Hydrological simulation for everywhere

Hydrologisk Simulering for Overalt (HSO)

RAPPORT NR 23 / 2026

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Abstract:

This report presents the Hydrological Simulation for Everywhere system (HSO), an experimental framework developed at NVE to simulate hydrology at arbitrary locations in Norway without local calibration. HSO combines national meteorological grids, GIS-derived catchment characteristics, and the DDD hydrological model to egerate runoff simulations at hourly to daily resolutions. The system was developed to be able to make hydrological predictions in ungauged basins (PUB) where direct observations are lacking but reliable hydrological information is needed for flood forecasting, infrastructure design, hydropower planning, low-flow estimation, and landslide studies. The report describes how HSO estimates model parameters from climate and catchment attributes, including response-time relationships and empirical rules for hillslopes, river networks, and lakes, and how users can delineate catchments and run simulations through dedicated internal web tools. Results show that HSO is already useful in several applications, including flood forecasting, low-flow assessment, flood estimation in ungauged catchments, and investigation of hydrological conditions associated with landslides. At the same time, the system remains a prototype in need of improved technical and operational robustness, urban catchment support, updated parameter estimation, and continued testing before broader operational use.

Key words: DDD model, Flood estimation, Flood forecasting, Landslide forecasting, Low flow estimation, Predictions in ungauged catchments, Web tool

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Preface

Reliable hydrological information is critical for flood risk management, landslide early warning, hydropower production, and infrastructure planning. Yet most locations in Norway lack direct hydrological observations, creating a persistent need for methods that can provide consistent hydrological information at ungauged sites.

This report documents the Hydrological Simulation for Everywhere system (Hydrologisk Simulering for Overalt, HSO), an experimental modelling framework developed within the Hydrology Department at the Norwegian Water Resources and Energy Directorate (NVE). HSO was developed as part of NVE's strategic FlomRisk project (2022–2025), which developed and tested a framework for risk-based flood forecasting in selected pilot municipalities. Within this context, HSO enables hydrological simulations at arbitrary locations using nationally available meteorological data, without local calibration.

As of June 2026, HSO is operated experimentally within the NVE firewall and is not publicly accessible. This report provides a basis for further development, evaluation, and potential future operational use of the system.

Oslo, June 2026

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This document is sent without signature. The content is approved according to internal routines.

Summary

This report presents the Hydrological Simulation for Everywhere system (HSO), an experimental framework developed at NVE to simulate hydrology at arbitrary locations in Norway without local calibration. HSO combines national meteorological grids, GIS-derived catchment characteristics, and the DDD hydrological model to generate runoff simulations at hourly to daily resolutions. The system was developed to be able to make hydrological predictions in ungauged basins (PUB) where direct observations are lacking but reliable hydrological information is needed for flood forecasting, infrastructure design, hydropower planning, low-flow estimation, and landslide studies.

The report describes how HSO estimates model parameters from climate and catchment attributes, including response-time relationships and empirical rules for estimating distance distributions for hillslopes, river networks, and lakes, and how users can delineate catchments and run simulations through dedicated internal web tools. Results show that HSO is already useful for several applications, including flood forecasting, low-flow assessment, flood estimation in ungauged catchments, and investigation of hydrological conditions associated with landslides. At the same time, the system remains a prototype in need of improved technical and operational robustness, urban catchment support, updated parameter estimation, and continued testing before broader operational use.

Sammendrag

Denne rapporten presenterer Hydrologisk Simulering for Overalt (HSO), et eksperimentelt rammeverk utviklet i NVE for å simulere hydrologi på vilkårlige steder i Norge uten lokal kalibrering. HSO kombinerer nasjonale meteorologiske grid, GIS-baserte nedbørfeltkarakteristika og den hydrologiske modellen DDD for å produsere avløpssimuleringer med tidsoppløsning fra time til døgn. Systemet er utviklet for å kunne gjøre hydrologiske prediksjoner i umålte felt (PUB), der direkte hydrologiske observasjoner mangler, men der det likevel er behov for hydrologisk informasjon til flomvarsling, infrastrukturplanlegging, vannkraft, lavvannsanalyser og jordskred analyser og prognoser.

Rapporten beskriver hvordan HSO estimerer modellparametere fra klima- og feltkarakteristika, blant annet gjennom hydrologisk responstid og empiriske regler for å estimere avstandsfordelinger for skråninger, elvenettverk og innsjøer, samt hvordan brukeren kan avgrense nedbørfelt og kjøre simuleringer via interne nettverktøy. Resultatene viser at HSO allerede er nyttig i flere anvendelser, inkludert flomvarsling, lavvannsestimering, flomberegning i umålte felt og undersøkelser av hydrologiske forhold knyttet til skred. Samtidig er systemet fortsatt en prototype med behov for bedre robusthet med hensyn på tekniske og operasjonelle løsninger, støtte for urbane felt, oppdaterte parameterestimater og videre testing før en bredere operativ bruk.

1 Introduction

There is a persistent demand for hydrological information in areas where no hydrological measurements exist. Modelling hydrology in ungauged basins, known as PUB (Predictions in Ungauged Basins), has since long posed a significant challenge for hydrologists. During the PUB initiative led by the International Association of Hydrological Sciences (IAHS) from 2003 to 2012, considerable progress was made in advancing this field (Blöschl et al., 2013; Skaugen et al., 2015).

There are numerous potential applications for a PUB system capable of modelling hydrology at any chosen location. For instance, municipalities in Norway require flood forecasts for small catchments that are not adequately covered by the flood forecasting service at the Norwegian Water Resources and Energy Directorate (NVE). Municipalities have expressed frustration with the spatial scale at which NVE issues its flood warnings and naturally seek timely and accurate information to ensure that their limited resources for flood mitigation are managed as effectively as possible.

Hydropower companies, in principle, require continuous hydrological information across all parts of their river and reservoir systems for hydropower production. Since installing and maintaining hydrometric gauges is expensive, a PUB system provides a cost-effective alternative by offering both historical data and forecasts. While it is important to acknowledge the considerable uncertainty associated with non-calibrated hydrological predictions from a PUB system, such a tool would still be highly valuable for production planning (pers. com. Troms Kraft).

To enhance landslide early warning systems, Mirus et al. (2024) emphasize the need for more thoroughly integrated hydrological information, particularly regarding local subsurface storage dynamics. A possible way to investigate the hydrological- meteorological states associated with landslides is to simulate the hydrology in the catchment of the landslide and at the time the landslide occurred. Unfortunately, it is very uncommon to have a calibrated hydrological model with sufficient temporal and spatial resolution for a specific catchment where a landslide has occurred. However, a hydrological model that can be implemented anywhere and use the national meteorological grid as input could provide valuable insight into the triggering mechanisms of landslides in Norway. The Hydrology Department at NVE has recently launched such an initiative, known as the HYMOJOFLO project (80547).

Furthermore, there is a persistent need for reliable design values in areas lacking hydrological measurements which, notably, includes most locations throughout Norway. Currently, essential infrastructure such as bridges and culverts, which support Norway's road and railway networks, are often designed using relatively simple event-based methods. Common approaches include the Rational Method (Grimaldi and Petroselli, 2014) and the Norwegian PQRUT model (Andersen et al., 1983; see also Filipova et al., 2019 for a stochastic version of PQRUT). Another option is regional flood frequency analysis (FFA, Engeland et al., 2020), where extreme values for ungauged basins are estimated using regression relationships. An increasingly popular alternative is continuous or semi-continuous simulation (Calver and Lamb, 1995; Paquet et al., 2013), where rainfall-runoff models are used to simulate long time series of hydrological data, allowing FFA to be performed on the simulated results. For instance, the semi-continuous simulation method SCHADEX (Paquet et al., 2013) calculates hydrological responses to numerous precipitation events under varying antecedent moisture conditions (AMC), thereby constructing a comprehensive frequency distribution of runoff from which flood estimates can be derived. The ability to simulate extended hydrological time series at any chosen location, even if the model remains uncalibrated, offers valuable insight into the current flood regime and a tool for flood estimation at ungauged sites.

This report provides documentation, to a certain extent, for the Hydrological Simulation for Everywhere system (in Norwegian, Hydrologisk Simulering for Overalt), hereafter referred to as **HSO**. As of June 2026, HSO is being operated experimentally on a local server within the NVE firewall and is therefore not available to the public.

2 Method of HSO

The HSO system consists of several subsystems. In broad terms, the method is the following: for any catchment with an outlet selected using the map tool (HydSim), the parameters for the Distance Distribution Dynamics (DDD) hydrological model (Skaugen and Onof, 2014) are determined based on information from static digital maps and general climate data. Model input, including both historical and forecasted precipitation and temperature at the chosen temporal resolutions (1h, 3h, and 24h), is sourced from national meteorological grids. After running the model, users can download the result file, which contains all relevant model outputs (as detailed below), as well as the parameter and input files. The following sections will provide a more detailed description of each subsystem.

2.1 The Distance Distribution Dynamics (DDDv2) hydrological model

The Distance Distribution Dynamics (DDD) rainfall-runoff model, first introduced by Skaugen and Onof (2014), was developed with the primary aim of minimising the number of calibrated parameters, whilst maintaining the necessary precision and detail in hydrological simulations.

Since 2013, the DDD model has been used operationally by the Norwegian flood forecasting service, demonstrating its versatility across a wide range of spatial scales, from as small as 50 m^2 up to 12,760 km^2, and temporal resolutions from 1 minute to 24 hours (Viker-Walsøe and Valle, 2020; Nazeer et al., 2021). Its ongoing development has focused on further reducing calibration parameters and expanding the model's applicability to various hydrological processes and environments.

Skaugen and Mengistu (2015) derived a method to estimate the model's subsurface capacity using mean annual runoff and mean subsurface water celerity. The term celerity (wave velocity) is used in this report since DDD models the catchments' hydrological response time rather than the travel time of water droplets which is governed by water velocity (see McDonnel and Beven, 2014). Later, Skaugen and Weltzien (2016) parameterised the spatial frequency distribution of snow water equivalent (SWE) based on precipitation data. In subsequent work, Skaugen et al. (2018) and Nazeer et al. (2021) incorporated energy balance equations for calculating snowmelt, glacial melt, and evapotranspiration, thereby removing the need to calibrate degree-day factors (see Omhura, 2001 for a description of these processes.)

Further developments include a version of the model tailored for urban runoff, presented by Skaugen et al. (2020). The latest iteration, sometimes referred to as DDDv2, accounts for infiltration and runoff from both permeable and impermeable surfaces, making it well-suited for urban environments. Additionally, it accommodates runoff from glaciers and wetlands, which hence makes it applicable for most areas in Norway.

DDDv2 is currently the standard model used in the HSO study. In the following, DDDv2 is referred to as DDD. The following sections will highlight some of the novel features of the

DDD model, with further details available in the referenced literature. Figure 1 illustrates the model structure, while Appendix A provides a comprehensive description of the parameter file with explanations.

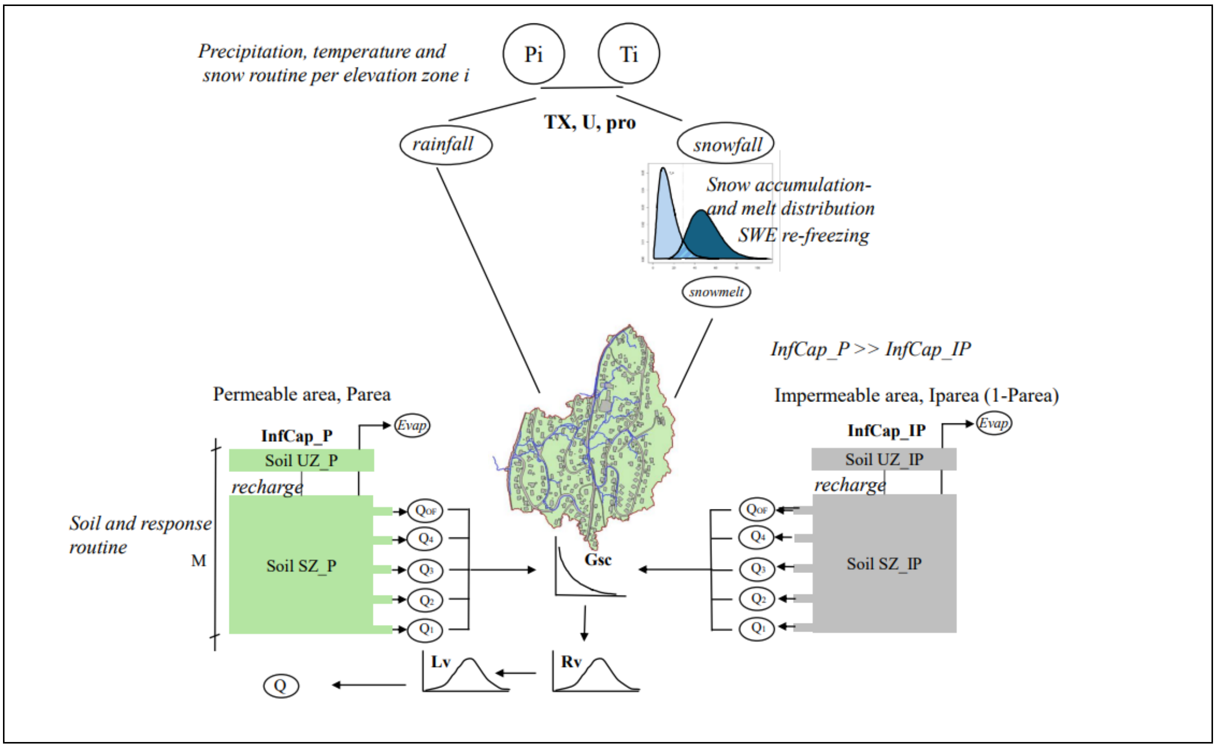


Figure 1. The DDD model consists of two DDD structures for different landscape types: permeable (green) and impermeable (grey). Bolded parameters are typically calibrated. Precipitation, snowmelt, and runoff are distributed over time by transfer functions, indicated by graphs with celerity parameters (Gsc, Lv, Rv), which account for hillslopes, the river network, and lakes, respectively.

