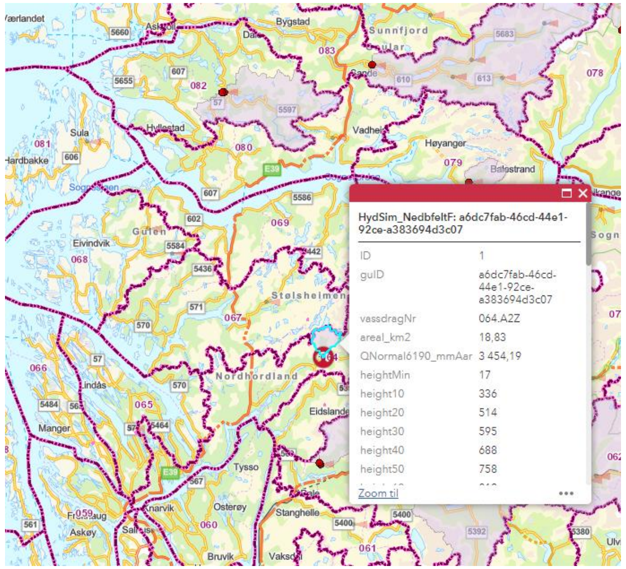
A pilotversion o a new service at NVE- HydSimOveralt (Hydrologiske simuleringer overalt)

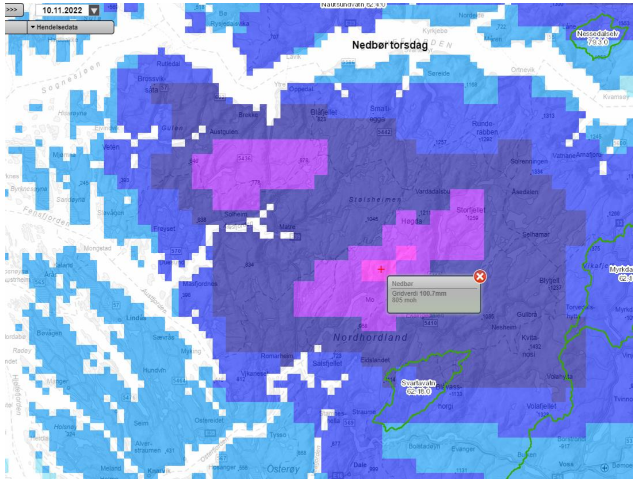


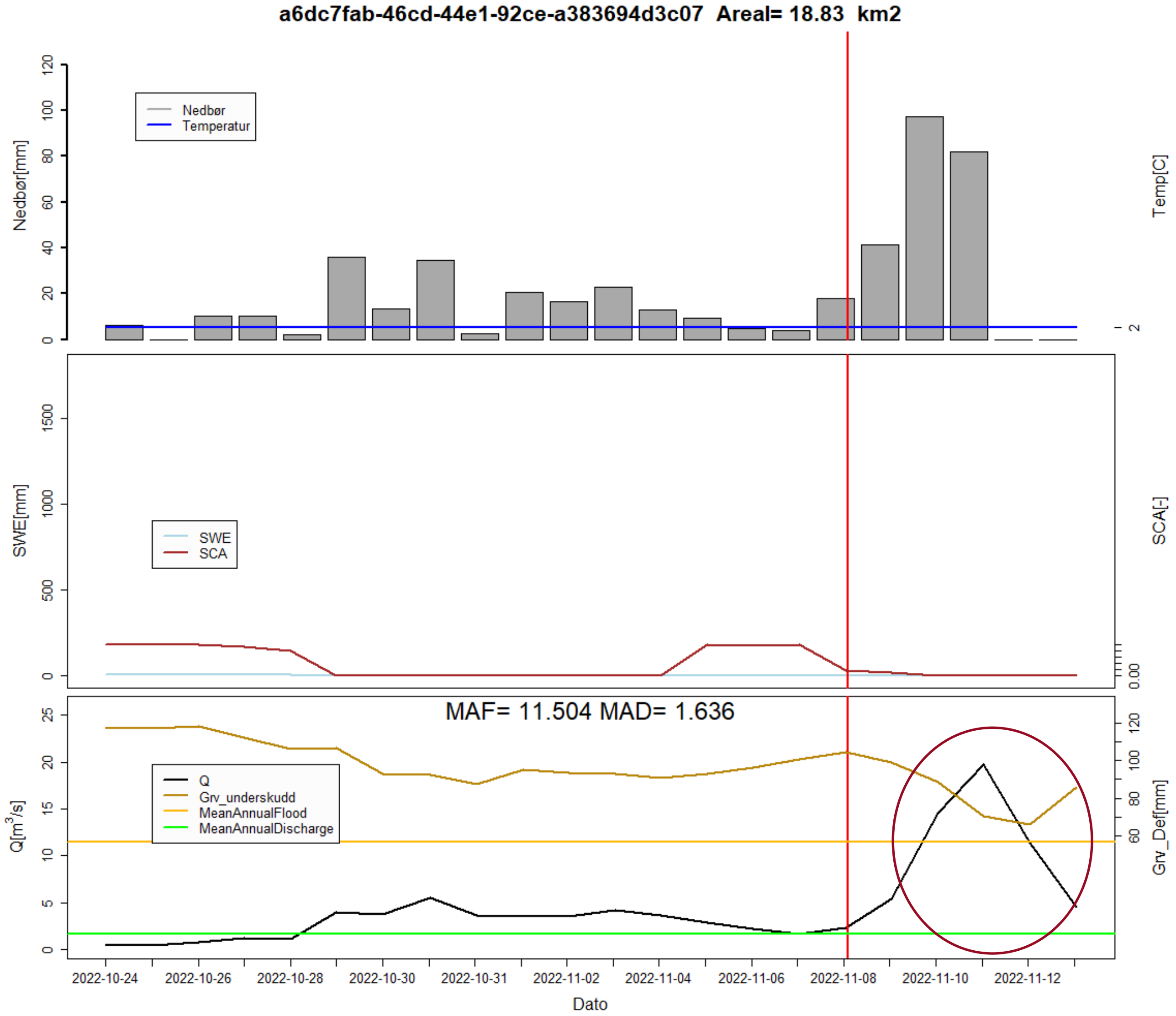


The HydSimOveralt maptool calculates catchment and model parameters for the catchment of interest (where the forecast is 100 + mm)

A pilotversion o a new service at NVE- HydSimOveralt (Hydrologiske simuleringer overalt)







30 years of metetorlogy + forecastsis extracted for catchment of interest mean annual flood and forecasts is simulated by the DDD model

NVE

Thank you for your attention!

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DDDUrban

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Modelling runoff dynamics from Glaciers

- How to conceptualize glaciers in rainfall-runoff models.

-impermeable/permeable surface?

-supraglacial/subglacial drainage system?

- Tried different versions and concluded that:

-Permeable surface (ignoring dynamical effects of of the supraglacial network)

-Subglacial soils and river network same as non-glaciated areas

Foto: Ine Refsdahl Fossen