Precipitation & Runoff modeling of Savinja catchment

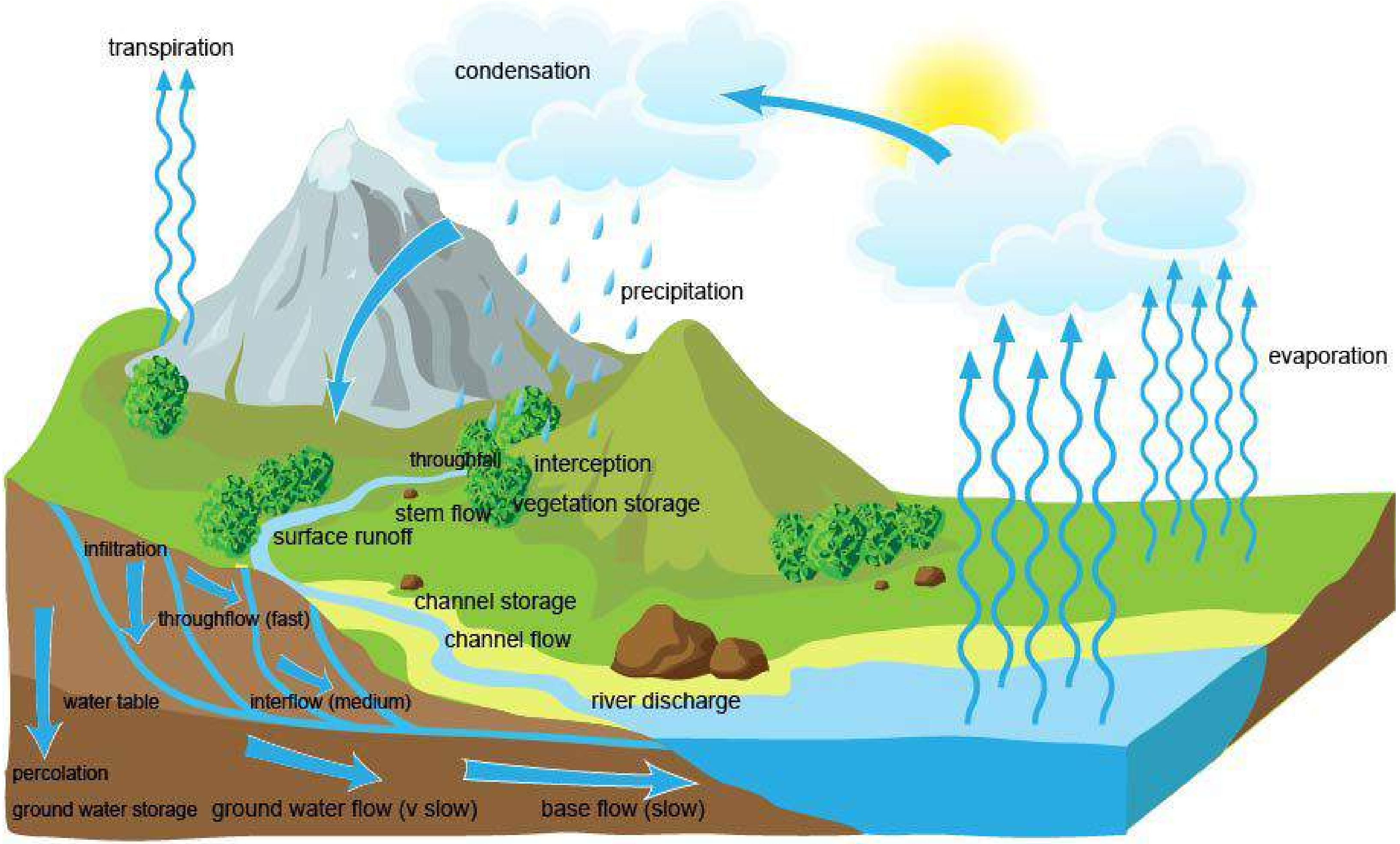
Hidrološko modeliranje porečja Savinje

36. Goljevščkov spominski dan
Ljubljana, 23.03.2017

Email: andrej.vidmar@fgg.uni-lj.si

University of Ljubljana
Faculty of Civil and Geodetic Engineering

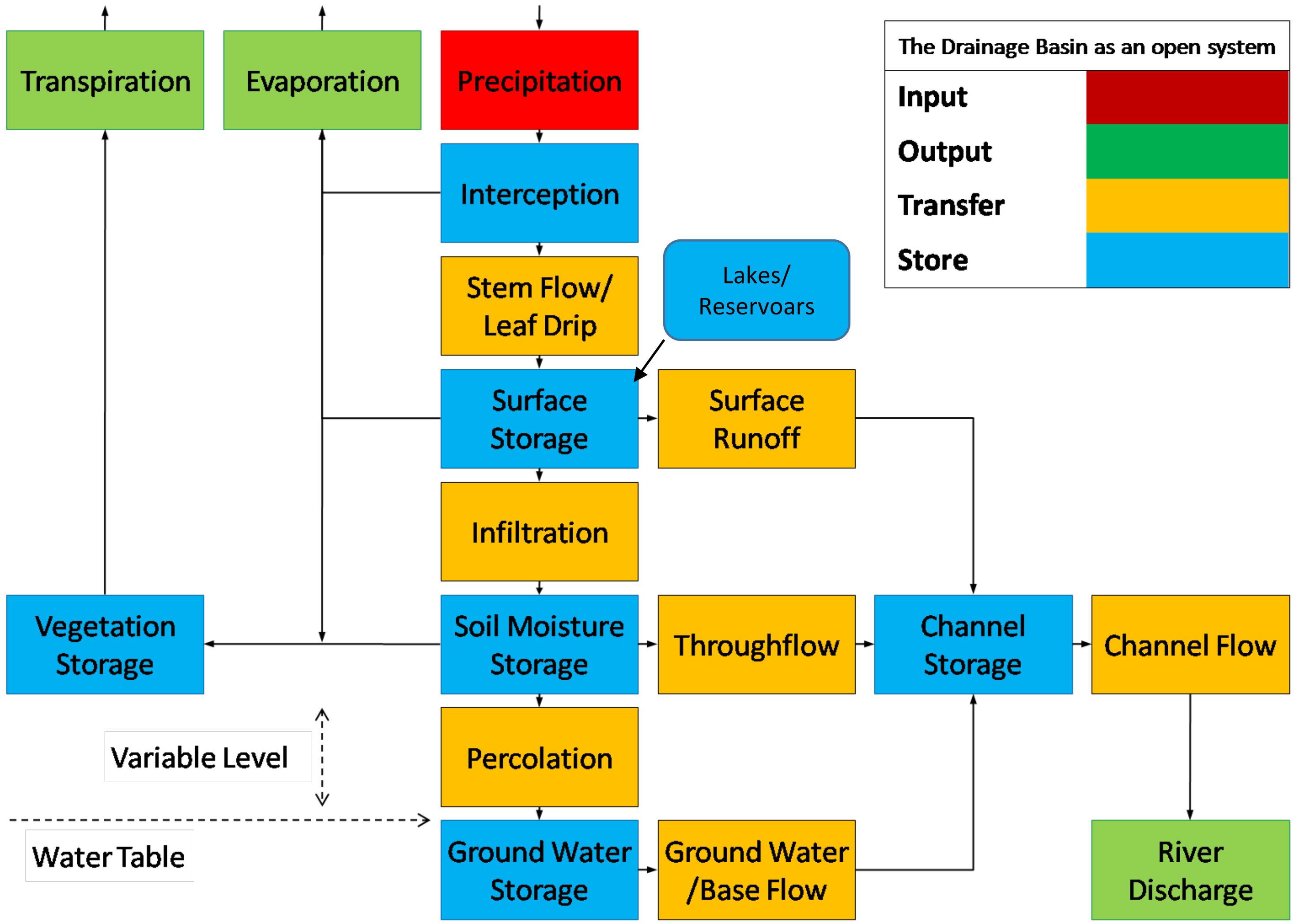
The drainage basin hydrological cycle



The drainage basin hydrological system

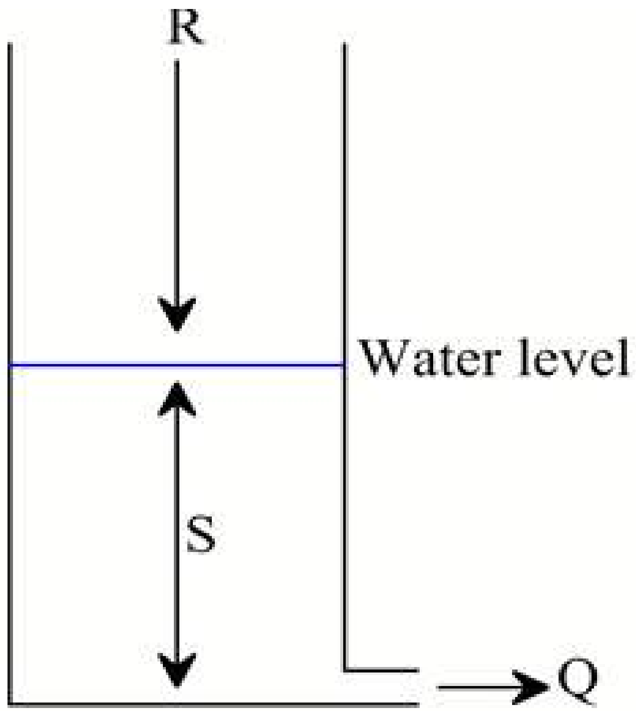
Source: http://www.alevelgeography.com/drainage-basin-hydrological-system

Drainage Basin Flow Chart



Source: http://www.alevelgeography.com

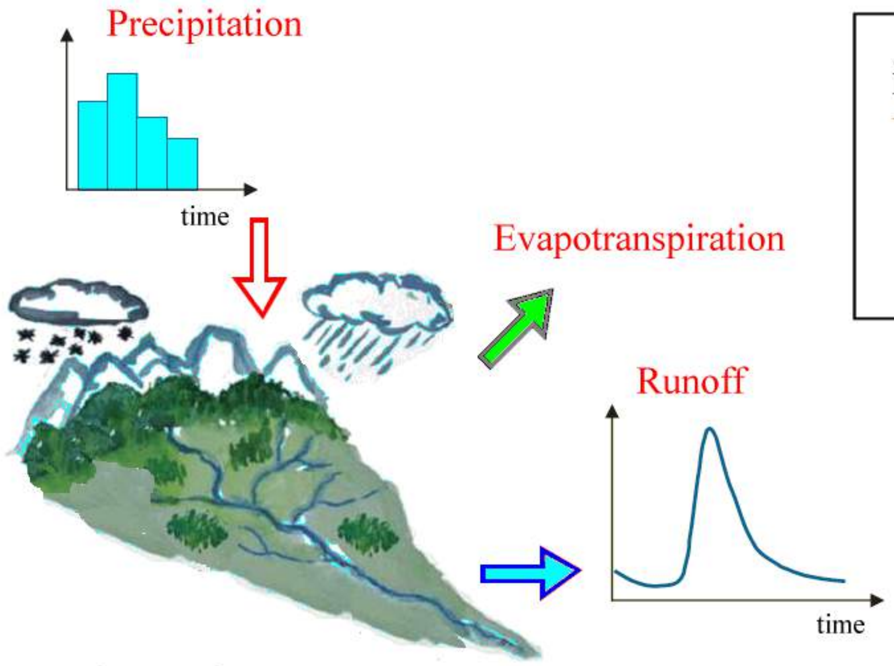
The basic principle

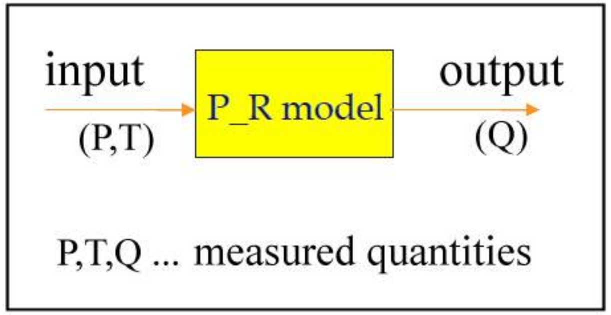


Relationship between precipitation and runoff

The water catchment area as a unique system,
in which the precipitation are transformed into the runoff!

- input: precipitation, temperature
- output: runoff





Which hydrological model?

- various ongoing researches are there on topics like which model will give more compatible results compared to P-R relations
- HSPF, HSPEXP+, TOPMODEL, HBV-96, WFLOW Py(distributed HBV), MIKE-SHE, SWAT, SWMM, RS Minerve…

HBV-light & PEST

HBV-light: http://www.geo.uzh.ch/en/units/h2k/services/hbv-model/
PEST: http://www.pesthomepage.org/

HBV - Hydrologiska Byråns Vattenbalansavdelning (Hydrological Agency Water Balance Department)

- The HBV model (Bergström, 1976, 1992) is a rainfall-runoff model, which includes conceptual numerical descriptions of hydrological processes at the catchment scale. The general water balance can be described as

$$P - E - Q = \frac{d}{dt}\left[SP + SM + TZ + UZ + LZ + lakes\right]$$

Where

P = precipitation

E = evapotranspiration

Q = runoff

SP = snow pack

SM = soil moisture

TZ = storage in soil top zone (introduced in HBV-light) UZ = upper groundwater zone storage

LZ = lower groundwater zone storage

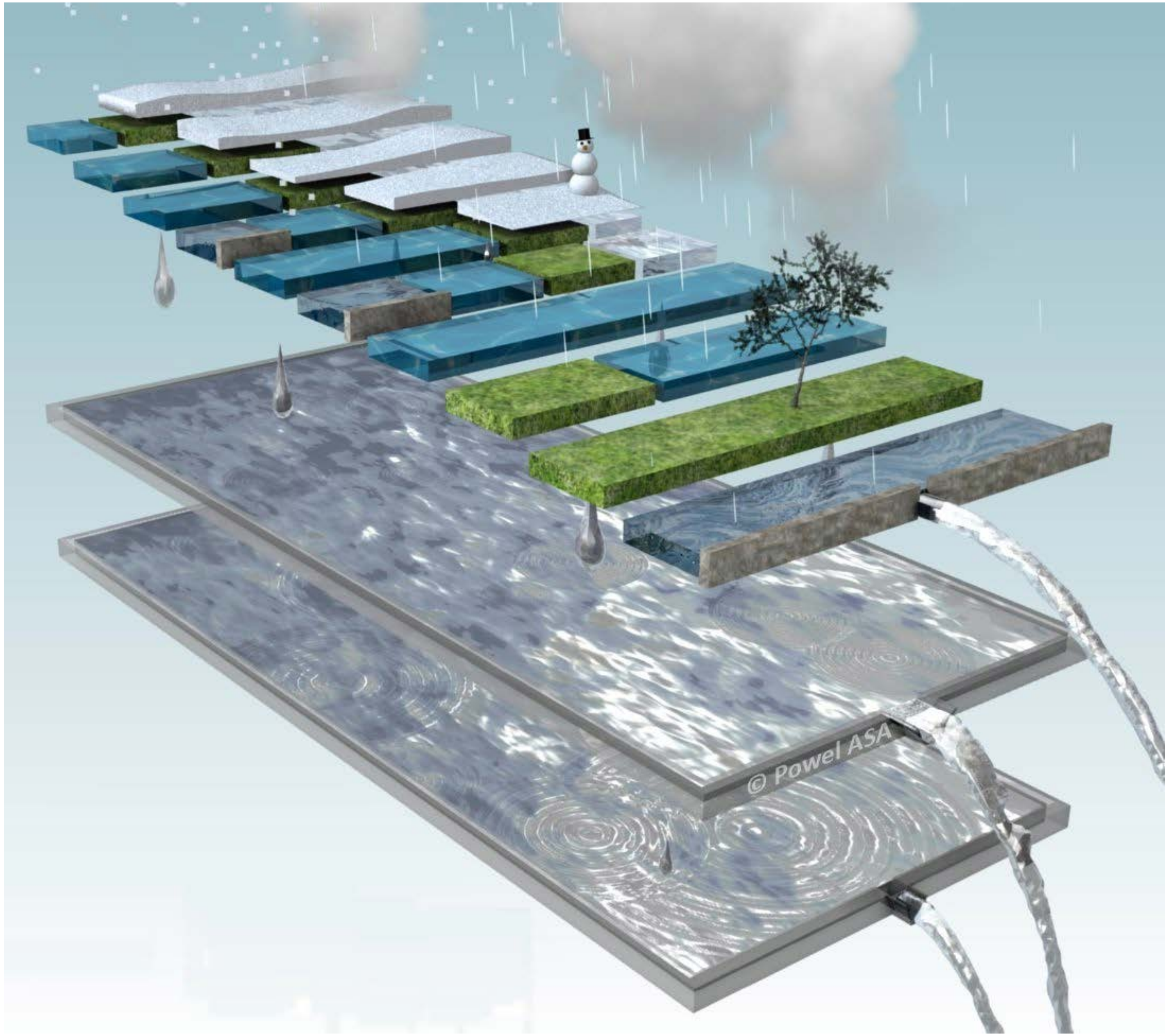
lakes = lake volume

Source: http://www.smhi.se/forskning/forskningsomraden/hydrologi/hbv-1.1566

Semi-distribution

Subdivides a large problem into smaller, simpler parts with unique characteristic

