



iAMP-Hydro

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**HYDROPOWER
& DAMS**



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Flow and available power forecasting model development



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WP6 – Flow & available power forecasting model development

Task 6.1: Data sources identification and data preparation for flow forecast

Task 6.2: Flow model analysis and available power forecasting pre-deployment validation

WP7 – Flow & available power forecasting

Task 7.1: Forecast algorithms development at every validation site

Task 7.2: Forecast validation and replicability guideline

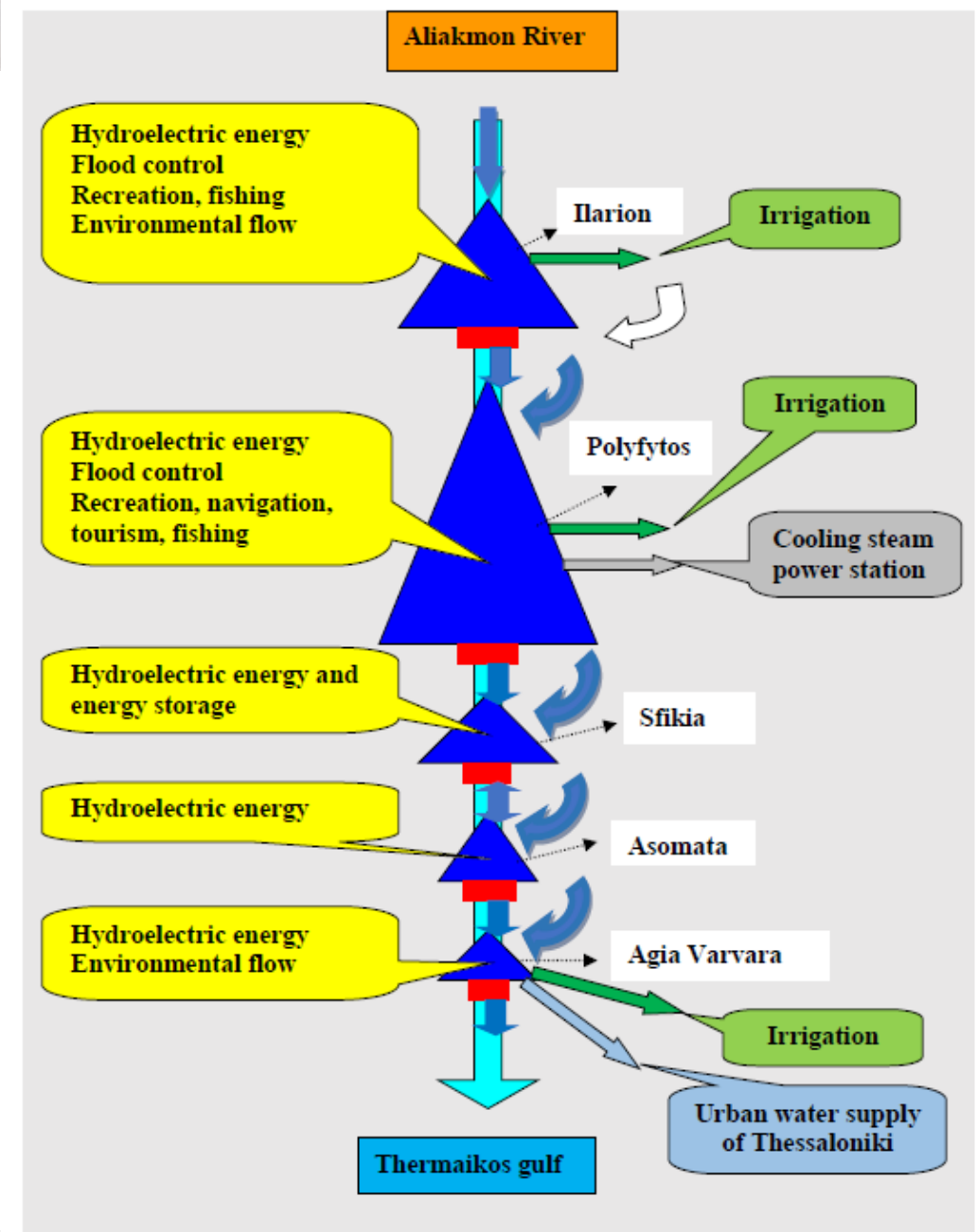
VALIDATION SITES FROM GREECE

Asomata Reservoir / HPP (PPC, Greece)

Agia Varvara Reservoir /
Makrochori SHPP (PPCR, Greece)

Ilarion Reservoir / HPP (PPC, Greece)

Schematic view of the Aliakmon River, resources and demands
[Panagiotis I. Bakanos, 2020]



VALIDATION SITES DATA

Validation site	Type	HOp	Vlive [hm ³]	Qm [m ³ /s]	Tfill [days]	P [MW]	Ean [GWh]	Approach
Asomata	RoR	PPC	10	59.84	1.93	110	~ 130	HBV, SWAT, HEC-HMS MATLAB: ARIMA, LSTM, RF
Agia Varvara / Makrochori	RoR	PPCR	3	47.57	0.73	10.8	~ 30	HBV, SWAT, HEC-HMS MATLAB: ARIMA, LSTM, RF
Ilarion	Reserv	PPC	270	33.98	92	155	~ 330	HBV, SWAT, HEC-HMS MATLAB: ARIMA, LSTM, RF

Asomata, Agia Varvara, Ilarion Reservoirs: Key Performace Indicators (KPIs)

Coefficient of determination

$$R^2 = \left\{ \frac{\sum_{i=1}^N [(Q_{i,obs} - \bar{Q}_{obs})(Q_{i,sim} - \bar{Q}_{sim})]}{\sqrt{\sum_{i=1}^N (Q_{i,obs} - \bar{Q}_{obs})^2 \sum_{i=1}^N (Q_{i,sim} - \bar{Q}_{sim})^2}} \right\}^2$$

$$R^2 > 0.9$$

Root mean square error

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (Q_{i,sim} - \bar{Q}_{obs})^2}{N}}$$

$$RMSE < \frac{1}{2} * \text{std (standard deviation)}$$

Nash-Sutcliffe efficiency

$$NASH = 1 - \frac{\sum_{i=1}^N (Q_{i,sim} - Q_{i,obs})^2}{\sum_{i=1}^N (Q_{i,obs} - \bar{Q}_{obs})^2}$$

$$NASH > 0.85$$



Application of the HBV model on Ilarion reservoir

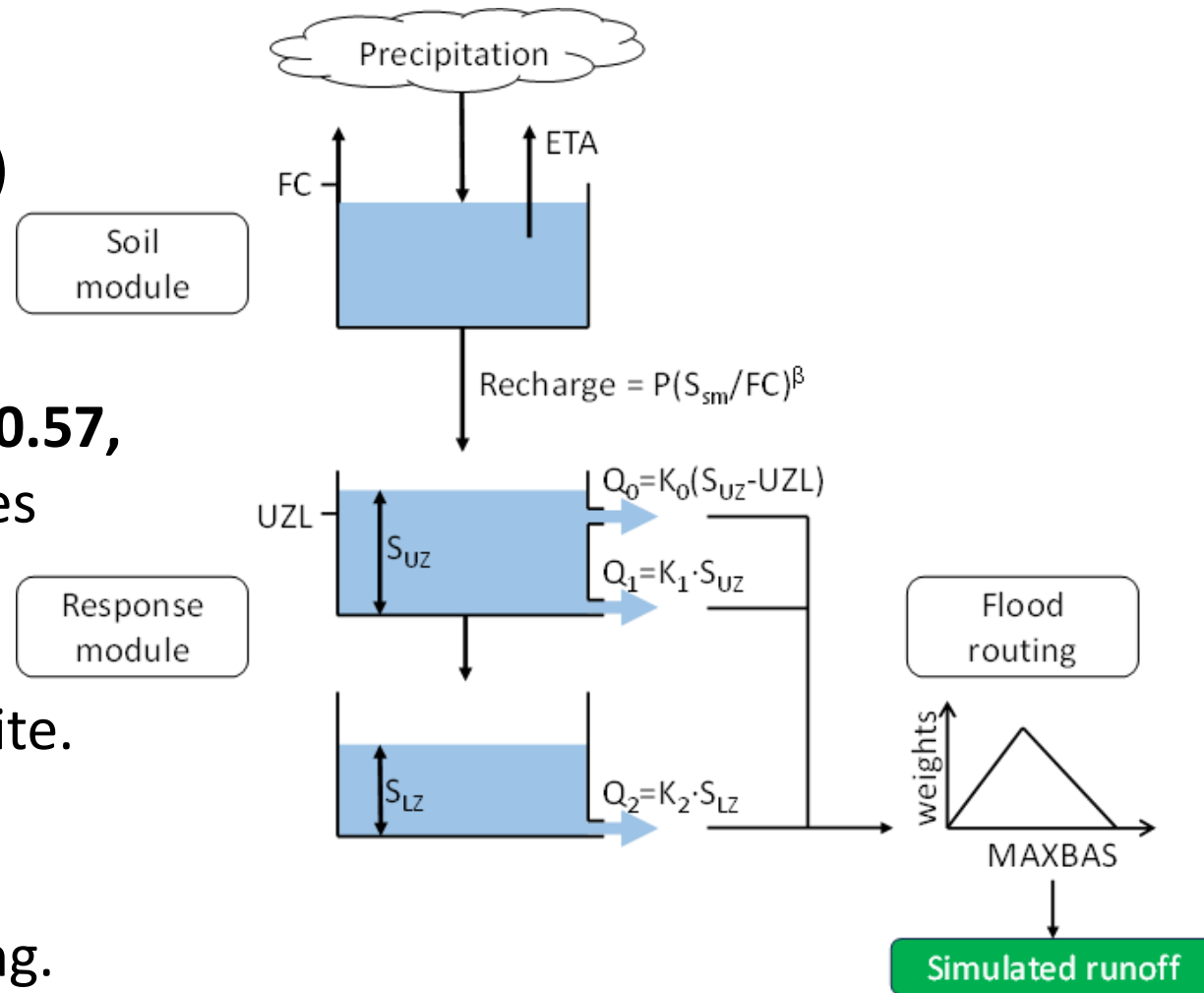
Input data series:

