Prediction in ungauged basins (PUB) - (still) the holy grail in hydrology

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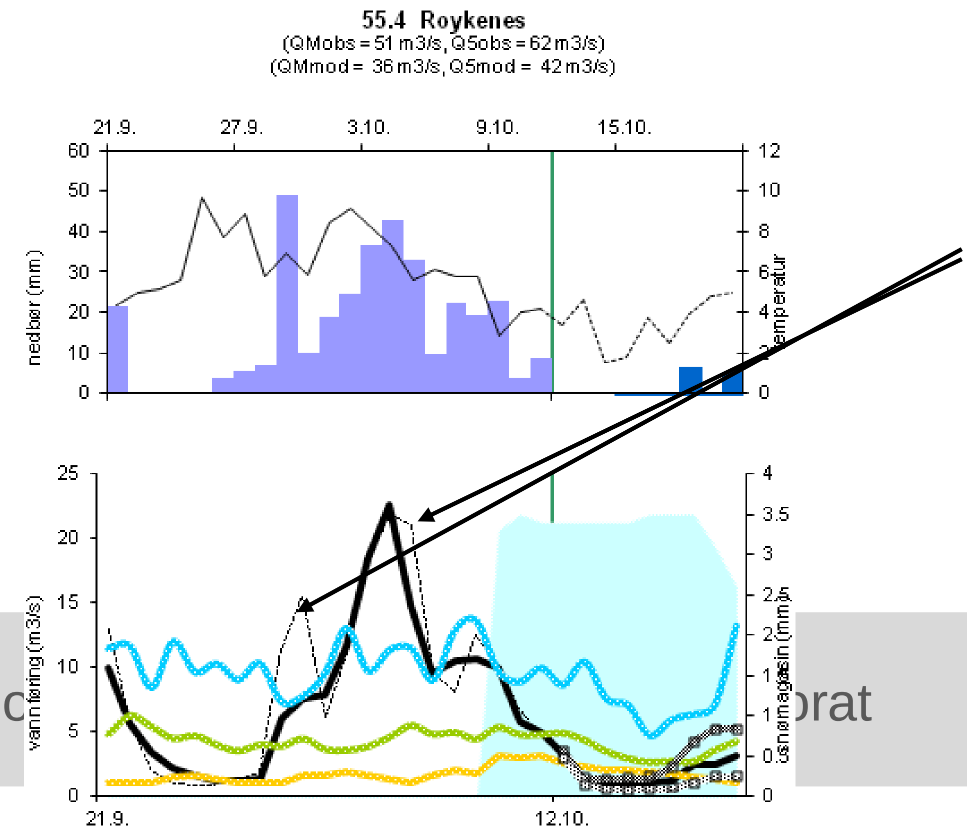
PUB (2003-2012)

- Wonderful theme for a community effort.
- Expressed the conscious (or unconscious) ambition of every hydrologist
- PUB results are easily evaulated. Did we manage to predict or did we not.

On my way to PUB

- After 10 years of using a very well-known scandinavian rainfall-runoff model as a flood forecaster, I realised the secrets of hydrology continued to be hidden somwhere in the mist.



Why?

What causes the mist?

- Calibration parameters are an evil! They make it impossible to disentangle the integrated processes that make up the hydrological response.

- We may end up with (depressive) conclusions like this:

  This finding corroborates the notion that it will be difficult, if at all possible, to find universal relationships between model parameters and catchment attributes, at least at the regional scale as examined in this study.

  R. Merz, G. Blöschl / Journal of Hydrology 287 (2004) 95–123

What causes the mist?

- Singular objective: If runoff is OK, then everything is OK ??

- A much quoted phrase:

Getting the right answers for the right reasons: Linking measurements, analyses, and models to advance the science of hydrology

Kirchner, J. W. (2006), Getting the right answers for the right reasons: Linking measurements, analyses, and models to advance the science of hydrology, *Water Resour. Res.*, *42*, W03S04, doi:10.1029/2005WR004362.

- If runoff is OK then so should: groundwater, soilwater, snow, evapotranspiration,..