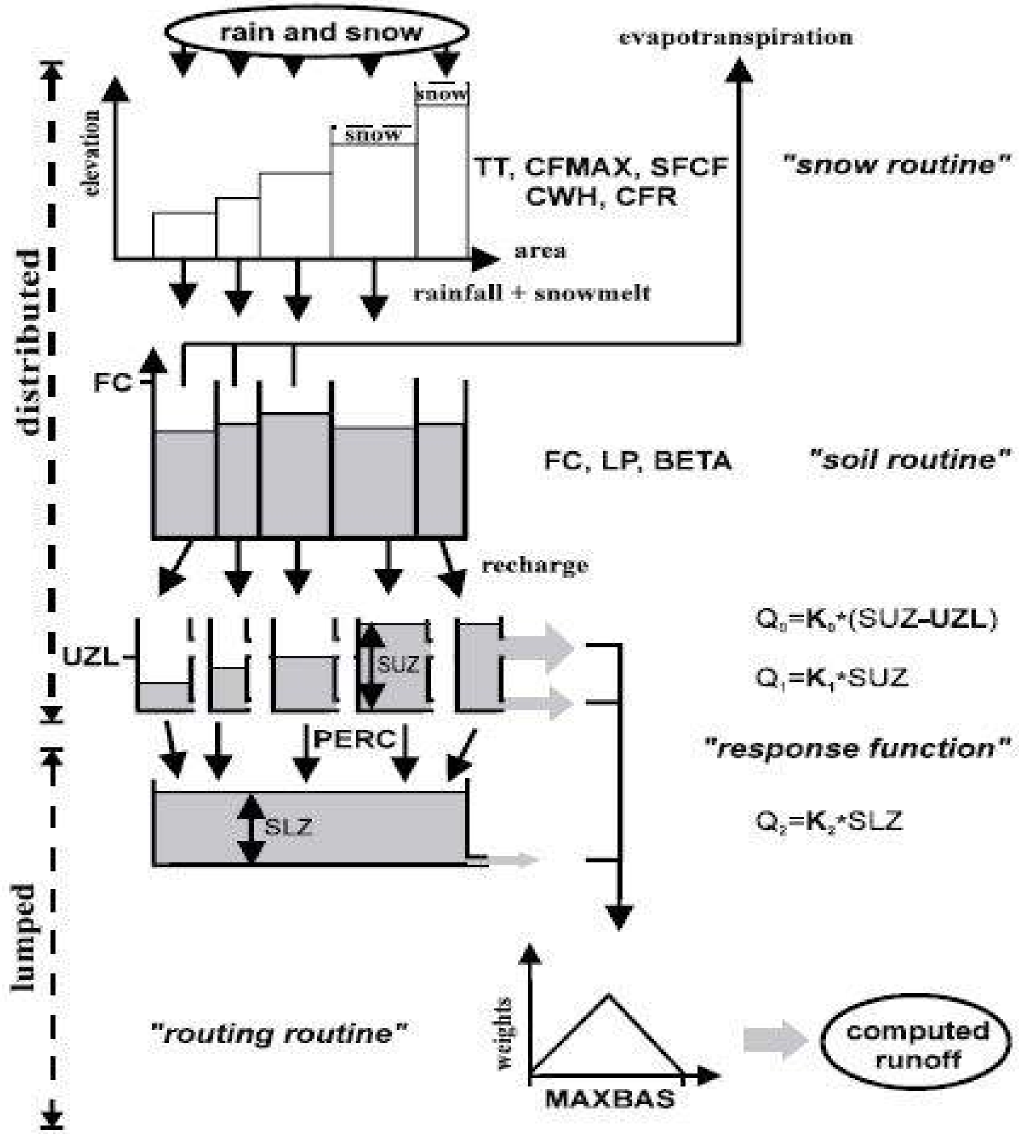
- Elevation zones
- Vegetation zones



HBV overview

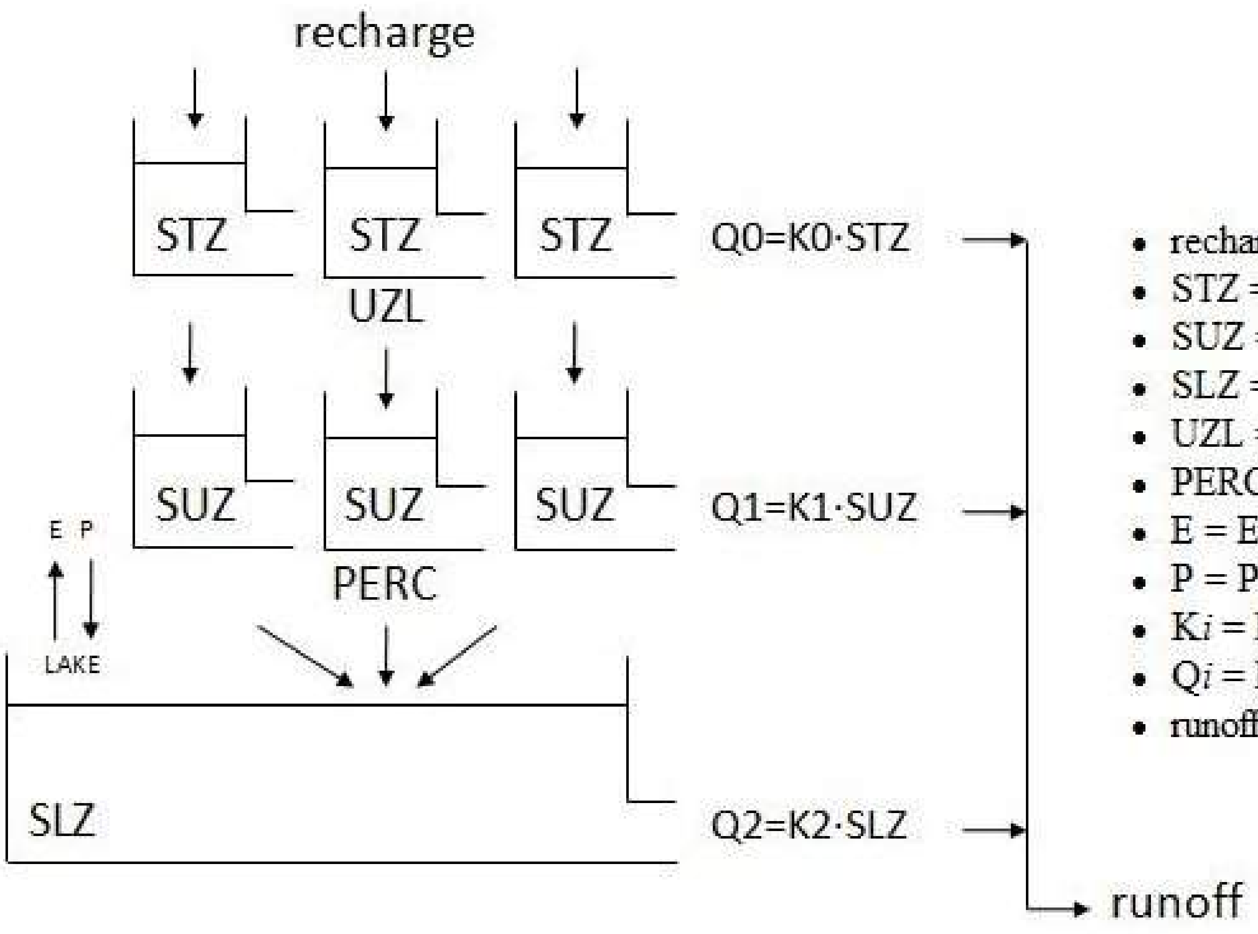
- The HBV model is a **simple multi-tank-type model** for simulating runoff.

- Rainfall and air temperature data as well as estimated potential evaporation data based on the American Society of Civil Engineers Penman–Monteith method are inputs to the model, which consists of four commonly used routines: snow; soil moisture; response; and routing.



Picture: Help HBV-light – An Overview of the HBV Model

Model of Computed Runoff



- recharge = Input from soil routine [mm/Δt]
- STZ = Storage in soil top zone [mm]
- SUZ = Storage in soil upper zone [mm]
- SLZ = Storage in soil lower zone [mm]
- UZL = Maximum percolation to the soil upper zone [mm/Δt]
- PERC = Maximum percolation to the soil lower zone [mm/Δt]
- E = Evaporation from the lake
- P = Precipitation into the lake
- K_i = Recession coefficient [1/Δt]
- Q_i = Runoff component [mm/Δt]
- runoff = Total amount of generated runoff [mm/Δt]

Source: Help HBV-light – Three GW Box (Distributed STZ and SUZ) Model

Equations Overview

$$melt = CFMAX(T(t) - TT)$$

$$refreezing = CFR\ CFMAX(TT - T(t))$$

$$\frac{recharge}{P(t)} = \left(\frac{SM(t)}{FC}\right)^{BETA}$$

$$E_{act} = E_{pot}\ \min\left(\frac{SM(t)}{FC \cdot LP},\ 1\right)$$

$$Q_{GW}(t) = K_2 SLZ + K_1 SUZ + K_0 \max(SUZ - UZL, 0)$$

$$Q_{sim}(t) = \sum_{i=1}^{MAXBAS} c(i)\ Q_{GW}(t - i + 1)$$

$$\text{where}\ \ c(i) = \int_{i-1}^{i} \frac{2}{MAXBAS} - \left|u - \frac{MAXBAS}{2}\right| \frac{4}{MAXBAS^2} du$$

$$P(h) = P_0\left(1 + \frac{PCALT\ (h - h_0)}{10000}\right)$$

$$T(h) = T_0 - \frac{TCALT\ (h - h_0)}{100}$$

$$E_{pot}(t) = \left(1 + C_{ET}\left(T(t) - T_M\right)\right) E_{pot,M}$$

$$\text{but}\ \ 0 \le E_{pot}(t) \le 2\ E_{pot,M}$$

Source: Help HBV-light – An Overview of the HBV Model

Catchment Parameters

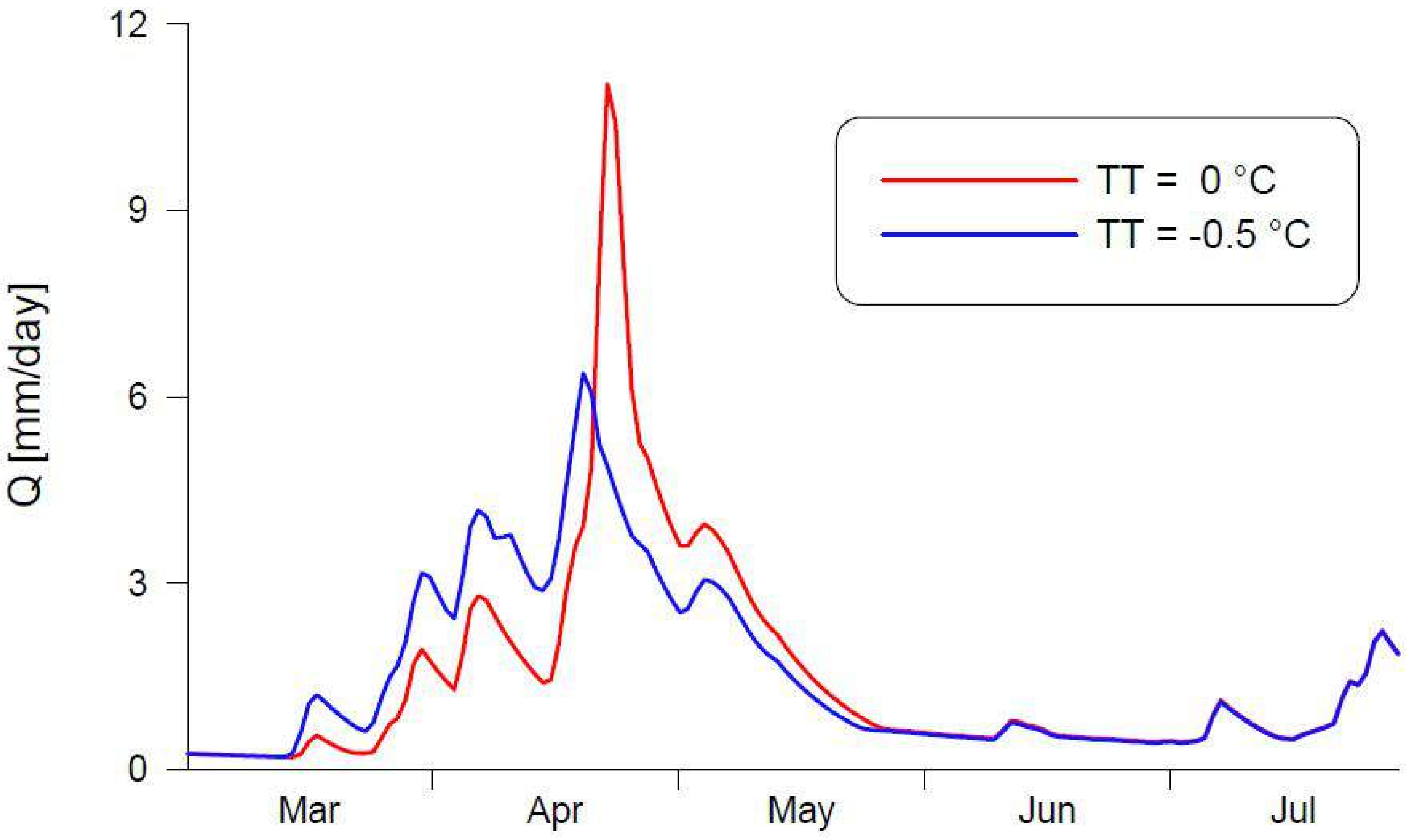
Name	Unit	Valid range	Default value	Description	See also
PERC	mm/Δt	[0,inf)	1	treshold parameter	Response Function
Alpha	-	[0,inf)	0	non-linearity coefficient	Response Function
UZL	mm	[0,inf)	20	treshold parameter	Response Function
K0	1/Δt	[0,1)	0.2	storage (or recession) coefficient 0	Response Function
K1	1/Δt	[0,1)	0.1	storage (or recession) coefficient 1	Response Function
K2	1/Δt	[0,1)	0.05	storage (or recession) coefficient 2	Response Function
MAXBAS	Δt	[1,100]	1	length of triangular weighting function	Routing Routine
Cet	1/°C	[0,1]	0	potential evaporation correction factor	An Overview of the HBV Model
PCALT	%/100m	(-inf,inf)	10	change of precipitation with elevation	Height Increment Variables
TCALT	°C/100m	(-inf,inf)	0.6	change of temperature with elevation	Height Increment Variables
Pelev	m	(-inf,inf)	0	elevation of precipitation data in the PTQ file	Height Increment Variables
Telev	m	(-inf,inf)	0	elevation of temperature data in the PTQ file	Height Increment Variables
PART	-	[0,1]	0.5	portion of the recharge which is added to groundwater box 1	Response Routine With Delay
DELAY	Δt	[0,inf)	1	time period over which recharge is evenly distributed	Response Routine With Delay

Vegetation Zone Parameters

Name	Unit	Valid range	Default value	Description	See also
TT	°C	(-inf,inf)	0	threshold temperature	Snow Routine
CFMAX	mm/Δt °C	[0,inf)	3	degree-Δt factor	Snow Routine
SFCF	-	[0,inf)	1	snowfall correction factor	Snow Routine
CFR	-	[0,inf)	0.05	refreezing coefficient	Snow Routine
CWH	-	[0,inf)	0.1	water holding capacity	Snow Routine
CFGlacier	-	[0,inf)	1	glacier correction factor	Glacier Model
CFSlope	-	(0,inf)	1	slope correction factor	Aspect Model Glacier Model
FC	mm	(0,inf)	200	maximum soil moisture storage	Soil Moisture Routine
LP	-	[0,1]	1	soil moisture value above which AET reaches PET	Soil Moisture Routine
BETA	-	(0,inf)	1	parameter that determines the relative contribution to runoff from rain or snowmelt	Soil Moisture Routine

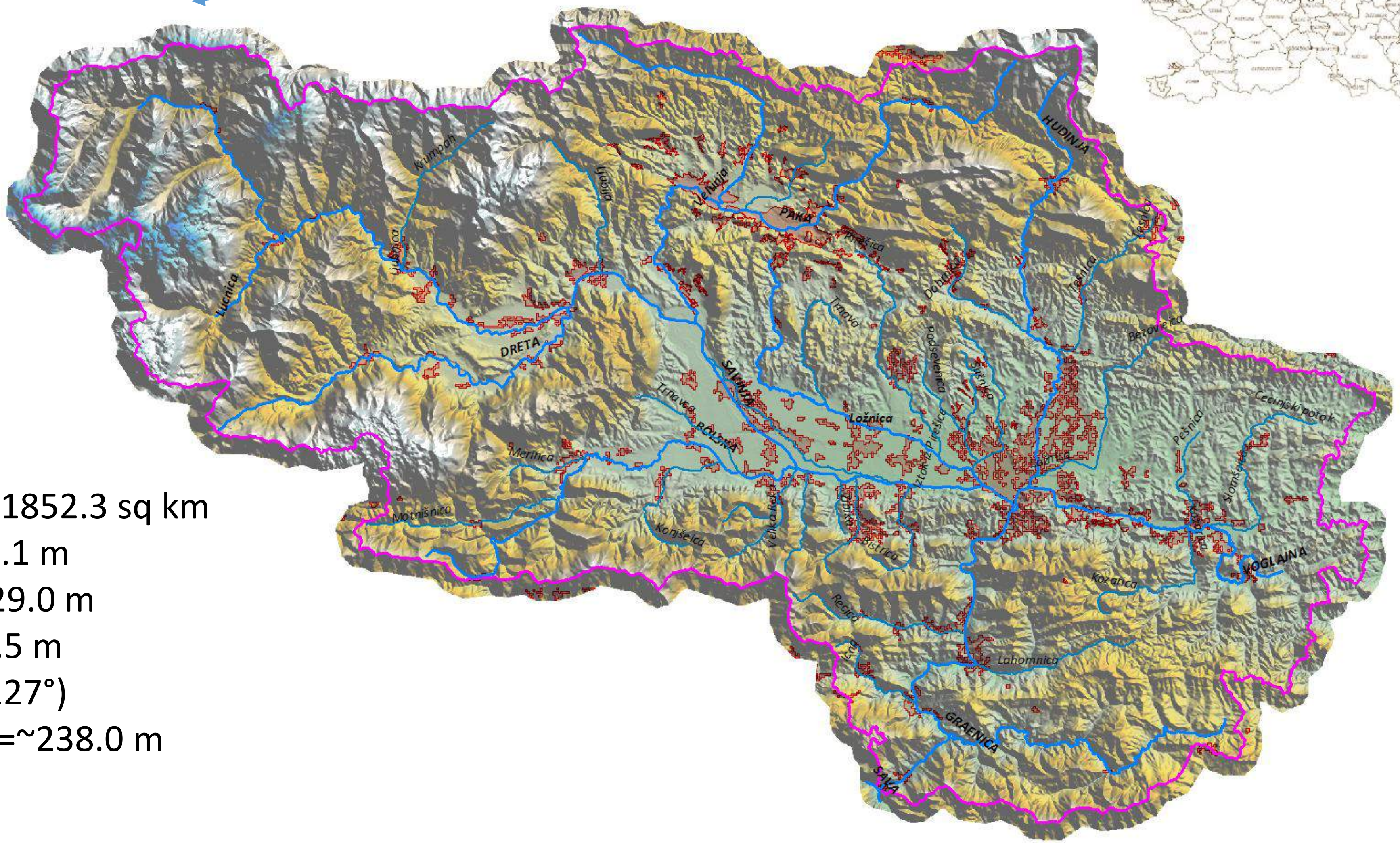
Source: Help HBV-light – Parameter Overview

Effect of T_T



Picture: Help HBV-light

Savinja Catchment



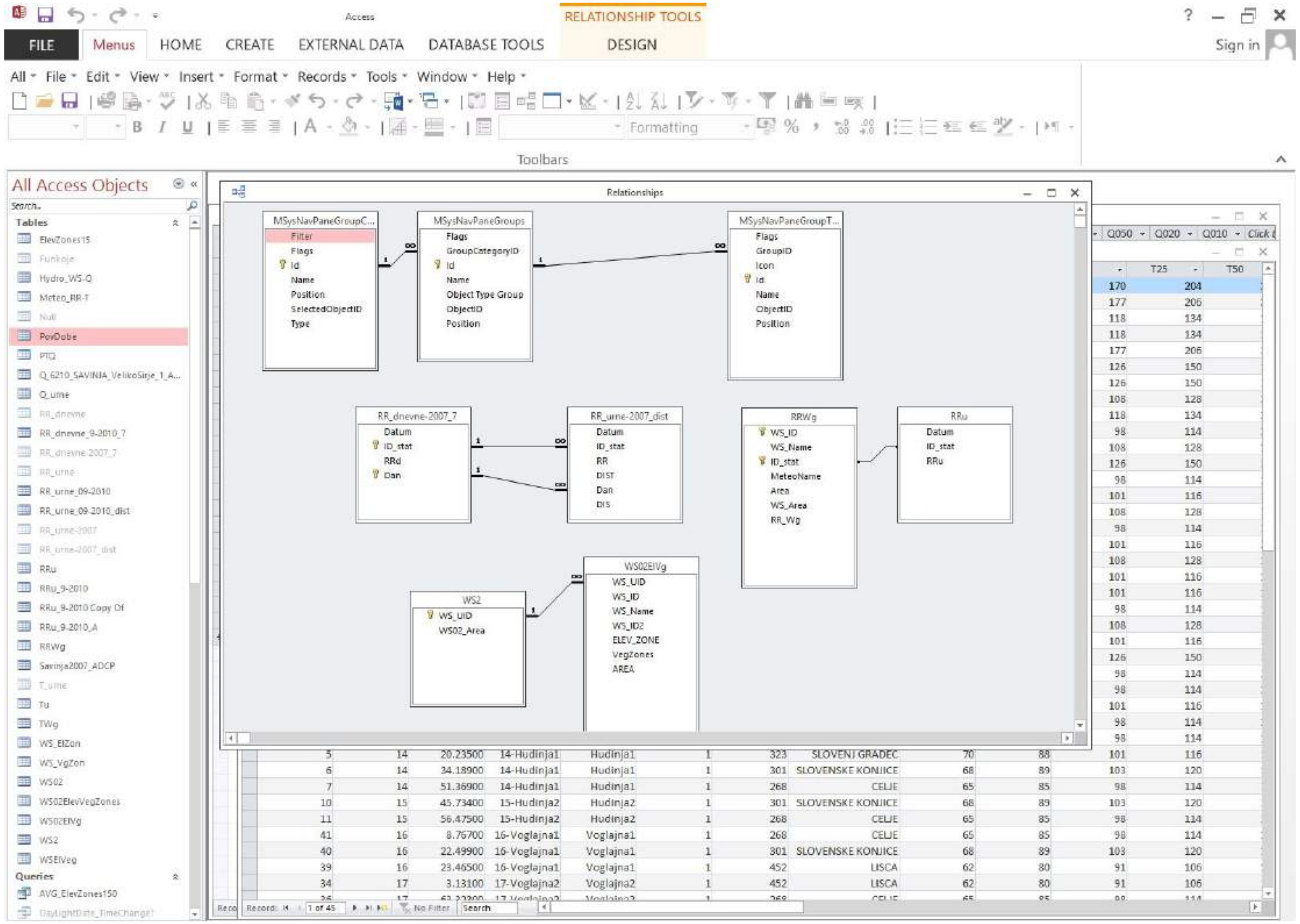
- Enclosed Area of 1852.3 sq km
- min_Elev_m=190.1 m
- max_Elev_m=2429.0 m
- avg_Elev_m=604.5 m
- avg_Aspect=SE (127°)
- Older_Celje_elev=~238.0 m

