Ukrainian Hydrometeorological Institute

LABORATORY OF THE RIVER SYSTEMS MODELING

TEXAS A&M AGRILIFE RESEARCH

IBM Research

The SWAT model for the restoration of Ukraine

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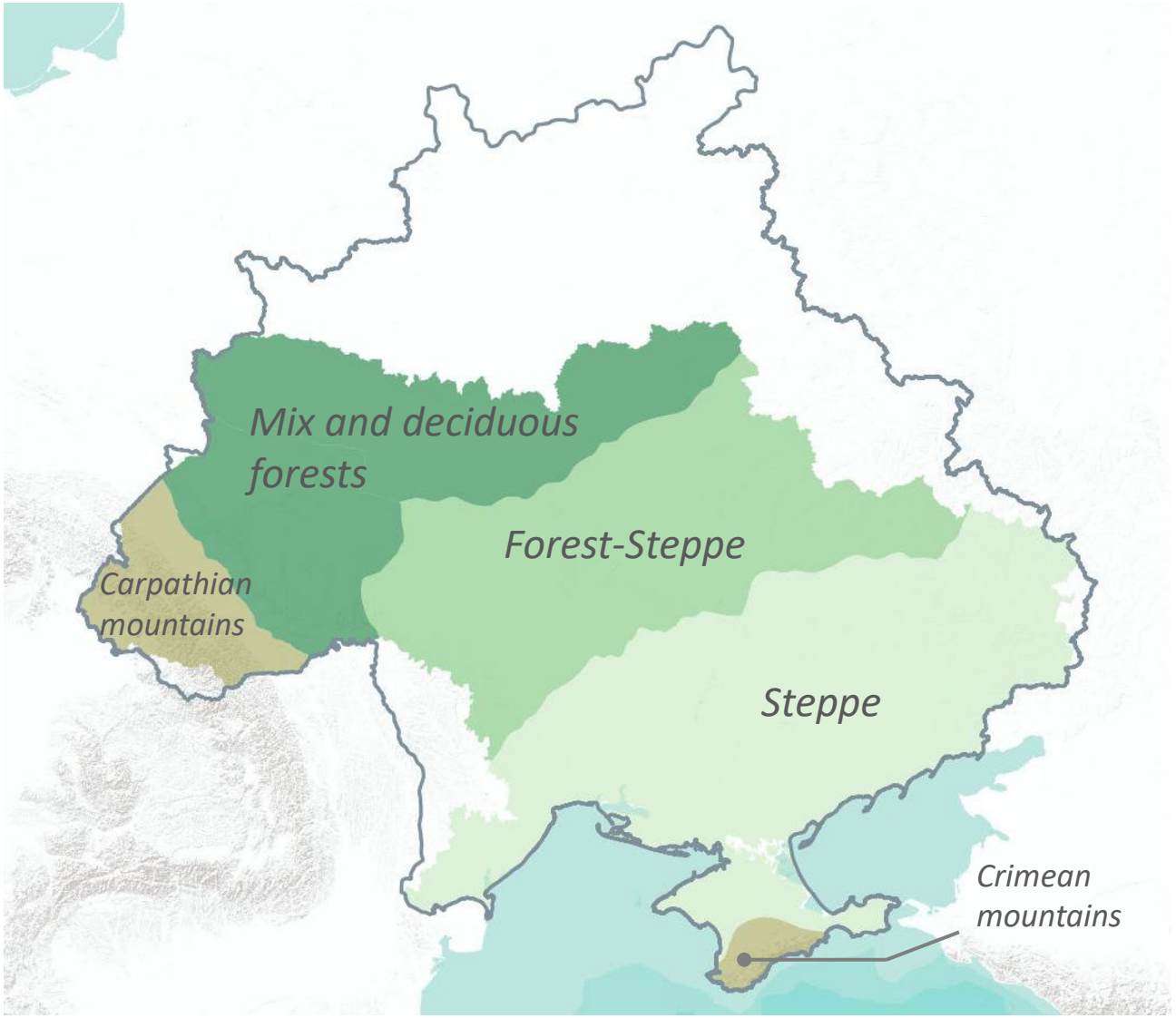
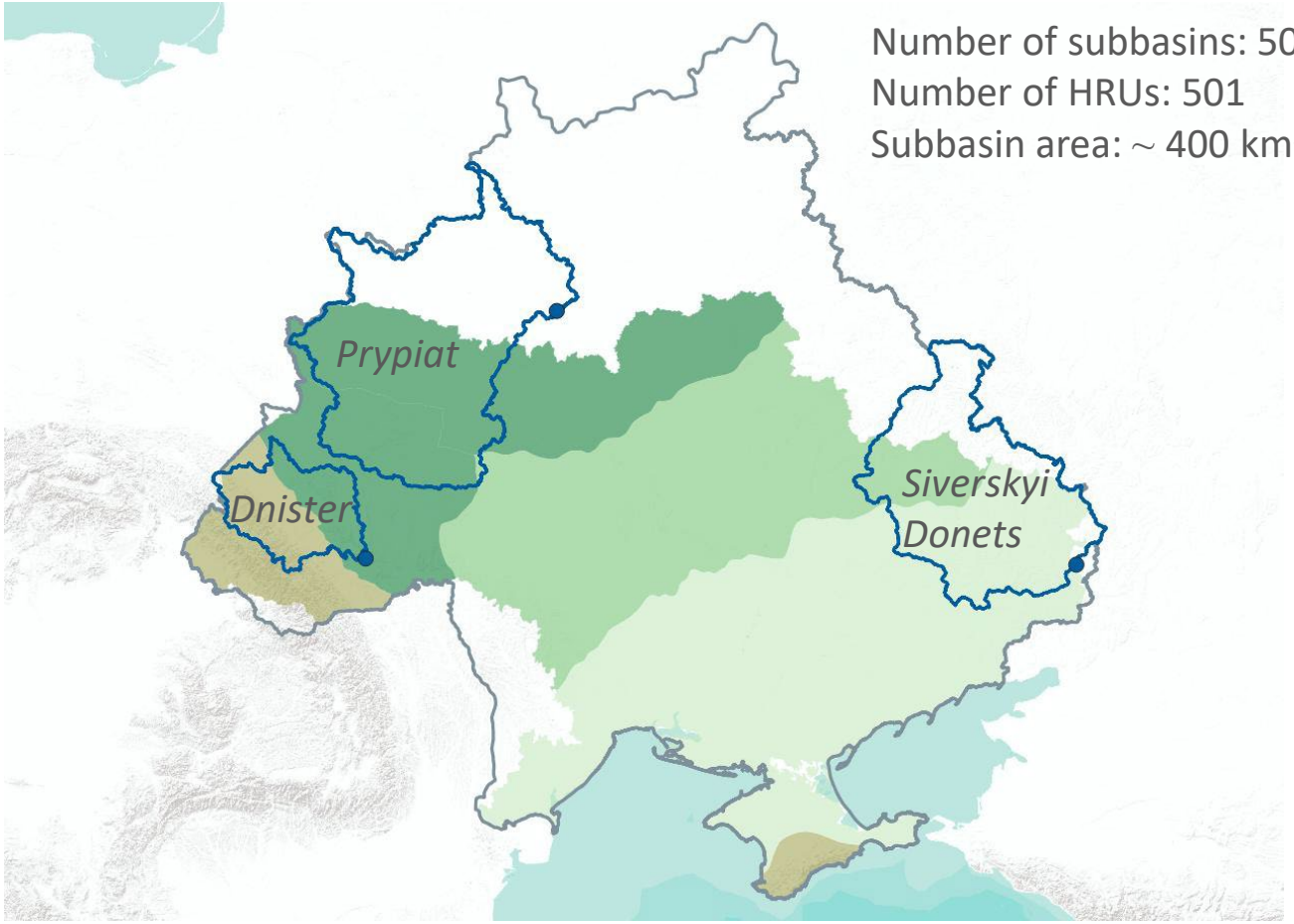
[1]Ukrainian Hydrometeorological Institute, Kyiv
[2]Texas A&M Agrilife Research
[3]IBM Research

June 2023 – Aarhus, Denmark

Ukrainian watershed and Physical-geographical zoning



Ukrainian watershed and Physical-geographical zoning



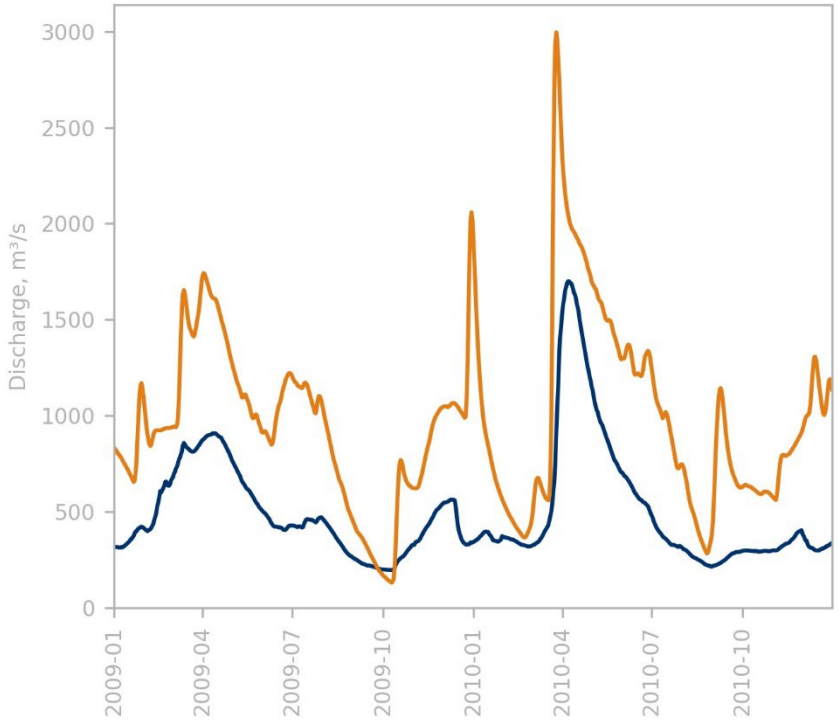
Number of subbasins: 501
Number of HRUs: 501
Subbasin area: ~ 400 km^2

First step – investigation of the SWAT model behavior in different zones

Calibration process

- Default parameters
  (except snow parameters)