Need to estimate (not calibrate) model parameters independently from observed data

- Such data (which really have been present for a long time) can be:

-Digitised river networks: describe shape of unit hydrograph (Skaugen and Onof, 2014)

-Spatial varability of precipitation: estimate the shape of spatial distribution of snow water equivalent (Skaugen and Weltzien, 2016)

-Energy balance (proxy) models: calculate snowmelt and evapotranspiration (Skaugen and Saloranta, 2015)

-Recession analysis: estimate subsurface celerity (Skaugen and Onof, 2014)

-Mean annual discharge: in combination with recession analysis we can estimate subsurface capacity in catchment models (Skaugen and Mengistu, 2016)

These are just my own efforts to get rid of calibration parameters, surely this topic is not exhausted..

The point is:

- PUB can be achieved by more physically based (catchment scale) models. Some information is always present.
- We cannot accept that there are no relations between hydrological response and catchment characteristics.
- It then follows: Since (good and relevant) model parameters quantify the hydrological response there have to be relations between model parameters and catchment characteristics.

The Distance Distribution Dynamics (DDD) model

- How far can we get in developing Rainfall-Runoff algorithms from data and information already present for a lot of catchments, i.e. from digitized maps and runoff?

DDD model

In PUB mode we have to:

-tune one parameter to a regional estimate of the mean annual discharge (to get the water balance rigth)

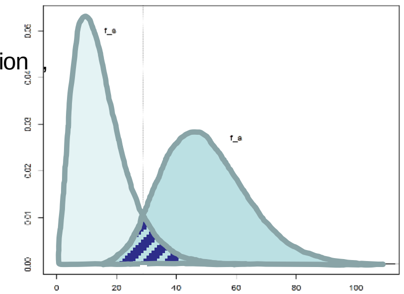
-estimate 6 parameters using regression against catchment and climate characteristics

-all other parameters are estimated using GIS or fixed

Input: precipitation and temperature
10 elevation zones.

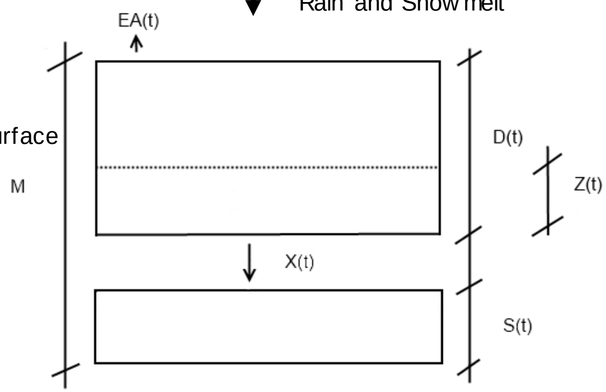
P, T,..

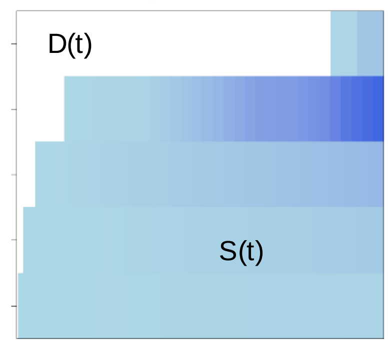
Snow distribution: accumulation, melt and snow-free area.
10 elevation zones.



Rain and Snow melt

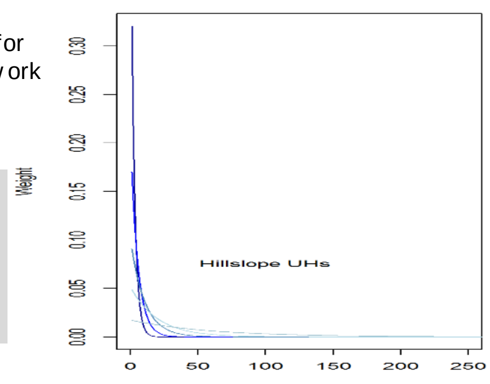
Subsurface: saturated and unsaturated zone.
Right: simulated subsurface moisture distribution in hillslope

