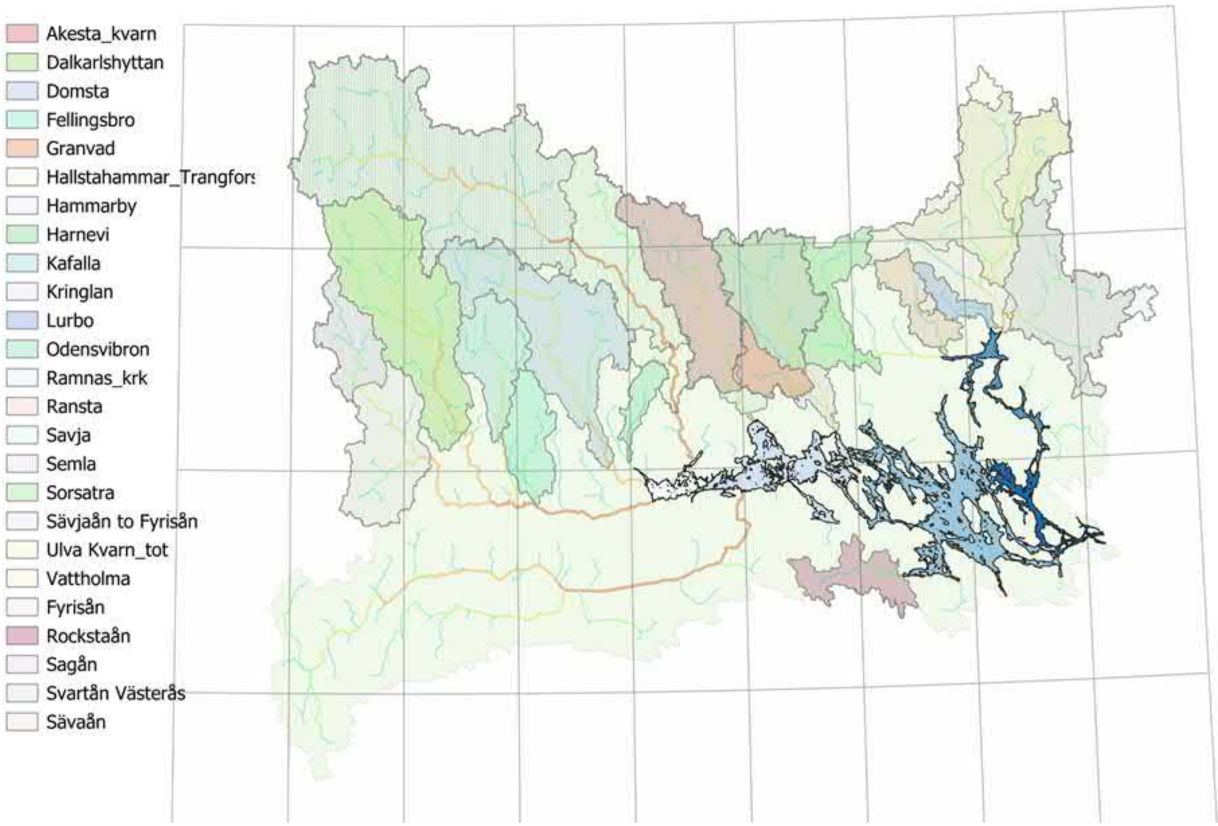
# Calibration of watersheds defined by SMHI stream gauging sites.

The GWLF hydrologic model was calibrated using a multi-step calibration procedure that can be executed from within the Vensim (https://vensim.com/) modeling software that was used to create the GWLF hydrology model. We looked for all SMHI measured discharge data within the Mälaren watershed that had a reasonable overlap with the ISIMIP3a meteorological data (1961-2019) that was used to force the historical simulations. The availability of these data allowed model calibration using objective functions that compared the simulated and measured stream discharge. In total we found 21 stream gauges and their associated watersheds that could be used.

