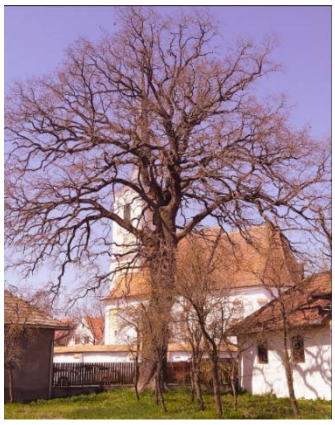
WATER HOLISTIC

RECOVERY PLAN TO INCREASE THE RESILIENCE OF THE LANDSCAPE IN THE WATERSHED OF DAIA VILLAGE AGAINST DROUGHT AND CLIMATE CHANGE











Michal Kravčík, Danka Kravčíková

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July 2026, Košice

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1. Introduction

1.1 Customer identification data

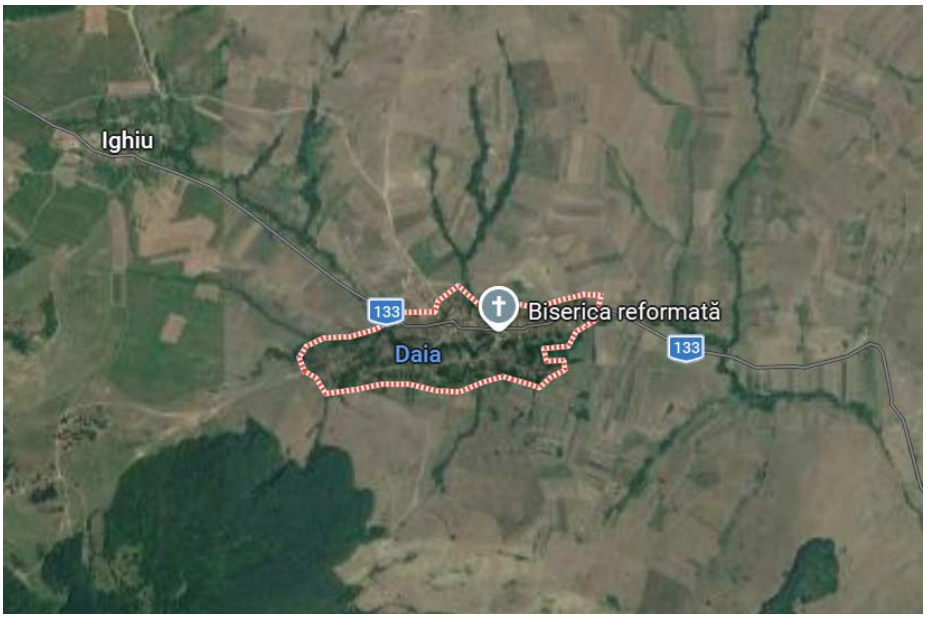
Agri-Cultura-Natura Transylvaniae Association
537231Sat. Delnița, Nr. 198, Com. Pauleni-Ciuc, Jud. Harghita
Registration ID: 19 din 20/12/2016, VAT ID: 36866319
Statutory representative: Rodics Gergely, director
bank account: Banca Transilvania filiala Miercurea Ciuc
IBAN: RO62BTRLRONCRT0T1018C001
e-mail: rodics.gergely@gmai.com

1.2 Identification data of the project developer

Water Holistic Ltd.
Čermeľská cesta 1439/24, 040 01 Košice
registered in the Commercial Register of the District Court Košice I, section Sro, vl. No. 50295 /V
ID: 53 411 421, VAT ID : SK2121368128
bank account: Fio banka,
IBAN: SK23 8330 0000 0025 0241 1693
Statutory representative: Danka Kravčíková, managing director
e-mail: info@waterholistic.com

1.3 Justification for conducting the study

The DAIA basin is located on the western side of the Carpathian foothills in central Romania. As it is a relatively small basin, it is vulnerable to various types of weather. The basin is particularly prone to flash floods, which pose a serious problem and threat to the community living in the central part of the valley, into which small streams flow from all sides of the municipality. With the increase in rainfall intensity, there is a high risk of increasing flood risks in the municipality, with a subsequent increase in drought and temperature and water deficiency in the country. According to the state of damage to the territory, there is an urgent need for ecosystem protection of the territory, as the loss of natural resources (soil, water, forest) is dramatically increasing, which could cause the complete extinction of the municipality. Given its compact size and the way in which the forest-agricultural landscape is used, the river basin is poorly resilient to climate change. The region is also facing increased heat waves, which further intensify the need for systemic changes in land management to effectively prevent gradual degradation and the growth of socio-economic problems in the long term.



Challenges facing the region

The way the land is used in the DAIA basin shows a high level of erosion activity in the agroforestry landscape, assuming that the water reserves in the landscape are fixed and that there will always be enough water. However, neglecting the care of the water in the landscape has led to an increase in temperatures. DAIA is one of the areas in Europe with the largest increase in average summer temperatures. The urgent need to increase resilience to climate change requires finding and offering solutions that prioritize slowing down the runoff of rainwater and enhancing its infiltration into the soil and underground, in order to restore already dried-up springs so that the landscape can cope with adverse weather conditions and drought periods.



2. Analysis of the current situation

The DAIA basin, which covers an area of 29,8 km^2, faces long-term serious environmental and climatic risks and, as a result, socio-economic problems. The more frequent occurrence of anomalous weather phenomena in historical records confirms that since 1980 there has been a trend of increasing temperatures with warm winters and hot summers, punctuated by rare intense storms.





The DAIA basin consists of the DAIA municipality cadastre and parts of the Ighiu and Badeni municipalities. The analyses we have developed in this area were based on the needs of individual administrative units, which will allow public institutions to use the acquired knowledge in decision-making within the framework of spatial planning.



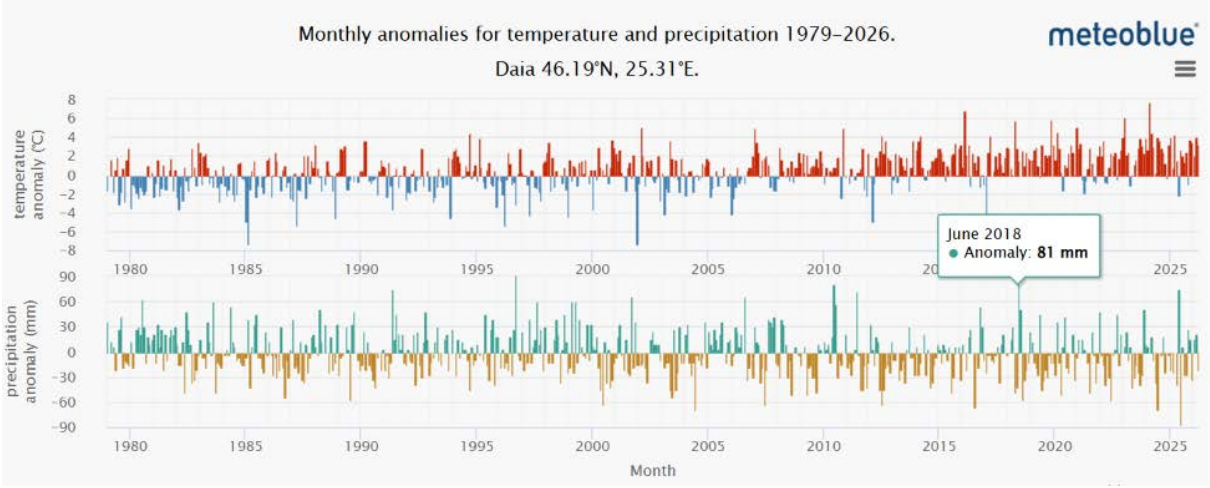
The simultaneous use of forest-agricultural and urbanized land increases the risk of frequent floods. The runoff of rainwater from forest transport infrastructure, managed conventional

agricultural land and the drainage of all roofed and paved areas into streams. This causes very rapid runoff of rainwater into the river system. The result is the frequent occurrence of flood anomalies with the transport of mud from erosion activity from the countryside to the village.





Frequent flood threats alternate with long periods of drought. The main cause of this adverse situation is the rapid runoff of water from drainage areas. The water then quickly accumulates in the river system, causing flooding and at the same time preventing the necessary infiltration of this rainwater into the soil.



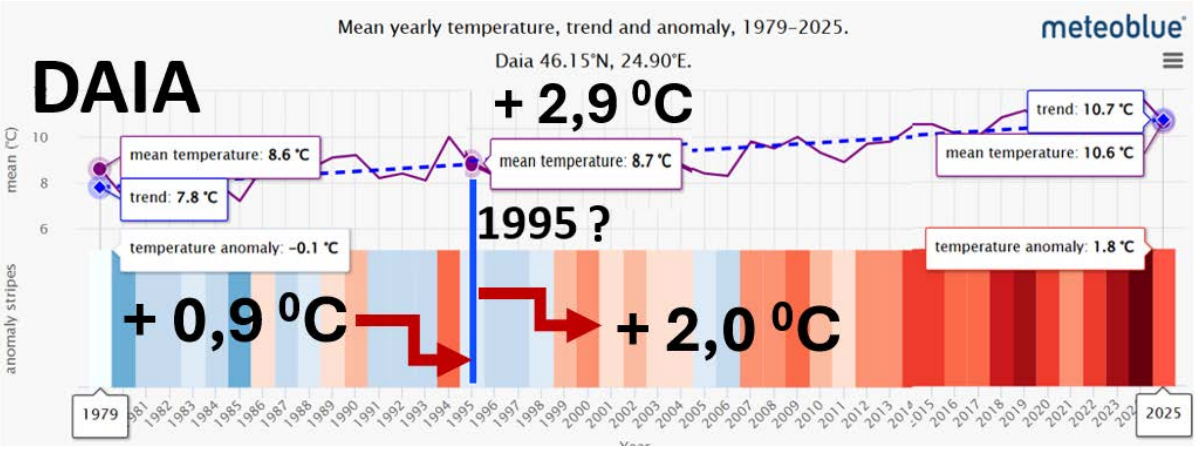
Source: www.meteoblue.com

Rapid runoff of rainwater from the landscape causes three serious changes in ecosystems:

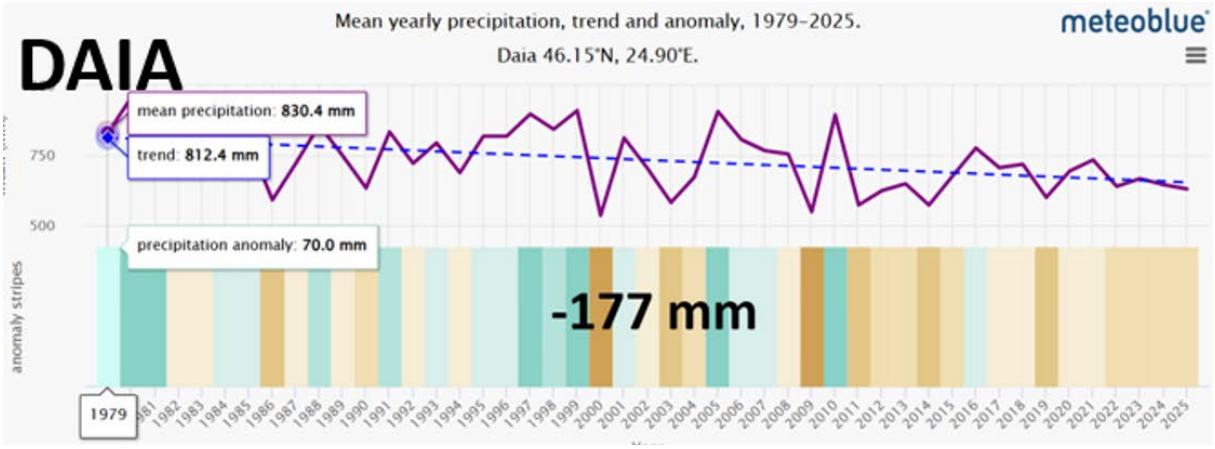
1. Decrease water in the landscape, loss of soil and groundwater, drying up of springs
2. Lack of water in the soil reduces evaporation through vegetation, which causes a decrease in biomass production in forests and on agricultural land
3. Reduced evaporation also means a decrease in the consumption of solar energy for evaporation and, consequently, the logical release of sensible heat into the troposphere and faster heating of the ground layers of the atmosphere.

The result of these changes is a deepening of the drought in the country and a deterioration of the harvest, which can be seen in the graph from Meteoblue. These changes bring a new reality that will also need to be reflected in the DAIA basin, because these changes have caused a trend increase in temperature and a decrease in precipitation.

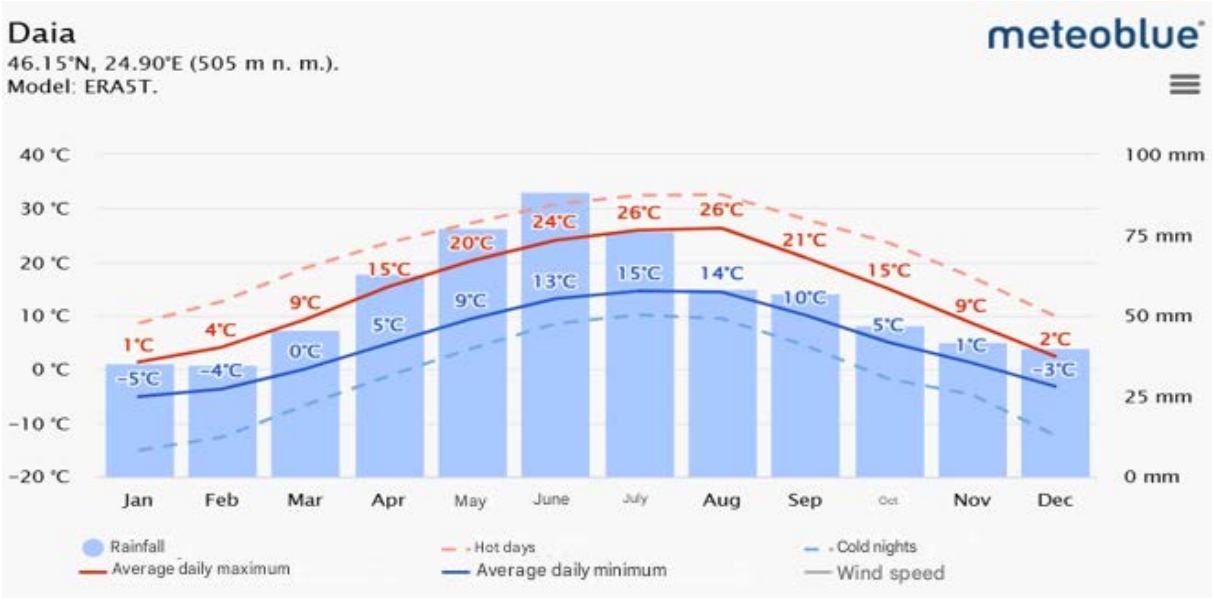
Average annual temperatures have increased in the DAIA area by 2,9°C since 1980, which significantly deepens the water deficit in the country and causes drought. An increase in temperature by 2,9 degrees Celsius means increased evaporation by 290 mm per year. With a trend decrease in precipitation by 177 mm, the water conditions in the area have changed with an annual increase in the water deficit by 367 mm!