Flood 1954 Savinja-Celje

Josephinische Landesaufnahme (1763-1787)

Flood 1990 Savinja-Laško

Relational Hydro and Meteo Data



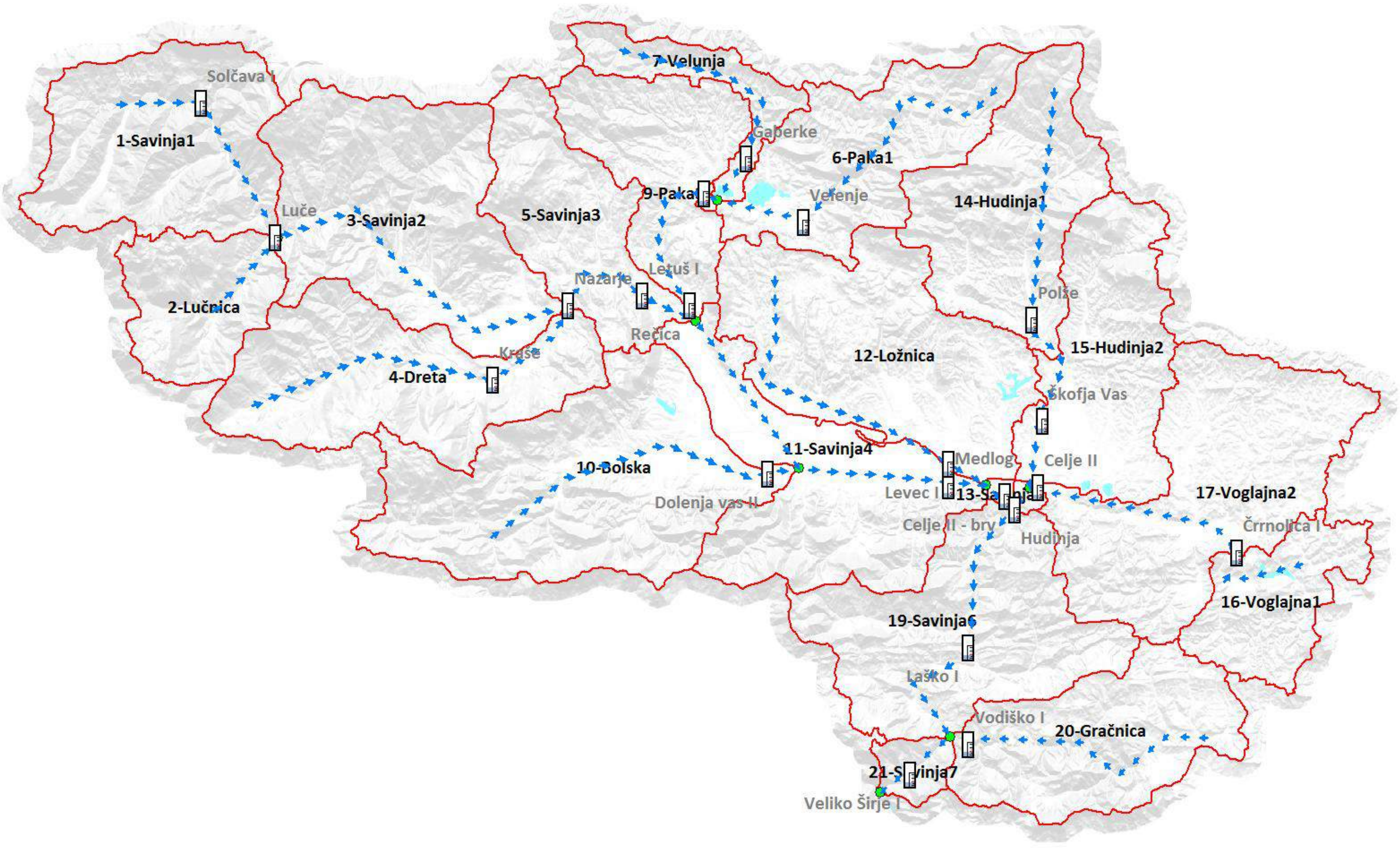
Data source:
MOP -ARSO, 2015

HIGRIS –Hydrologic Graphical IS

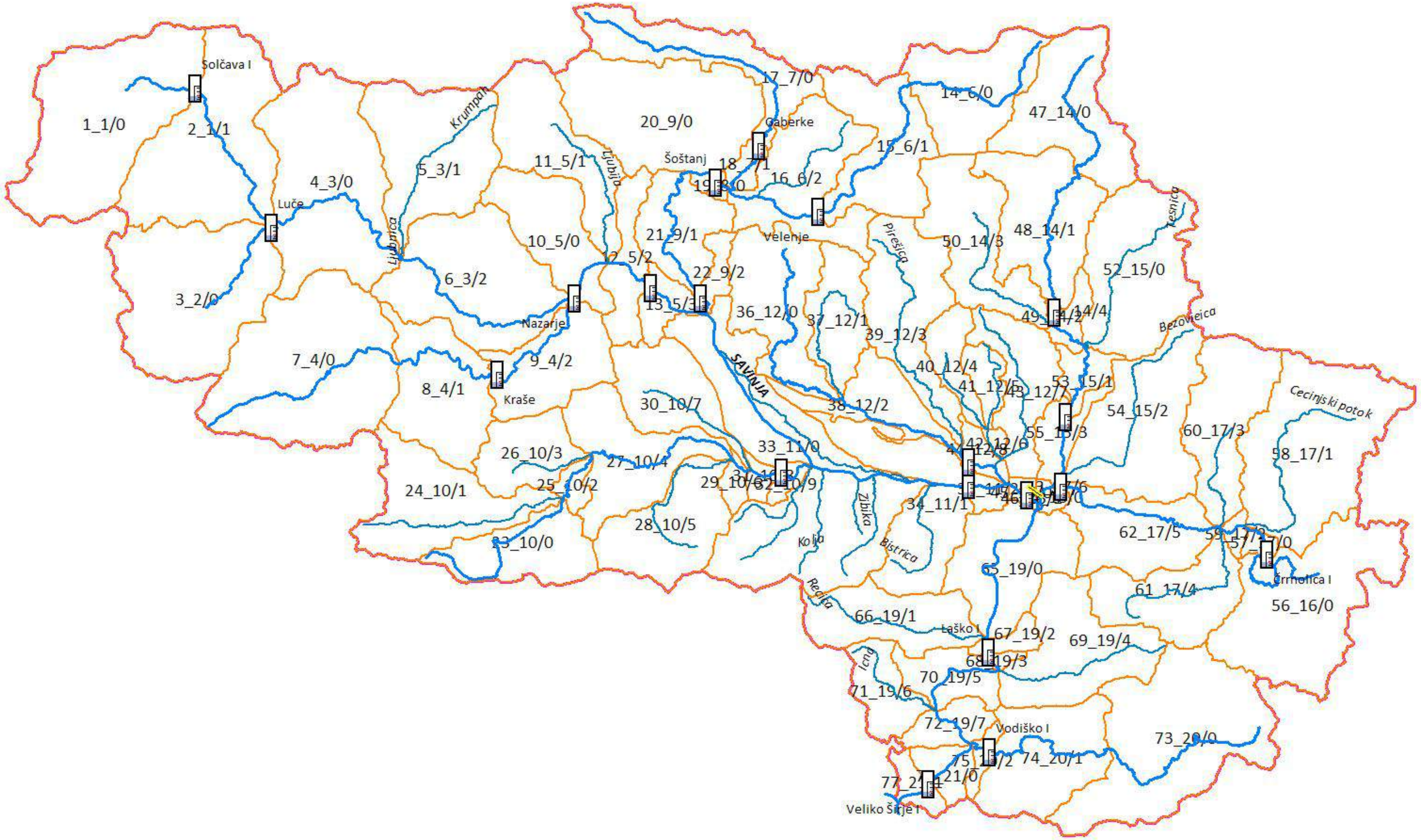
- basically designed with Global Mapper and has more than 160 layers and a lot of external links

- GIS (Global Mapper [LiDAR], Map Window, SAGA, ILWIS, Google Earth Pro)
- CAD (AutoCAD MAP 3D, QuickSurf, Surfer)
- Graphic design (PhotoLine, PaintShop)
- DB (ASCII, MS Access, PostGIS)
- Statistic (MS Excell, Origin, Scilab)
- Programming (SQL, PowerBasic_CC, Python with NumPy)
- P-R model (HBV-light_CLI, HBV-light-GUI)
- Calibration Tools (PEST, GAP and Monte Carlo are included in HBV-light)
- File navigation and data preview (Total Commander, IrfanView, Acrobat)

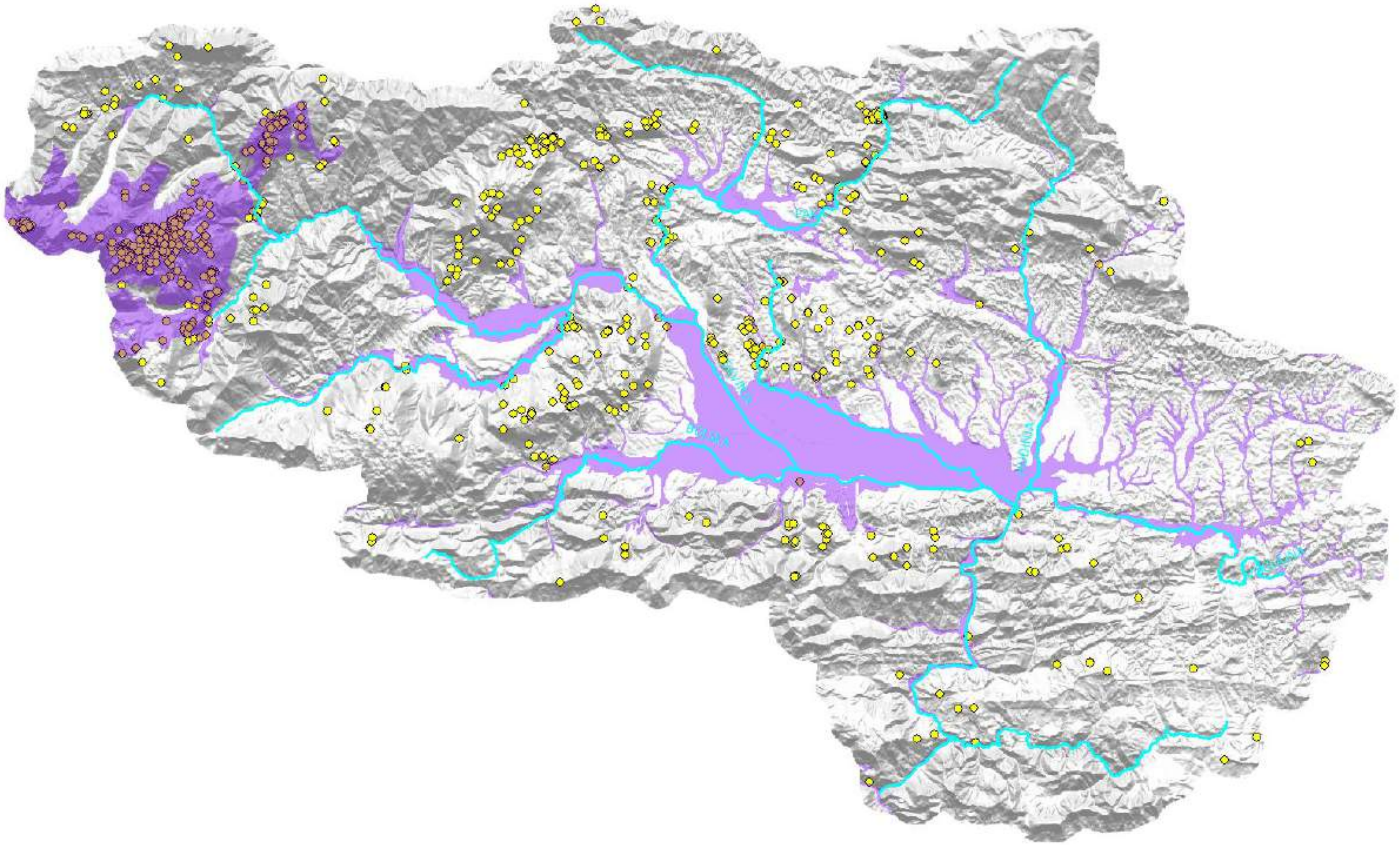
Savinja 21 sub-catchments; I. model



Savinja 77 sub-catchments; II. model

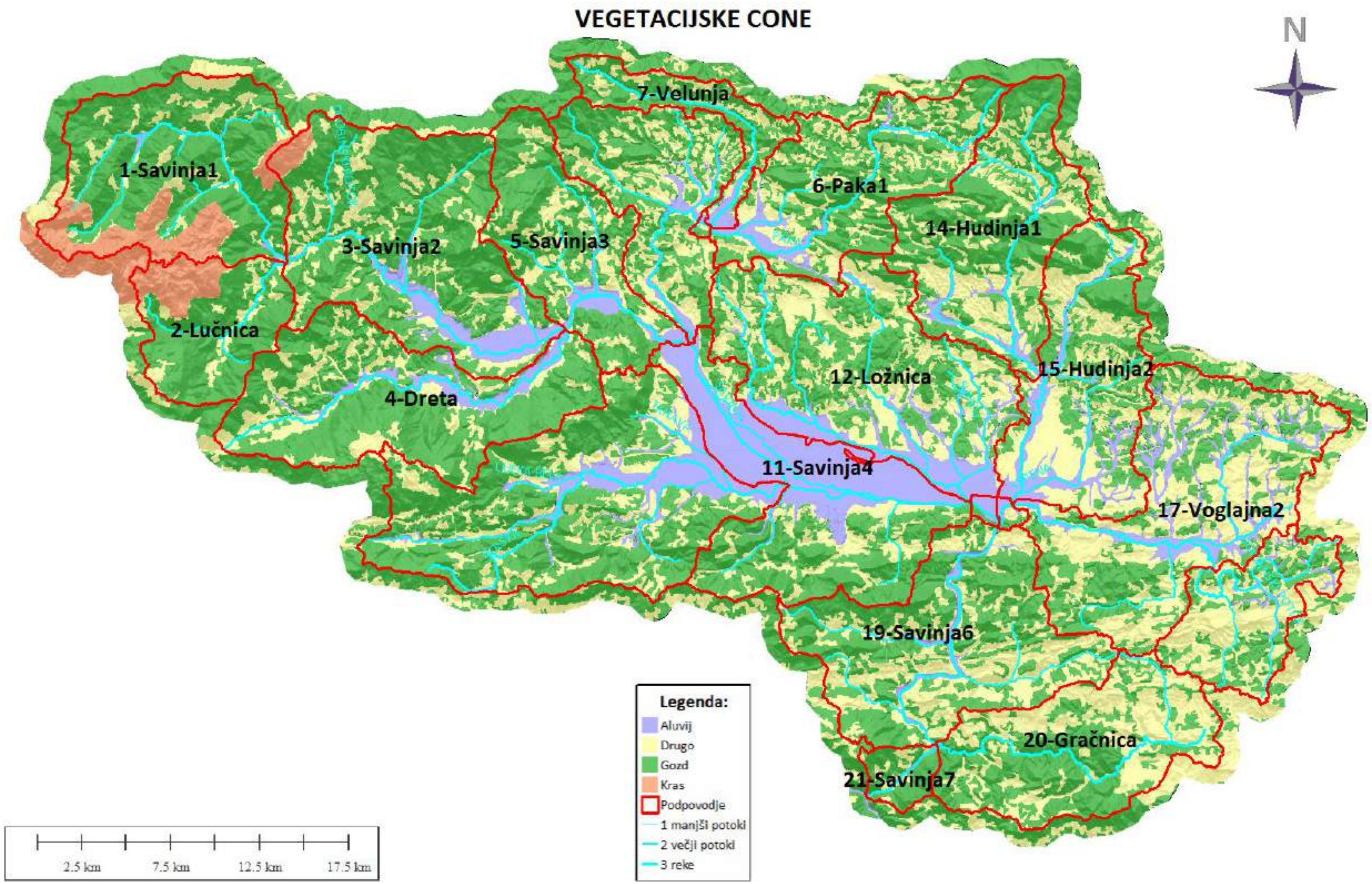


Geology [Alluvi-Karst]



