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"BLACK SEA BASIN 2007-2013" project:

UTILIZING STREAM WATERS IN THE SUPPRESSION
OF FOREST FIRES WITH THE HELP OF NEW TECHNOLOGIES:
'STREAMS-2-SUPPRESS-FIRES'

Forest Fires Prevention by Application of New Technologies

Eco-TIRAS
Chișinău * 2015

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Joint Operational Programme "*BLACK SEA BASIN 2007-2013*" project:

UTILIZING STREAM WATERS IN THE SUPPRESSION OF FOREST FIRES WITH THE HELP OF NEW TECHNOLOGIES: '*STREAMS-2-SUPPRESS-FIRES*'

Project coordinator: ***Dr. G.N. Zaimes (Greece)***
Moldova local project manager: ***Dr. I.D.Trombitsky***

PROJECT OBJECTIVES:

Overall objective: *To share competencies and innovative tools for the protection of protected areas from wildfires*

Principal specific objective: *To develop a holistic and complete approach to wildfire suppression for the Black Sea Region with demonstration of its implementation on six pilot areas*

PROJECT PARTNERS

Greek	Romania	Ukraine	Armenia	Moldova	Turkey
Eastern Macedonia & Thrace Institute of Technology	*The Prefecture of Braila*	*National University of Life and Environmental Sciences*	*Zikatar Environmental Center*	*Eco-Tiras International Association of River Keepers*	*Artvin Coruh University*

Fig. 1 The location of pilot areas

Principal activities

- *Creation of geodatabase*
- *Forest fuel sampling and fuel model mapping*
- *Fire risk and fire behavior mapping*
- *Validation & modification of the runoff model*
- *Assessment of reservoirs location and properties for their use in fires control*
- *Dissemination of the project results*

Moldova' Pilot Area – The Codrii Natural Reserve

The "Codrii" Forest Reserve (hereafter – *Reserve)* is the first national reserve of Moldova. It was founded in 1971 with the aim to conserve the most representative areas of forests, specific for Moldavian Central Upland. The Reserve is located in 49 km to southeast from Chisinau; 99.9% of its total area is located in the northwest part of Straseni rayon with the head office in the neighborhood of Lozova community (Fig. 2).

Fig. 2 Codrii Reserve on the map of Moldova

The area of Reserve covers 51.59 km^2 (with an adjacent territory – 350 km^2) that is divided into three functional zones (Fig. 3):

Fig. 4.3 Functional zones of the Codrii Reserve

- *Strictly protected zone (720 ha),* which forms the Reserve's nucleus and comprises sectors with habitats of rare animal and plant species of exceptional scientific and conservation value. Here, any human activity, except scientific and protection research, is forbidden;
- *Buffer zone (4,457 ha)* surrounds the strictly protected zone to limit the human impacts. It represents forest types similar to the surrounded and requires an ecological reconstruction through scientifically based interventions;
- *Transition zone (12,300 ha)* – 2-km area around the buffer zone – includes mainly private or public agriculture lands with all kinds of economic activities that don't break the protective limits of natural systems.

Climate and geological conditions of the Reserve have formed a rich and varied flora that have almost 1000 species of protected plants – a half of those specific for Moldova. The main types of forest vegetation are characterized by a highest floristic complexity, primary of basic species such as oak (Fig. 4). All protected forests are of the 1st functional group that is subject to the regime of complete nature protection Other species are main or secondary mixtures, depending on the flora dominant position – ash, linden, maple, hornbeam, apple and pear tree, strainer, etc.

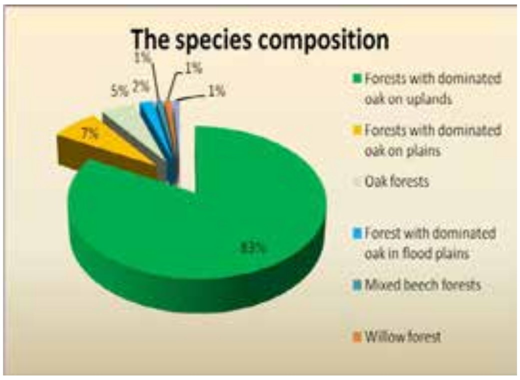


Fig. 4 Composition of forest

Climate of the Reserve is temperate continental with short mild winter and long hot summer. Here, in the last two decades a mean annual air temperature was 9.5°C, with the averages -1.3°C in winter, 20.2°C – in summer and 9.7°C and 9.6°C in spring and autumns, respectively.