2.1.1 Attenuation and delays caused by hillslopes, rivers and lakes

We propose that the delay and attenuation of precipitation or snowmelt before it becomes runoff at the catchment outlet is primarily governed by three key elements: (1) hillslopes, (2) the river network (RN), and (3) effective lakes (see section 2.2.1.3). Each component uniquely modulates the timing and distribution of incoming water.

Simply put, the hillslopes distribute precipitation/snowmelt in time to the river network, the river network distributes water in time to the lakes, and lakes distributes the water in time to the outlet. While the actual hydrological system is more complex, with dynamic interactions among all these elements, this simplified framework provides an effective basis for hydrological modeling.

The temporal distribution of water by hillslopes and the river network is comprehensively described by Skaugen and Onof (2014). The model uses distance distributions (DDs) for both hillslopes and the river network, combined with celerity estimates, to construct transfer functions. These functions partition the incoming water (precipitation or hillslope water) into sequential time segments for the next receiving element (hillslope or river). The estimation of the parameters describing the distribution of the distances for lakes is described below in section 2.2.1.3.

The response times of the lake routing can be substantial compared to that of the rivernetwork. For the catchment 16.75 Tannsvatn which has a high effective lake percentage, $ELPerc$ of 5%, the estimated time of routing water through the (effective) lake versus that of the rivernetwork was 25 hours vs 6 hours with lake and river celerities of 0.03 m/s and 1 m/s respectively. Figure 2 shows the estimated transport time (in terms of distances and celerities) for rivernetwork, lakes and hillslopes respectively.

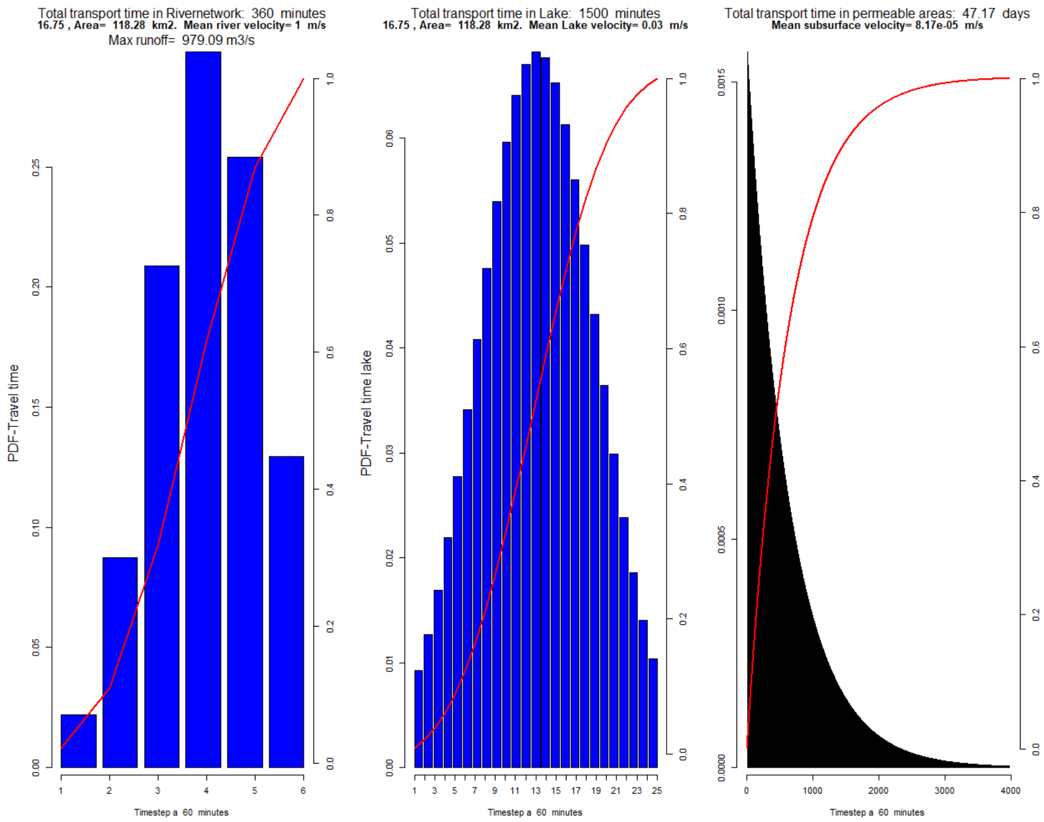


Figure 2. Total response time for rivernetwork (left panel) effective lake, (middle panel) and hillslopes (right panel) for catchment 16.75 Tannsvatn. The calibrated celerities are found in the heading of the panels.

2.1.2 Overland flow celerities in DDD

Overland flow celerities in DDD are now determined within the model code rather than being specified directly in the parameter file. Specifically, the celerities are set as twice the estimated celerities of the top soil layer. This adjustment, derived from the work carried out in the ECCO project (Skaugen et al. 2026 in prep.), ensures greater alignment with the equifinality between celerity and distances highlighted in Skaugen et al. (2023). The overland flow celerities hence remain consistent with the celerity–distance regime unique to each catchment. Moreover, this approach simplifies the calibration process by reducing the number of calibration parameters by two.

```
#Dynamic Subsurface Celerities
k[1,2] = CeleritySubSurface1UH(GshInt, GscInt,prob,Ltymid[1],Timeresinsec ) # Gammadistributed Celerity of subsurface flow
k[2,2] = k[1,2]
#println("k[1,2]= ", k[1,2])


# Fixed Subsurface celerities
#for Lst in 1:Lty
#  k[Lst,1:NoL] = CeleritySubSurface(NoL, Gshape, Gscale, Ltymid[Lst], Timeresinsec) # Celerity of subsurface (and overland) flow
#end

cel = round(k[1,2], digits = 6)
# println("cel= ",round(k[1,2], digits = 6))
#Overlandflow celerities

k[1,1] = 2*CeleritySubSurface1UH(GshInt, GscInt,0.99,Ltymid[1],Timeresinsec ) # Overland flow celerites P. Fixed- non dynamical
k[2,1] = k[1,1]                                                  # Overland flow celerites IP Fixed- non dynamical
########################################################################################
```

Figure 3. location in the DDD code (version of March 2026) where overland flow is calculated.

2.2 The PUB version of DDD- estimating model parameters from GIS and catchment characteristics

Skaugen et al. (2015) demonstrated that climate data and catchment characteristics (CCs) could be linked to calibrated model parameters using multiple linear regression equations (MLREs). Later, the number of calibration parameters in the DDD model was further reduced by incorporating an energy balance approach for snowmelt and evapotranspiration calculations. Building on this, Heltberg (2021) revisited the original study and developed updated MLREs for the DDD model parameters. More recently, Skaugen et al. (2023) identified an equifinality relationship (Beven, 2001) between hillslope distance distributions (DDs) and subsurface celerities, showing that different combinations of DDs and subsurface celerities can produce equally robust hydrological simulations.

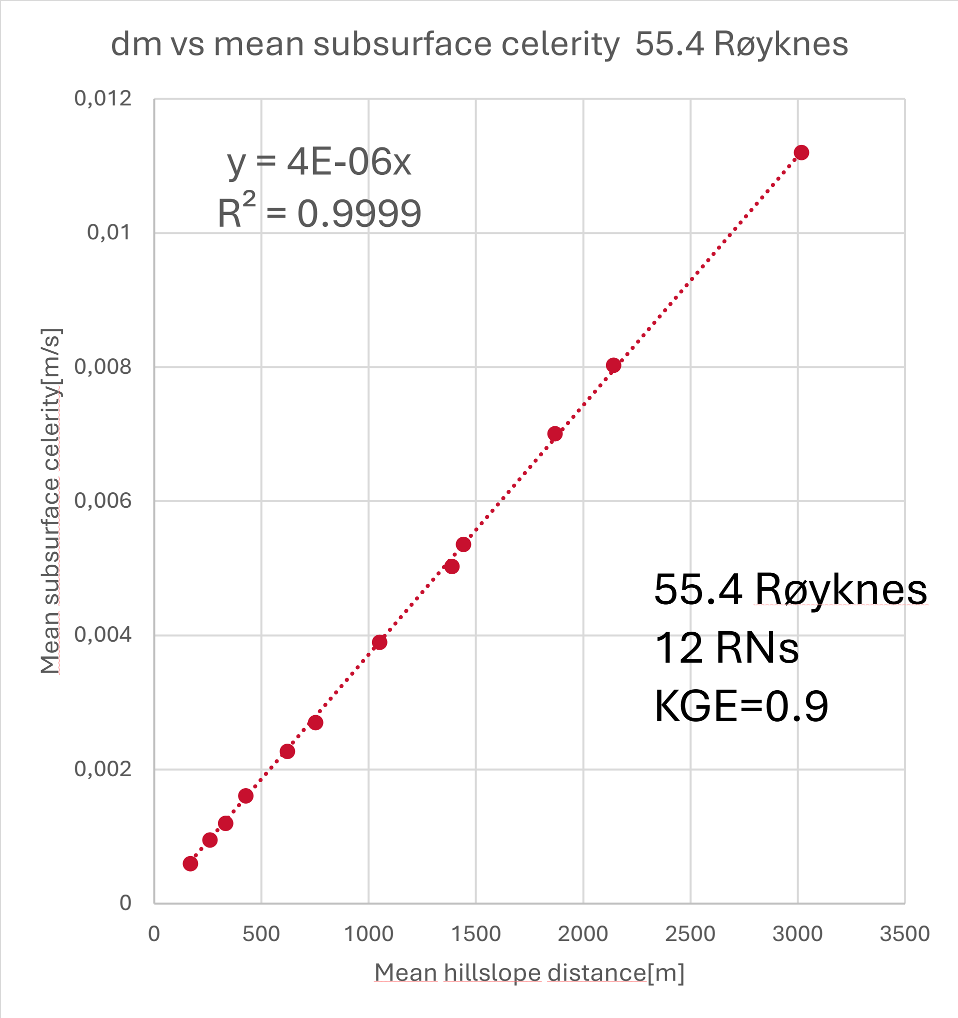


Figure 4. Mean hillslope distance derived from 12 river networks of different density and their respective calibrated subsurface celerities for the Røyknes catchment (55.4). The calibration of these 12 parameterisations all gave a KGE of KGE=0.9. This figure is a very clear illustration of the equifinality concept- different parameter sets give the same result.

A consequence of the equifinality is that DDs and celerities cannot be expected to be well determined by catchment characteristics and MLREs. In their place, the Mean Response Time (MRT) emerged as a unique description of the catchment runoff dynamics and was well determined from the catchment characteristics and MLREs. The MRT is the slope of the regression line in Figure 4 and has the unit of seconds. Given the equifinality between DDs and celerities we can, with an estimated MRT from MLRE choose the mean hillslope celerity $\bar{v}_{HS}$, and calculate the DD represented by the mean hillslope distance $\bar{d}_{HS}$by (Skaugen et al., 2023):

$$\bar{d}_{HS} = MRT_{HS}\bar{v}_{HS} \quad , \tag{1}$$

where the subscript HS indicates hillslope.

Currently, the following model parameters (see Appendix A) are calculated from the MLREs in HSO, with adjusted coefficient of determination R2 (explained variance):

$$MRT = \exp(2.74 + 0.1613 * ELPerc - 0.0185 * (SpQ) - 0.005 * ForestPerc + 0.152 * log(A) - 0.061 * meanT - 0.11 * log(MirePerc) + 0.0067 * GoodInfiltr), \quad (R2{=}\ 0.8) \quad (2)$$

$$a0 = exp(13.81 - 0.086 * log(MountainPerc) + 0.4 * log(meanP) - 2.627 * log(latitude)) \quad (R2{=}\ 0.62) \quad (3)$$

$$D = (493.47 + 170.96 * log(meanP) - 51.92 * log(meanElev)) \quad (R2{=}\ 0.36) \quad (4)$$

$$Skorr = exp(-6.386 + 0.71 * log(SpQ) - 0.826 * log(meanP) + 1.178 * log(latitude)) \quad (R2{=}\ 0.63) \quad (5)$$

$$U = exp(13.32 + 0.08 * log(MountainPerc) + 0.31 * log(meanP) - 3.24 * log(latitude)) \quad (R2{=}\ 0.35) \quad (6)$$

$$pro = exp(-0.281 + 0.02 * (LakePerc) - 0.0058 * MountainPerc - 0.41 * log(SpQ) - 0.29 * log(elev)) \quad (R2{=}\ 0.58) \quad (7)$$

$$TX = -1.085 - 0.021 * MountainPerc + 0.012 * SpQ + 0.00064 * meanElev + 0.0087 * (BadInfiltr) \quad (R2{=}\ 0.49) \quad (8)$$

The parameters which determine the hillslope celerities are calculated from MRT as:

$$GshInt = 1.0, \quad (9)$$

and

$$GscInt = \frac{Timeresinsec}{MRT * 86400 * GshInt}. \quad (10)$$

Where $ELPerc$ is effective lake %, SpQ is specific discharge [l/s/km^2], $meanT$ is the mean annual temperature, $meanP$ is the mean daily precipitation, $MirePerc$ is the % of mires, $GoodInfiltr/Badinfiltr$ is the % of the catchment classified to have soils with good/bad infiltration by the Norwegian Geological Survey, and $MountainPerc$ is the % of bare rock and $meanElev$ is the mean elevation of the catchment. From the regression analysis of MRT, we find that the SpQ, $ELPerc$ and the catchment size A explains most of the variability of MRT (69%).