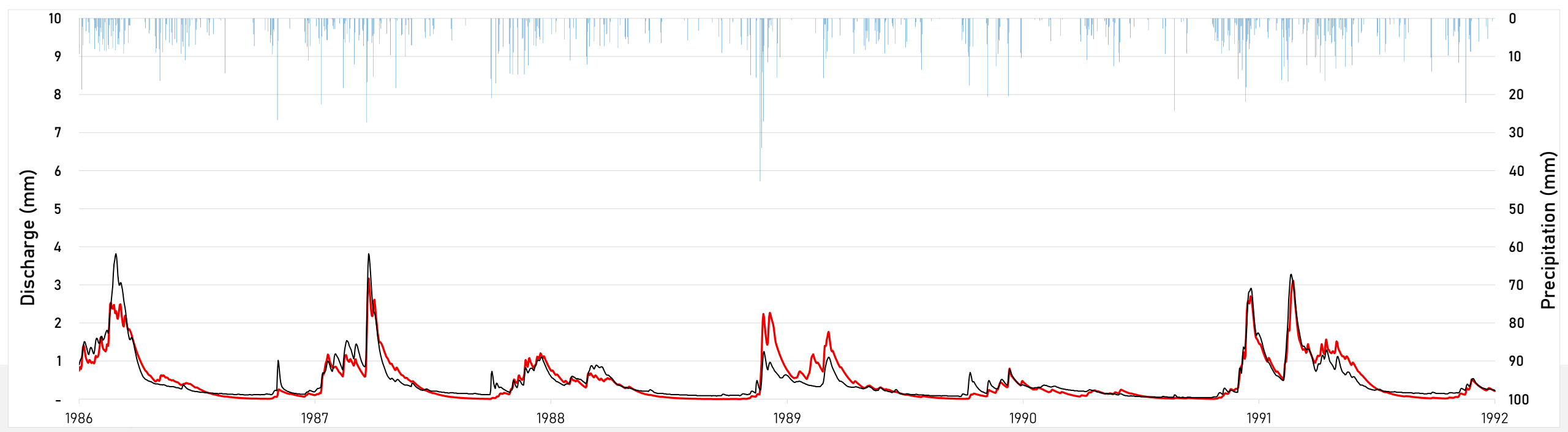
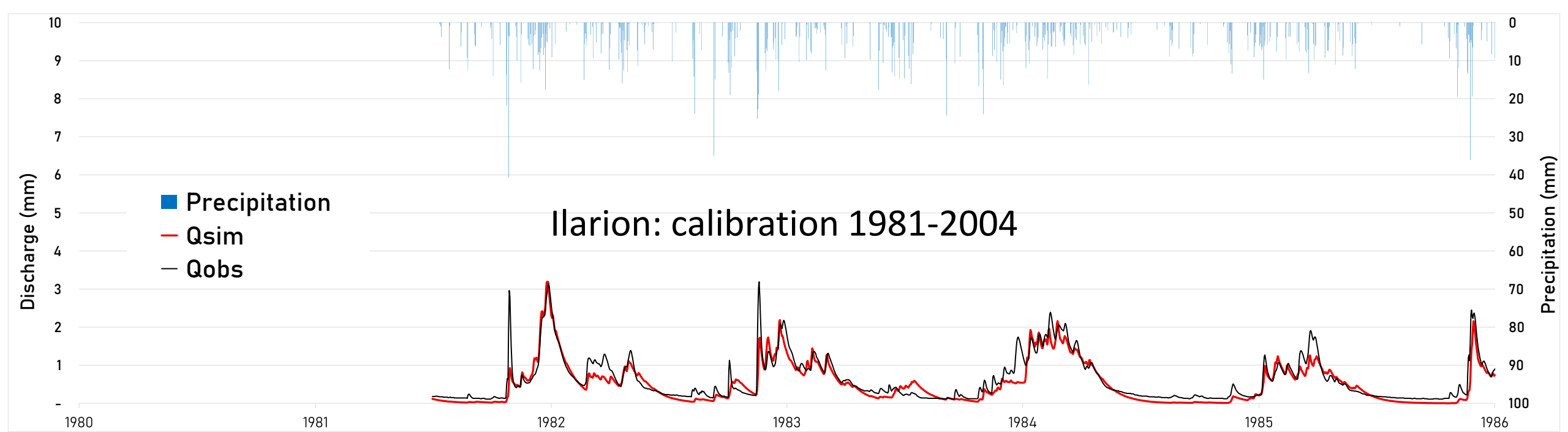
- Daily precipitation and air temperature
- Monthly evapotranspiration (multiannual mean)

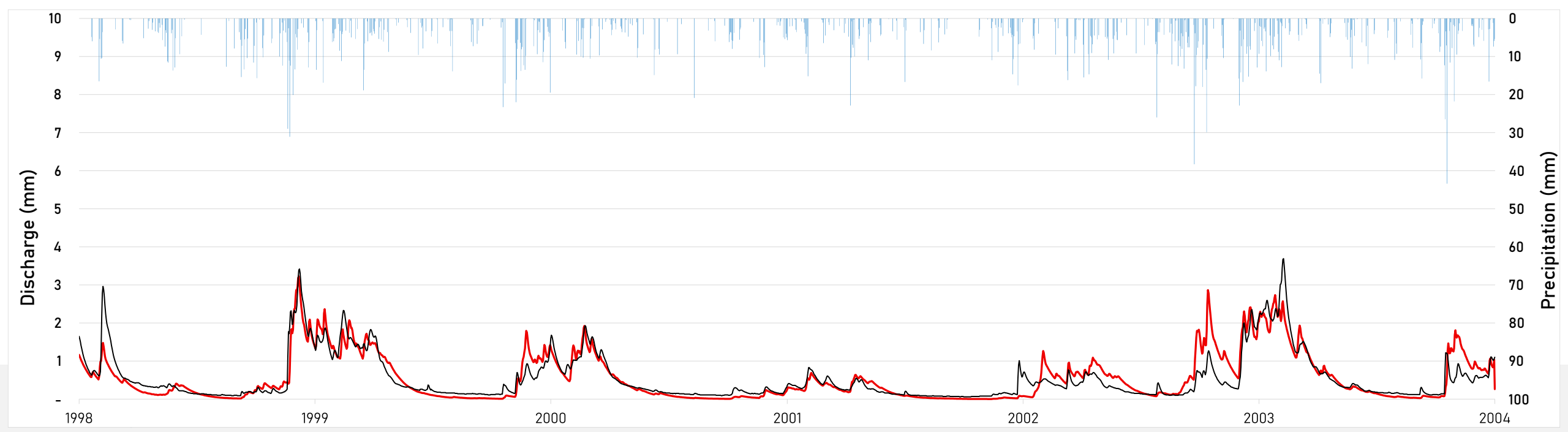
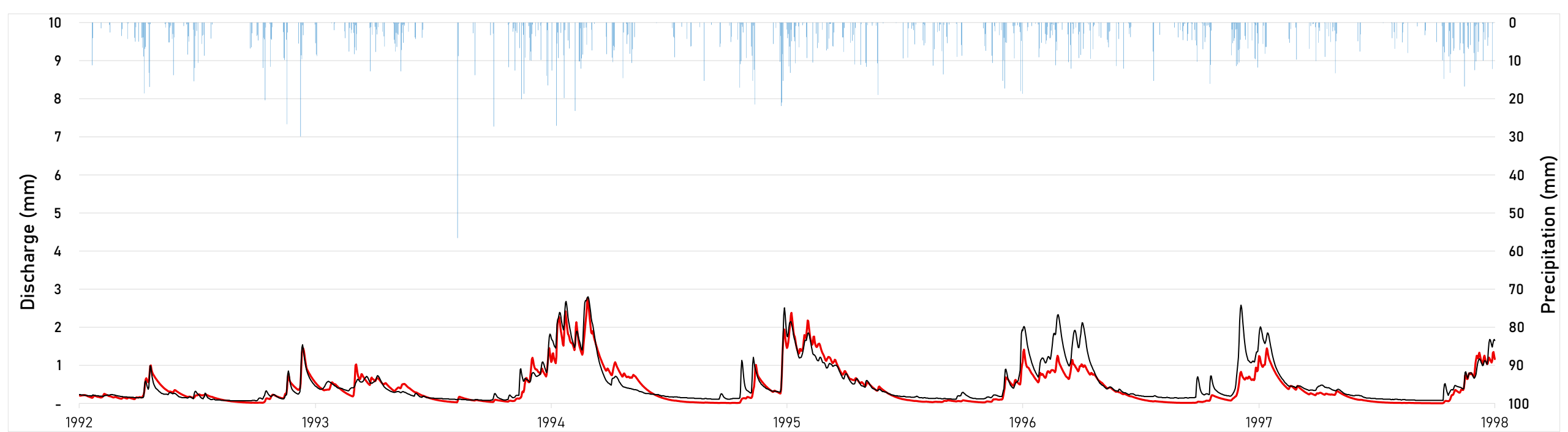
Output: daily streamflow