Prypiat River, 2009-2010



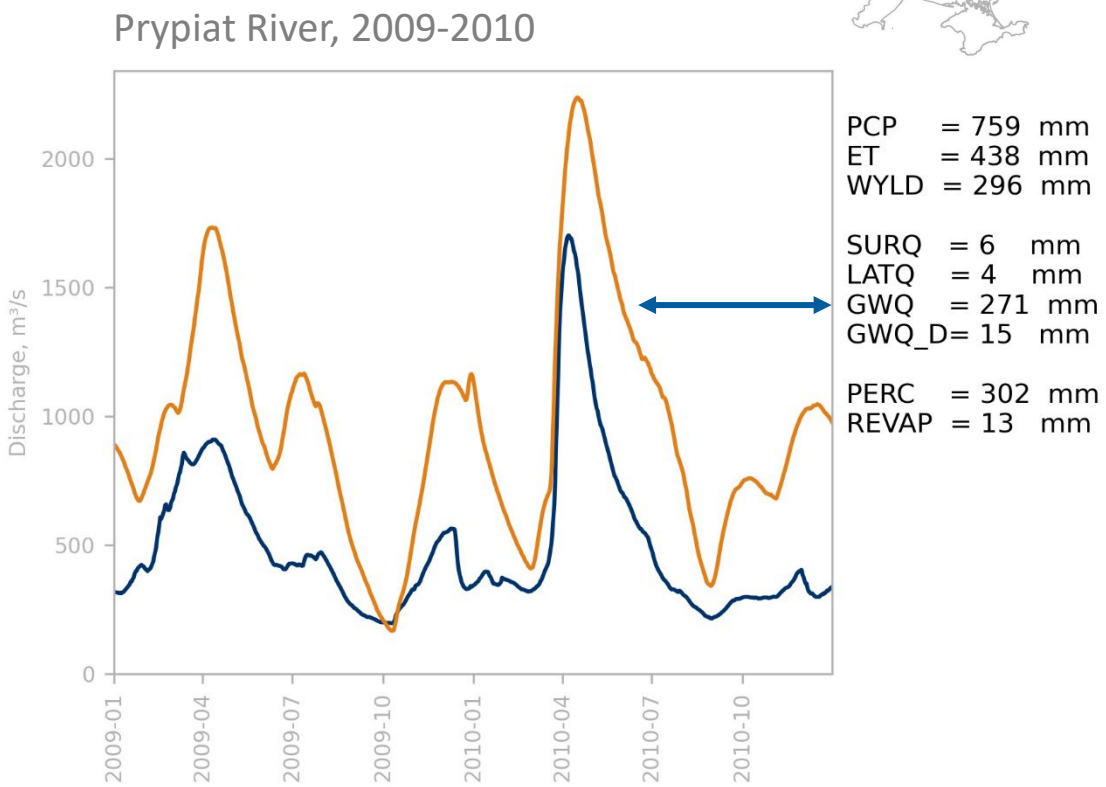
PCP = 759 mm
ET = 435 mm
WYLD = 300 mm

SURQ = 56 mm
LATQ = 4 mm
GWQ = 228 mm
GWQ_D= 12 mm

PERC = 257 mm
REVAP = 13 mm

Calibration process: Sensitivity analysis

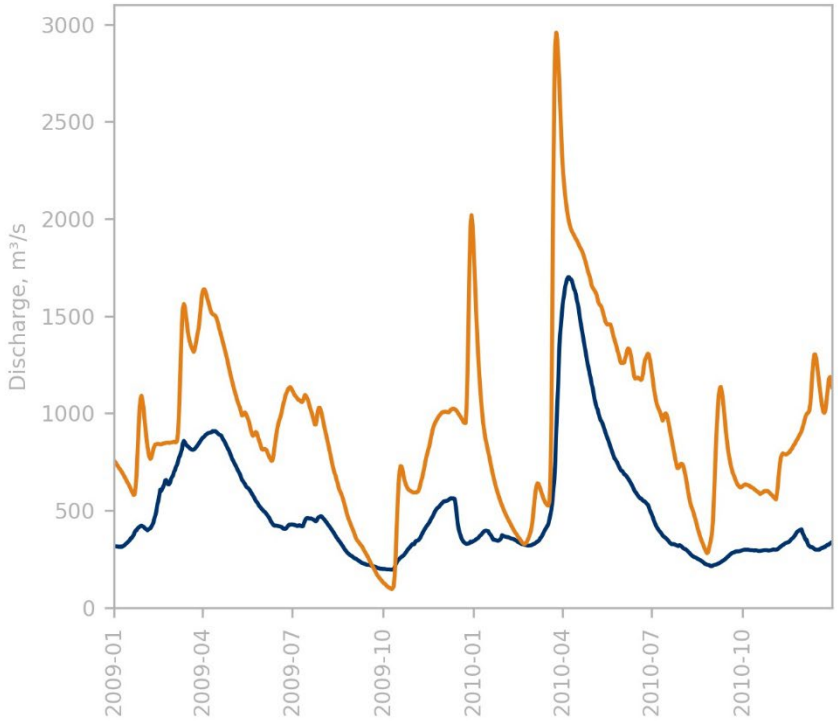
- r_CN2.mgt = -0.3



Calibration process

- CN2.mgt = default
- v_GWQMN.gw = 2000

Prypiat River, 2009-2010



PCP = 759 mm
ET = 435 mm
WYLD = 258 mm

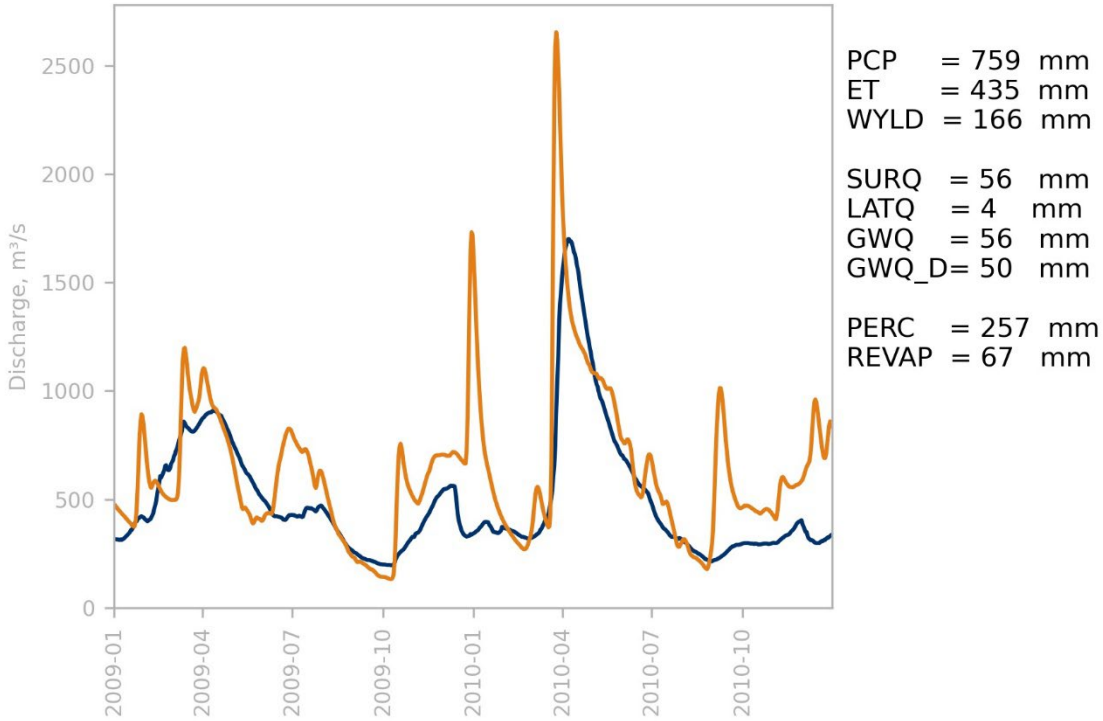
SURQ = 56 mm
LATQ = 4 mm
GWQ = 185 mm
GWQ_D= 12 mm

PERC = 257 mm
REVAP = 13 mm

Calibration process

- CN2.mgt = default
- v_GWQMN.gw = 2000
- v_RCHRG_DP.gw = 0.2
- v_GW_REVAP.gw = 0.1

Prypiat River, 2009-2010



PCP = 759 mm
ET = 435 mm
WYLD = 166 mm

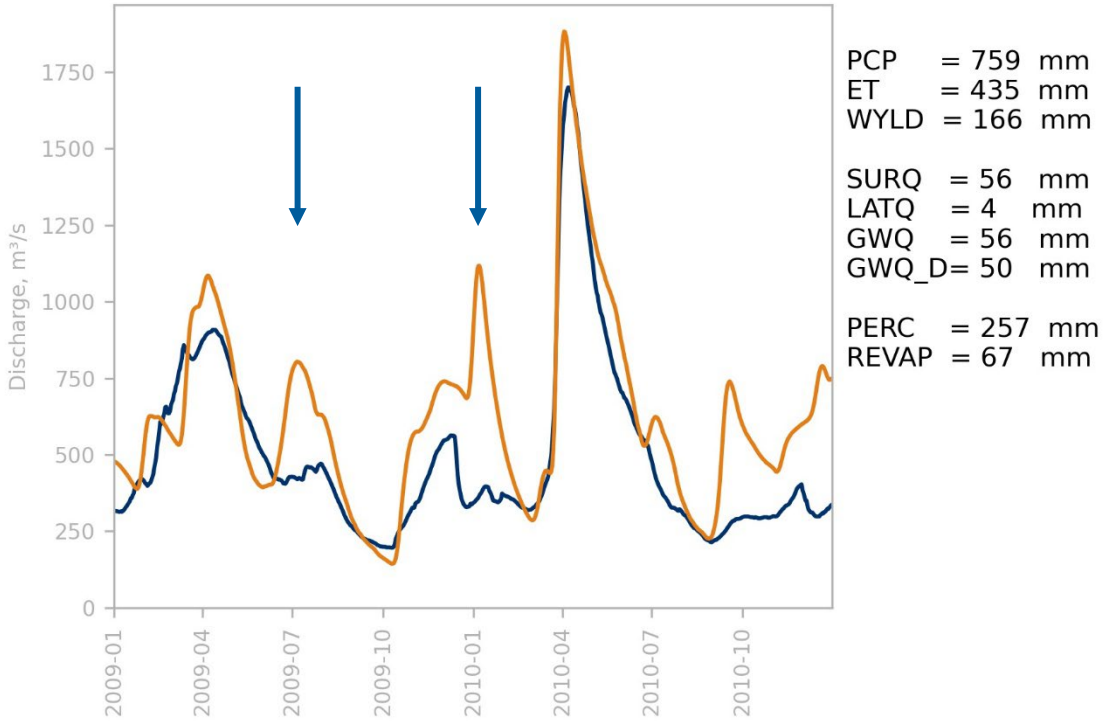
SURQ = 56 mm
LATQ = 4 mm
GWQ = 56 mm
GWQ_D= 50 mm

PERC = 257 mm
REVAP = 67 mm

Calibration process

- CN2.mgt = default
- v_GWQMN.gw = 2000
- v_RCHRG_DP.gw = 0.2
- v_GW_REVAP.gw = 0.1
- v_CH_N1.sub = 0.075
- v_CH_N2.rte = 0.075

Prypiat River, 2009-2010



PCP = 759 mm
ET = 435 mm
WYLD = 166 mm

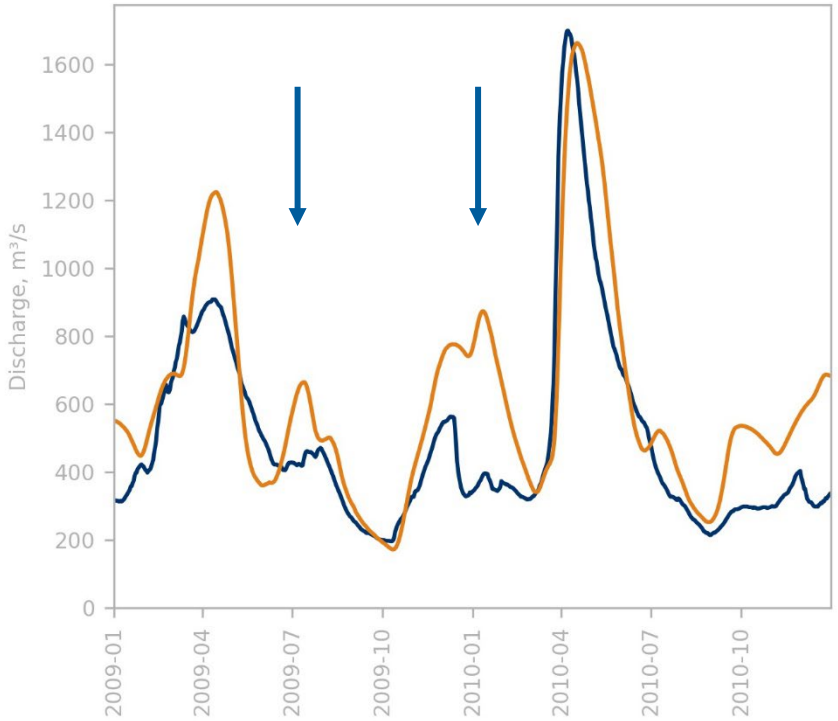
SURQ = 56 mm
LATQ = 4 mm
GWQ = 56 mm
GWQ_D= 50 mm

PERC = 257 mm
REVAP = 67 mm

Calibration process

- CN2.mgt = default
- v_GWQMN.gw = 2000
- v_RCHRG_DP.gw = 0.2
- v_GW_REVAP.gw = 0.1
- v_CH_N1.sub = 0.075
- v_CH_N2.rte = 0.075
- v_Surlag.hru = 1

Prypiat River, 2009-2010



PCP = 759 mm
ET = 435 mm
WYLD = 180 mm

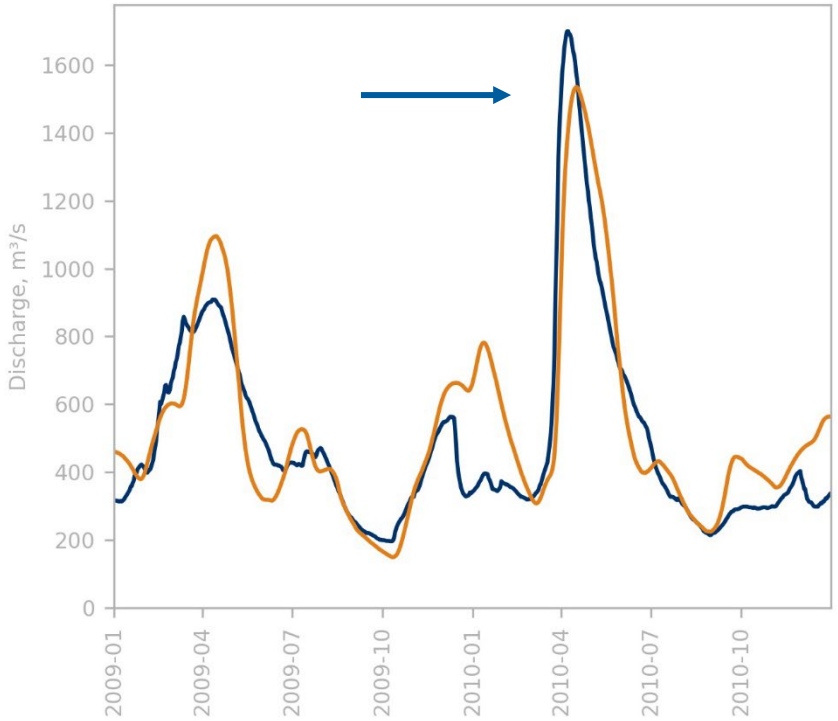
SURQ = 56 mm
LATQ = 4 mm
GWQ = 71 mm
GWQ_D= 50 mm

PERC = 257 mm
REVAP = 101 mm

Calibration process

- CN2.mgt = default
- v_GWQMN.gw = 2000
- v_RCHRG_DP.gw = 0.2
- v_GW_REVAP.gw = 0.1
- v_CH_N1.sub = 0.075
- v_CH_N2.rte = 0.075
- v_Surlag.hru = 1
- v_ESCO.hru = 0.9

Prypiat River, 2009-2010



PCP = 759 mm
ET = 460 mm
WYLD = 154 mm

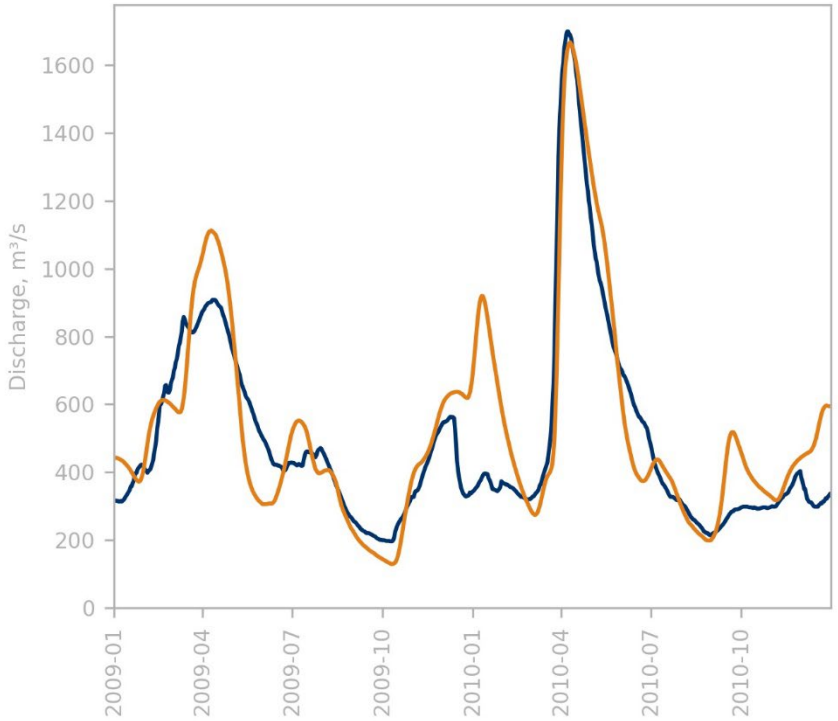
SURQ = 53 mm
LATQ = 4 mm
GWQ = 52 mm
GWQ_D= 45 mm

PERC = 234 mm
REVAP = 101 mm

Calibration process

- CN2.mgt = default
- v_GWQMN.gw = 2000
- v_RCHRG_DP.gw = 0.2
- v_GW_REVAP.gw = 0.1
- v_CH_N1.sub = 0.075
- v_CH_N2.rte = 0.075
- v_Surlag.hru = 2 (default)
- v_ESCO.hru = 0.9