**Figure 1** *Gauged watersheds used for calibration of the GWLF hydrologic model*




Nine model parameters were calibrated which influenced the overall water balance, the seasonality of stream flow, and the inputs of surface and sub-surface flow to the streams. The results of the calibrations are shown below.

**Table 1** *Calibrated model parameters Shaded blue are at maximum or minimum of allowed range of variation*

| Calibrated Parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Major Basin | Guage Basin | | | | | | | | | | | |
| Major Basin | Gauge Name | Area (km2) | Area (km2) | SWC | DeepGWC | precipCor | MeltCoeff | RecessCoeff | SlowRecess | UnsatLeakC | ChannelCoeff | CNAdj | NSE | KGE |
| Arbogaan | Dalkarlshytta | 3805.9 | 1183.8 | 6.851 | 3.035 | 0.943 | 0.327 | 0.016 | 0.001 | 0.001 | 0.062 | 15.21 | 0.635 | 0.750 |
| Arbogaan | Kafalla | 3805.9 | 394.3 | 8.417 | 3.050 | 0.973 | 0.276 | 0.014 | 0.010 | 0.001 | 0.095 | 13.35 | 0.683 | 0.718 |
| Arbogaan | Hammarby | 3805.9 | 890.7 | 9.251 | 3.995 | 0.939 | 0.230 | 0.023 | 0.014 | 0.001 | 0.057 | 14.82 | 0.662 | 0.802 |
| Arbogaan | Kringlan | 3805.9 | 294.9 | 6.949 | 3.864 | 0.882 | 0.305 | 0.023 | 0.012 | 0.005 | 0.073 | 17.38 | 0.706 | 0.775 |
| Arbogaan | Fellingsbro | 3805.9 | 299.0 | 14.196 | 2.895 | 0.902 | 0.370 | 0.020 | 0.010 | 0.010 | 0.099 | 10.23 | 0.690 | 0.788 |
| | | | | | | | | | | | | | | |
| Kolbacksan | Hallstahamm | 3115.3 | 2969.2 | 11.475 | 2.996 | 0.981 | 0.182 | 0.016 | 0.011 | 0.001 | 0.059 | 18.90 | 0.448 | 0.675 |
| Kolbacksan | Ramnas_krk | 3115.3 | 2828.5 | 10.505 | 2.998 | 0.942 | 0.600 | 0.015 | 0.009 | 0.001 | 0.010 | 14.58 | 0.610 | 0.663 |
| Kolbacksan | Selma | 3115.3 | 2185.7 | 9.785 | 3.007 | 0.961 | 0.590 | 0.016 | 0.009 | 0.001 | 0.010 | 22.22 | 0.462 | 0.612 |
| | | | | | | | | | | | | | | |
| Fyrisan | Ulva | 2003.2 | 962.3 | 11.979 | 3.999 | 0.748 | 0.244 | 0.020 | 0.007 | 0.006 | 0.084 | 16.28 | 0.489 | 0.653 |
| Fyrisan | Vattholma | 2003.2 | 263.6 | 14.630 | 2.905 | 0.836 | 0.195 | 0.017 | 0.010 | 0.004 | 0.010 | 15.60 | 0.694 | 0.758 |
| Fyrisan | Uppsala_Bark | 2003.2 | 1148.9 | 17.193 | 8.000 | 0.865 | 0.324 | 0.028 | 0.037 | 0.005 | 0.010 | 16.58 | 0.864 | 0.801 |
| Fyrisan | Savja | 2003.2 | 779.3 | 14.171 | 2.955 | 0.883 | 0.239 | 0.027 | 0.008 | 0.010 | 0.087 | 18.55 | 0.675 | 0.760 |
| | | | | | | | | | | | | | | |
| Rockstaan | Akers_Krutbr | 261.7 | 12.3 | 14.889 | 2.936 | 0.891 | 0.221 | 0.014 | 0.008 | 0.006 | 0.010 | 13.59 | 0.660 | 0.712 |
| Lilån | Granvad | | 173.6 | 12.064 | 3.306 | 0.901 | 0.334 | 0.054 | 0.008 | 0.010 | 0.135 | 19.05 | 0.641 | 0.596 |
| Sagan | Sorsatra | 856.4 | 612.1 | 5.781 | 2.907 | 1.103 | 0.330 | 0.048 | 0.010 | 0.010 | 0.010 | 19.86 | 0.434 | 0.444 |
| Svartån | AkrestaKvarn | 775.3 | 725.2 | 14.580 | 7.715 | 0.940 | 0.172 | 0.027 | 0.002 | 0.010 | 0.061 | 12.96 | 0.750 | 0.808 |
| Hedstrommen | Domsta | 1047.9 | 1007.2 | 11.201 | 2.966 | 1.009 | 0.284 | 0.020 | 0.010 | 0.001 | 0.070 | 13.67 | 0.691 | 0.783 |
| Kopingsan | Odensvibron | 284.6 | 110.2 | 16.290 | 3.357 | 0.990 | 0.342 | 0.020 | 0.009 | 0.010 | 0.074 | 14.57 | 0.560 | 0.690 |
| Hågaån | Lurbo | | 108.9 | 8.556 | 4.970 | 1.029 | 0.287 | 0.043 | 0.005 | 0.010 | 0.111 | 20.07 | 0.778 | 0.780 |
| Savaan | Ransta | 199.8 | 210.5 | 13.332 | 2.942 | 0.989 | 0.225 | 0.039 | 0.014 | 0.010 | 0.143 | 18.28 | 0.640 | 0.723 |
| Orsundaan | Harnevi | 735.5 | 350.5 | 13.918 | 3.351 | 1.017 | 0.279 | 0.047 | 0.010 | 0.010 | 0.138 | 18.71 | 0.626 | 0.682 |

