Including hydrologic signatures in the calibration of a groundwater-surface water model to improve representation of artificial drain

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EGU2020-9283

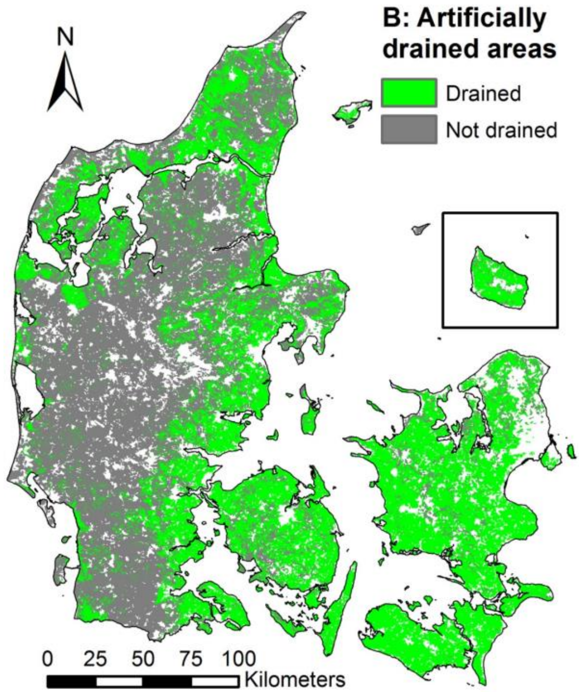
G E U S

08-05-2020

The significance of artificial drainage…

Significant share of agricultural land around the world is artificially drained, often by tile drains (pipes). Such tile drains have profound effect on

- hydrological cycle and groundwater flow patterns
- related transport and retention of contaminants (nitrate)

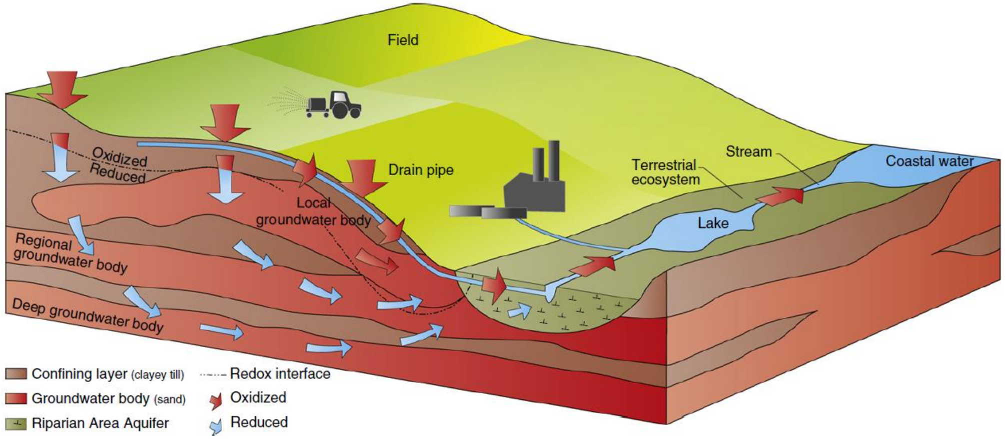


Machine learning-based estimate of artificially drained areas in DK (Møller et al., 2018)

Denmark is no exception to this:

~66% of Denmark is used for agriculture, of which **~50% is artificially drained** (Olesen, 2009; Møller et al., 2018)

→**significance of artificial drain in hydrologic modelling**



Conceptualized water flow paths and related nitrate reduction in Danish glacial till landscape (Refsgaard et al., 2014)