Prypiat River, 2009-2010



PCP = 759 mm
ET = 460 mm
WYLD = 154 mm

SURQ = 53 mm
LATQ = 4 mm
GWQ = 52 mm
GWQ_D= 45 mm

PERC = 234 mm
REVAP = 101 mm

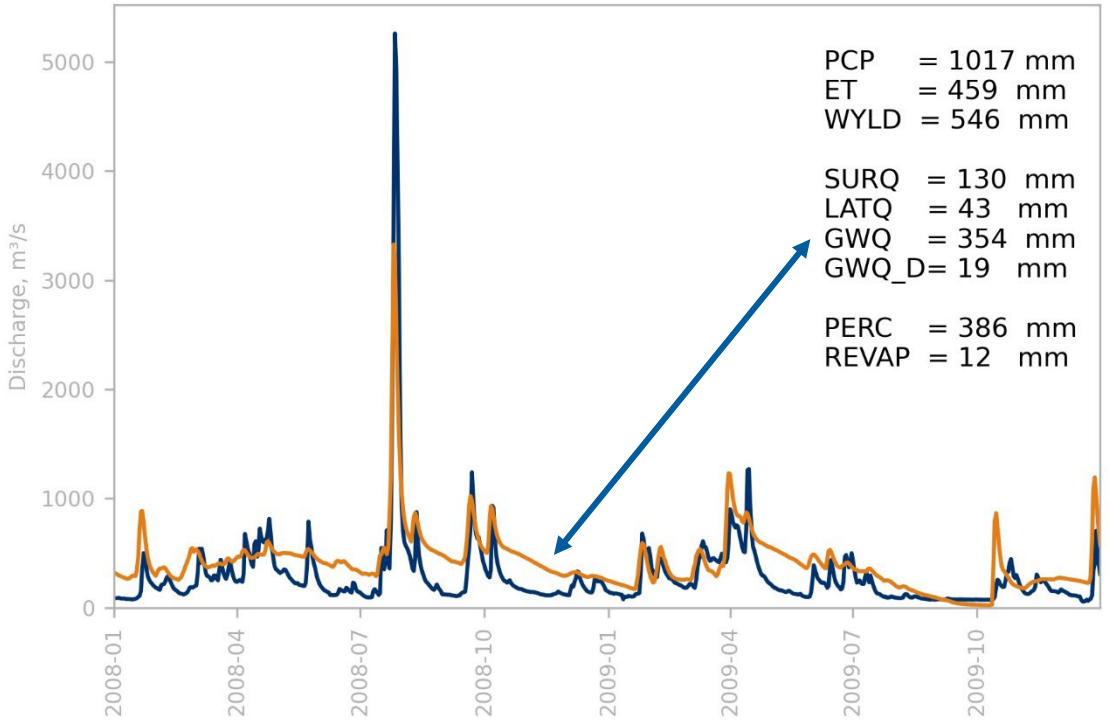
Performance criteria (5 years):

- NS = 0.76
- R2 = 0.77
- PBIAS = 5%

Calibration process

- Default parameters

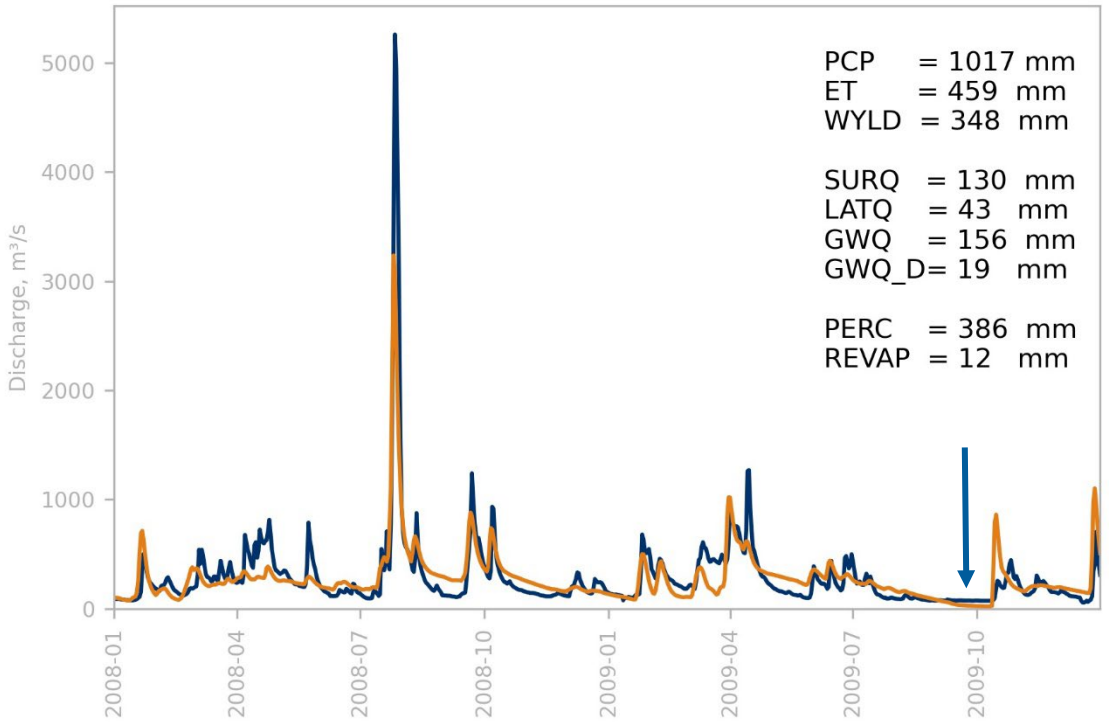
Dnister River, 2008-2009



Calibration process

- v_GWQMN.gw = 4000

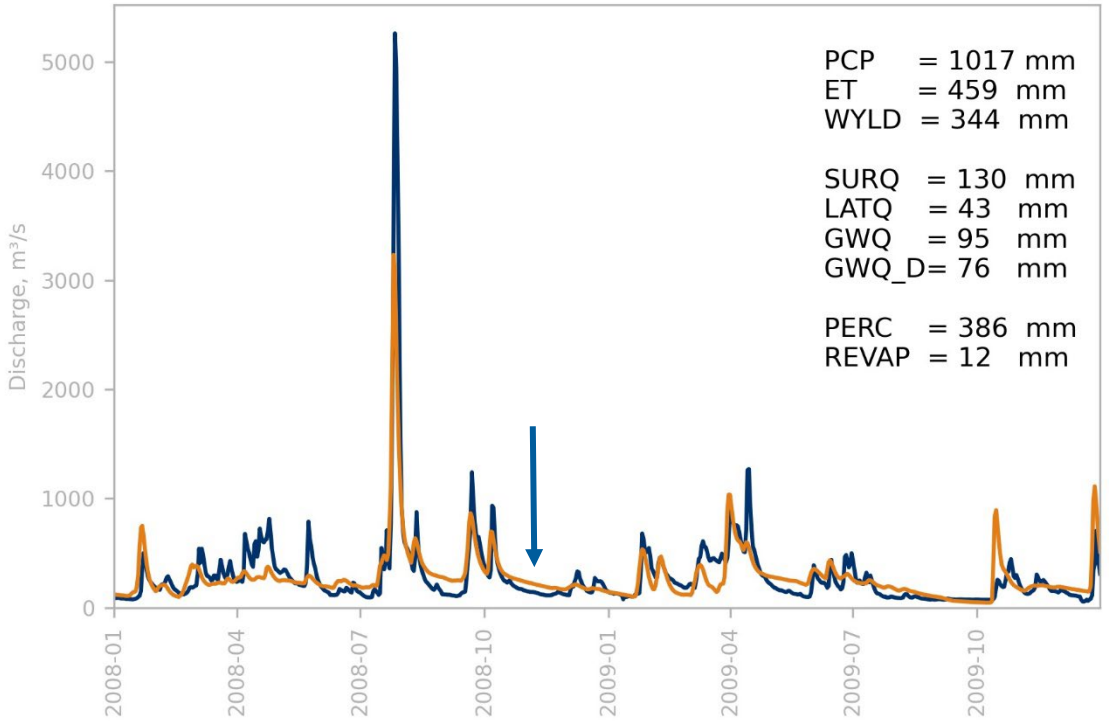
Dnister River. 2008-2009



Calibration process

- v_GWQMN.gw = 4000
- v_RCHRG_DP.gw = 0.2

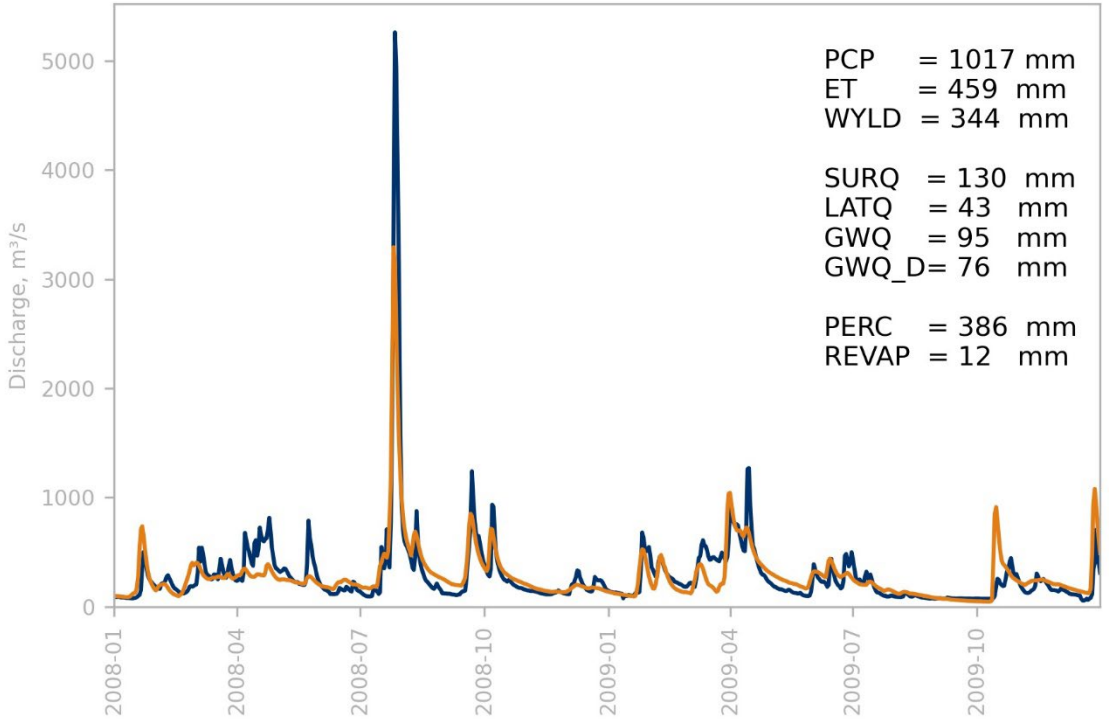
Dnister River. 2008-2009



Calibration process

- v_GWQMN.gw = 4000
- v_RCHRG_DP.gw = 0.2
- v_ALPHA_BF.gw = 0.2

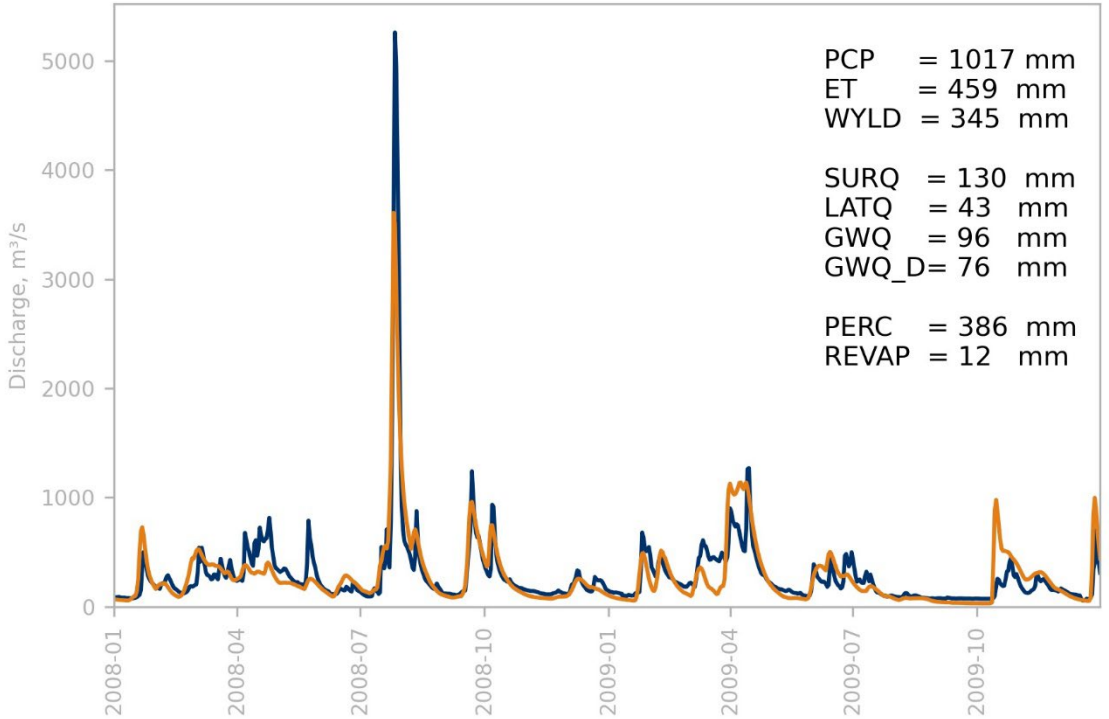
Dnister River, 2008-2009



Calibration process

- v_GWQMN.gw = 4000
- v_RCHRG_DP.gw = 0.2
- v_ALPHA_BF.gw = 0.2
- v_GW_DELAY.gw = 5

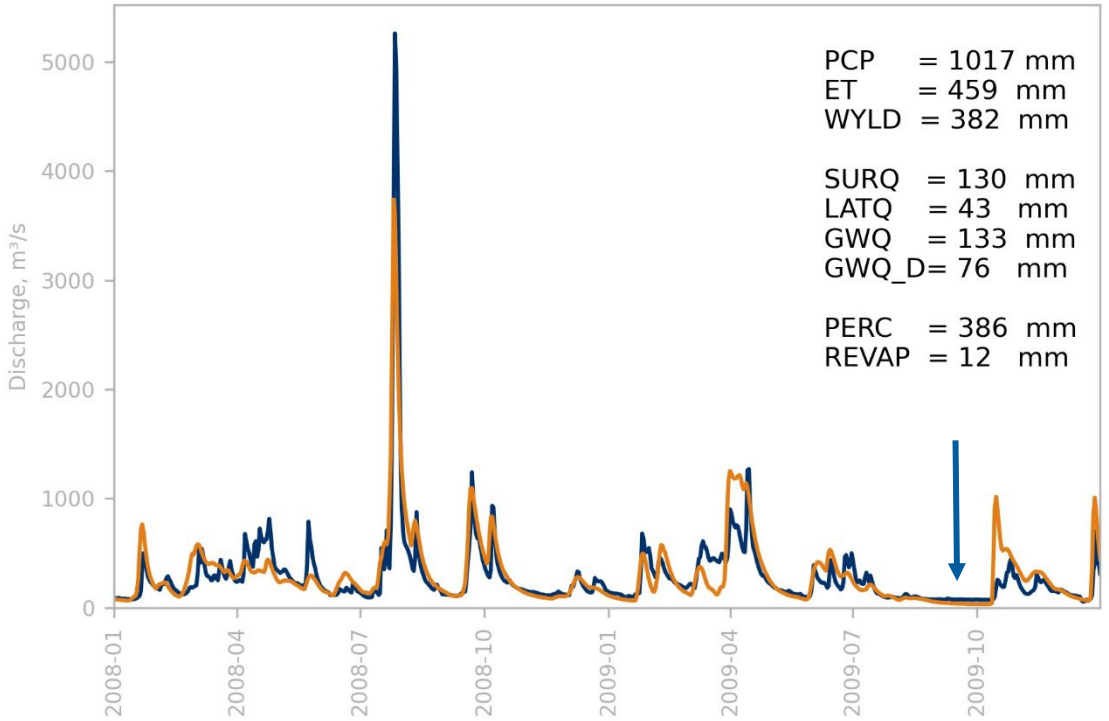
Dnister River, 2008-2009



Calibration process

- v_GWQMN.gw = 3500
- v_RCHRG_DP.gw = 0.2
- v_ALPHA_BF.gw = 0.8
- v_GW_DELAY.gw = 10