In general the results are quite satisfactory All basins have high NSE and KGE values (statistics of model fit that at best are 1.0) when considering simulations of daily discharge. Furthermore, although there is some variability in the parameter values between basins. This is not extreme, suggesting that relatively consistent sets of parameters can be obtained that represent the physiographic characteristics of the sub-basins making up the greater Mälaren basin. There were however, some cases (blue shading) where the calibrated parameter values were at the top or bottom of the allowed range of variation. We will investigate this further, but given the high NSE KGE values this first set of calibrations in clearly sufficient for estimating the water inputs to Mälaren.

We also checked for correlation between the measured parameters values and the area of total sub-basin and the major land use areas in each sub-basin.

**Table2** *Correlation between model parameters, basin area and land use area*

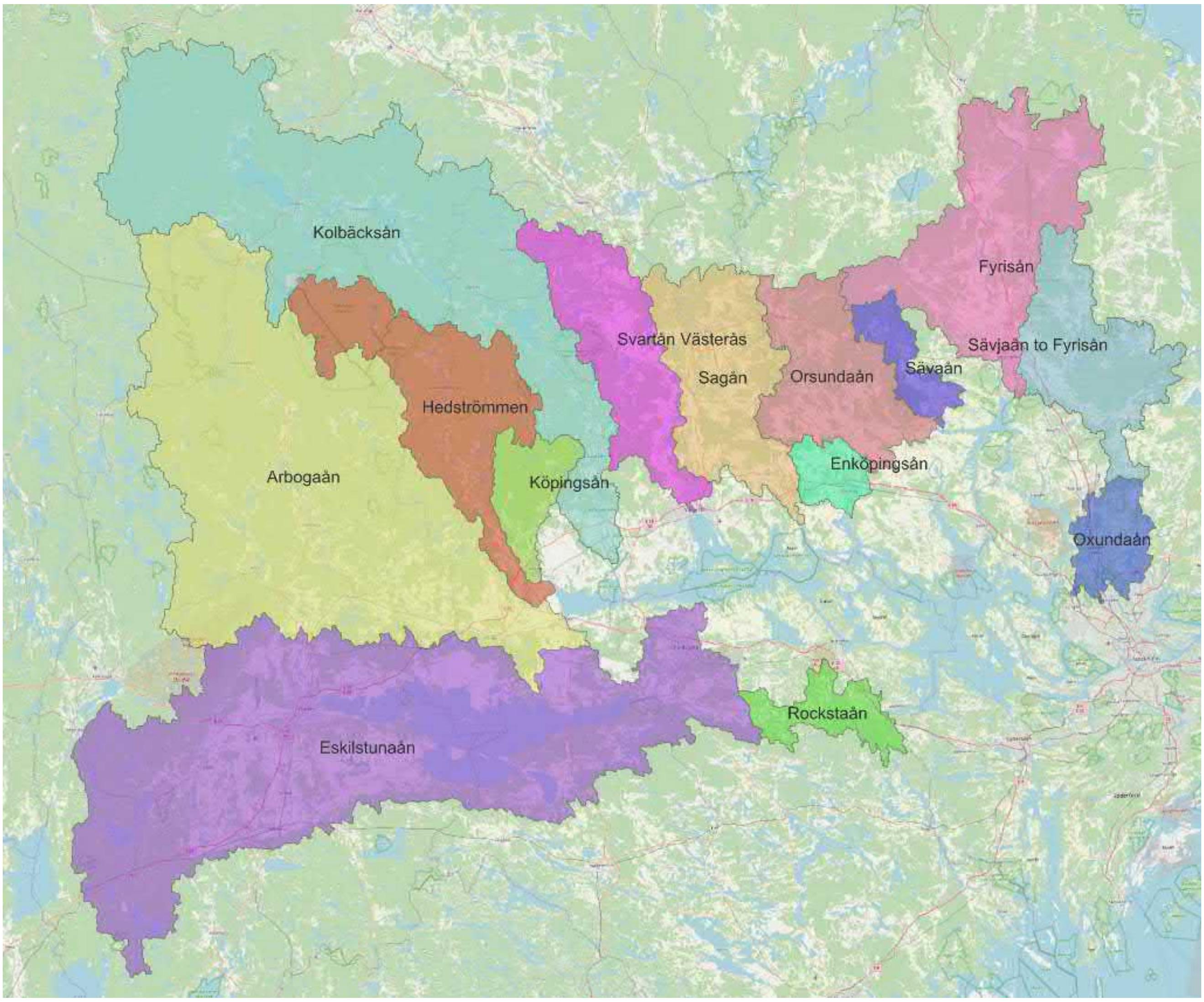
| Parameter Correlation Matrix | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total area | Ag | Forest | Wetland | Water | SWC | DeepGWCap | precipCorr | MeltCoeff | RecessCoeff | SlowRecessCo | UnsatLeakCoeff | ChannelCoeff | CNAdj |
