# Water balance assessment using SWAT for Russian subcatchment of Western Dvina (Zapadnaya Dvina) river

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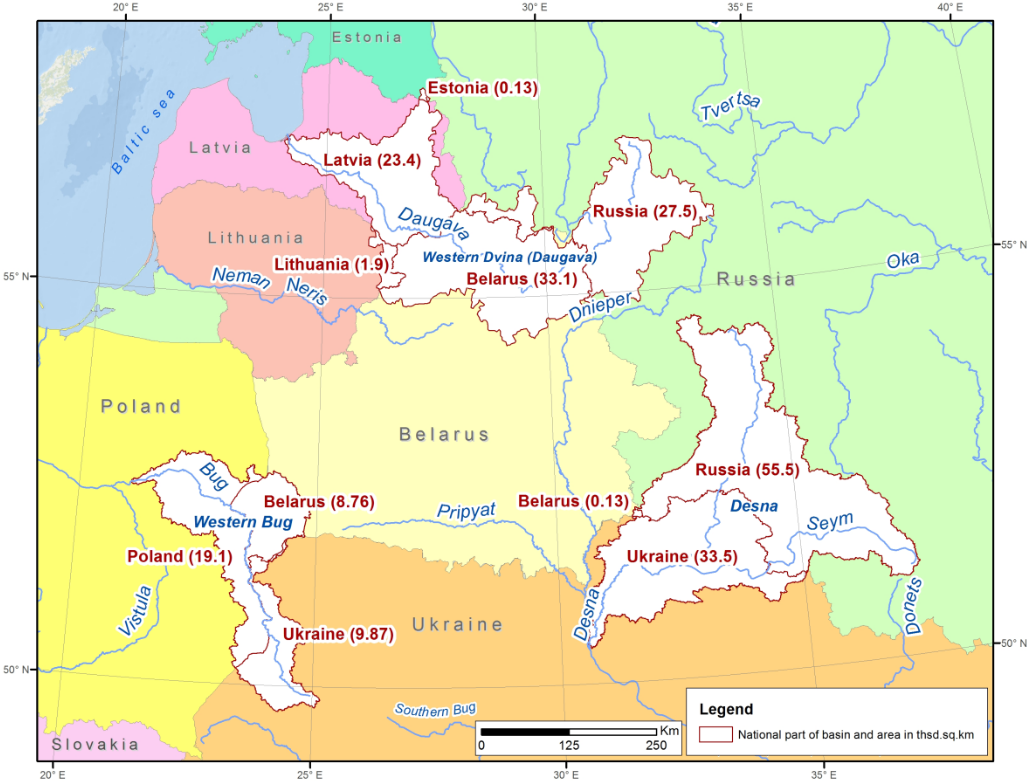
**2nd Baltic Earth conference**
**Danmark, Helsingor – 11-15 june 2018**

Baltic Earth

# MANTRA-Rivers (Management of Transboundary Rivers)

**Funding agency:**
Volkswagen Stiftung (2017-2018)
**Project coordinator:**
Technische Universitat Dresden (TUD), Germany
**Project partners:**
Helmholtz Center for Environmental Research (UFZ), Germany
Lomonosov Moscow State University (LMSU), Russia
Ukrainian Hydrometeorological Institute (UHMI), Ukraine
**Goal:**
Improvement of transboundary water resources management
**Objectives:**
Investigate the scientific basis for IWRM (Integrated Water Resources Management)
Promote trilateral dialog and cooperation

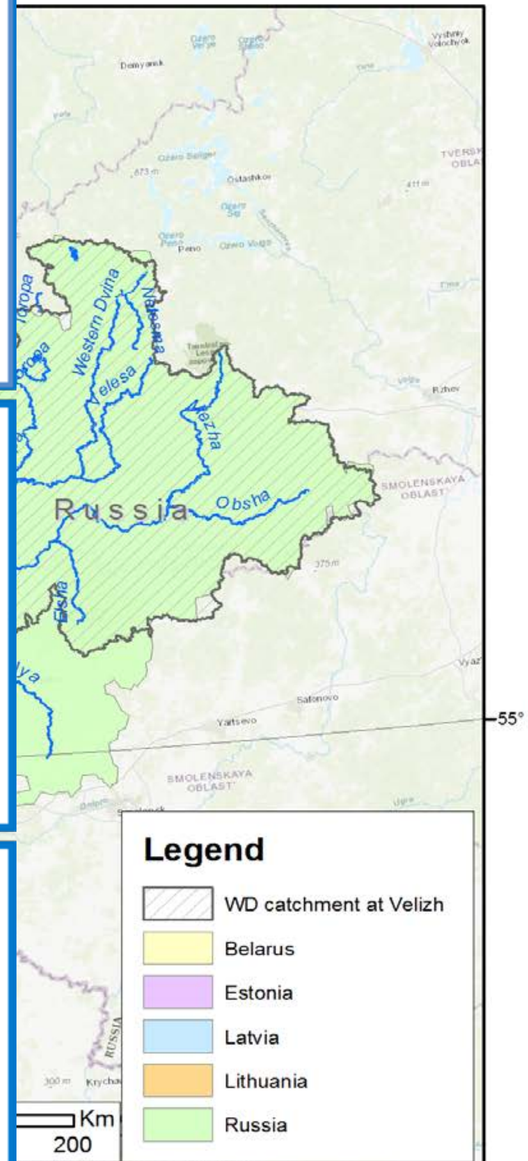



https://tu-dresden.de/bu/umwelt/hydro/ihm/meteorologie/forschung/forschungsprojekte/projekt-mantra-rivers

# Why this catchment and SWAT model?

**Background**

**Russian partner** aims to provide transnational system analysis and dialogue within IWRM for Western Dvina in connection to Belhydromet , Institute for Nature Management NAS RB (Minsk) and LEGMS (Latvian Environment, Geology and Meteorology Centre - Riga)



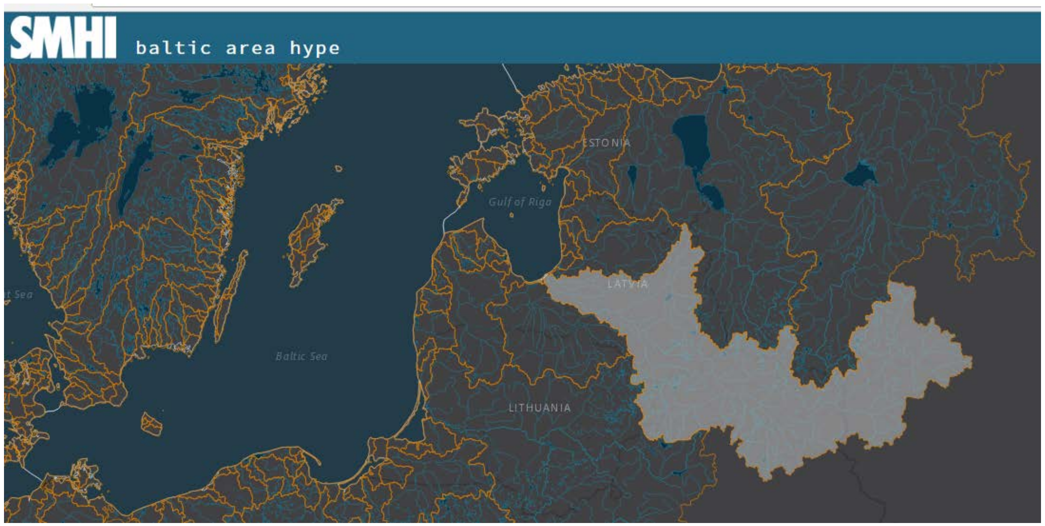

## Interim tasks

1) To choose international hydrological model and develop unified catchment-based tool
2) To find out the open-source data, its quality and suitability
3) To prepare the model and obtain first results on water balance assessment

## Why SWAT model?

1) Open access with proved international efficiency
2) Sediment and nutrient load calculation ability
3) Absence of limitations on catchment area
4) Partners have experience with it’s implementation