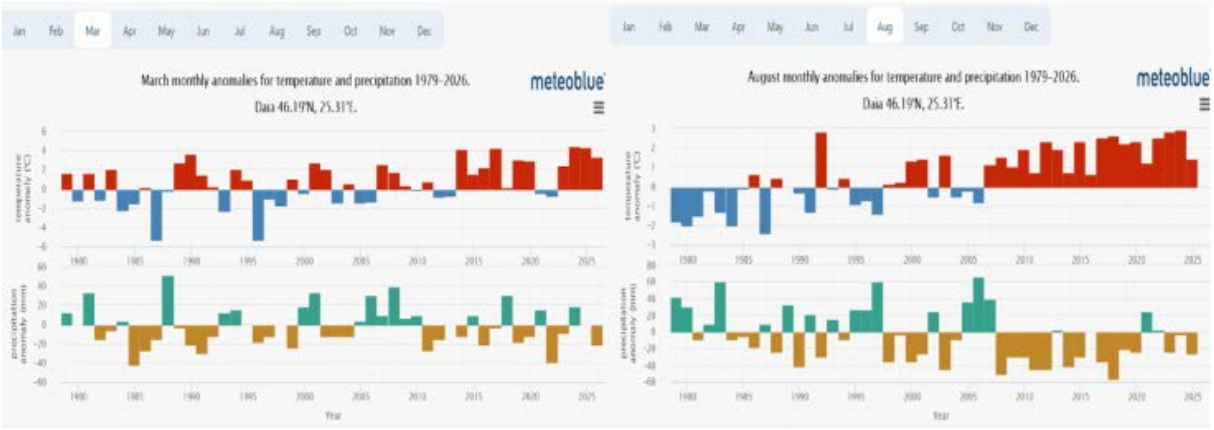
The temperature increase trend since 1979 on meteoblue is calculated using ERA5 reanalysis data, which combines historical measurements with physical models. Temperature anomalies are determined by the deviation from the 30-year climate normal (1980–2010), and linear regression is then applied to the annual averages to show the warming trend. More information about the methodology can be found on meteoblue.com.



source: meteoblue.com



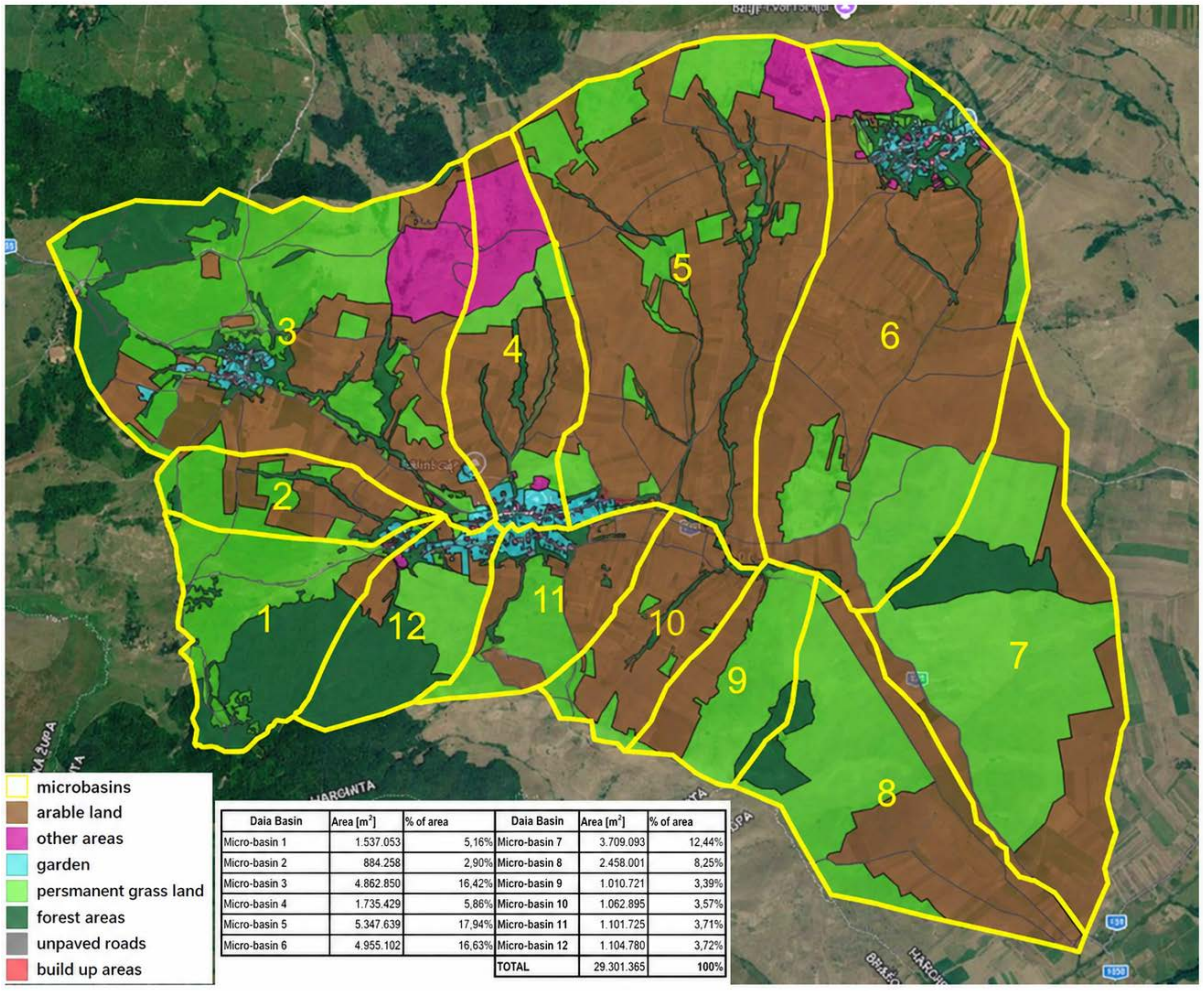
It is also very important to understand temperature anomalies throughout the year in order to recognise their relations with the agricultural activity, which is dominant here. Cultivated crops are sensitive to the temperature regime of the landscape, and in order for them to withstand dramatic weather changes (such as frequent spring frosts), it is necessary to strengthen the landscape's resilience against drying. Longer periods without frost in winter affect the early onset of vegetation, which is then threatened by subsequent spring frosts. See the development of temperature anomalies, especially in winter and with the onset of spring, in the lower part of the river basin in the following diagram.



To better understand the current situation and implement solutions, we divided the DAIA River basin into 12 natural drainage areas and recommended solutions and quantified the benefits for each.

In DAIA village we have determined the natural drainage area, where we mapped the landscape structure and the extent of its degradation. The results are shown in the following figure, along with the location of microbasins. The basin is dominated by intensively cultivated agricultural land (47% arable land), which, together with permanent grassland (33%), accounts for up 80% of the

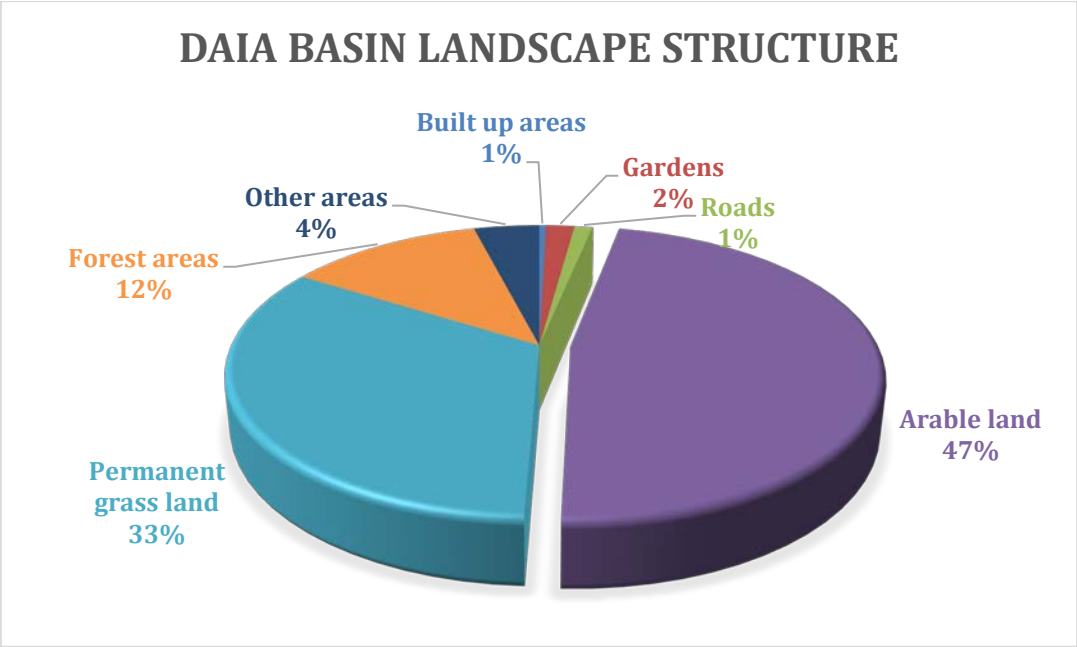
basin's total area. Forest ecosystems make just 12% of the landscape structure of the river basin, which is less than half the percentage of forests in the whole of Romania (29%).



Daia Basin	Area [m²]	% of area	Daia Basin	Area [m²]	% of area
Micro-basin 1	1.537.053	5,16%	Micro-basin 7	3.709.093	12,44%
Micro-basin 2	884.258	2,90%	Micro-basin 8	2.458.001	8,25%
Micro-basin 3	4.862.850	16,42%	Micro-basin 9	1.010.721	3,39%
Micro-basin 4	1.735.429	5,86%	Micro-basin 10	1.062.895	3,57%
Micro-basin 5	5.347.639	17,94%	Micro-basin 11	1.101.725	3,71%
Micro-basin 6	4.955.102	16,63%	Micro-basin 12	1.104.780	3,72%
			TOTAL	29.301.365	100%

Proposal of volumes of ecosystem-based water retention measures for individual micro-basins in the DAIA basin. The necessary plan achieves the construction of 513 thousand m³ of water retention measures

DAIA Basin	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Other areas	Total
Area [ha]	12,16	52,11	32,41	1 412,95	992,124	359,16	119,52	2 980,43
% of area	0,40%	1,70%	1,10%	47,40%	33,30%	12,10%	4,00%	100%



These negative phenomena are also caused by the drying and overheating of the landscape, with the subsequent frequent occurrence of late-night frosts in the area, which causes significant damage to fruit growing in the region. Strategically, these risks can be prevented if more water remains in the landscape structures to slow down the processes of cooling and heating of the landscape.

Framework analyses indicate that it is necessary to strengthen water retention based on the ecosystem principles in any form of farming and land use. In agricultural land, it is essential to implement Nature-based Solutions (NbS) that will act as air conditioning units in the landscape. This fact is also confirmed by the thermal images shown (page 12), which show that on 1 May, the temperature of the dry earth surface already exceeds 40 °C.

In agricultural landscapes, it is necessary to support soil water reserves across the board. The priority is to enhance the replenishment of water resources in landscape structures, with permanent availability of sufficient water to sustain the growth of vegetation of any kind. We need to air-condition/cool the landscape environment by evaporating water from vegetation.

Each cubic meter (1,000 litres) of rainwater that remains in the landscape contributes approximately 300 litres to the replenishment of groundwater reserves. The remaining 700 litres of water evaporates, and solar energy is consumed for its evaporation, which removes approximately 500 kWh of heat from the environment. This improves conditions for vegetation growth and contributes to increasing the landscape's resilience to climate change. Water evaporated from the landscape returns to the small water cycle and can form dew, which is much needed and useful free water that contributes to vegetation growth. Areas where more rainwater is captured can increase horizontal precipitation (dew) by more than 50 litres per square meter of soil annualy.

As mentioned above, rainwater from degraded and man-made parts of the landscape drains away quickly, which also contributes to the drying of the landscape and its subsequent overheating.

In open agricultural landscapes, there has been a significant decline in annual precipitation balances because the landscape is drier, heats up rapidly, and creates higher pressure over dry areas. Under such conditions, clouds and subsequent rainfall form less frequently over these parts of the landscape. This is confirmed by trend analyses of annual precipitation totals. In the open countryside, the decline has reached approximately 8% over the last 50 years. In even more exposed agricultural areas with intensive farming activity, the decline in annual precipitation exceeds 12%.

The following findings emerge from the presented integrated framework analysis in the DAIA basin:

b) Less frequent rainfall alternating with intense downpours and rapid runoff from intensively used land.

c) Landscape drying, declining groundwater levels, and loss of soil fertility.

d) Overheating of the land, increased sensible heat flux into the atmosphere, and rising ambient temperatures due to insufficient moisture.

e) The DAIA small river has effectively become a canal that collects rainwater and drains it into the Danube river systems, thereby losing its function as a stable water ecosystem.

If no measures are taken, the DAIA basin faces the following future threats:

1. More frequent dry and hot summers, alternating with extremely intense rainfall.
2. Increased flood damage, demographic decline.
3. Threat to the remaining biodiversity.
4. Higher costs for agricultural production and deterioration of the forest management.

Climate change in the DAIA basin manifests through negative effects such as reduced water availability, greater temperature extremes, alternating torrential floods and long periods of drought, and loss of soil fertility.

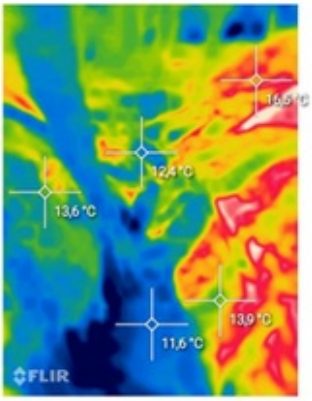
The most effective technology for monitoring temperature changes in the landscape is the use of thermal imaging cameras. Thermal imaging allows us to effectively identify the need for and positive impact of NbS (Nature-based Solutions) on the temperature regime of the landscape. Thermal imaging cameras are commonly used in construction. For example, when mapping heat loss from buildings. This technology can also be used effectively to map the temperature regime of the earth's surface/landscape/ecosystems and to quickly identify not only the current state of landscape drying, but it can also be used to design specific measures. Thermal imaging can also be used to understand the impact of changes in the temperature regime of the landscape, for example, through the implementation of NbS, helping us to understand the air conditioning effect.

