Anthropogenic and climate change contributions to uncertainties in hydrological modeling of sustainable water supply

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The Republic of Moldova

Several words about Moldova

The Republic of Moldova (Moldova) is a small landlocked country in the EE, bordered with Ukraine and Romania. The capital city is Chisinau. Moldova, as a former republic of the USSR, declared its independence on August 27, 1991, and now is a parliamentary republic; the President is also elected by the Parliament. ***Total population*** – about 3.5 mil.

Total land area ~ 33.9 sq.km. Most of the country is hilly (the highest point – 428 m). *Climate* of Moldova's is moderately continental, with warm and long summers (Tmean about 20°C) and relatively mild and dry winters (Tmean about –1.5 °C). The highest temperature (41.5 °C) was observed in July of 2007); the lowest (–35.5 °C) – in January 1963. Annual precipitation are from 600 mm in the North to 400 m in the South; long dry spells and droughts are usual.

Moldova's water

The surface waters of Moldova include:

- two transboundary rivers - *Dniester* (annual discharge ~10.7 km^3) and *Prut* (~2.9 km^3)
- some small rivers (total discharge ~1.22 km^3)
- about 3,500 natural and manmade ponds
- two big reservoirs for providing a seasonal water regulation: *Costeşti-Stînca* on the Prut River, joint with Romania (678 mil. m^3) & *Dubăsari* (235 mil. m^3) on the Dniester River

In whole, Moldova lies in the zone of general water deficiency.

All towns and over *65%* of rural settlements have centralized drinking water supply systems, but about *44%* of local population don't have *sustainable* access to safe drinking water.

Background of this research

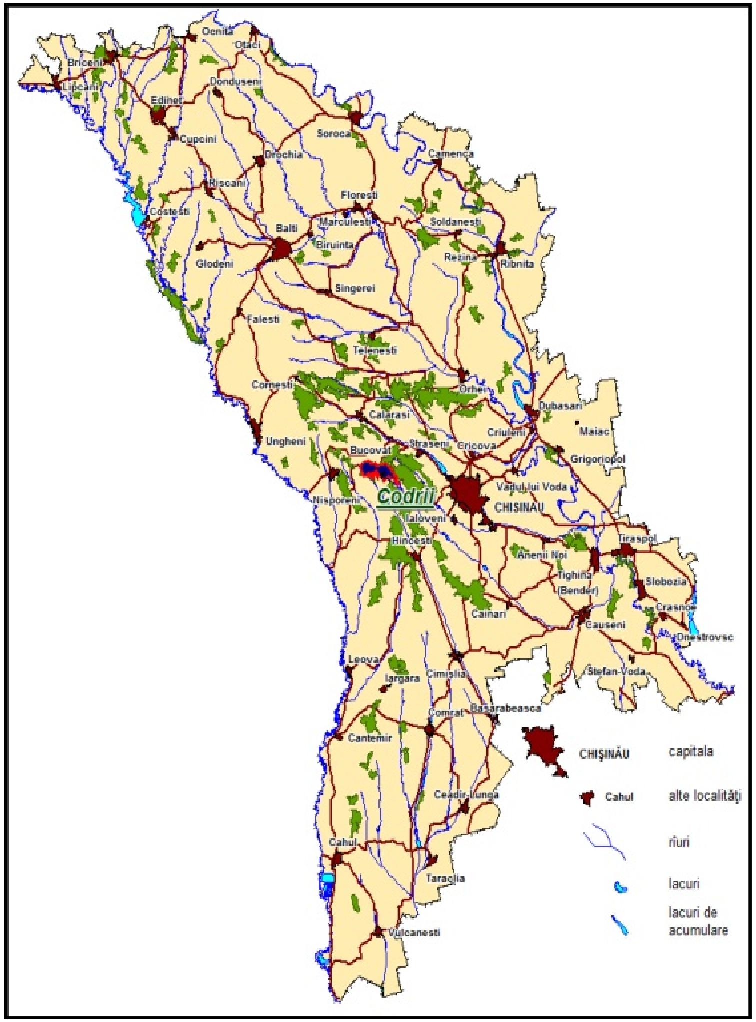
International project: ***“UTILIZING STREAM WATERS IN THE SUPPRESSION OF FOREST FIRES WITH THE HELP OF NEW TECHNOLOGIES”*** **that was realized by six countries in 2013-2015 in the framework of ‘*BLACK SEA BASIN*’ Programme**

One of the Project’s activities:

‘Validation & modification of the runoff models for the following assessment of reservoirs location and properties for their use in the fires control’.