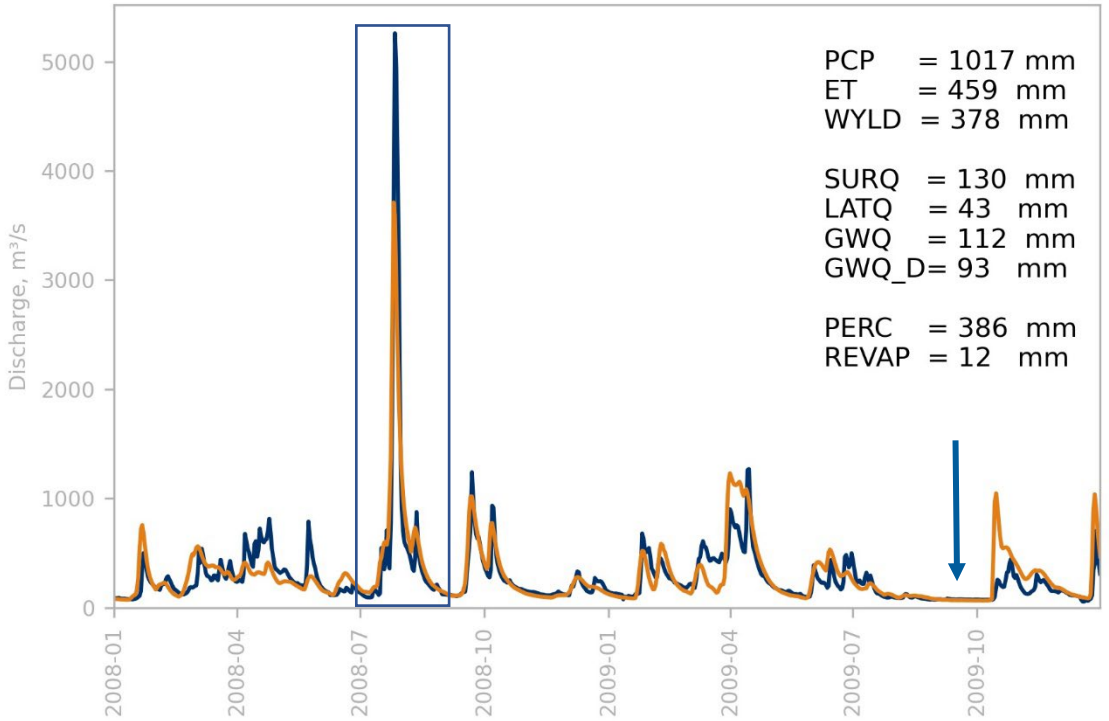
Dnister River. 2008-2009

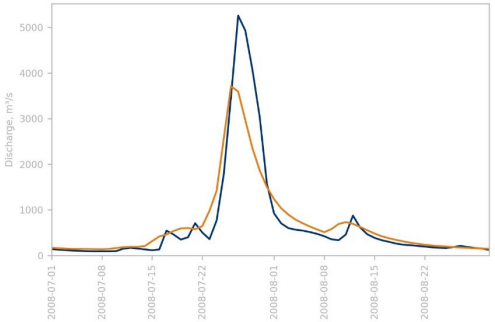


Calibration process

- v_GWQMN.gw = 3500
- v_RCHRG_DP.gw = 0.2
- v_ALPHA_BF.gw = 0.8
- v_GW_DELAY.gw = 10
- v_ALPHA_BF_D.gw = 0.003

Dnister River. 2008-2009

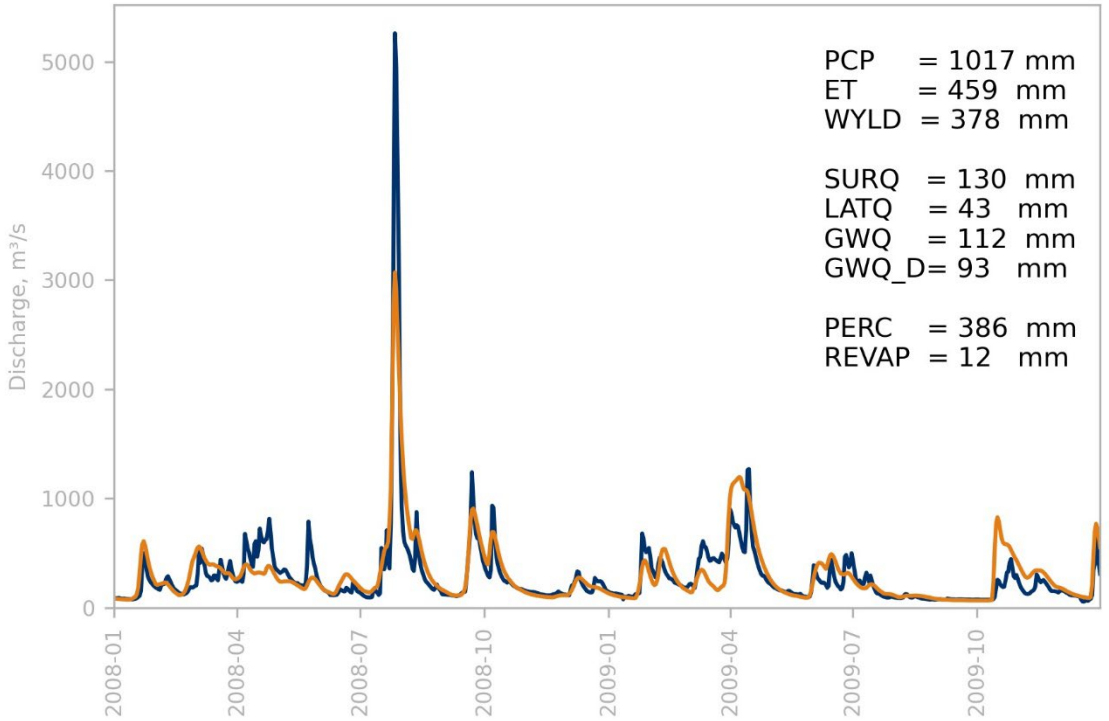


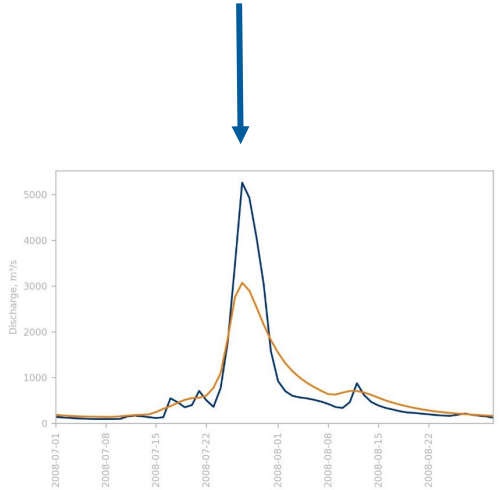


Calibration process

- v_GWQMN.gw = 3500
- v_RCHRG_DP.gw = 0.2
- v_ALPHA_BF.gw = 0.8
- v_GW_DELAY.gw = 10
- v_ALPHA_BF_D.gw = 0.003
- v_CH_N1.sub = 0.025
- v_CH_N2.rte = 0.025

Dnister River. 2008-2009

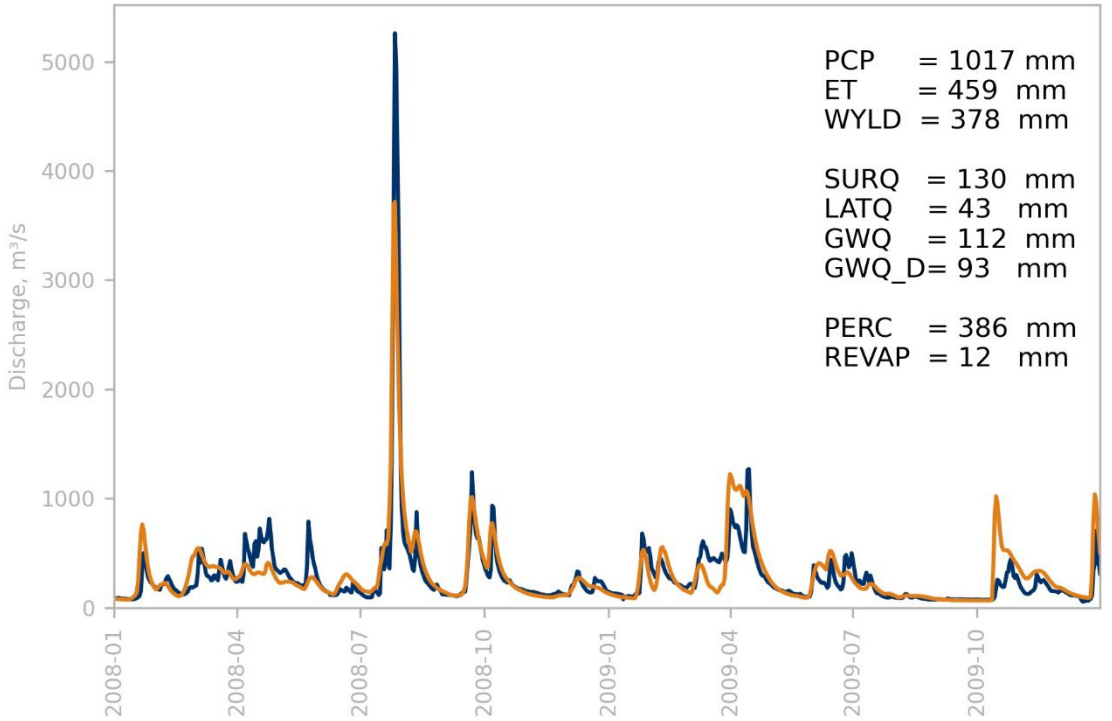


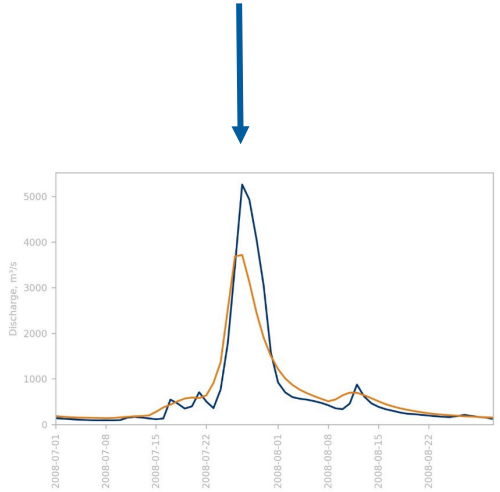


Calibration process

- v_GWQMN.gw = 3500
- v_RCHRG_DP.gw = 0.2
- v_ALPHA_BF.gw = 0.8
- v_GW_DELAY.gw = 10
- v_ALPHA_BF_D.gw = 0.003
- v_CH_N1.sub = 0.025
- v_CH_N2.rte = 0.025
- v_Surlag.hru = 4

Dnister River. 2008-2009





Performance criteria (5 years):

- NS = 0.67
- R2 = 0.68
- PBIAS = 5%

SWAT calibration: Future plans

- Calibration on another monitoring sites
- Greater number of subbasins and HRUs
- Longer period (20 yrs)