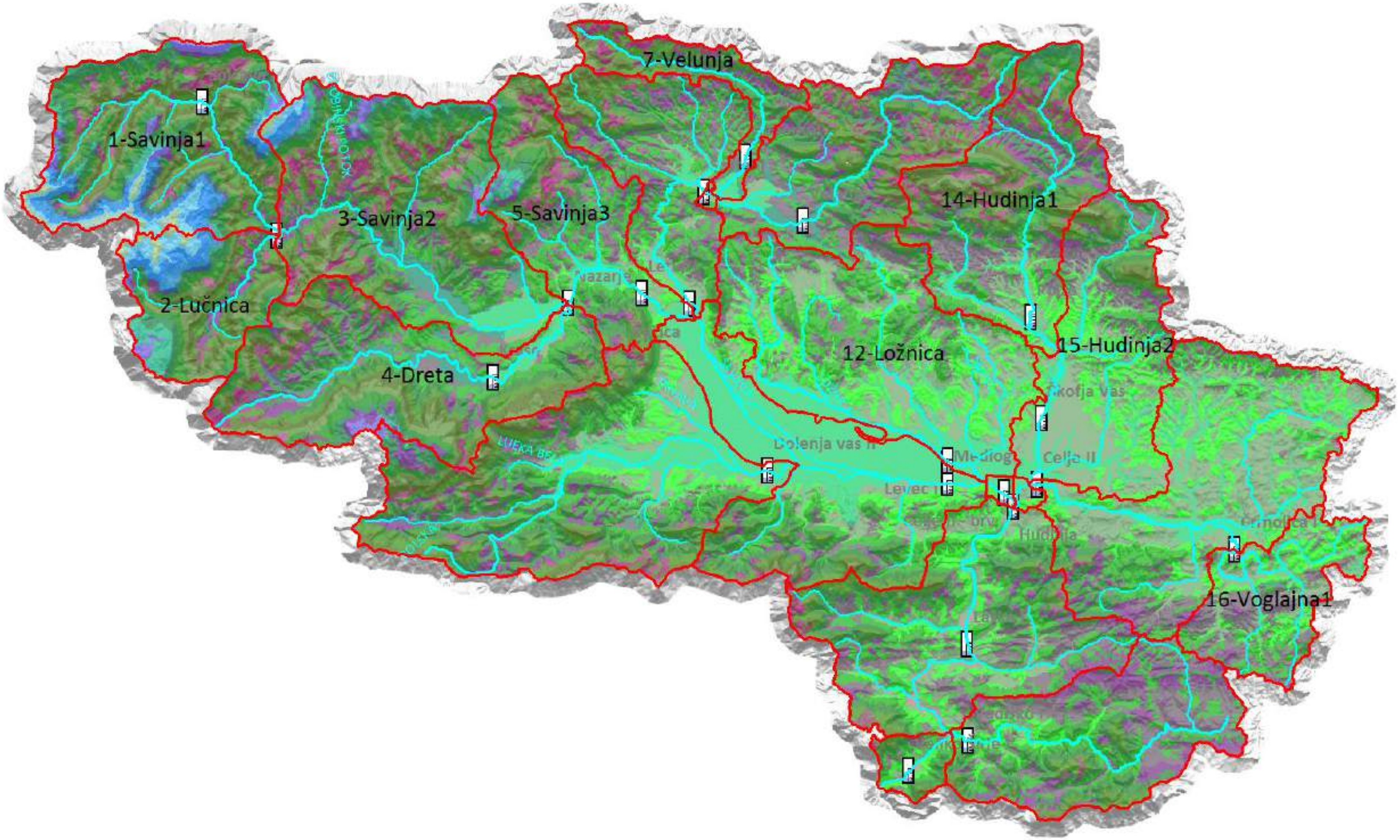
Vegetation zones

- **3 vegetation zones**



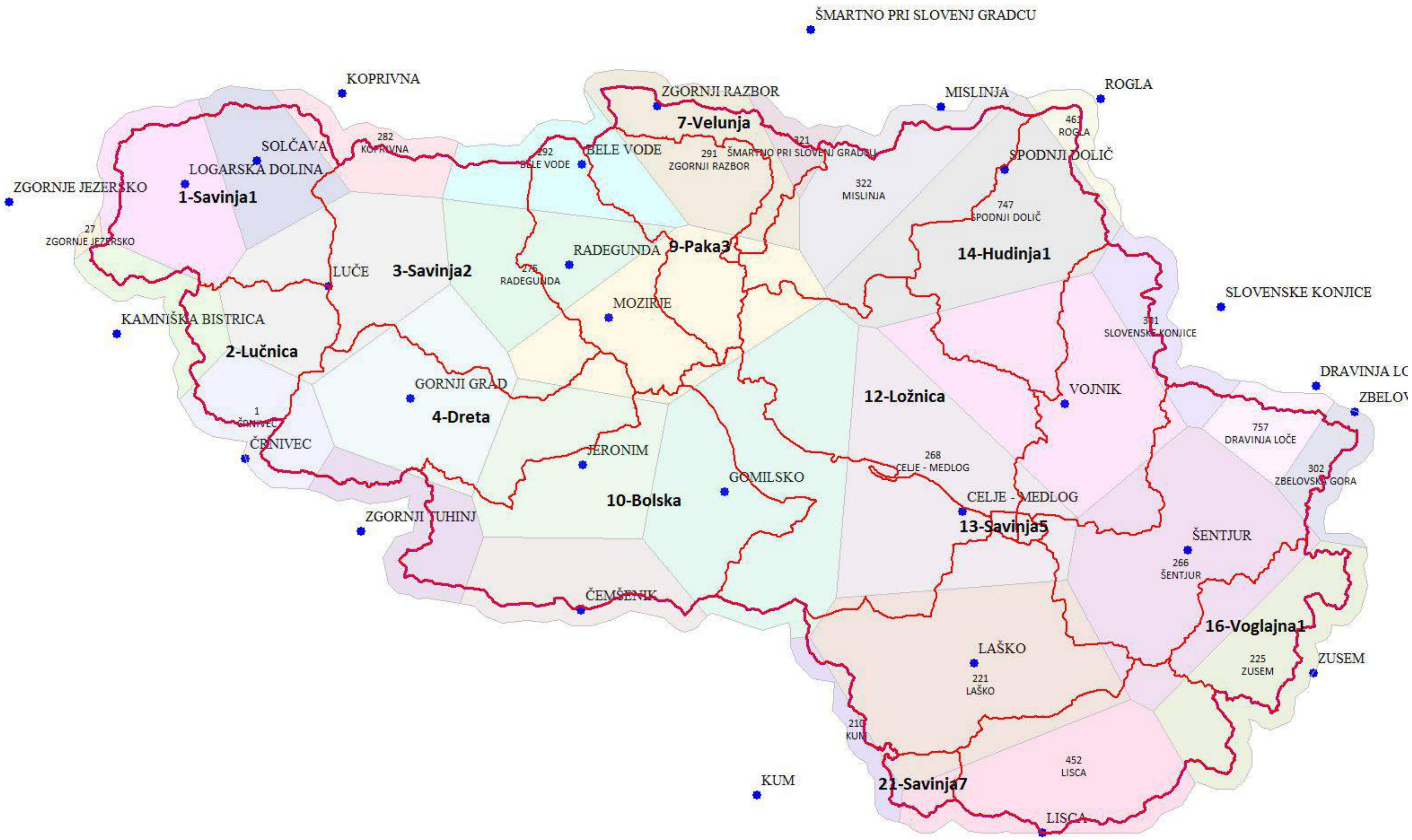
Elevation zones

- **16 elevation zones**



Precipitation RR_{hour}

- **33 precipitation stations**



What is PEST?

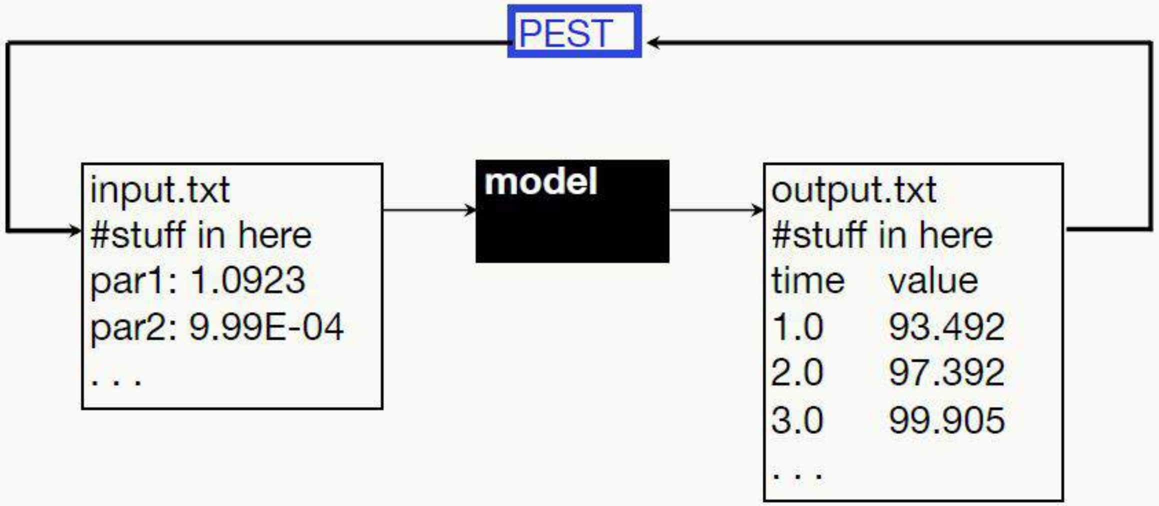
Written by John Doherty/Watermark Numerical Computing

Model-independent parameter estimation code

Writes ASCII model input, **reads** ASCII model output

Takes control of a model and runs it many, many times

Pleasingly parallel



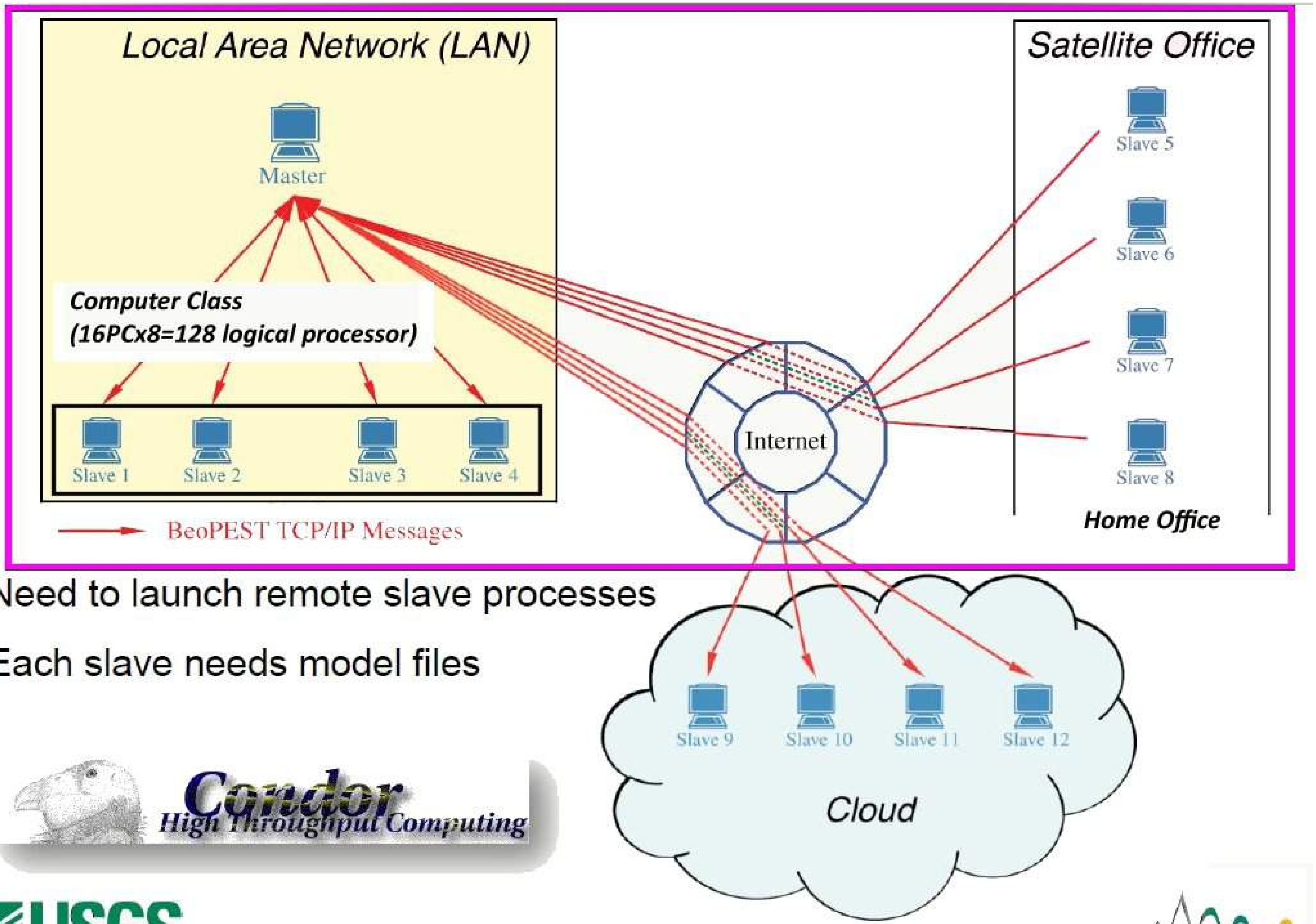
USGS science for a changing world

CIDA Center for Integrated Data Analytics

Parameter Estimation and Uncertainty Analysis

* parameter are estimated on the basis of past events
* some of them cannot be estimated uniquely

BeoPEST, PEST++ are tools for model calibration and uncertainty analysis



Need to launch remote slave processes

Each slave needs model files

Condor High Throughput Computing

USGS science for a changing world

CIDA Center for Integrated Data Analytics

Model Calibration

The calibration of the model is usually made by manual try and error technique (Bergström, 1992).

The coefficient of efficiency, R_{eff}, is normally used for assessment of simulations by the HBV model.

$$R_{eff} = 1 - \frac{\sum (Q_{Sim}(t) - Q_{Obs}(t))^2}{\sum (Q_{Obs}(t) - \overline{Q}_{Obs})^2}$$

Different criteria can be used to assess the fit of simulated runoff to observed runoff:

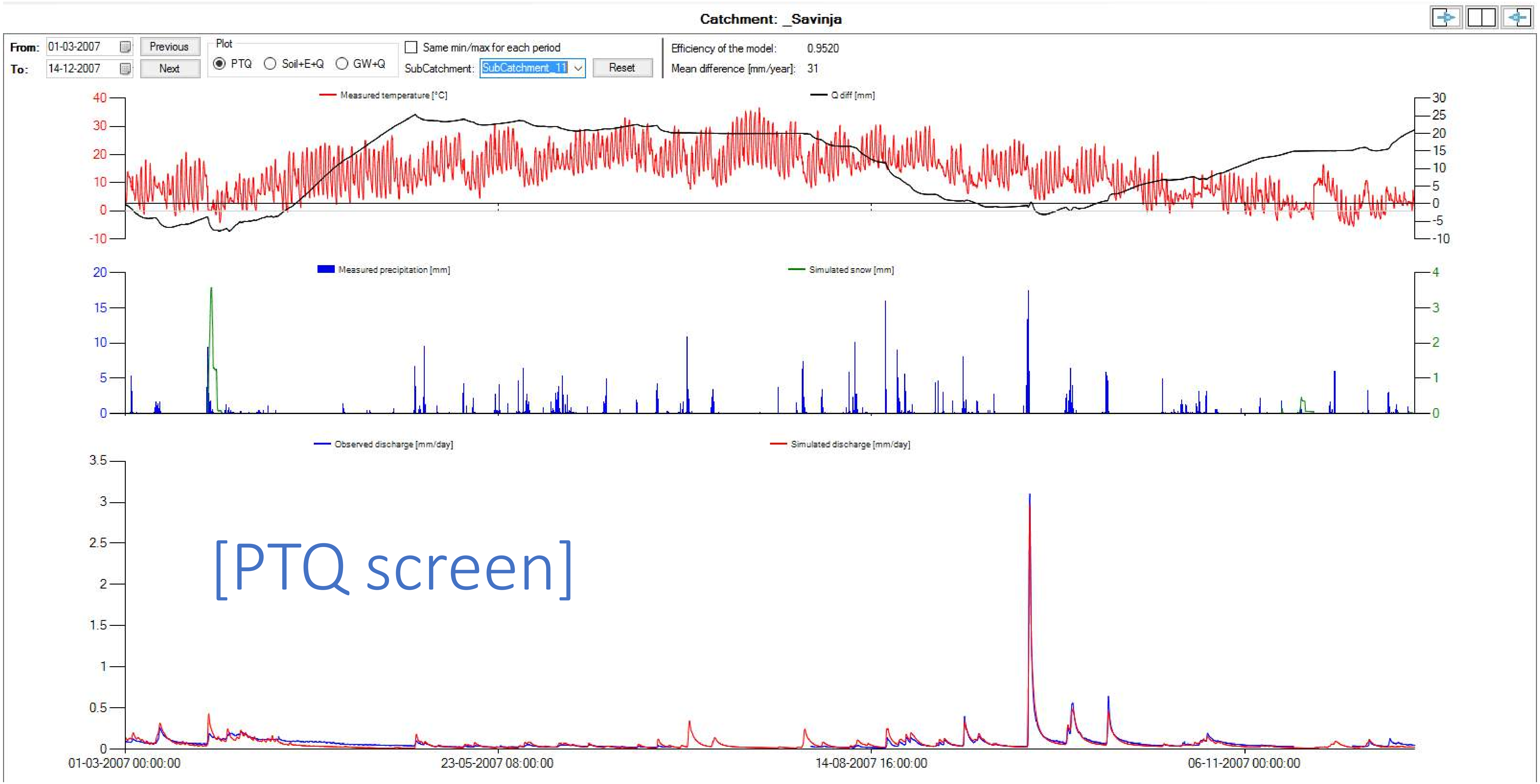
- visual inspection of plots with Qsim and Qobs
- accumulated difference
- statistical criteria

R_{eff} compares the prediction by the model with the simplest possible prediction, a constant value of the observed mean value over the entire period.