Greek	Romania	Ukraine	Armenia	Moldova	Turkey

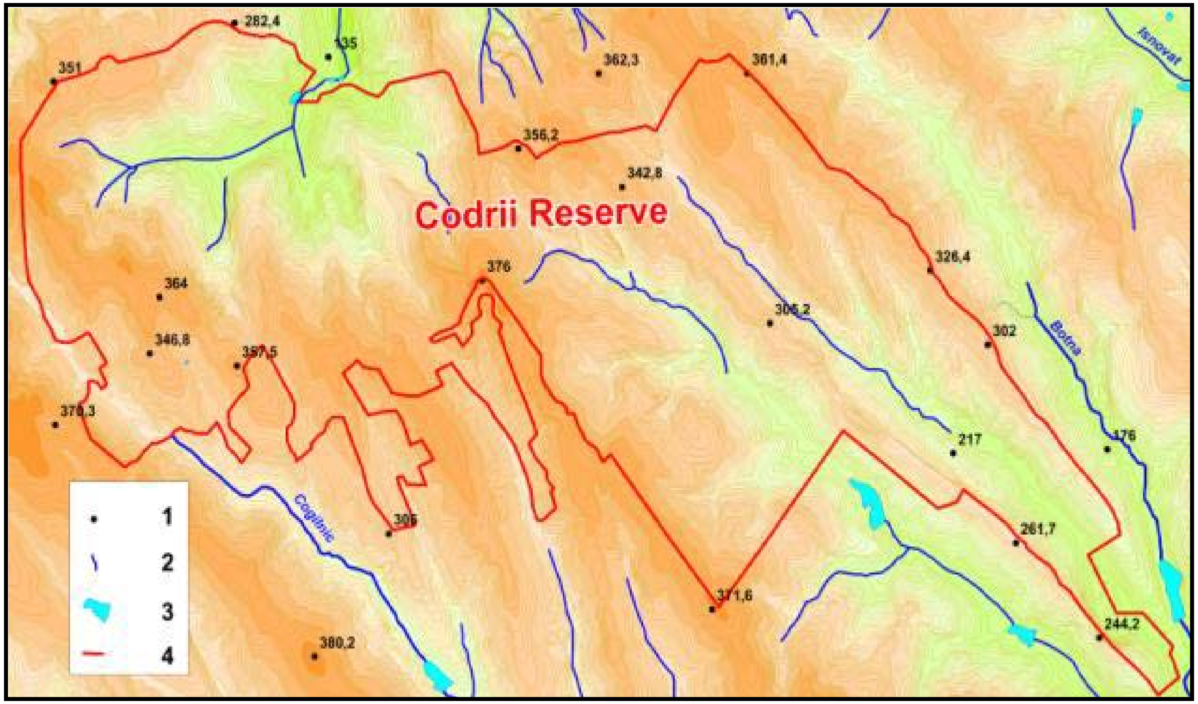
A pilot area in Moldova – *Codrii Forest Reserve*



***Creation* –** 27/09/1971

Task: to conserve the most representative forest areas, specific for the Central part of Moldova.

River network of the Codrii Reserve



1 Above-sea level; 2 Rivers (streams);
3 Ponds; 4 Contour of Reserve.

Small stream in summer time

SWAT model as a main research tool

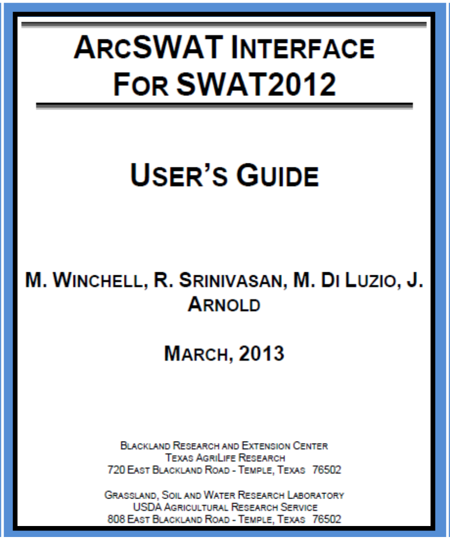
SWAT *(Soil and Water Assessment Tool)* is a river basin/watershed scale model developed to predict the impact of land-use and land treatment management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and environmental conditions over long periods of time.

It was developed mainly by the Agricultural Research Service and Texas Agricultural Experiment Station (Temple, Texas) primary for USA needs.

Soil and Water Assessment Tool

Theoretical Documentation

Version 2009


ArcSWAT Interface For SWAT2012

User's Guide

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March, 2013

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Soil and Water Assessment Tool

Input/Output Documentation

Version 2012

SWAT in the reported research

SWAT's performance capabilities were used in our work for addressing two principal problems:

- *the assessment of uncertainties in small rivers surface runoff simulation, considering these uncertainties as a function of anthropogenic loads on rivers watershed;*
- *the assessment of likely changes in the watersheds runoff due to expected changes in regional climate.*

Solutions of these tasks will be demonstrated on two examples.

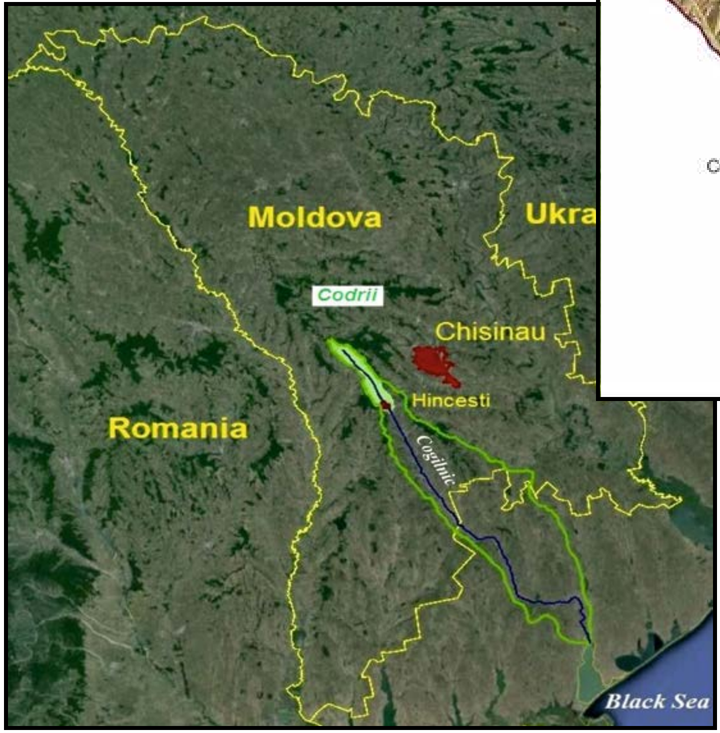
Task 1: Anthropogenic factor in surface runoff modeling