In order to be able to use thermal imaging in the assessment of the climatic characteristics of ecosystems and their damage, we present three examples of conventional land use in its current

state, and also three examples of the temperature ecosystem temperature regime after the implementation of Nature-based Solutions. These technologies can be effectively used to assess the real impact of implemented NbS on the temperature regime of the landscape and also to quantify the climatic characteristics.

We selected three characteristic ecosystems: agricultural land sown with soybean, a forest ecosystem with trees, and an urbanized, drained landscape with grass surfaces.

In agricultural landscapes, the ground surface beneath the crops is dry, so the temperature often exceeds 40 °C. The temperature of the leaves is 10 degrees lower. This temperature difference indicates that the ecosystem does not have enough water for evaporation and that the plants suffer from a lack of moisture, which limits their growth. We also chose this thermal image to highlight the sensitivity of the recordings and the calibration of the temperature regime. If the temperature difference between the ground surface and the plants were smaller, crops would have better conditions for achieving higher yields.



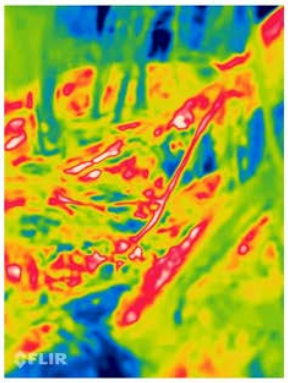
MEASUREMENTS

Point 1	Average 16.5	°C
Point 2	Average 13.9	°C
Point 3	Average 13.6	°C
Point 4	Average 11.6	°C
Point 5	Average 12.4	°C



INFORMATION

File name flir_20260414T1 03259.jpg	
Date	14. 4. 2026 10:32
Geographical width	46.18927
Geographical length	25.28823
Palette	Rainbow
Emissivity	Matte
Max.	21.6 °C
Min.	8.4°C



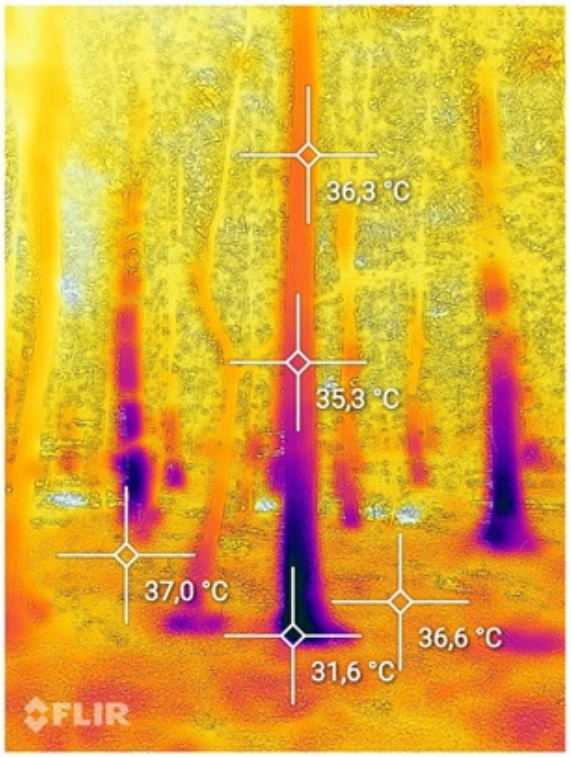


MEASUREMENTS

No measurements allowed

INFORMATION

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Min.	2.7°C

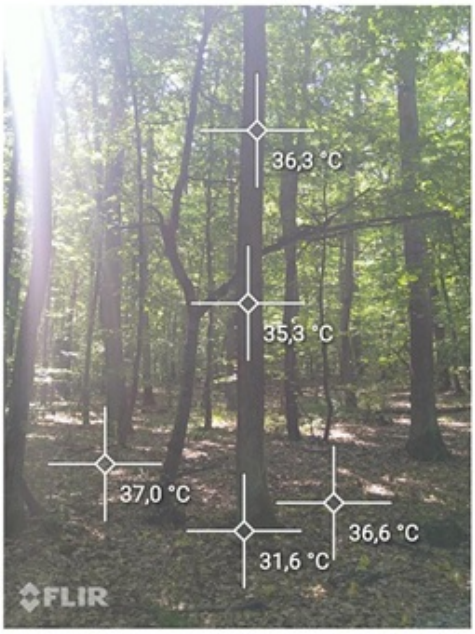


MEASUREMENTS

Point 1	Average 35.3°C
Point 2	Average 36.3°C
Point 3	Average 31.6°C
Point 4	Average 36.6°C
Point 5	Average 37.0°C

INFORMATION

File name flir_20260628T125946.jpg	
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Geographical length	21.16253
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Emissivity	Matte
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Min.	31.3°C

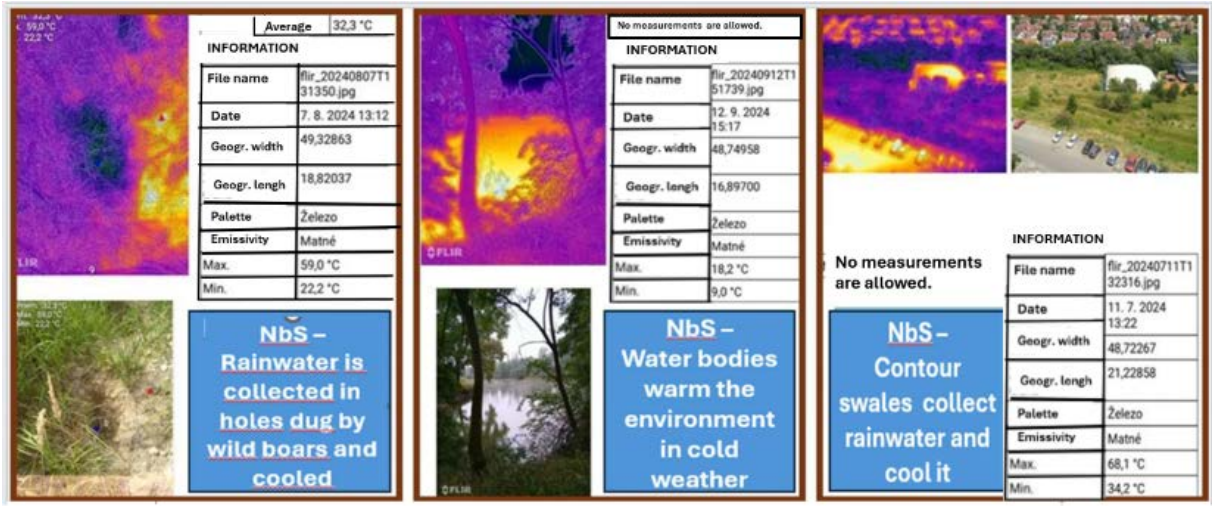


The temperature regime of forest trees clearly indicates drought, as the cooler parts of the ecosystem have tree trunks near the ground level. The upper parts of the tree trunks have a relatively high temperature, which confirms that the trees are suffering from a lack of water for their growth.

Trees suffer from water deficit and therefore overheat quickly because they transpire less. This weakens photosynthesis in the forest ecosystem and has a negative impact on wood increments. It is also possible to observe a relatively high temperature difference between the lower parts of tree trunks and the tree crowns, reaching up to 5 °C. This confirms a significant moisture deficit in the soil with a negative impact on wood increments and the economic results of forest managers.

The following three examples highlight the possibility of using thermal imaging to assess the impact of Nature-based Solutions (NbS). We selected three examples. A micro-pit in the terrain where rainwater is collected and seeps into the soil, a water surface in the forest, and implemented contour infiltration strips where rainwater is collected, and what impact these elements have on the thermoregulation of the landscape in both hot and cold weather.

The first image clearly shows how the rainwater collected in a micro-pit, dug by wild boars while foraging, causes cooling. The water retained and absorbed in the pit, which is about 0,3 m deep, creates a cooling effect. In the height of summer, the surface temperature of bare soil can reach up to 59 °C. This example shows the importance of retaining every litre of rainwater to reduce surface overheating.



The second example is a thermal image of a small body of water taken on 12 September during cooler weather. In colder conditions, bodies of water warm the earth's surface. This means that while the temperature in the surrounding vegetation dropped significantly to 9 °C, the body of water, which was heated during the summer, cools down more slowly in the autumn and helps balance temperature differences. This is a very important insight for landscape use proposals so that the landscape remains resilient in both hot and cold weather.

The third example of a thermal image from 11 July 2024 is from NbS implemented in a completely degraded site without vegetation. Thermal imaging shows that the restoration of degraded land through rainwater retention has regenerative effects and promotes not only the restoration of the degraded ecosystem by retaining rainwater through NbS, but also the air conditioning of the ecosystem through water evaporation from vegetation. We estimate that the temperature of the earth's surface without vegetation at the peak of summer can exceed 60 °C.

Because all rainwater at the site is collected, i.e., it does not run off the surface but evaporates after being retained on site, the temperature according to thermal imaging records reaches less than 35 °C. The NbS implemented on a 3-hectare site reduces the temperature of the monitored surface by more than 25 degrees. The timeline from the site confirms the rapid regeneration of the ecosystem when sufficient rainwater is retained in the landscape.



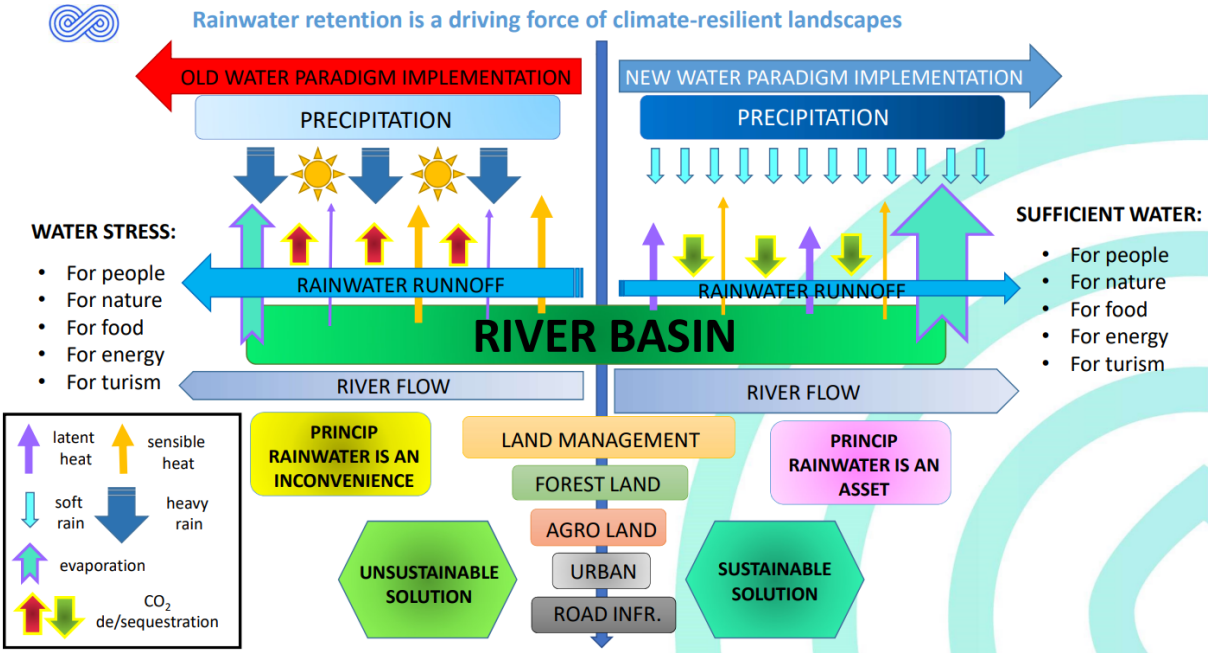
Transformation of degraded land through ecosystem rainwater retention

Based on our knowledge of the state of landscape degradation, trends in temperature regime changes, and the need to increase landscape resilience, we conclude that the greatest potential lies in utilizing rainwater that rapidly runs off during periods of heavy rainfall without benefit, causing flood risks. Effective methods of using Nature-based Solutions (NbS) that can retain rainwater in the landscape during periods of heavy rainfall, then allow this rainwater to infiltrate into the soil, replenishing soil and groundwater so that there is enough water for vegetation during periods of low rainfall. We developed this model as part of the SIM4NEXUS scientific research project[1].

Our primary objective was to quantify the volume of rainwater runoff during extreme rainfall and to define its frequency throughout the year so that we could determine the extent of NbS we need to implement in order not only to reduce flood risks, but also to determine how ecosystem retention of rainwater in the landscape contributes to climate resilience.

The holistic restoration of degraded landscapes in the river basin through innovative actions, with the possibility to generalize and replicate the knowledge gained, opens up opportunities for effective practical use in integrated plans for landscape resilience to climate change. The fundamental principle is to use Nature-based Solutions that can retain rainwater in an ecosystem, regenerate natural resources, and thereby strengthen the economic benefits for land managers, increase the resilience of the landscape to weather risks, and restore biodiversity.