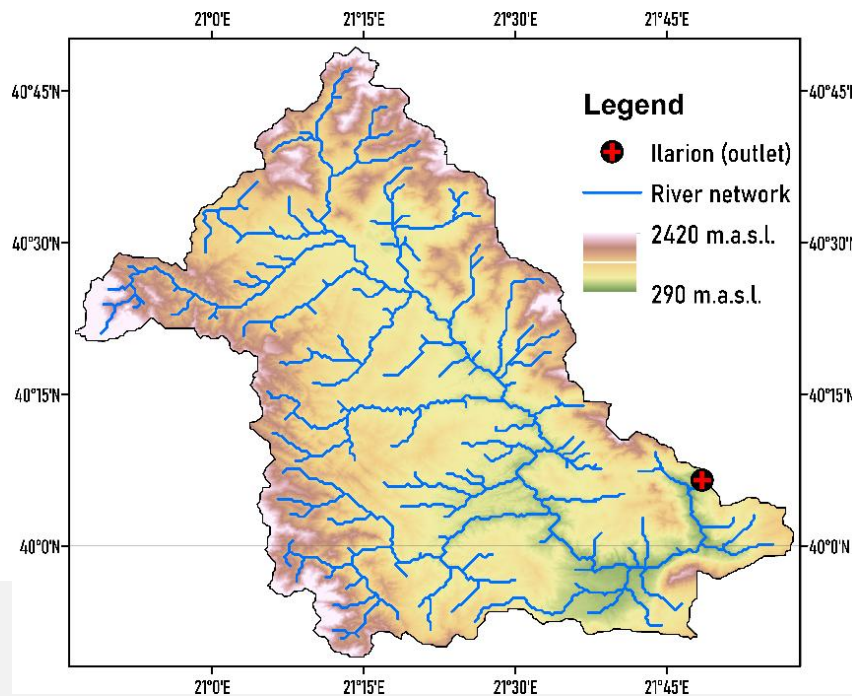
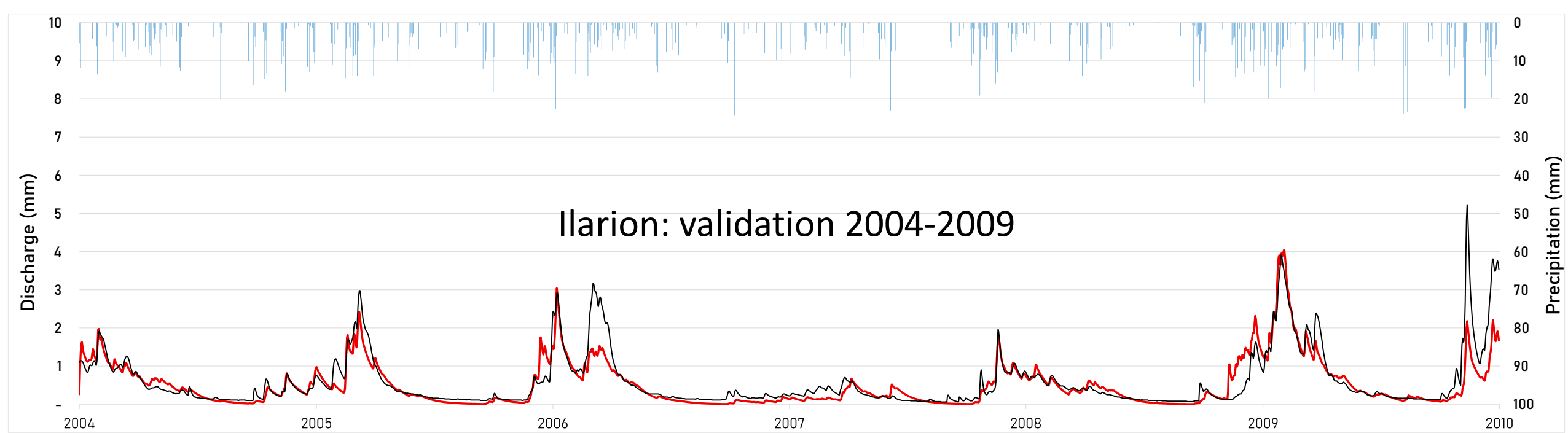
Applied on the following catchments:

- **Asomata, Greece (2007-2018): $R^2=0.16$, $RMSE=0.57$, $NSE=0.03$** Bad results => physical modelling does not yield reliable results for sites with regulated flows => selection of Ilarion, the first reservoir and HPP in the cascade, as the third validation site.
- **Ilarion, Greece (1981-2009);**
- Bermejales, Spain (2015-2024);
- Izvorul Muntelui, Romania (2010-2020) – ongoing.









The HBV model managed to reproduce well the observed streamflow while keeping the parameters values physically meaningful.

Some simulated flood events had underestimated peak flows, while others were overestimated.

Overall, the streamflow was underestimated (positive *PBIAS*) for both calibration and validation.