Within the Reserve the large water bodies are missing, but there are many creeks and springs. Available rivers (Botna, Cogîlnic and Bucovăț) are poor by water resources and sometimes dry up, especially in dry years and in their upper parts. In wintertime they usually freeze because of absence of a continuous water stream. Within the Reserve and in the neighborhood there are six springs with a small debit, as well as small ponds with areas from 0.4-0.5 ha to 5-12 ha.

Fire risk and fire behavior mapping

Predicting the potential behavior and risks of forest fires is a mandatory step in fire management. This procedure is based on the initial field fuel sampling and is carried out through the *FlamMap* soft specifically designed to generate fire behavior characteristics in a landscape's raster cells.

The field work on ***fuel sampling*** in the Codrii Reserve has resulted in four fuel complexes (Fig. 5) that have different fuel loads and thus different forest fire risks.

Mixed forest in the zone of an eligible economic activity	*Forests in the strictly protected zone and willow forests*	*Grasslands and forage fields*	*Reforestation and shrub vegetation*
			

Fig. 5 Main forest complexes of the Codrii Reserve

Fuel model mapping was realized through a conjugate analysis of full sampling results and a satellite imagery of the pilot area by the satellite *"GEOEYE-1"* that provided an image in the multispectral four-channel mode (Fig. 6) with a spatial resolution of 5.01 m on the ground.

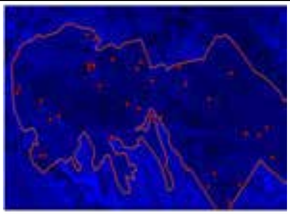
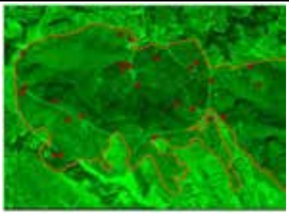
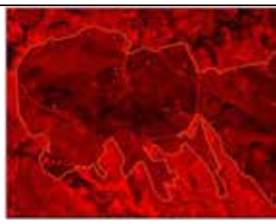
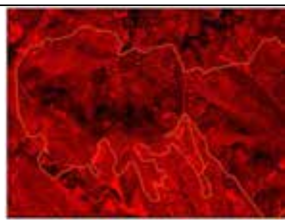
Spectral bands			
Blue (B)	*Green (G)*	*Red (R)*	*Near infrared (NIR)*
			

Fig. 6 Multispectral satellite image of the Codri Reserve in four spectral bands.
Red line – the Reserve's border; *red points* – fuel sampling plots

To mitigate the effect of noises in spectral images and to amplify a useful for research purposes signal, the original spectral data were transformed into two so-called v*egetation Indexes (VI),* expressed as different combinations of reflectance in selected spectral bands:

Normalized Difference Vegetation Index (NDVI):

$$NDVI = (NIR - R)(NIR + R)$$

Greenness Vegetation Index (GVI):

$$GVI = 0.1253*Blue + 0.2435*Green + 0.3343*Red + 0.9018*NIR$$

The 'weight' of each diapason in their linear combination in the GVI equation was estimated through the *Principal Component Analysis.* Using these equations, the spectral values in four bands were recalculated into *NDVI* and *GVI* values for each pixel of the satellite image. This procedure resulted in the spectral image of the Codrii Reserve expressed in Vegetation Indexes. To classify the spectral image by fuel models the *Cluster Analysis* was used. This procedure groups all observations (pixels) into clusters based upon similarities between them. As initial '*seeds'* for each clustering, the mean values of *NDVI* and *GVI* for each fuel model were selected (Fig. 7).

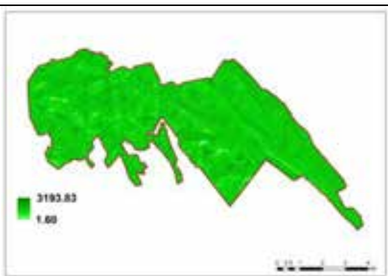
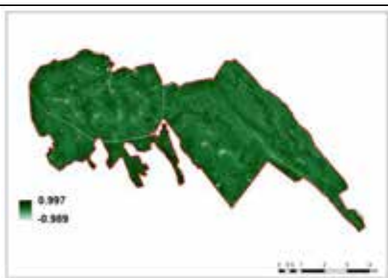
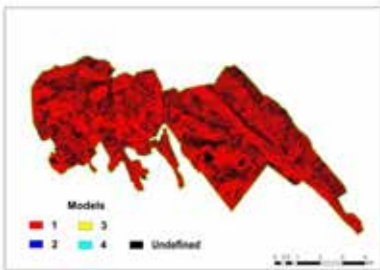
Greenness VI	*Normilized Difference VI*	*Clustering by Fuel Models*
		

Fig. 7 Spectral image of the Codrii Reserve, transformed in two Vegetation Indexes with a following clusterization by four fuel models

Potential behavior and risks of forest fires

The corresponding analysis was based on the outputs of the *FlamMap* fire behavior modeling and mapping system. FlamMap inputs can be divided into four major categories: topographic data, forest characteristics, the weather scenario and fuel moisture data.