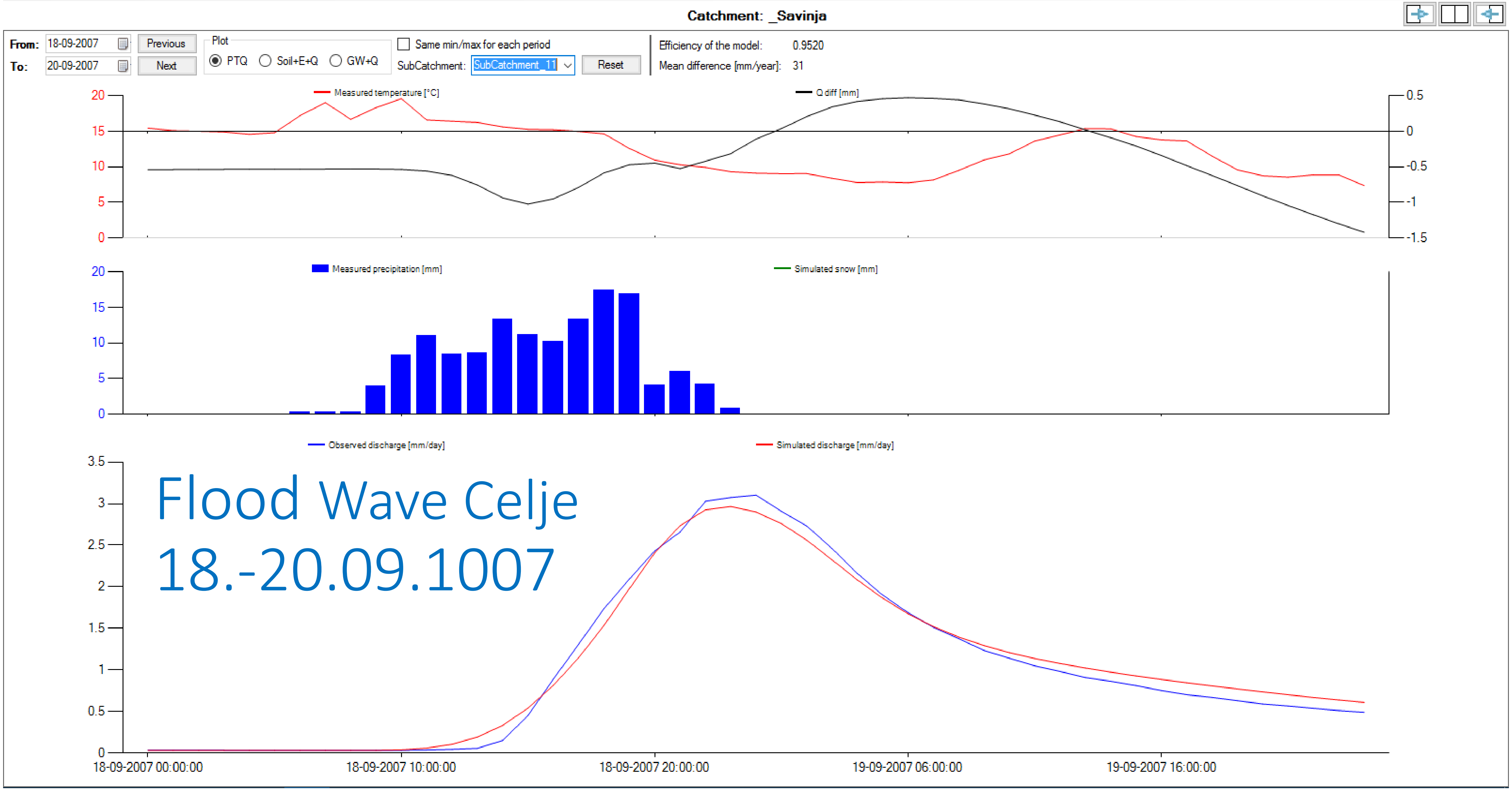
$R_{eff} = 1$	Perfect fit, QSim(t)= QObs(t)
$R_{eff} = 0$	Simulation as good (or poor) as the constant-value prediction
$R_{eff} < 0$	Very poor fit

Note:
- the calibration period should include a variety of hydrological events
- normally 5 to 10 years sufficient to calibrate the model
- validation: test of model performance with calibrated parameters for an independent period

Source: Help HBV-light – Model Calibration


Catchment: _Savinja
From: 01-03-2007
To: 14-12-2007
Previous
Next
Plot
PTQ
Soil+E+Q
GW+Q
Same min/max for each period
SubCatchment: SubCatchment_11
Reset
Efficiency of the model: 0.9520
Mean difference [mm/year]: 31
Measured temperature [°C]
Q diff [mm]
Measured precipitation [mm]
Simulated snow [mm]
Observed discharge [mm/day]
Simulated discharge [mm/day]
01-03-2007 00:00:00
23-05-2007 08:00:00
14-08-2007 16:00:00
06-11-2007 00:00:00

[PTQ screen]

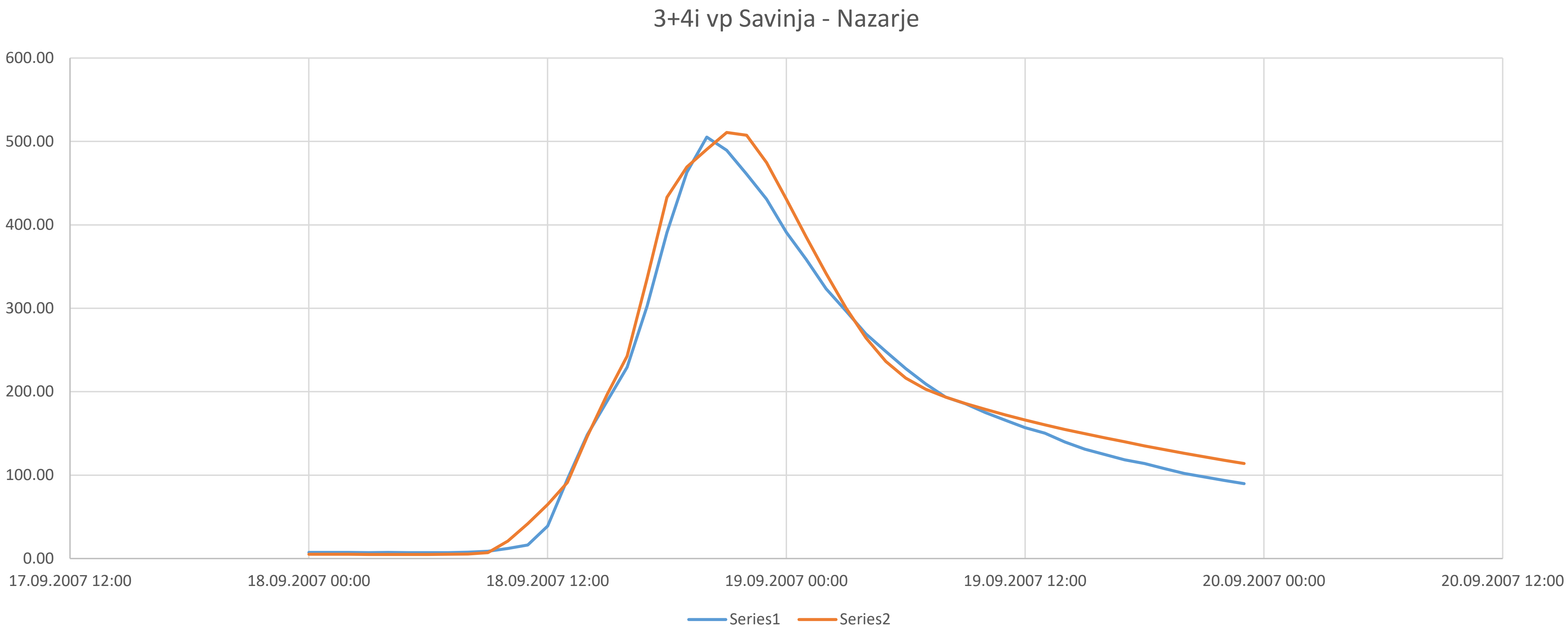


Catchment: _Savinja
From: 18-09-2007
To: 20-09-2007
Previous
Next
Plot
PTQ
Soil+E+Q
GW+Q
Same min/max for each period
SubCatchment: SubCatchment_11
Reset
Efficiency of the model: 0.9520
Mean difference [mm/year]: 31
Measured temperature [°C]
Q diff [mm]
Measured precipitation [mm]
Simulated snow [mm]
Observed discharge [mm/day]
Simulated discharge [mm/day]
Flood Wave Celje
18.-20.09.1007
18-09-2007 00:00:00
18-09-2007 10:00:00
18-09-2007 20:00:00
19-09-2007 06:00:00
19-09-2007 16:00:00

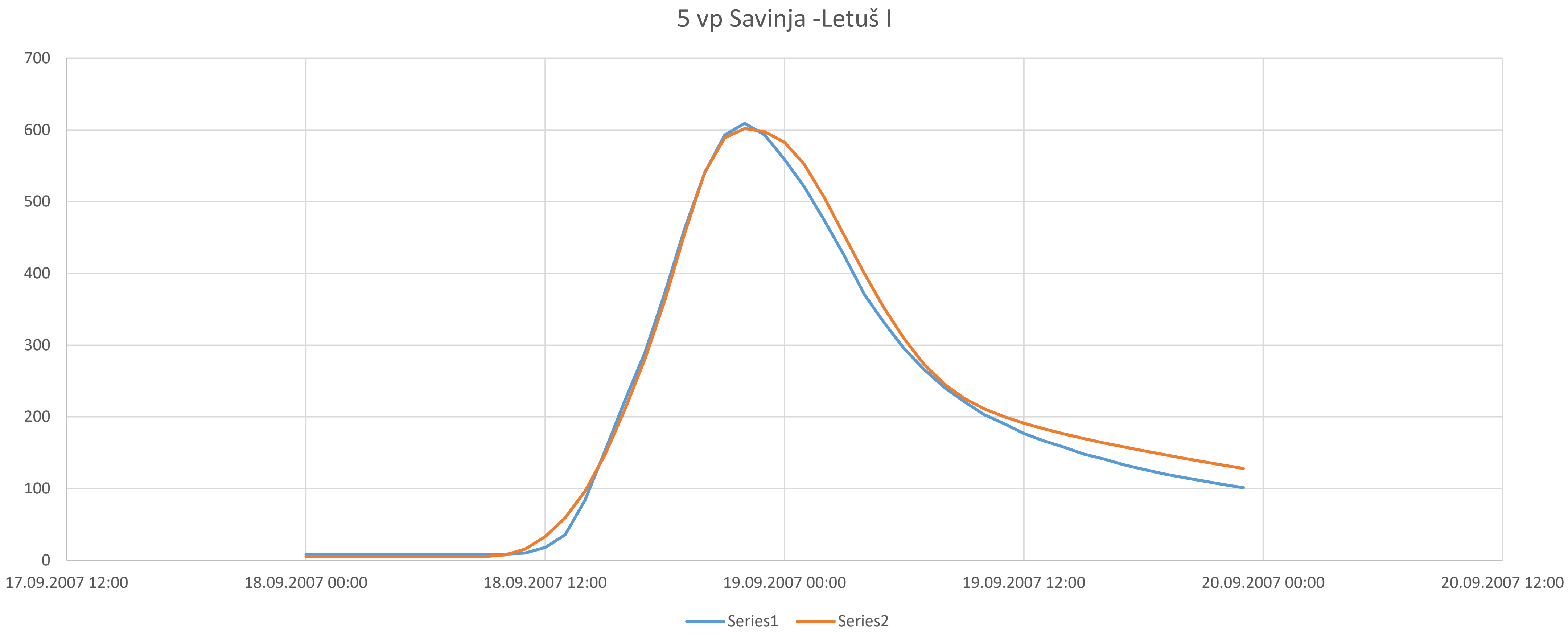
Goodnes of Fit for calibration period - year 2007

Average model efficiency of Savinja River to Gračnica inflow for whole calibration period 2007	**0.952**
Average model efficiency for **flood wave** 18.-22.09.2007	0.988