Benefits of the SWAT-HAWQS linkage

User-friendly interface to adjust SWAT parameters

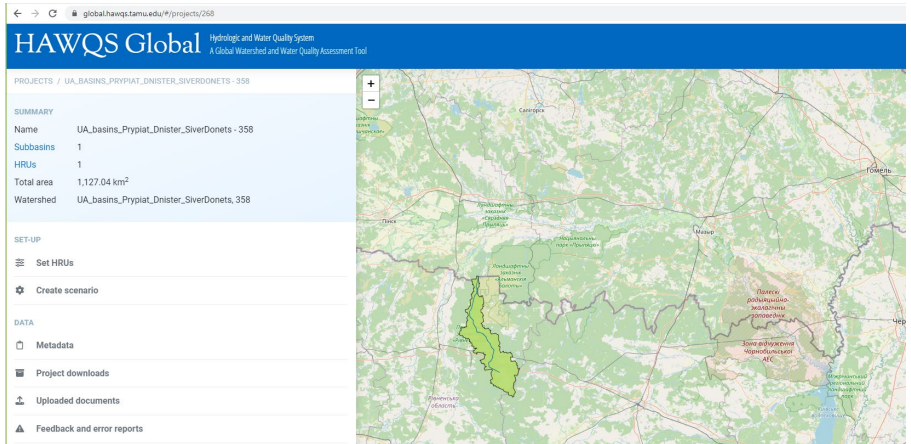
External servers

Scenarios comparison

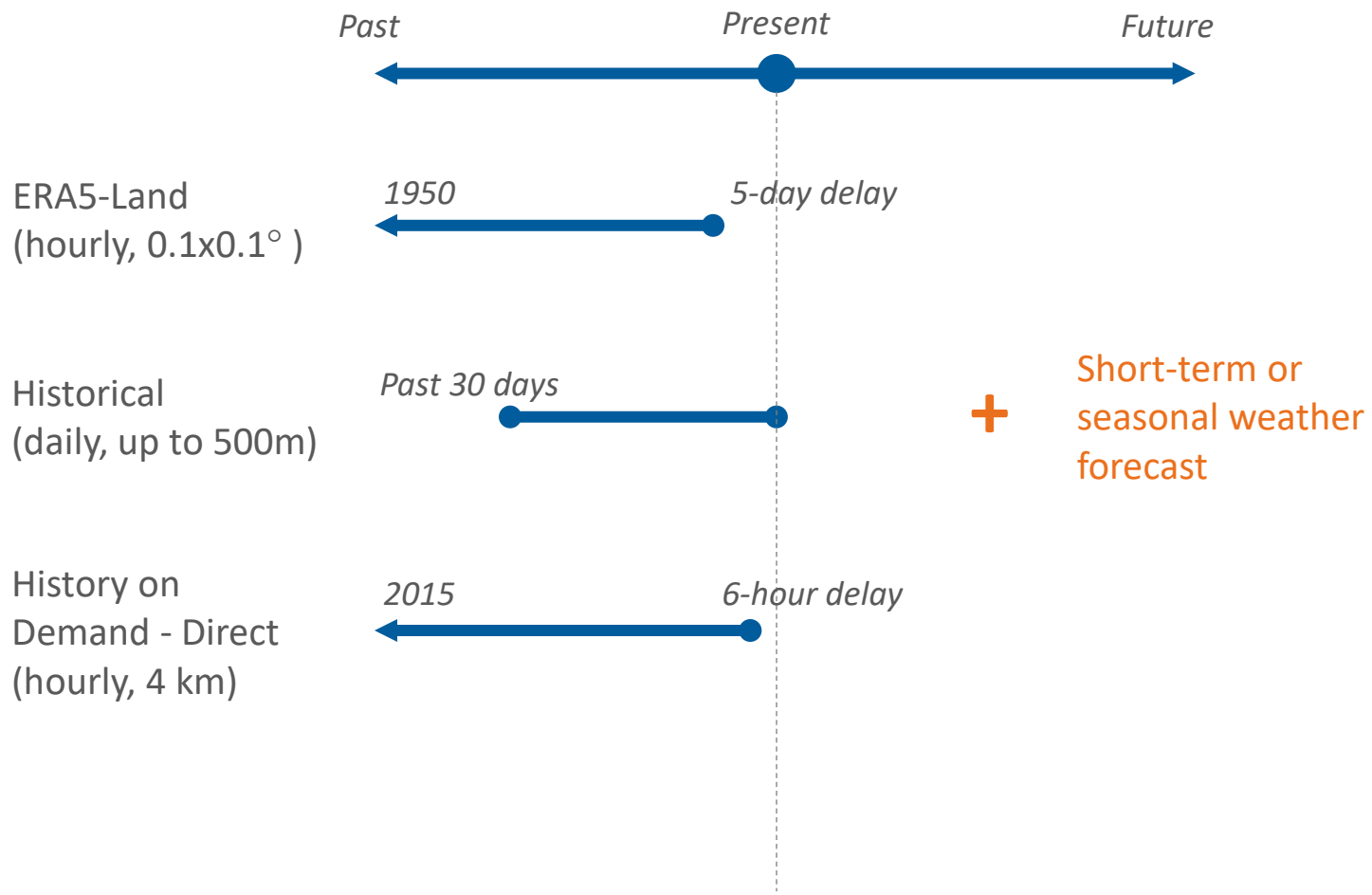
Maps and charts

90% reduction in time

Additional datasets



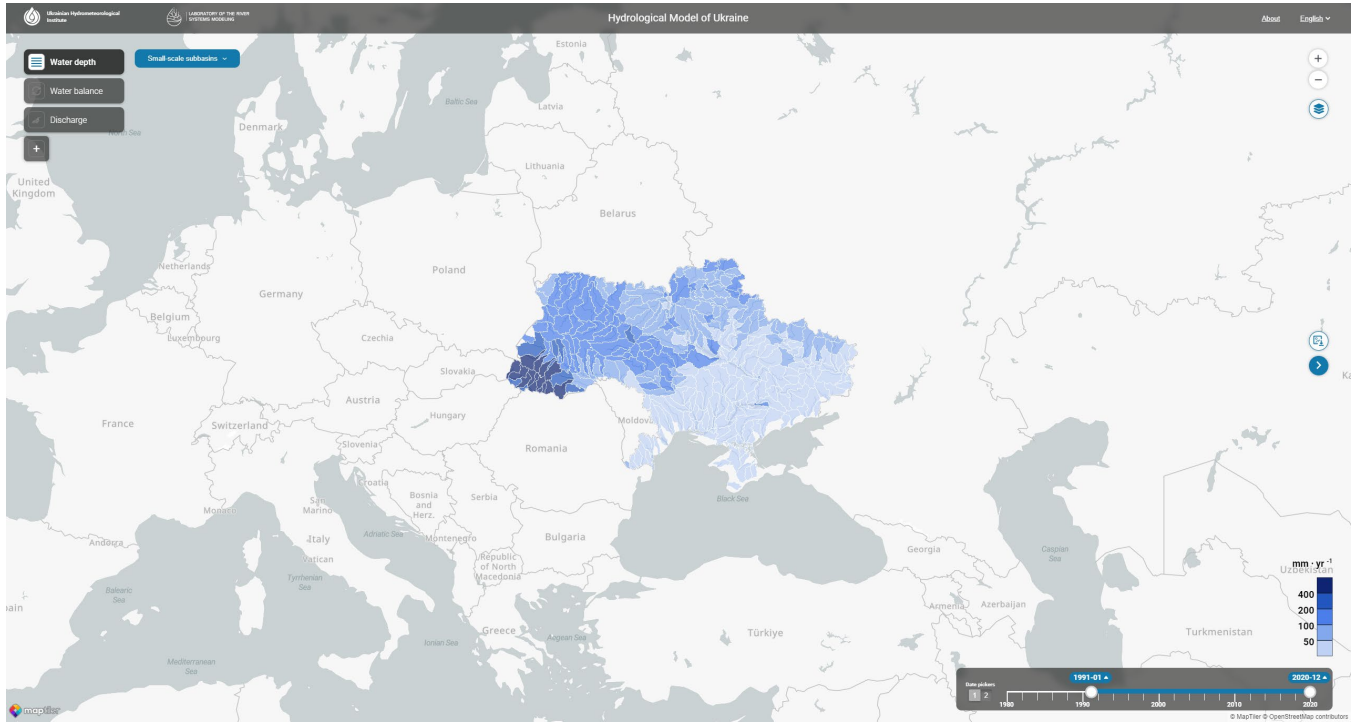
Connecting the SWAT model with near-real time data using IBM API

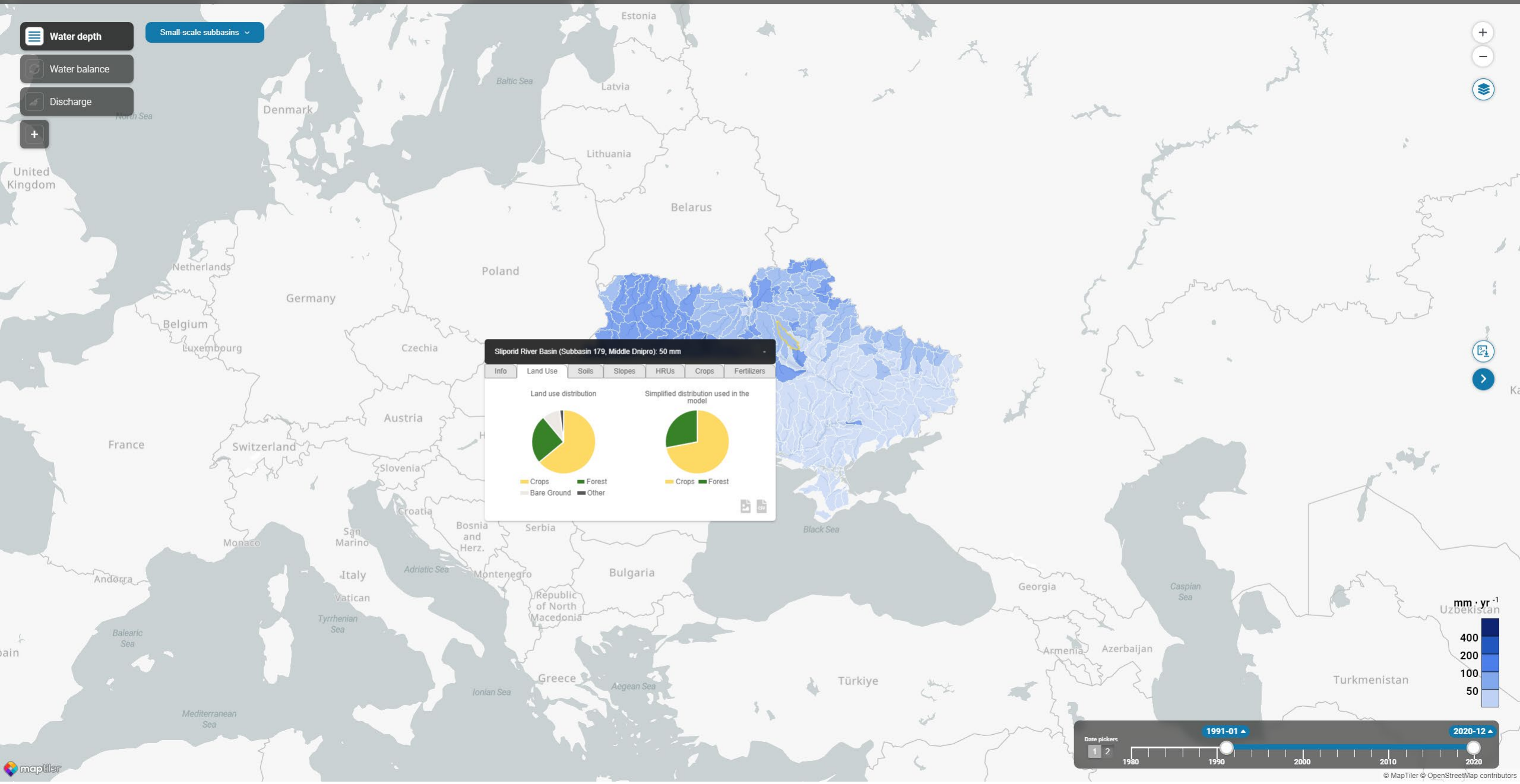


Web platform “Hydrological model of Ukraine”: Introducing the SWAT model for potential users

- Model inputs for each subbasin: topography, soils, land use, crop rotation, fertilizers
- SWAT simulation results with daily time step
- Downloading maps and graphs
- Smooth transition to HAWQS