The basic themes of ***topographic inputs*** that form a Landscape File include an elevation, slope and aspect, which in two formats are shown in Fig. 8.

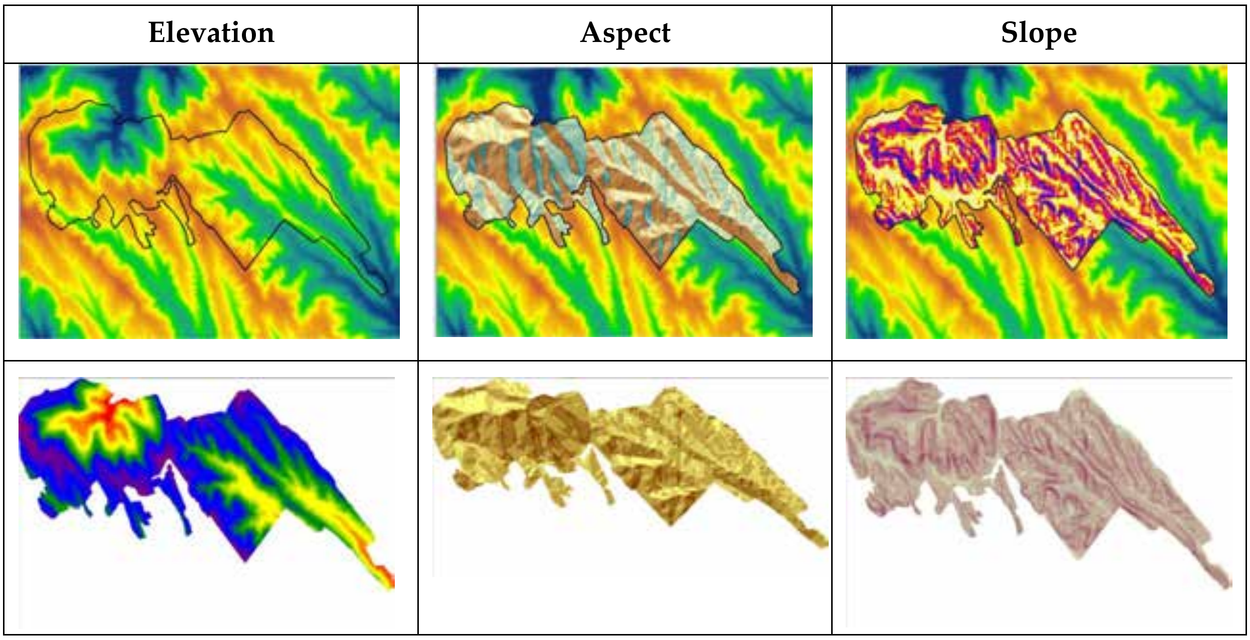


Fig. 8 Basic topographic themes used as an input for creating the Codrii Landscape file in ArcGIS *(above)* and FlamMap5 *(below)* formats

Forest characteristics were expressed as the *Fuel Model File (FMD)* with the values corresponding to fuel parameters resulted from the field fuel sampling (Table 1).

Table 1 Parameters of the Fuel model for the Codrii Reserve

Component name	Component field	Metric units[2]	Fuel models			
			1	***2***	***3***	***4***
Fuel Model Number	FMN	number	21	22	23	24
Fuel Model Code	FMCode	char	FM21	FM22	FM23	FM24
Fuel Model Code1[1]	FMCode	char	TU1(161)	TL9(189)	GR4(104)	GS1(121)
Fuel Loading	1h, 10h,100h, LiveH, Live W	t/ac	0.27 1.03 1.03 0.00 0.27	0,40 1.55 2.10 0.00 0.23	0.00 0.00 0.00 2.30 0.00	0.21 2.75 2.13 0.00 1.30
Fuel Model Type	FMT	dynamic	dynamic	dynamic	dynamic	dynamic
Surface to Volume Ratio	1hSAV, LiveH(W)SAV	1/ft	2000 1800 1600	1800 9999 1600	2000 1800 9999	2000 1800 1800
Fuel Bed Depth	Depth	ft	0,054	0,63	0,082	0,026
XtMoist	Moisture of Extinction	percent	30	30	30	30
Heat content, live & death fuel	DHt, LHt	Btu/lb	8 000	8 000	8 000	8 000
Fuel Model Name	FMName	character	*Mixed forest*	*Protected zone forests*	*Grasslands and forage*	*Reforestation and shrubs*

Note: 1. Fuel model Code1[1] is given according to Scott & Burgan (2005) classification
2. In the model English metric units were used

Weather scenario included the mean maximum wind speed at Codrii weather station in summer (14 m/s) and dominant northwest wind direction (270º) observed in 1996-2013 yrs.