# Common investigations
# HYPE, SWAT, HYDROGRAPH models




**HYPE Baltic**

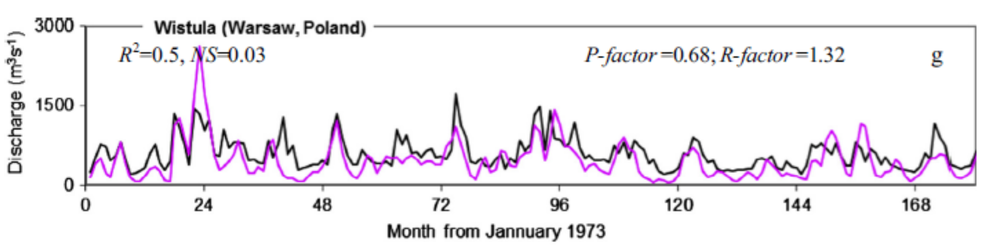
**Scale:** Whole catchment

**Period**: 1981-2014

**Time step:** daily

**Elements:** Q, N, P

Arheimer, B., Dahné, J., Donnelly, C., Lindström, G., Strömqvist, J. 2011



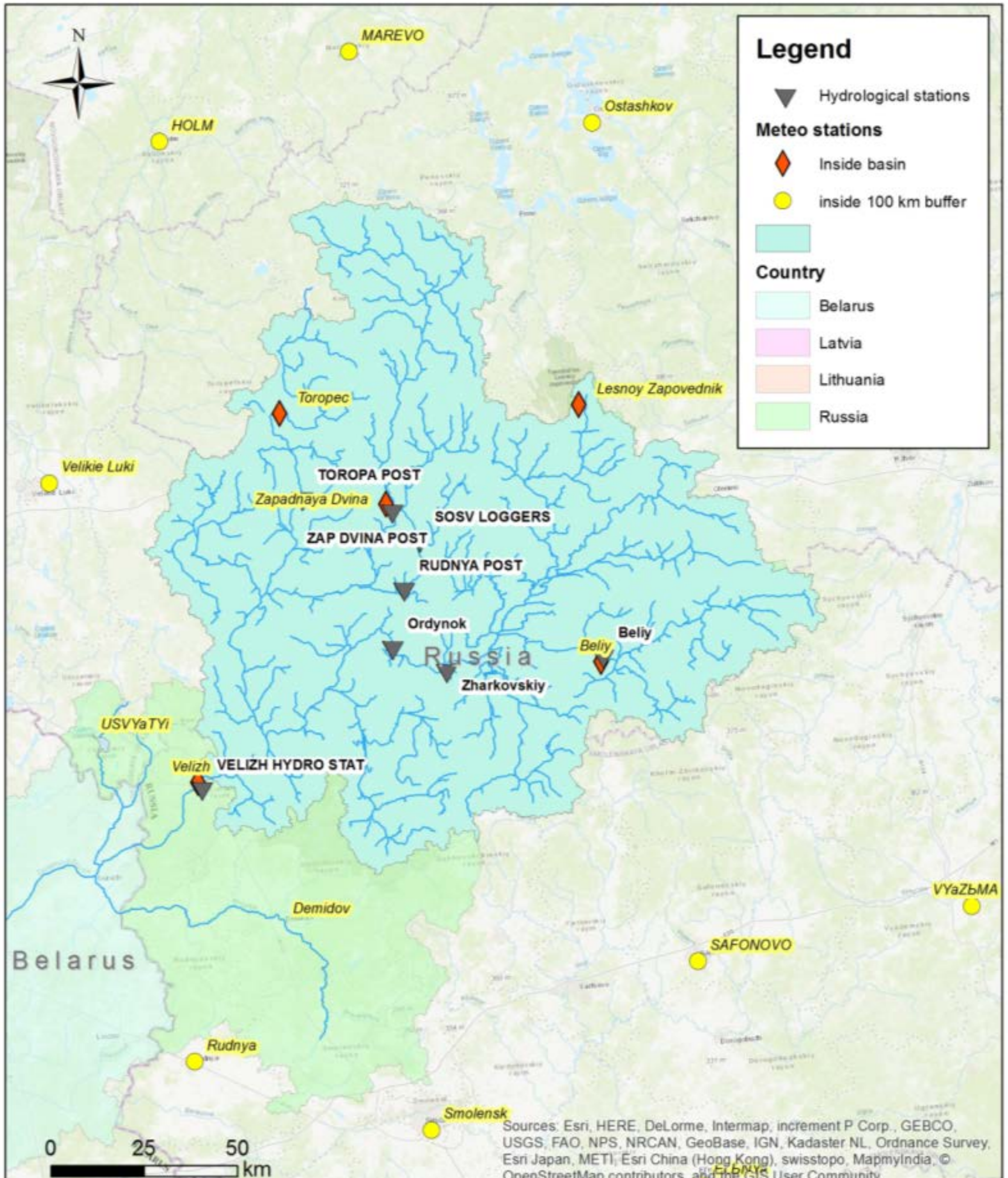

eawag aquatic research

Abbaspour K., et. al. A continental-scale hydrology… 2015

Osypov V.V. Modeling of the nitrogen and phosphorus compounds yields from the small rivers catchments of the Ukrainian forest zone … 2017

Zhuravlev S., Danilovich I., Kurochkina L., Kvach A. Model based estimations of Western Dvina flow changes…

# Hydrological and meteorological gauging network



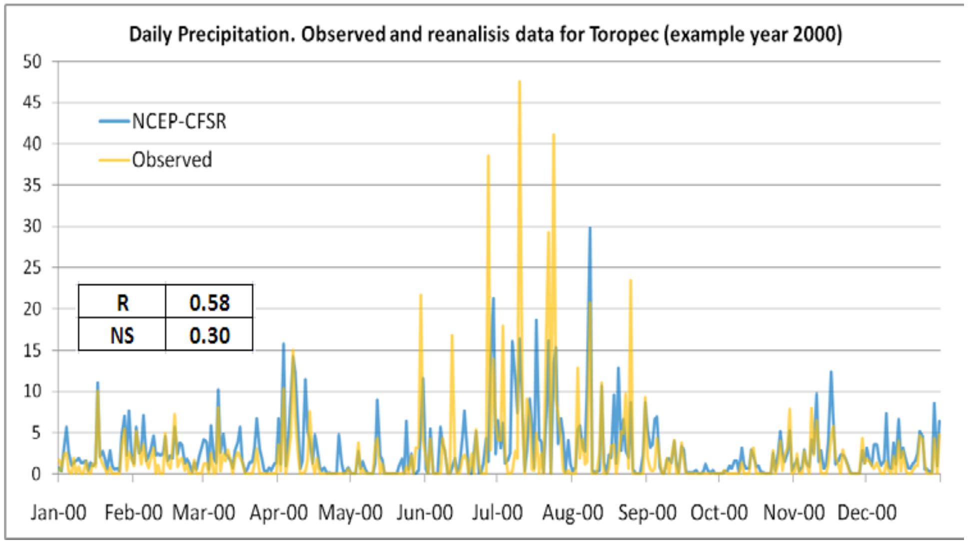

| Western Dvina - Russian part (at Velizh st.) | |
|---|---|
| Area, sq.km | 17600 |
| River length, km | 366 |
| Main human activities | agriculture, industry |
| Average runoff, cms (km3) | 142 (4.5) |
| EcoRegion | Mixed sarmatic forest |
| Dominate soil group (HWSD) | Podzoluvisols |

Meteorological stations 1979-2016

Hydrological stations (lot of gaps)

| Code | River | Station | Q daily periods |
|---|---|---|---|
| 73108 | Western Dvina | Zapadnaya Dvina | Before 1993 |
| 73110 | Western Dvina | Velizh | Before 2004, 2007-2014 |
| 73182 | Velesa | Rudnya | Before 2004 |
| 73186 | Toropa | Staraya Toropa | before 2004, 2009-2014 |
| 73190 | Mezha | Ordynok | Before 1996, 2009-2014 |
| 73196 | Obsha | Beliy | Before 1996 |

# Weather data uncertainty (unreliable components)




Precipitation:

**(observed data need)**

**Daily sum of precipitation correlation (1979-2016)**

| | | | | | |
|---|---|---|---|---|---|
| Smolensk | 1 | | | | |
| VelLuki | 0.61 | 1 | | | |
| Beliy | 0.31 | 0.21 | 1 | | |
| Velizh | 0.55 | 0.74 | 0.29 | 1 | |
| Toropec | 0.60 | 0.56 | 0.48 | 0.57 | 1 |
| | Smolensk | VelLuki | Beliy | Velizh | Toropec |

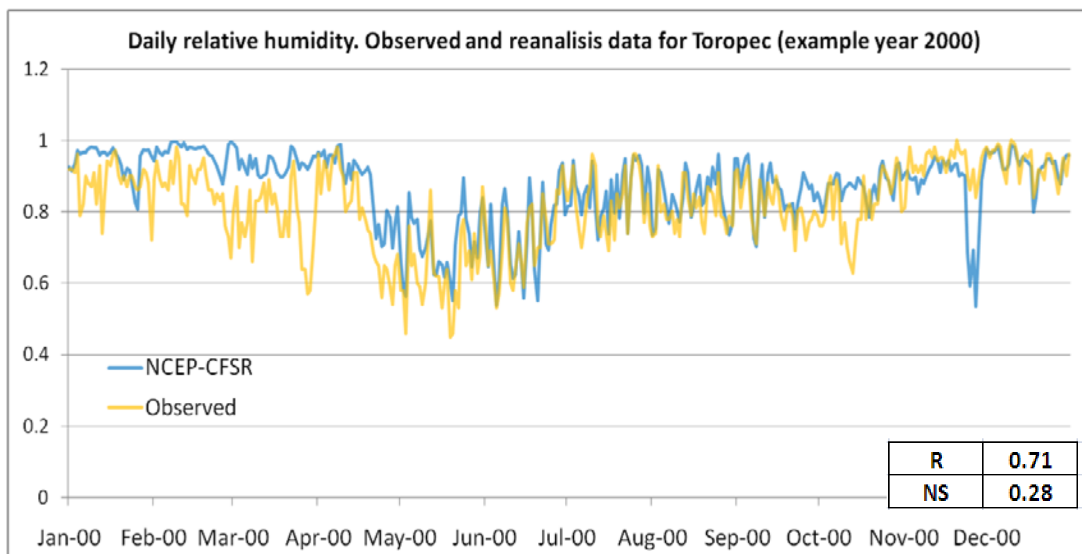
High spatial variability

Density of stations (approx.):