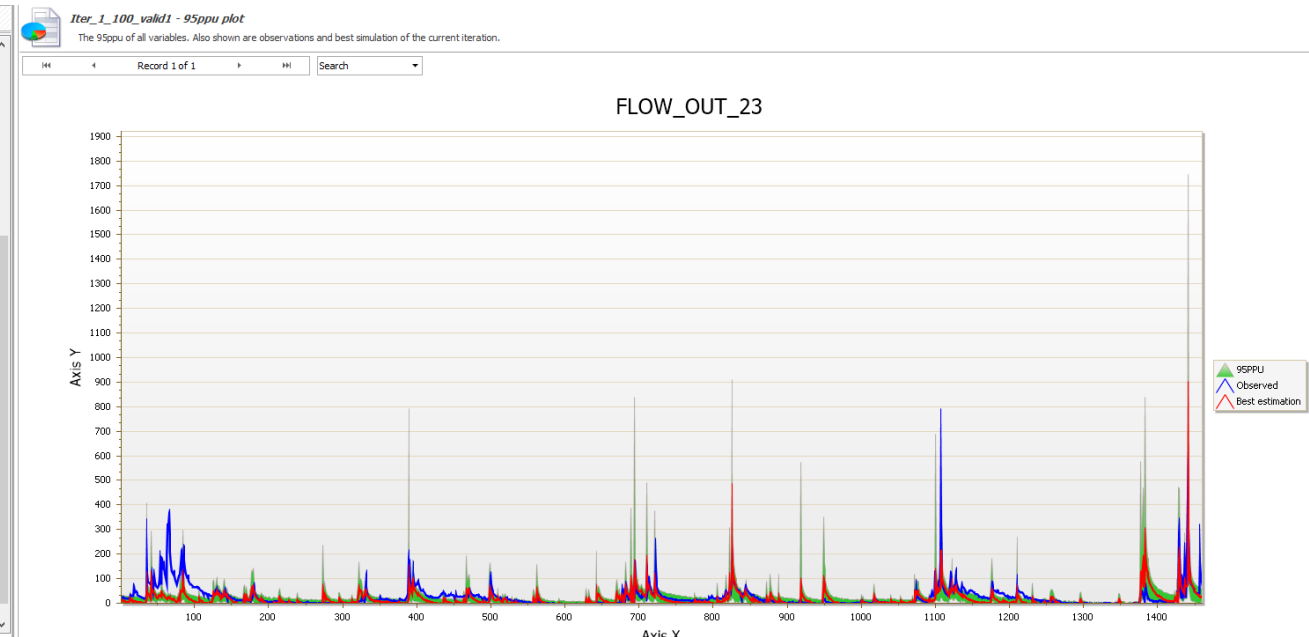
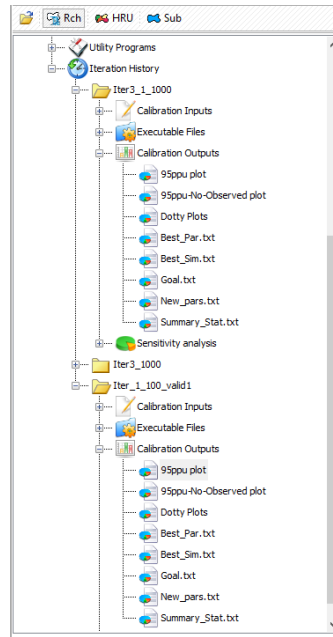
Index	Formula (Value range and Ideal value)	Calibration	Validation
NSE (Nash-Sutcliffe Efficiency)	$NSE = 1 - \frac{\sum_{i=1}^N (Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^N (Q_{obs,i} - \bar{Q}_{obs})^2}$ (Range: $-\infty \dots 1$. Ideal value: 1)	0.805	0.751
MKGE (Modified Kling-Gupta Efficiency)	where: $KGE = 1 - \sqrt{(r - 1)^2 + (\beta - 1)^2 + (\gamma - 1)^2}$ $r = \frac{\sum_{i=1}^N [(Q_{obs,i} - \bar{Q}_{obs})(Q_{sim,i} - \bar{Q}_{sim})]}{\sqrt{\sum_{i=1}^N (Q_{obs,i} - \bar{Q}_{obs})^2 \sum_{i=1}^N (Q_{sim,i} - \bar{Q}_{sim})^2}}; \beta = \frac{\bar{Q}_{sim}}{\bar{Q}_{obs}}; \gamma = \frac{\sigma_{sim}/\bar{Q}_{sim}}{\sigma_{obs}/\bar{Q}_{obs}}$ (Range: $-\infty \dots 1$. Ideal value: 1)	0.867	0.760
PBIAS (Percent Bias)	$PBIAS = 100 \frac{\sum_{i=1}^N (Q_{obs,i} - Q_{sim,i})}{\sum_{i=1}^N (Q_{obs,i})}$ (Range: $-100 \dots \infty$. Ideal value: 0)	8.198	12.305
R² (Coefficient of Determination)	$R^2 = \left\{ \frac{\sum_{i=1}^N [(Q_{obs,i} - \bar{Q}_{obs})(Q_{sim,i} - \bar{Q}_{sim})]}{\sqrt{\sum_{i=1}^N (Q_{obs,i} - \bar{Q}_{obs})^2 \sum_{i=1}^N (Q_{sim,i} - \bar{Q}_{sim})^2}} \right\}^2$ (Range: $0 \dots 1$. Ideal value: 1)	0.814	0.763
EV (Explained Variance)	$EV = 1 - \frac{\sum_{i=1}^N \left[(Q_{sim,i} - Q_{obs,i}) - \frac{1}{N} \sum_{i=1}^N (Q_{sim,i} - Q_{obs,i}) \right]^2}{\sum_{i=1}^N (Q_{obs,i} - \bar{Q}_{obs})^2}$ (Range: $-\infty \dots 1$. Ideal value: 1)	0.811	0.761
MAE (Mean Absolute Error)	$MAE = \frac{1}{N} \sum_{i=1}^N Q_{obs,i} - Q_{sim,i} $ (Range: $0 \dots \infty$. Ideal value: 0)	0.439	0.435
RMSE (Root Mean Square Error)	$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (Q_{obs,i} - Q_{sim,i})^2}$ (Range: $0 \dots \infty$. Ideal value: 0)	0.553	0.604



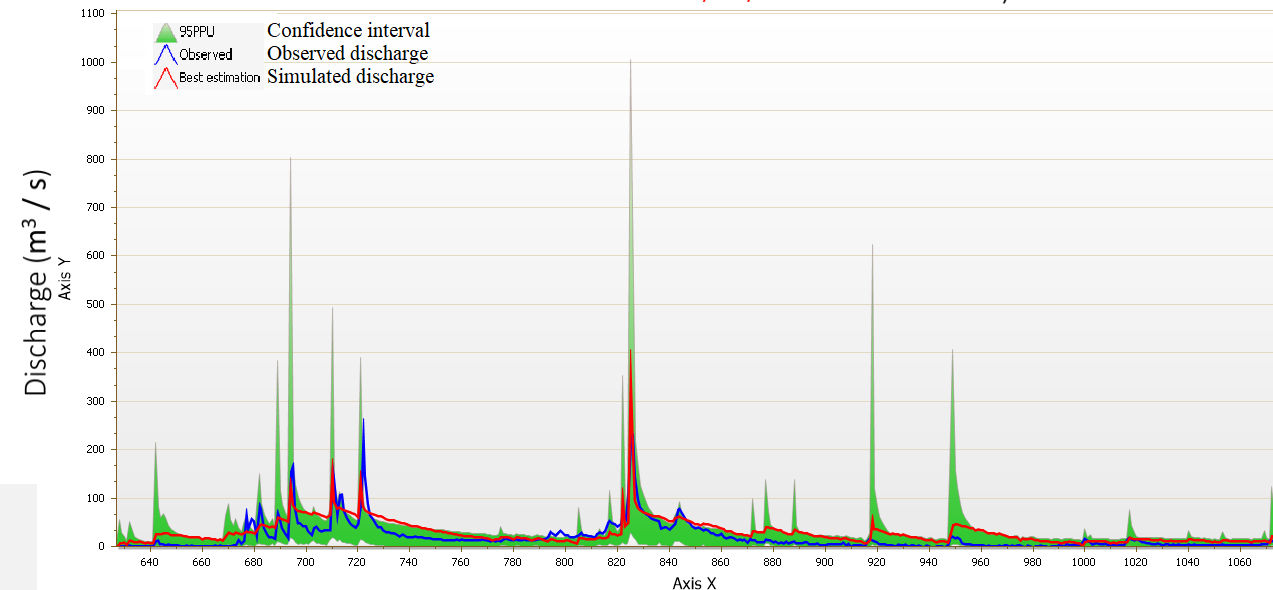
Application of the SWAT model on Ilarion reservoir

Simulated outflow
(01.01.2015 – 31.12.2021)

The **SWAT** model (Soil and Water Assessment Tool) is a widely used model for evaluating soil erosion prevention and control, pollution management, and regional watershed management. In this case, the SWAT model was used to simulate runoff discharges in the Ilarion basin.



Zoom to 20/09/2016 – 15.12.2017)



Time period (Days)

1/01/2015 – 31/12/2021

Key Performance Indicators

p factor: 0.78
 r factor: 0.82
R² : 0.4
NSE : 0.4

Acceptance:

p > 0.7
 r < 1.5
 R² > 0.9
 NSE > 0.85

Model performance
 (Moriasi et al, 2015)

Performance rating	RSR	NSE&R ²	PBIAS
Very good	0.00 ≤ RSR ≤ 0.5	0.75 < NSE ≤ 1.00	PBIAS < ±10
Good	0.5 < RSR ≤ 0.60	0.65 < NSE ≤ 0.75	±10 ≤ PBIAS < ±15
Satisfactory	0.6 < RSR ≤ 0.7	0.5 < NSE ≤ 0.65	±15 ≤ PBIAS < ±25
Unsatisfactory	RSR > 0.7	NSE ≤ 0.5	PBIAS ≥ ±25

p factor - shows the percentage of measured data that fall within the 95PPU confidence interval

r factor - represents the width of this interval (r < 1.5) and reflects the dispersion of the measured data around a mean value (the standard deviation) (Abbaspour, 2015)

```

Iter3_1_1000 - Summary_Stat.txt
This file has the statistics comparing observed data with the simulation band through p-factor and r-factor and the best simulation of the current iteration by using R2, NS, bR2, MSE, and SSQR.

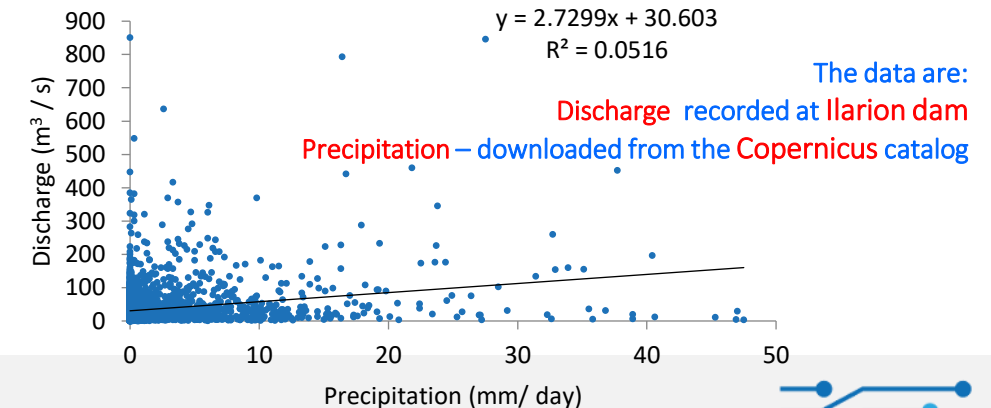
Goal_type= R2 No_sims= 1000 Best_sim_no= 928 Best_goal= 4.047052e-001

Variable p-factor r-factor R2 NS bR2 MSE SSQR PBIAS KGE RSR MNS VOL_FR
FLOW_OUT_23 0.78 0.82 0.40 0.40 0.1664 1.8e+003 6.4e+002 6.9 0.49 0.77 0.34 1.07
    
```

Low KPIs? Why?