Fuel moisture was applied as a single set of values for all fuel models components: *1hr dead*

– 8%; *10hr dead* – 10%; *100hr dead* – 12%; *Live herbaceous* – 100%; *Live woody* – 120%.

***FlamMap* outputs** is described by two parameters: rate of spread and fireline intensity. *Rate of spread* (m/min) establishes the size of a fire ellipse emanating from a raster cell. *Fire line intensity* is the rate of a heat energy released per unit time per unit length of fire front (kW/m) and is calculated as the product of available fuel energy and the fires rate of advance (Table 2, Fig. 9). According to the used fire risk gradation, about half on the Codrii area is subjected to a moderate fire risk, about 40% – to a high risk, and the rest area – to a very high risk.

Table 2 Fireline intensity and fire risks in the Codrii Reserve area

Fireline intensity, kw/m	*Fire risk*	*% of area*	*Rate of spread, m/min*	*Fire risk*	*% of area*
350	Low	0.6	2	Low	0.003
1,700	Moderate	48.0	15	Moderate	55.1
3,500	High	39.0	30	High	41.1
>3,500	Very high	12.4	<30	Very high	3.8

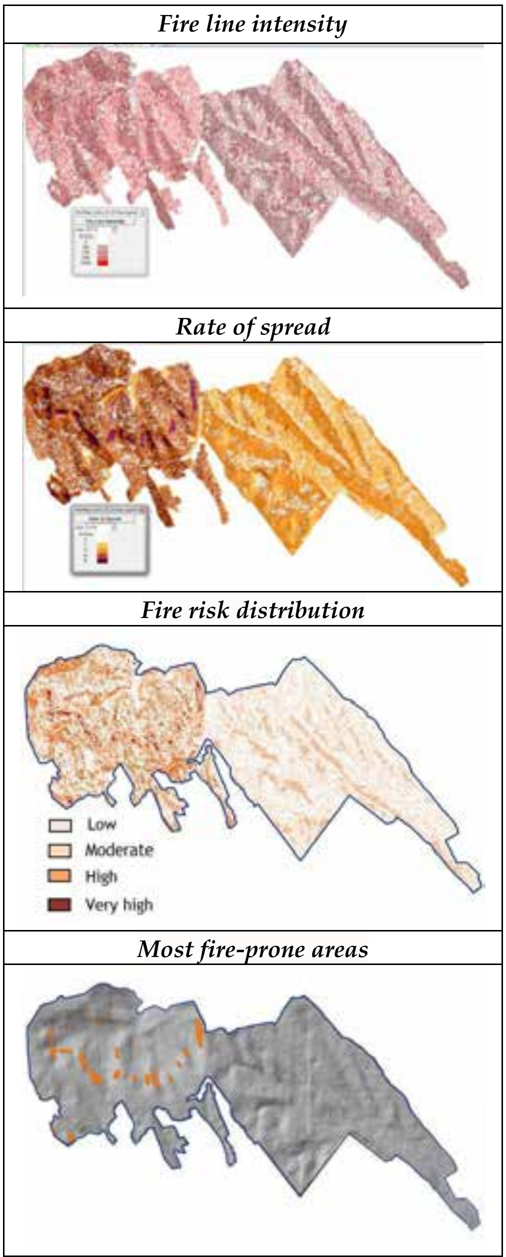


Fig. 9 Fires line intensity and rate of spread & spatial distribution of forest fire risks in the Codrii Reserve

Fire risk maps generation was carried through transforming the *Fire line intensity* and *Rate of spread* in the *Fire risk factors*, which for *low, moderate, high* and *very high* risks were taken as 5, 10, 15 and 20, respectively. The resulted final fire risk maps have been received through overlay of these two transformed layers (Fig. 9). The obvious difference in fire risks on left and right sides of the Reserve can be explained by their location on the opposite slopes of the area: the most fire-prone left slopes are mainly west and east; the right slopes are mainly northwest and southeast.