…and the challenges of including drain in models

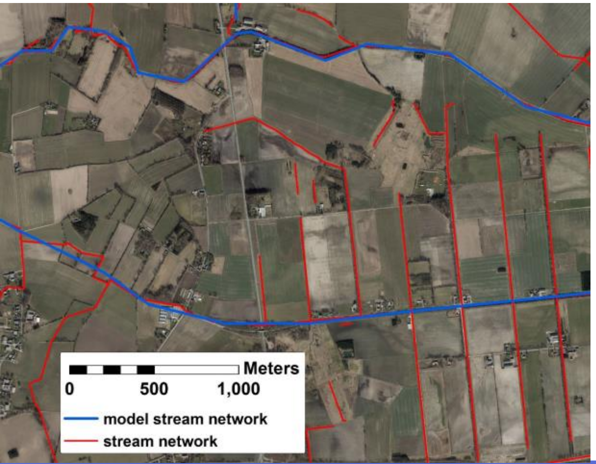
We are facing some challenges if we want to include artificial drain in regional-scale (or Denmark-wide) hydrological models:

on the model-side

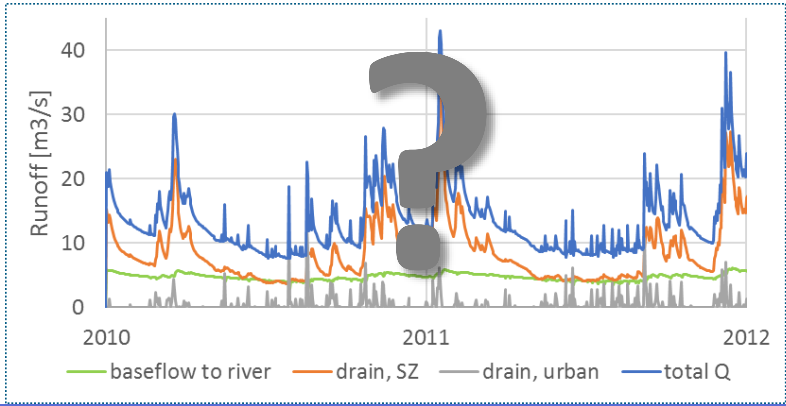
- scale issues: distributed model grid with grid sizes of 500m or 100m
- Inevitable aggregation of processes in hydrological models In the example of MIKE SHE, the modelling framework we used, drain is implicitly represented (and acts as compensation for often inevitable underrepresentation of natural drainage network) (DHI, 2019)

and due to insufficient data

- Unknown distribution of actual tile drain (precise knowledge limited to small, selected catchments)
- Lack of drain flow observations at scales relevant for regional-scale models



results in challenges regarding the **model parameterization** and **evaluation of model results**



Hypothesis: Link between hydrologic signatures and drain flow

The just mentioned challenges lead to the idea to exploit the **information contained in hydrologic signatures** to **improve the representation of artificial drain** in hydrologic models:

Assuming there is a correlation between

- physical catchment properties, dominating runoff processes – including artificial drain