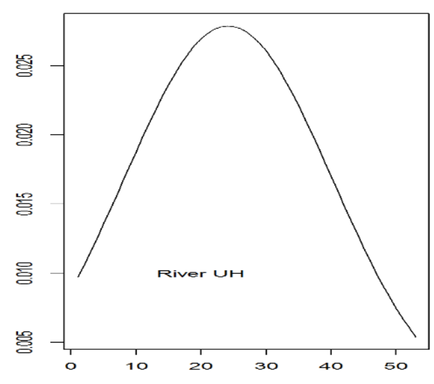




X(t) distributed in time by UHs conditioned on subsurface state, S

Runoff dynamics: UHs for hillslopes and river network





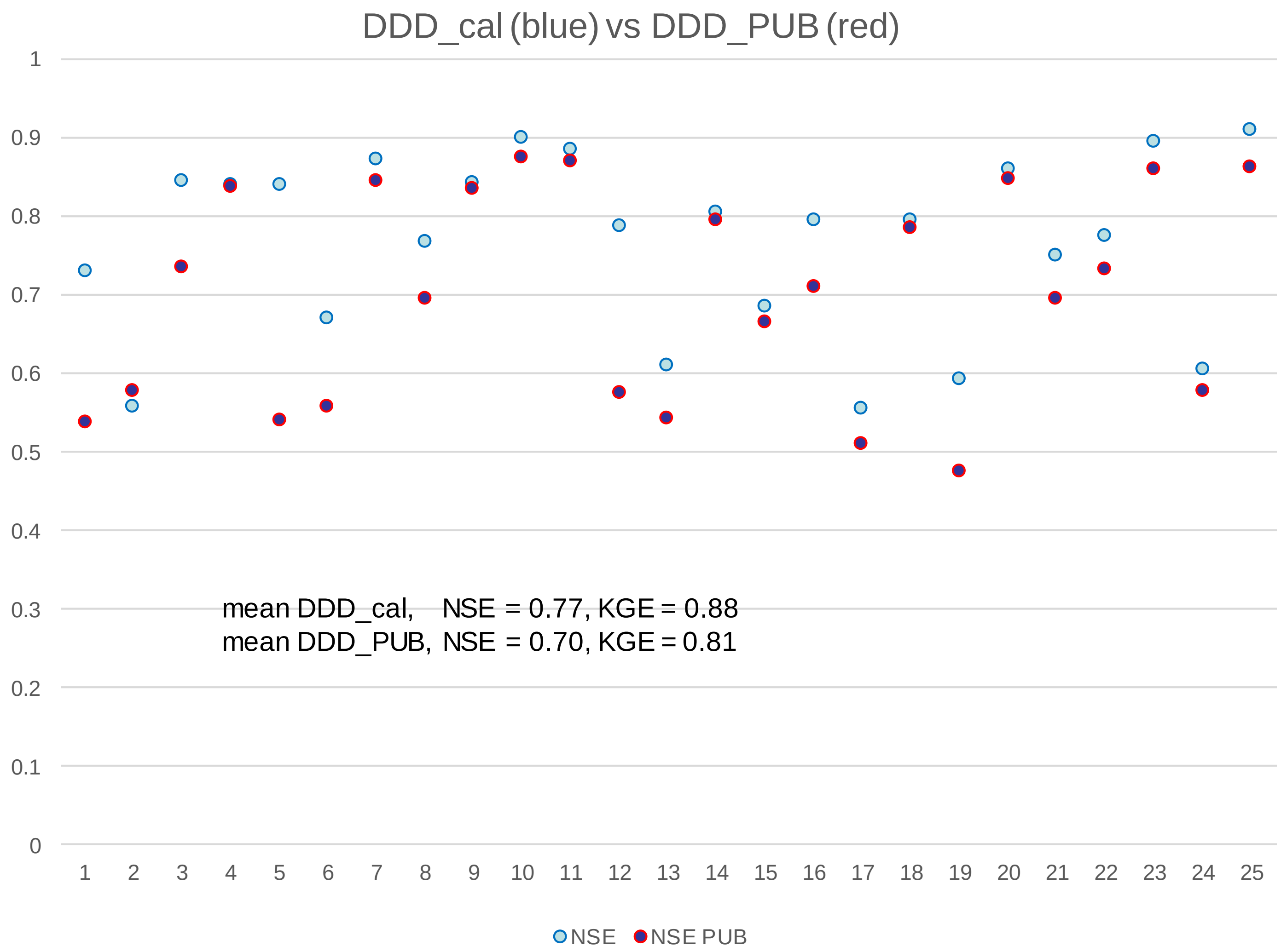
Model parameters are indeed correlated to catcment characteristics
(111 calibrated catchments, significance: p-value < 0.01)