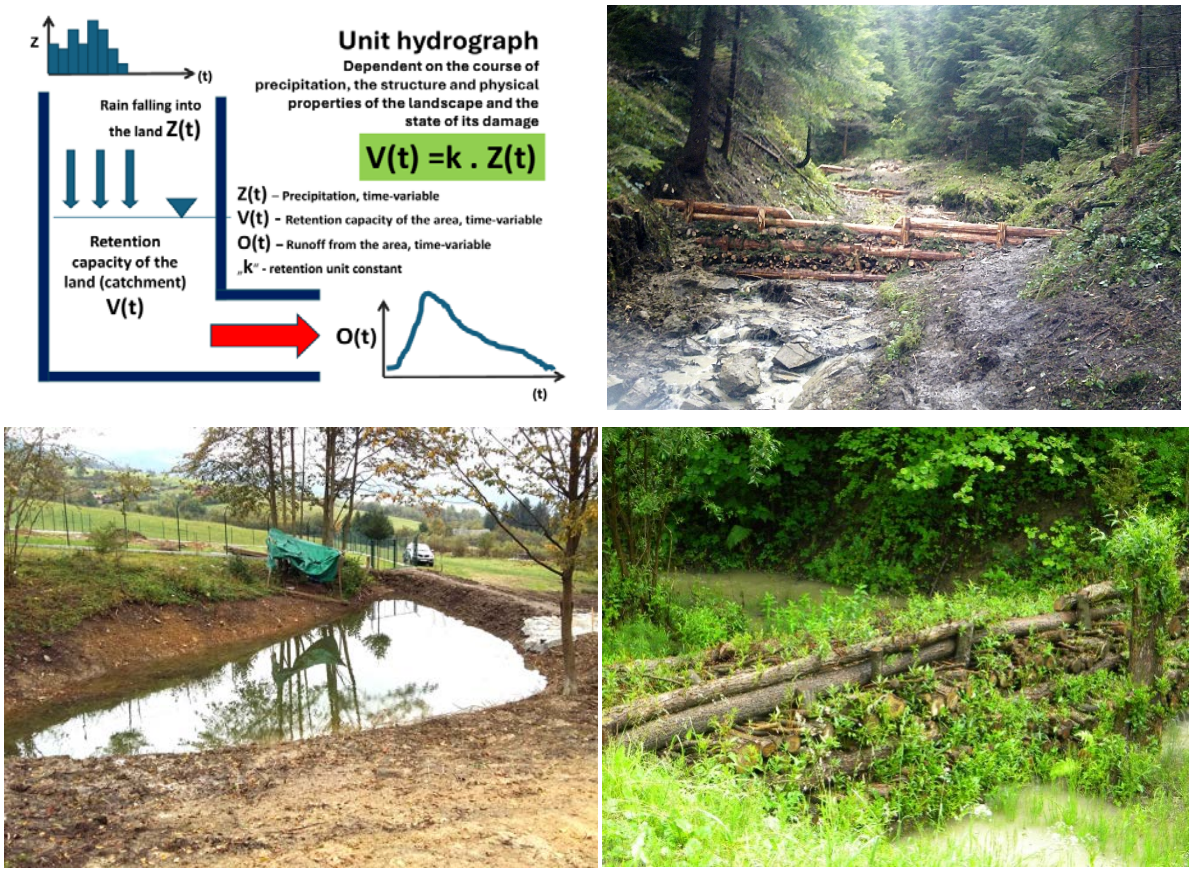
[1] Kravčík, M., Mulkerin, Z., Kravčíková, D. (2025). Climate Resiliency Through Restoration Using New Water Paradigm Methods. In: Leal Filho, W., Nagy, G.J., Ayal, D.Y. (eds) Handbook of Nature-Based Solutions to Mitigation and Adaptation to Climate Change. Springer, Cham. https://doi.org/10.1007/978-3-030-98067-2_94-1



Supporting rainwater retention in the landscape comprehensively addresses the principle (NEXUS) that rain is wealth, and when multiplied through sufficient water retention, it benefits all stakeholders

A Nature-based Solution (NbS) that can retain rainwater and reduce the relative fluctuation of flows has a positive effect on the hydrological regime of any watercourse and is defined in the following unit hydrograph (see diagram). Any Nature-based Solution that can retain rainwater and promote its infiltration into the soil or underground, and also enhance evaporation through ecosystems, brings the following multiple benefits:

1. Replenishment of soil moisture and improvement of biomass increment in both forest and agricultural landscapes
2. Replenishment of groundwater reserves to create underground water sources, supporting increased spring yield
3. Improvement of conditions for vegetation growth
4. Increased evaporation and heat removal from the environment by water evaporated into the atmosphere
5. Promotion of dew formation (daily condensation of water vapour if there is sufficient water available in ecosystems)
6. Promotion of cloud formation and potentially more frequent gentle rainfall if the plan is implemented on a larger scale



Principle of a unit diagram of rainwater runoff slowing through water retention measures in a degraded landscape

3. Runoff analysis

A possible and in all respects more suitable solution for minimizing all risks from climate change, regardless of the cause, is to improve rainwater management so that rainwater can remain in the structures of the agro-forestry and urban landscape and create reserves of water resources and minimize the risks of floods. In this way, it is possible to increase protection against floods, droughts and manifestations of those climate changes that are related to water shortages in the landscape, overheating of the landscape from drought or excess water.

From this point of view, it is very important to know the state of the waters in the area and especially how much water flows away from the area without benefit and whether it can be used for protection and sustainable development in the ongoing climate change. Several factors influence the runoff of rainwater. The frequency and intensity of precipitation, the method of land use and management, the structure of the landscape cover, slope, soil quality and the set management of rainwater in the area.

Based on the best water management practice, it is ideal that only that rainwater that the territory cannot absorb flows away from the territory. It is ideal that as much rainwater as possible remains in the territory, so that rainwater seeps into the soil, evaporates and participates in the permanent water cycle in nature and contributes to the thermoregulation of the landscape.

In order to set an appropriate regime and management of rainwater, we need to know not only the state of the landscape, but we also need to quantify how much rainwater will flow away and how much of it we can use in the territory, so that we can prevent the territory from drought, strengthen the natural production potential by increasing photosynthesis and carbon sequestration, strengthen biodiversity and thermoregulation of the landscape, in the interests of water, food and climate security of the region.

So the subject of this analysis is to quantify how much rainwater from the territory of the region flows away without benefit, so that we can subsequently make strategic decisions when improving the water balance for sustainable development and for the needs of ensuring the vital functions of the country. To obtain high-quality and real results, it is good to use methods that give us a relatively realistic picture of the volume of rainwater flowing away from a small basin.

3.1 CN Curves Method

The most suitable method for this type of calculations in small basins is the CN curve method. The basic idea was to work out how much rainwater flows from the selected basin and to consider it as a potential source for such land use that will open up potential opportunities to regenerate natural resources to ensure sufficient resources (water, soil, food) and climate for the local community with significant benefits for the entire region.

Therefore, when planning flood prevention or other rainwater management measures, we need to work out the volume of surface runoff from extreme precipitation. Surface runoff is a function of several factors: precipitation yield, catchment area and catchment properties (soil properties and landscape structure), which are usually expressed by empirical or semi-empirical coefficients of runoff from rain.

There are several methods of calculation. The most reliable methods for calculating runoff from small basins include the CN (Curve Number Method) runoff curve method, which was developed by the American hydrologist and hydraulic engineer of Chinese origin, Ven Te Chow[2], at the American Soil Conservation Service (SCS). It was adapted and published by Janeček[3] for our conditions.

The CN curve method is relatively simple and, within its validity for small basins/areas, is a good compromise between laboriousness and accuracy of calculation.

[2] CHOW, V.T.: Handbook of Applied Hydrology , New York: Mc. Graw-Hill Book Company 1964
[3] JANEČEK, M. a kol.: Ochrana zemědělské půdy před erozí, Praha, 2001

To obtain the value of the CN curve, we need to know:

1. hydrological characteristics of the soil properties in the basin,

2. hydrological characteristics of the soil cover,

3. hydrological characteristics of individual methods of soil cultivation,

4. hydrological characteristics of soil moisture status.

Hydrological properties of soils

Hydrological properties of soils in a catchment are a basic characteristic that needs to be analyzed for drainage areas. For the purposes of using the CN-curve method, we divide soils into 4 categories according to their infiltration properties.

Soil category	Infiltration and drainage properties of soils	Characteristic soil types
A	*Soils with high infiltration capacity even when fully saturated with water*	*Deep sands and gravels*
B	*Soils with medium infiltration capacity even when fully saturated with water and with good drainage*	*Medium to deep sandy and loamy sandy soils*
C	*Soils with low infiltration capacity even when fully saturated and with poor drainage*	*Clay loam to clayey shallow soils*
D	*Soils with very low infiltration capacity and no drainage*	*Clays, or soils with otherwise limited drainage and infiltration capacity*

The village of DAIA is located mainly on soils of **category C** - Soils with low infiltration capacity at full saturation and with low drainage Clayey loam to clayey shallow soils

Total precipitation

Total precipitation total is the basic input for the CN curve method. It is assumed to be evenly distributed over the entire area of the investigated area. The amount of precipitation is given according to the precipitation activity in the investigated area. In the case of the municipality of DAIA, this is a one-time extreme **rainfall of 60 mm.**

For the purpose of calculating flood runoff, a CN value is determined, ranging from 0 to 100, where a CN value of 100 means that all precipitation that falls on the catchment area or part of it will flow away as surface runoff, and a CN value of 0 means that all precipitation will soaks in. For each type of surface in each micro-catchment, we need to determine the CN curve number, which depends on the type of soil (from a hydrological point of view) and its vegetation cover.

To determine the volume of rainwater runoff for each type of surface, it was necessary to know the area in m^2 of various types of land use in the cadastral territory of the municipality. It was also

necessary to know the annual maximum of 1-day precipitation totals with a probability of recurrence once a year in mm, in the studied location this is a precipitation of 60 mm. Another parameter that entered the calculation of surface rainwater runoff is the CN curve. It was assigned to each type of land according to the soil category separately.

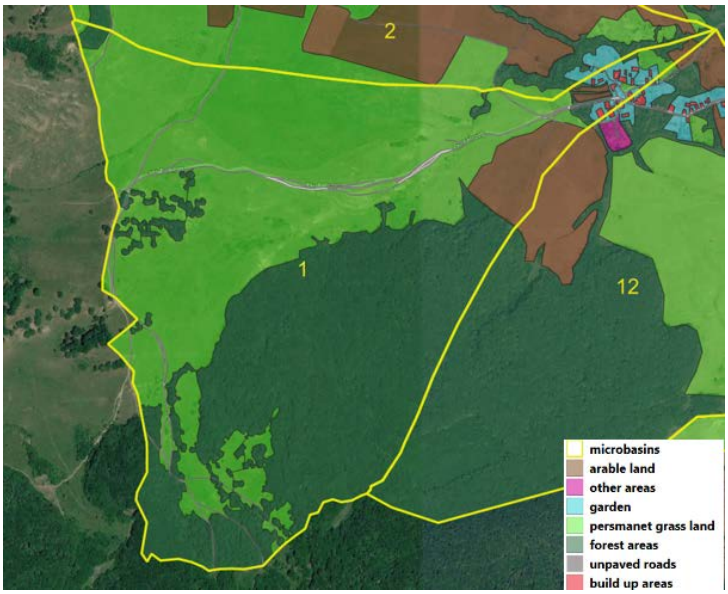
The SCS CN method is a very popular method due to its simplicity and low input requirements with really good results. When setting appropriate input parameters, the SCS CN method showed very good results. The limiting factor for it was primarily the factor of intermittent precipitation and long precipitation episodes. Under these conditions, the method showed significant differences compared to the actually observed flow. However, according to objective criteria, the results from these problematic events were also more satisfactory and acceptable compared to the Green-Ampt method. The assumption that the SCS CN method underestimates the runoff volume values overall was also confirmed, but this underestimation was not significant.[4]

3.2 Representation of individual types of landscape structure

Based on the criteria defined above, we calculated the volume of runoff for individual areas of drainage areas and their landscape structure at an extreme torrential rainfall of 60 mm. In each drainage area, size of area, type of area, and the calculated volume of flood water runoff at an extreme torrential rainfall of 60 mm are defined. Each drainage area has one table and at its end the total flood water runoff that participates in the formation of the flood wave is given.

Micro-basin 1

Micro-catchment 1 has a funnel shape with an area of 153,7 ha and is dominated by forest ecosystems and pastures, which are highly eroded.



[4] Bc. DUBEN J.:Modelování odtoku pomocí metod SCS CN a Green Ampt v povodí ostrovské Bystřice v Krušných horách, Diplomová práca, Praha 2014




The state of damage means that when 60 mm of precipitation occurs, surface runoff reaches almost 19 thousand cubic meters of water. This means that in the micro-catchment it will be necessary to implement Nature based Solutions (NbS) on the basis of the ecosystem principle, which can retain all rainwater (19 thousand m^3) flowing during a 60 mm precipitation with a probability of occurring once a year.





Micro-basin 1	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Total
Area [m^2]	3 888	13 340	21 933	57 557	790 341	650 034	1 537 093
% of area	0,30%	0,90%	1,40%	3,70%	51,40%	42,30%	100%
Runoff volume [m^3]	162,96	207,6	666,69	1 236,02	8 514,95	8 168,19	18 956,40
% of runoff	0,90%	1,10%	3,50%	6,50%	44,90%	43,10%	100%

Micro-basin 2

In micro-basin 2 with an area of 86,4 hectares, pastures dominate in the upper part of the micro-basin and arable land in the lower part.





The analysis showed that during an extreme rainfall event, which is likely to occur once a year, 14 thousand cubic meters of rainwater flows from the area. It is necessary to build NbS that can cyclically retain rainwater with such a water retention volume.

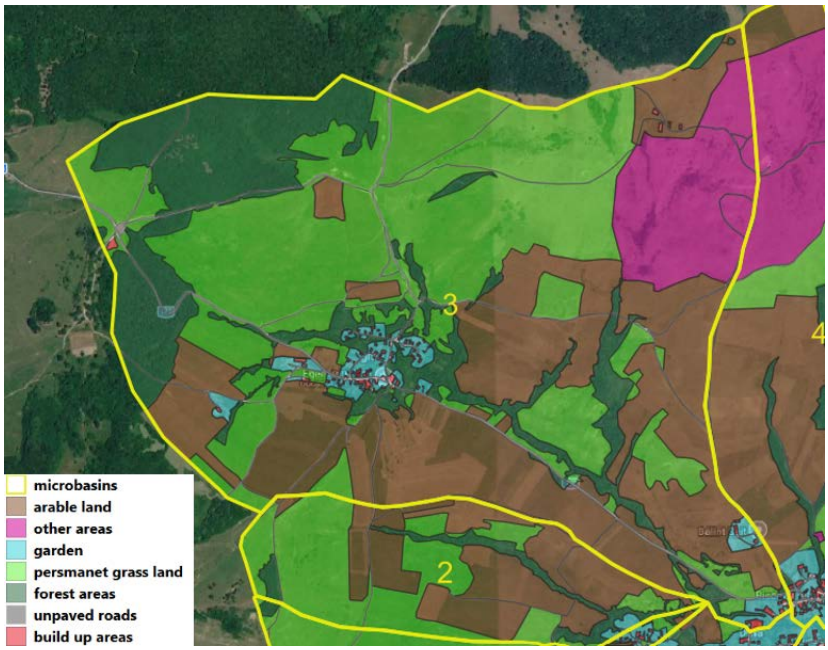
Micro-basin 2	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Total
Area [m^2]	132	8 157	7 291	389 164	387 268	72 226	864 238
% of area	0,00%	0,90%	0,80%	45,00%	44,80%	8,40%	100%
Runoff volume [m^3]	5,53	126,94	221,62	8 357,22	4 172,33	907,58	13 791,22
% of runoff	0,00%	0,90%	1,60%	60,60%	30,30%	6,60%	100%

Micro-basin 3

Micro-basin No. 3 is the third largest micro-basin in the entire DAIA basin (489,29 ha). It is dominated by arable land and pastures. The village of Ighiu is located in the valley of the upper part of the micro-basin. The volume of runoff here reaches 81 thousand cubic meters of rainwater. This implies the need to create 81 thousand m^3 of water retention measures in the landscape structures, depending on the type of landscape structure. Local residents have already started to implement water retention measures on the river (see pictures).