2.2.1 Estimating Distance Distributions (DDs) from empirical rules

Estimating the DDs from actual digital terrain models (DTMs) within a GIS can be time consuming and, at times, demanding on the availability of popular GIS servers. For a tool like HSO, where flood forecasts are in demand as quickly as possible there is hence a need for more practical and quicker ways of obtaining the DDs. Also see appendix B where examples for estimating parameters are given in Julia code.

2.2.1.1 Hillslope DDs

Relationships between DDD model parameters and the MRT were explored in Skaugen et al. (2023). In principle, the DD parameters can be estimated given the MRT and a chosen mean celerity (or the mean hillslope distance, see Skaugen et al., 2023). If MRT is given and we choose the mean celerity v, we can, since $GshInt$ and $GscInt$ are determined from eqs. 9 and 10, determine the mean hillslope distance as (see eq. 3 in Skaugen et al., 2023):

$$\bar{d} = \frac{v\Delta t}{\bar{\Lambda}} = \frac{v\Delta t}{\text{GscInt*GshInt}} = \frac{v\Delta t}{GscInt} \quad (11)$$

Under the assumption that the hillslope DD is exponential (Tucker et al. 2001; Skaugen and Onof, 2014), we can get an estimate of the maximum hillslope distance as the 0.99 quantile of the exponential distance distribution

$$dmax = quantile(Exp, 0.99). \quad (12)$$

Note that the difference between the parameter file generated by HSO and the one used in DDD is that MRT is used in HSO and $GshInt$ and $GscInt$ is used in DDD. The parameter file used in DDD hence has an extra parameter.

2.2.1.2 River network DDs

For describing the river network distances, we need the mean, $midRN$, the standard deviation, $stdRN$ and the maximum $maxRN$ distance. If we can get a reasonable estimate of $midRN$**,** we can estimate $maxRN$ from a quantile estimate and $stdRN$ from what appears to be a stable relationship to $midRN$ (a constant coefficient of variation, CV). We find a linear relationship between $\bar{d}$ and $midRN$ for all catchments investigated. The intercept, $midRN$ when $\bar{d} \to 0$**,** invariably turns out to be twice the catchment length (CaL), which is the parameter “Feltlengde”, a standard catchment characteristic found in HYSOPP from the catchment characteristics derived from GIS. We further assume that the relations $midRN$ for $\bar{d} \to 0$ and $\bar{d}$ for $midRN \to 0$ hold. This assumption implies that the linear relationship between $\bar{d}$ and $midRN$ has a slope equal to -1. Several of the catchments where we have estimated the distance distributions for hillslope distances and RN distances for CAs over many orders of magnitudes display such relationships. In Figures 5, 6 and 7 we see such a relationship for 55.5 Dyrrdalsvatn (3.3 km^2) and 26.20 Årdal (73 km^2) and 28.11 Lye2 (1.7 km^2) with a slope close to -1. The procedures for estimating the distance distribution parameters for river network are hence:

$$midRn = CaL/2 - 1.0 * \bar{d}, \quad (13)$$

$$stdRn = 0.5 * midRn, \quad (14)$$

and we can get an estimate of the maximum riverlength distance as the 0.99 quantile of the normal distance distribution:

$$maxRn = quantile(Norm, 0{,}99) \quad (15)$$

Table 1 Shows estimated slope between $\bar{d}$ and $midRN$, the intercept is when $\bar{d} \to 0$, catchment length and the mean estimated CV, for the distance distribution $(stdRN/midRN)$.

Station	Area	Slope	Intercept	Catchment length	Intercept/Catchment length	Mean CV
12.178	310.6	-1.23	14227	29880	0.48	0.51
26.20	77.2	-1.19	6393	13080	0.49	0.49
27.24	184.7	-1.2	12986	27310	0.48	0.52
28.11	1.7	-1.08	1027	2000	0.51	0.49
55.4	50.1	-1.03	7904	15920	0.5	0.5
55.5	3.3	-0.91	1020	2290	0.45	0.55
174.11	2.84	-1.18	1230	2620	0.47	0.54

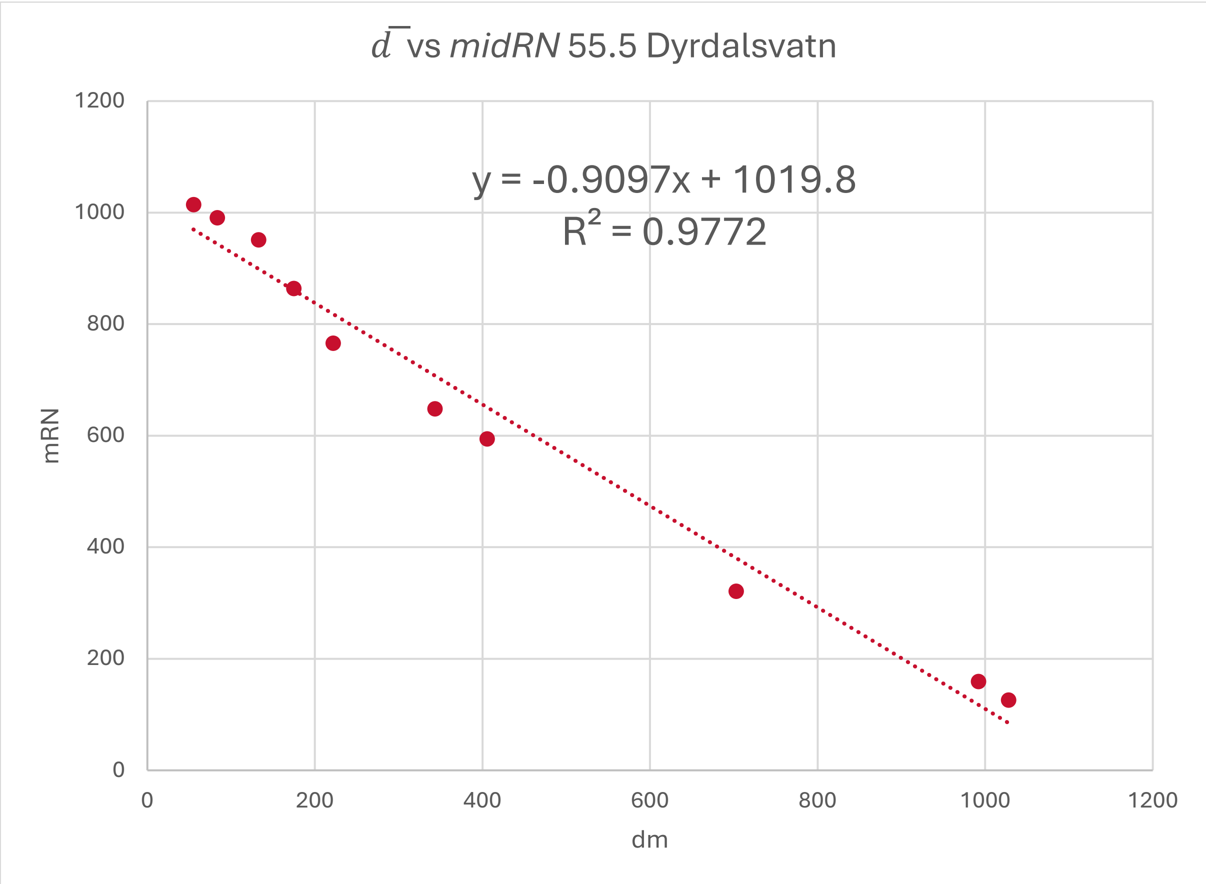


Figure 5. $\bar{d}$ vs midRN for 55.5 Dyrdalsvatn from GIS derived rivernetworks (RNs). Note that the minimum values for $\bar{d}$ and mRN represent an extremely dense RN and almost no RN respectively. These RNs are not necessarily probable, but illustrate the limiting behaviour of rivernetwork density.

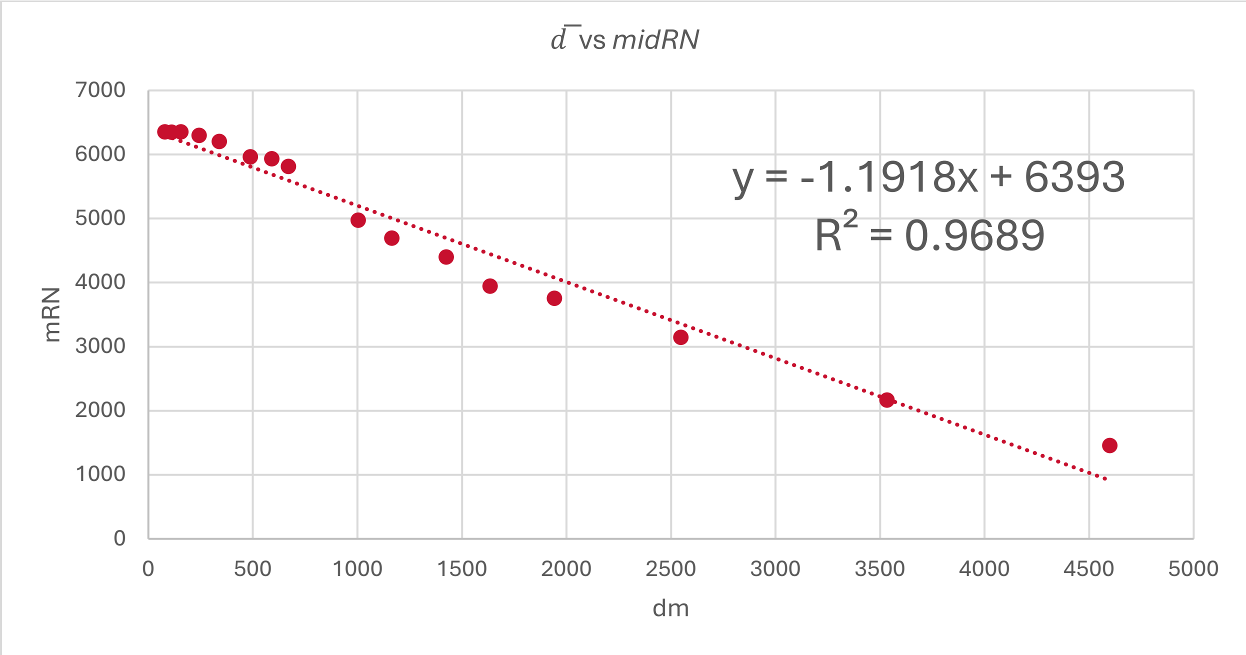


Figure 6. $\bar{d}$ vs midRN for 26.20 Aardal from GIS derived rivernetworks (RNs).

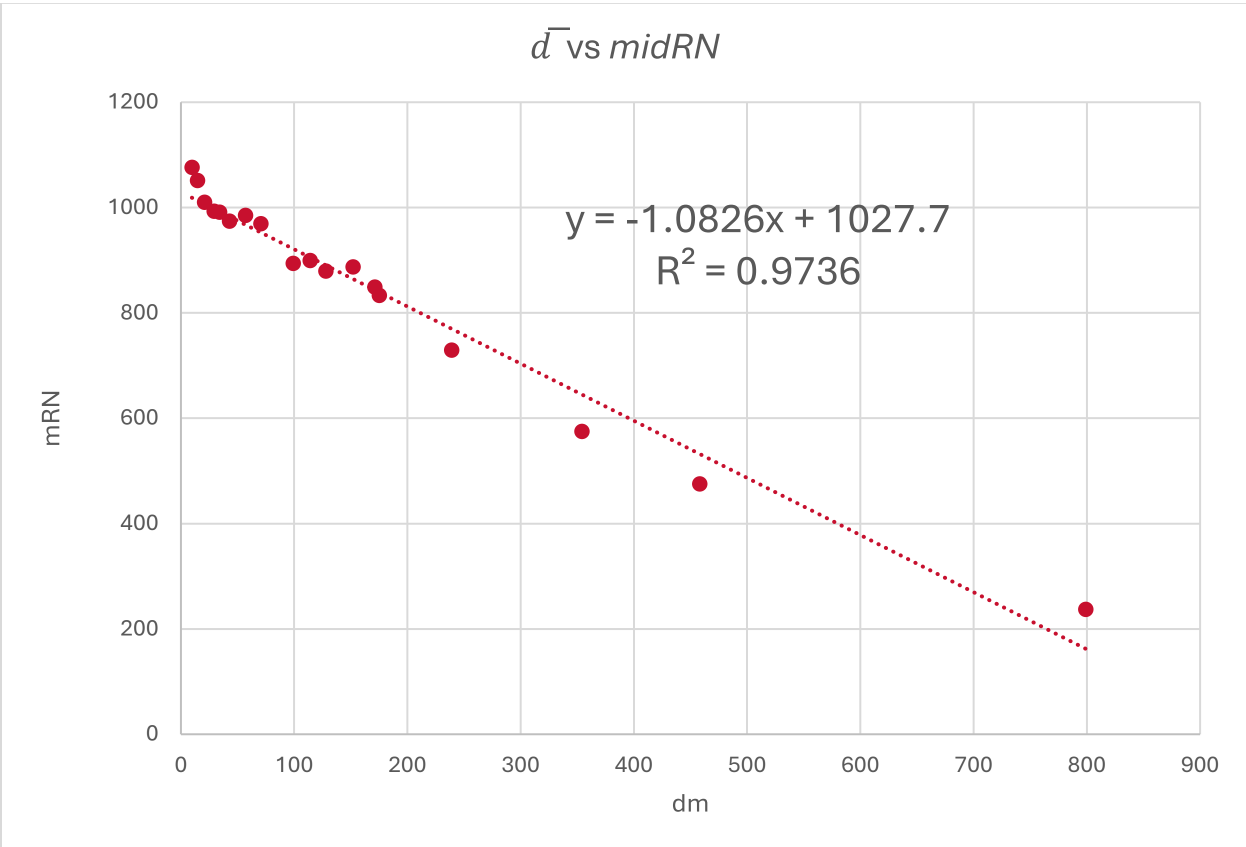


Figure 7. $\bar{d}$ vs midRN for 28.11 Lye2 from GIS derived river networks (RNs).