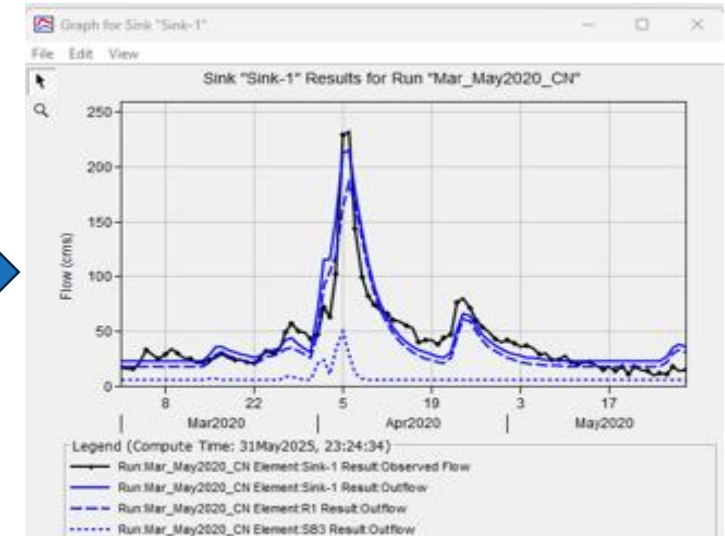
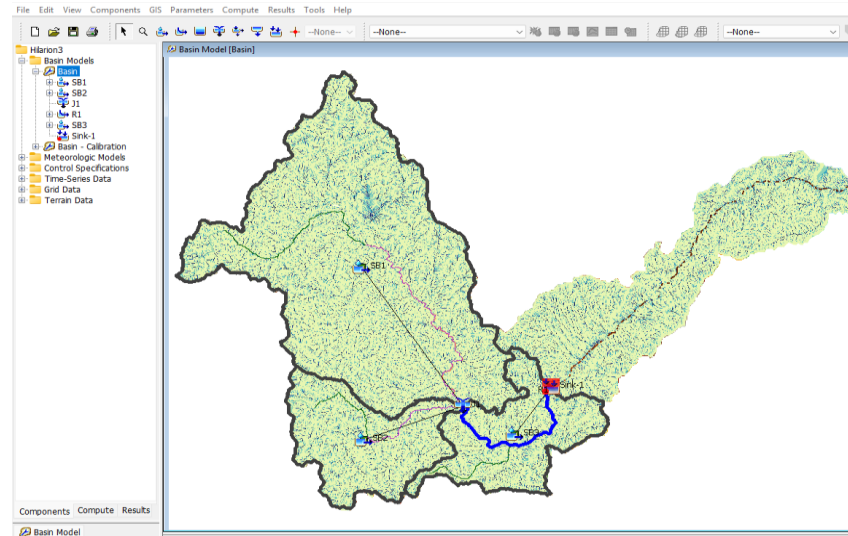
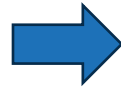
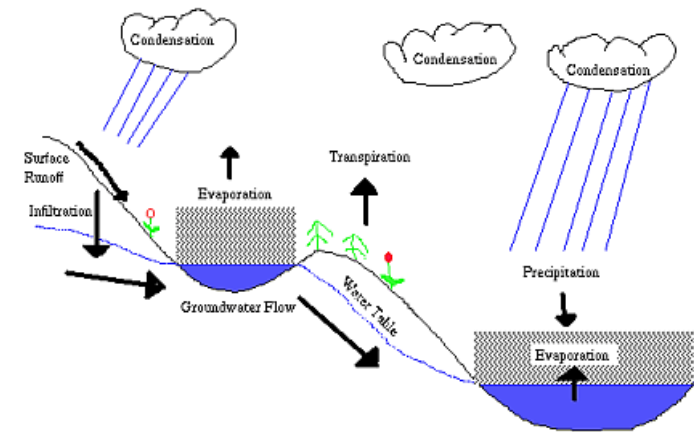
Because each watershed exhibits a distinct hydrological response, and since the SWAT model simulates runoff through complex interactions involving surface runoff, infiltration, retention, lateral flow, evapotranspiration, soil characteristics, and land use, it is essential that all input data be obtained directly from measurements within the study watershed.

The climatic factors found and downloaded from specialized websites do not fully correspond to the flow rates recorded at the Ilarion station.
 Correlation between online precipitation data and measured flows



Application of the HEC-HMS model on Ilarion reservoir

The hydrological model was **developed using HEC-HMS**, an open-source hydrologic simulation software, to **simulate inflows** into the Ilarion Reservoir.



Source: <https://www.weather.gov/abr/cf/stmethods>

HEC-HMS: Hydrologic Modeling System
US Army Corps of Engineers Hydrologic Engineering Center

Observed vs. Simulated Hydrograph at the
Breakpoint of the HEC-HMS Model

1. Acquisition and preprocessing of input data

2. The development of the hydrological model in HEC-HMS

3. HEC-HMS simulation results after manual calibration for Ilarion breakpoint

Acquisition and processing of input data

- Data used for the development of the physical model: **DEM-SRTM**
(Digital Elevation Model – Shuttle Radar Topography Mission)

Spatial resolution: 30 meters (SRTM 1 arc-second)

Used for: automatic watershed delineation, slope calculation, time of concentration estimation, stream length measurement, generation of the river network and sub-basins.

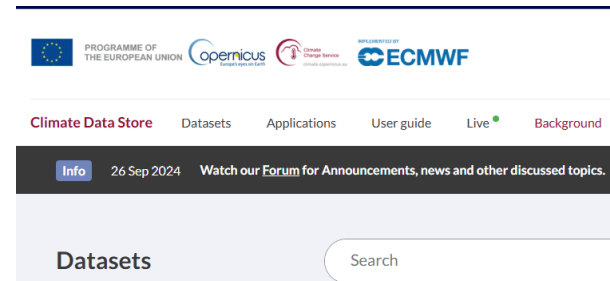
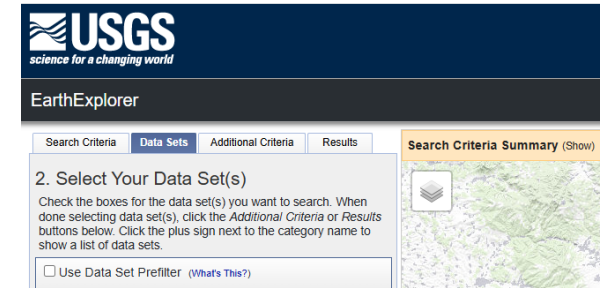
Land cover: CORINE Land Cover (CLC 2018), ESRI Sentinel 2 =>

Curve Number (CN) – a parameter that represents the capacity of soil and land cover to promote infiltration and limit surface runoff, [<https://land.copernicus.eu/pan-european/corine-land-cover/>]

- Meteorological input data include **PRECIPITATION** (mm/h) and **AIR TEMPERATURE** (°C), used for simulating rainfall-runoff processes.

Examples:

- Copernicus.eu (ERA5-Land Hourly Data from 1950 to Present database),
- Copernicus.eu (E-OBS daily gridded meteorological data for Europe),
- Open-meteo.com (Historical Weather API from 1940 until now).