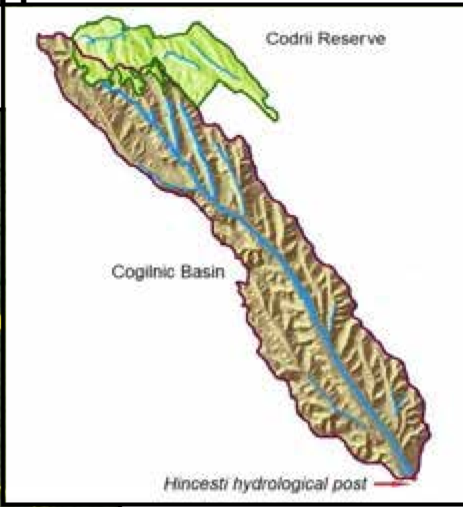
The working hypothesis: an anthropogenic loading on the watershed is a difference between the simulated runoff into the river bed and the actually observed runoff

Watershed under study:

The upper part of the Cogilnic River basin from its source to the hydrological post *Hincesti* where observations of the streamflow are carried out:

- *drainage area* – about 243 km^2
- *length* of the river main channel in the studied area – 45.6 km
- *mean channel slope* – 6.1 m/km, lowering from 393.7 in the river source to 115.7 m in *Hincesti.*





Research approach

SWAT simulation of three-years *(2010 - 2012)* monthly and annual runoffs from the studied subwatershed and its comparison with the observed Cogilnic River streamflow in this period

Observed streamflow of the Cogilnic River in 2010-2012 *(m^3/s)*

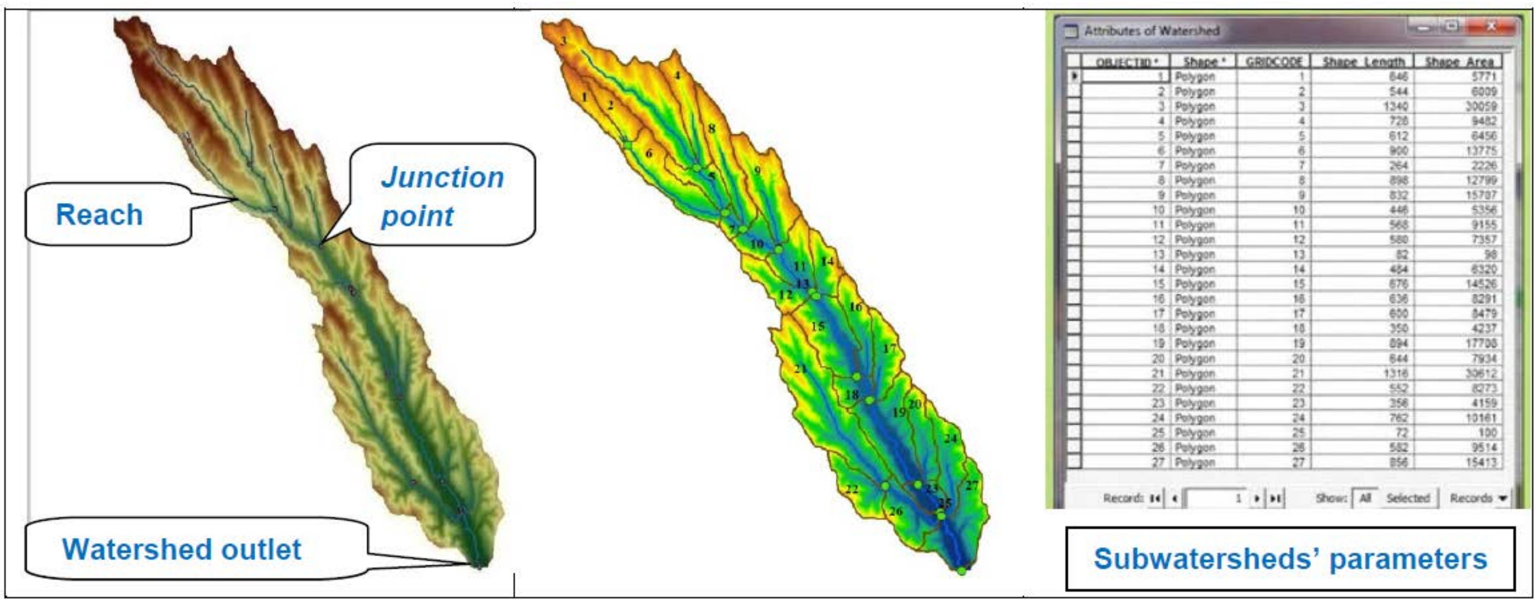
Year	***Months***											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
2010	0.08	0.17	0.17	0.15	0.31	0.17	0.17	0.3	0.2	0.11	0.12	0.21
2011	0.20	0.21	0.19	0.31	0.18	0.28	0.15	0.08	0.06	0.13	0.11	0.14
2012	0.10	0.10	0.17	0.17	0.12	0.11	0.15	0.15	0.15	0.16	0.07	0.17