**1 st. per 5000 sq.km**

Daily relative humidity:

**(observed data need)**



# Open weather data sources used in study

- Global Surface Summary of the Day (NOAA)
- Internet database ECA&D
- ECMWF ERA-Interim reanalysis

| | Global Surface Summary of the Day (GSOD) | European Climate Assessment & Dataset (ECA&D) | Earth Reanalysis ERA-Interim |
|---|---|---|---|
| **Source** | NOAA NCDC | KNMI | ECMWF |
| **Spatial coverage** | Global | Europe | Global |
| **Temporal coverage** | 1929 – present | 1851 – present | 1979-present |
| **Measurement frequency** | Daily | Daily | Every 6 hours |
| **Total number of stations** | > 9000 | > 6500 | - |

# Which database should be used for swat modeling?

**For analysis:**

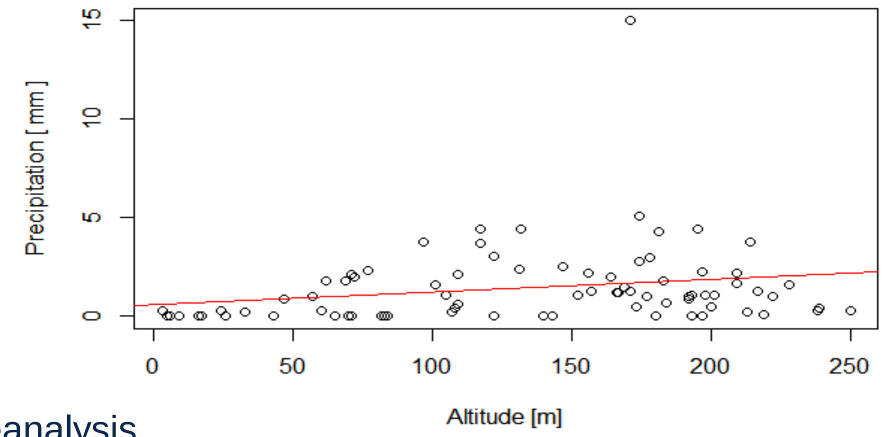
- index of agreement (d)
- correlation coefficient (r)

$$d = 1 - \frac{\sum_{i=1}^{n}(y_i - x_i)^2}{\sum_{i=1}^{n}(|x_i - \bar{y}| + |y_i - \bar{y}|)^2}$$

$$r = \frac{1}{(n-1)} \cdot \sum_{i=1}^{n} \frac{(x_i - \bar{x}) \cdot (y_i - \bar{y})}{(x_i - \bar{x})^2 \cdot (y_i - \bar{y})^2}$$

**Data processing:**

1. Plausibility analysis, detection of outliers
2. Regionalization of station data



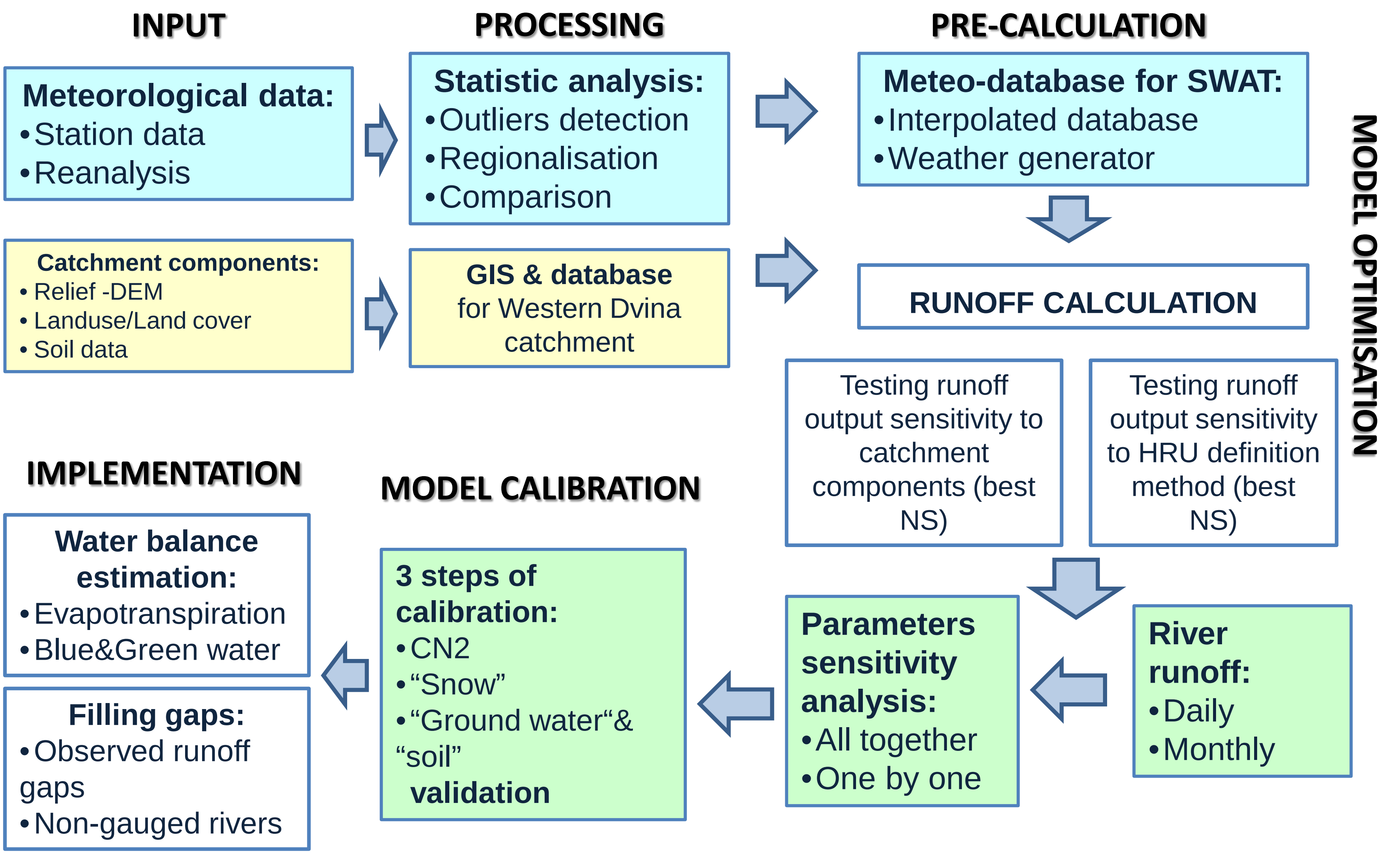

Comparing Interpolated Station Data and Reanalysis

| | RR | TN | TM | TX | FF | HU |
|---|---|---|---|---|---|---|
| **r** | **0.72** | 0.98 | > 0.99 | 0.99 | **0.86** | 0.95 |
| **d** | **0.84** | 0.99 | > 0.99 | > 0.99 | **0.74** | 0.97 |

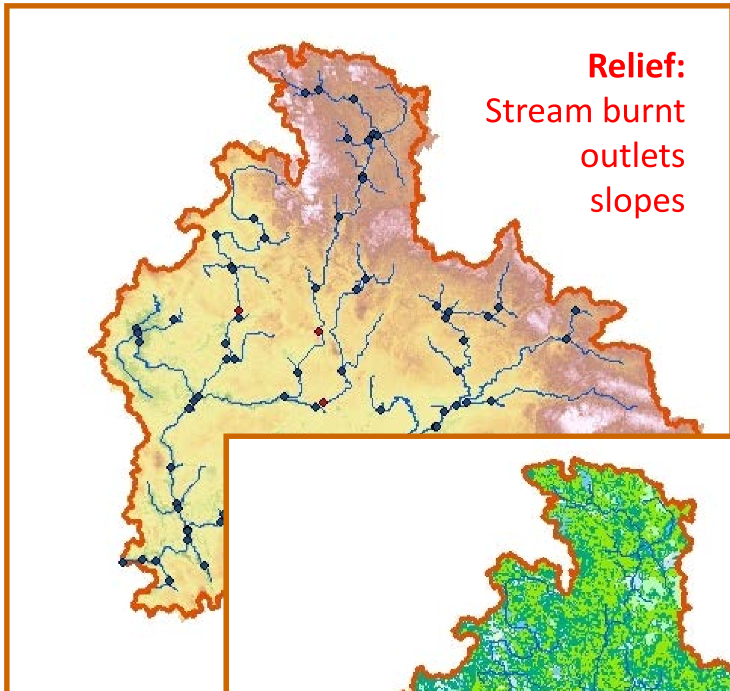
| | Interpolated Station Data | Reanalysis |
|---|---|---|
| **Availability of data** | RR, TN, TM, TX, HU, FF | RR, TN, TM, TX, HU, FF, SSRD |
| **Problematic elements** | **absence of SSRD** | **RR, FF** |