Assessment of reservoirs properties and location

As an effective tool for assessing the water resources for a wide range of scales and environmental conditions, the Soil and Water Assessment Tool *(SWAT)* model has proven to be (Arnold et al., 2012; Neitsch et al., 2011; Winchell et al., 2013). In this research the SWAT was used to reliable streams flow prediction for typical conditions of the central part of Moldova. A preliminary SWAT validation served as a basis for its use in the follow-up investigation whether the total runoff from the Codrii Reserve area is adequate for creating or maintaining the water bodies necessary for water supply to suppress possible forest fires here.

Modification and validation of the runoff model

Usually, the SWAT validation is carried through the comparison of its modeling outputs with runoff measurements. For such validation the historical records of the Cogîlnic River daily runoff were used. This river originates in Codrii and forms one of its sub-basins on the Reserve territory (Fig. 10). The hydrological post *Hincesti* where monitoring observations of streamflow are being conducted is located in 20 km from the Reserve. Thus, the area of validation is the watershed of the Cogîlnic River from its head to *Hincesti.* The validation *per se* was a comparison of simulated runoff with this river real flow observed in 2010-2012.

According to validation results, the discrepancy between simulations and observations was very significant to be eliminated by any adjustment of SWAT, and its capabilities

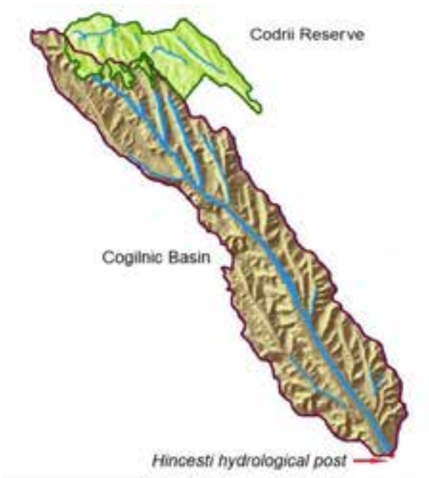


Fig. 10 Sub-basin of the Cogîlnic River used for SWAT validation

are quite limited in relation to small rivers of Moldova, exposed to great anthropogenic changes. In different years the observed flow of the Cogîlnic River amounted from ~10% to 15% of the modeled runoff from its watershed. However these results are in good agreement with a real picture. Available estimations (Cazac and Lalikin, 2005) show that an approximate reduction of Cogîlnic's stream flow due only a part of anthropogenic factors is: land treatment – up to 20%; artificial reservoirs – 10-15%; irrigation – 4-5%; urbanization – 10%. Moreover, its drying influences seriously the general state of the watershed ecosystems, changing the plant cover and evapotranspiration. As a result, the river channel was altered, it lost their sources and tributaries, and precipitations and snow-melt more intensively evaporate or infiltrate into the soils. Thus, SWAT modeling for small rivers yields a certain hypothetic runoff from the watershed that can be real only for "a pristine environment", e.g. for natural reserves.

SWAT modeling of reservoirs location

On the final stage, the locations of reservoirs for water supply of fires suppression and the optimal entrance ways to them for ground vehicles were identified. This modeling activity was based on previously developed digital maps, then validated through *in situ* visits. Because within the Codrii Reserve the large water bodies are missed, the posed problem could only be solved by expanding the study area. As such, a wider watershed was investigated where there are a number of streams and ponds (Fig. 11).

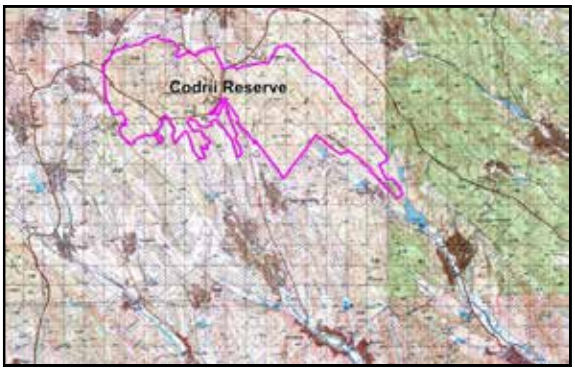


Fig. 11 Topographic map of a watershed used to plan the reservoirs, suitable for fires fighting in the Codrii Reserve

To identify reaches and subwatersheds, the watershed initial delineation was carried out in the ArcSWAT environment, using the Digital Elevation Model (1:25000) built for this area (Fig. 13).