2.2.1.3 Lake DDs

In DDD we have used the same principle as for hillslopes and rivers to account for the delays and attenuations caused by the lakes. We estimate a DD for a conceptual lake and with a celerity estimate we can route water from the river network through the conceptual lake placed at the end/outlet of the catchment. We assume that a conceptual lake has a generic elliptic shape where the area, A_L is calculated as

$$A_L = \pi * a * b, \tag{16}$$

where a is the length [m] of the long axis and b the length [m] of the short axis. If we let $b = a/4$ we have that $a = \sqrt{(4A_L/\pi)}$. The maximum distance in the lake to the outlet is a, the mean distance is $a/2$ and we let the standard deviation be half of the mean distance, $a/4$. We then approximate the DD to be a normal distribution with parameters truncated at 0 and at a. In order to quantify a, we need A_L.and we use the concept of "Weighted percentual lake area Index" (Tjomsland et al., 1978), or "Effective lake percentage", $ELPerc$, which gives us the effective area percentage of a lake if it was located at the outlet of the catchment as: $ELPerc = 100(\sum A_{Li} * A_i)/ A^2$, where A_{Li} is the area of actual lake i, A_i is the cathment draining to lake i and A is the total catchment area. The area of the effective lake becomes $A_{EL} = ELPerc * A$, and the DD for the A_{EL} can be calculated.

2.2.1.3 Dynamic river networks and DDs for impermeable areas

Currently, the map tool described in the next section, does not provide catchment characteristics relevant for urban hydrology modelling. Nevertheless, we can deduce some of the distance parameters from unpublished theoretical work relating catchment moisture (e.g. saturation) to the density of the river network. For a period Δt of time, a certain river network (RN) is derived from a contributing area $CA(t)$ $[m^2]$ The given RN implies distance distributions of hillslope to river distances and distances within the RN to outlet distances. For this RN configuration, there is associated a catchment scale state of saturation S $[mm/\ \Delta t]$. The RN exists because the saturation S, over the area CA constitutes a volume of water of such a quantity that a channel is needed to evacuate the water. We further state that this volume CV, is a constant and a feature of the catchment. The saturation, $S(t)$ varies in time due to precipitation, snowmelt and evapotranspiration. Since CV is a constant feature of the catchment, then CA must vary in time, which again implicate temporally varying river network and distance statistics

$$CV = S(t) * CA(t),\ \left[\frac{m^3}{\Delta t}\right]. \tag{17}$$

From a given RN, we can estimate an average saturation $Sm[m]$ using the mean annual discharge (MAD) and an estimated celerity (see the method developed in Skaugen and Mengistu, 2016). The CV, the "sufficient volume of water to generate a channel" is an unknown.

$$CV = Sm * CA_{Sm},\ \left[\frac{m^3}{\Delta t}\right]. \tag{18}$$

For calibrated models we find that Sm is a constant, and hence independent of CA. Since we have stated above that CV also is a constant and a catchment characteristic. Eq. (18) then implies that CA_{Sm} is a constant. What we are searching for is a mean CA, CA_m, which, of

course, implies a mean RN. G. Botter and N. Durighetto of the University of Padua claim that the mean CA, CA_m appears for the mean runoff (personal communication, 2024).
In Skaugen et al. (2023) a regularity between $\bar{d}$ and CA was observed for the various catchments, and the following relationship is proposed:

$$\bar{d} = a * CA^{0.5} \tag{19}$$

Where a is a constant and appears to be unique for each catchment and is probably related to the shape and the terrain features of the catchment.

If we combine eqs. 17 and 19, we get $\bar{d}(t)$ expressed as a function of saturation S(t).

$$\bar{d}(t) = aCA(t)^{0.5} = a(\frac{CV}{S(t)})^{0.5} \tag{20}$$

And including eq. 18 gives us $dm(t)$ expressed from known quantities

$$\bar{d}(t) = a(CA_{Sm})^{0.5}(\frac{Sm}{S(t)})^{0.5} \tag{21}$$

We note that see that for $S(t)$ equal to Sm, eq. (21) becomes eq. (19). Furthermore, the right hand side of eq. 21 consists of constants except for $S(t)$, so the mean distance $\bar{d}$ for a particular saturation dependent distance distribution relates to saturation according to $S(t)^{-0.5}$. We continue the search for the mean of the mean distributions, $E(\bar{d})$, but we cannot derive the mean of $\bar{d}$ by replacing $S(t)$ by Sm into eq. 21. Such an approach would be fine if $\bar{d}$ and S are linearly related, but not otherwise. To calculate the mean of $\bar{d}$, we must include the density function of S in the integration. We assume S being exponentially distributed (recall estimation of M as the 99'th quantile of the exponentially distributed S, Skaugen and Mengistu (2016)), with density function:

$$f(S) = \frac{1}{Sm}e^{-S/Sm} \text{ for } S > 0, \text{where } Sm = E(S) \tag{22}$$

Then by eq. (21)

$$E(\bar{\boldsymbol{d}}) = \int_0^\infty aCA_{Sm}{}^{0.5}S_m^{0.5}\frac{1}{S^{0.5}}f(S)dS\,, \tag{23}$$

So

$$E(\bar{\boldsymbol{d}}) = \int_0^\infty aCA_{Sm}{}^{0.5}S_m^{0.5}\frac{1}{S^{0.5}}\frac{1}{S_m}e^{-S/S_m}dS\,, \tag{24}$$

and rearranging:

$$E(\bar{\boldsymbol{d}}) = aCA_{Sm}{}^{0.5}S_m^{-0.5}\int_0^\infty \frac{1}{S^{0.5}}e^{-S/S_m}dS. \tag{25}$$

With the change of variables in the integral: $t = S/S_m$, and recall that $dS = S_m dt$, we get:

$$E(\bar{\boldsymbol{d}}) = aCA_{Sm}{}^{0.5}S_m^{0.5}S_m{}^{-0.5}\int_0^\infty t^{-0.5}\,e^{-t}dt \tag{26}$$

Where the integral is the Gamma function: $\Gamma(0.5)$, which gives:

$$E(\overline{\boldsymbol{d}}) = aCA_{Sm}{}^{0.5}\Gamma(0.5) \tag{27}$$

And since $\Gamma(0.5) = 1.77$, the mean of the variable $\overline{\boldsymbol{d}}(t)$, being a function to the power of -0.5 of the exponentially distributed $S(t)$, is 1.77 times the relationship you get when estimating $\bar{d}$ from eq. 21 using the mean saturation, S_m. Again, the lesson here is that you will not have the mean $\bar{d}$ for the mean S.

Since the point of this subsection was to estimate the DDs of impermeable areas, the above may seem only loosely relevant. However, if we consider that the distance distribution for impermeable areas is the same as that we assume for saturated conditions S_{sat} (equal to M in the DDD model), Eq. 21 can aid us to derive an expression for the DDs for saturated conditions. Since for *average* conditions, $S(t) = S_m$, eq. 21 yields that

$$\bar{d} = a(CA_{Sm})^{0.5} \tag{28}$$

for *saturated* conditions, when $S(t) = M$, eq 21 yields

$$\bar{d}_{sat} = a(CA_{Sm})^{0.5}(\frac{Sm}{M})^{0.5} = \bar{d}(\frac{Sm}{M})^{0.5} \tag{29}$$

Where Sm is already estimated from the procedure described in Skaugen and Mengistu, (2016), also see Appendix B.

The GIS maptool

The architecture (Fig. 8) of the maptool HydSim is designed by I. Peerebom and Z. Mengistu at NVE and partly based on the NEVINA (address NEVINA) platform.

Current architecture HydSimOveralt

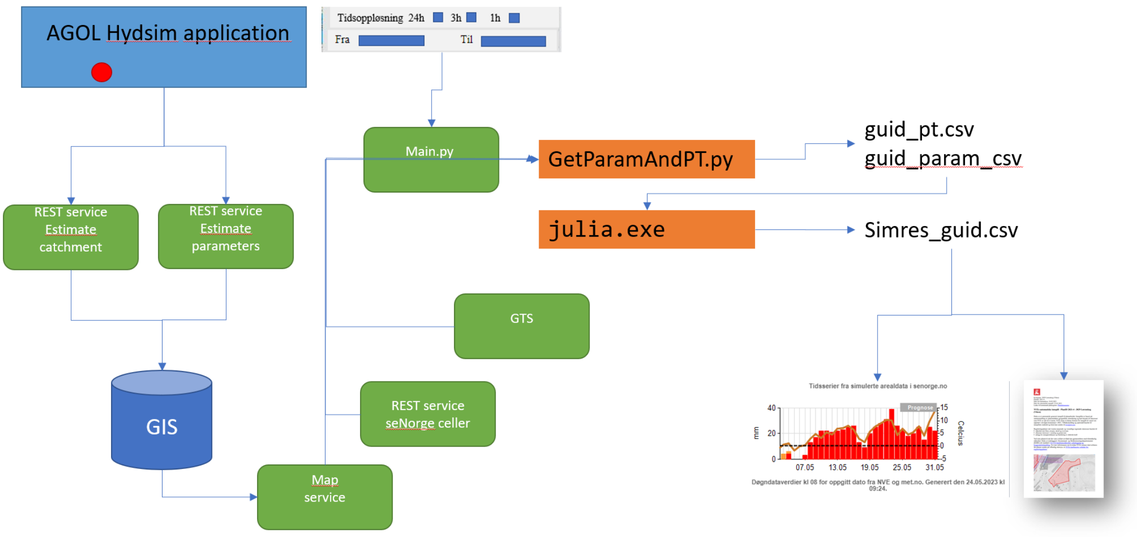


Figure 8. Architecture of the map tool HydSim and of running the DDD model (HydSimOveralt)

The maptool is accessed by opening the HydsimOveralt website (address: HydsimOveralt) and click on the link or the button on the bottom of the page.

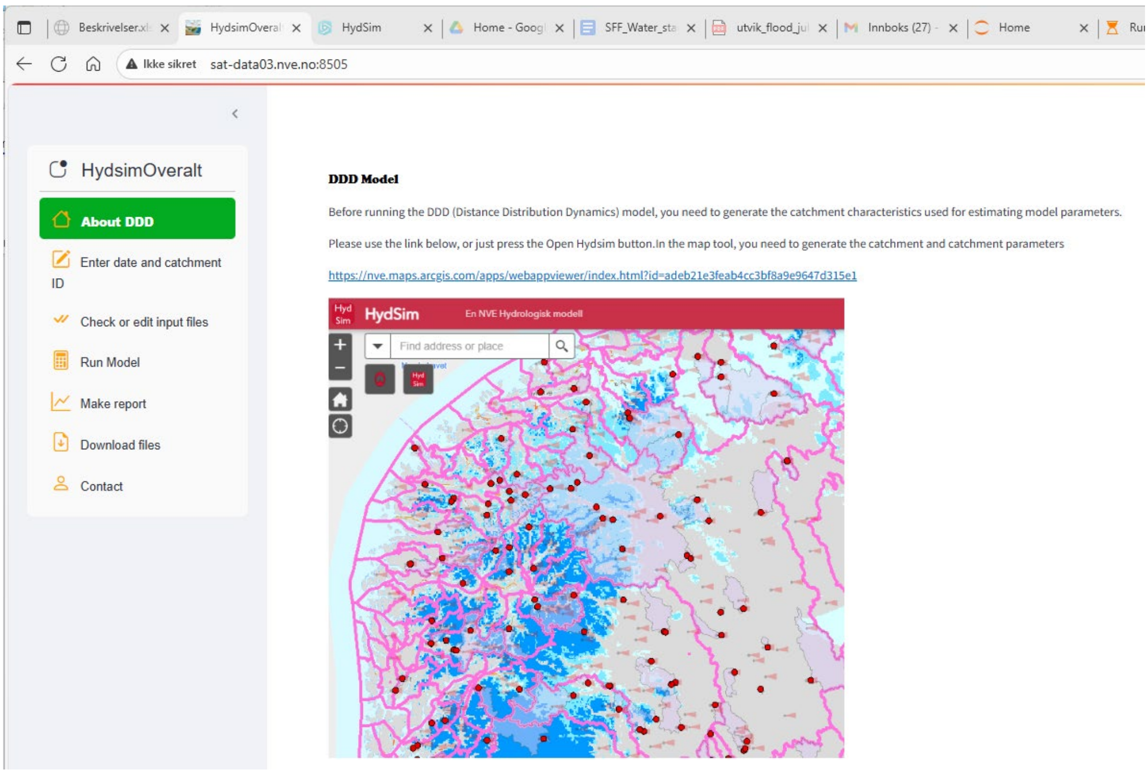


Figure 9. The opening page of the website HydSimOveralt shows the link for accessing the maptool HydSim.