**Authors would recommend using the values obtained by interpolated stations data with SSRD from ERA-Interim reanalysis**

# SWAT setup, uncertainty analysis, calibration and implementation – general scheme

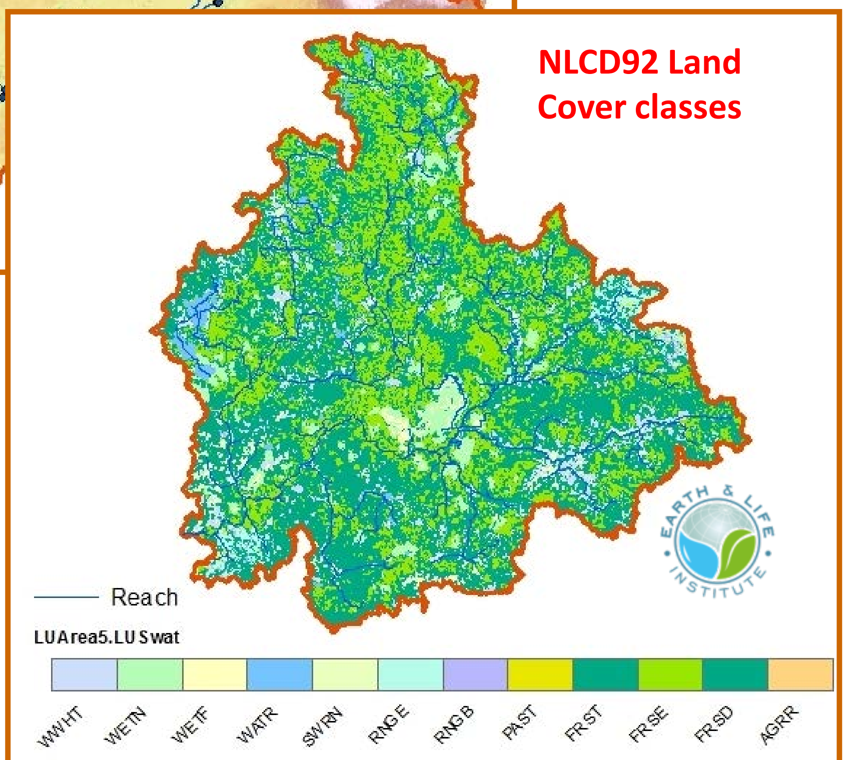


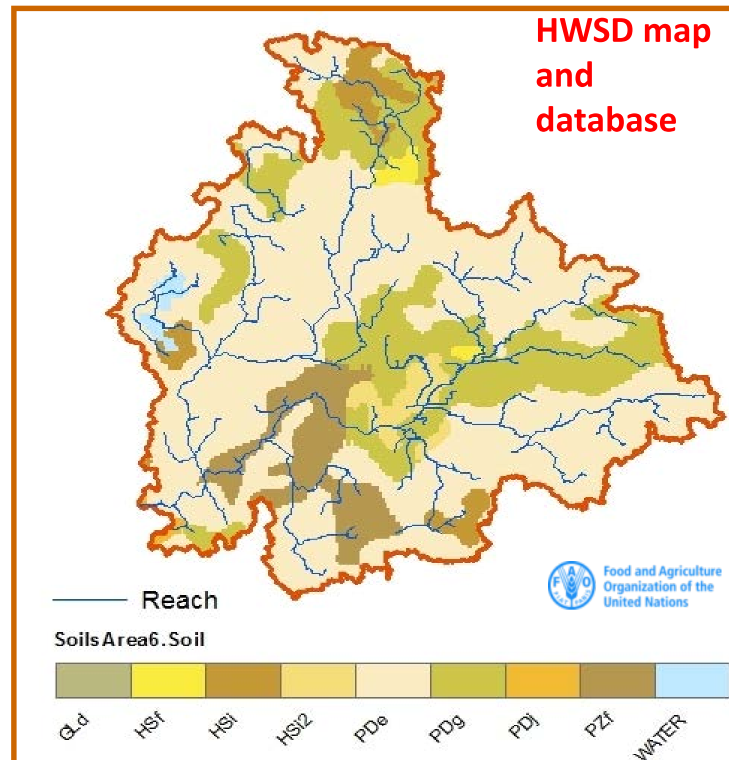
# SWAT model building – monthly time step




**Global and regional datasets:**

- **LandCover/LandUse** - GlobCORINE (res. 235m),
- **DEM** – SRTM (30 m)
- **Soil** - HWSD-FAO-EAWAG database
- **Weather** – Special DATABASE (interp)
- **31 subbasins, 467 HRUs**



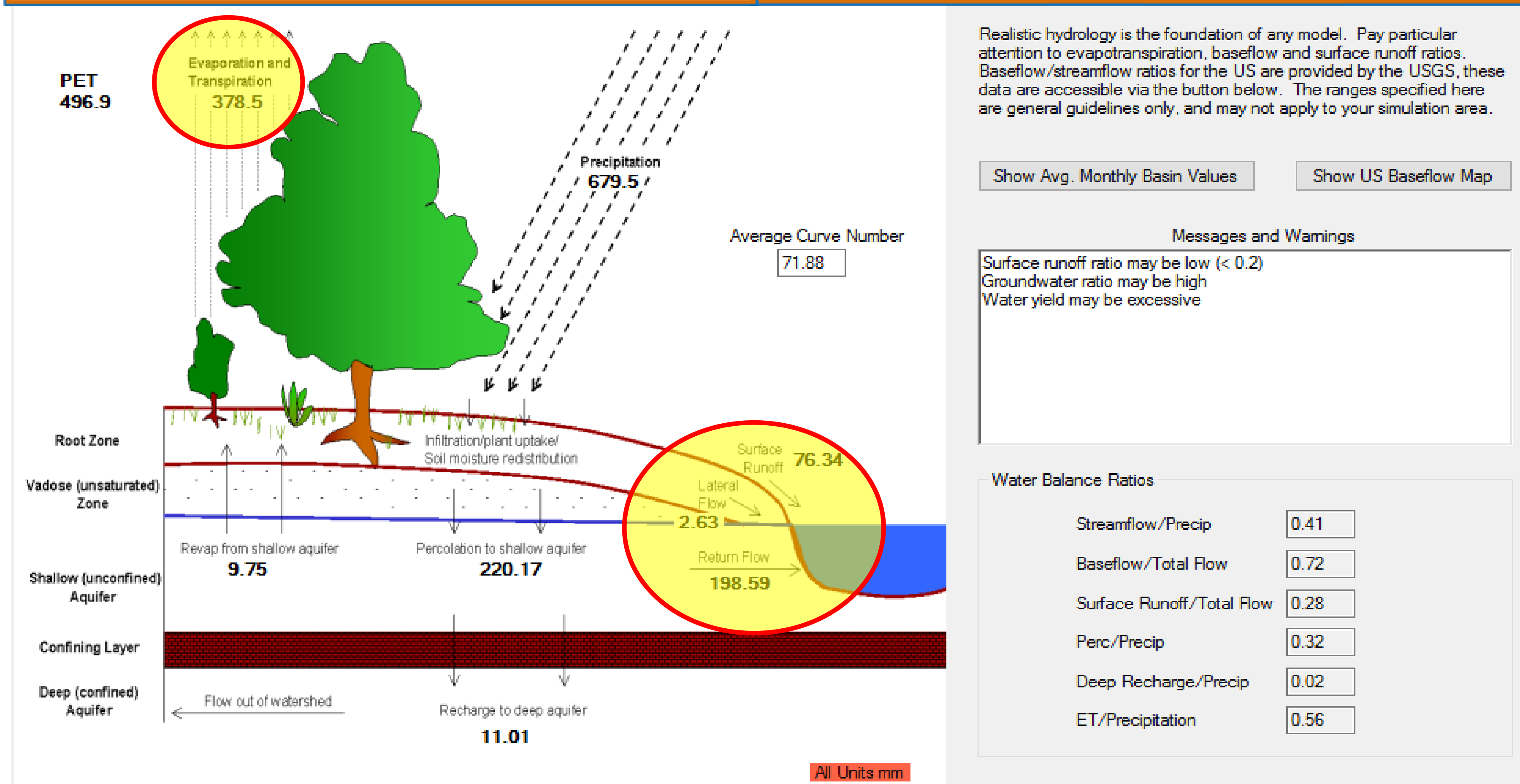
# Initial model. Annual water balance

**Datasets:**

- **LandCover** – GlobCORINE 235 m
- **DEM** – SRTM (30 m)
- **Soil** - HWSD-FAO-EAWAG database