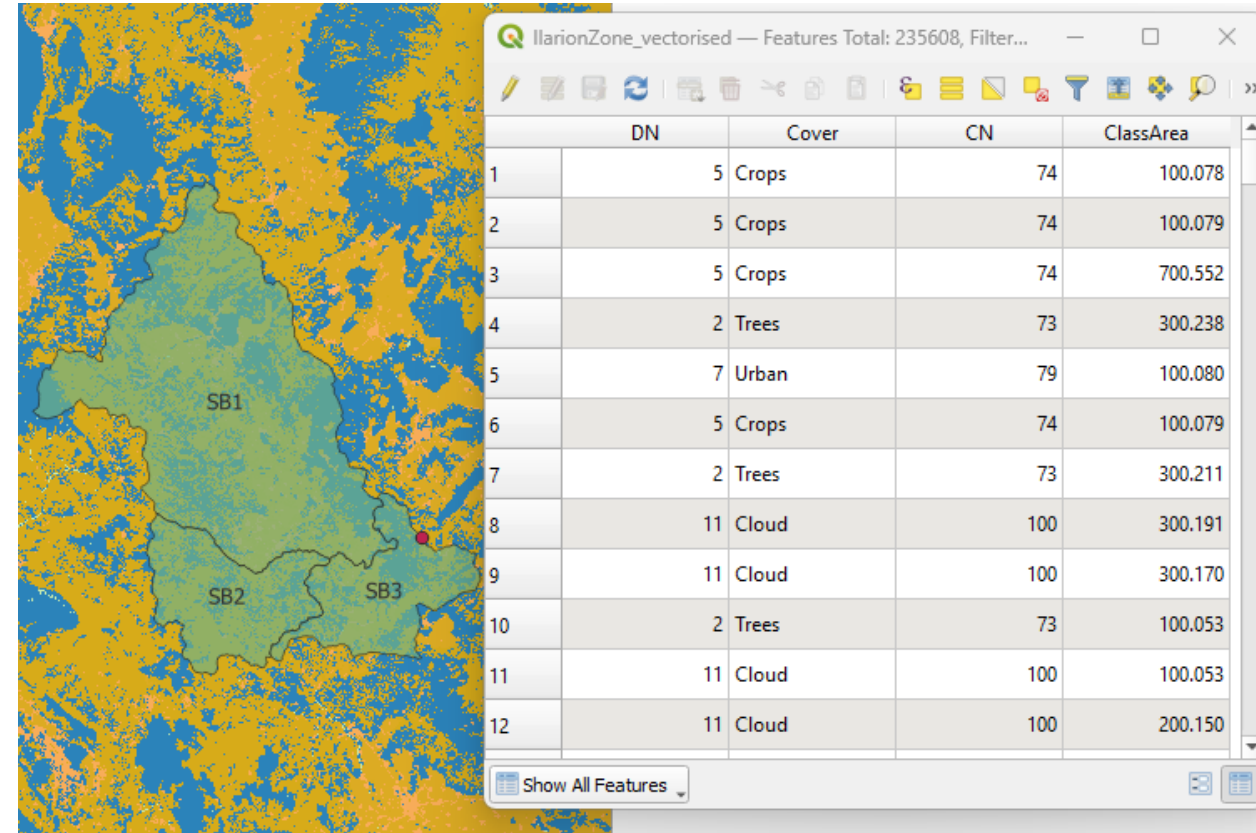
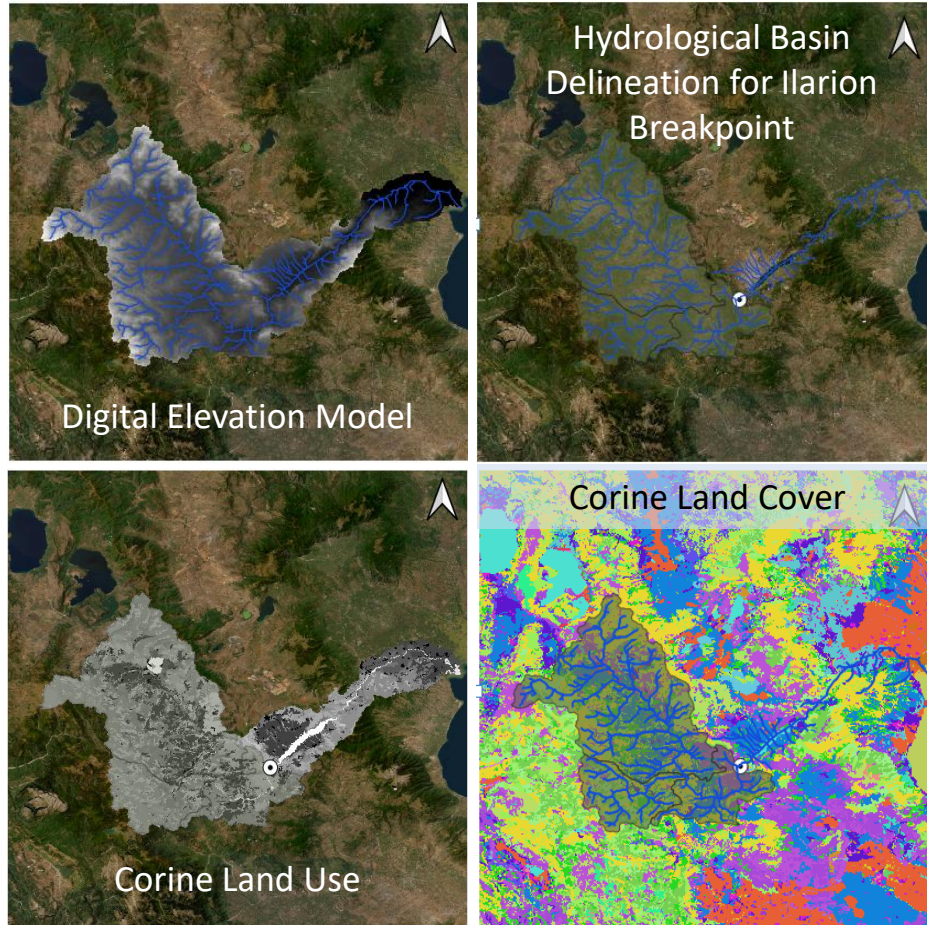
<https://cds.climate.copernicus.eu/datasets>



<https://open-meteo.com/en/docs/historical-weather-api>

Acquisition and processing of input data

- The **DEM-SRTM**, hydrological basin delineation (<https://mghydro.com/>), Corine Land Use, and the 2018 Corine Land Cover were processed and analyzed in QGIS 3.38.



Curve Number (CN) values calculated for each sub-basin delineated in HEC-HMS.

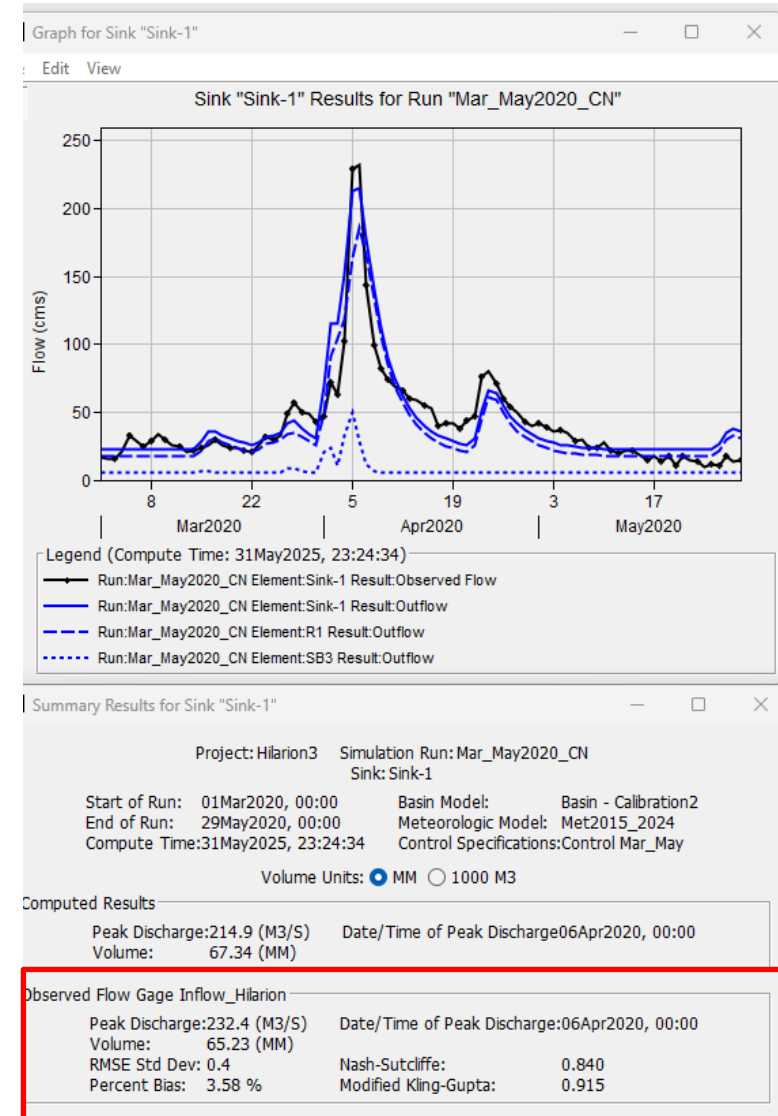
Hydrological Model Setup and Configuration in HEC-HMS + Results

Model calibration = adjusting hydrological parameters (runoff coefficient or time of concentration), so that the simulated flow closely matches measured data.

Historical data series are used for comparison and validation. Performance indicators (KPIs), after manual calibration, fall into “good” to “very good” range for the validation period, March-April 2020.