Principal steps of runoff modeling in the SWAT

- *Watershed Delineation*
- *Definition of Hydrological Response Units (HRU)*
- *Creation of Import Weather Data*
- *SWAT run*
- *SWAT Validation*
- *SWAT Calibration*

Watershed Delineation

The goal of watershed delineation is to identify the *reaches* and *subwatersheds; **reaches*** were defined as parts of the river with drainage areas more than a ***threshold value*** – a critical area of a minimum upstream subwatershed required to form the origin of a stream. In our case it was ***500 ha.***



OBJECTID *	Shape *	GRIDCODE	Shape_Length	Shape_Area
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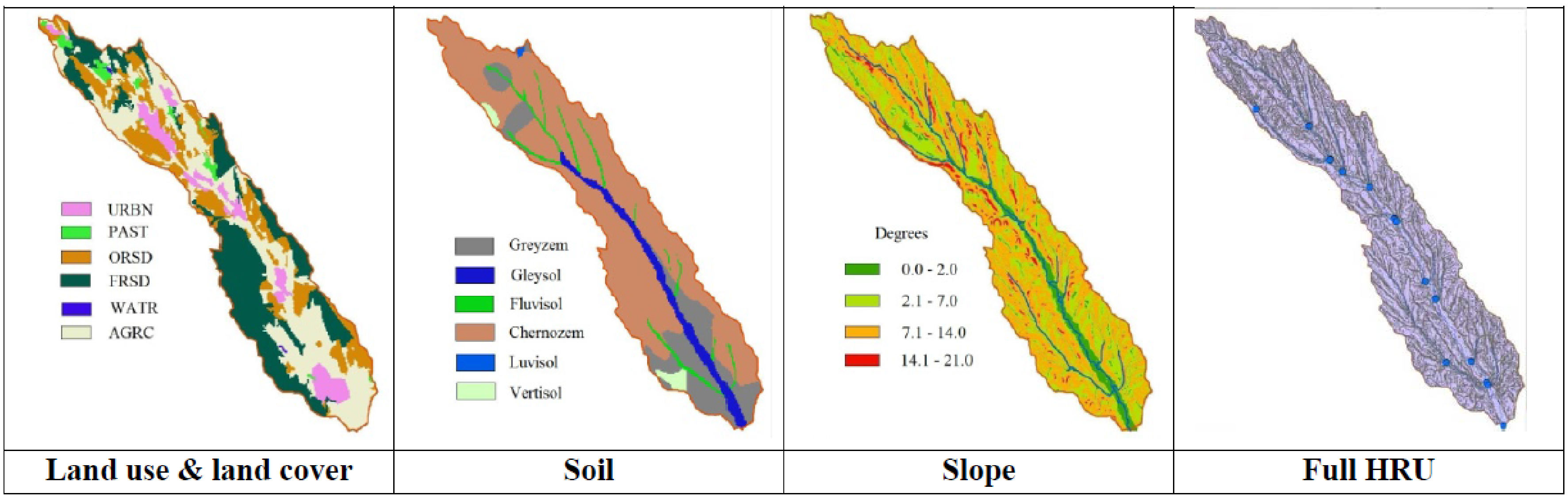
2	Polygon	2	544	6009
3	Polygon	3	1340	30059
4	Polygon	4	728	9482
5	Polygon	5	612	6456
6	Polygon	6	900	13775
7	Polygon	7	264	2226
8	Polygon	8	898	12799
9	Polygon	9	832	15707
10	Polygon	10	446	5356
11	Polygon	11	568	9155
12	Polygon	12	580	7357
13	Polygon	13	82	98
14	Polygon	14	484	6320
15	Polygon	15	676	14526
16	Polygon	16	636	8291
17	Polygon	17	600	8479
18	Polygon	18	350	4237
19	Polygon	19	894	17708
20	Polygon	20	644	7934
21	Polygon	21	1316	30612
22	Polygon	22	552	8273
23	Polygon	23	356	4159
24	Polygon	24	762	10161
25	Polygon	25	72	100
26	Polygon	26	582	9514
27	Polygon	27	856	15413

Upper Cogilnic's drainage network, overlapped with the DEM *(left),* delineated on subwatersheds and their outlets, defined as stream junction points *(centre),* and their parameters *(right)*

HRU definition

Hydrologic response units (HRUs) are small entities with the same characteristics of hydrologic *soil type*, *land use* and *slopes*. Delineation of the watershed into HRUs allows to reflect its spatial heterogeneity.