| Total area | 1 | 0.22 | 0.99 | 0.95 | 0.96 | -0.18 | -0.04 | 0.04 | 0.45 | -0.40 | 0.07 | -0.62 | -0.43 | 0.19 |
| Ag | | 1.00 | 0.12 | 0.16 | -0.07 | 0.29 | 0.53 | -0.27 | -0.08 | 0.22 | 0.45 | 0.20 | -0.15 | 0.17 |
| Forest | | | 1.00 | 0.95 | 0.98 | -0.21 | -0.10 | 0.06 | 0.47 | -0.43 | 0.02 | -0.66 | -0.43 | 0.18 |
| Wetland | | | | 1.00 | 0.92 | -0.11 | -0.02 | -0.02 | 0.37 | -0.52 | 0.06 | -0.69 | -0.44 | -0.02 |
| Water | | | | | 1.00 | -0.25 | -0.20 | 0.13 | 0.49 | -0.45 | -0.06 | -0.67 | -0.39 | 0.15 |
| SWC | | | | | | 1.00 | 0.32 | -0.37 | -0.23 | -0.06 | 0.35 | 0.35 | 0.03 | -0.29 |
| DeepGWCap | | | | | | | 1.00 | -0.18 | -0.19 | 0.13 | 0.43 | 0.18 | -0.12 | -0.09 |
| precipCorr | | | | | | | | 1.00 | 0.14 | 0.38 | -0.16 | 0.12 | 0.12 | 0.26 |
| MeltCoeff | | | | | | | | | 1.00 | -0.12 | 0.04 | -0.24 | -0.30 | 0.17 |
| RecessCoeff | | | | | | | | | | 1.00 | 0.05 | 0.70 | 0.50 | 0.52 |
| SlowRecessCoeff | | | | | | | | | | | 1.00 | -0.09 | -0.21 | 0.06 |
| UnsatLeakCoeff | | | | | | | | | | | | 1.00 | 0.49 | 0.13 |
| ChannelCoeff | | | | | | | | | | | | | 1.00 | 0.07 |
| CNAdj | | | | | | | | | | | | | | 1.00 |