KPIs: Nash-Sutcliffe Efficiency (NSE),
Ratio of the Root Mean Square Error to the Standard Deviation Ratio (RSR),
Percent Bias (PBIAS)

Run \ Performance indicator	NSE	RSR	PBIAS (%)
1	0.129	0.9	-21.88
2	0.856	0.4	1.15
3	0.84	0.4	3.58



Asomata, Agia Varvara, Ilarion Reservoirs (PPC – PPCR)

Time series forecasting using ARIMA, LSTM & Random Forest (MATLAB)

Data measured: daily inflows [m³/s]

Asomata Reservoir: training 2011 to 2021, forecast for 2022

Agia Varvara Reservoir: training 2010 to 2021, forecast for 2022

Ilarion: training 2015-2023, forecast for 2024

Characteristics for daily inflows:

Reservoir	min [m ³ /s]	max [m ³ /s]	mean [m ³ /s]	std [m ³ /s]
Asomata	0	242.36	56.83	37.28
Agia Varvara	0.37	244.36	47.58	35.98
Ilarion	0.04	600	33.77	49.94

LSTM

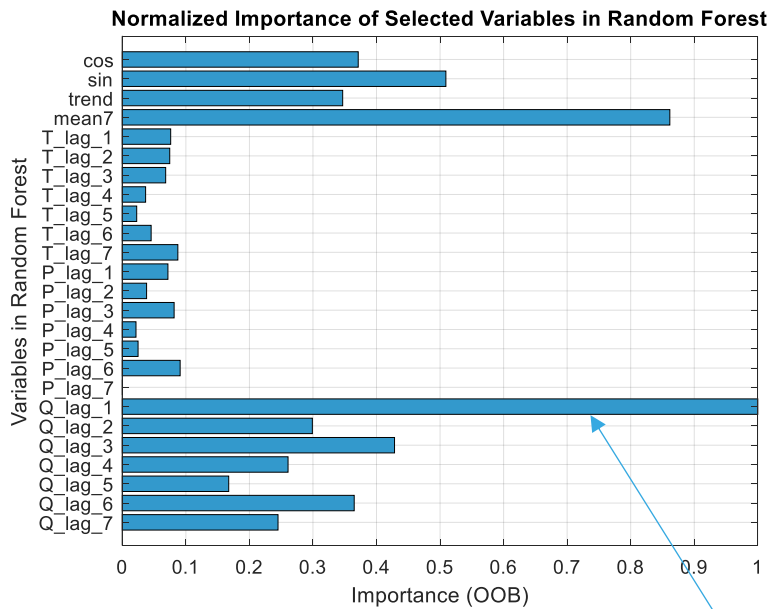
- **Windowing & Splitting**
 - Use a 30-day sliding window
- **Train/Validation Split** 80% training, 20% validation
- **Testing** : last 365 days of available data
- **Normalization**
 - Scale Q , P, and T between 0 and 1 using training min/max
- **Seasonality Features**
 - Add sine/cosine components for yearly cycles
- **Preparing Model Inputs**
 - Sequence length of 30 normalized values
 - Adding:
 - Mean of last 7 days
 - Trend (last value – mean)
 - Seasonal components (sin/cos)
 - 7-day lags for P and T
- **Output: next value of Q**



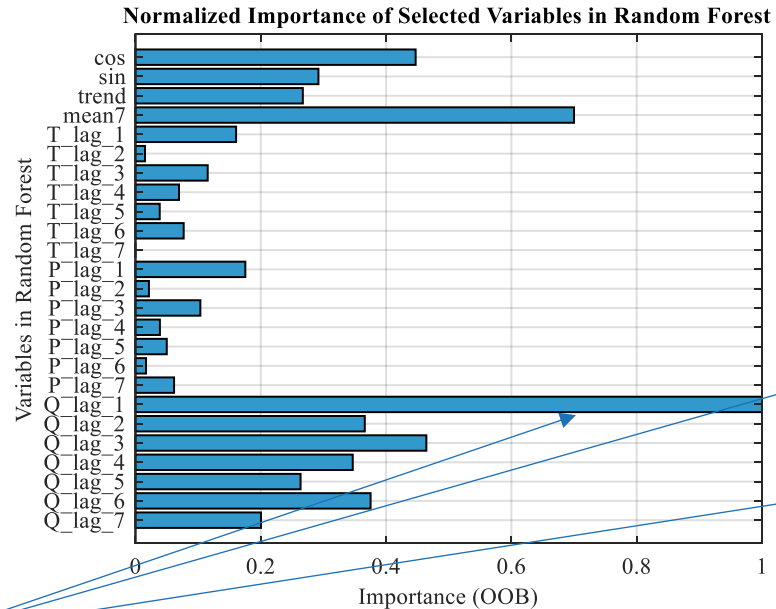
Random Forest

- Builds multiple trees, each based on conditional logic (if this, then that)
- **Trees:** 300 decision trees
- **Features per split:** 34 randomly sampled

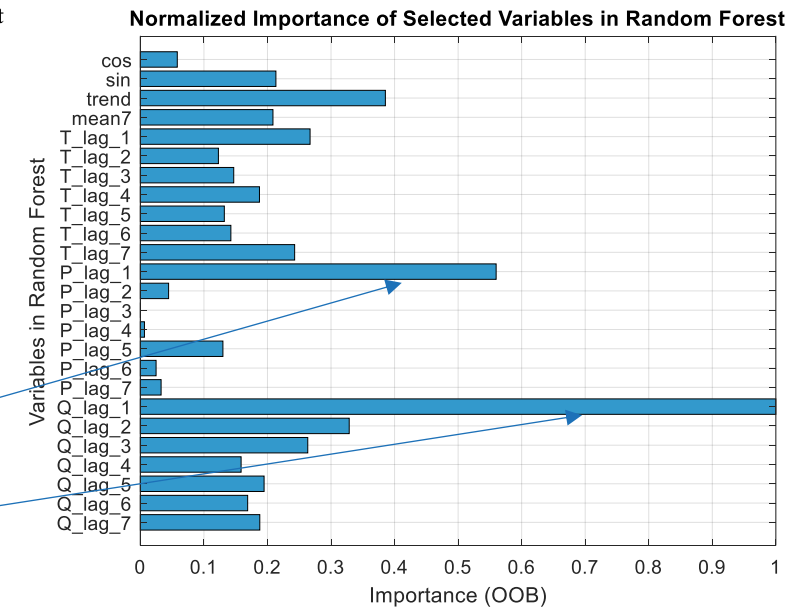
ASOMATA



Agia Varvara



ILARION

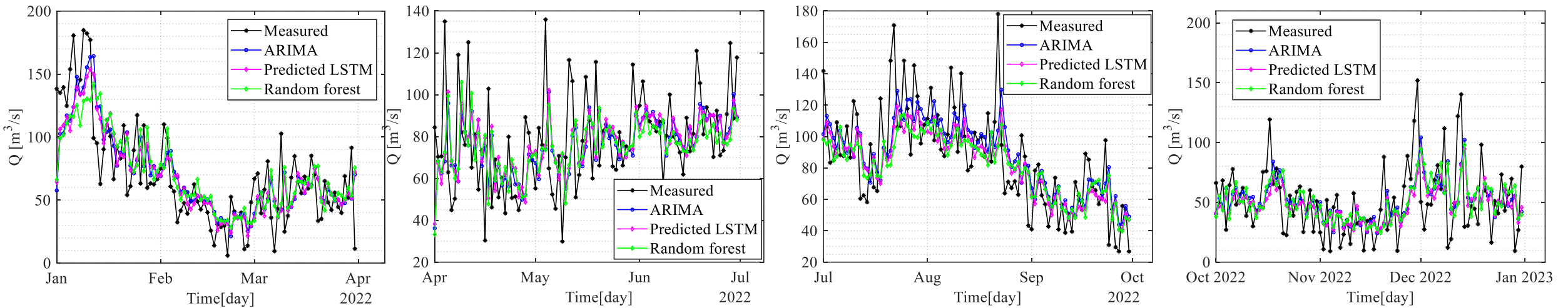


Very important feature for all is $Q(t-1)$, also precipitations for Ilarion.