**Water balance annual means (1989-2004):**

- Surface runoff 278 mm simulated (275 mm – observed)
- Annual ET 378 mm  simulated (395 mm – MODIS based)



# Monthly calibration and validation

| # | Parameter | Type | Min | Max |
|---|---|---|---|---|
| 1 | CN2_FRSE,FRSD,FRST | r | -0.17 | -0.02 |
| 2 | CN2_RNGE,WWHT | r | -0.07 | 0.10 |
| 3 | SFTMP | v | -0.80 | 2.54 |
| 4 | SMTMP | v | 4.71 | 5.60 |
| 5 | SMFMX | v | 11.1 | 12.4 |
| 6 | SMFMN | v | 3.45 | 4.52 |
| 7 | SNOCOVMX | v | 45.2 | 84.1 |
| 8 | SNO50COV | v | 0.21 | 0.37 |
| 9 | SOL_AWC() | r | -0.08 | 0.11 |
| 10 | GWQMN | a | 222 | 567 |
| 11 | GW_DELAY | a | -103 | 103 |
| 12 | RCHRG_DP | a | 0.01 | 0.17 |
| 13 | GW_REVAP | a | 0.01 | 0.02 |
| 14 | ALPHA_BF | v | 0.34 | 0.84 |
| 15 | TIMP | v | 0.09 | 0.27 |
| 16 | ESCO | r | -0.03 | 0.06 |
| 17 | SNO_SUB_19,10,30,16,7,26,2,24,23,20,31,22,6,27,5,3 | r | 0.00 | 0.19 |
| 18 | SNO_SUB_21,12,14,32,1,29,17,4,28,9,13,15,25,11,8,18 | r | 0.00 | 0.21 |
| 19 | REVAPMN.gw | r | 0.01 | 0.07 |

Runoff curve number CN2 – distributed parameter

SNOWMELT parameters – lumped - separate from others calibration

Snow cover distribution – separate calibration. 80% forested area threshold

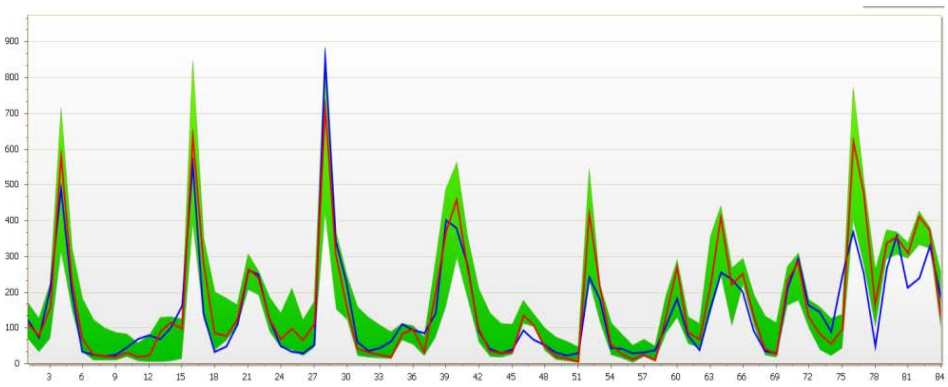
$$R^2 = \frac{\left[\Sigma_i (Q_{p,i} - \bar{Q}_p)(Q_{M,i} - \bar{Q}_M)\right]^2}{\Sigma_i (Q_{p,i} - \bar{Q}_p)^2 \Sigma_i (Q_{M,i} - \bar{Q}_M)^2}$$

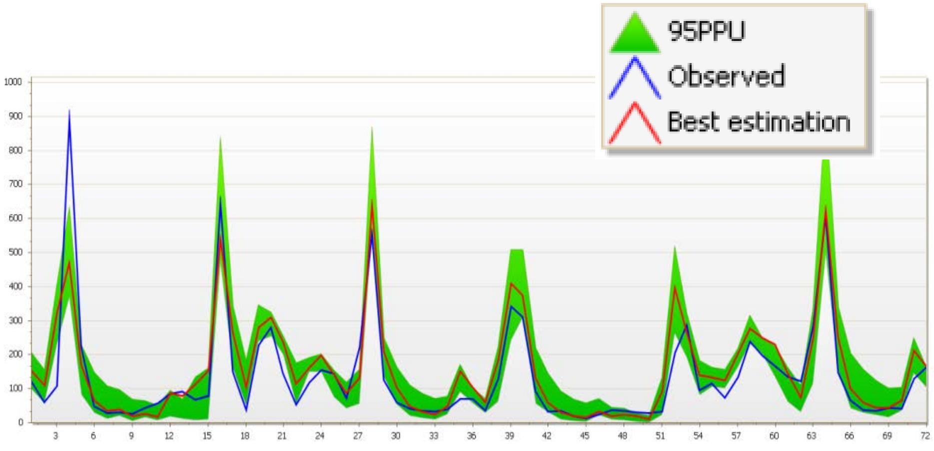
$$NS = 1 - \frac{\Sigma_i (Q_p - Q_M)_i^2}{\Sigma_i (Q_{p,i} - \bar{Q}_p)^2}$$

$$PBIAS = \frac{\Sigma_{i=1}^{n} (Q_p - Q_M)}{\Sigma_{i=1}^{n} Q_{p,i}} 100$$

$$KGE = 1 - \sqrt{(r-1)^2 + (\alpha - 1)^2 + (\beta - 1)^2}$$

# Monthly calibration and validation






Calibration 1992-1998

| R2 | NS | PBIAS | KGE |
|---|---|---|---|
| **0.83** | **0.77** | **-11.5** | **0.8** |

Validation 1999-2004

| R2 | NS | PBIAS | KGE |
|---|---|---|---|
| **0.78** | **0.76** | **-15.5** | **0.78** |

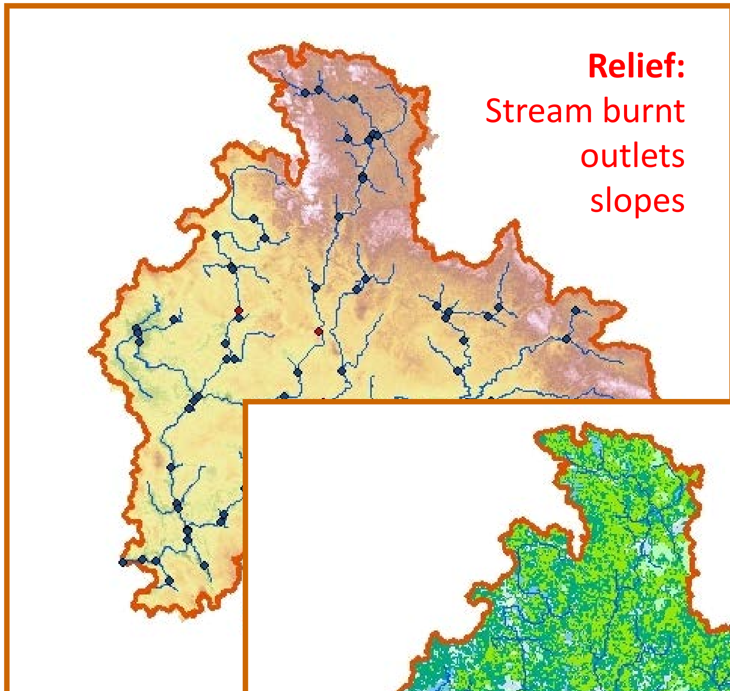
| **Quality level** | **NS и $R^2$** | **PBIAS, %** |
|---|---|---|
| Very good | **0,75 < NS ≤ 1** | PBIAS ±10 |
| Good | 0,65 < NS ≤ 0,75 | **±10 ≤ PBIAS < ±15** |
| Satisfactory | 0,5 < NS ≤ 0,65 | ±15 ≤ PBIAS < ±25 |
| Not satisfactory | NS ≤ 0,5 | PBIAS ≥ ±25 |