These results did show correlations between watershed areas and land use areas , but no strong correlation between watershed size or land use area and the other model parameters. This is somewhat surprising since we expected that watershed size might affect the damping of stream flow and the shape of the hydrograph, particularly in regards to the channel flow coefficient which effects the retention and draining of water from the channel network, and the CN Adj coefficient that effects the magnitude of surface runoff. Apparently it is the factors that affect sub-surface processes that are most important in controlling the timing and magnitude of discharge in these large sub-basins. With this in mind, we made no attempt to adjust the parameter values obtained from a gauged sub-basin to the larger area of a major river inflow.

## Major basin parameters

Even though there is no strong correlation between parameters it does appear that the best results for a particular basin are obtained from a basin specific set of parameters - an assumption that could be further tested. For now, we have simply used the sub-basin parameters associated with each major river basin for simulations of that river basin under present and future climate conditions.

**Figure 2** *Major river basins that provide input to Mälaren and will be simulated with GWLF*




For cases where there are more than one sub-basin in a major river basin we choose the sub-basin parameters considering in Table 1

- NSE KGE values
- The size of the sub-basin relative to the size of the entire basin
- The consistency of the parameter values with the total parameter set shown in Table 1. The such chosen sub-basin in marked in yellow in table 1.

The choice of which sub-basin parameters are applied to each major river basin are shown below in table 3.

**Table 3** *Paramter set assigned to major river basins in Mälaren watershed*

| Major Basin | Stream gauge in basin | Stream gauge used for calibrated parameters |
|---|---|---|
| Arbogaan | Yes | Dalkarlshyttan |
| Enkopingsan | No | Harnevi |
| Eskilstunaan | No | |
| Fyrisan | Yes | Ulva |
| Savjaan_to_Fyrisan | Yes | Savja |
| Hågaån | Yes | Lurbo |
| Hedstrommen | Yes | Domsta |
| Kolbacksan | Yes | Hallstahammar |
| Kopingsan | Yes | Odensvibron |
| Orsundaan | Yes | Harnevi |
| Oxundaan | No | Savja |
| Rockstaan | Yes | Akers_Krutbruk |
| Sagan | Yes | Sorsatra |
| Savaan | Yes | Ransta |
| Svartan_Vasteras | Yes | AkrestaKvarn |
| Unguaged area | No | |

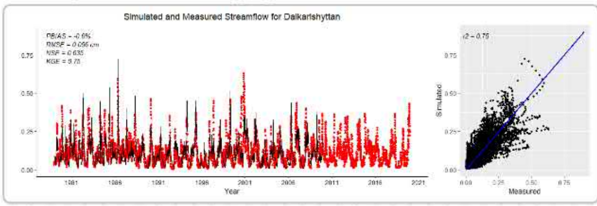
I the few cases where there were no gauged sub-basins in a major basin we chose a parameter set from a near by gauged basin that had land use that had similar land use proportions. In two cases we are still need to define a parameter set for the GWLF model. Eskilstunaån which is the outflow of lake Hjälmaren and strongly effected by the lake, and the ungauged area not covered by any of the major river basins in Figure 2.