Catchment and climate characteristics

Model parameters

	M_elev	a0	d	M_d	L%	Myr%	Area	EL%	1085	C_len	Fores	BRock	M_P	M_T	M_q
Skorr						-0,26					-0,51	0,47		-0.31	0,44
CX			0.28	-0,34	0.46		-0,31	0,47		-0.27			0,6		0,58
Cea		0.56	0.25	-0,43							0,38	-0,42	0,27	0,43	
Gsh	-0.31	0.39	0,27		0,29			0,49			0,32	-0,38	0,29	0,46	
Gsc				-0,27	-0,42			-0,40	0,42				0,39		0,38
MaxCel				-0,38		0,40					0,48	-0,44			-0,41

PUB results


DDD_cal (blue) vs DDD_PUB (red)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
mean DDD_cal, NSE = 0.77, KGE = 0.88
mean DDD_PUB, NSE = 0.70, KGE = 0.81
NSE
NSE PUB

«Work well for the right reasons»

- should be a guiding principle for all modelling
- PUB can be achieved by more physically based (at the catchment scale) models
- Use information to constrain models
- I believe this is the way forward also for Panta Rhei

On my way to PUB

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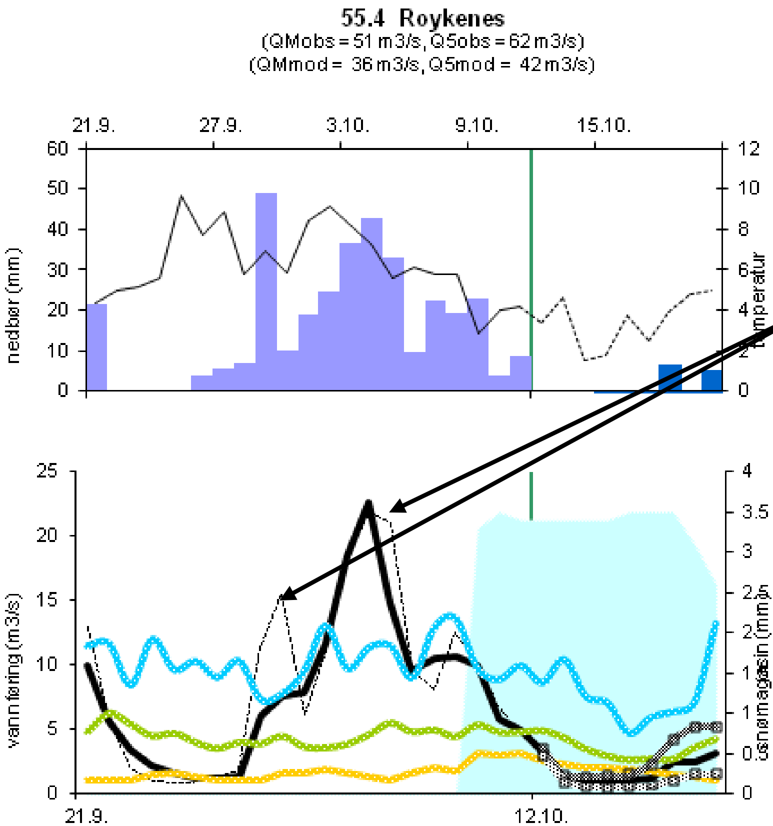
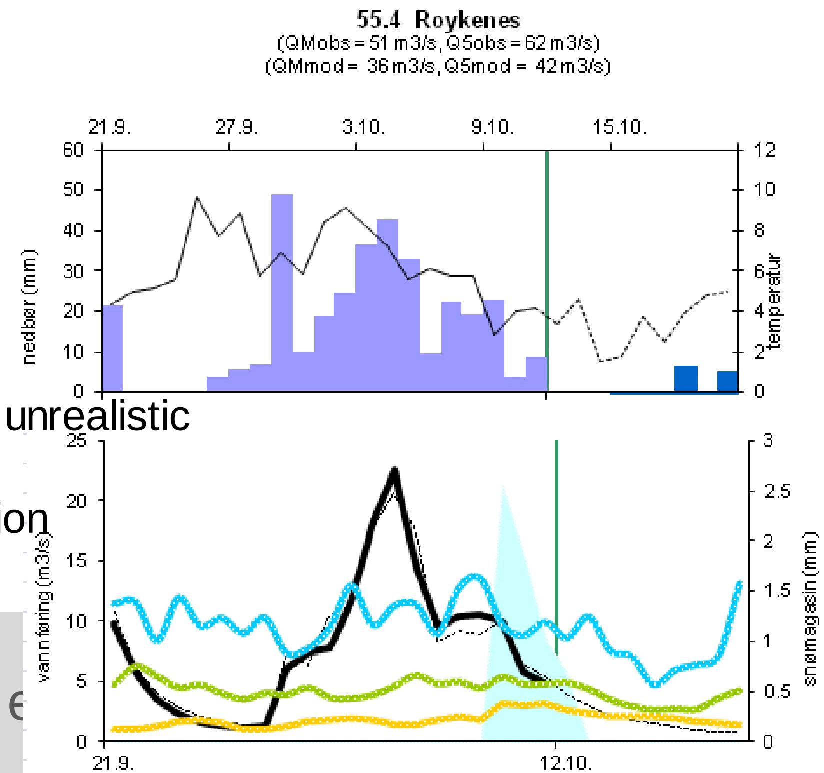


Why?

In this case:
Probably an unrealistic
subsurface
representation

sdrags- og e



References:

Presentation of the DDD model:

Skaugen T. and C. Onof, 2014. A rainfall runoff model parameterized form GIS and runoff data. *Hydrol. Process*. **28**, 4529-4542,DOI:10.1002/hyp.9968.

Application of DDD to prediction in ungauged basins (PUB):