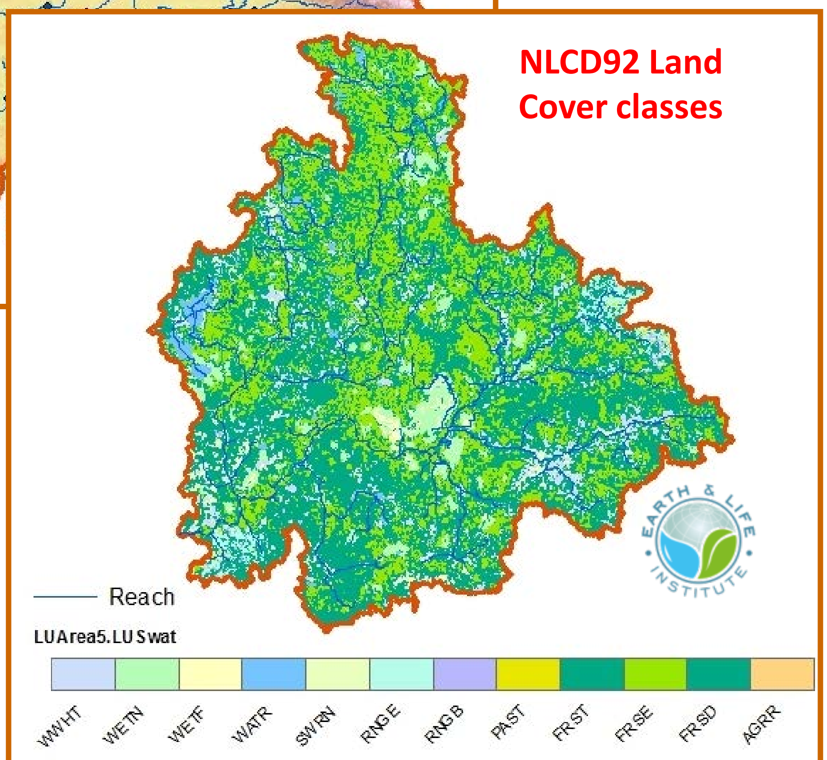
Moriasi D.N. et.al  Model evaluation guidelines … *2007*

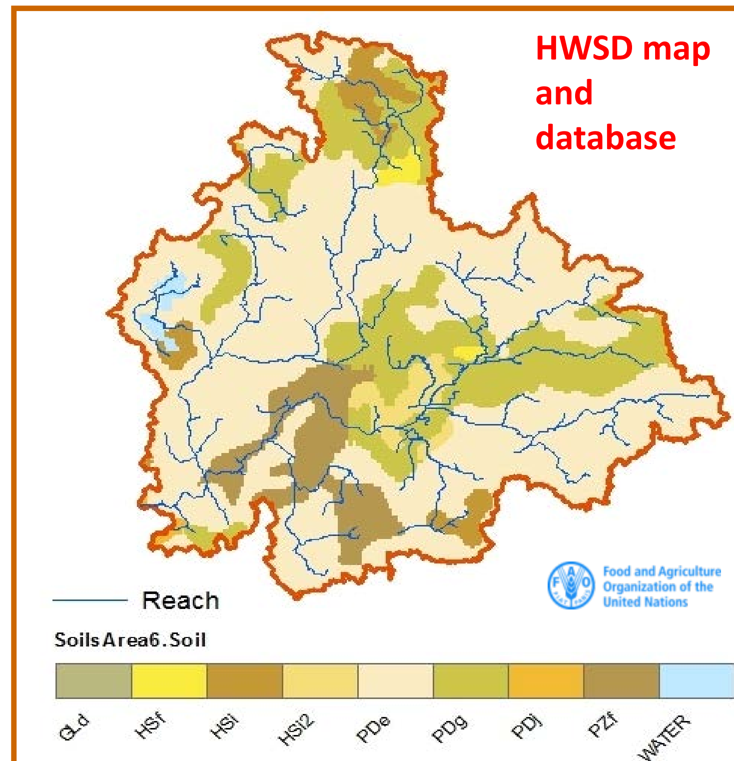
# Daily model building

**Global and regional datasets:**

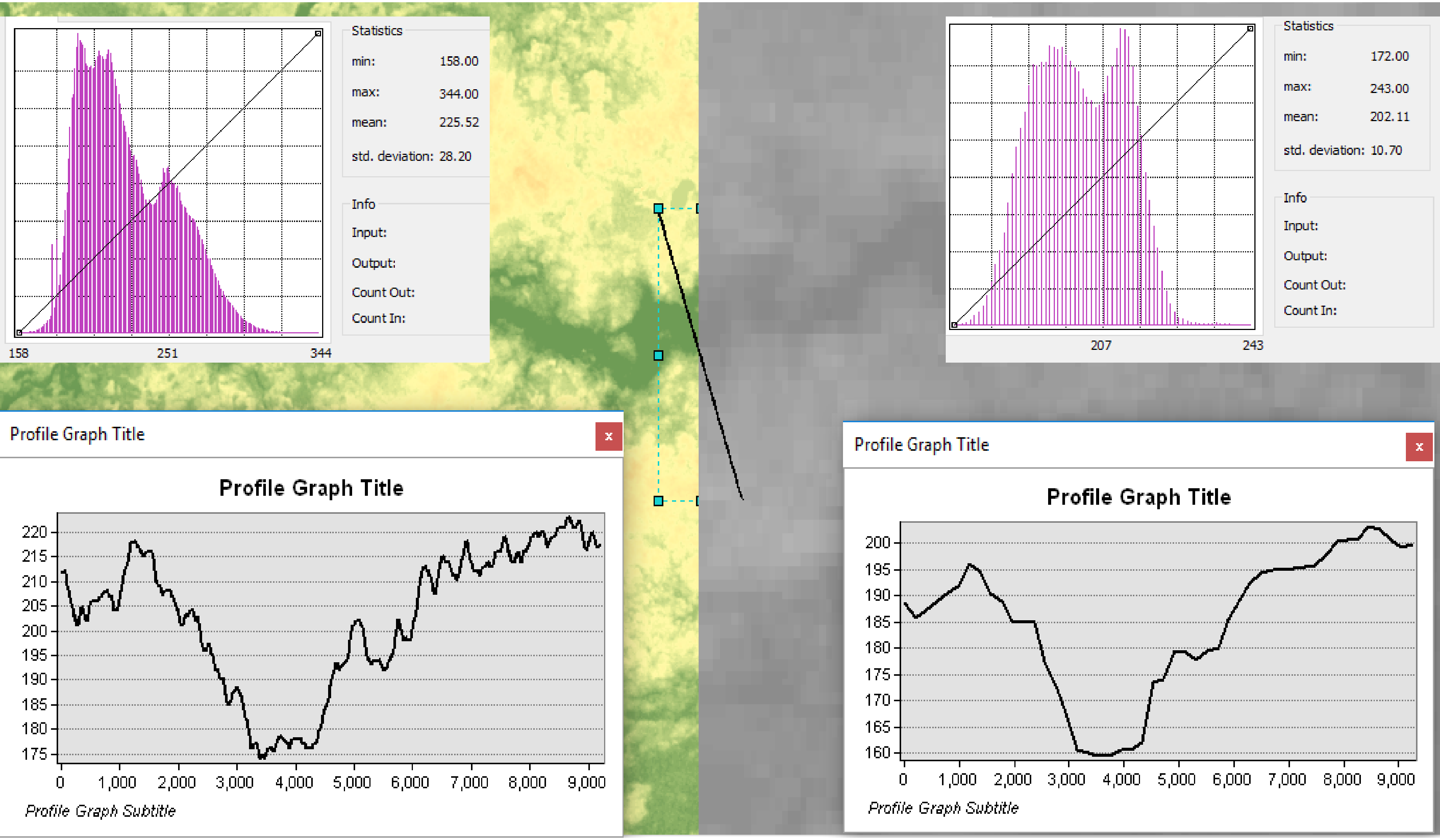
- **LandCover** – Globallandcover (China) (30 m),
- **DEM** – ALOS PalSAR (12.5 m) – ellipsoid based
- **Soil** - HWSD-FAO-EAWAG database
- **Weather** – Special-Database (interpolated)