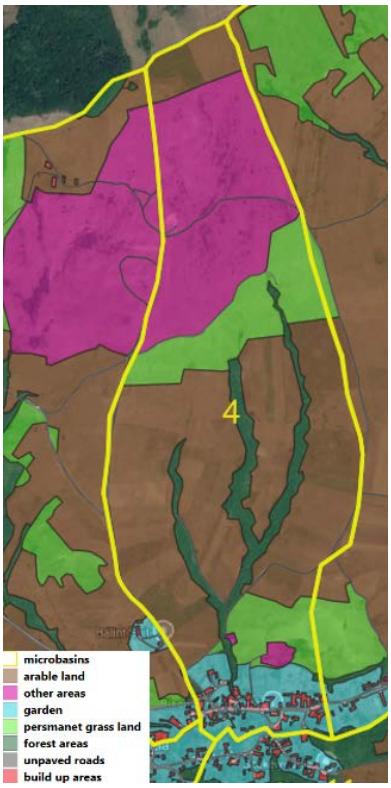


Micro-basin 3	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Other areas	Total
Area [m^2]	24 690	105 438	91 502	1 551 221	1 839 954	882 556	397 629	4 892 990
% of area	0,50%	2,20%	1,90%	31,70%	37,60%	18,00%	8,10%	100%
Runoff volume [m^3]	1034,82	1 640,82	2781,34	33 312,15	19 823,23	11 090,01	11431,81	81 114,16
% of runoff	1,30%	2,00%	3,40%	41,10%	24,40%	13,70%	14,10%	100%

Micro-basin 4

Micro-catchment No. 4 with an area of 175 hectares collects rainwater from an area almost half of which is occupied by arable land. Therefore, there is a relatively high volume of runoff (almost 39 thousand m^3). This is reflected in the need to implement water retention measures with a volume that can absorb the currently flowing rainwater that causes severe erosion.





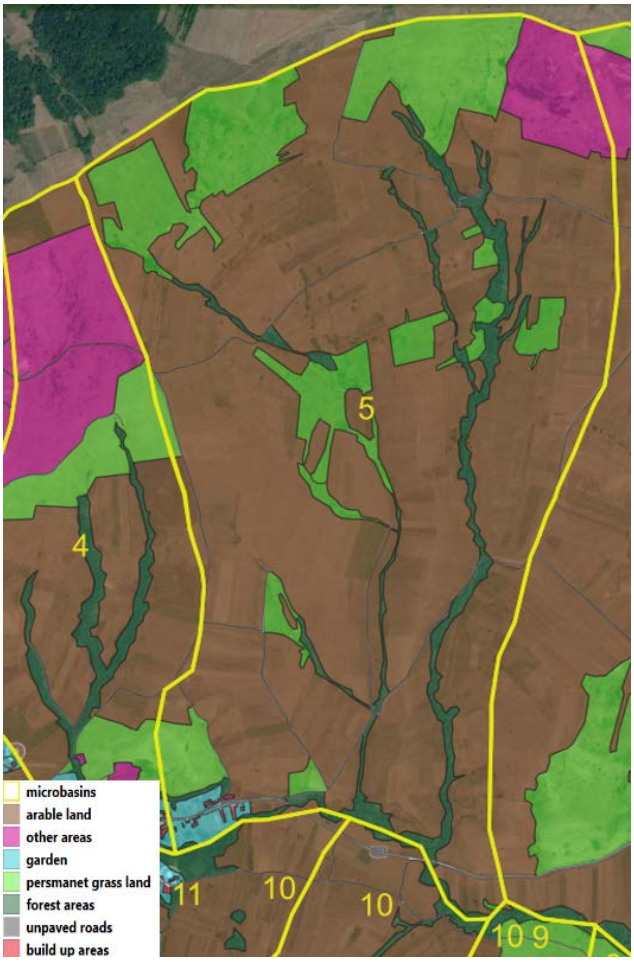
Micro-basin 4	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Other areas	Total
Area **[m²]**	21 388	97 506	23 913	843 791	240 110	124 683	402 048	1 753 439
% of area	1,20%	5,60%	1,40%	48,10%	13,70%	7,10%	22,90%	100%
Runoff volume [m³]	896,42	1 517,38	726,87	18 120,24	2 586,89	1 566,74	11558,85	36 973,39
% of runoff	2,40%	4,10%	2,00%	49,00%	7,00%	4,20%	31,30%	100%

Micro-basin 5

The micro-basin 5 has the largest area of the Dalia basin. It has an area of almost 535 hectares and contributes to the formation of a flood wave on the DAIA River with a volume of 104 thousand m³. Some water retention measures have already been implemented in this micro-basin.

Micro-basin 5	**Built up areas**	**Gardens**	**Roads**	**Arable land**	**Permanent grass land**	**Forest areas**	**Other areas**	**Total**
Area [m²]	3 910	44 163	36 562	3 934 759	885 416	273 947	168 782	5 347 539
% of area	0,10%	0,80%	0,70%	73,60%	16,60%	5,10%	3,20%	100%
Runoff volume [m³]	163,88	687,26	1111,36	84 498,13	9 539,26	3 442,36	4852,47	104 294,72
% of runoff	0,20%	0,70%	1,10%	81,00%	9,10%	3,30%	4,70%	100%



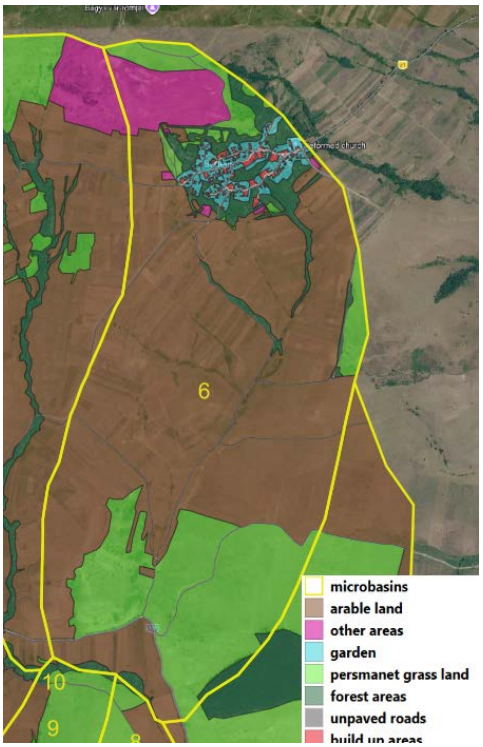

5
4
11
10
10
10 9
microbasins
arable land
other areas
garden
persmanet grass land
forest areas
unpaved roads
build up areas

Micro-basin 6

The second largest micro-basin (6) is located in the upper part of the Badeni municipality, and the extreme runoff of rainwater from this basin reaches 94 thousand m³. This is matched by an adequate volume of water retention measures.

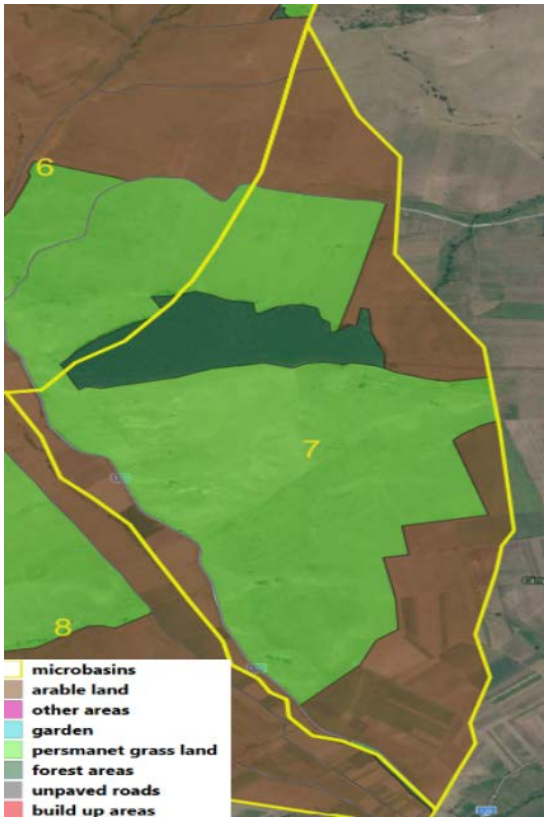


Micro-basin 6	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Other areas	Total
Area [m²]	45 352	116 003	61 623	3 080 044	1 146 845	284 114	221 121	4 955 102
% of area	0,90%	2,30%	1,20%	62,20%	23,10%	5,70%	4,50%	100%
Runoff volume [m³]	1900,81	1 805,23	1873,12	66 143,31	12 355,84	3 570,12	6357,21	94 005,63
% of runoff	2,00%	1,90%	2,00%	70,40%	13,10%	3,80%	6,80%	100%



Micro-basin 7

A classic agricultural runoff area with an area of 371 hectares dominated by arable land and pastures. With an extreme rainfall of 60 mm, up to 55 thousand m^3 of rainwater flows away.



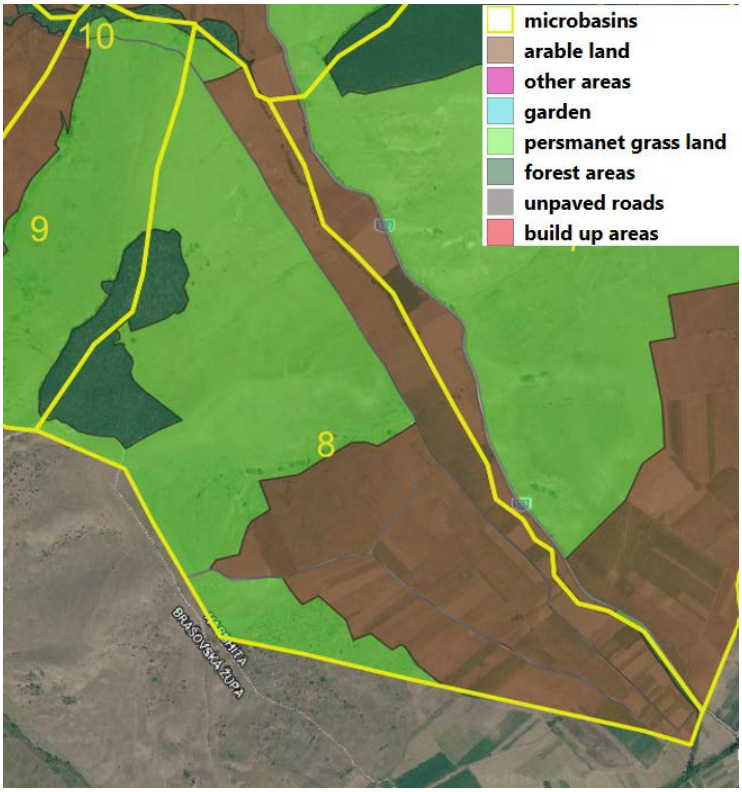


Micro-basin 7	Roads	Arable land	Permanent grass land	Forest areas	Other areas	Total
Area [m^2]	23 615	1 331 210	2 023 796	330 474	0	3 709 095
% of area	0,60%	35,90%	54,60%	8,90%	0,00%	100%
Runoff volume [m^3]	717,81	28 587,46	21 803,90	4 152,66	0	55 261,84
% of runoff	1,30%	51,70%	39,50%	7,50%	0,00%	100%

Micro-basin 8

Micro-catchment 8 with an area of 246 hectares of mostly agricultural land contributes to the runoff of rainwater with a volume of almost 40 thousand m³. By creating water retention measures with cyclic retention of rainwater of an adequate volume, the processes of restoration of ecosystem services will be started.

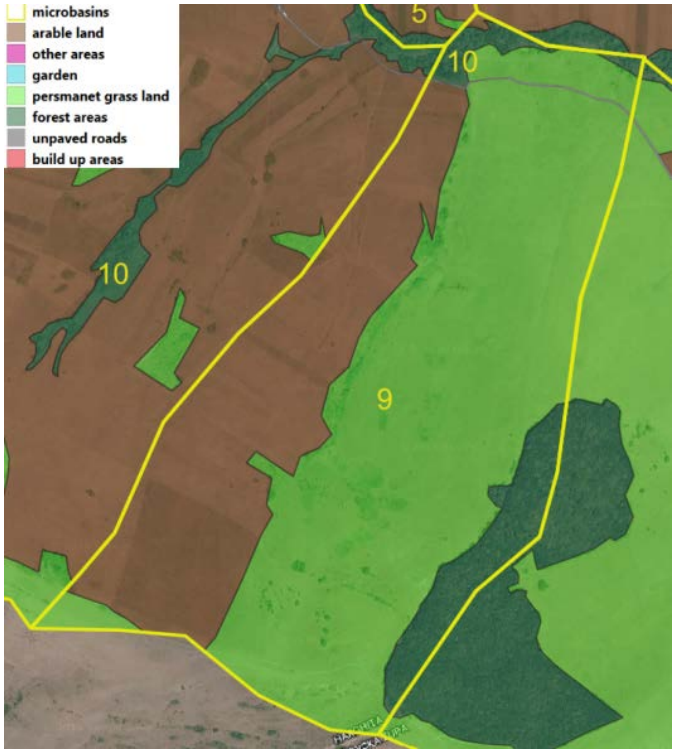
Micro-basin 8	Roads	Arable land	Permanent grass land	Forest areas	Total
Area **[m²]**	22 639	1 131 980	1 138 417	164 971	2 458 007
% of area	0,90%	46,10%	46,30%	6,70%	100%
Runoff volume [m³]	688,15	24 309,04	12 265,04	2 072,99	39 335,21
% of runoff	1,70%	61,80%	31,20%	5,30%	100%



Micro-basin 9

The drainage area with an area of 101 hectares mostly of agricultural land contributes to the runoff of rainwater with a volume of more than 14 thousand m³ of rainwater. The creation of water retention measures with cyclic retention of rainwater of an adequate volume will start the processes of restoration of ecosystem services in the territory and strengthen the climate resilience of the territory.