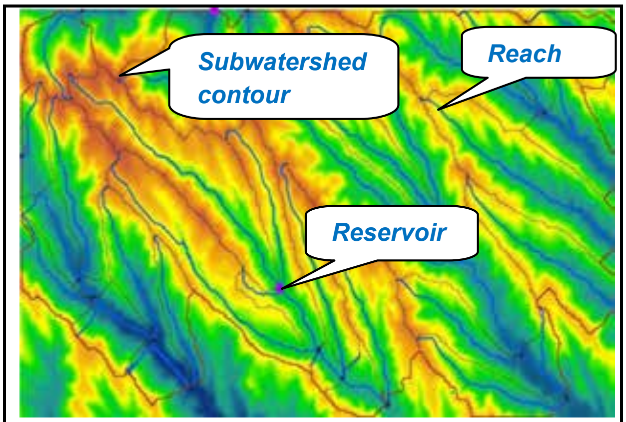


Fig. 12 The delineated Codrii watershed's drainage networks, overlapped with the DEM

Reaches were defined as lengths of the river where a threshold drainage area was than 500 ha. According to this threshold, 34 subwatersheds were defined. The lengths of reaches were between 0.3 km and 11.5 km, with mean value of 4.2 km; the mean, maximum and minimum areas of their basins were 11.94, 28.07 and 1.07 sq. km, respectively, the corresponding altitudes above sea level – 191.6, 308.1 and 124.4 m. Three planned reservoirs were placed on outlets of the Bucovăț, Cogîlnic and Botna Rivers' subwatersheds.

Following the SWAT methodology, to reflect differences in local hydrological conditions the entire watershed was subdivided into Hydrological Response Units (HRU). Due to relatively small areas of the delineated subwatersheds, only a single HRU was identified for each, and thus 34 HRUs were received in whole, proceeding from the dominant land-use category, soil type and slope class; these characteristics were expressed as the GIS's vector layers and then converted to the SWAT codes and formats.

In Fig. 13, the ***land-use*** forms are distributed as follows: Residential (*URML*) – 4.6% of the watershed, Orchard *(ORCD)* – 19.1%, Pastures *(PAST)* – 2.2%; Deciduous forest *(FRSD)* – 48.1%, Water (WATR) – 0.5%; Agricultural Land *(AGRL)* – 25.6%. ***Soils,*** according to FAO classification, were also grouped into six classes: Chernozem *(CH)* – 24.2% of the watershed; Fluvisol *(FL)* – 11.8%, Gleysol *(GL)* – 3.6%; Vertisol *(VR)* – 0.8%, Luvisol *(LV)* – 2.6%; Greyzem *(GR)* – 57.5%.

Unlike to Fig. 13, in the SWAT environment the ***slopes*** were divided into three categories reflecting areas with a low, mean and relatively high steepness: <10⁰ (41.9%), 10-30⁰ (57.1%) and >30⁰ (~1%). Overlapping of these thematic layers has resulted in a new layer needed for predicting the runoff from each HRU.

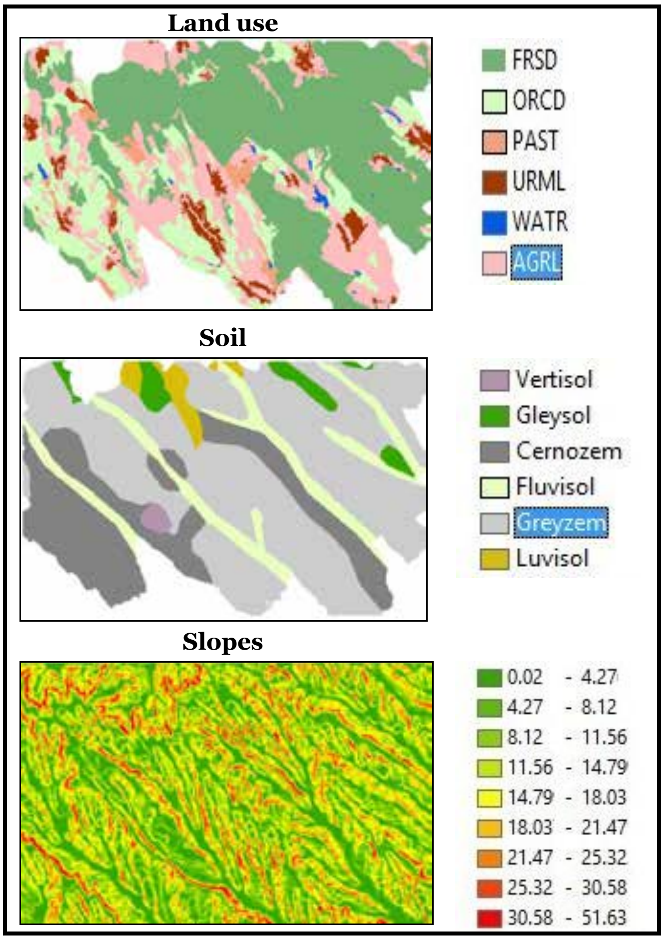


Fig. 13 Thematic layers for predicting the HRUs' runoff

To simulate daily climatic information the historical (1996-2013 yrs) monthly mean maximum and minimum air temperatures and their standard deviations, as well as precipitation at the Codrii weather station were used. Other weather parameters, needed for runoff modeling, were simulated by the Weather Generator *(WGEN)*, which is embedded in the SWAT.