Test version http://hydrological.uhmi.org.ua/




Water depth
Water balance
Discharge
Small-scale subbasins
Slipорid River Basin (Subbasin 179, Middle Dnipro): 50 mm
Info
Land Use
Soils
Slopes
HRUs
Crops
Fertilizers
Land use distribution
Simplified distribution used in the model
Crops
Forest
Bare Ground
Other
mm · yr -1
400
200
100
50
Date pickers
1991-01
2020-12
1980
1990
2000
2010
2020
Estonia
Latvia
Lithuania
Belarus
Poland
Germany
Netherlands
Belgium
Luxembourg
Czechia
Austria
France
Switzerland
Slovenia
Croatia
Bosnia and Herz.
Serbia
Montenegro
Bulgaria
Italy
Vatican
San Marino
Monaco
Andorra
Spain
Greece
Türkiye
Georgia
Armenia
Azerbaijan
Uzbekistan
Turkmenistan
Denmark
United Kingdom
Baltic Sea
North Sea
Black Sea
Caspian Sea
Adriatic Sea
Tyrrhenian Sea
Balearic Sea
Ionian Sea
Aegean Sea
Mediterranean Sea
Republic of North Macedonia
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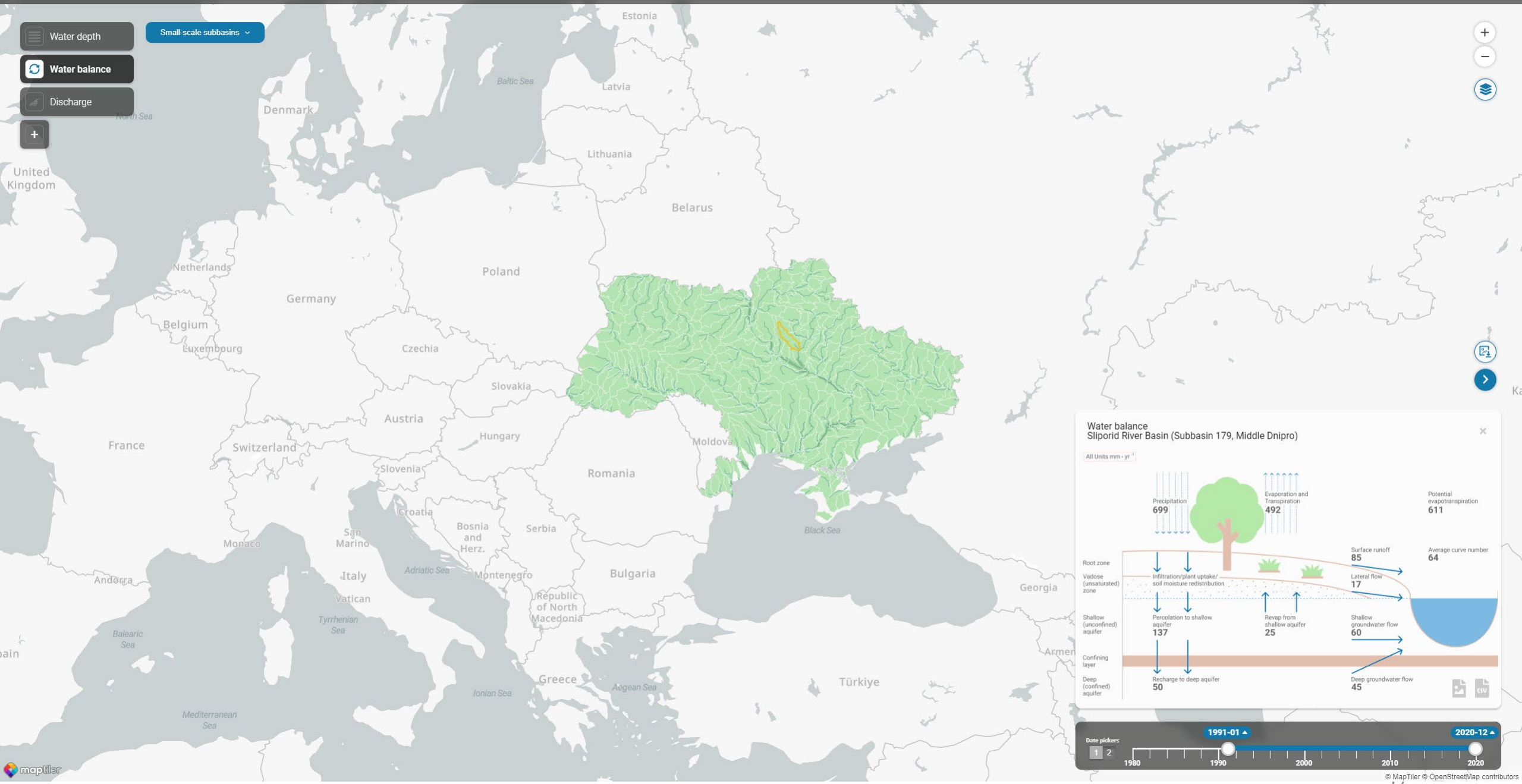
Water depth
Water balance
Discharge
Small-scale subbasins
Water balance
Sliporid River Basin (Subbasin 179, Middle Dnipro)
All Units mm - yr⁻¹
Precipitation
699
Evaporation and Transpiration
492
Potential evapotranspiration
611
Root zone
Vadose (unsaturated) zone
Infiltration/plant uptake/ soil moisture redistribution
Surface runoff
85
Average curve number
64
Lateral flow
17
Shallow (unconfined) aquifer
Percolation to shallow aquifer
137
Revap from shallow aquifer
25
Shallow groundwater flow
60
Confining layer
Deep (confined) aquifer
Recharge to deep aquifer
50
Deep groundwater flow
45
Date pickers
1 2
1991-01
2020-12
1980
1990
2000
2010
2020
Estonia
Latvia
Lithuania
Belarus
Poland
Germany
Netherlands
Belgium
Luxembourg
Czechia
Slovakia
Austria
Hungary
Moldova
Romania
Slovenia
Croatia
Bosnia and Herz.
Serbia
Montenegro
Bulgaria
Republic of North Macedonia
Greece
Türkiye
Georgia
France
Switzerland
Italy
Monaco
San Marino
Andorra
Vatican
Denmark
United Kingdom
Baltic Sea
North Sea
Black Sea
Adriatic Sea
Tyrrhenian Sea
Balearic Sea
Ionian Sea
Aegean Sea
Mediterranean Sea
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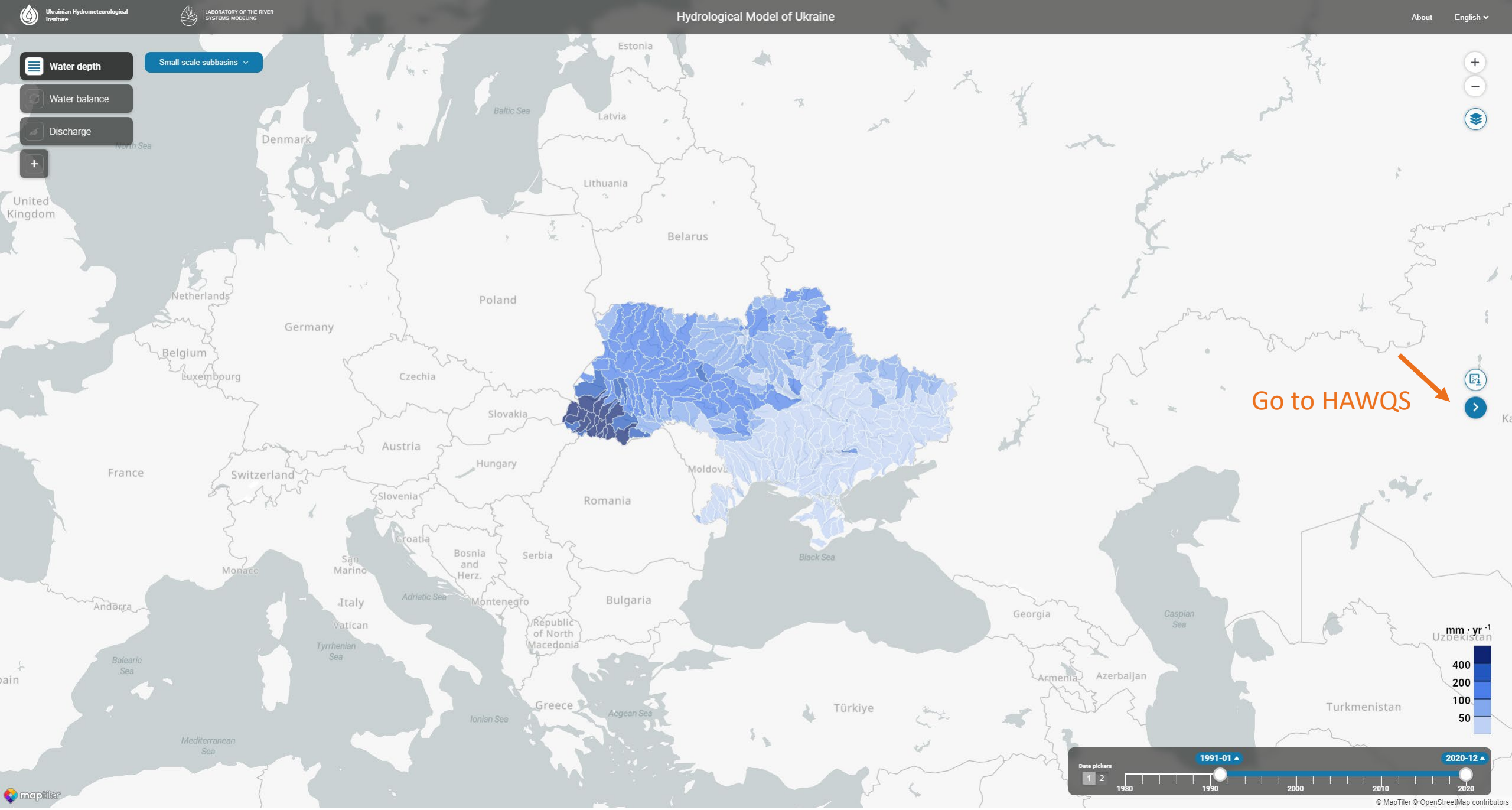
Ukrainian Hydrometeorological Institute
LABORATORY OF THE RIVER SYSTEMS MODELING
Hydrological Model of Ukraine
About
English
Water depth
Water balance
Discharge
Small-scale subbasins
Go to HAWQS
mm · yr -1
400
200
100
50
1991-01
2020-12
Date pickers
1980
1990
2000
2010
2020
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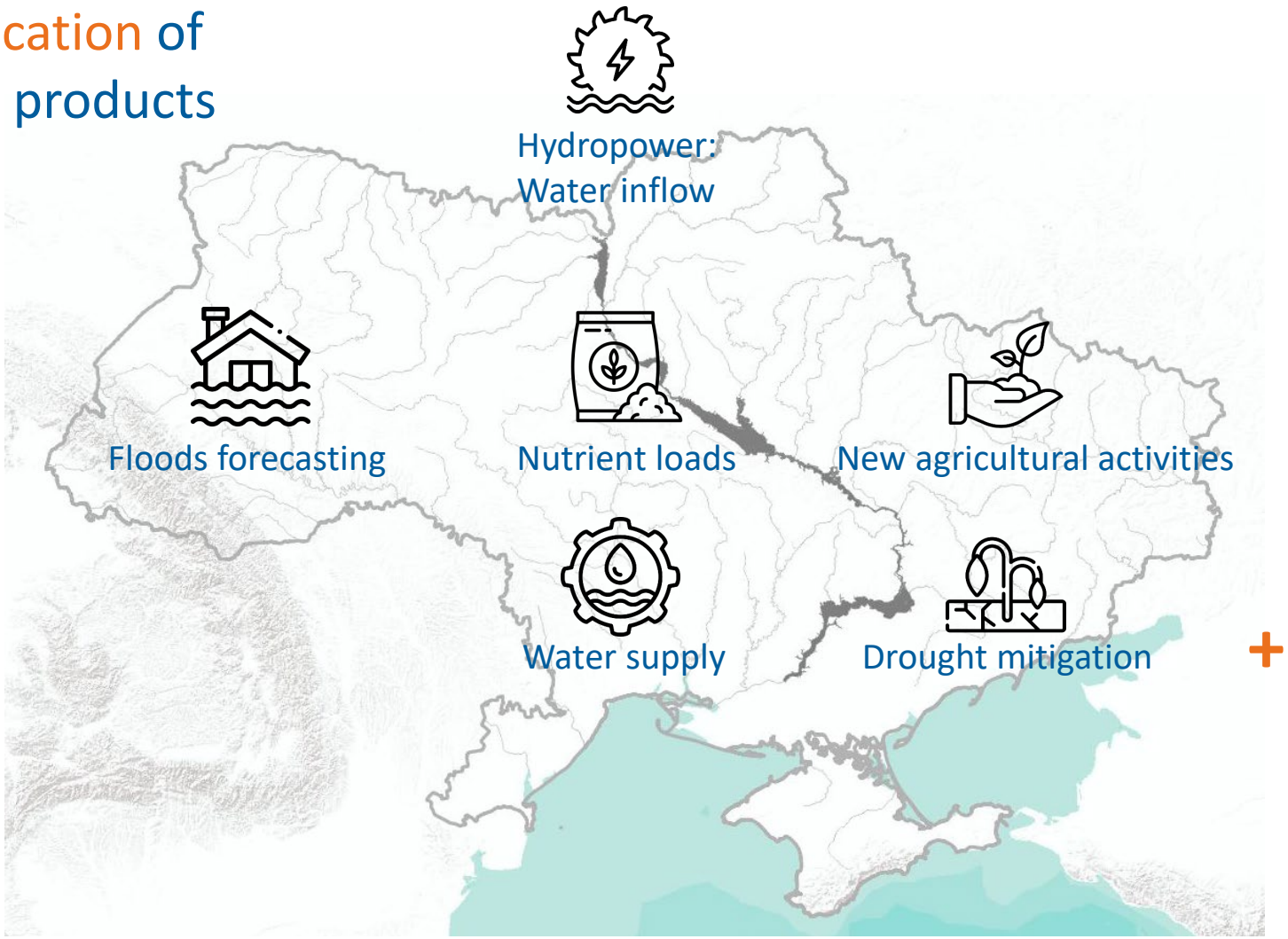
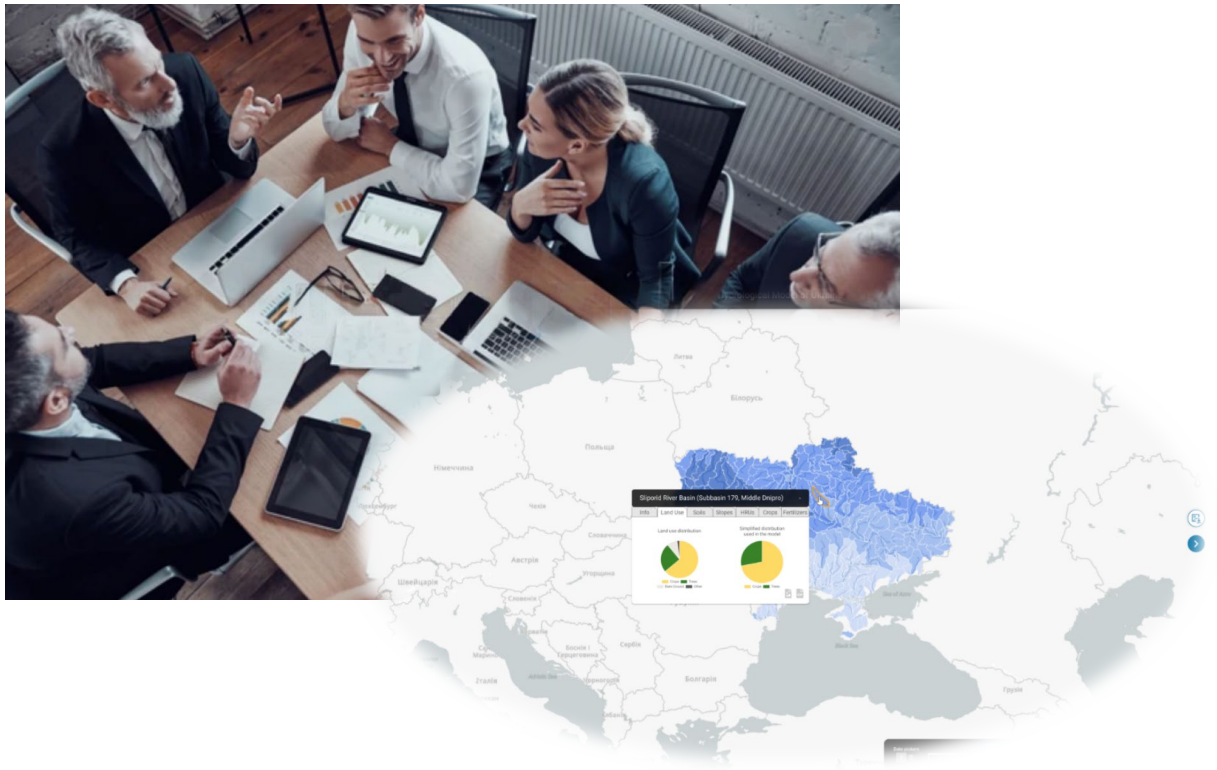
Possible application of SWAT-related products in Ukraine



\+ Climate change impact

Future plans: User research in order to adapt SWAT-related products for Ukrainian users

- The functionality and interface of the platform should address users needs, goals, motivation, and technical level
- User research with water and agro-sector authorities, and farmers



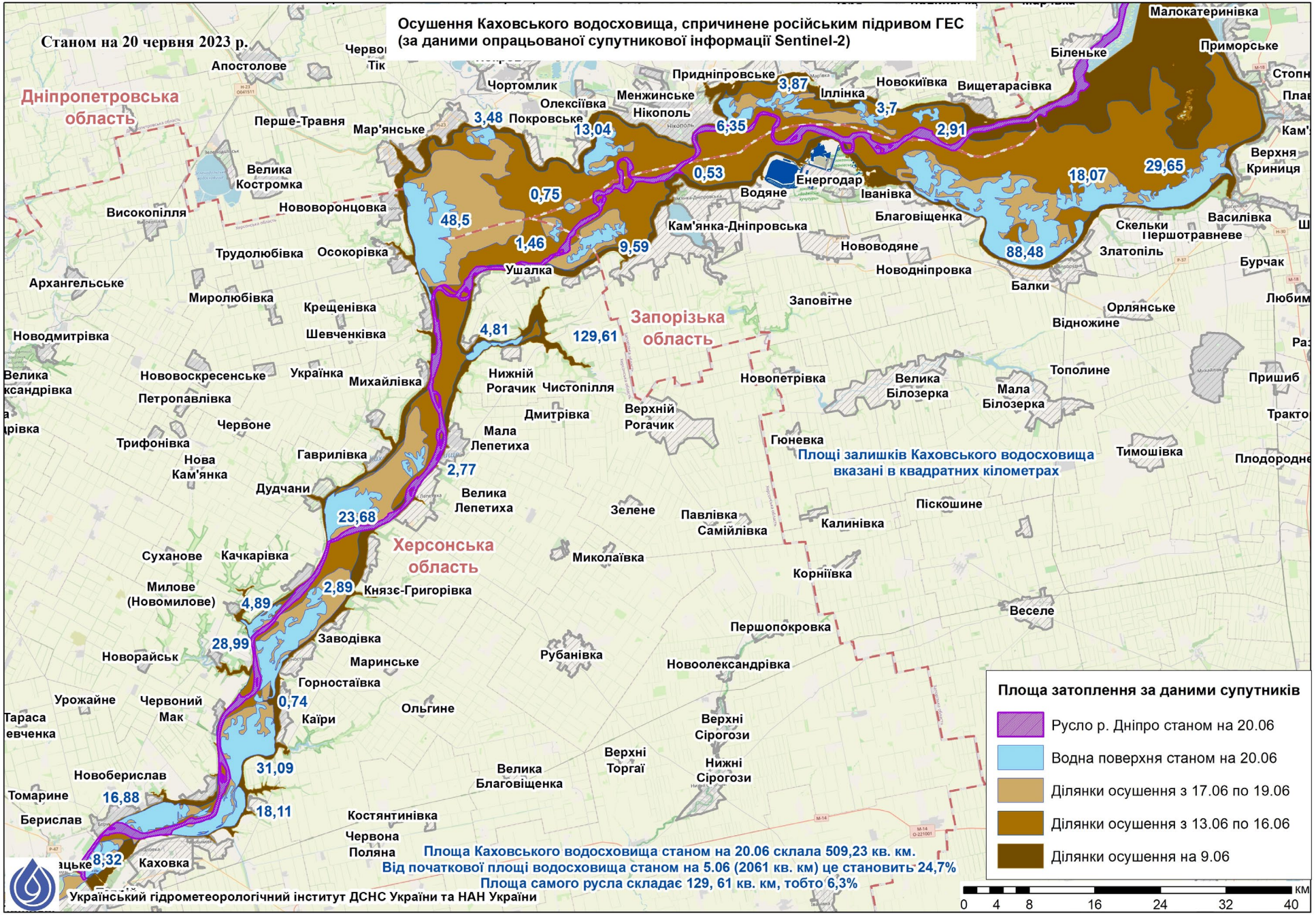
Conclusions

- The best hydrological model for Ukraine
- HAWQS: Web platform for your model
- IBM API: Additional datasets and infrastructure
- Possible applications: Water and agro-sector restoration
- Future plans: User research and better products