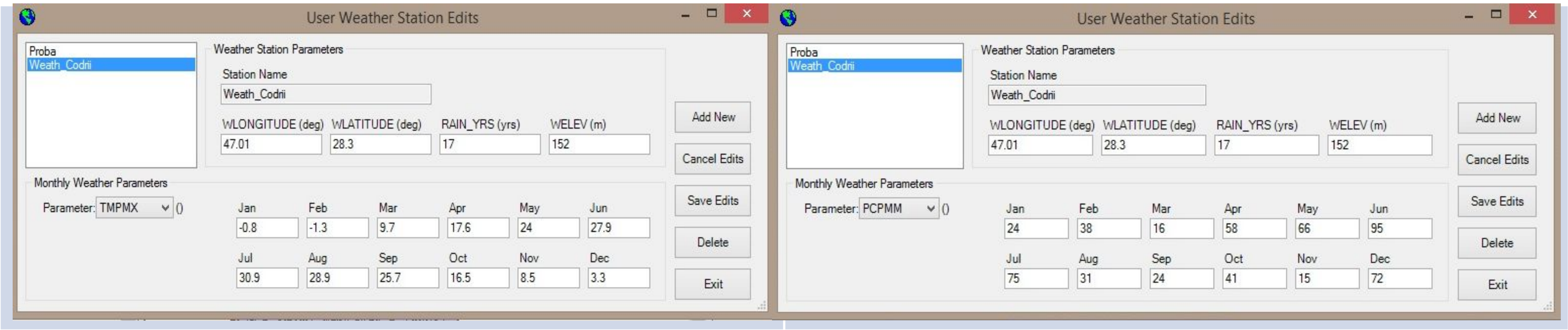


Thematic layers for HRUs identification and the result of their overlay

Weather information

A watershed's ***climate*** provides moisture and energy inputs that control a water balance. The SWAT allows imputing daily ***observations*** (precipitation, maximum & minimum air temperatures, solar radiation, wind speed and relative humidity) or their simulation from averaged monthly values by ***Weather Generator*** embedded in the SWAT. We used the second option.

Input of information for building the SWAT weather file



Run SWAT

Results of the water yield simulation

Year	SWAT Outputs, mm								
	PREC	Runoff to river flow			Ground water		Evapo-transpiration		*Water Yield*
		SURQ	*LATQ*	*GWQ*	*LATE*	*SW*	*ET*	*PET*	
2010	759.6	82.2	51.9	56.1	86.5	32.3	297.1	852.6	**192.8**
2011	549.0	53.1	37.6	26.2	49.3	32.4	246.5	853.3	**118.5**
2012	563.4	46.5	64.0	71.3	132.0	35.0	287.6	847.8	**185.0**

Abbreviations: *RREC* – average amount of simulated precipitation; *SURQ* –surface runoff contribution; *LATQ* – lateral subsurface contribution; *GWQ* – ground water contribution; *LATE* – water percolation past bottom of soil profile; *SW* –water stored in soil profile; *ET* – actual evapotranspiration; *PET* – potential evapotranspiration; *WATER YIELD* – watershed runoff to streamflow.

SWAT validation

Inherently, ***SWAT validation*** is direct comparison of modeled water yields from watershed (the modeled runoff into a river's streamflow) with its real value.

Cogilnic River observed streamflow *(S)* and simulated runoff *(R)* from the corresponding subwatershed (*both in m^3*) as their ratio *(R/S)*

Month	2010			2011			2012		
	S	R	R/S	S	R	R/S	S	R	R/S
1	202176	0	0.0	544320	0	0.0	256003	0	0.0
2	416189	2430	0.0	499392	2430	0.0	238205	1579364	6.6
....	…	…	..	…	…	..	…	…	..
12	558490	5170593	9.3	368064	3766175	10.2	449280	6164377	13.7
Year	4640285	4685364	10.1	5313341	2879301	5.4	4225997	4396948	10.4

SWAT calibration

SWAT calibration aims to adjust the model to local conditions, thereby reducing its inherent uncertainty.

Itself, *the procedure of calibration* is the correction of input parameters targeted at the selection of a set of their values that produce a water yield similar to that was observed.

Calibration parameters concerning a water yield are usually divided into those governing surface runoff and those governing subsurface runoff, or baseflow. The most effective of them is ***CN2*,** or a runoff curve number.

Change of the Water Yield *(WY)* with 10% sequential decrease of *CN2*

CN2	2010				2011				2012			
	SURQ	*LATQ*	*GWQ*	***WY***	*SURQ*	*LATQ*	*GWQ*	***WY***	*SURQ*	*LATQ*	*GWQ*	***WY***
78.8	131.9	70.9	100.9	***307.7***	41,5	62.1	85.4	***193.1***	43.5	61.9	84.4	***193.4***
71.0	91.5	77.6	128.8	***303.0***	16.3	66.6	101.0	***188.8***	190.0	66.8	90.1	***191.2***
63.,1	69. 8	81.1	144.2	***300.8***	6.4	68.5	107.2	***187.2***	6.5	68.3	106.5	***186.4***
56.2	55.4	83.3	154.7	***299.6***	4.2	69.0	108.7	***187.0***	4.0	68.8	108.2	***186.2***

Anthropogenic loading on the Cogilnic River watershed

According to available information as of 1995, the approximate reductions of Cogilnic streamflow, caused only partially due to some anthropogenic factors, are: land treatment – up to 20%; artificial reservoirs – 10-15%; irrigation – 4-5%; urbanization – 10%. Unfortunately, over the two following decades the situation only worsened.