Surface runoff in current climate

A surface runoff is predicted separately for each HRU, and then their contributions to the streamflow and in the soil profile is summed to obtain a total runoff for the watershed. A *runoff* occurs whenever the water application to ground surface exceeds its infiltration into the soil. As one can see from Fig. 14, the maximal annual runoff (>350 mm) takes place in the northwest part of the watershed, the minimal (<320 mm) – in the southwest part; however, on the most part of the watershed it amounts 330-340 mm per year.

Multiplication of a runoff per unit area *(water yield, mm)* by an area gives both the value of its total runoff (as in Fig. 14) and the volume of water potentially available for filling the reservoirs (Table 3). The minimal runoff is observed in January–May, the maximal – in the second part of a year. An annual total runoff in the Codrii area can be up to 0.135 km³, the water flow in the selected reservoirs – from ~0.008 to above 0.13 km³. Given the intensive economic activity in the Reserve's area is limited, these figures are fairly objective.

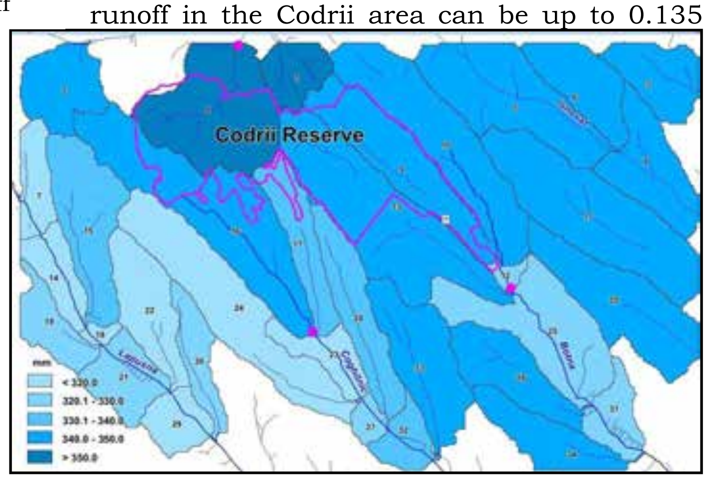


Fig. 14 Spatial distribution of the annual runoff from the Codrii watershed

Table 3 Watershed runoff into reservoirs

Reservoir	Months												Annual runoff	
	1	2	3	4	5	6	7	8	9	10	11	12	mm	km³
Bucovăţ	0.0	11.4	27.6	9.6	6.3	4.7	56.2	53.4	51.3	32.4	40.5	45.9	339.2	0.0075
Cogîlnic	0.0	11.2	23.5	10.8	8.0	3.3	42.3	56.1	52.1	38.7	36.5	51.7	334.2	0.0094
Botna	0.0	12.3	25.7	10.2	7.3	3.6	48.0	53.6	50.9	35.1	37.3	48.8	332.8	0.0132
Codrii	***0.0***	***12.0***	***26.0***	***10.1***	***7.1***	***3.8***	***48.7***	***52.6***	***50.1***	***34.0***	***37.2***	***47.6***	***329.2***	***0.1346***

Surface runoff under changing climate

The projection of a likely runoff in the condition of climate change is based on the latest high resolution (12.5 km) data set from a multi-model ensemble of regional climate simulations for impact research (Jacobs *et al.*, 2013). For these simulations, the concentration-driven experiments were used, in which, rather than greenhouse gases emissions, their concentrations were prescribed. These so-called *Representative Concentration Pathways* (*RCPs)* scenarios (Moss et al., 2010) assume achievement of certain radiative forcing for different time horizons. Projections of climatic variables that are necessary for the SWAT weather generation are shown in Table 5.

Table 4 Projections of annual temperature and precipitation change in the Codrii area

Time horizons, yrs											
2021-2050						2071-2100					
Representative concentration pathways *(RCPs)*											
RCP2.6		*RCP4.5*		*RCP8.5*		*RCP2.6*		*RCP4.5*		*RCP8.5*	
Air temperature (°C)											
Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
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	%
-30	***-5.2***	***-2***	***-0.3***	***2***	***0.3***	***-35***	***-2.1***	***21***	***3.6***	***12***	***2.1***

The increase of air temperature, even with a slight change in total annual precipitations, will be accompanied by an increase in evapotranspiration and, accordingly, by a corresponding reduction of a surface runoff. The SWAT modeling of a surface runoff in the Codrii area (Table 6), based on the projected values of air temperature and precipitation, has confirmed these assumptions. A possible reduction of the surface runoff in streams providing water flows into reservoirs could reach, depending on a time horizon and radiative forcing, from about 2% to 21%. On average, this value can reach 6.5% in the 2021-2050s and 16% in the last thirty years of the current century.