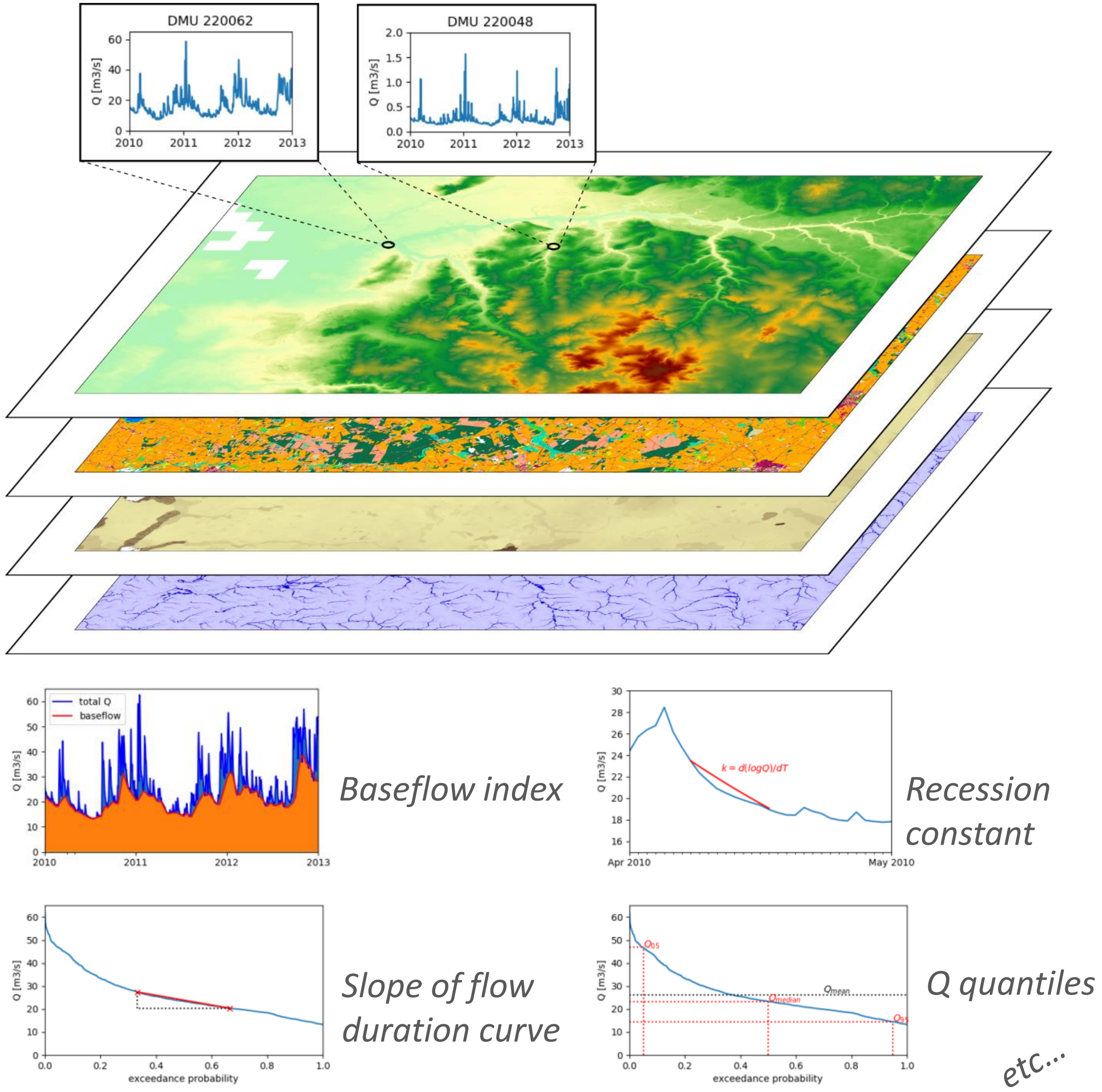
  and

- signature values

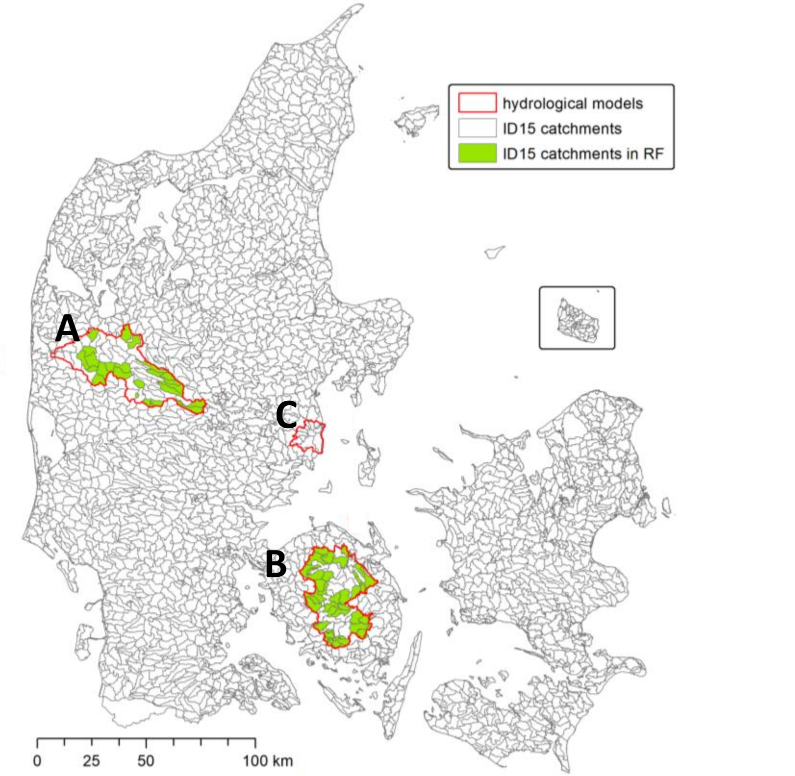
It should be possible to fit models to better represent observed signature values