Legend: OOB = Out Of Bag



ASOMATA



Model	Training			Validation			Testing		
	R ²	RMSE	NSE	R ²	RMSE	NSE	R ²	RMSE	NSE
ARIMA	-	-	-	-	-	-	0.42	26.24	0.419
LSTM	0.65	22.50	0.65	0.55	20.51	0.55	0.43	25.92	0.43
Random Forest	0.90	12.2	0.89	0.53	21.02	0.53	0.39	27.00	0.38

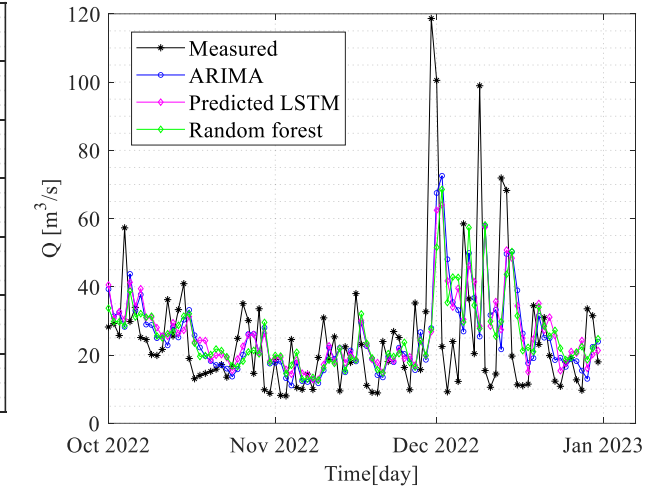
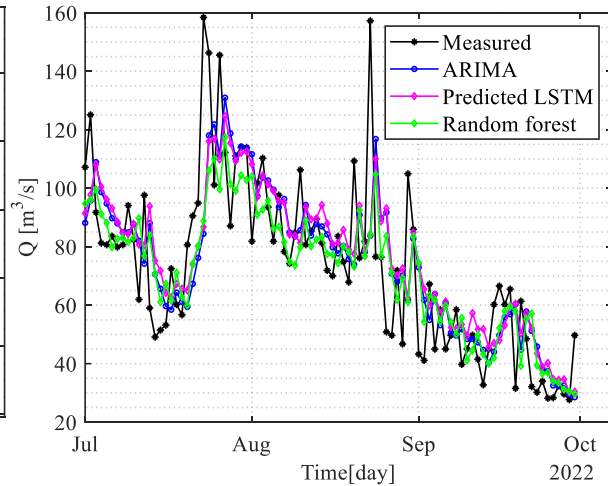
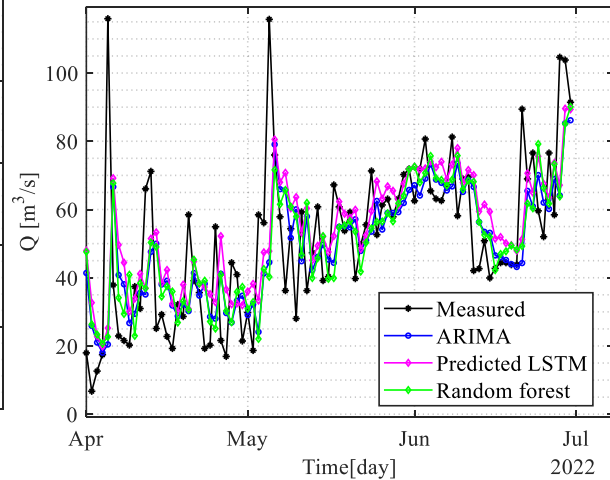
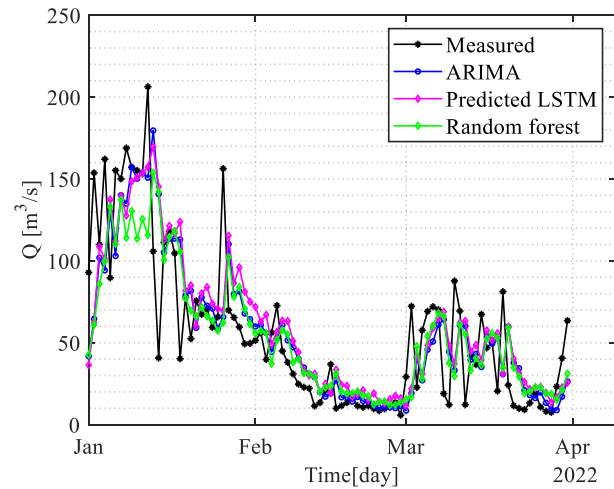
R² > 0.9

RMSE < std/2=19

NSE > 0.85



AGIA VARVARA



Model	Training			Validation			Testing		
	R ²	RMSE	NSE	R ²	RMSE	NSE	R ²	RMSE	NSE
ARIMA							0.60	22.93	0.59
LSTM	0.75	18.74	0.74	0.74	14.47	0.73	0.60	23.11	0.58
Random Forest	0.92	10.38	0.92	0.74	14.18	0.74	0.59	22.98	0.59

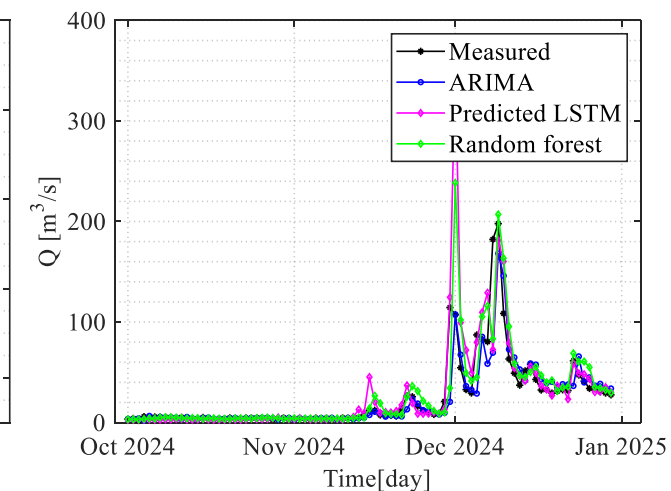
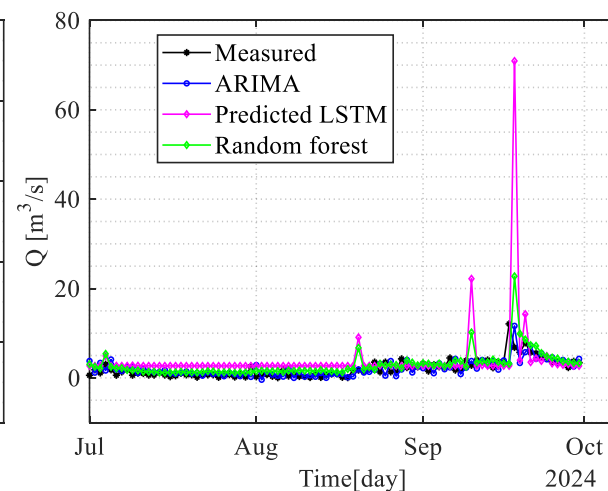
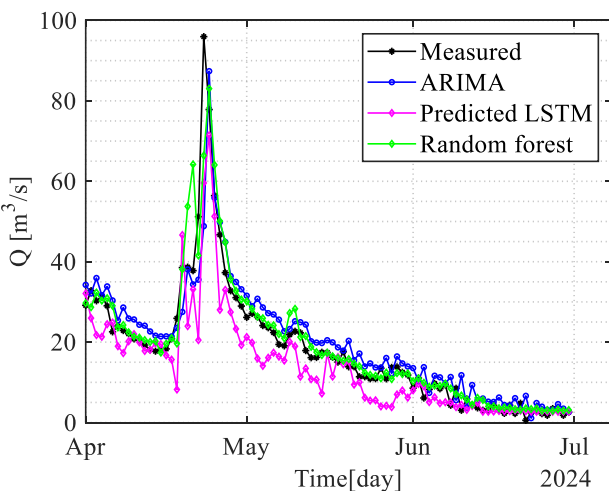
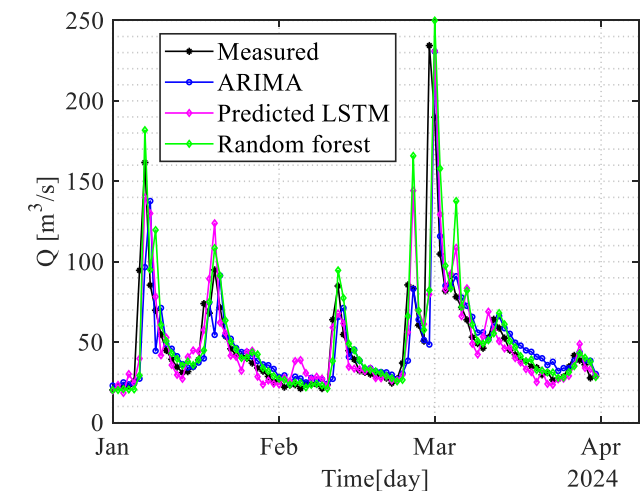
R² > 0.9

RMSE < std/2=18

NSE > 0.85



ILARION



Model	Training			Validation			Testing		
Model	R ²	RMSE	NSE	R ²	RMSE	NSE	R ²	RMSE	NSE
ARIMA							0.73	16.01	0.73
LSTM	0.78	26.05	0.78	0.65	18.47	0.62	0.69	19.48	0.60
Random Forest	0.91	16.56	0.91	0.73	17.49	0.66	0.76	16.73	0.71

R² > 0.9

RMSE < std/2 = 25 m³/s ✓

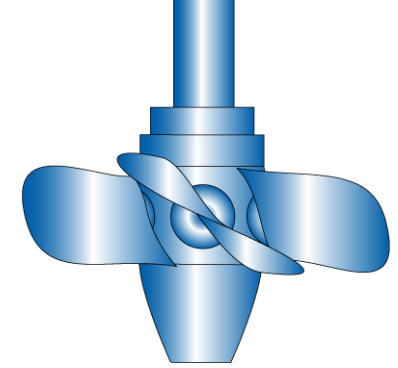
NSE > 0.85





Thank you!

**HYDRO
2025**



POLITEHNICA

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(on behalf of POLI team)