# ALOS (12.5 m) DEM vs SRTM (30 m)

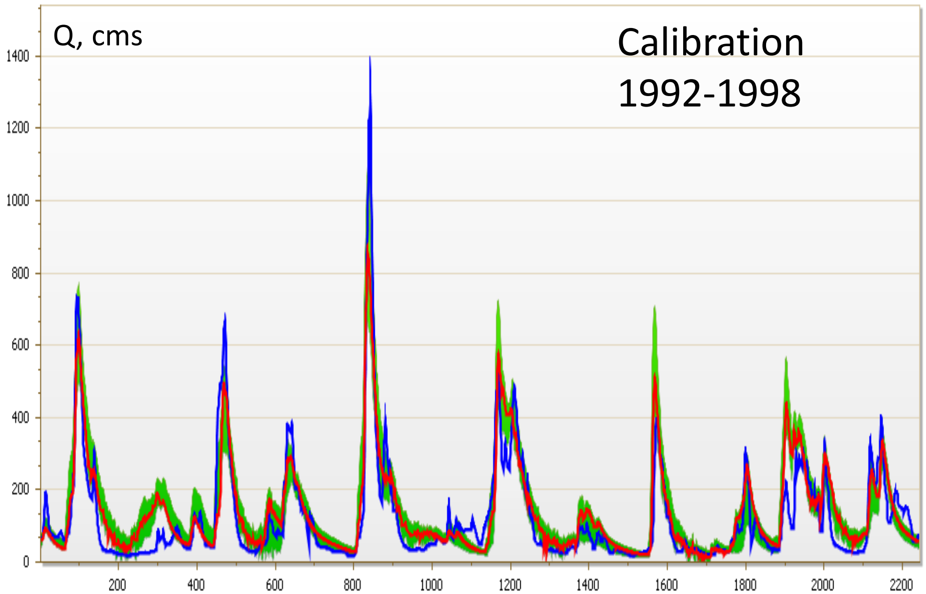


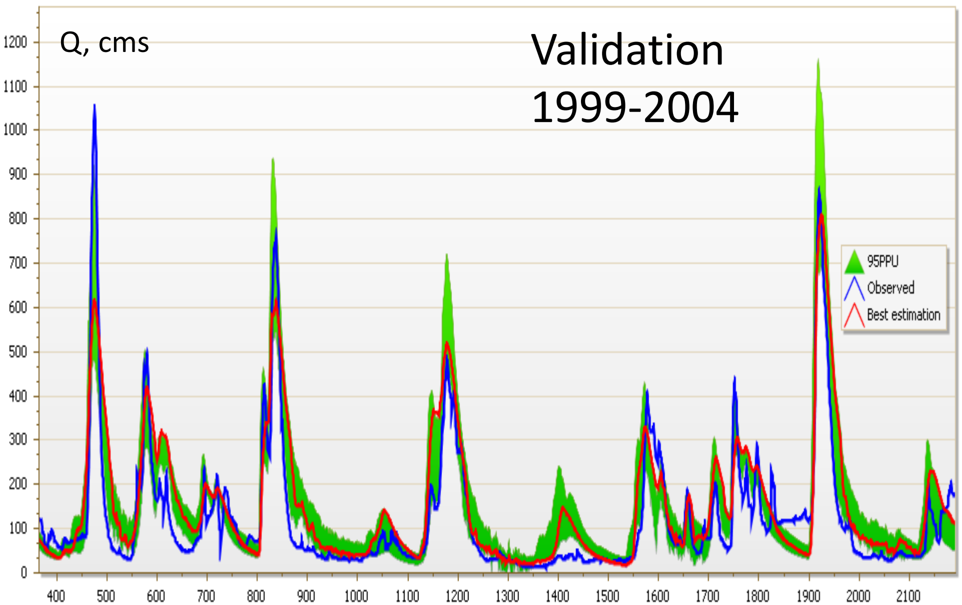

This difference affects:

- stream network delineation
- slope classes distribution

# SWAT model 4rd step (superdetailed). Daily calibration and validation – Velizh

***ET method – plant ET, Ch routing - Muskingum***




Calibration 1992-1998

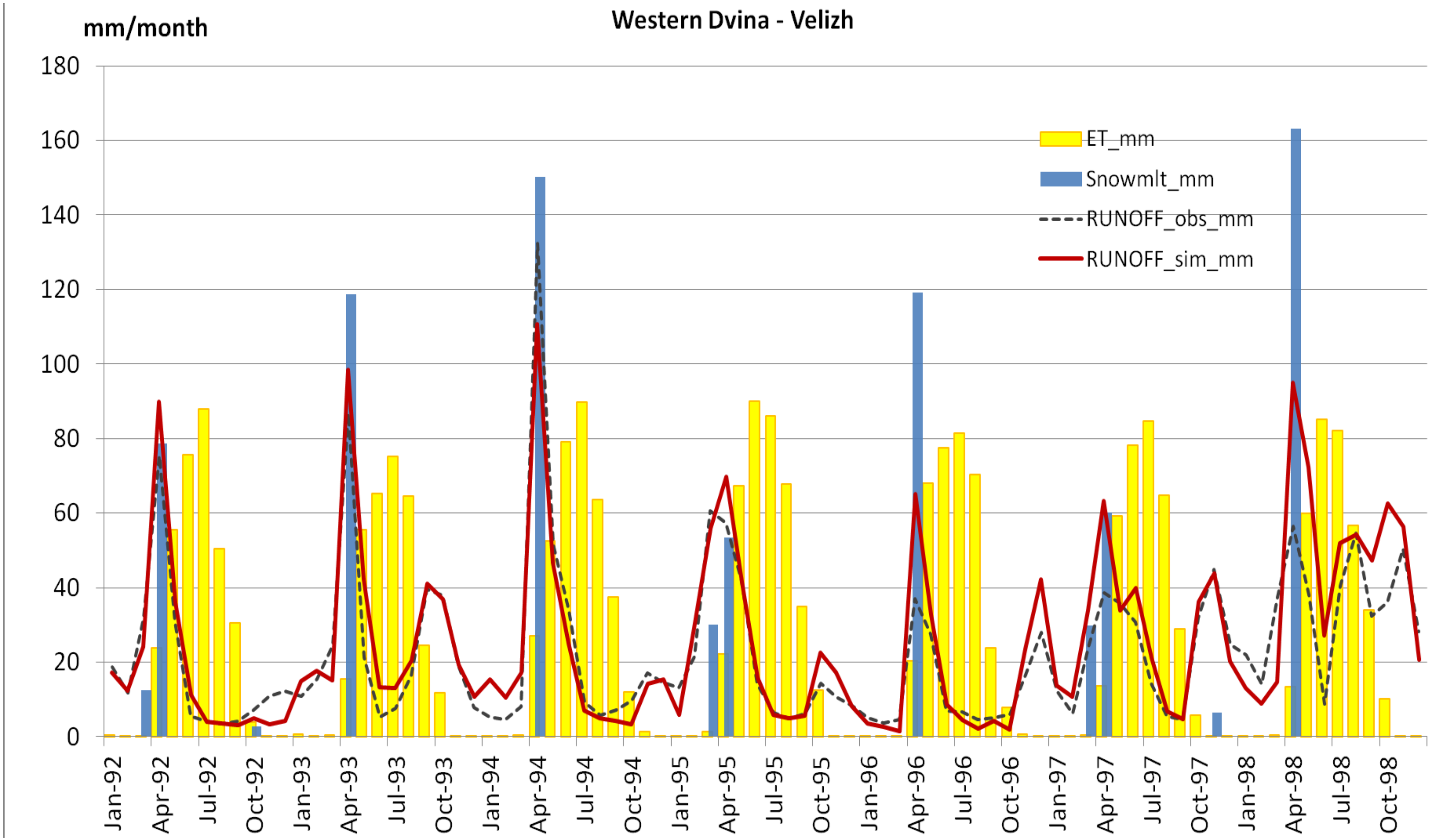
| R2 | NS | PBIAS | KGE |
|---|---|---|---|
| 0.77 | 0.76 | -11.7 | 0.8 |

Validation 1999-2004

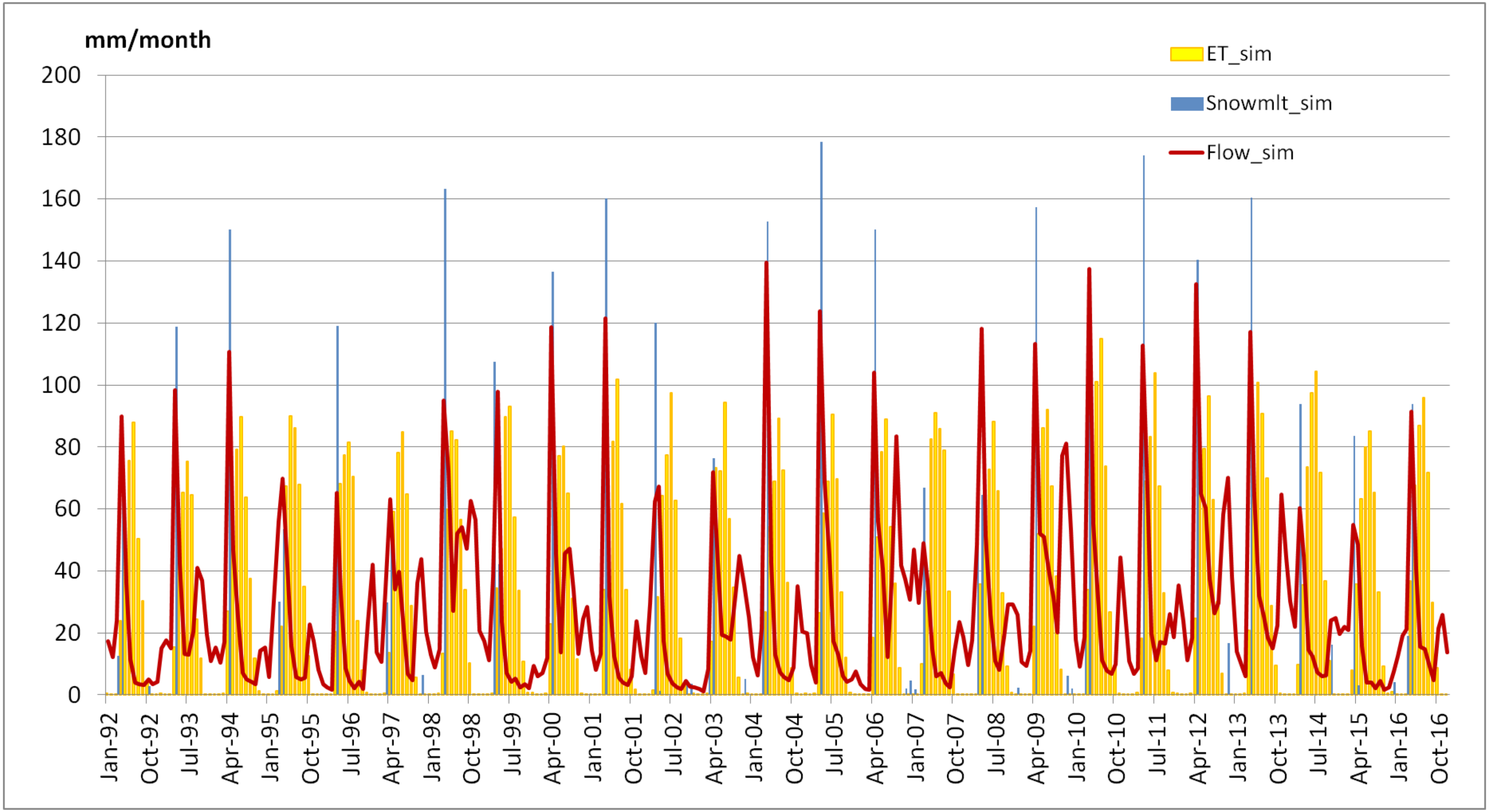
| R2 | NS | PBIAS | KGE |
|---|---|---|---|
| 0.78 | 0.76 | -16.5 | 0.75 |