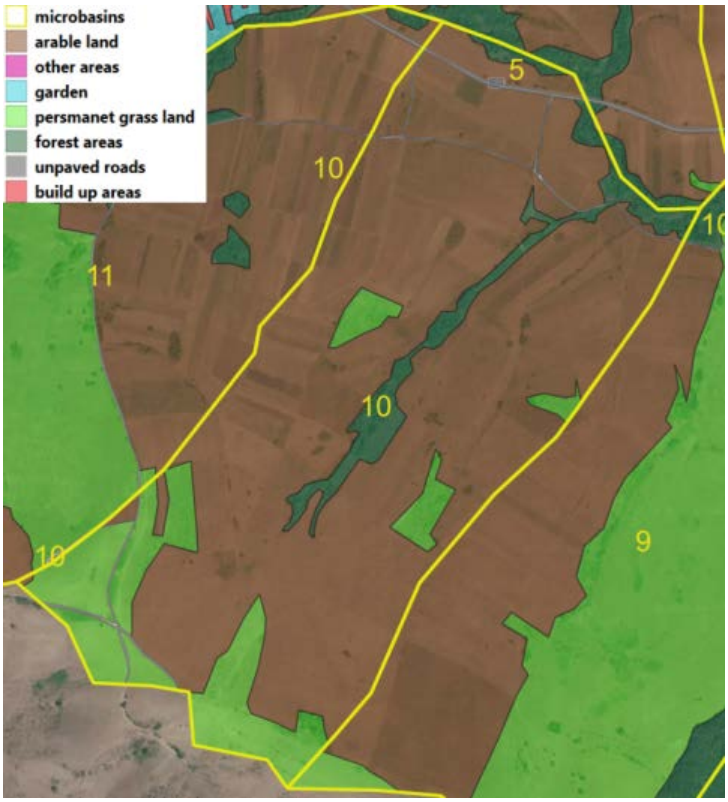
Micro-basin 9	Roads	Arable land	Permanent grass land	Forest areas	Total
Area [m²]	1 496	307 221	623 900	78 104	1 010 721
% of area	0,10%	30,40%	61,70%	7,70%	100%
Runoff volume [m³]	45,47	6 597,51	6 721,75	981,44	14 346,17
% of runoff	0,30%	46,00%	46,90%	6,80%	100%



Micro-basin 10

The drainage area with an area of 106 hectares mostly of agricultural land contributes to the runoff of rainwater with a volume of more than 20 thousand m³ of rainwater. By creating water retention measures with cyclic retention of rainwater of an adequate volume, the processes of restoration of ecosystem services will be started.

Micro-basin 10	Roads	Arable land	Permanent grass land	Forest areas	Total
Area [m²]	9 987	843 010	150 619	59 220	1 062 836
% of area	0,90%	79,30%	14,20%	5,60%	100%
Runoff volume [m³]	303,57	18 103,46	1 622,73	744,15	20 773,91
% of runoff	1,50%	87,10%	7,80%	3,60%	100%



Micro-basin 11

The drainage area with an area of 110,5 hectares of mostly agricultural land contributes to the runoff of rainwater from agricultural areas with a volume of almost 19 thousand m^3 of rainwater. By creating water retention measures with cyclic retention of rainwater of an adequate volume, the processes of restoration of ecosystem services will be started, supporting the local economy.

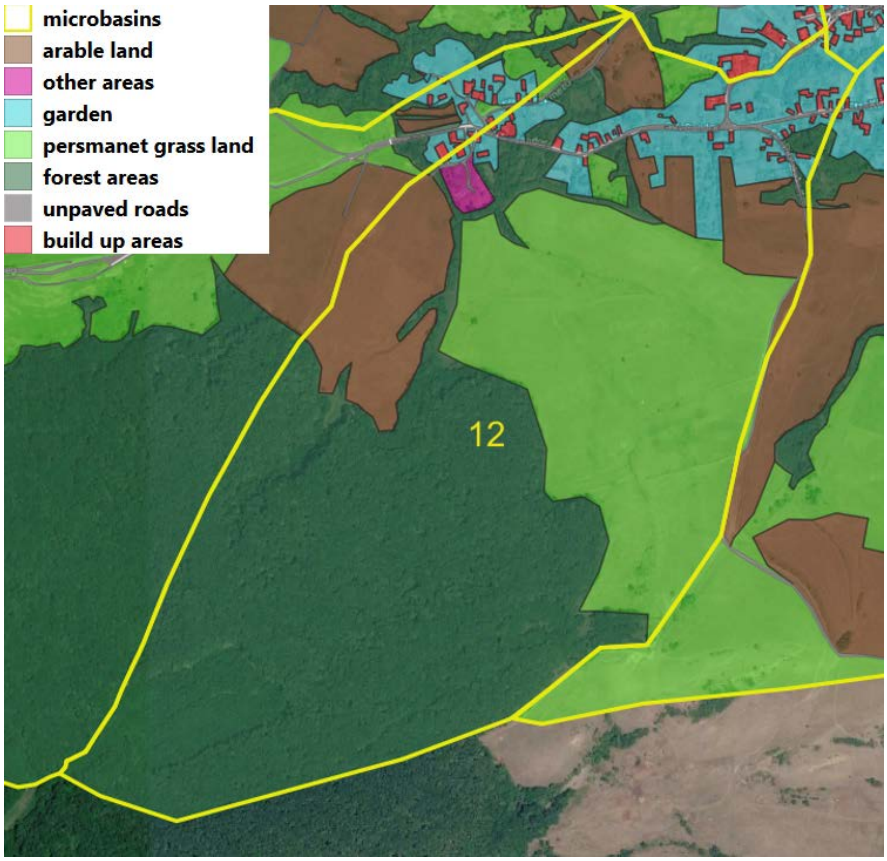
Micro-basin 11	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Total
Area [m^2]	13 959	62 075	12 671	534 227	392 543	89 650	1 105 125
% of area	1,30%	5,60%	1,10%	48,30%	35,50%	8,10%	100%
Runoff volume [m^3]	585,06	966	385,15	11 472,41	4 229,17	1 126,52	18 764,32
% of runoff	3,10%	5,10%	2,10%	61,10%	22,50%	6,00%	100%



Micro-basin 12

A micro-basin 12 with an area of almost 110 hectares contributes to flood risks by draining rainwater from an area with a volume more than 15 thousand m³. By implementing water retention measures with such volumes, it is possible to achieve the restoration of damaged landscapes and start the fertility of forests and agricultural areas.

Micro-basin 12	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Other areas	Total
Area [m²]	8 306	74 416	10 866	125 338	301 985	581 601	5 668	1 108 180
% of area	0,70%	6,70%	1,00%	11,30%	27,30%	52,50%	0,50%	100%
Runoff volume [m³]	348,12	1 158,05	330,29	2 691,61	3 253,51	7 308,27	162,95	15 252,82
% of runoff	2,30%	7,60%	2,20%	17,60%	21,30%	47,90%	1,10%	100%

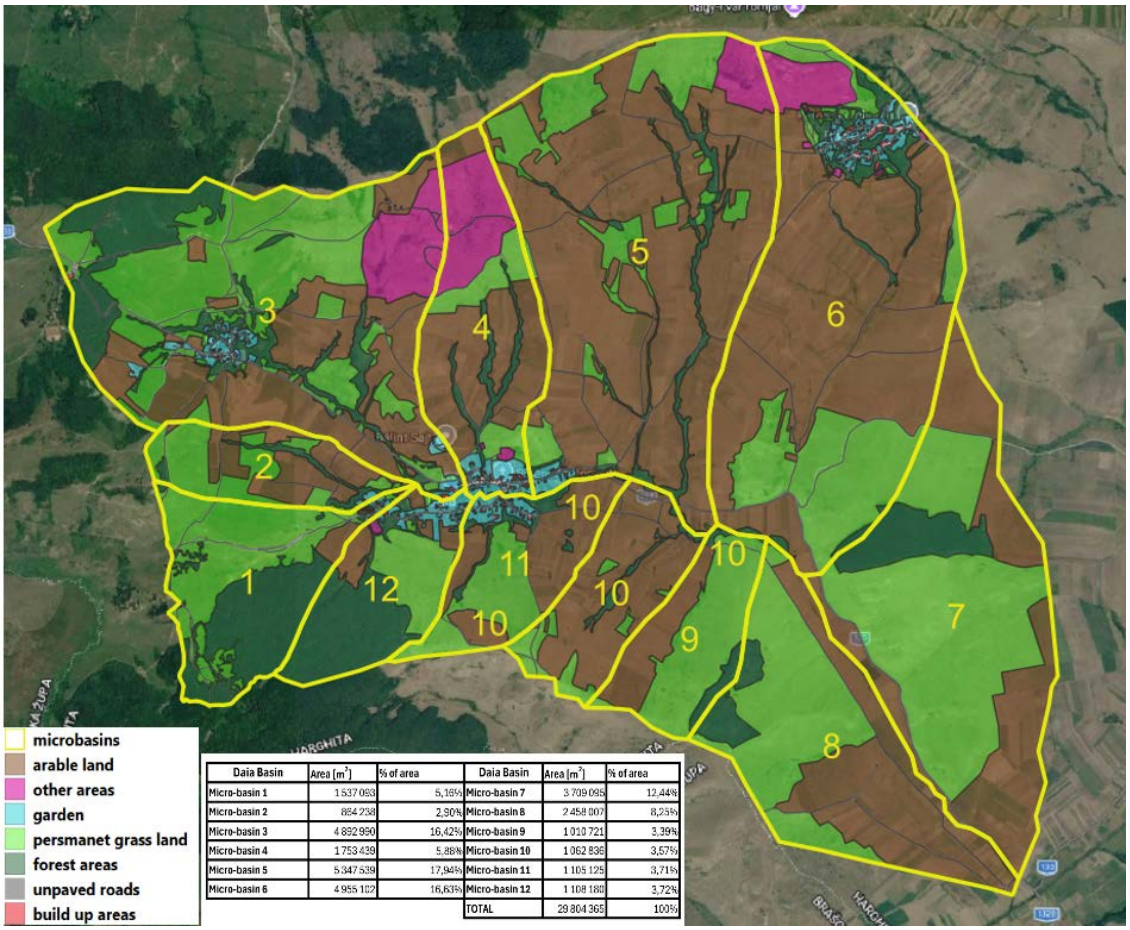




DAIA municipality

The municipalities of DAIA, Ighiu and Badeni are located in the DAIA river basin, which has a total area of 2 890 hectares. The area is dominated by arable land (59,2%) and permanent grassland (20,8%). The entire basin is divided into 12 drainage areas, from which 510 thousand cubic meters of rainwater flow away during intense rains without benefit. This volume is obtained by calculating for an extreme precipitation with a probability of occurring once a year (60 mm).

It is necessary to realize that this water source, which is currently unused and which still causes risks of watersheds, erosion and drought, has a chance to remain in the area by implementing water retention measures and start the renewal processes in the country and promote the development of the local economy.



Daia Basin	Area [m²]	% of area	Daia Basin	Area [m²]	% of area
Micro-basin 1	1 537 093	5,16%	Micro-basin 7	3 709 095	12,44%
Micro-basin 2	864 238	2,90%	Micro-basin 8	2 458 807	8,25%
Micro-basin 3	4 892 990	16,42%	Micro-basin 9	1 010 721	3,39%
Micro-basin 4	1 753 439	5,88%	Micro-basin 10	1 062 836	3,57%
Micro-basin 5	5 347 539	17,94%	Micro-basin 11	1 105 125	3,71%
Micro-basin 6	4 955 102	16,63%	Micro-basin 12	1 108 180	3,72%
			TOTAL	29 804 365	100%





DAIA Basin	Built up areas	Gardens	Roads	Arable land	Permanent grass land	Forest areas	Other areas	Total
Area **[m²]**	121 625	521 098	324 098	14 129 522	9 921 194	3 591 580	1 195 248	29 804 365
% of area	0,40%	1,70%	1,10%	47,40%	33,30%	12,10%	4,00%	100%
Runoff volume [m³]	5 097	8 109	9 851	303 428	106 888	45 131	34 363	512 869
% of runoff	1,00%	1,60%	1,90%	59,20%	20,80%	8,80%	6,70%	100%

4. Proposal of water retention measures and their integration in spatial planning documentation

Considering the character and challenges of the area and local flooding, it is necessary to create water retention measures in forest, agricultural, urbanized landscapes, and transport infrastructure, as summarized in the runoff volume table.

The results of this analysis need to be reflected in land consolidation, forest management plans (FMPs), municipality spatial plan, and transport infrastructure, with the creation of a plan for the implementation of green and blue infrastructure that can cyclically retain all rainwater during precipitation of less than 60 mm. This can be achieved by strengthening ecosystem services in degraded ecosystems as part of flood and drought prevention at the local level, with significant benefits to ecological stabilization of the landscape and climate resilience.

It is entirely within the competence of land consolidation, forestry, and municipal spatial planners to incorporate this knowledge in their spatial planning documentation. The choice of solutions may be inspired by the specific solutions presented here. However, the decisive factor will depend on the public policies at the municipality level. The approval of this document as a binding document for all stakeholders - forest managers, agricultural landowners, and property owners – would be an appropriate form.

Based on the nature and problems of the area and local flooding, it is necessary to create water retention measures in forest, agricultural, urbanized landscapes, and transport infrastructure, as summarized in the runoff volume table.

4.1 Benefits of water retention measures

The plan is structured so that it can be implemented at different levels in individual drainage areas, separately in the forest landscape, on arable land, on pastures, on transport infrastructure and in urban areas of municipalities. Ideally, it should connect all stakeholders who own or manage land or real estate.

The plan can also be initiated by a public figure who perceives the need to support or activate public ecosystem services that are beneficial to the public. Ideally, a public-private partnership should be created with the aim of improving the climate in the entire territory and making it a living laboratory at least for the entire region and in a broader context.

In each micro-basin (a total of 12 micro-basins), a range of nature-friendly solutions is proposed for a given type of landscape structure and its area, the main indicator of which is the increased retention capacity of the given location.

Based on the methodology of the developed landscape restoration plans for the Košice region[5] in Slovakia, which is published on the European Commission's website (Landscape and watershed Recovery Programme for the Košice region and the scientific study "Climate Resiliency Through Restoration Using New Water Paradigm Methods"[6], which was published in the scientific journal Springer, we quantified the benefits of ecosystem-based rainwater retention in individual catchment areas and for the entire DAIA basin.