→which results in a better representation of runoff processes, including drain

?



Step 1: Establish link between signature values and drain



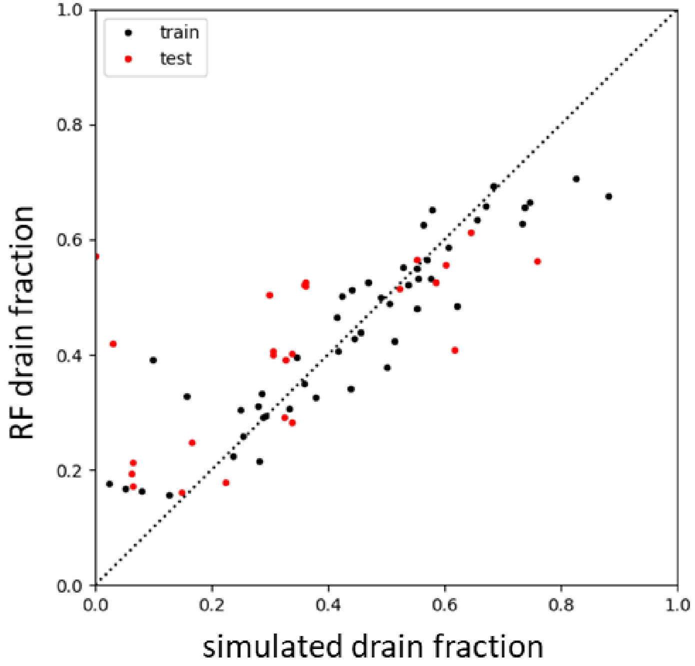
Denmark with all ID15 catchments outlined. Models used for RF regression are the Storå (A) and the Odense catchment (B). The Norsminde catchment (C) was used in the subsequent model calibration experiments; see next slides.

Analysis of simulated drain and simulated hydrologic signatures in two Danish catchments (A: Storå, B: Odense)

- each ~1000km^2 in size
- set up as distributed, integrated groundwater-surface water model in MIKE SHE

Analysis is based on **hydrologic signatures of total streamflow** at ID15 catchment* outlets, limited to catchments with an aggregated area < 50km^2**
We focus on total streamflow, as observation data exists for this

Can we use simulated hydrologic signatures to predict the simulated drain fraction (drain Q/total Q)?
→yes, we can, using a Random Forest (RF) regressor!