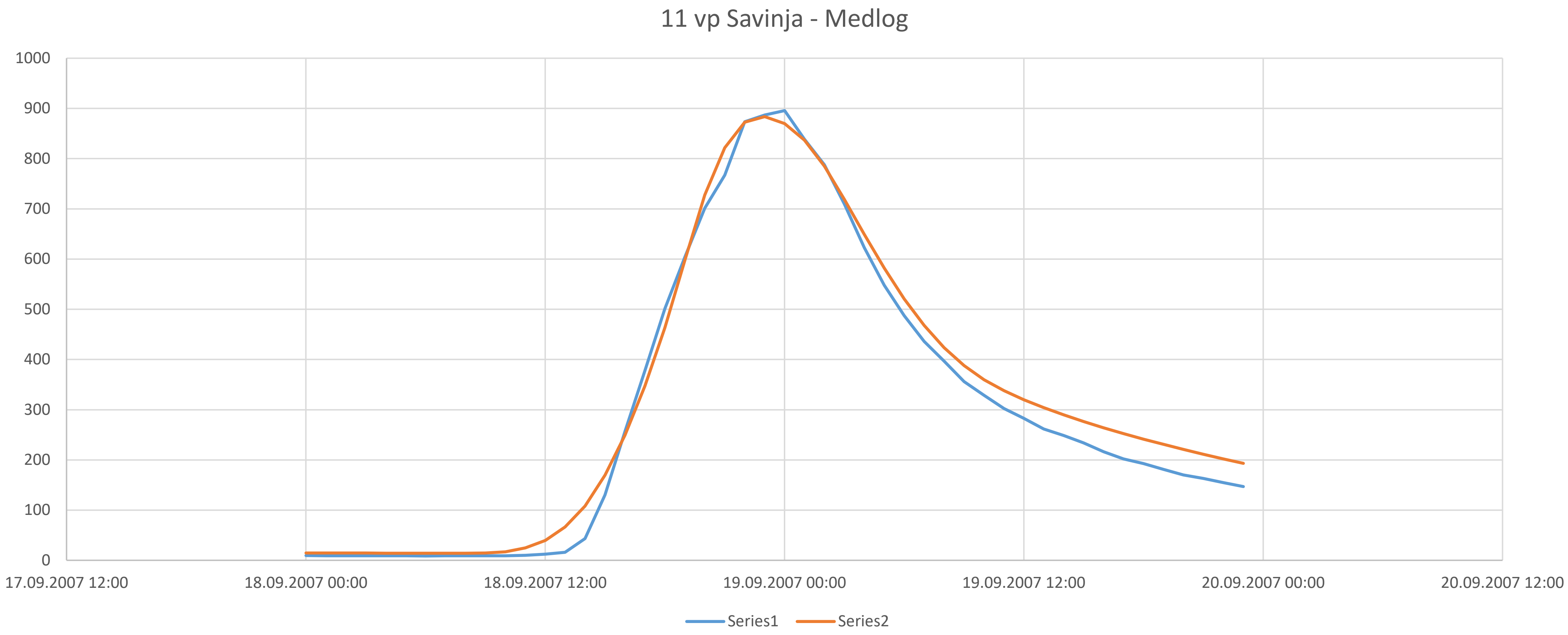
Savinja - vp Nazarje



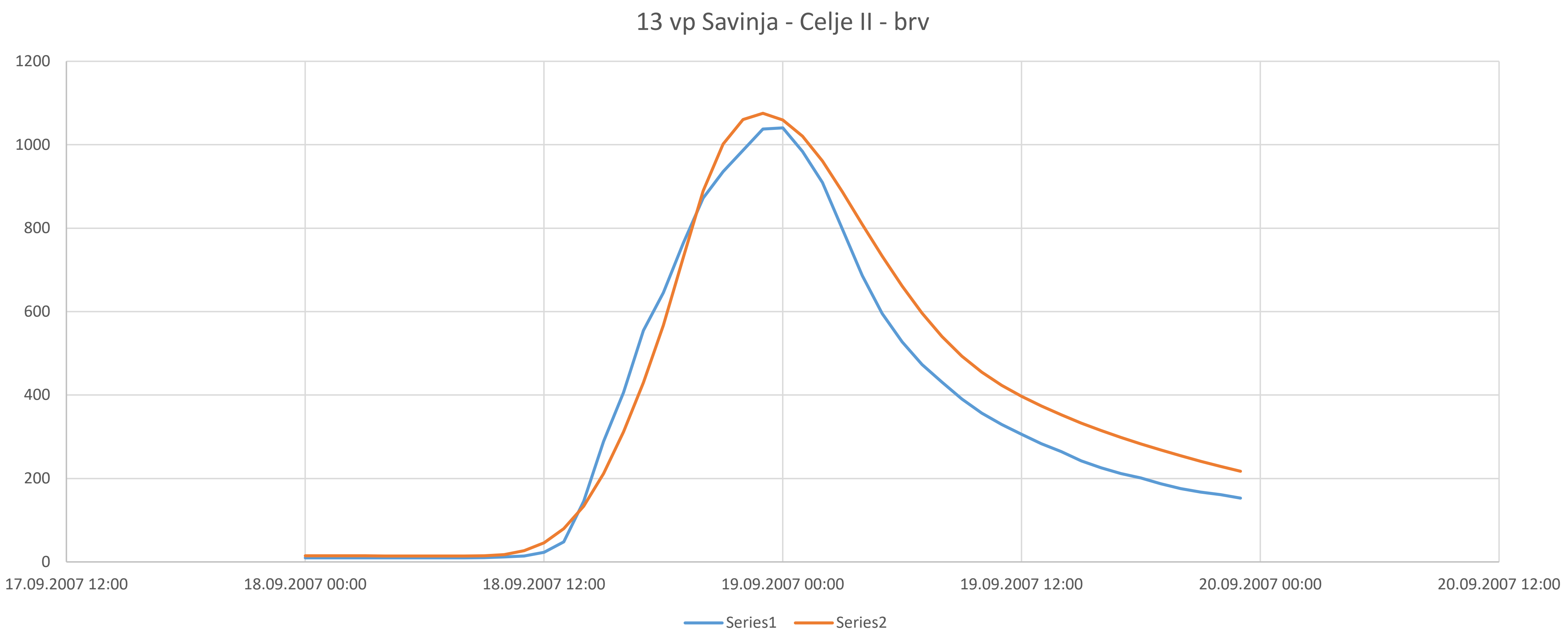
Savinja - vp Letuš 1



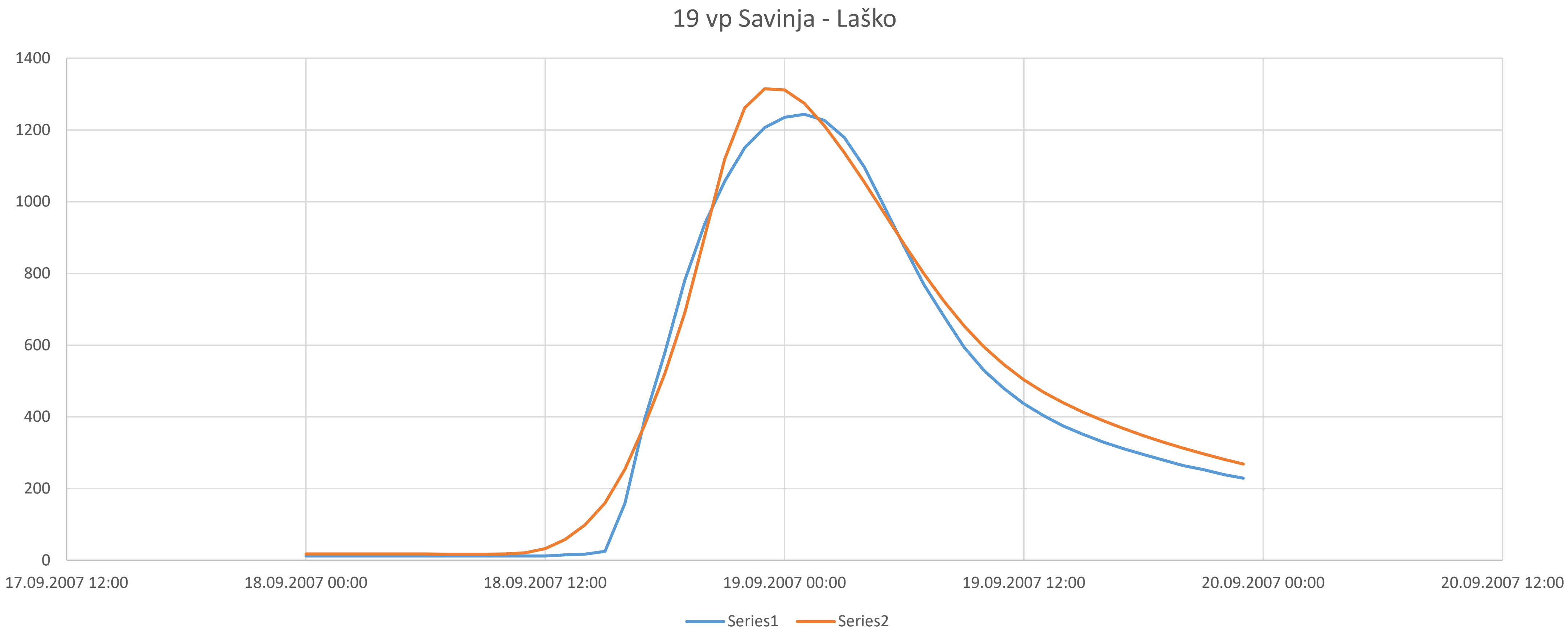
Savinja – vp Medlog



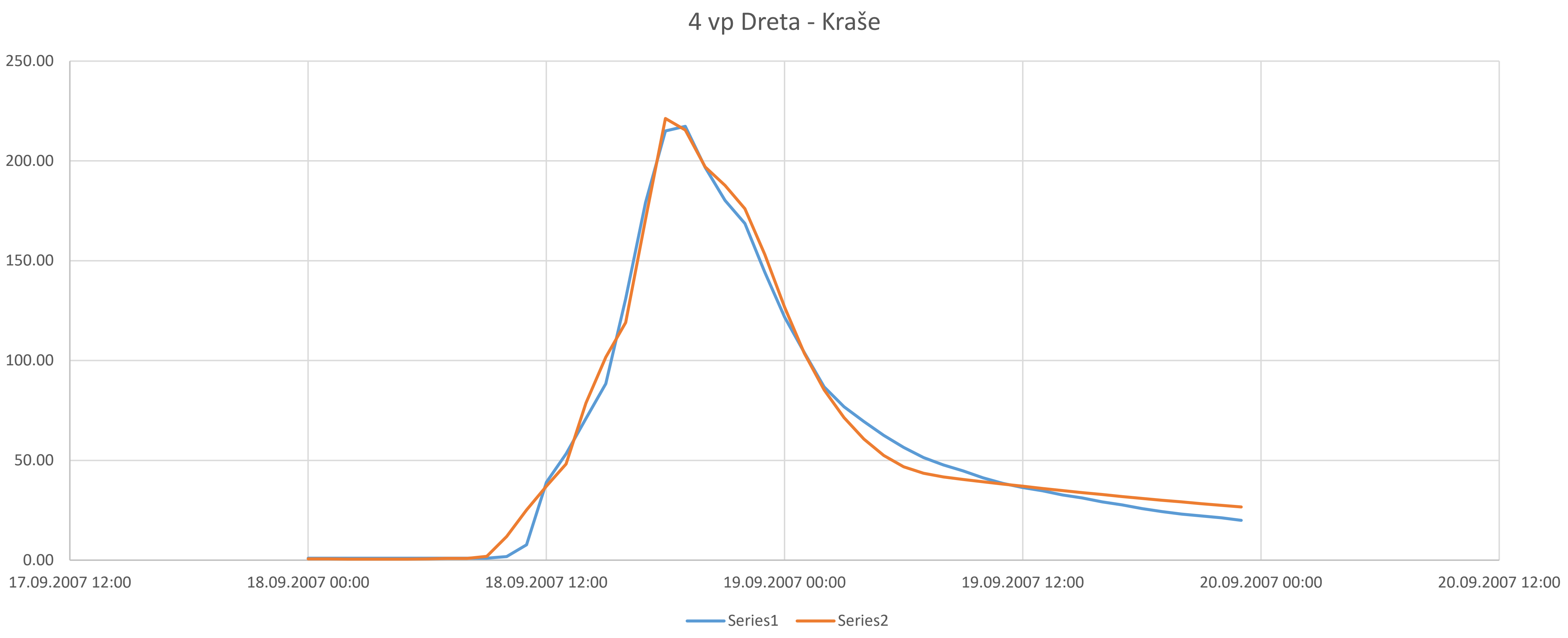
Savinja – vp Celje II _ brv



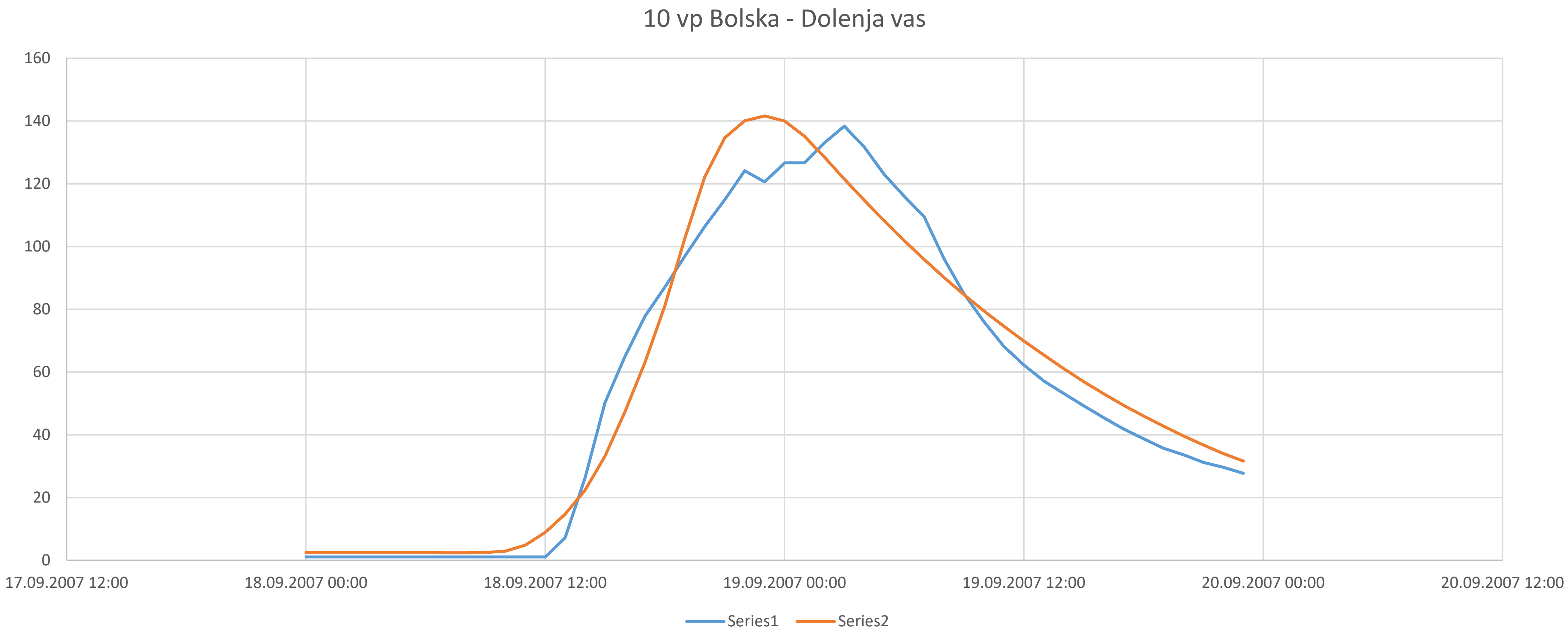
Savinja – vp Laško



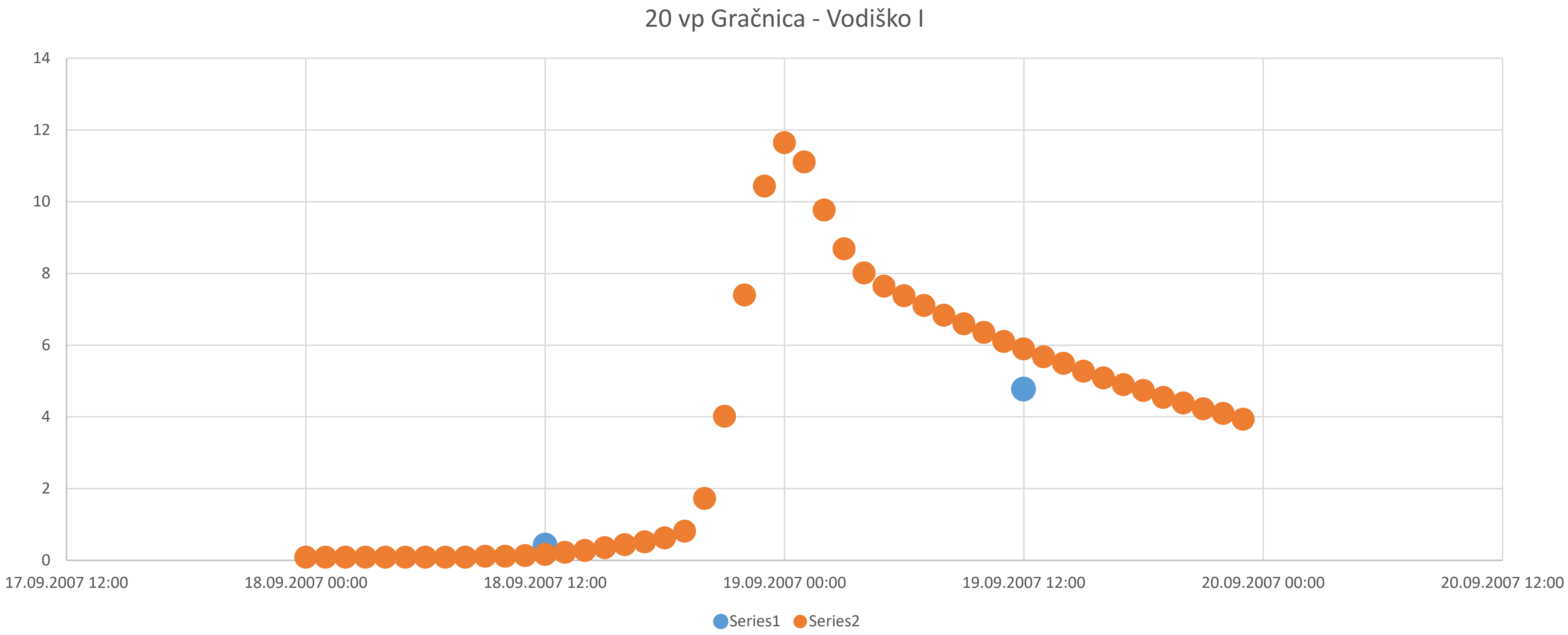
Dreta – vp Kraše



Bolska – vp Dolenja vas



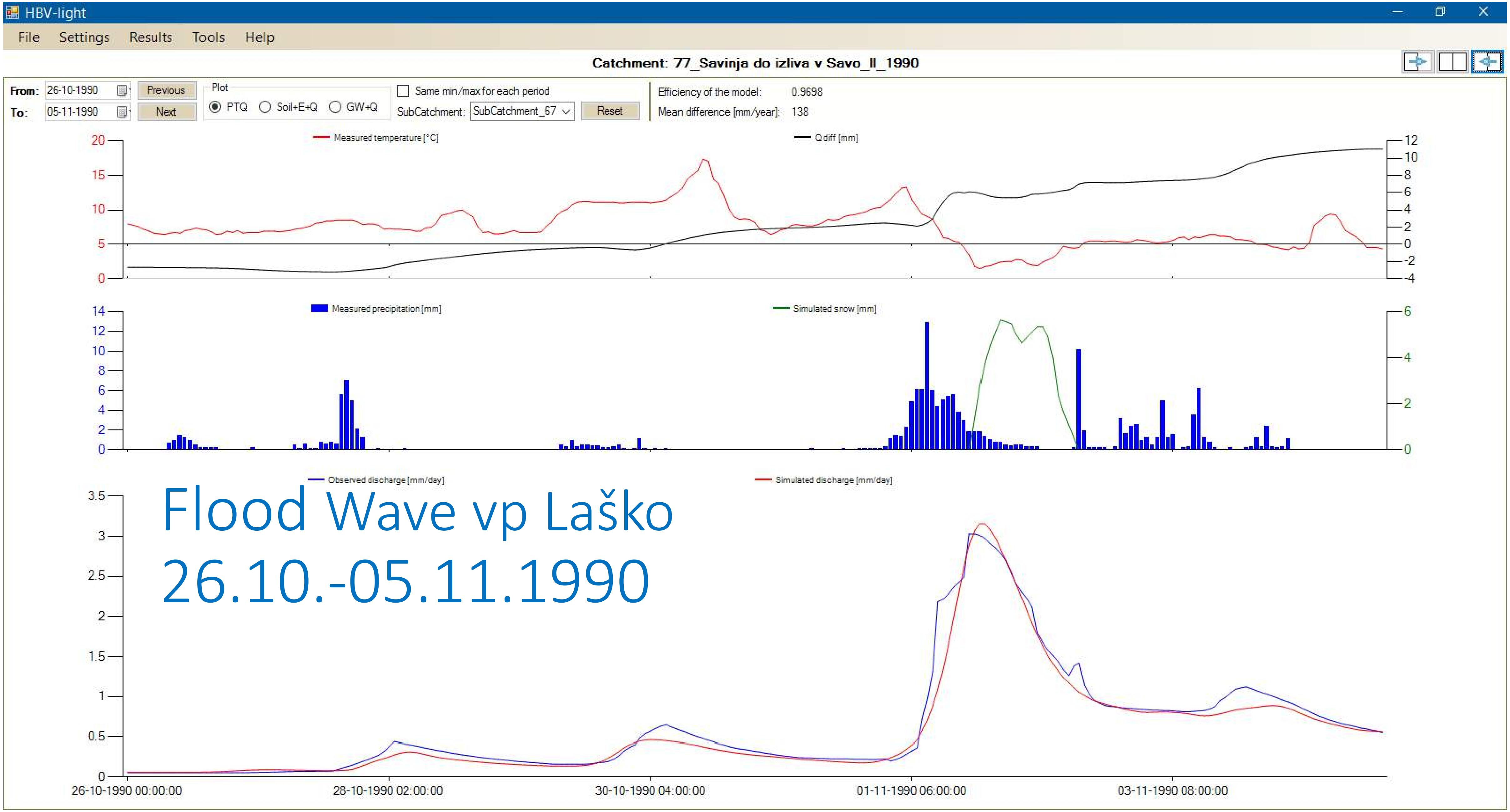
Gračnica – vp Vodiško I



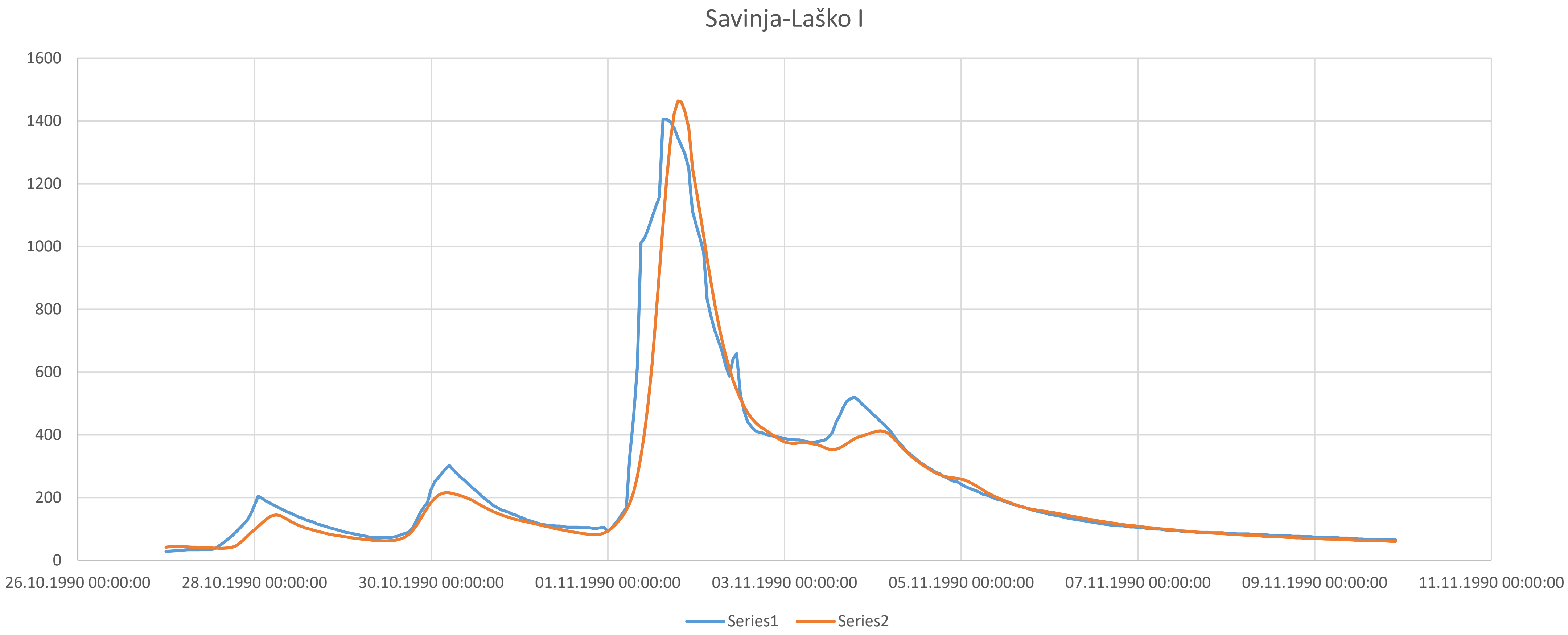
Goodnes of Fit for validation period - year 1990

WS2	WS2_Name	NS (1.10-14.11.1990)
1	Savinja do VP Solčava I	0.85
8	Dreta do VP Kraše	0.90
38	Ložnica do VP Levec I	0.94
45	Savinja do VP Celje II - brv	0.97
53	Hudinja do VP Škofja Vas	0.8
62	Voglajna do VP Celje II	0.8
67	Savinja do VP Laško	0.97
76	Savinja do VP Veliko Širje I	0.84