Two examples of the anthropogenic disturbance of the Cogilnic River watershed

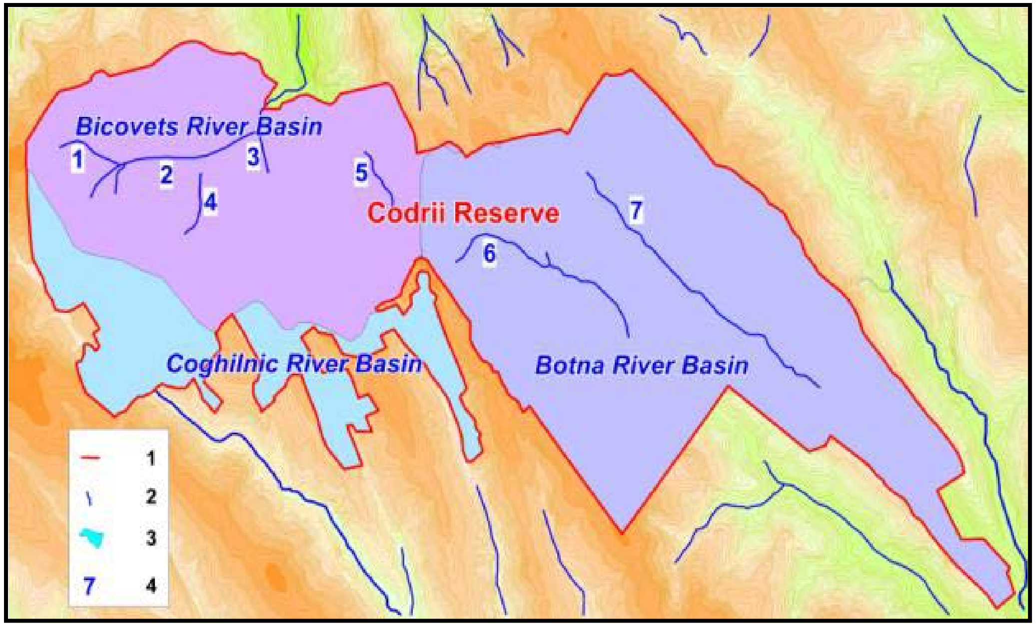
A pond in the river bed

Domestic pollution and complete drying of a tributary

We consider this situation as the first driver of uncertainties in a hydrological modeling

Task 2: Uncertainties in the runoff modeling due to climate change

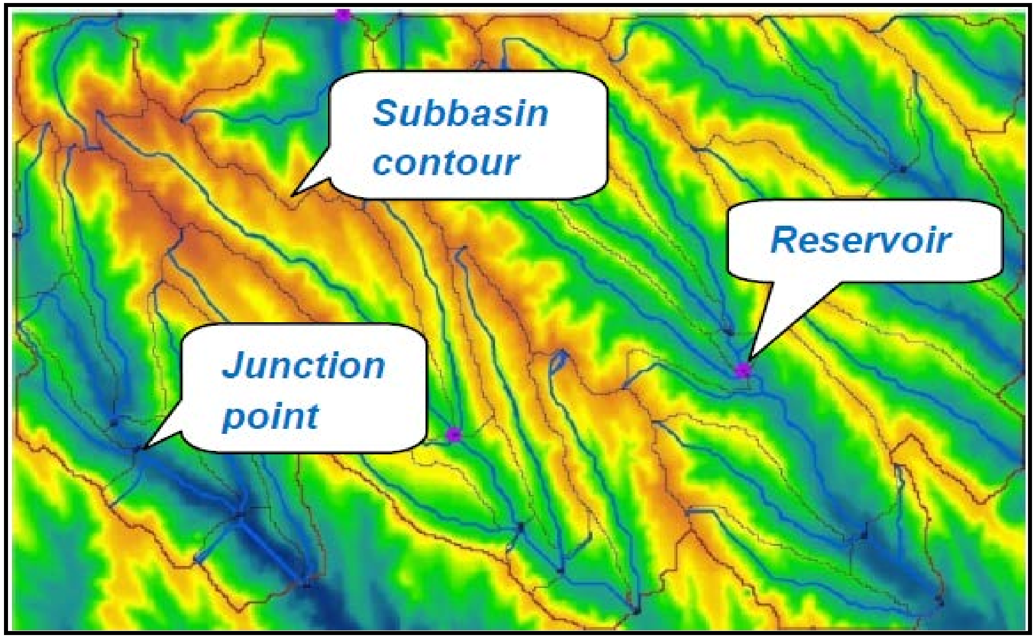
- Scenarios of likely alterations in rivers streamflow due to climate change were based on their latest high resolution projections from a multi-model ensemble of regional climate simulations developed for the IPCC Fifth Assessment Report.
- In turn, these simulations are based on new approaches to accounting for GG concentrations that are known as ***Representative Concentration Pathways (RCPs),*** which assume the different targeted radiative forcing in the 21st century.
- The hydrological modeling of the current and future runoff was also carried out in the SWAT environment.