Once inside the maptool HydSim, you can turn on and off different map layers

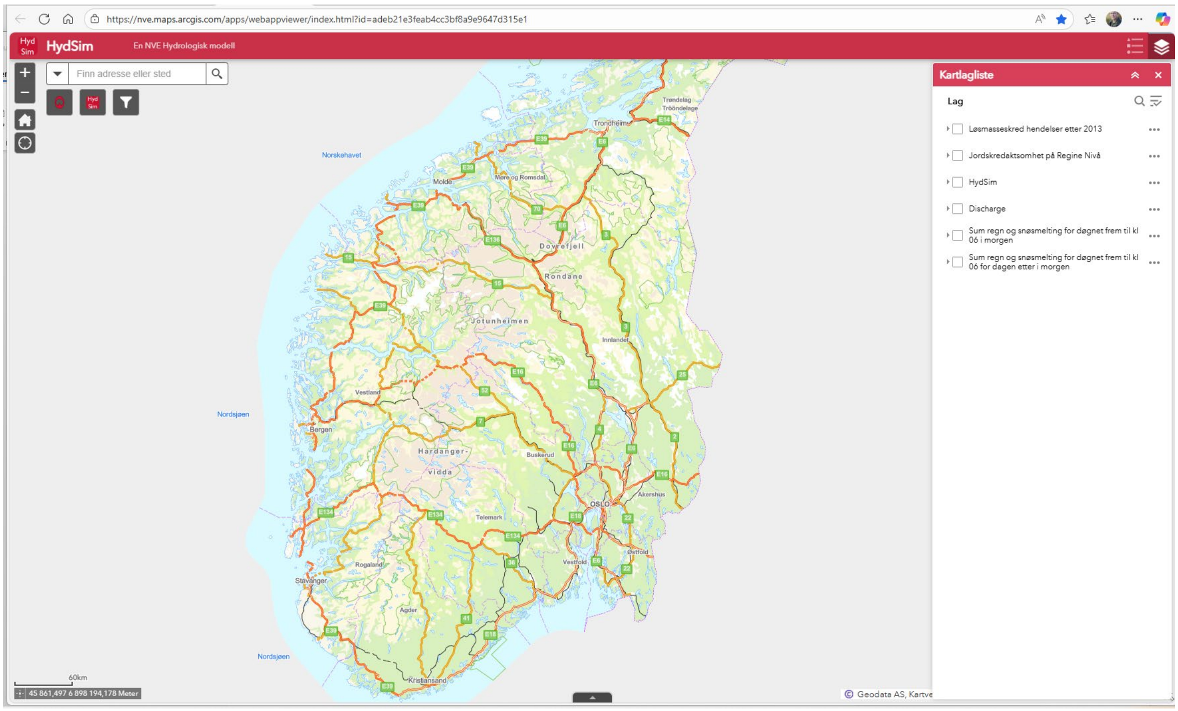
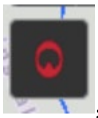


Figure10. Map layers in HydSim

When you are going to run the HSO system for a new catchment, zoom in to the desired Location of the outlet (it needs to be in a river reach) and click the left of the horizontally arranged buttons

,

then click "Kjør".

Figure 11. Push "Kjør" after the outlet is marked

The tool now delineates the catchment upstream from the point that is marked and assigns a unique ID to the catchment. When successful and finished, this will appear:

Figure 12 HydSim is finished delineating the catchment and has assigned a unique ID to the catchment.

The next step is to extract catchment and climate characteristics particular to the chosen catchment needed to estimate DDD model parameters at a later stage. Click the next of the horizontally arranged buttons,

copy the GUID and paste into the appropriate field and click "Kjør".

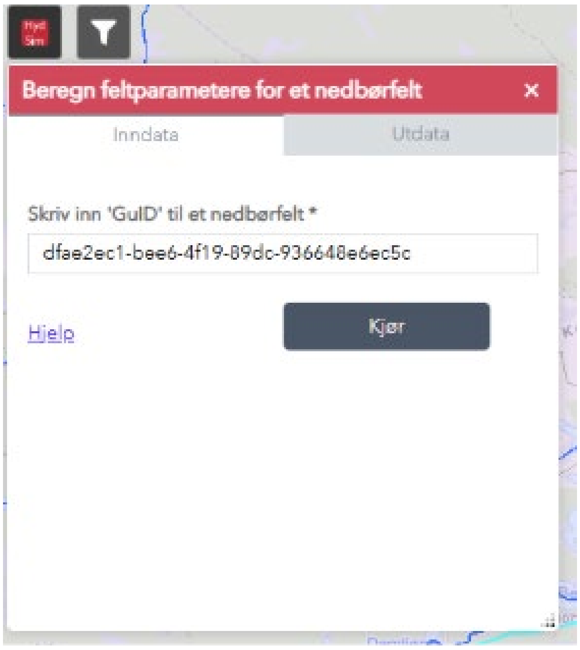


Figure 13. Activating "Kjør" will extract catchments and climate characteristics used for estimating DDD model parameter for this particular catchment.

If extracting the catchment- and climate characteristics was successful, a box with all the relevant catchment characteristics and will appear when you click in the map at the catchment (note that the map layer HydSim must be turned on).

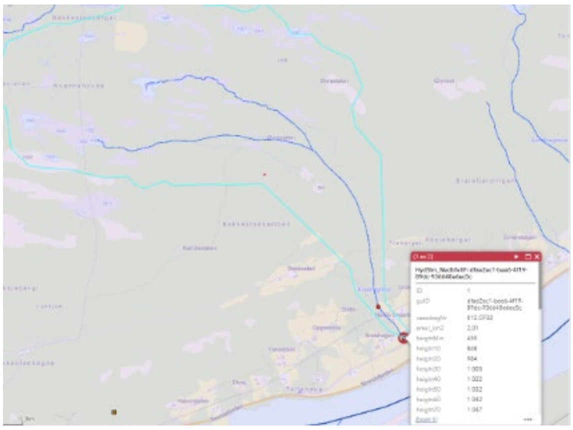
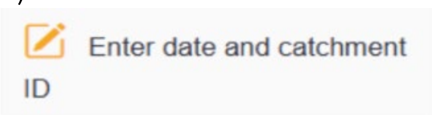


Figure 14. This is how a successful execution of the maptool, HydSim looks like

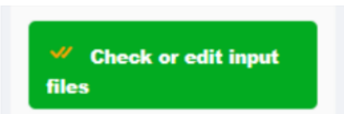
2.3 The Web application of HSO - running the DDD model-

The GUID is the identifier to the database where all relevant information about the catchment is stored. With the copy of the GUID you can go to the "HydSimOveralt" (see Fig. 9) and click



Paste in the GUID, choose the temporal resolution and for which period you will want to run the model. For 24 hrs, 3hrs and 1hrs the model can run for timeseries 1.9.1958-dd,1.9.1972-dd and 1.9.2013-dd, respectively. When you enter "Submit", a parameter file for the DDD model and an input file (PTQ file) with time series of temperature, precipitation and runoff will be created. The times series of runoff are just -9999 values.

There is an opportunity to edit the parameter- and the input meteorological file in the HSO. It may, for example, be necessary to manipulate the subsurface celerity (MRT- mean response time) or the precipitation correction (pkorr). Manipulating the MRT changes the recession (quicker or slower) and low flows and floods. Precipitation correction may be useful if you know that too little/too much water is simulated. You push this button in HydsimOveralt



,

and the following window appears

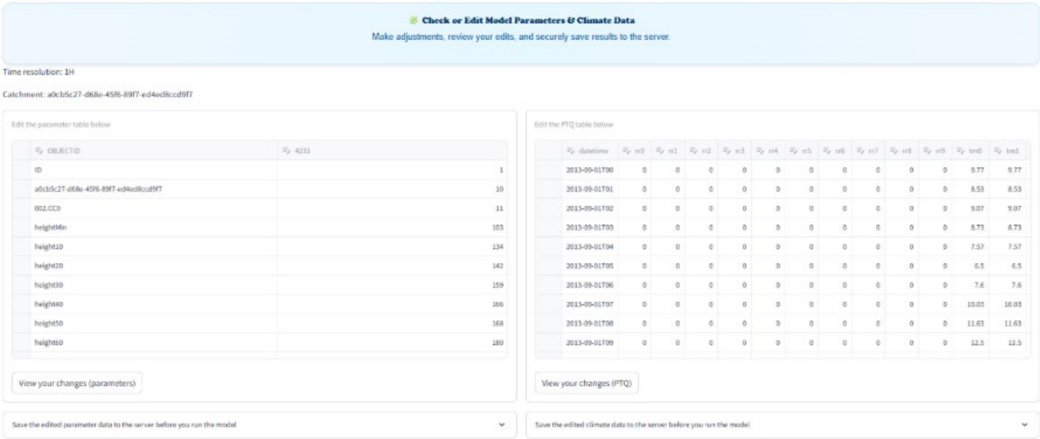


Figure 15. The edit window is of the parameter file and the input file (PTQ)

Do your alterations in the parameter file (left) or the input file (PTQ file) (right) and enter “View your changes” and be certain that your edits are saved by enter the “save” button at the bottom. Your edits will not be stored in the database, but if you download the parameter- or input file, the edits are included.

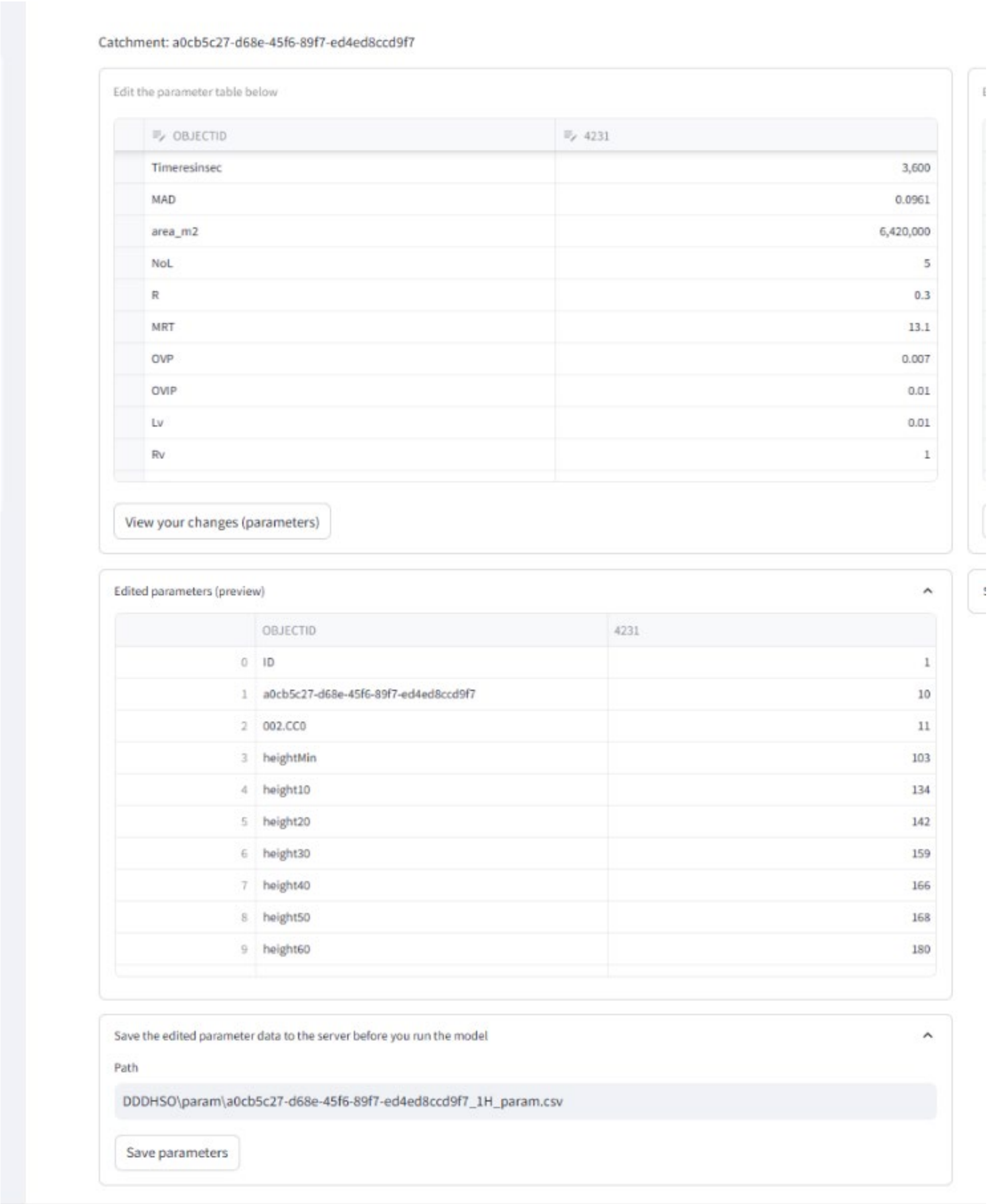
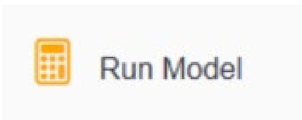
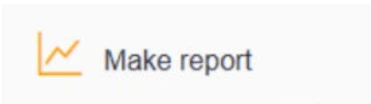


Figure 16. Note the "save button at the bottom of the figure

The next button



runs the model. When the model is finished, the next button



will produce plots of various hydrological parameters, including runoff, precipitation and temperature for the forecast period and a period preceding the forecast period.