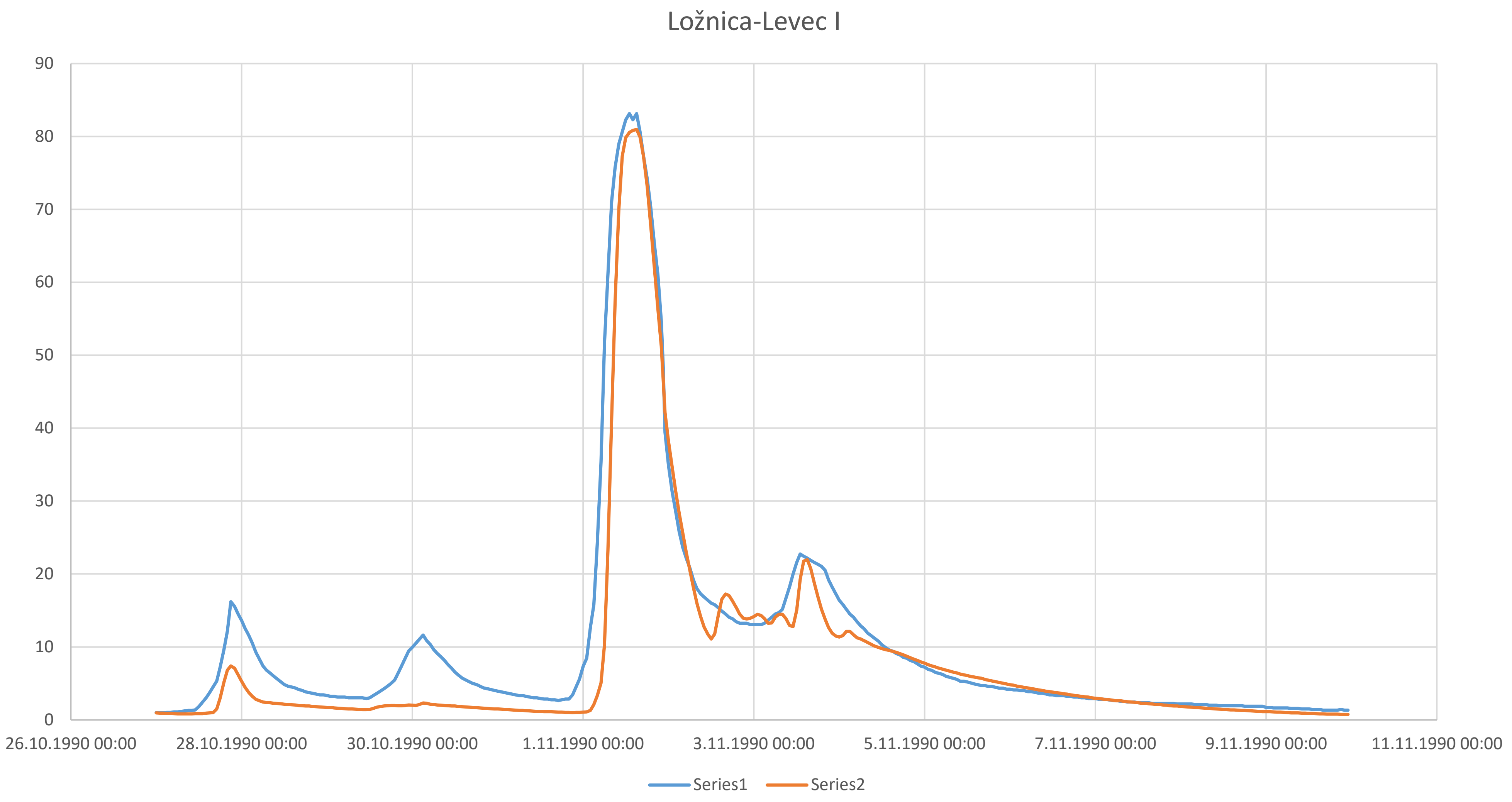
Flood Wave vp Laško 26.10.-05.11.1990



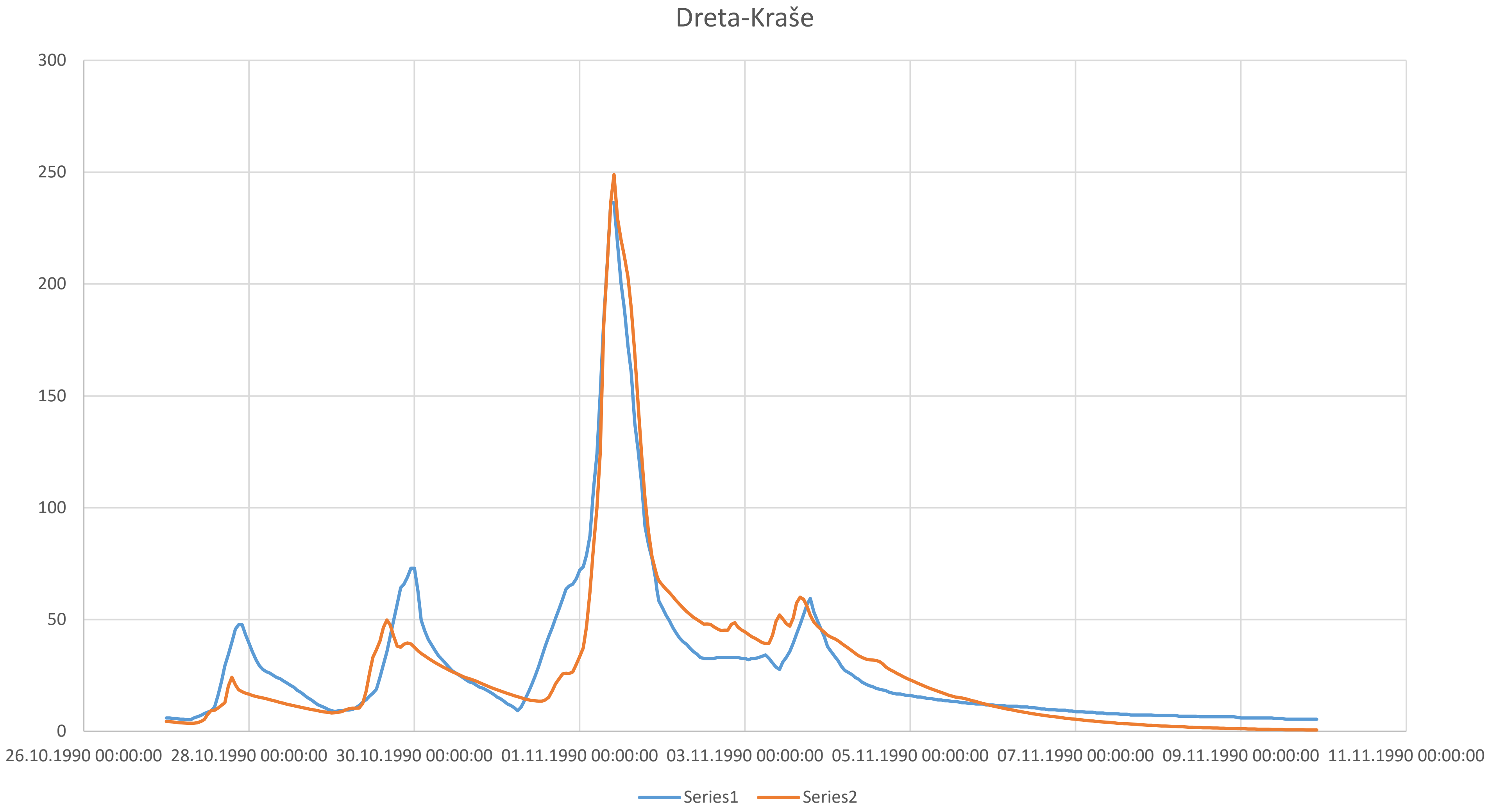
Savinja – vp Laško



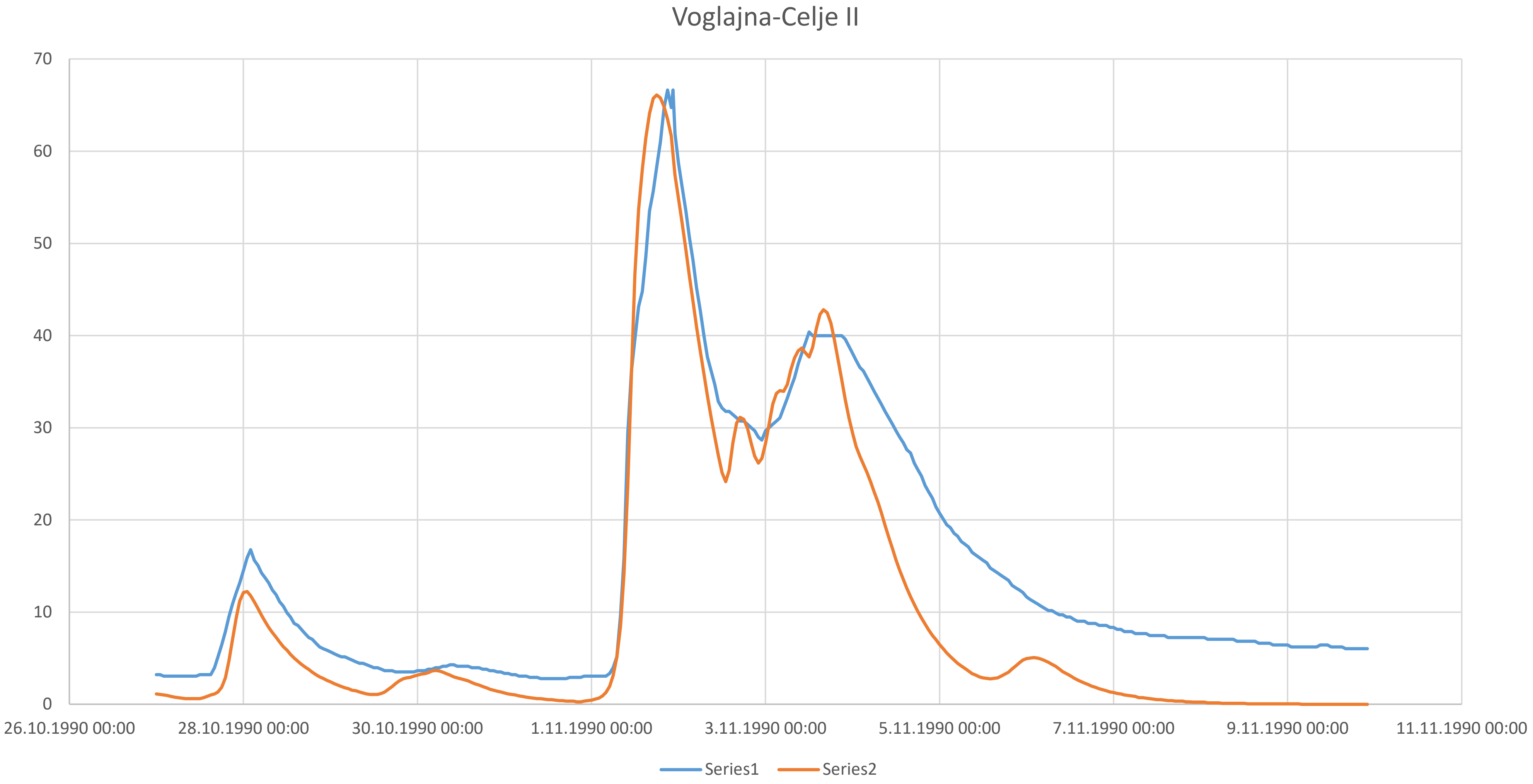
Ložnica – vp Levec I



Dreta – vp Kraše



Voglajna – vp Celje II



1. Why use a P-R modeling?

- for education
- for decision support
- for data quality control
- for water balance studies
- for drought runoff forecasting (irrigation)
- for fire risk warning
- for runoff forecasting/prediction (flood warning and reservoir operation)
- for what happens if' questions

2. Why use a P-R modeling?

- to compute design floods for flood risk detection
- to extend runoff data series (or filling gaps)
- to compute design floods for dam safety
- to compute energy production
- to investigate the effects of land-use changes within the catchment
- to simulate discharge from ungauged catchments
- to simulate climate change effects

Designed Flood Predictions

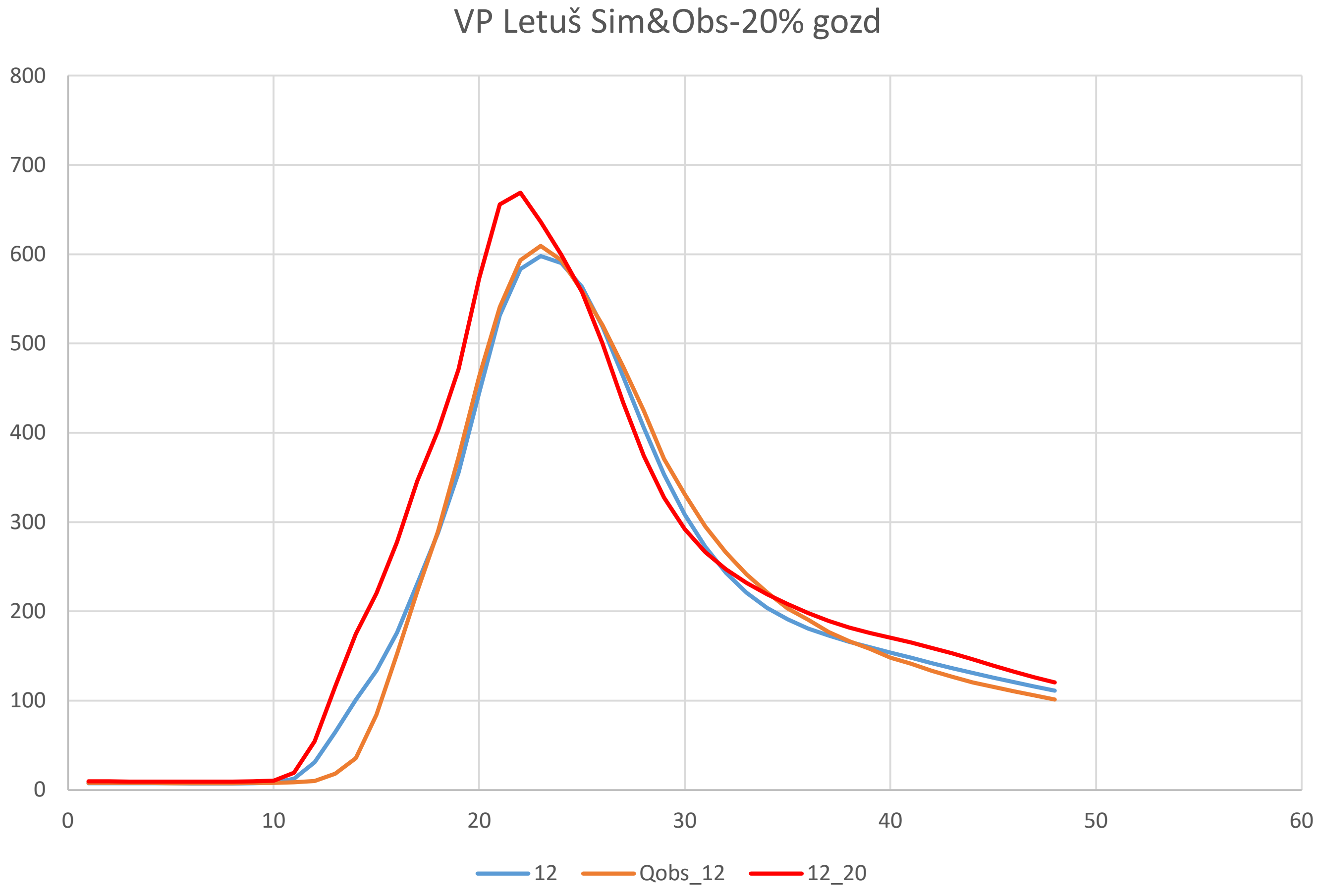
- based on flood event 2007 (50 year return period)

  24 hour Precipitation Event for Q10, Q20, Q50, Q100, Q200 and Q500

- based on flood event 1990 and 1998 (100 year return period)

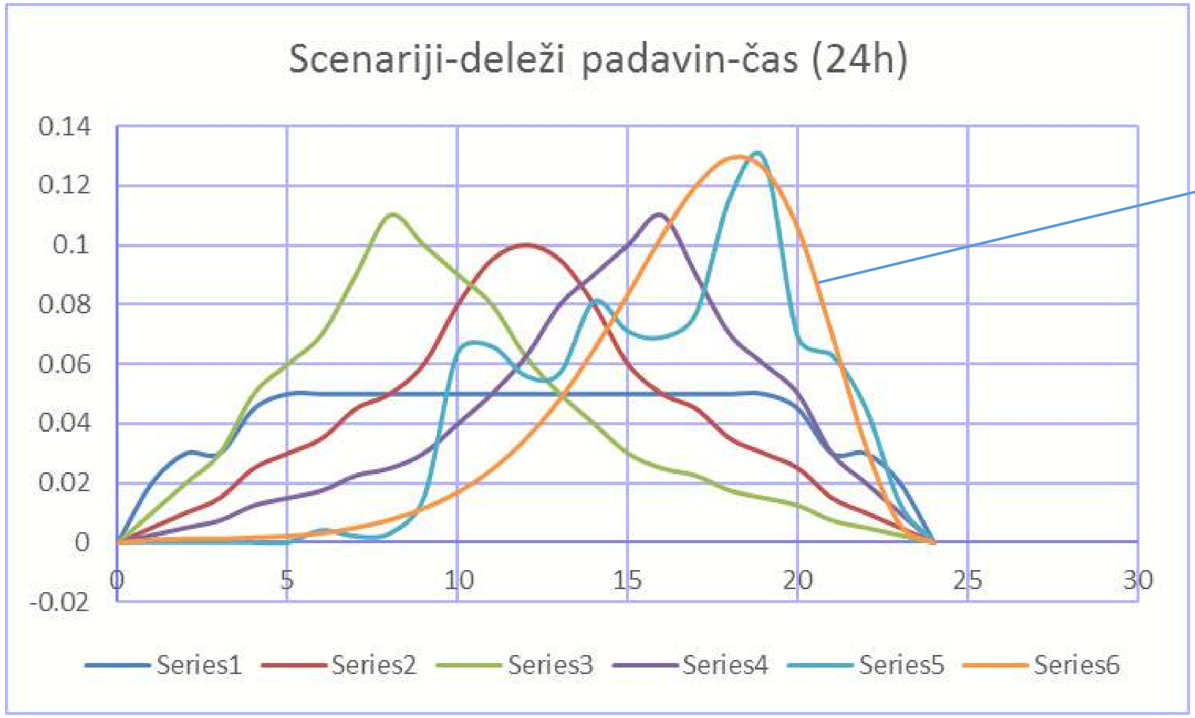
  48 hour Precipitation Event for Q10, Q20, Q50, Q100, Q200 and Q500

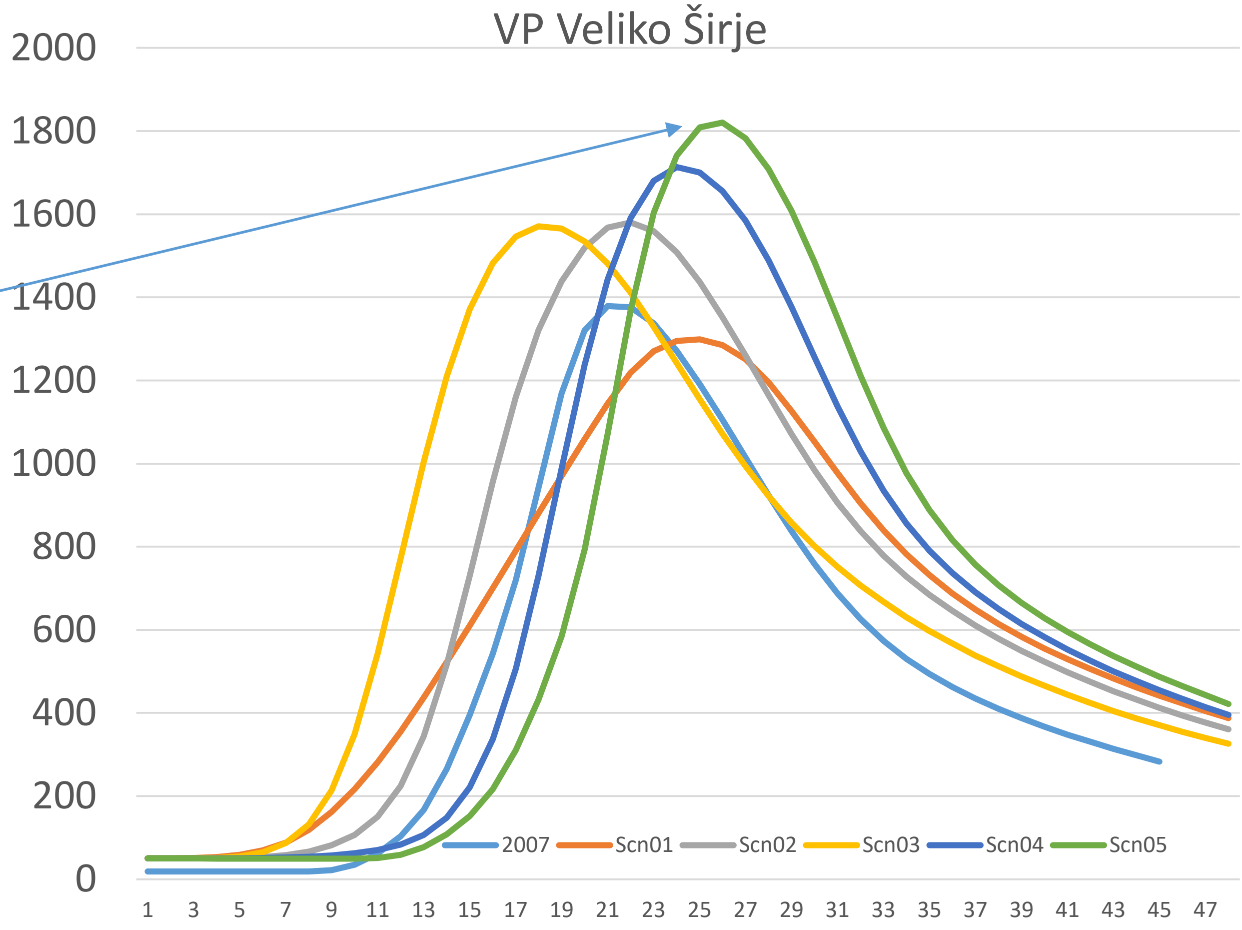
Sprememba rabe tal – zmanjšanje površine gozda za 20%