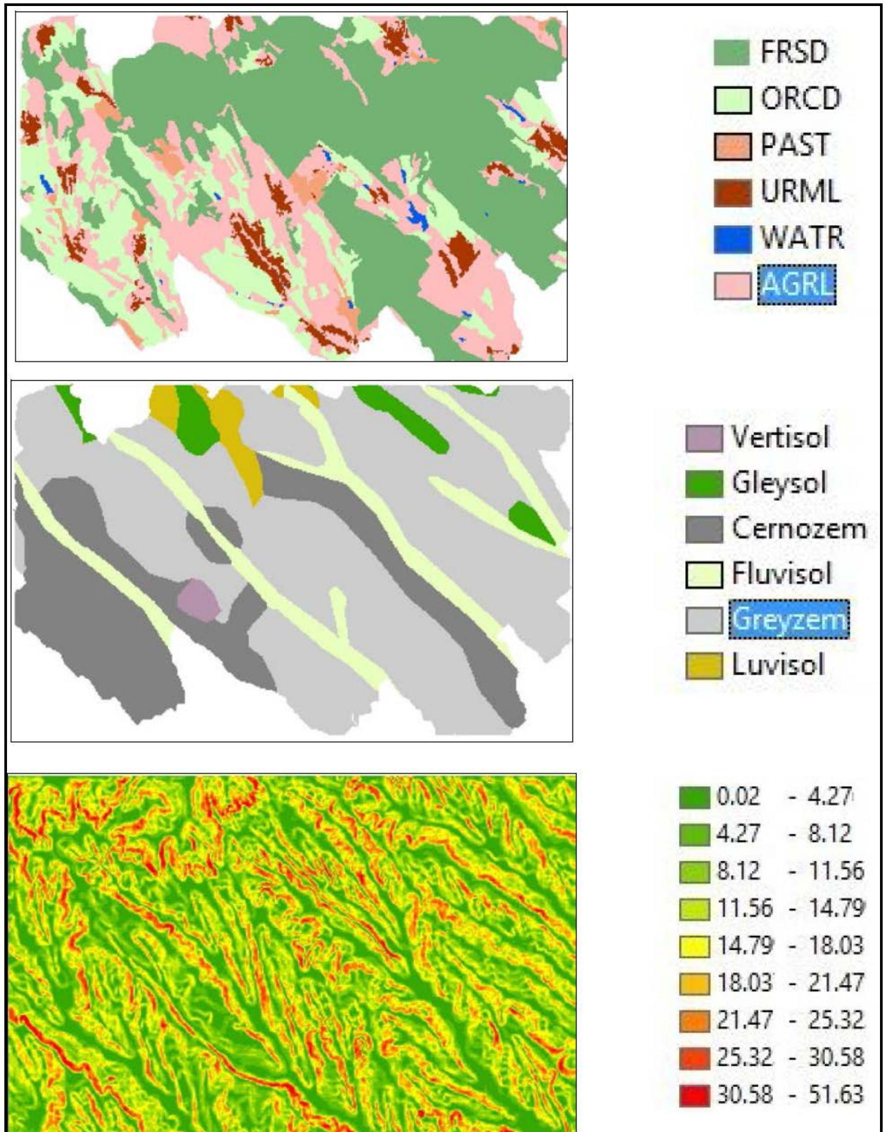
Study area

Rivers’ basins under study

The Codrii watershed’s drainage network, delineated in 34 subbasins, overlapped with DEM



SWAT input data



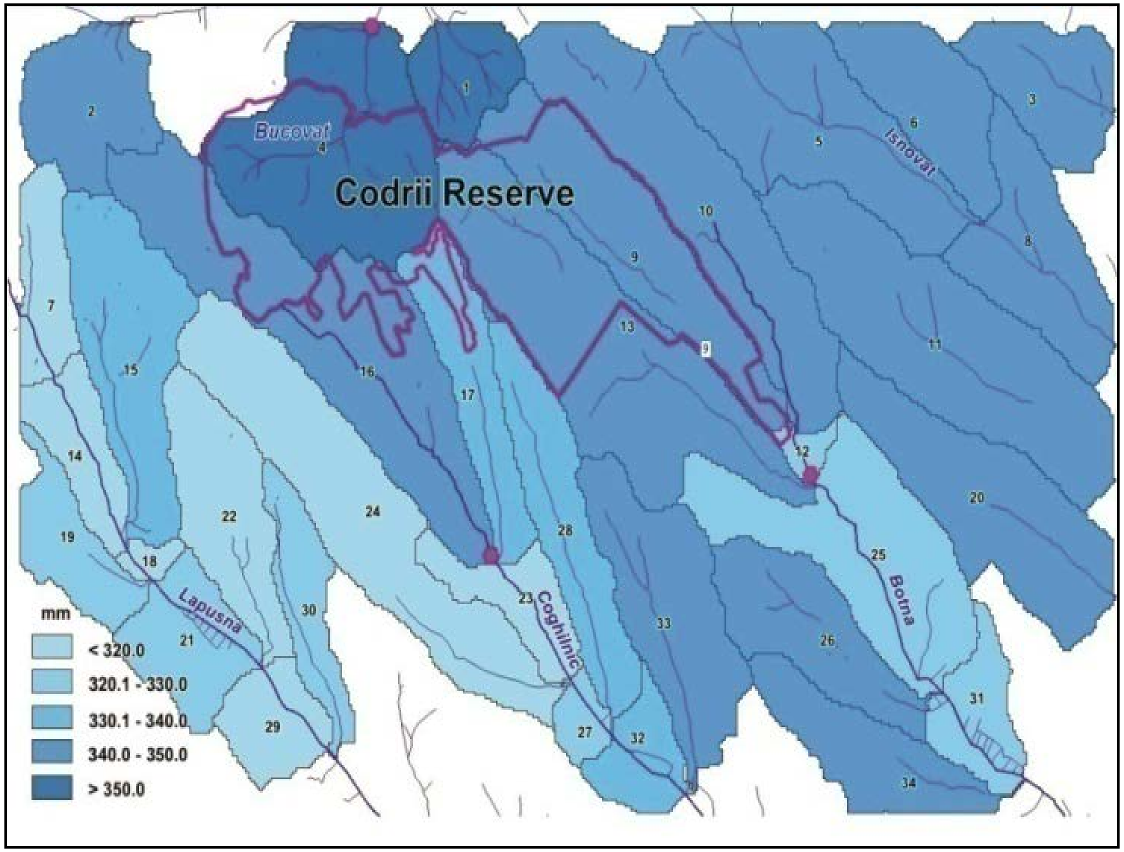
Thematic layers for creating the Codru watersheds' HRUs