Model Result

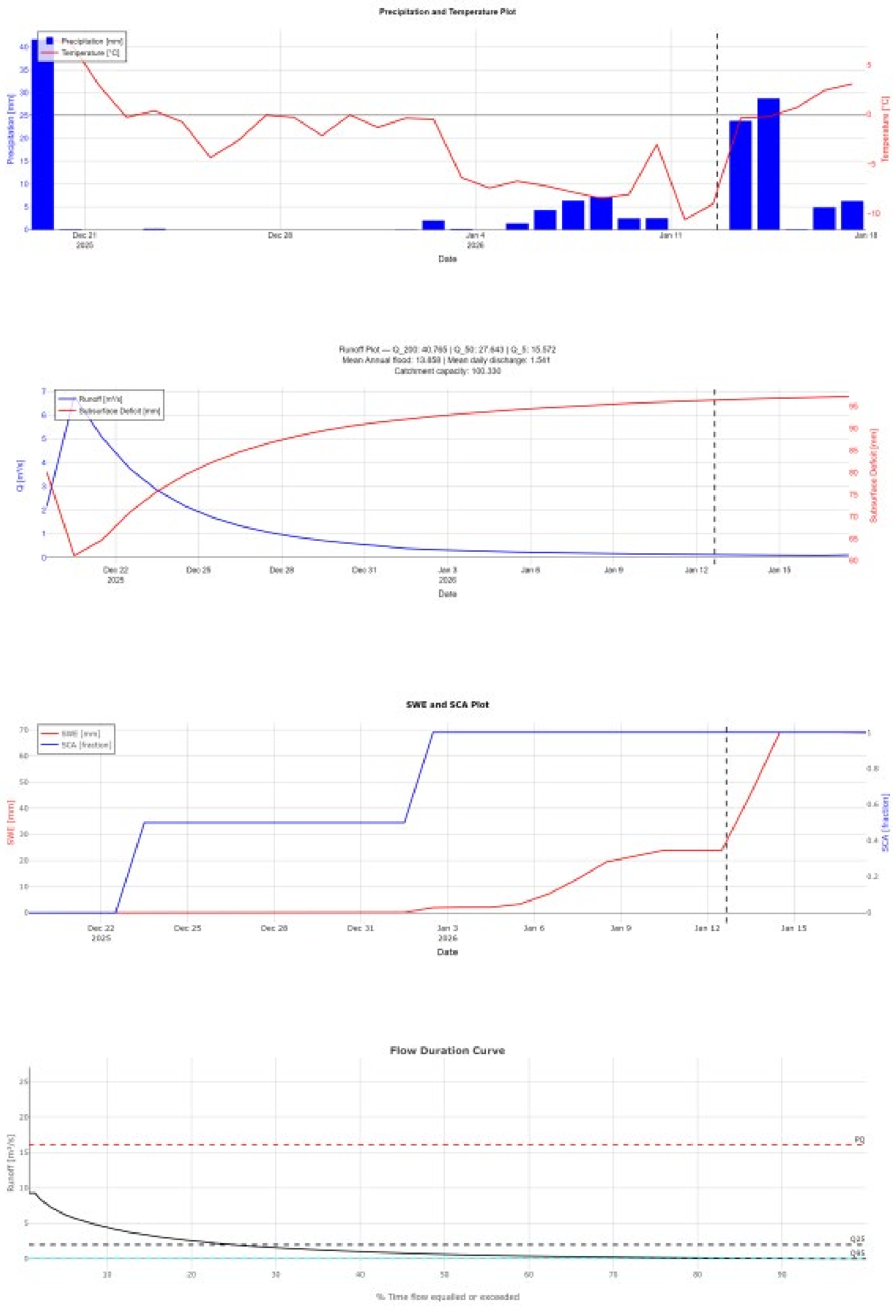
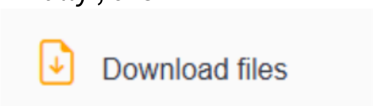


Figure 17. Simulation results of the DDD model. Note that these plots are primarily for flood forecasting purposes. If the forecasting period is not included, the appearance of the plots may be strange.

Finally , the



button allows you to download relevant files:

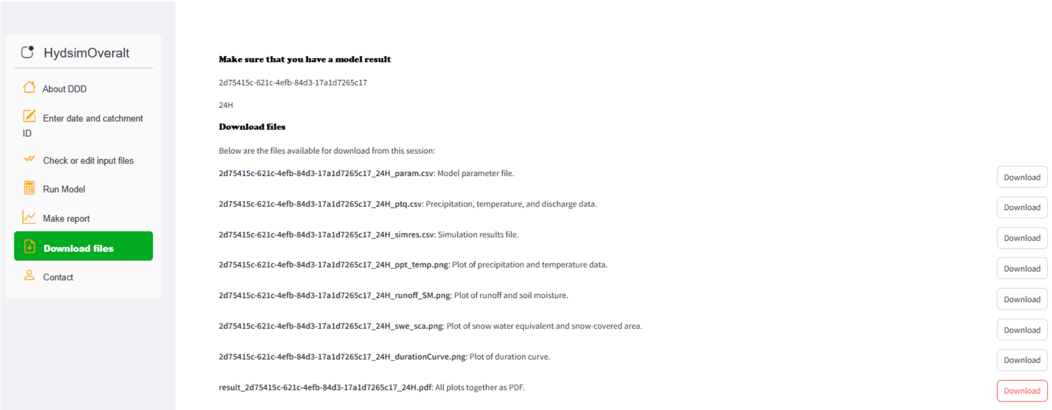


Figure 18. From here you can download the files you need for further analysis.

3 Applications of HSO

Although initially thought of as a tool for flood forecasting at ungauged sites, the HSO system has already been tested for several different applications. The system can, in principle, provide very detailed, although potentially uncertain, hydrological information for anywhere in Norway. There are limitations with respect to catchment size which is limited by some elements of the GIS used and the spatial resolution of the meteorological grid (1X1 km^2). Below are briefly described some of the applications so far of HSO.

3.1 Flood forecasting

The HSO system was initially developed to support flood forecasting. Its primary objective was to enable rapid model setup at locations with particularly vulnerable infrastructure or where intense precipitation was forecasted. By running the model over an extended time series, extreme values can be estimated and compared to the forecasted runoff.
It is of great importance that the HSO system is easy to set up, allowing the flood forecasters on duty to quickly conduct analyses while actively evaluating flood risk. Such analysis may include the delineation of flood hazard areas, assessing the severity of an event and investigating how the form of the forecasted precipitation (solid/liquid) influences the forecasted runoff. As shown in Figure 19. the simulated runoff from the HSO system agrees well with the observed values during the extreme "Hans" event in southern Norway in August 2023.

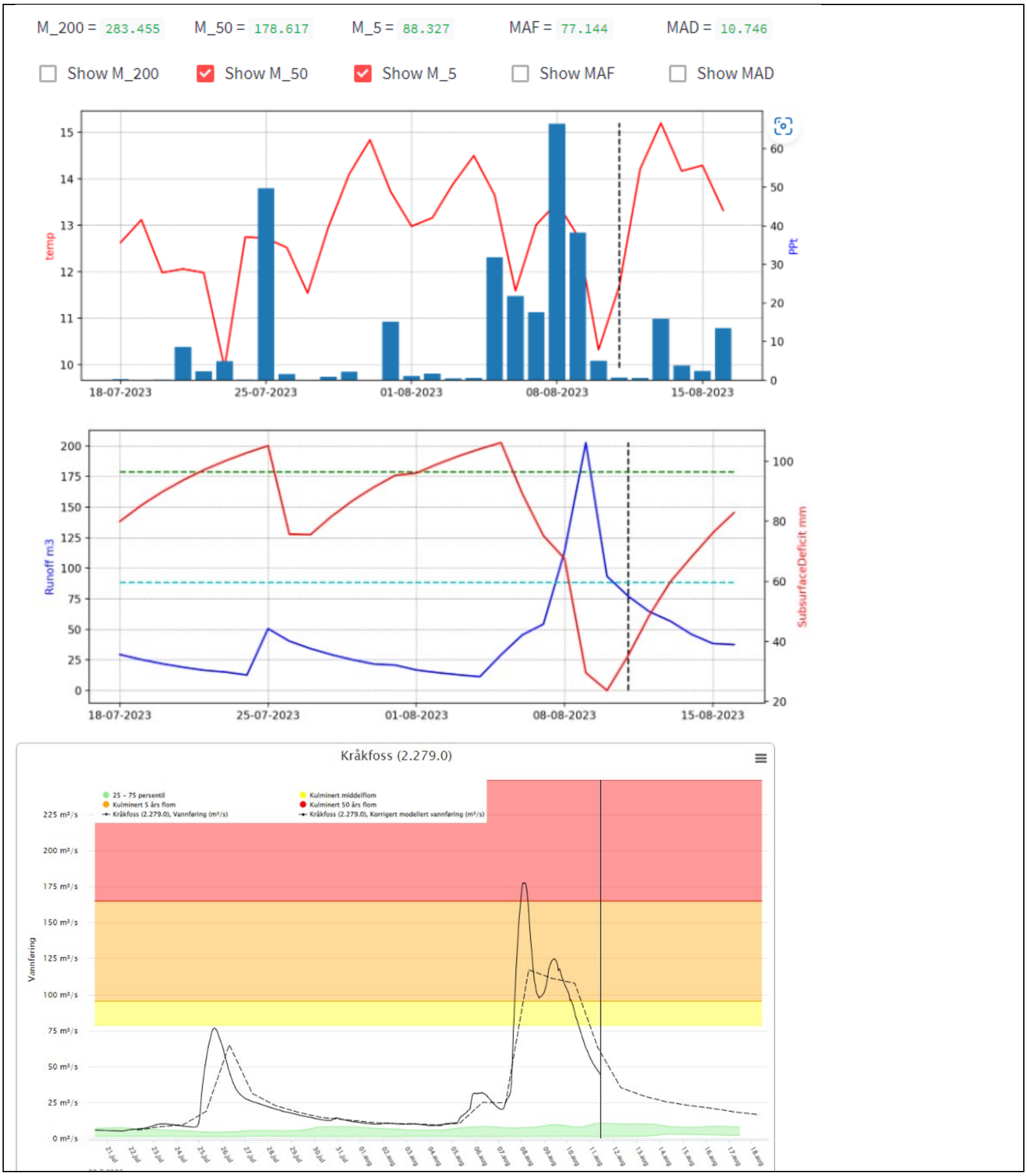


Figure 19. Plots of HSO results for the period around the extreme weather "Hans" in beginning av august 2023. Top panel: observed precipitation and temperature at the time. Middle panel: simulated runoff (blue line) during the extreme "Hans" event in August 2023, where the simulated runoff surpasses the estimated 50-year flood level. Bottom panel: demonstrates that the observed runoff (solid line) also exceeds the 50-year return level (highlighted in red). The dashed line represents the HBV simulation of the NVE's Flood Forecasting service. Note also that the estimated 50 year flood estimated with HSO (178.6 m^3/s) agrees well with that estimated from observed data (165.0 m^3/s)

3.2 Low flow estimation

There is a need for low flow estimates in Norwegian rivers in order to secure the environmental minimum flow critical for aquatic ecosystems. NVE has for many years provided the web service NEVINA which is a map-based tool where the public can obtain such estimates for anywhere in Norway. In the internal project “Indekser for lavannføring”, the objective is to exploit new methods and more and better data to provide an improved NEVINA. The HSO system has been tested as a new method. For 157 gauged catchments the HSO systems has been applied and the low flow indices derived from the simulated time series. Figure 20 shows the mean annual minima over 7 days for the summer season (MAM7-summer) estimated and observed on a regular scale and on a log scale for the 157 catchments. Although regression methods are more accurate than the DDD-HSO system, the latter provides reasonable estimates and in addition, gives the hydrological states such as groundwater, snow and the corresponding meteo-hydrological history.