# Final results

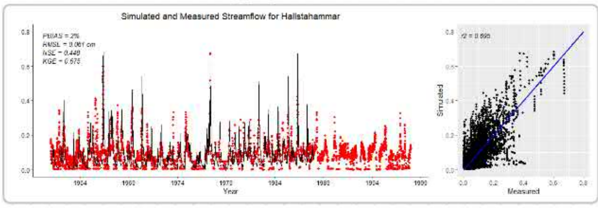
Below are graphs that show the final results of of the simulated and measured discharge on a daily and monthly time step. These are for all major basins ,except Eskilstunaån and the ungauged area.

Simulated vs Measured **Daily** Discharge (cm/day) for sub-basins used to derive paramters for Major Basins

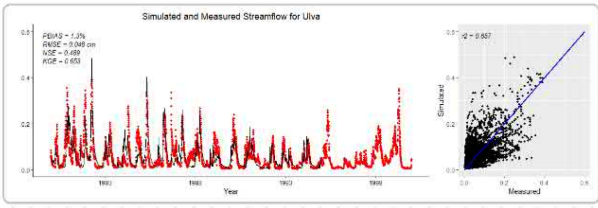
Dalkarlshyttan_StreamFlow_Day.png



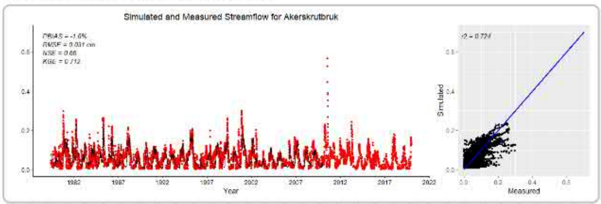

Hallstahammar_StreamFlow_Day.png



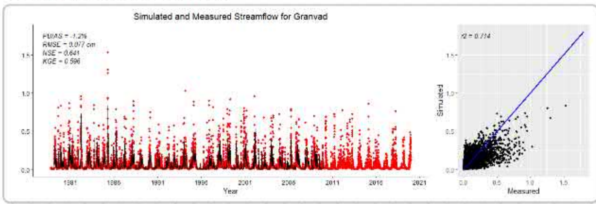

Ulva_StreamFlow_Day.png



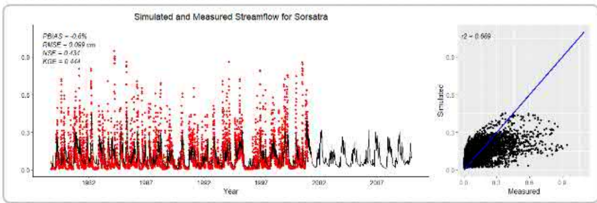

Akerskrutbruk_StreamFlow_Day.png




Granvad_StreamFlow_Day.png

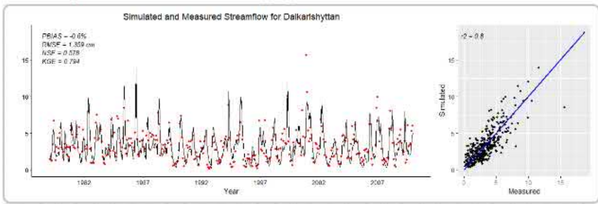



Sorsatra_StreamFlow_Day.png

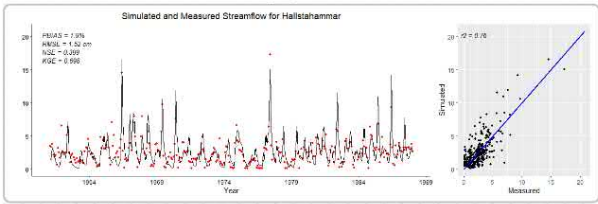



Simulated vs Measured **Monthly** Discharge (cm/day) for sub-basins used to derive paramters for Major Basins