Climatic parameter	Month 1	2	3	4	5	6	7	8	9	10	11	12
Tmax, °C	0,7	2,4	8,0	15,4	21,7	24,7	26,7	26,5	21,0	14,8	7,2	1,9
SD	3,0	3,8	3,4	2,2	2,1	1,7	2,0	1,9	2,2	1,5	2,9	2,6
Tmin, °C	-5,1	-4,2	-0,3	5,4	10,7	13,9	15,9	15,4	10,9	6,0	0,8	-3,7
SD	3,2	3,2	2,2	1,6	1,3	1,1	1,4	1,3	1,3	1,2	2,9	2,7
Precipitation, mm	32	33	35	54	61	98	86	57	69	35	44	39

Monthly regional climatic variables in 1970-2000

Annual runoff in the Codrii watershed in 1970-2000

Spatial distribution



Water yields from three subwatersheds and runoff into planned reservoirs

Drainage area	Water yield, mm	Runoff, cubic km
Bucovăţ	339.2	0.0075
Coghilnic	334.2	0.0094
Botna	332.8	0.0132
Codrii	***329.2***	***0.1346***

Projections of climate change in Codri area in the 21st century

Seazon	**Time horizons, yrs**											
	2021-2050						2071-2100					
	Representative concentration pathways *(RCPs)*											
	RCP2.6		*RCP4.5*		*RCP8.5*		*RCP2.6*		*RCP4.5*		*RCP8.5*	
	Mean air temperature (°C)											
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
Winter	0.5	0.5	2.1	2.1	2.2	2.1	0.9	0.9	3.1	3.1	5.5	5.2
Spring	-0.2	-0.1	1.8	0.9	2.2	1.1	0.4	0.2	3.4	1.6	5.2	2.5
Summer	0.2	0.1	2.0	1.4	1.7	1.2	-0.2	-0.1	3.3	2.3	5.5	3.9
Autumn	0.2	0.1	1.2	1.0	1.6	1.4	0.0	0.0	2.3	2.0	4.1	3.4
Year	***0.2***	***0.1***	***1.8***	***1.3***	***1.9***	***1.4***	***0.3***	***0.2***	***3.1***	***2.1***	***5.2***	***3.5***
	Precipitation, mm											
	Abs	%	Abs	%	Abs	%	Abs	%	Abs	%	Abs	%
Winter	3	3.3	17	18.9	12	13.3	3	3.3	13	17.4	23	25.6
Spring	21	15.6	8	5.9	10	7.4	-46	-34.1	13	16.0	17	12.6
Summer	-49	-21.5	-26	-11.4	-18	-7.9	-3	-1.3	-16	-7.0	-33	-14.5
Autumn	-5	4.0	-1	-0.8	-2	-1.6	11	8.8	11	8.8	5	4
Year	***-30***	***-5.2***	***-2***	***-0.3***	***2***	***0.3***	***-35***	***-2.1***	***21***	***3.6***	***12***	***2.1***

Note: *RCP2.6, RCP4.5, RCP8.5 – low, moderate* and *strong* radiative forcing *(W/m^2)* on climate system, respectively

The modeling annual surface runoff *(Abs, mm)* and its relative decrease *(%)* as to 1970-2000

Time horizons, yrs												
Baseline climate (1970-2000)	*2021-2050*						*2071-2100*					
	Representative concentration pathways *(RCPs)*											
	RCP2.6	***RCP4.5***	***RCP8.5***	***RCP2.6***	***RCP4.5***	***RCP8.5***	***RCP2.6***	***RCP4.5***	***RCP8.5***	***RCP2.6***	***RCP4.5***	***RCP8.5***
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
329 mm	310	***5.8***	323	***1.8***	290	***11.9***	260	***21.0***	286	***13.1***	283	***14.0***

Conclusions

- *The modeled runoff, which eventually enter to the river stream, does not reflect water losses resulted from agricultural, municipal, industrial and other human activities, causing inevitable uncertainties.*
- *The SWAT modeling of the future runoff from small rivers' watersheds, confirmed IPCC assumptions about expected decrease of water resources. This decrease depends on changes in air temperature and precipitation and thus – on the uncertainties inherent in their projections.*
- *These uncertainties also strongly depend on the future socio-economic loading on the river watersheds as well as time horizons and scenarios of climate projections.*
- *Nevertheless, the up-to-date hydrological modeling tools, in a case of their correct application, allow accounting for runoff losses due to anthropogenic pressures on surface waters caused by their poor management, which combining with climate change impacts can negatively affect the quantity and quality of water supply necessary for sustainable functioning of national economies and ecosystems services.*


Thanks a lot for your
kind attention!