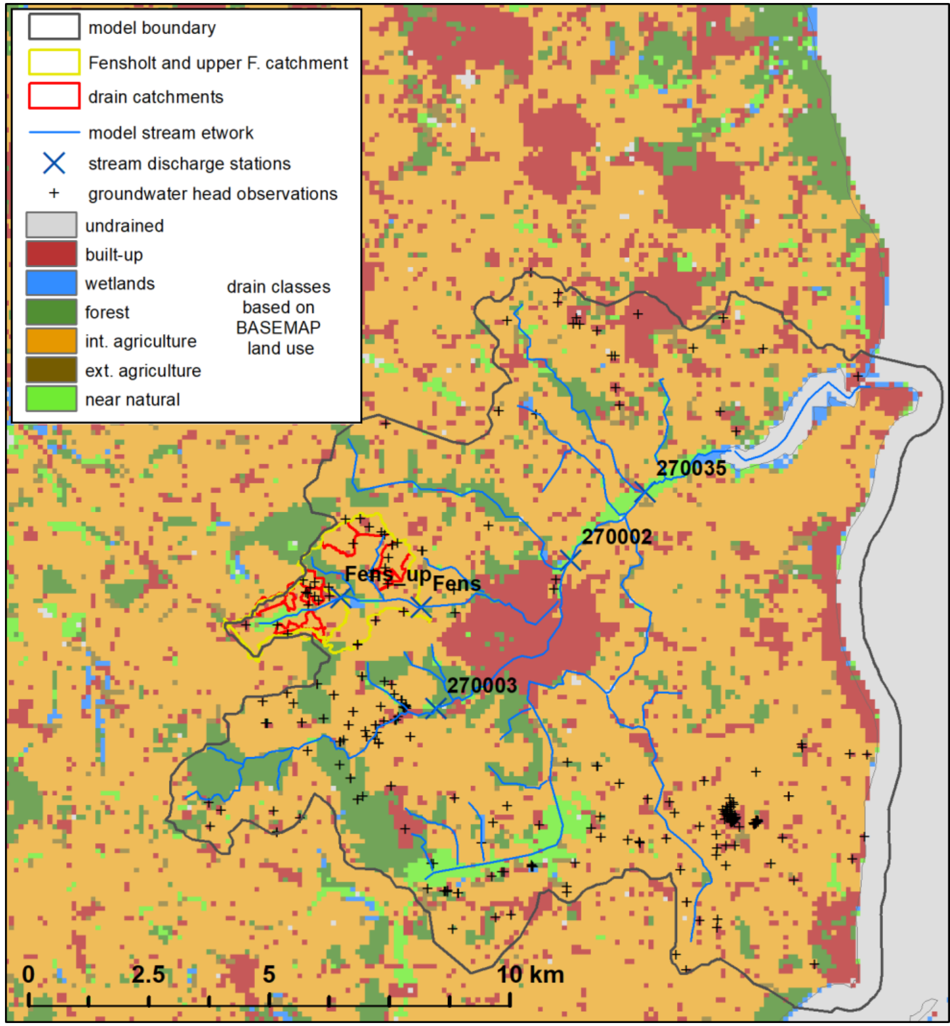


*) all of Denmark is divided into hydrologic catchments with an average size of 15km^2, the so called ID15 catchments
**) limited to smaller catchments, as we assume that effects of drain will be diluted with increasing catchment size

Step 2: Model calibration including hydrologic signatures in objective function

All model calibration experiments were conducted for a 100m grid-scale model of the Norsminde catchment (C on previous slide) in eastern Jutland, Denmark (based on work by Hansen et al., 2014, updated e.g. to include new geology, Stisen et al., 2019)

- area ~145km^2, of which 65% intensive agriculture
- daily timestep, run from 2007 to 2017
- daily observations of drain flow available for **Fensholt subcatchment** (plus daily discharge data and groundwater heads)



*Basemap of the Norsminde catchment, displaying available data, and the **Fensholt subcatchment (yellow)**, for which detailed drain flow data exists*

Calibration against objective functions comprised of different metrics:

S1	groundwater heads and KGE in 3 discharge stations
S2	gw heads, KGE, and 1 signature
S3	gw heads, KGE, and 2 signatures
S4	gw heads, KGE, and 6 signatures

Signatures were chosen mainly based on insight from the RF regressor:

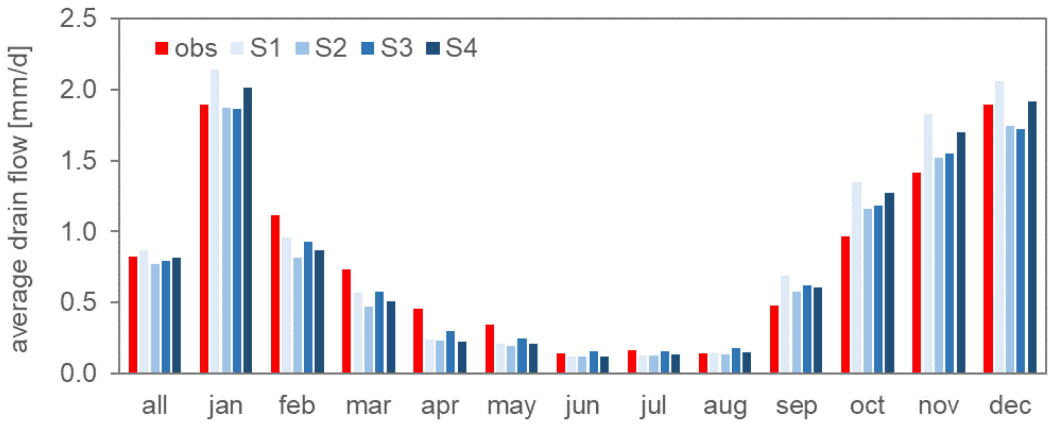
- high flow event duration **S2**
- skewness
- coefficient of variation, median q summer/winter, low flow event duration, slope of FDC

(high flow event duration and skewness: **S3**; all: **S4**)

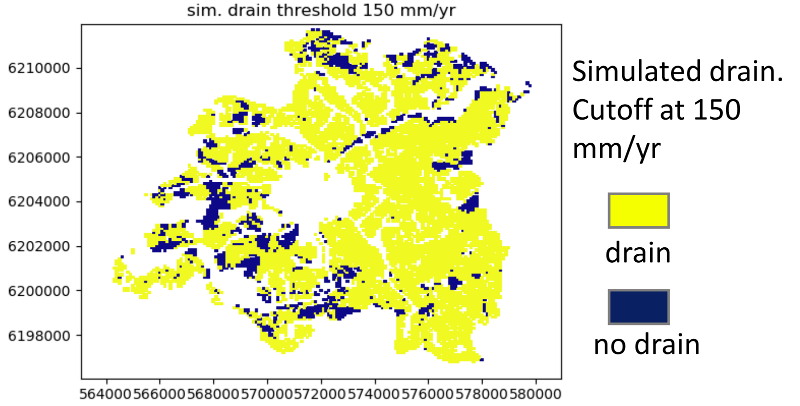
Step 2: Model calibration including hydrologic signatures – Results

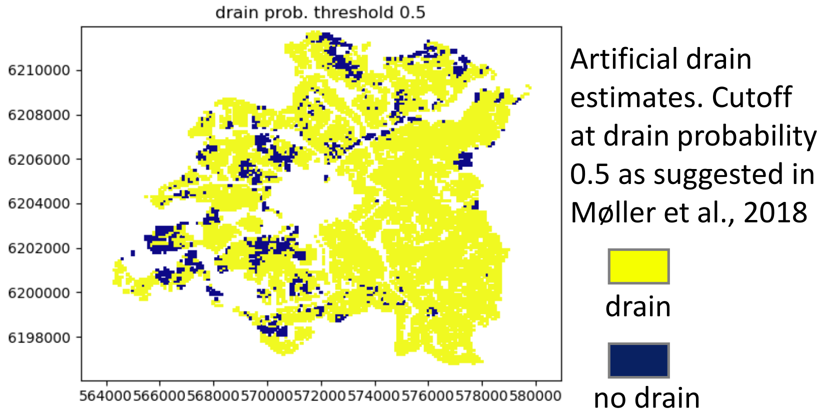
Lack of data on drain not only is a **challenge** for model parameterization, but also for the **evaluation of model results.** Possibilities:

- For the Fensholt subcatchment, there exist daily data of drain flow from 8 tile drain outlets/subcatchments (sized 4ha to 34ha), and streamflow data
  →can be used as raw data, or aggregated in time (monthly)
  →can be used to estimate drain fraction (drain Q/total Q)
- Artificially drained area was estimated independent of this study for all of DK (Møller et al., 2018, see slide 2)



Monthly aggregated drain flow in the Fensholt subcatchment, comparison of observed and simulated values from the different calibration scenarios





Spatial patterns of simulated drain flow in the Norsminde model, in comparison to the estimated artificial drain distribution.