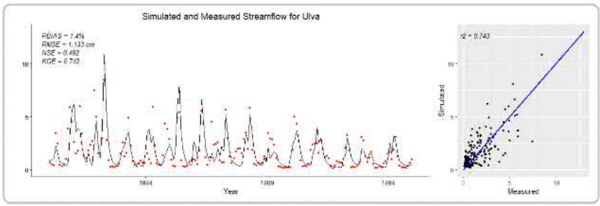
Dalkarlshyttan_StreamFlow_Month.png



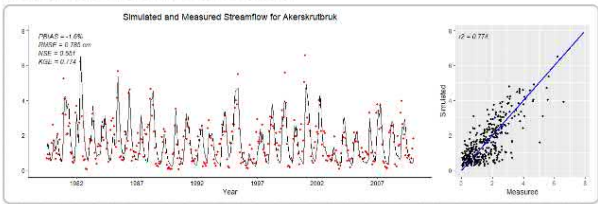

Hallstahammar_StreamFlow_Month.png



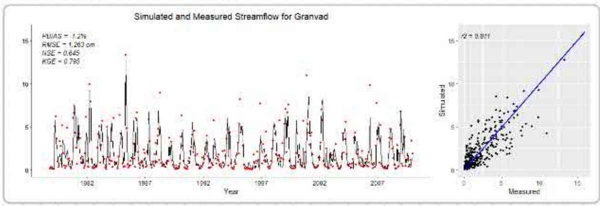

Ulva_StreamFlow_Month.png



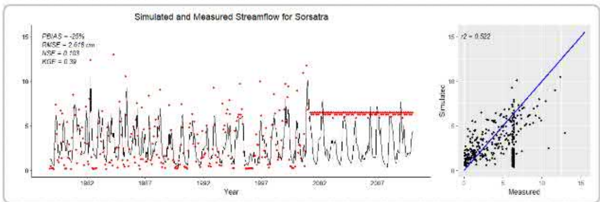

Akerskrutbruk_StreamFlow_Month.png



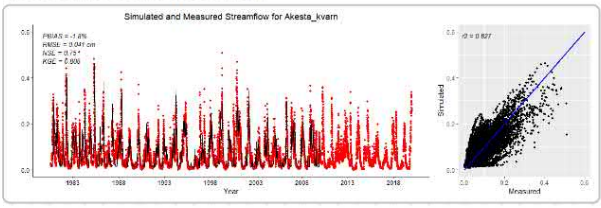

Granvad_StreamFlow_Month.png



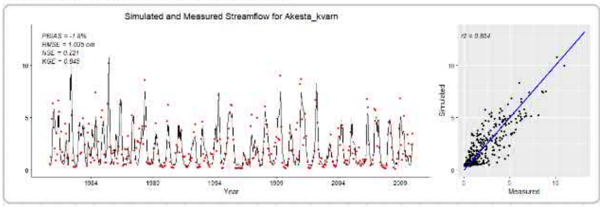

Sorsatra_StreamFlow_Month.png



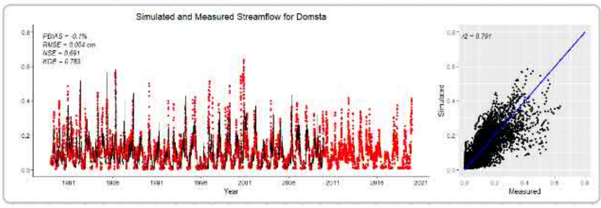
Akesta_kvarn_StreamFlow_Day.png



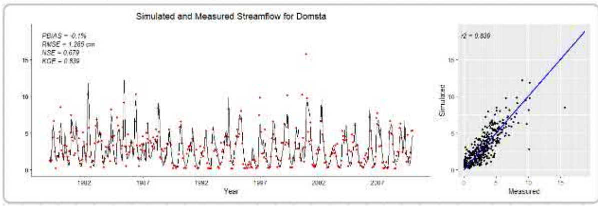

Akesta_kvarn_StreamFlow_Month.png