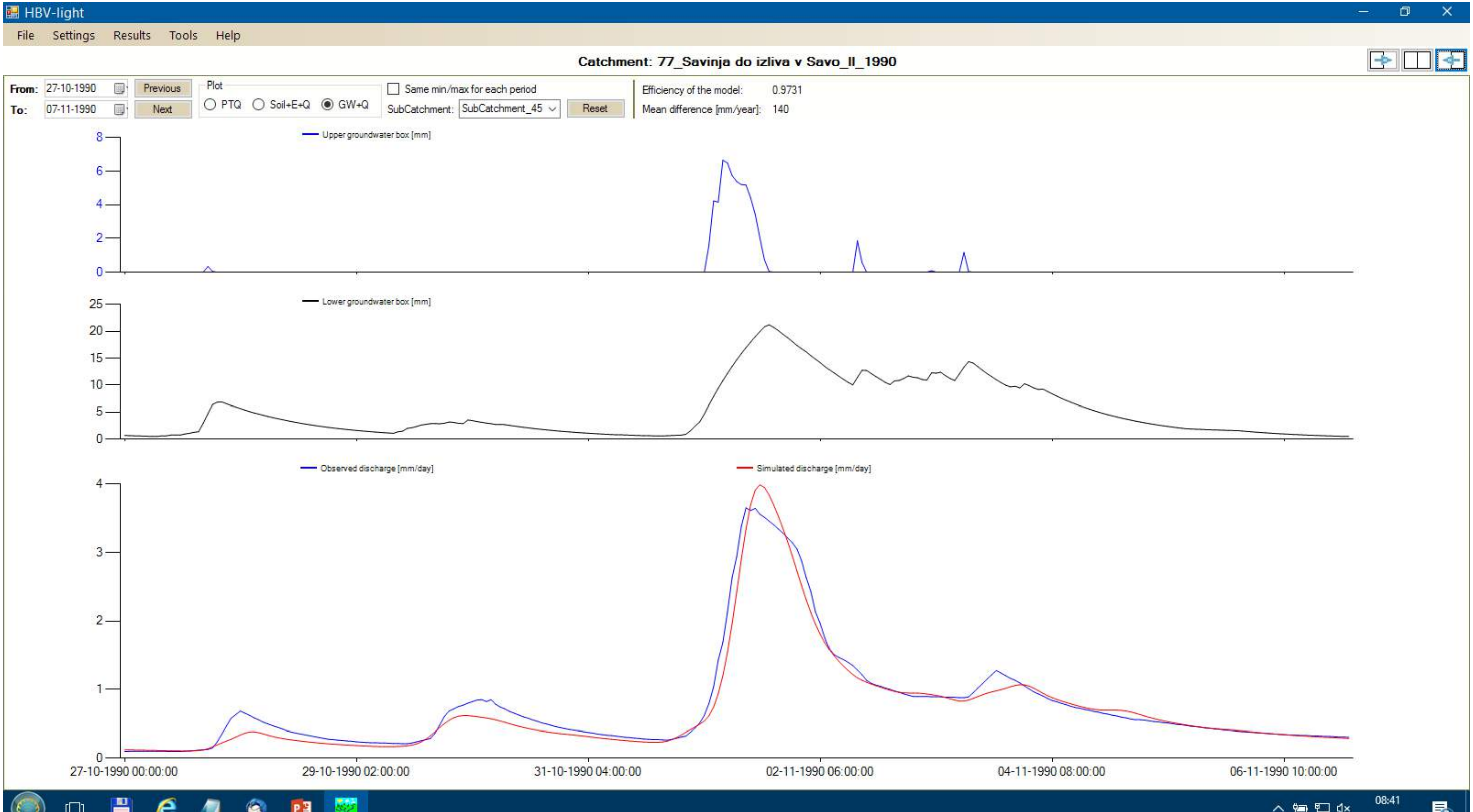
10	% povečanje konice vala
13	% povečanje volumna
4.5	mio. m3 bi zadržal gozd
1h	visokovodni val nastopi 1 uro prej

Razporeditev padavin

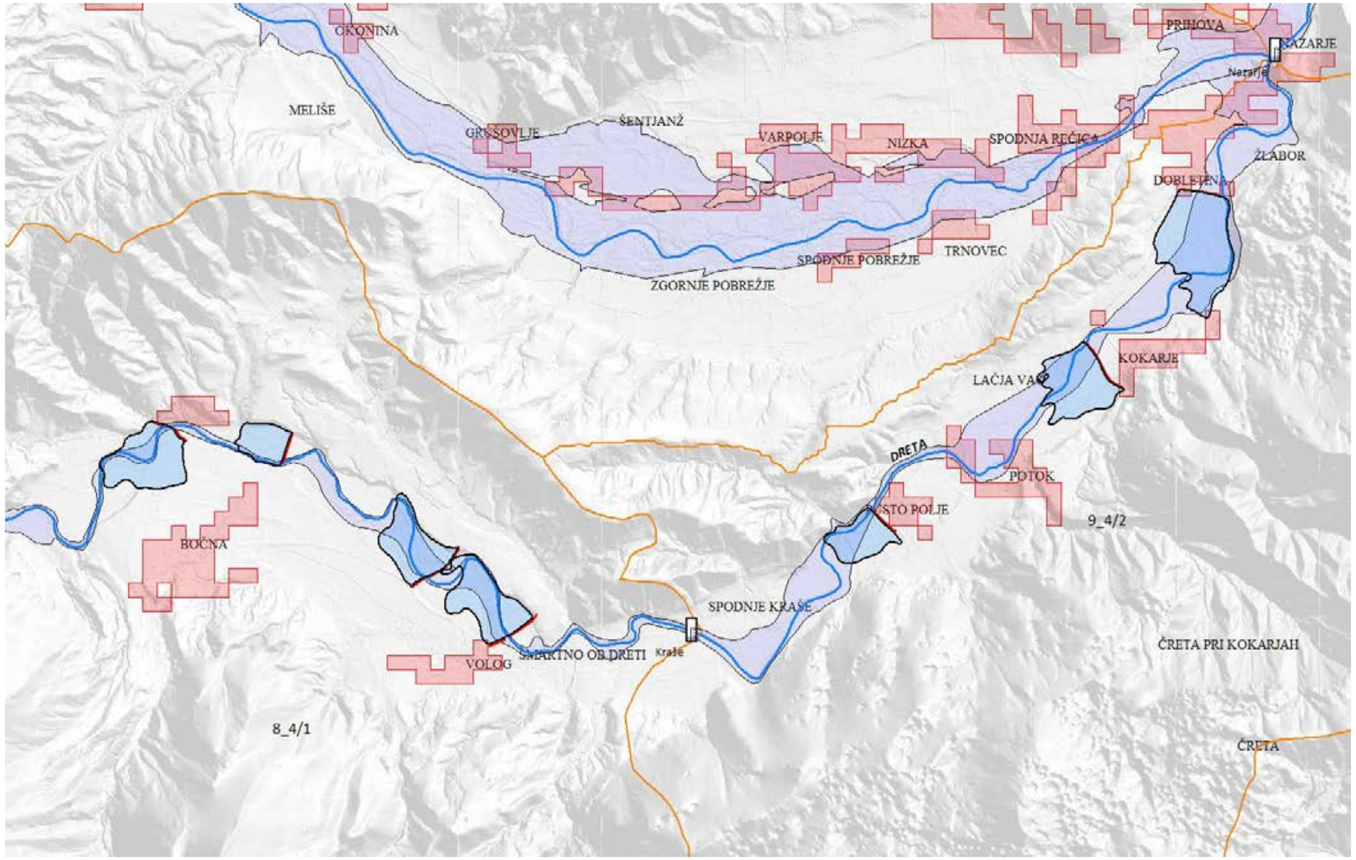


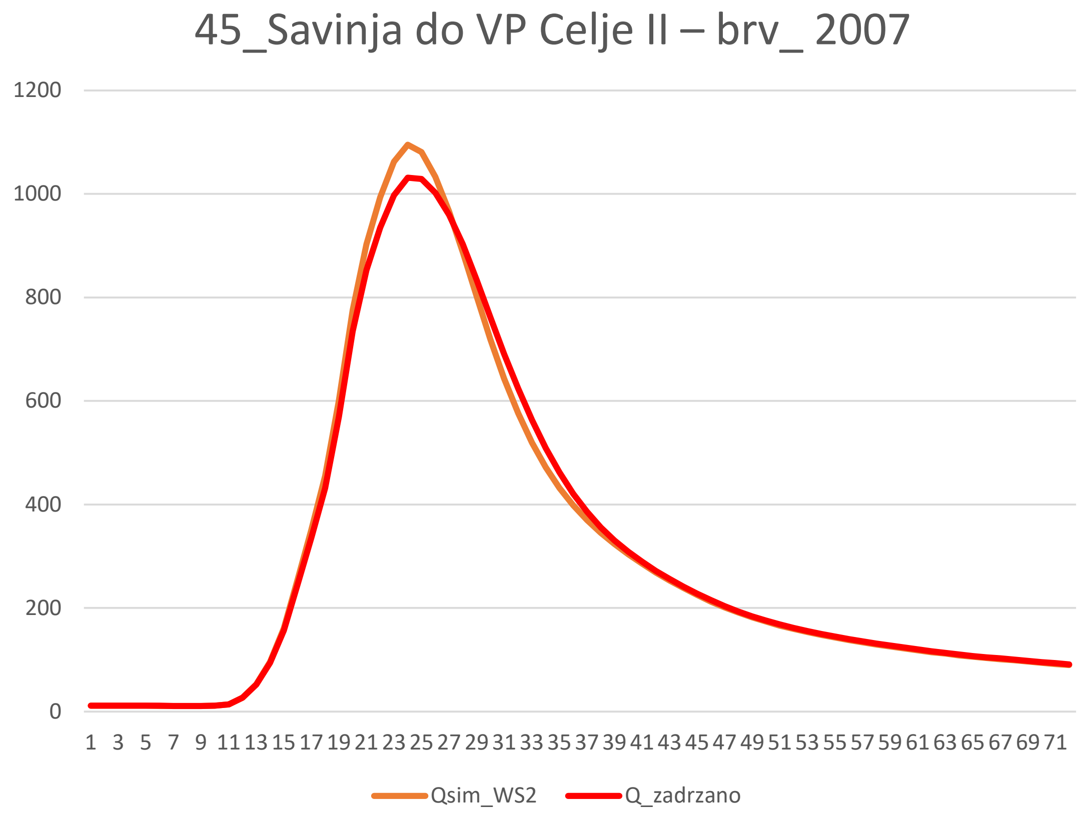


Ground water



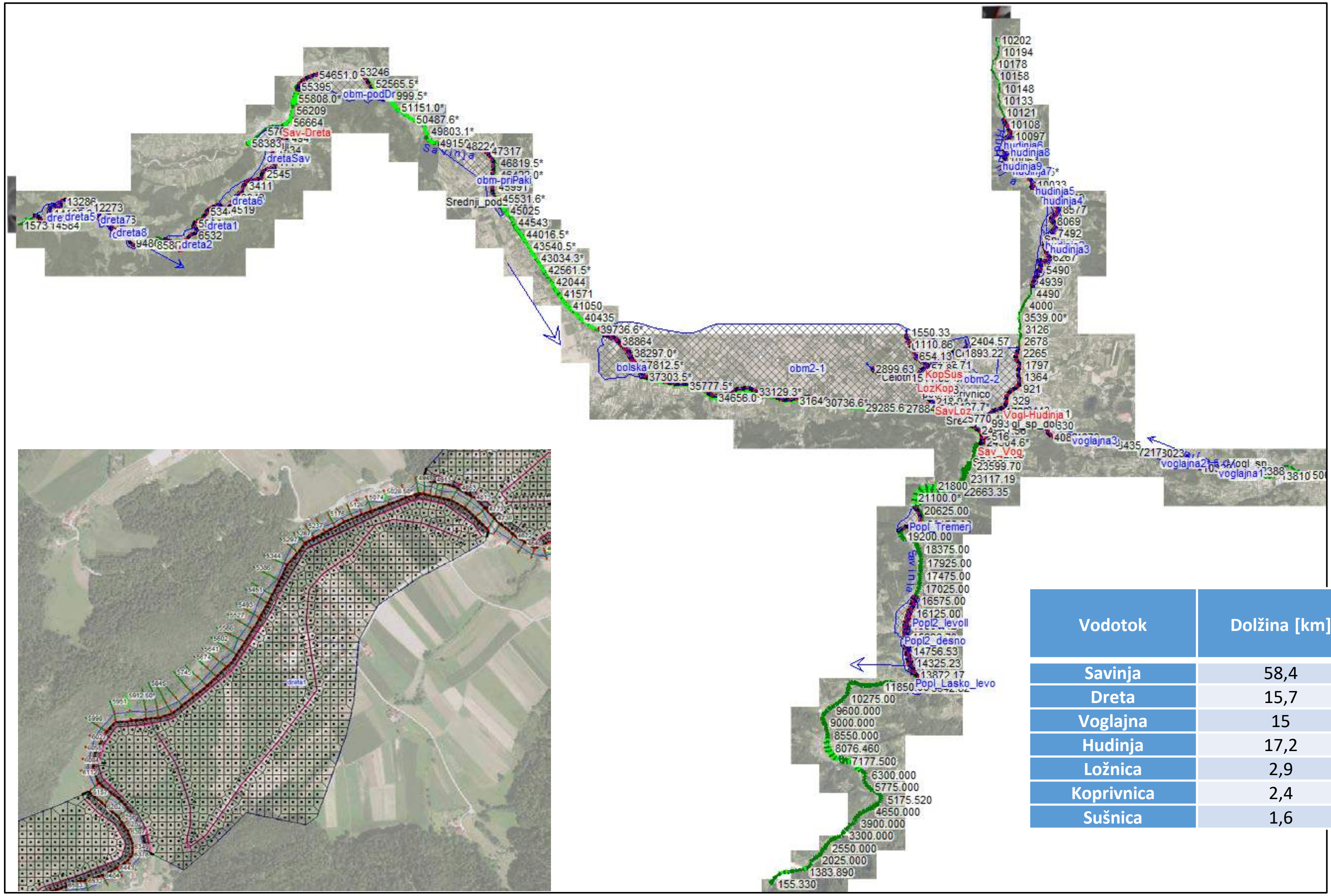
Vpliv zadrževalnikov na Dreti -VP Celje

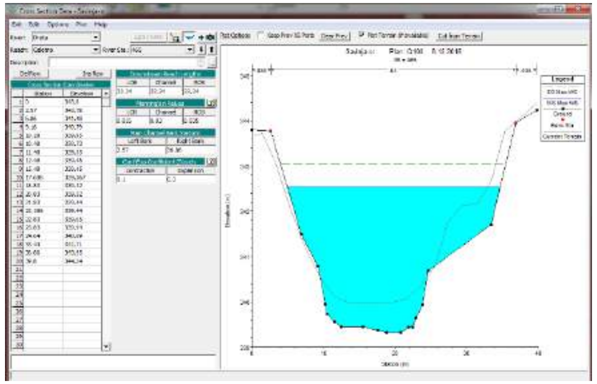




-5.78	sprememba Qvk [%]
-63.24	sprememba Qvk [m3]
1.63	zadržani volumen [mio. m3]

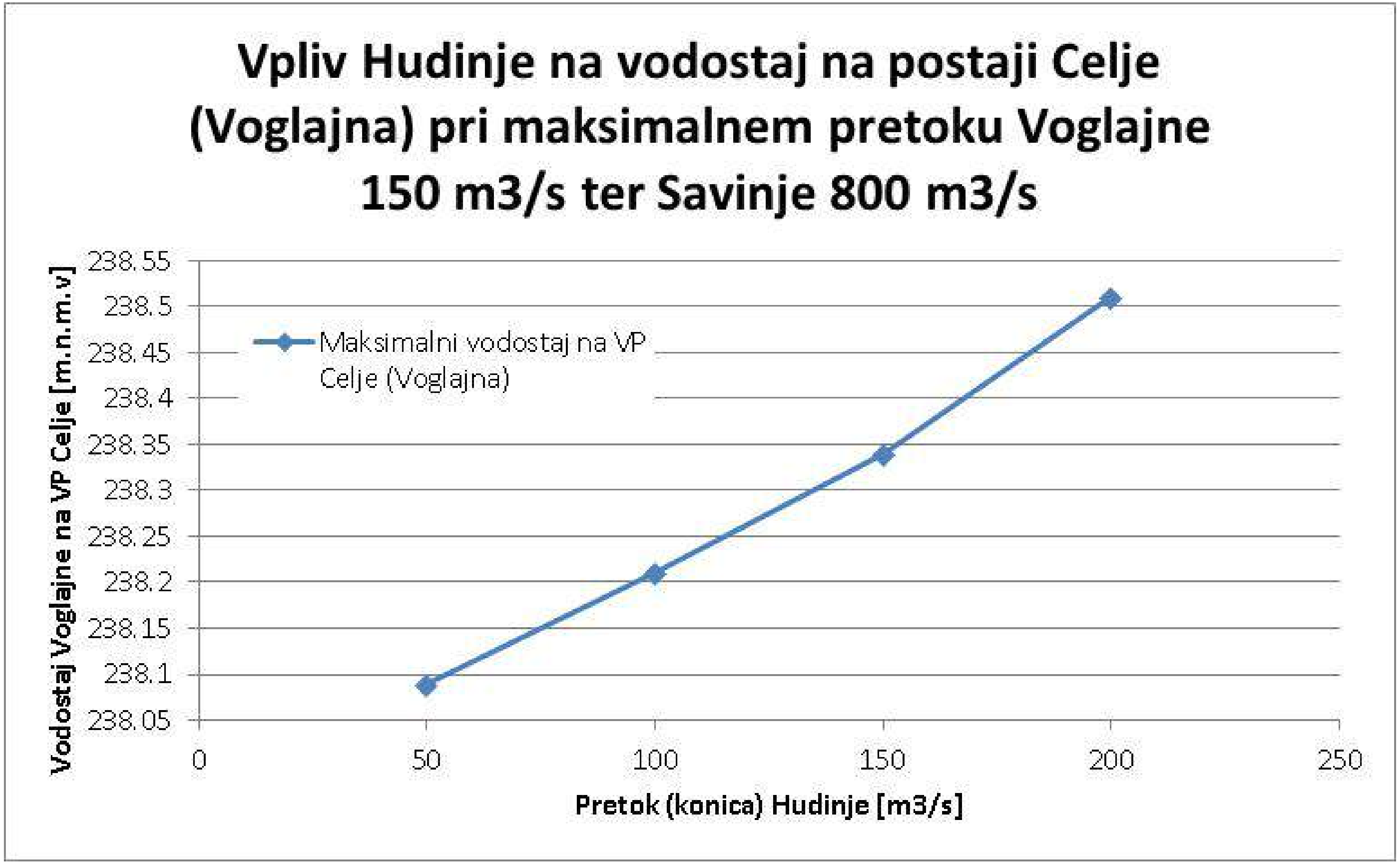
River Analysis System (HEC-RAS)5.0.3 (1D,2D)





Vodotok	Dolžina [km]	Število profilov	Povprečna oddaljenost med profili [m]	Povprečni padec odseka [%]
Savinja	58,4	934	62,5	0,3
Dreta	15,7	407	38,8	0,4
Voglajna	15	400	37,5	0,2
Hudinja	17,2	466	36,9	0,6
Ložnica	2,9	87	33,3	0,3
Koprivnica	2,4	61	39,3	0,2
Sušnica	1,6	56	28,6	0,4

Vpliv zajezitve Voglajne zaradi povečanih pretokov Hudinje



Vpliv zadrževalnikov na Savinji v spodnji Savinjski dolini - VP Celje