| Quality level | NS и $R^2$ | PBIAS, % |
|---|---|---|
| Very good | **0,75 < NS ≤ 1** | PBIAS ±10 |
| Good | 0,65 < NS ≤ 0,75 | **±10 ≤ PBIAS < ±15** |
| Satisfactory | 0,5 < NS ≤ 0,65 | **±15 ≤ PBIAS < ±25** |
| Not satisfactory | NS ≤ 0,5 | PBIAS ≥ ±25 |

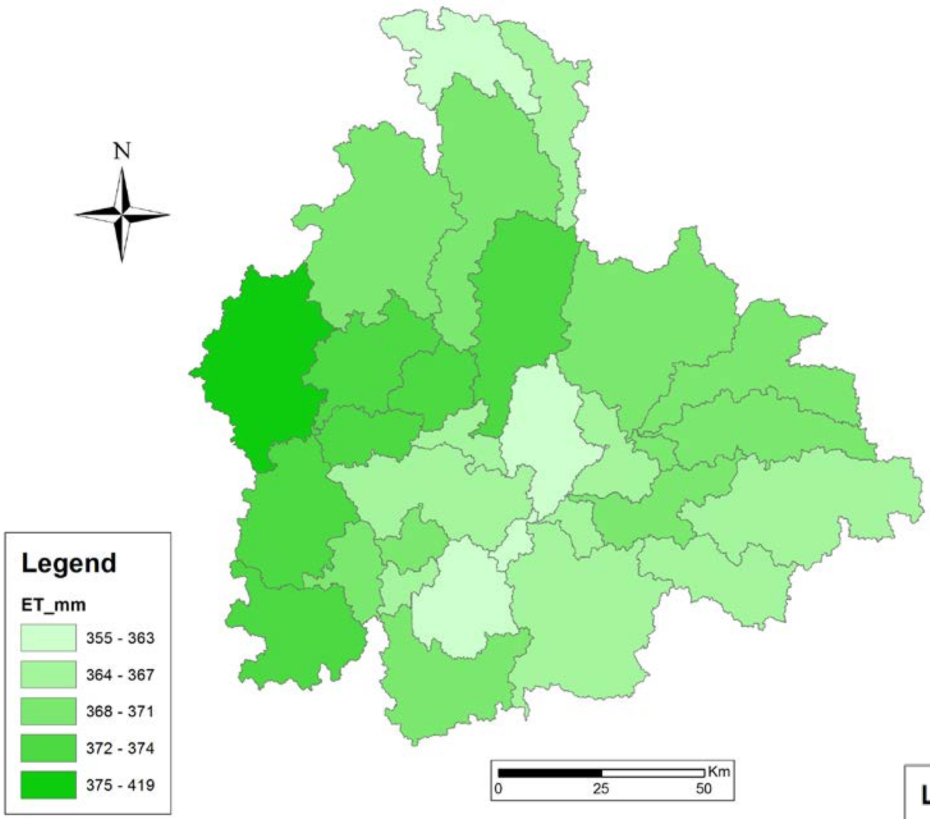
# Water balance time series (example)

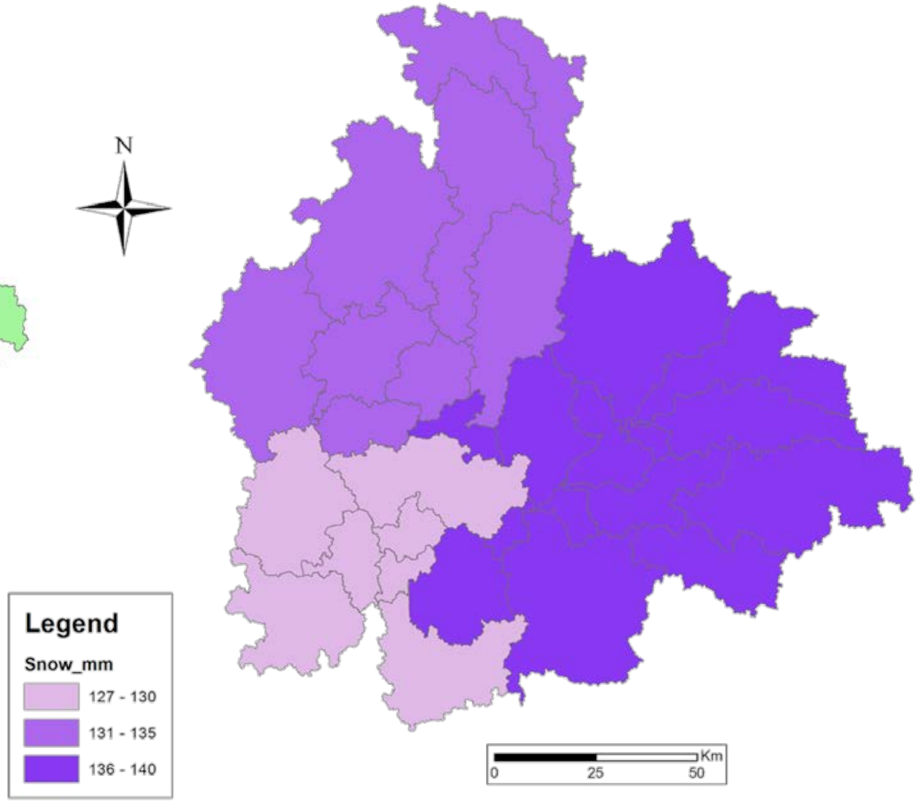


# Water balance time series



# Water balance components distribution



# Conclusions

1. The most important input data – precipitation meets with the most data deficit because of low spatial distribution and data leakage for “in-catchment” scale
2. Authors recommend to use interpolated observed weather data against reanalysis (except downward solar radiation)
3. Using detailed DEM (12.5 m) and LandUse/LandCover (30 m) significantly improve results for daily time step, but almost does not have effect for monthly
4. The most sensitive are some ”snow” and “groundwater” parameters, and also distributed CN2 parameter. Calibration of “snow” parameters should be done separately from others
5. Evaporation is simulated well, but snow water equivalent is slightly overestimated (in comparison to observed)
6. Soil database should be more detailed for daily time step calculations

# How to improve results?

**OBVIOUS REASONS OF UNCERTAINTIES:**

1. Sparse gauging network and gaps in data
2. Global spatial data does not consider local features
3. Whole year calibration procedure does not reflect snowmelt processes well
4. Modeler’s experience

**LIKELY REASONS:**

1.Undistributed snowmelt parameters in SWAT model
2. Equifinality causes water balance errors despite of good NS with runoff
3. Different scale of processes, interactions and it’s description

**HOW TO IMPROVE MODEL BASED RESULTS?**

1. Use local spatial data – especially soil cover, but it is not open source data
2. Investigate in-catchment flow drivers functional roles and distribution
3. Set adequate objectives based on understanding the uncertainties
4. Use alternative data for calculations and constant controlling (e.g. Remote sensing, LSM models etc., field data)