Skaugen, T., I. O. Peerebom and A. Nilsson, 2015. Use of a parsimonious rainfall-runoff model for predicting hydrological response in ungauged basins. *Hydrol. Process*. **29**, 1999-2013, DOI:10.1002/hyp.10315.

New subsurface routine in DDD:

Skaugen, T. and Z. Mengistu, 2016. Estimating catchment scale groundwater dynamics from recession analysis- enhanced constraining of hydrological models. *Hydrol. Earth. Syst. Sci*. **20**, 4963-4981, doi: 10.5194/hess-20-4963-2016.

New snowmelt routine in DDD:

Skaugen, T. and T. Saloranta, 2015. Simplified energy-balance snowmelt modelling, NVE-report 31-2015.

New routine for the spatial distribution of SWE in DDD:

Skaugen, T. and Weltzien, I. H., 2016. A model for the spatial distribution of snow water equivalent parameterized from the spatial variability of precipitation, *The Cryosphere*. **10**, 1947-1963, doi:10.5194/tc-10_1947_2016.

My Panta Rhei journey

- Has not really started yet…
- Revealing statistics from insurance showed that urban flooding causes damages three times the cost as flooding in natural catchments (the flooding we have been forecasting in Norway for 35 years)
- This is a global problem which impacts on peoples lives in many ways: houses, livelyhoods and health.
- The problem is increasing, cities are growing and climate change gives us more frequent and intense precipitation.