Step 2: Model calibration including hydrologic signatures – Results

Overview over different metrics of drain flow and its spatial distribution

	mean KGE drain, D1 to D8	KGE drain, Fensholt	ME drain fraction, all	MAE monthly drain fractions	ME drain [mm/d], all	MAE monthly drain flow [mm/d]	R2 drain p – sim drain
S1	0.52	0.82	0.02	0.06	-0.05	0.18	0.31
S2	0.45	0.79	0.09	0.12	0.05	0.13	0.35
S3	0.36	0.72	0.07	0.09	0.03	0.11	0.31
S4	0.49	0.82	0.06	0.11	0.01	0.15	0.34

By including hydrologic signatures in objective function:

→spatial fit of active/inactive drain cannot be improved consistently
(however, also validation data has significant uncertainties)

→match of daily timeseries of observed and simulated drain cannot be improved consistently
(however, general fit is good, and some drain catchments (4ha to 34ha) only encompass few model cells (1ha)

→monthly aggregated values for drain flow [mm/d] can be slightly improved

Conclusions

Random Forest regressors could show that there is a correlation between (simulated) hydrologic signatures in streamflow and simulated artificial drain

(e.g. also Boland-Brien et al, 2014)

However, it remains challenging to exploit the information in hydrologic signatures to improve the representation of artificial drain in hydrological models

Possible ways forward?

- further investigations into which signatures constrain model in best manner
- apply more flexible parameterization
- try to incorporate more realistic representation of drain flow in model concept
- …?

Background slides

Including hydrologic signatures in the calibration of a groundwater-surface water model to improve representation of artificial drain

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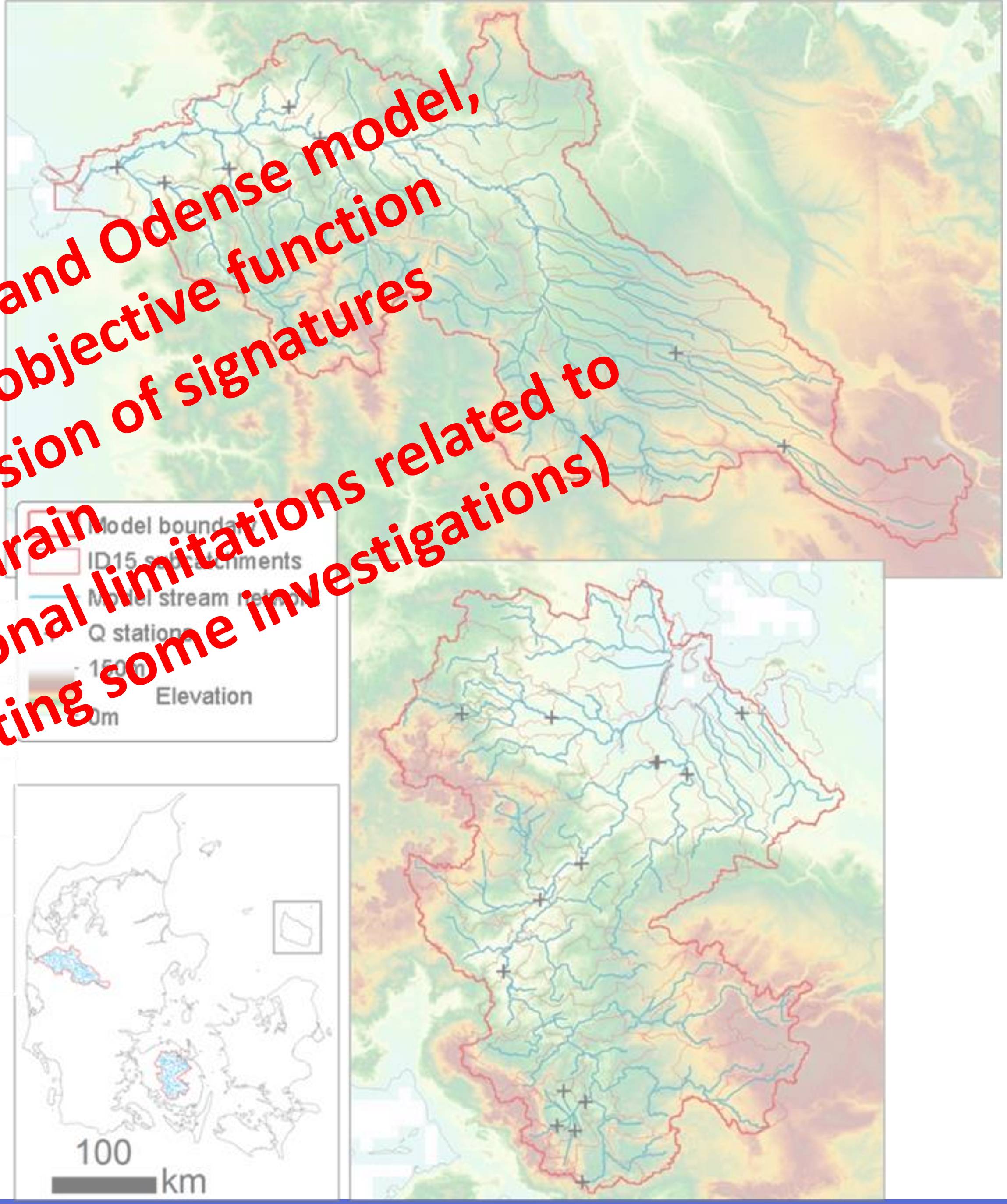
Overview over two model areas