Table 5 The Codrii area's modeling annual surface runoff (Abs, mm) and its relative changes (%)

Time horizons, yrs												
1996-2013	**2021-2050**						**2071-2100**					
	Representative concentration pathways *(RCPs)*											
	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***

Optimal access roads to the probable fires

Overlapping the most fire-prone areas on the roads network, now available in the Codrii Reserve allowed identifying and assessing the ways of water supply to these areas from three scheduled reservoirs. At present, there is a fairly extensive network of roads here, including the arterial, regional and local with a hard surface (asphalt or crushed stone/gravel), as well as unpaved roads and forest clearings. So, there is practically no need for construction of new roads and a main challenge is their optimal routing. Results of such analysis are shown in Fig.15 and Table 6.

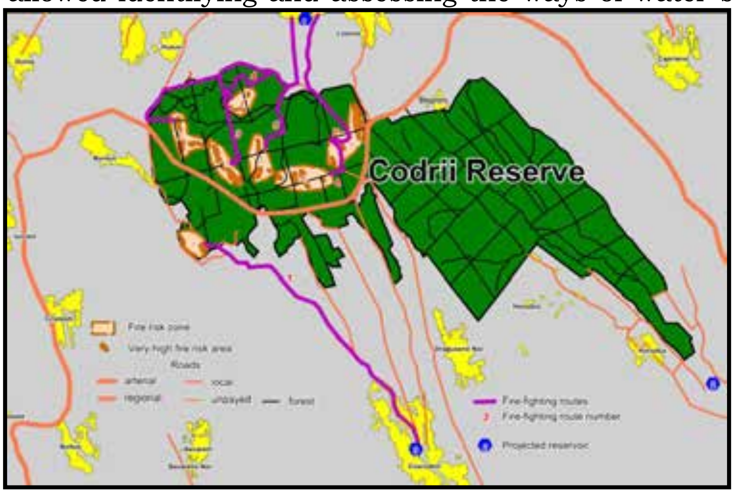


Fig. 15 Available access road to forest fire-prone zones

Analytical calculations were verified through a field visit in the studied watershed. The visual inspection of selected reservoirs and approach roads to them confirmed, in general, the representativeness of the results. It is also clear that the volumes of water in existing ponds, considered as potential reservoirs, are sufficient to suppress any possible fires in the Codrii Forest Reserve (Photos).

Table 6 Description of optimal routes of water delivery to fire zones from the proposed reservoirs

Fire risk zone	Reservoir	Route	Road type			Distance, km	Time of water supply, min
			Local	*Unpaved*	*Forest clearing*		
1	2	1		8.5		8.5	10
2	1	2	1.8	5.0	0.7	7.5	15
3	1	3	1.8	2.5	2.6	6.9	15
4	1	4	1.6	0.9	2.0	4.5	10
5	1	5	3.4	0.9	2.1	6.4	12
6	1	6	5.4		0.4	5.8	8
7	1	7	4.1			4.1	5
SE part	3			8-10	2-5	10-15	15-20

A pond near the Codrii Reserve's administration building southward from *Reservoir 1*

A pond on the northern outskirts of Ciuciuleni village in the Cogîlnic River bed

Reservoir №3 in the floodplain of the Botna River between Horodca и Ulmu villages

A regional road in the direction of Ciuciuleni village

A typical local road

A typical forest road

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This booklet presents a short summary of the activity of Moldavian partner of the Project "Utilizing stream waters in the suppression of forest fires with the help of new technologies" that was carried out in the framework of the EU Joint Operational Programme "BLACK SEA BASIN 2007-2013" in 2013-2015 yrs. Undoubtedly, the objective limitations by the size and purpose of this publication have not allowed to present in detail the used methodological approaches and their implementation; this is the subject of interim reports and scientific publications produced in the course of the project. Therefore, the aim of the publication was only to give certain information about the opportunities provided by modern technologies in exploring the increasing risk of forest fires, as well as water supply for their suppression in case of this event. The booklet is designed for professionals in the relevant fields, and as such requires a certain level of scientific knowledge. From this point of view it may be also useful as a guide for the organization of similar studies.

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