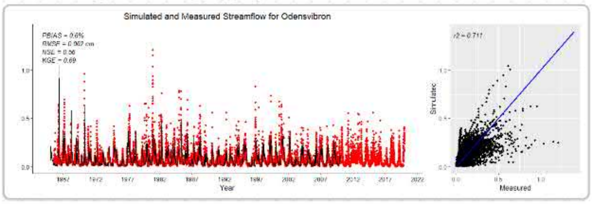

Domsta_StreamFlow_Day.png



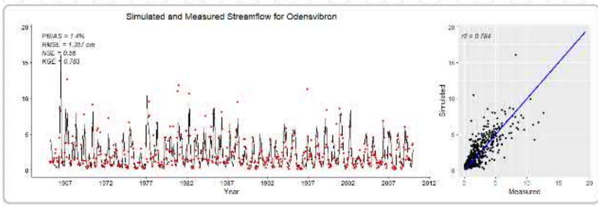

Domsta_StreamFlow_Month.png



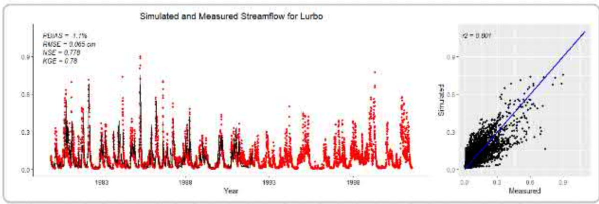

Odensvibron_StreamFlow_Day.png



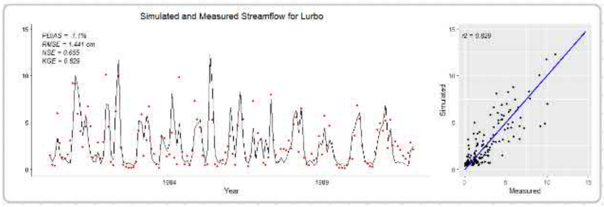

Odensvibron_StreamFlow_Month.png



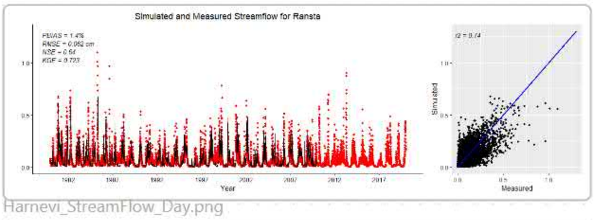

Lurbo_StreamFlow_Day.png



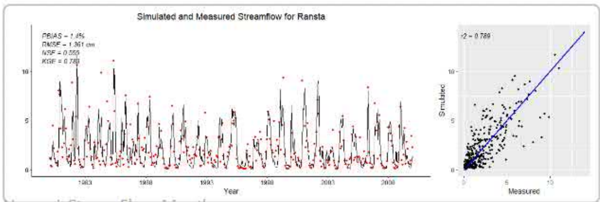

Lurbo_StreamFlow_Month.png



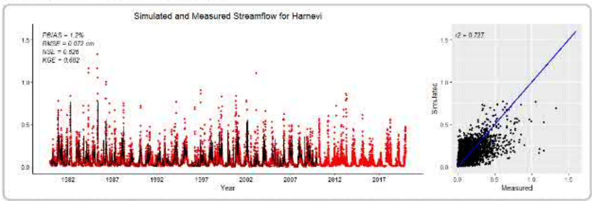

Ransta_StreamFlow_Day.png




Ransta_StreamFlow_Month.png




Harnevi_StreamFlow_Day.png




Harnevi_StreamFlow_Month.png