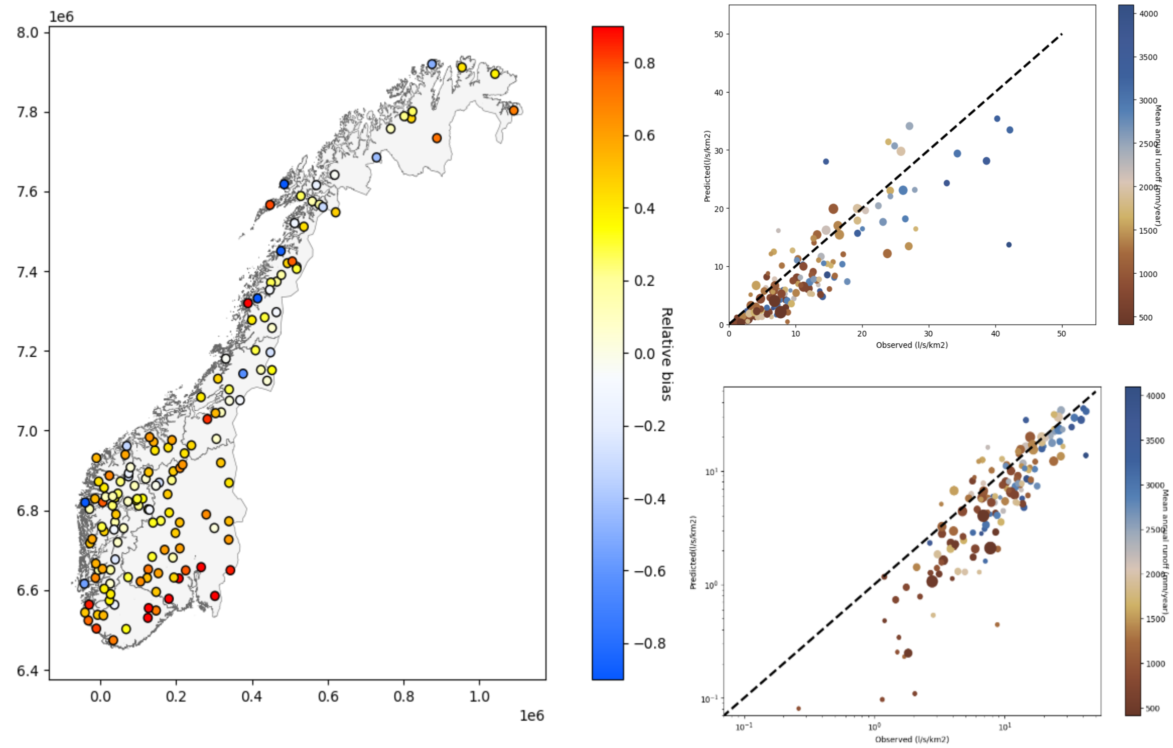


Figure 20. Comparison between HSO estimates measured values for 157 gauging stations in Norway(left panel). The deviations are shown on both a regular(top righ panel) and a logarithmic scale(bottom left panel) Figure by Kolbjørn Engeland, NVE.

3.3 Flood estimation in ungauged catchments

In the Water4All project ECCO, and the internal project PMFlom, the intention is to develop tools for the estimation of floods in gauged and ungauged catchments. ECCO has an emphasis on urban catchments which are often small (< 1km^2) and where the temporal resolution is high (minutes), whereas PMFlom focusses on natural, larger catchments (> 1 km^2) and lower temporal resolutions (hours). The method developed for these projects involve setting up the DDD model for the catchment in question using the HSO system and run the model for the time series available in the desired temporal resolution. The simulated times series of soil moisture from the DDD model is then used to condition an event model, DDDEvent, which also "inherits" most of its model parameters from the DDD model. For each specified extreme value of precipitation, the DDDEvent draws a value of soil moisture state and simulates peak flow. This is repeated many times giving a distribution of runoff conditioned on extreme precipitation. When this is carried out for many precipitation values, a distribution of precipitation conditioned on runoff is developed. Using Bayes theorem, an estimate of runoff with exceedance probability matching that of the precipitation value can be estimated. The HSO system is, of course, instrumental for performing this procedure for ungauged catchments, providing model parameters and time series of input data and simulated hydrological data. The system is, however, also a very practical tool for obtaining input data (precipitation and temperature) at different temporal resolutions for any catchment in Norway, along with DDD model parameter files, which may serve as a starting point for more detailed calibration. In Figure 21 we see flood estimates by various methods for the catchment 148. Mevatnet. We can note that the flood estimates based on HSO (green line) are actually better than those obtained with a calibrated DDD model (blue line).

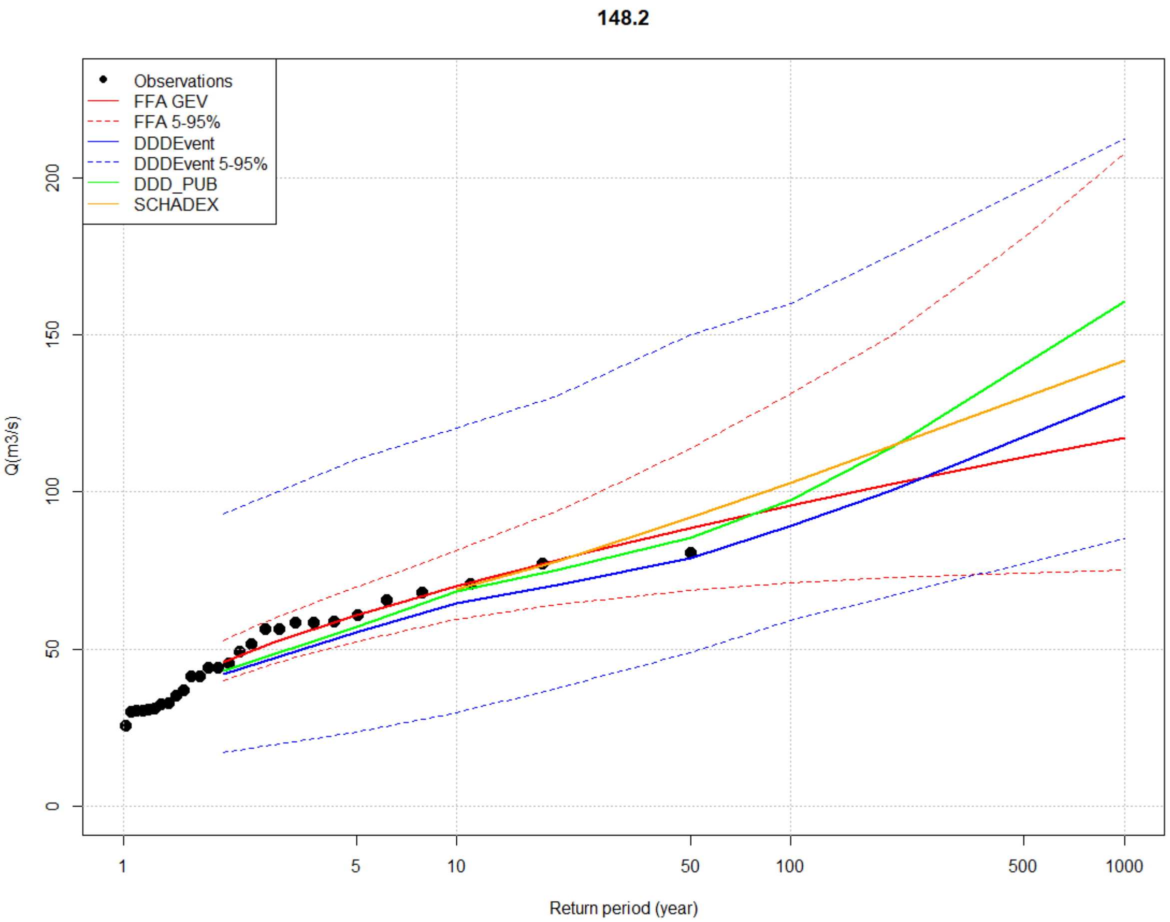


Figure 21. Flood estimates by various methods investigated in the ECCO project. Flood estimates based on HSO (DDD_PUB) is, for this particular catchment, 148.2 Mevatnet, better than those using a calibrated version of DDD (DDDEvent).

3.4 Searching for hydrological signatures of landslides (the HYMOJOFLO-project)

Heavy rainfall and/or snowmelt is known to be the main triggering factor of shallow landslides (i.e. debris avalanches and debris flows) in Norway. In addition, it is well recognized that high subsurface saturation is another important player in the initiation and preconditioning of landslides (Mirus et al, 2024). Given the obvious and intuitive hydrological nature of the triggering and preconditioning of landslides, HSO poses as an potential tool for explaining why and when landslides occur. Since landslides seldom occur in gauged catchments with calibrated hydrological models, we can use HSO, to simulate hydrology at the site and time of registered landslide events. We simulate hydrological timeseries at 1h temporal resolution from 2013-dd and extract a suite of hydrological variables such as water in the saturated and unsaturated zone, snow variables and flood values together with runoff and, of course, precipitation and temperature. Preliminary results from HYMOJOFLO indicate that subsurface saturation, aggregated precipitation and the rate of change of the subsurface filling and of runoff are important players in the preconditioning and triggering of shallow landslides. This is an ongoing project, and more landslides are being investigated and we intend to test different indexes based on the above identified important variables to see which best indicate and forecast shallow landslides.

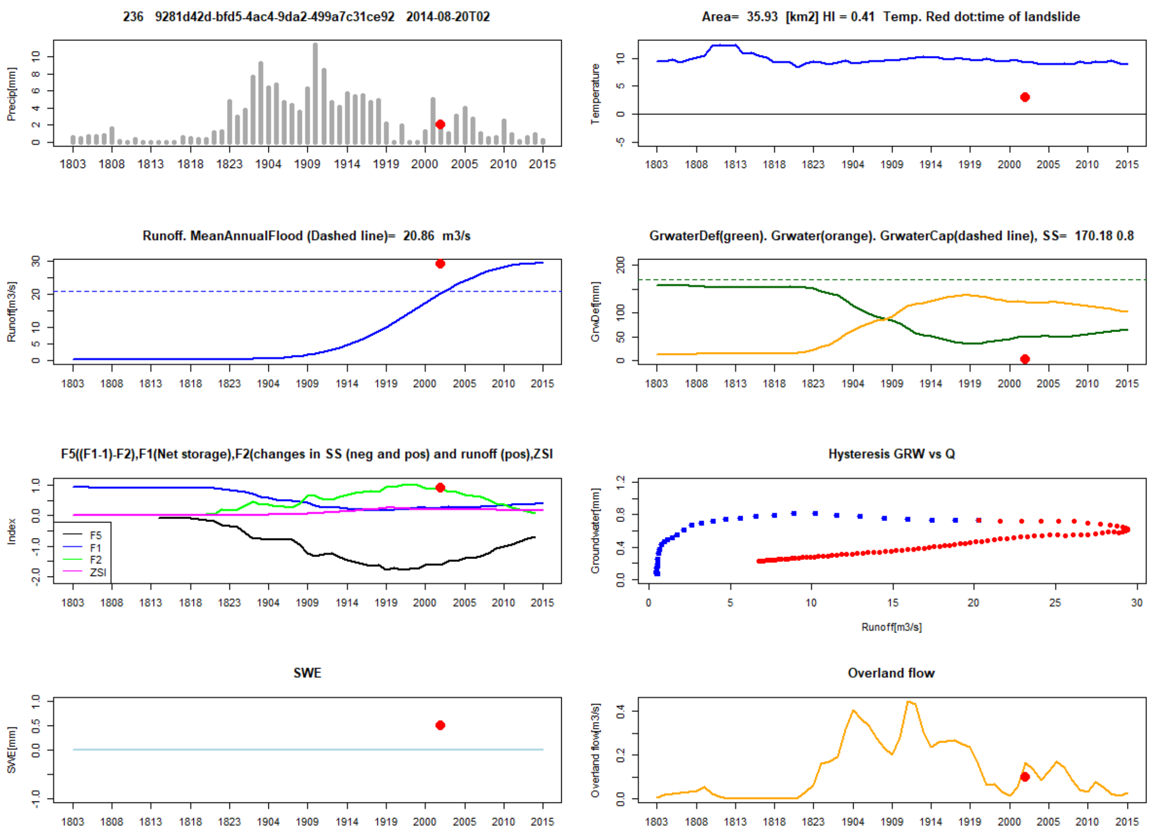


Figure 22. Hydrological parameters simulated by the HSO system for a landslide occurring 30.08.2014. The red dot signifies the time of the landslide as registered by the national landslide database at NVE: The third panel at the right hand side from the top shows a set of possible indices that has the potential to indicate the triggering of landslide. Notably, for this particular landslide, is the difference in timing between the filling up of the subsurface with the increase in runoff shown in the third panel from the top at the left hand side.

4 Current Status and Future Development of the HSO System

4.1 Prototype Status and Testing

The HSO system is currently a prototype designed for internal use within NVE. It has undergone testing by several colleagues at NVE and by master's students to identify its weaknesses, potential areas for improvement, and general usability. As with most expert systems, effective operation of the HSO system requires hands-on practice, accumulated experience, an understanding of the system and knowledge of hydrological rainfall runoff models. These skills are especially important in the context of flood forecasting, where time constraints mean that operational experience and troubleshooting skills are essential.