Acknowledgment

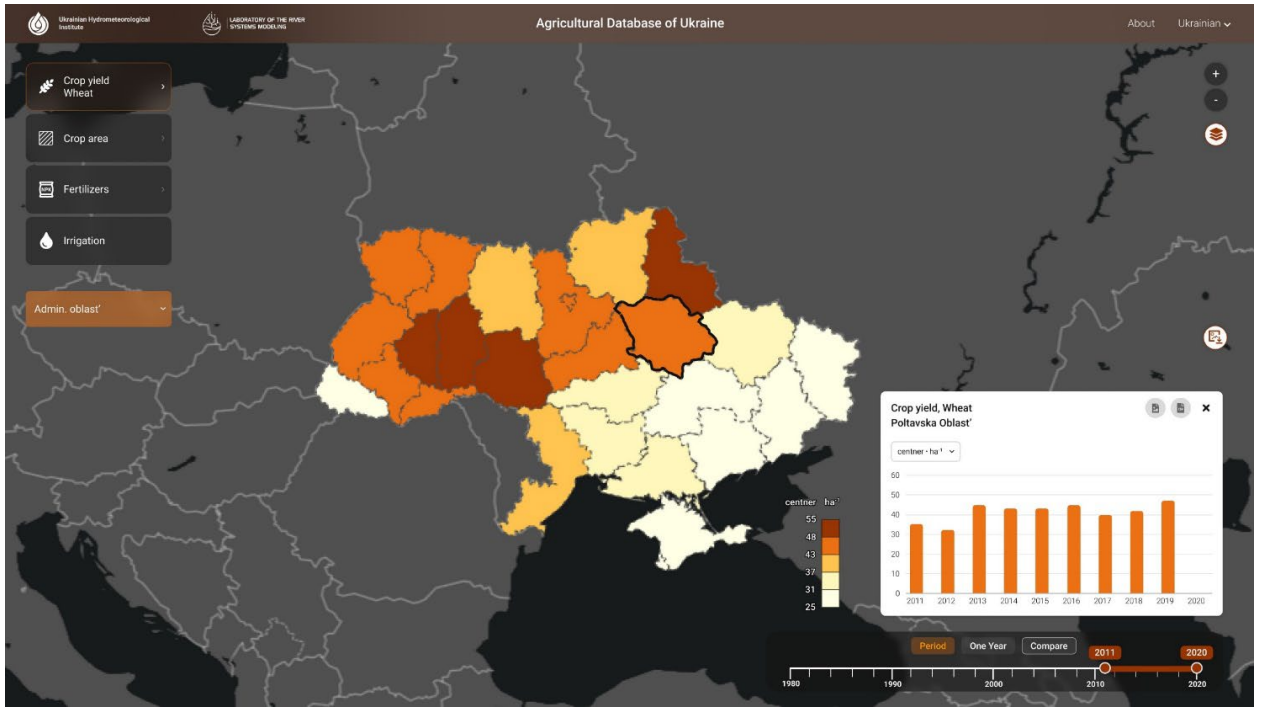
Thank you for your attention!

Additional slides


Осушення Каховського водосховища, спричинене російським підривом ГЕС
(за даними опрацьованої супутникової інформації Sentinel-2)
Станом на 20 червня 2023 р.
Дніпропетровська область
Запорізька область
Херсонська область
Площі залишків Каховського водосховища вказані в квадратних кілометрах
Площа затоплення за даними супутників
Русло р. Дніпро станом на 20.06
Водна поверхня станом на 20.06
Ділянки осушення з 17.06 по 19.06
Ділянки осушення з 13.06 по 16.06
Ділянки осушення на 9.06
Площа Каховського водосховища станом на 20.06 склала 509,23 кв. км.
Від початкової площі водосховища станом на 5.06 (2061 кв. км) це становить 24,7%
Площа самого русла складає 129, 61 кв. км, тобто 6,3%
Український гідрометеорологічний інститут ДСНС України та НАН України
0 4 8 16 24 32 40 КМ
3,87
3,48
13,04
6,35
3,7
2,91
0,53
0,75
48,5
1,46
9,59
18,07
29,65
88,48
4,81
129,61
2,77
23,68
2,89
4,89
28,99
0,74
31,09
16,88
18,11
8,32
Малокатеринівка
Приморське
Біленьке
Придніпровське
Чортомлик
Менжинське
Олексіївка
Нікополь
Новокиївка
Вищетарасівка
Іллінка
Покровське
Мар'янське
Перше-Травня
Велика Костромка
Нововоронцовка
Високопілля
Енергодар
Водяне
Іванівка
Благовіщенка
Кам'янка-Дніпровська
Нововодяне
Новодніпровка
Скельки
Василівка
Першотравневе
Златопіль
Балки
Бурчак
Заповітне
Орлянське
Відножине
Трудолюбівка
Осокорівка
Ушалка
Архангельське
Миролюбівка
Крещенівка
Шевченківка
Новодмитрівка
Нижній Рогачик
Чистопілля
Верхній Рогачик
Дмитрівка
Мала Лепетиха
Новопетрівка
Велика Білозерка
Мала Білозерка
Тополине
Гюнівка
Тимошівка
Пришиб
Нововоскресенське
Українка
Михайлівка
Петропавлівка
Червоне
Трифонівка
Нова Кам'янка
Гаврилівка
Дудчани
Велика Лепетиха
Зелене
Павлівка
Самійлівка
Калинівка
Піскошине
Суханове
Качкарівка
Миколаївка
Корніївка
Милове (Новомилове)
Князе-Григорівка
Веселе
Першопокровка
Заводівка
Новорайськ
Маринське
Рубанівка
Новоолександрівка
Горностаївка
Урожайне
Червоний Мак
Каїри
Ольгине
Верхні Сірогози
Нижні Сірогози
Верхні Торгаї
Велика Благовіщенка
Новоберислав
Томарине
Берислав
Костянтинівка
Червона Поляна
Каховка

Interactive web platform “Agricultural database of Ukraine”: Decision support tool for agro-sector

- Analysis of trends in sown area, crop yields, and fertilizer use
- Data for environmental modeling (e.g., SWAT)
- Downloading maps and graphs



Study area and calibration process

- [x] Input data (Ukraine and transboundary parts)
- [x] Snowmelt calibration
- [x] Model setup
- [x] Sensitivity analysis (visual)
- [x] Calibration: 3 gauges
- [ ] Calibration: 19+ gauges
- [ ] Calibration: Soft data

Inputs	Source
DEM	SRTM, 90m
River network	Real streams
Soils	Country-scale maps
Land use	ESRI, 10 m
Agriculture	Official statistics at regional scale
Climate	Reanalysis ERA5-Land (1980-2020)
Snow cover	Monitoring sites (Ukraine)
Discharge	Monitoring sites (Ukraine and Belarus)

Snow parameters in SWAT+

Snow parameters of the SWAT+ model (ranges and best simulation value in brackets)

	fall_tmp	melt_tmp	melt_max	melt_min	tmp_lag
▲	1.1..1.4 (1.3)	0.2..0.5 (0.3)	2.5..3.0 (2.5)	2.0..2.5 (2.5)	0.7..0.9 (0.8)
▲	1.0..1.2 (1.0)	-0.4..0 (-0.2)	2.0 (2.0)	2.0..2.5 (2.0)	0.7..0.9 (0.8)
▲	0.7..0.9 (0.8)	-0.3..-0.5 (-0.3)	2.0..2.5 (2.0)	2.5..3.0 (3.0)	0.7..0.9 (0.9)
▲	0.3..0.5 (0.3)	-0.6..-0.9 (-0.8)	2.5..3.0 (2.5)	2.5..3.0 (3.0)	0.7..0.9 (0.8)
▲	0..0.2 (0)	-0.2..-0.4 (-0.3)	2.5..3.5 (3.0)	2.5..3.0 (2.5)	0.7..0.9 (0.8)

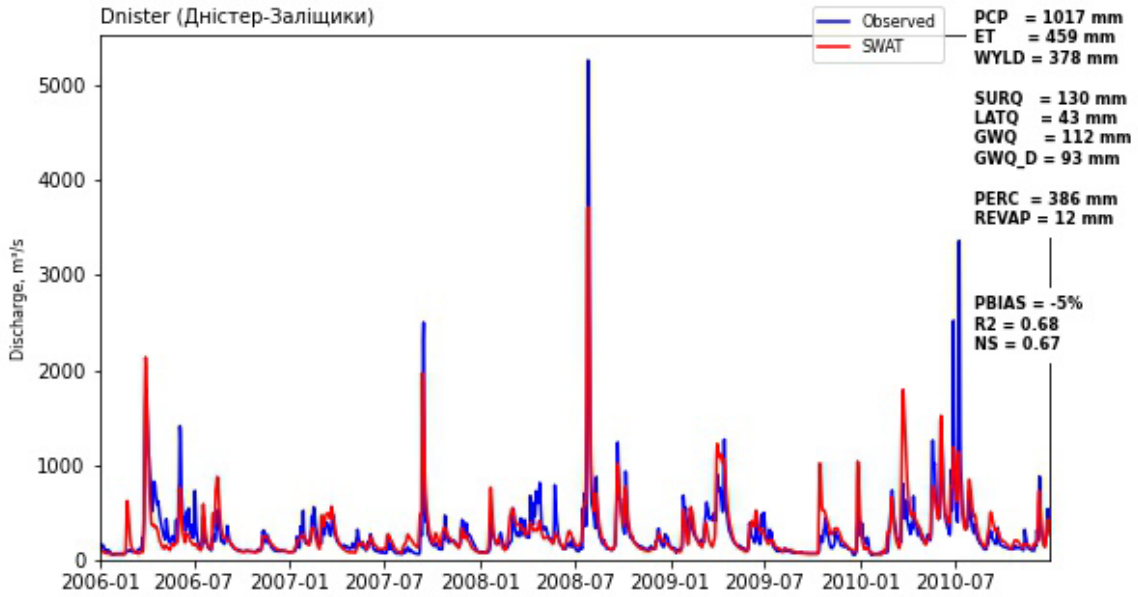
* For the forested areas tmp_lag = 0.3..0.4

Performance criteria* of the snow cover height calibration using SWAT+

	Calibration (39 sites, 1998-2014)			Validation (22 sites, 1998-2014)		
	NS	R2	PBIAS	NS	R2	PBIAS
▲	0.65	0.8	1%	0.75	0.81	-3%
▲	0.56	0.71	-6%	0.8	0.85	-3%
▲	0.58	0.73	-3%	0.71	0.8	1%
▲	0.55	0.72	2%	0.62	0.73	5%
▲	0.77	0.81	3%	-	-	-

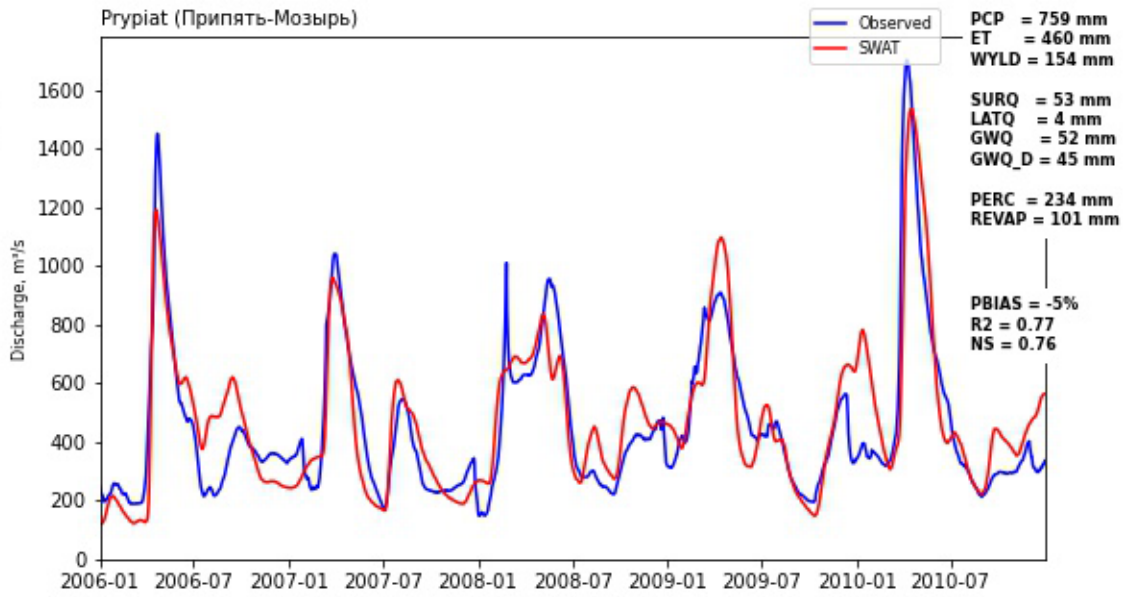
* Additionally, visual control was made

SWAT calibration: Dnister river basin - Carpathian mountains



- Manual calibration to understand the model behavior
- Performance criteria:
  NS > 0.65
  PBIAS < 5%

SWAT calibration: Prypiat river basin – Mix and deciduous forests zone



- Manual calibration to understand the model behavior
- Performance criteria:
  NS > 0.75
  PBIAS < 5%

SWAT calibration: Siverskyi Donets river basin – Steppe zone

- Manual calibration to understand the model behavior
- Performance criteria:
  NS > 0.6
  PBIAS < 5%