Models set up in **MIKE SHE**, a distributed integrated groundwater-surface water model

100 m horizontal resolution

	Storå	Odense
Size	1124 km²	1004 km²
ID15 sub-catchments[a)]	56	68
sub-catchments < 50km²[b)]	26	48
Q stations	7	14



Previous calibration of the Storå and Odense model, with and without signatures in objective function

→ Failed to validate that inclusion of signatures improves representation of drain (possibly due to computational limitations related to these larger models, inhibting some investigations)

Abstract

About half of the Danish agricultural land is artificially drained to make land arable and increase crop yield. Those artificial drains, mostly in the form on tile drains, have a significant effect on the groundwater flow patterns and the whole water cycle. Consequently, the drainage system must also be represented in hydrological models that are used to understand and simulate, for example, recharge patterns, groundwater flow paths, or the transport and retention of nutrients. However, representation of drain in regional- and large-scale hydrological models is challenging due to i) issues with scale, ii) a lack of data on the distribution of the drain network, and iii) a lack of direct observations of drain flow. This calls for more indirect methods to inform such models.

We assume that drain flow leaves a signal in certain hydrograph signatures, as it impacts the generation of streamflow. Based on a dataset of observed discharge covering all of Denmark, and simulation results from regional-scale hydrological models, we use machine learning regressors to shed light on possible correlations between hydrograph signatures and artificial drainage. Building up on this step, we run a series of calibration exercises on a hydrological model of the agriculturally dominated Norsminde catchment, Denmark (~100 km2). The model is set up in the DHI MIKE SHE software, as distributed coupled groundwater-surface water models with a grid size of 100 m. The different calibration exercises differed in the objective functions used: either we only use conventional stream flow metrics (KGE), or also include hydrograph signatures that showed sensitive towards drain flow in our regression analysis. We then evaluate the results from the different calibration exercises, in terms of how well the model reproduces directly observed drain flow, and spatial drainage patterns.

Despite including hydrologic signatures in the calibration process, the representation of drain flow in large-scale models remains challenging. Eventually, the insight gained from this and similar studies will be incorporated in the National Water Resources Model for Denmark, to help improving national targeted regulation of nitrate application through fertilizers.

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This work is part of WP 9 of Future Cropping
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