This involves assessing the impact of implemented water retention measures on the creation of new water resources in the area, how biomass production in forest ecosystems and on agricultural land will increase, how the sensible heat released from the dried-out landscape will be consumed, how this will reduce the temperature in the area, and also CO_2 consumption due to increased photosynthesis production in the agroforestry landscape.

Micro-basin 1	**Arable land**	**Gardens**	**Permanent grass land**	**Forest areas**	**Built up areas**	**Roads**	**Total**
Area [ha]	**5,8**	**1,3**	**79,0**	**65,0**	**0,4**	**2,2**	**1 53,7**
Rainwater retention measures RWM [m³]	**1 236**	**208**	**8 515**	**8 168**	**163**	**667**	**18 956**
Estimated volume of retained rainwater (m³/yr)	2843	291	12 772	10 619	1 467	4 667	**32 658**
Estimated costs in €	14 832	2 491	102 179	98 018	6 518	20 001	**244 040**
Retrieved water resource (l/s)	0,09	0,009	0,405	0,337	0,047	0,148	**1,00**
Increased evaporation from retained rainwater (m³)	1895	194	8515	7079	978	3111	**21 772**
Increased dew formation (m³)	2 878	667	39 517	32 502	194	1 097	**76 855**
Increased water balance in ecosystems (m³)	4 773	861	48 032	39 581	1 172	4 208	**98 627**
Estimated increased biomass production in t	9,55	1,72	96,06	79,16	2,34	8,42	**197**
Reduction in sensible heat (MWh)	1 327	136	5 960	4 955	684	2 178	**15 240**
Reduction in current summer temperature (°C)	-0,58	-0,26	-0,19	-0,19	-4,44	-2,5	**-0,25**
Carbon sequestration (t)	13,36	2,41	134,49	110,83	3,28	11,78	**276,15**
Carbon credit in € at price (€78,46/ton)	1 049	189	10 552	8 695	258	924	**21 667**
Return on investment on carbon credit (years)	**14,1**	**13,2**	**9,7**	**11,3**	**25,3**	**21,6**	**11,3**

3

[5] Lanscape and waterhed Recovery Programme for the Košice region (Landscape and watershed Recovery Programme for the Košice Region of Slovakia | Case studies | Discover the key services, thematic features and tools of Climate-ADAPT Climate-ADAPT)

[6] Kravčík, M., Mulkerin, Z., Kravčíková, D. (2025). Climate Resiliency Through Restoration Using New Water Paradigm Methods. In: Leal Filho, W., Nagy, G.J., Ayal, D.Y. (eds) Handbook of Nature-Based Solutions to Mitigation and Adaptation to Climate Change. Springer, Cham. https://doi.org/10.1007/978-3-030-98067-2_94-1

Micro-basin 2	Arable land	Gardens	Permanent grass land	Forest areas	Built up areas	Roads	Total
Area [ha]	**38,9**	**0,8**	**38,7**	**7,2**	**0,01**	**0,7**	**86,4**
Rainwater retention measures RWM [m³]	**8 357**	**127**	**4 172**	**908**	**6**	**222**	**13 791**
Estimated volume of retained rainwater (m³/yr)	19222	178	6 258	1 180	50	1 551	**28 439**
Estimated costs in €	100 287	1 523	50 068	10 891	221	6 649	**169 639**
Retrieved water resource (l/s)	0,61	0,006	0,198	0,037	0,002	0,049	**0,90**
Increased evaporation from retained rainwater (m³)	12814	118	4172	787	33	1034	**18 959**
Increased dew formation (m³)	19 458	408	19 363	3 611	7	365	**43 212**
Increased water balance in ecosystems (m³)	32 273	526	23 536	4 398	40	1 399	**62 171**
Estimated increased biomass production in t	64,55	1,05	47,07	8,8	0,08	2,8	**124**
Reduction in sensible heat (MWh)	8 970	83	2 921	551	23	724	**13 271**
Reduction in current summer temperature (°C)	-0,58	-0,26	-0,19	-0,19	-4,43	-2,5	**-0,39**
Carbon sequestration (t)	90,36	1,47	65,9	12,31	0,11	3,92	**174,08**
Carbon credit in € at price (€78,46/ton)	7 090	116	5 171	966	9	307	**13 658**
Return on investment on carbon credit (years)	**14,1**	**13,2**	**9,7**	**11,3**	**25,3**	**21,6**	**12,4**

Micro-basin 3	Arable land	Gardens	Permanent grass land	Forest areas	Built up areas	Roads	Other areas	Total
Area [m²]	15,5	10,5	1 84,0	88,3	2,5	9,2	39,8	**489,3**
Rainwater retention measures RWM [m³]	33 312	1641	19 823	11 090	1035	2781	11432	**81 114**
Estimated volume of retained rainwater (m³/yr)	76618	2297	29 735	14 417	9 313	19 469	80023	**231 872**
Estimated costs in €	399 746	19 690	237 879	133 080	41 393	83 440	80 023	**995 250**
Retrieved water resource (l/s)	2,43	0,073	0,943	0,457	0,295	0,617	3	**7,40**
Increased evaporation from retained rainwater (m³)	51079	1531	19823	9611	6209	12980	53348	**154 582**
Increased dew formation (m³)	77 561	5 272	91 998	44 128	1 235	4 575	19 881	**244 650**
Increased water balance in ecosystems (m³)	128 640	6 803	111 821	53 739	7 443	17 555	73 230	**399 231**
Estimated increased biomass production in t	257,28	13,61	223,64	107,48	14,89	35,11	106,7	**759**
Reduction in sensible heat (MWh)	35 755	1 072	13 876	6 728	4 346	9 086	37 344	**108 207**
Reduction in current summer temperature (°C)	-0,58	-0,26	-0,19	-0,19	-4,44	-2,5	-2,37	**-0,56**
Carbon sequestration (t)	360,19	19,05	313,1	150,47	20,84	49,15	149,38	**1062,18**
Carbon credit in € at price (€78,46/ton)	28 261	1 495	24 566	11 806	1 635	3 857	11 720	**83 339**
Return on investment on carbon credit (years)	14,1	13,2	9,7	11,3	25,3	21,6	6,8	**11,9**

Micro-basin 4	Arable land	Gardens	Permanent grass land	Forest areas	Built up areas	Roads	Other areas	Total
Area [ha]	**84,4**	**9,8**	**24,0**	**12,5**	**2,2**	**2,4**	**40,2**	**175,3**
Rainwater retention measures RWM [m³]	**18 120**	**1517**	**2 587**	**1 567**	**896**	**727**	**11559**	**36 973**
Estimated volume of retained rainwater (m³/yr)	41677	2124	3 880	2 037	8 068	5 088	80912	**143 786**
Estimated costs in €	217 443	18 209	31 043	18 801	35 857	21 806	80 912	**424 070**
Retrieved water resource (l/s)	1,322	0,067	0,123	0,065	0,256	0,161	3	**4,60**
Increased evaporation from retained rainwater (m³)	27784	1416	2587	1358	5379	3392	53941	**95 857**
Increased dew formation (m³)	42 190	4 875	12 006	6 234	1 069	1 196	20 102	**87 672**
Increased water balance in ecosystems (m³)	69 974	6 292	14 592	7 592	6 448	4 588	74 044	**183 529**
Estimated increased biomass production in t	139,95	12,58	29,18	15,18	12,9	9,18	107,88	**327**
Reduction in sensible heat (MWh)	19 449	991	1 811	950	3 765	2 374	37 759	**67 100**
Reduction in current summer temperature (°C)	-0,58	-0,26	-0,19	-0,19	-4,44	-2,5	-2,37	**-0,96**
Carbon sequestration (t)	195,93	17,62	40,86	21,26	18,05	12,85	151,04	**457,59**
Carbon credit in € at price (€78,46/ton)	15 372	1 382	3 206	1 668	1 417	1 008	11 850	**35 903**
Return on investment on carbon credit (years)	**14,1**	**13,2**	**9,7**	**11,3**	**25,3**	**21,6**	**6,8**	**11,8**

Micro-basin 5	Arable land	Gardens	Permanent grass land	Forest areas	Built up areas	Roads	Other areas	Total
Area [ha]	**393,8**	**4,4**	**88,5**	**27,4**	**0,4**	**3,7**	**16,9**	**534,8**
Rainwater retention measures RWM [m³]	**84 498**	**687**	**9 539**	**3 442**	**164**	**1111**	**4852**	**104 295**
Estimated volume of retained rainwater (m³/yr)	194346	962	14 309	4 475	1 475	7 780	33967	**257 314**
Estimated costs in €	1 013 978	8 247	114 471	41 308	6 555	33 341	33 967	**1 251 867**
Retrieved water resource (l/s)	6,163	0,031	0,454	0,142	0,047	0,247	1	**8,20**
Increased evaporation from retained rainwater (m³)	129564	641	9539	2983	983	5186	22645	**171 542**
Increased dew formation (m³)	196 738	2 208	44 271	13 697	196	1 828	8 439	**267 377**
Increased water balance in ecosystems (m³)	326 302	2 850	53 810	16 681	1 179	7 014	31 084	**438 919**
Estimated increased biomass production in t	652,6	5,7	107,62	33,36	2,36	14,03	45,29	**861**
Reduction in sensible heat (MWh)	90 695	449	6 677	2 088	688	3 630	15 851	**120 080**
Reduction in current summer temperature (°C)	-0,58	-0,26	-0,19	-0,19	-4,44	-2,5	-2,37	**-0,57**
Carbon sequestration (t)	913,64	7,98	150,67	46,71	3,3	19,64	63,41	**1205,34**
Carbon credit in € at price (€78,46/ton)	71 685	626	11 821	3 665	259	1 541	4 975	**94 571**
Return on investment on carbon credit (years)	**14,1**	**13,2**	**9,7**	**11,3**	**25,3**	**21,6**	**6,8**	**13,2**

Micro-basin 6	Arable land	Gardens	Permanent grass land	Forest areas	Built up areas	Roads	Other areas	Total
Area [ha]	30,8	11,6	114,7	28,4	4,5	6,2	22,1	**495,5**
Rainwater retention measures RWM [m^3]	66 143	1805	12 356	3 570	1901	1873	6357	**94 006**
Estimated volume of retained rainwater (m^3/yr)	152130	2527	18 534	4 641	17 107	13 112	44500	**252 551**
Estimated costs in €	793 720	21 663	148 270	42 841	76 032	56 194	44 500	**1 183 220**
Retrieved water resource (l/s)	4,824	0,08	0,588	0,147	0,542	0,416	1	**8,00**
Increased evaporation from retained rainwater (m^3)	101420	1685	12356	3094	11405	8741	29667	**168 368**
Increased dew formation (m^3)	154 002	5 800	57 342	14 206	2 268	3 081	11 056	**247 755**
Increased water balance in ecosystems (m^3)	255 422	7 485	69 698	17 300	13 672	11 822	40 723	**416 123**
Estimated increased biomass production in t	510,84	14,97	139,4	34,6	27,34	23,64	59,33	**810**
Reduction in sensible heat (MWh)	70 994	1 179	8 649	2 166	7 983	6 119	20 767	**117 857**
Reduction in current summer temperature (°C)	-0,58	-0,26	-0,19	-0,19	-4,44	-2,5	-2,37	**-0,6**
Carbon sequestration (t)	715,18	20,96	195,15	48,44	38,28	33,1	83,07	**1134,19**
Carbon credit in € at price (€78,46/ton)	56 113	1 644	15 312	3 801	3 004	2 597	6 518	**88 988**
Return on investment on carbon credit (years)	**14,1**	**13,2**	**9,7**	**11,3**	**25,3**	**21,6**	**6,8**	**13,3**

Micro-basin 7	Arable land	Permanent grass land	Forest areas	Roads	Total
Area [ha]	**133,1**	**202,4**	**33,0**	**2,4**	**370,9**
Rainwater retention measures RWM [m^3]	**28 587**	**21 804**	**4 153**	**718**	**55 262**
Estimated volume of retained rainwater (m^3/yr)	65751	32 706	5 398	5 025	**108 880**
Estimated costs in €	343 050	261 647	49 832	21 534	**676 063**
Retrieved water resource (l/s)	2,085	1,037	0,171	0,159	**3,50**
Increased evaporation from retained rainwater (m^3)	43834	21804	3599	3350	**72 587**
Increased dew formation (m^3)	66 561	101 190	16 524	1 181	**185 455**
Increased water balance in ecosystems (m^3)	110 395	122 994	20 123	4 531	**258 042**
Estimated increased biomass production in t	220,79	245,99	40,25	9,06	**516**
Reduction in sensible heat (MWh)	30 684	15 263	2 519	2 345	**50 811**
Reduction in current summer temperature (°C)	-0,58	-0,19	-0,19	-2,5	**-0,35**
Carbon sequestration (t)	309,1	344,38	56,34	12,69	**722,52**
Carbon credit in € at price (€78,46/ton)	24 252	27 020	4 421	995	**56 689**
Return on investment on carbon credit (years)	14,1	9,7	11,3	21,6	**11,9**

Micro-basin 8	Arable land	Permanent grass land	Forest areas	Roads	Total
Area [ha]	113,2	113,8	16,5	2,3	245,8
Rainwater retention measures RWM [m³]	24 309	12 265	2 073	688	39 335
Estimated volume of retained rainwater (m³/yr)	55911	18 398	2 695	4 817	81 820
Estimated costs in €	291 708	147 180	24 876	20 645	484 409
Retrieved water resource (l/s)	1,773	0,583	0,085	0,153	2,60
Increased evaporation from retained rainwater (m³)	37274	12265	1797	3211	54 547
Increased dew formation (m³)	56 599	56 921	8 249	1 132	122 900
Increased water balance in ecosystems (m³)	93 873	69 186	10 045	4 343	177 447
Estimated increased biomass production in t	187,75	138,37	20,09	8,69	355
Reduction in sensible heat (MWh)	26 092	8 586	1 258	2 248	38 183
Reduction in current summer temperature (°C)	-0,58	-0,19	-0,19	-2,5	-0,39
Carbon sequestration (t)	262,84	193,72	28,13	12,16	496,85
Carbon credit in € at price (€78,46/ton)	20 623	15 199	2 207	954	38 983
Return on investment on carbon credit (years)	14,1	9,7	11,3	21,6	12,4