SWAT calibration: Parameters values

Zonal pattern for groundwater parameters

Parameter[1]	Description	Dnister	Prypiat	Siverskiy Donets
r_CN2.mgt	Runoff curve number for moisture condition II	0 (default)	0 (default)	-0.08
v_ESCO.hru	Soil evaporation compensation factor	0.95 (default)	0.9	0.95 (default)
v_Surlag.hru	Surface runoff lag coefficient	4	1	2 (default)
v_GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur, mm H2O	3500	1500	1500
v_ALPHA_BF.gw	Shallow groundwater alpha factor, 1/days	0.8	0.048 (default)	0.1
v_GW_DELAY.gw	Groundwater delay time (days)	10	31 (default)	31 (default)
v_RCHRG_DP.gw	Deep aquifer percolation fraction	0.25	0.2	0.45
v_ALPHA_BF_D.gw	Deep groundwater alpha factor, 1/days	0.003	0.01 (default)	0.0005
v_GW_REVAP.gw	Groundwater "revap" coefficient	0.02 (default)	0.15	0.02 (default)
v_CH_N1.sub	Manning's "n" value for the tributary channels	0.025[2]	0.075[2]	0.075[2]
v_CH_N2.rte	Manning's "n" value for the main channel	0.025[2]	0.075[2]	0.075[2]

[1] Snow parameters presented on additional slide

[2] Recommended values for natural streams with stones or brush

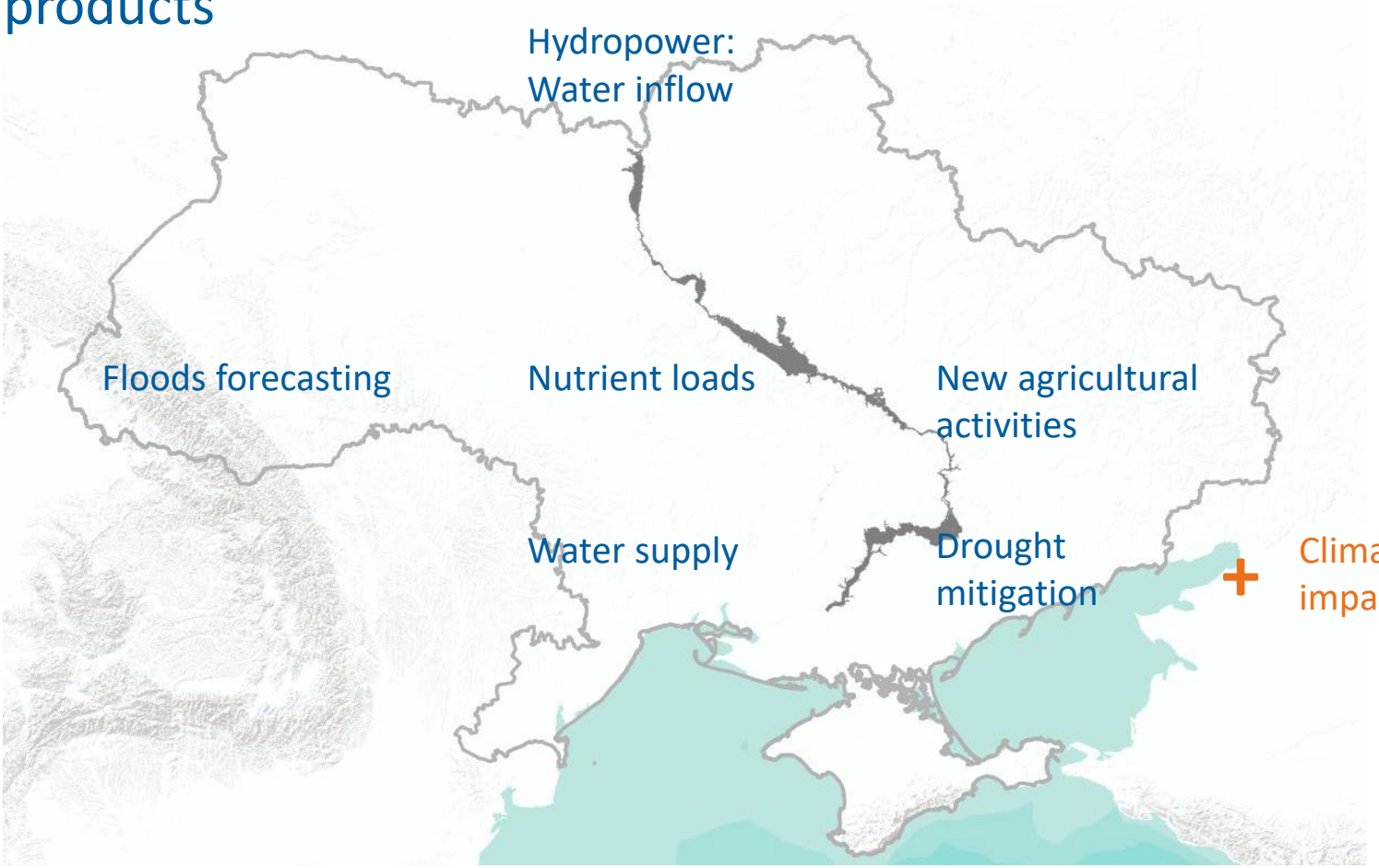
Future plans: Investigation of IBM Environmental Inelegance Suite API

Api Details	Spatial resoulition	Temporal resolution	Data Period	Columns
Historical	Past 30 days Daily Summaries	Daily	Past 30 days, collection start ~ 20.06.2023	'precip24Hour', 'snow24Hour', 'temperatureDewPoint', 'temperature','windSpeed', ,'relativeHumidity'
Historical	Past 24 hours Hourly Summaries	Hourly	Past 24 hours, collection start ~ 20.06.2023	precip24Hour, snow24Hour, temperatureMax, temperatureMin
History on Demand - Direct	4km	Hourly	2015-06-29 to Present, 6 hours delay	'precip1Hour', 'snow1Hour', 'temperature', 'temperatureDewPoint', 'relativeHumidity', 'windSpeed'
Historical data for Analytical Tooling	4km	Daily	2015-06-29 to Present, 1 day delay	'DewpointLocalDayAvg', 'RelativeHumidityLocalDayAvg', 'TemperatureLocalDayAvg', 'TemperatureLocalDayMax', 'TemperatureLocalDayMin', 'WindSpeedLocalDayAvg', ‘pcp’, ‘snow’

Benefits of the SWAT-HAWQS linkage

- External servers and built-in data processing capabilities
- Collaborative modeling
- No GIS software or knowledge required
- User-friendly interface to adjust SWAT parameters
- 90% reduction in time
- Additional datasets
- Scenarios comparison
- Maps and charts

Possible application of SWAT-related products in Ukraine

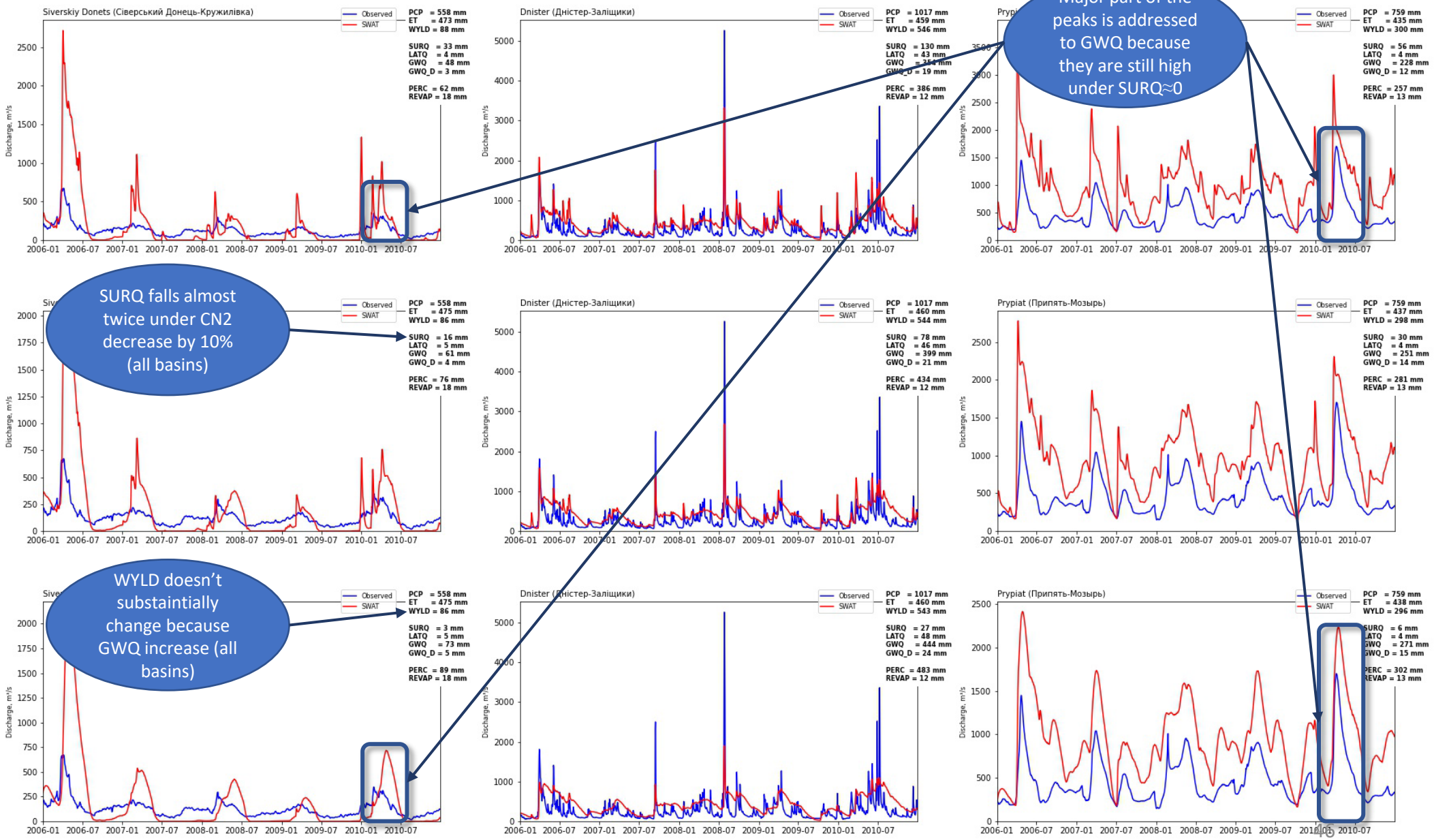


Example of a sensitivity analysis: default values of the SWAT model (except calibrated snowmelt parameters that were set previously) and variations of CN2.mgt

default

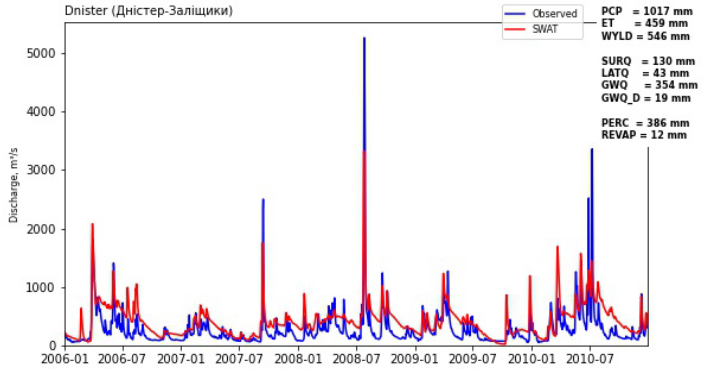
r_CN2_-0.1

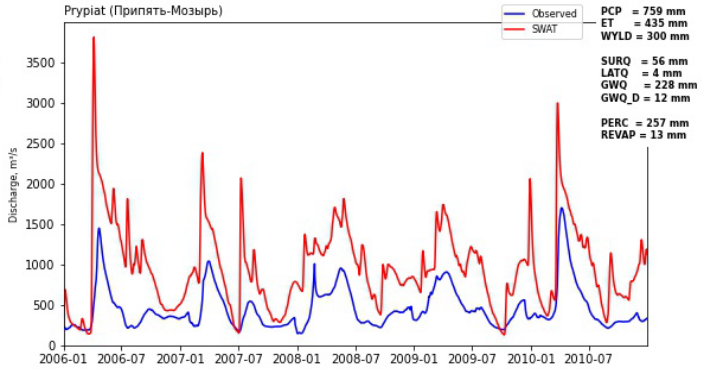
r_CN2_-0.3



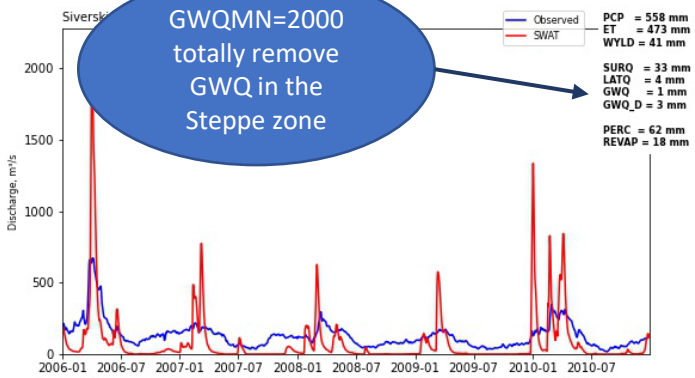
Example of a sensitivity analysis: default values of the SWAT model (except calibrated snowmelt parameters that were set previously) and variations of GWQMN.gw

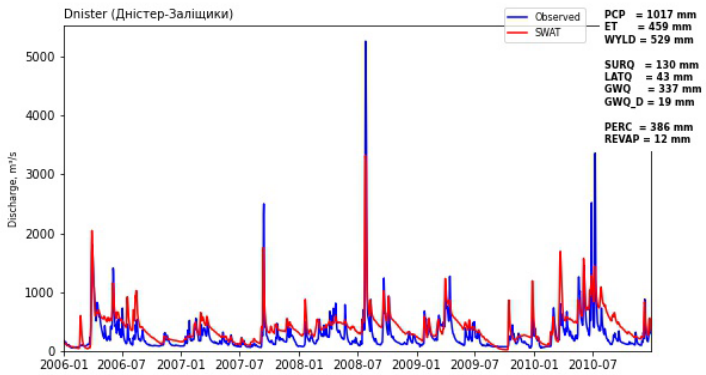
Default
(v_GWQMN = 1000)

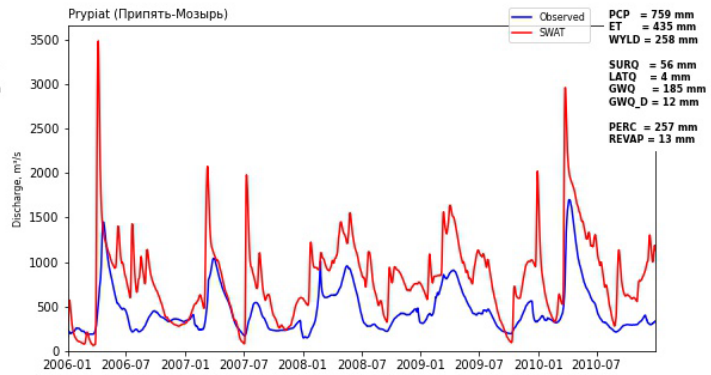




v_GWQMN = 2000







v_GWQMN = 4000