4.2 Technical Robustness and Operational Challenges

At present, the robustness of the HSO system is limited. The map tool component contains bugs, and the model itself runs on a server that is not actively supervised, which occasionally necessitates a manual restart. However, it is believed that with some dedicated effort, the map tool can be made more stable and reliable. Furthermore, transferring the model to a supervised server would enable continuous operation of the Python scripts, thereby improving overall system reliability.

4.3 Requirements for Urban Application

In order to make the HSO system effective for urban hydrological applications, further development of the map tool is required. Specifically, it should be enhanced to estimate the proportions of impermeable surfaces (roofs and roads) and permeable areas, which (excluding wetlands) would be the remainder of the area. Additionally, improvements in the spatial resolution of the digital terrain model (DTM) and river networks is necessary to adequately resolve smaller, urban catchments of less than 1 km^2. Evidently, over time, it will also be important to ensure that the system can accept model input—such as precipitation and temperature—at a temporal resolution suitable for small urban catchments (< 1hr).

4.4 Prospects for Improvement and Parameter Estimation

The system is expected to improve further as both the model structure and the quality of input data will improve. Artificial intelligence offers a potential for enhancing the estimation of model parameters, which are currently determined by multiple linear regression. Moreover, a re-estimation of these parameters is necessary, as several years have passed since the last update and additional data have since become available.

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Appendix A

The parameter file

The parameter file is a *.csv file. The following shows the parameter file with comments and a suggestion on how to estimate.

Name	Value	What	How to estimate
ObjectID	56.1	Any number for value will do	
ID	1	Any number for value will do	
56.1	1	Any number for value will do	
56.1	1	Any number for value will do	
a00	37	Hypsografic curve, minimum [m]	GIS
a01	50	Hypsografic curve, lower 10% [m]	GIS
a02	51	Hypsografic curve, lower 20% [m]	GIS
a03	53	Hypsografic curve, lower 30% [m]	GIS
a04	54	Hypsografic curve, lower 40% [m]	GIS
a05	55	Hypsografic curve, lower 50% [m]	GIS
a06	56	Hypsografic curve, lower 60% [m]	GIS
a07	57	Hypsografic curve, lower 70% [m]	GIS
a08	58	Hypsografic curve, lower 80% [m]	GIS
a09	61	Hypsografic curve, lower 90% [m]	GIS
a10	67	Hypsografic curve, maksimum [m]	GIS
lat	60.2931	Latitude, middle point catchment	GIS
lon	5.28004	Longitude, middlepoint catchment	GIS
pkorr	0.7	Correction of precip. [-]	Used in HSO as that estimated by Sjur Kolberg from the discrepancy between estimated precipitation, runoff and evapotranspiration
skorr	0.7	Correction of precip. as snow [-]	MRE
u	2.84	Average wind speed [m/s]	Fixed/calibrate
pro	0.05	Fraction possible liquid water content in snow [-]	Fixed/calibrate
TX	0.425	Threshold temperature rain/snow [°C]	Fixed/calibrate
a0P	38.33	Snow distribution parameter, see Skaugen Weltzien (2016) [-]	Calibrate/literature/measure
aoIP	38.33	Snow distribution parameter, see Skaugen Weltzien (2016) [-]	Calibrate/literature/measure
dP	505.7	Snow distribution parameter, see Skaugen Weltzien (2016) [-]	Calibrate/literature/measure
dIP	505.7	Snow distribution parameter, see Skaugen Weltzien (2016) [-]	Calibrate/literature/measure
Timeresinsec	300	Timeresolution in seconds [s]	
MAD	0.0035	Annual mean discharge [m^3/s]	Measure/Calibrate
area	61000	Area in [m^2]	GIS
NoL	5	No of layers , 1 overland lag and 4 subsurface layer [-]	Fixed
R	0.3	Field cap., degree of saturation before percolation to saturated zone [-]	Fixed

GshInt	1	Shape par. for dist. of recession charact.: for subsurface and overland fl.velocities [-]	Fixed
GscInt	0.0019	Shape par. for dist. of recession charact.: for subsurface and overland fl.velocities [-]	Calibrate
OFVP	-999	Overland flow celerity [m/s] peremable areas	Estimated within the model as 2*k[1,1]. k[1,1:5] is the vector of celerities for the saturation layers
OFVIP	-999	Overland flow celerity [m/s] impermable areas	Estimated within the model as 2*k[2,1]. k[2,1:5] is the vector of celerities for the saturation layers
Lv	0.01	Water celerity in lake [m/s]	Calibrate
rv	1.45	Water celerity in river network [m/s]	Measure/Calibrate
Pfrac	0.81	Fraction permeable areas [-]	GIS
IPfrac	0.19	Fraction impermeable areas [-]	GIS
Bogfrac	0	Fraction wetlands [-]	GIS
Elakefrac	0	Fraction effective lake [-]	GIS
Glacfrac	0	Fraction glacier [-]	GIS
maxP	149	Max distance permable areas [m]	GIS
maxIP	98	Max distance impermable areas [m]	GIS
maxBog	0	Max distance wetlands [m]	GIS
maxGl	0	Max distance glaciers [m]	GIS
maxRN	929	Max distance in rivernetwork [m]	GIS
midP	39.33	Mean distance permable areas [m]	GIS
midIP	27.9	Mean distance impermable areas [m]	GIS
midBog	20	Mean distance wetlands [m]	GIS
midGl	0	Mean distance glaciers [m]	GIS
midRN	436	Mean distance in rivernetwork [m]	GIS
stdGl	0	Standard deviation distance glaciers [m]	GIS
stdRN	274.8	Standard deviation distance in rivernetwork [m]	GIS
Pz	0.085	Areafraction of 0 m distance to rivernetwork, permeable area [-]	GIS
IPz	0.08	Areafraction of 0 m distance to rivernetwork, impermeable area [-]	GIS
zBog	0	Areafraction of 0 m distance to rivernetwork, wetlands [-]	GIS
g1	0	Fraction glacier in 1'st elev.zone [-]	GIS
g2	0	Fraction glacier in elev. zone 2 [-]	GIS
g3	0	Fraction glacier in elev. zone 3 [-]	GIS
g4	0	Fraction glacier in elev. zone 4 [-]	GIS
g5	0	Fraction glacier in elev. zone 5 [-]	GIS
g6	0	Fraction glacier in elev. zone 6 [-]	GIS
g7	0	Fraction glacier in elev. zone 7 [-]	GIS
g8	0	Fraction glacier in elev. zone 8 [-]	GIS
g9	0	Fraction glacier in elev. zone 9 [-]	GIS
g10	0	Fraction glacier in elev. zone 10 [-]	GIS
meandailyP	7.8	Mean daily precipittaion [mm]	Measure/estimate
meandailyT	5.5	Mean daily temperature [°C]	Measure/estimate
Snfjellfrac	0	Fraction of bare rock	GIS

Persons	0	Number of persons with water use [180 L/day/person] , external water	Measure/estimate
ICapP	100	Infiltration capacity [mm/hour], permeable areas	Measure/estimate
ICapIP	1	Infiltration capacity [mm/hour], impermeable areas	Measure/estimate
PCritflux	2.78	Crit. flux for creating a channel [m3/Timeresinsec], Tsegaw et al., 2019, P area	Fixed/calibrate
IPCritflux	1.5	Crit. flux for creating a channel [m3/Timeresinsec], Tsegaw et al., 2019, IP area	Fixed/calibrate

Appendix B

DD parameter in Julia code

```
#GshInt,GscInt,Timeresinsec,maxDl,midDL, MAD, area2, NoL, gtcel)

using Distributions
include("\\\\nve.no\\fil\\h\\HB\\HB-
modellering\\DDDtestbenk\\DDD_Julia\\DDDFunctions\\SingleUH.jl")
#Input:

# MAD
# Area
# MRT:   mean response times in days
# Timeresinsec: scalar float
# NoL: scalar integer
# Area: scalar float
# gtcel: scalar float

gtcel= 0.99        # quantile for start overland flow, when subsurface reservoir is full!
MRT = 11.0          # [days]
Area = 64920000     # [m2]
Timeresinsec = 10800 # [s]
MAD = 71.092        # [m3/s]
NoL= 5
celerity = 0.0001  # Helt ok
Glacfrac= 0.73
CaL = 92420 # [m] Catchment length NEW catchment characteristic we need to extract from
GIS 14610 er for 16.75

#GshInt = 1.0
#GscInt = 0.00595
```

```
#mLam = GshInt*GscInt = Timeresinsec/(MRT*86400)     # Eq. 6 Skaugen etal HSJ 2023
#varLam = GshInt*(GscInt)^2 = mLam^2                    # Yevjevich p.145
mLam = Timeresinsec/(MRT*86400)                # Eq. 6 Skaugen etal HSJ 2023
varLam = mLam^2                          # Note that GshInt = 1, also see Yevjevich p.145

#Estimating the mean and max distance from MRT with assumed mean celerity = 0.0001 m/s
and average moisture conditions
midD = round(celerity* (MRT*86400),digits=2)# assumes a average celerity of 0.0001 m/s
eksp = Exponential(midD)
maxD=round(quantile(eksp,gtcel),digits=2)
#end distance parameters for averaged conditions permable areas

#Estimating subsurface capacity M according to Skaugen and Mengistu (2016)
meanIntk = midD/(MRT*86400)   #mean celerity
antBox = Int(trunc(maxD/(meanIntk*Timeresinsec)))+1 #Temporal length UH_MAD
UH_MAD = zeros(Float64,antBox)
sRes = zeros(Float64,antBox) # saturation sum

UH_MAD = SingleUH(meanIntk,Timeresinsec, midD, maxD, 0) #Unit hydrograph for MAD

StSt = (1000*MAD*Timeresinsec)/(Area)       # Steady state Input eq. output in mm
sRes[1] = 0
sRes[2:antBox] .= StSt.*UH_MAD[2:antBox]

for i in 3: antBox
  sRes[i:antBox] .= sRes[i:antBox] + StSt.*UH_MAD[i:antBox]
end

mRes = sum(sRes)                    # #mean saturation
Fact = mLam/mRes
stdRes = (varLam/Fact^2)^0.5            # see Haan p.51

GshRes = mRes^2/stdRes^2              # gamma parameters for subsurface storage
GscRes = stdRes^2/mRes

MLev = [1/(NoL-1):1/(NoL-1):1.0;]           # (sequence)Quantiles  to calculate reservoir levels
[0.1:0.1:0.9;]

MLev[NoL-1] = gtcel                # quantile for start overland flow
Res_prob = zeros(Float64,(NoL-1))
Magkap = zeros(Float64,NoL)
g = Gamma(GshRes,GscRes)
#calculates the reservoir levels associated with quantiles. Mean is GshRes*GscRes
Res_prob .= quantile.(g,MLev)

#Capasity of Layers
```

```
ssRes1 = zeros(Float64,NoL)
ssRes1[1] = 2000                    # capacity of overland flow level

for i in 2:(NoL-1)
 ssRes1[i] = Res_prob[NoL-i+1]-Res_prob[(NoL-i)]
end

ssRes1[NoL] = Res_prob[1]               # capasity for the first slowest level

Magkap = ssRes1                     # capasity for Layers
M = Res_prob[(NoL-1)]                  # Total groundwater reservoir

println("Estimation of Saturation parameters")
println("Max saturation-capacity, M= ",round(M, digits=2))
println("Mean saturation, Sm= ",round(mRes,digits =2))

#end subsurface capacity M according to Skaugen and Mengistu (2016) neede for estimating distances for IP and Wetlands

println("DD parameters for Impermeable areas")
#Estimating the mean and max distance impermeable areas using Mfrom MRT with assumed mean celerity = 0.0001 m/s and saturated moisture conditions forimpermeable areas asumed equal to saurated conditions
midDIP = round(midD*(mRes/M)^0.5, digits=2)
ekspIP = Exponential(midDIP)
maxDIP = round(quantile(ekspIP,gtcel),digits=2)
#end distance parameters for saturated conditions, i.e. impermable areas"

println("DD parameters for Rivernetwork")
mRn = CaL/2 -1.0*midD
stdRn= 0.5*mRn
normRn= Normal(mRn, stdRn)
maxRn = round(quantile(normRn,gtcel),digits=2)

println("DD parameters for glaciers")
#We apply the same reasoning as for lakes
Glacarea = Glacfrac*Area
maxGl= round(sqrt(4*Glacarea/pi),digits=2)
midGl= round(maxGl/2,digits =2)
stdGl= round(midGl/2,digits = 2)
println("DD parameters for Wetlands bogs same as for IP")

#same DD parameters as for impermeable areas
println("DD parameters max values")
println("Par#42: maxP= ",maxD)
println("Par#43: maxIP= ",maxDIP)
```

```
println("Par#44: maxBog= ",maxDIP)
println("Par#45: maxGl= ", maxGl)
println("Par#46: maxRn= ", maxRn)
println("DD parameters mean values")
println("Par#47: midP= ",midD)
println("Par#48: midIP= ",midDIP)
println("Par#49: midBog= ",midDIP)
println("Par#50: midGl= ", midGl)
println("Par#51: midRn= ", mRn)
println("DD parameters standard deviations")
println("Par#52:stdGl= ", stdGl)
println("Par#53: stdRn= ", stdRn)
println("DD parameters for zerodistance fractions")
println("Par#54: Pz= 0.01")
println("Par#55: IPz= 0.01")
println("Par#56: zBog= 0.01")
```

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