Micro-basin 9	Arable land	Permanent grass land	Forest areas	Roads	Total
Area [ha]	30,7	62,4	7,8	0,1	101,1
Rainwater retention measures RWM [m³]	6 598	6 722	981	45	14 346
Estimated volume of retained rainwater (m³/yr)	15174	10 083	1 276	318	26 851
Estimated costs in €	79 170	80 661	11 777	1 364	172 973
Retrieved water resource (l/s)	0,481	0,32	0,04	0,01	0,90
Increased evaporation from retained rainwater (m³)	10116	6722	851	212	17 901
Increased dew formation (m³)	15 361	31 195	3 905	75	50 536
Increased water balance in ecosystems (m³)	25 477	37 917	4 756	287	68 437
Estimated increased biomass production in t	50,95	75,83	9,51	0,57	137
Reduction in sensible heat (MWh)	7 081	4 705	595	149	12 530
Reduction in current summer temperature (°C)	-0,58	-0,19	-0,19	-2,5	-0,31
Carbon sequestration (t)	71,34	106,17	13,32	0,8	191,62
Carbon credit in € at price (€78,46/ton)	5 597	8 330	1 045	63	15 035
Return on investment on carbon credit (years)	14,1	9,7	11,3	21,6	11,5

Micro-basin 10	Arable land	Permanent grass land	Forest areas	Roads	Total
Area [ha]	84,3	15,1	5,9	1,0	106,3
Rainwater retention measures RWM [m³]	18 103	1 623	744	304	20 774
Estimated volume of retained rainwater (m³/yr)	41638	2 434	967	2 125	47 164
Estimated costs in €	217 242	19 473	8 930	9 107	254 751
Retrieved water resource (l/s)	1,32	0,077	0,031	0,067	1,50
Increased evaporation from retained rainwater (m³)	27759	1623	645	1417	31 443
Increased dew formation (m³)	42 151	7 531	2 961	499	53 142
Increased water balance in ecosystems (m³)	69 909	9 154	3 606	1 916	84 585
Estimated increased biomass production in t	139,82	18,31	7,21	3,83	169
Reduction in sensible heat (MWh)	19 431	1 136	451	992	22 010
Reduction in current summer temperature (°C)	-0,58	-0,19	-0,19	-2,5	-0,52
Carbon sequestration (t)	195,75	25,63	10,1	5,36	236,84
Carbon credit in € at price (€78,46/ton)	15 358	2 011	792	421	18 582
Return on investment on carbon credit (years)	14,1	9,7	11,3	21,6	13,7

Micro-basin 11	Arable land	Gardens	Permanent grass land	Forest areas	Built up areas	Roads	Total
Area [ha]	53,4	6,2	39,3	9,0	1,4	1,3	110,5
Rainwater retention measures RWM [m³]	11 472	966	4 229	1 127	585	385	18 764
Estimated volume of retained rainwater (m³/yr)	26387	1352	6 344	1 464	5 266	2 696	43 509
Estimated costs in €	137 669	11 592	50 750	13 518	23 402	11 555	248 486
Retrieved water resource (l/s)	0,837	0,043	0,201	0,046	0,167	0,085	1,40
Increased evaporation from retained rainwater (m³)	17591	902	4229	976	3510	1797	29 006
Increased dew formation (m³)	26 711	3 104	19 627	4 483	698	634	55 256
Increased water balance in ecosystems (m³)	44 302	4 005	23 856	5 459	4 208	2 431	84 262
Estimated increased biomass production in t	88,6	8,01	47,71	10,92	8,42	4,86	169
Reduction in sensible heat (MWh)	12 314	631	2 960	683	2 457	1 258	20 304
Reduction in current summer temperature (°C)	-0,58	-0,26	-0,19	-0,19	-4,44	-2,5	-0,46
Carbon sequestration (t)	124,05	11,21	66,8	15,28	11,78	6,81	235,93
Carbon credit in € at price (€78,46/ton)	9 733	880	5 241	1 199	925	534	18 511
Return on investment on carbon credit (years)	14,1	13,2	9,7	11,3	25,3	21,6	13,4

Micro-basin 12	Arable land	Gardens	Permanent grass land	Forest areas	Built up areas	Roads	Other areas	Total
Area [ha]	125 338	74 416	301 985	581 601	8 306	10 866	5668	1 108 180
Rainwater retention measures RWM [m^3]	2 692	1158	3 254	7 308	348	330	163	15 253
Estimated volume of retained rainwater (m^3/yr)	6191	1621	4 880	9 501	3 133	2 312	1141	28 779
Estimated costs in €	32 299	13 897	39 042	87 699	13 925	9 909	1 141	197 911
Retrieved water resource (l/s)	0,196	0,051	0,155	0,301	0,099	0,073	0	0,90
Increased evaporation from retained rainwater (m^3)	4127	1081	3254	6334	2089	1541	760	19 186
Increased dew formation (m^3)	6 267	3 721	15 099	29 080	415	543	283	55 409
Increased water balance in ecosystems (m^3)	10 394	4 802	18 353	35 414	2 504	2 085	1 044	74 595
Estimated increased biomass production in t	20,79	9,6	36,71	70,83	5,01	4,17	1,52	149
Reduction in sensible heat (MWh)	2 889	757	2 277	4 434	1 462	1 079	532	13 430
Reduction in current summer temperature (°C)	-0,58	-0,26	-0,19	-0,19	-4,44	-2,5	-2,37	-0,31
Carbon sequestration (t)	29,1	13,44	51,39	99,16	7,01	5,84	2,13	208,07
Carbon credit in € at price (€78,46/ton)	2 283	1 055	4 032	7 780	550	458	167	16 325
Return on investment on carbon credit (years)	14,1	13,2	9,7	11,3	25,3	21,6	6,8	12,1

As can be seen from the summary table, the implementation of water retention measures in the area will cause a spontaneous increase in groundwater levels with the gradual formation of springs that have dried up due to damage to the landscape. Conservative calculations show that the yield in the basin would increase in total to the level of 40 liters per second.

According to estimates, the proposed NbS would be able to capture up to 1,2 million cubic meters of water per year. The evaporation from this amount would gradually become part of a small water cycle with enhanced air conditioning (cooling the lower layer of the atmosphere by more than 0,5 degrees Celsius). This value is calculated based on conservative calculations and it is possible that the temperature drop after implementation will be higher depending on hydrological conditions and rain formation, because the reduction of sensible heat due to the consumed solar energy by water evaporation also starts the processes of dew renewal. To verify this fact, we recommend setting up a monitoring system that can quantify the balance of dew formation.

DAIA-basin	Arable land	Gardens	Permanent grass land	Forest areas	Built up areas	Roads	Other areas	Total
Area [ha]	**1 413,0**	**52,1**	**992,1**	**359,6**	**12,2**	**32,4**	**119,5**	**2 980,4**
Rainwater retention measures RWM [m³]	**303 429**	**8109**	**106 889**	**45 131**	**5098**	**9851**	**34363**	**512 870**
Estimated volume of retained rainwater (m³/yr)	697886	11353	160 333	58 670	45 878	68 960	240543	**1 283 623**
Estimated costs in €	3 641 143	97 311	1 282 663	541 572	203 904	295 543	240 543	**6 302 679**
Retrieved water resource (l/s)	22,13	0,36	5,084	1,86	1,455	2,187	8	**40,70**
Increased evaporation from retained rainwater (m³)	465257	7569	106889	39114	30586	45973	160362	**855 749**
Increased dew formation (m³)	706 476	26 055	496 060	179 579	6 081	16 205	59 762	**1 490 218**
Increased water balance in ecosystems (m³)	1 171 733	33 624	602 948	218 693	36 667	62 178	220 124	**2 345 967**
Estimated increased biomass production in t	2343,47	67,25	1205,9	437,39	73,33	124,36	320,72	**4572**
Reduction in sensible heat (MWh)	325 680	5 298	74 822	27 379	21 410	32 181	112 253	**599 024**
Reduction in current summer temperature (⁰C)	-0,58	-0,26	-0,19	-0,19	-4,44	-2,5	-2,37	**-0,51**
Carbon sequestration (t)	3280,85	94,15	1688,26	612,34	102,67	174,1	449,01	**6401,37**
Carbon credit in € at price (€78,46/ton)	257 416	7 387	132 461	48 044	8 055	13 660	35 230	**502 252**
Return on investment on carbon credit (years)	**14,1**	**13,2**	**9,7**	**11,3**	**25,3**	**21,6**	**6,8**	**12,5**

Estimated quantification of benefits after implementation of the Plan in the entire DAIA basin

We also estimated how the invested money would be returned if carbon credits were introduced into the region at the current market price of €78,46/ton. The costs of implementing NbS were estimated based on average market prices (they may fluctuate over time). To increase the water retention capacity of the country to capture 513 thousand m³ of rainwater at a time (in the event of an extreme rainfall of 60 mm with a probability of occurring once a year), it is necessary to invest €6,3 million (an investment per hectare of €2 114 on average).

A well-managed project with carbon credit investment would return the invested resources in less than 13 years. Other benefits that emerged from the analyses (acquisition of water resources, wood production, hay on pastures) would significantly shorten the return on investment. This can be the subject of implementation research.

Therefore, we recommend coordinating the work as a joint strategic investment plan for stakeholders with significant private and public benefits. In addition to the private interest in increasing economic benefits, there is a public interest (protection of water resources, climate, well-being and security of the population) in ensuring sustainable prosperity in rural areas for decades to come.

The benefits that result from this for all partners in the territory are water resources, biomass growth, changes in the temperature regime of the country and carbon sequestration. The plan can also be implemented in phases, and we recommend implementing it in partnership between the municipality and foresters, farmers, water managers, fishermen and nature conservationists.

The table also shows how much CO_2 storage will increase through photosynthesis in one year. In this case, CO_2 is the source for biomass production. Partners may, at their discretion, offer emission quota holders the opportunity to invest their quotas in the real estate cadastre, thereby providing municipalities in the basin with a competitive advantage. In addition to creating new water resources, fertilizing the soil, increasing wood production and improving the temperature regime of the country, NbS also contributes to the protection of biodiversity.

5. Design of water retention measures

Integrated water resource management and climate protection can be achieved by reducing surface runoff of rainwater. In ecosystems, rainwater retained in forest landscapes promotes infiltration into the soil and subsoil, replenishing water resources, enabling vegetation growth with the support of evaporation, and improving the microclimate as part of ecosystem services.

The aim is to collect rainwater in concentrated, regularly replenished NbS measures. We recommend selecting locations for NbS in suitable ***places with sufficient volume capacity and an appropriate slope to minimize costs***.

Based on the nature of the drainage areas and the problems of local flooding, we propose to implement preventive flood measures on the principle of soft (revitalization) measures and hard (technical) measures. This means that the share of soft measures will be implemented faster (due to the simpler approval process). At the time of implementation of soft measures, the approval process of technical measures will begin, which require the start of the approval process of construction and water law procedures. Soft measures require a zoning decision on the use of the territory. Such a combination brings several advantages. However, the main advantage is the possibility of immediate start of implementation in those parts where the municipality can take the initiative to decide and act. This chapter proposes the types of measures for individual drainage areas and the volume of water retention measures in full.

The draft measures were designed for average volumes of water retention measures, namely:

Technical measures:

Infiltration Areas: 0,66 m^3/m^2

Infiltration ditches along roads: 1,5 m^3/ lin.m

Soaking pits: 350 m^3/pcs

Revitalization measures:

Rain Gardens: 0,5 m^3/m^2

Contour trenches with tree line: 2,5 m^3/lin.m

Small check dams: 40 m^3/pcs

Surface cross drains with soaking pits: 7 m^3/pcs

When building any water retention measures, we always apply the top-down principle. This is very important. During the implementation process, precipitation events may occur. If we started building water retention measures in the lower parts of the basin, they could be destroyed by the strong impact of the flood wave. With the gradual implementation of the NbS from the upper parts of the basin, this risk is eliminated.

DAIA Basin	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Built up areas	121 625	5 097,60	Rain Gardens	2 730	5 460	m^2
			Infiltration Areas	2 660	4 030	m^2
Gardens	521 098	8 109,27				
Roads	324 098	9 851,44	Infiltration ditches along roads	3 795	2 530	lm
			Surface cross drains with soaking pits	5 502	786	pcs
Arable land	14 129 522	303 428,55	Contour trenches	278 438	111 375	lm
			Soaking pits	37 100	106	pcs
Permanent grass land	9 921 194	106 888,59	Check dams	200	5	pcs
			Soaking pits	1050	3	pcs
			Contour trenches with tree line	110 875	44 350	lm
Forest areas	3 591 580	45 131,02	Small check dams	35 280	882	pcs
Other areas	1 195 248	34 363,30	Contour trenches	35 250	14 100	lm
Total	29 804 365	512 869,77		512 879		

Overview of water retention measures for DAIA basin

Micro-basin 1	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Built up areas	3 888	162,96	Rain Gardens	100	200	m^2
			Infiltration Areas	99	150	m^2
Gardens	13 340	207,6				
Roads	21 933	666,69	Infiltration ditches along roads	300	200	lm
			Surface cross drains with soaking pits	210	30	pcs
Arable land	57 557	1 236,02	Contour trenches	750	300	lm
			Soaking pits	700	2	pcs
Permanent grass land	790 341	8 514,95	Check dams	200	5	pcs
			Soaking pits	1050	3	pcs
			Contour trenches with tree line	7575	3030	lm
Forest areas	650 034	8 168,19	Small check dams	8 000	200	pcs
Total	1 537 093	18 956,41		18984		

Micro-basin 2	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Built up areas	132	5,53	Rain Gardens	0	0	m^2
			Infiltration Areas	0	0	m^2
Gardens	8 157	126,94				
Roads	7 291	221,62	Infiltration ditches along roads	0	0	lm
			Surface cross drains with soaking pits	224	32	pcs
Arable land	389 164	8 357,22	Contour trenches	6 063	2 425	lm
			Soaking pits	2 450	7	pcs
Permanent grass land	387 268	4 172,33	Contour trenches with tree line	4 250	1 700	lm
Forest areas	72 226	907,58	Small check dams	800	20	pcs
Total	864 238	13 791,22		13 787		

Micro-basin 3	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Built up areas	24 690	1034,82	Rain Gardens	550	1 100	m^2
			Infiltration Areas	528	800	m^2
Gardens	105 438	1640,82				
Roads	91 502	2781,34	Infiltration ditches along roads	1 350	900	lm
			Surface cross drains with soaking pits	1 400	200	pcs
Arable land	1 551 221	33 312,15	Contour trenches	27 500	11 000	lm
			Soaking pits	7 000	20	pcs
Permanent grass land	1 839 954	19 823,23	Contour trenches with tree line	20 500	8 200	lm
Forest areas	882 556	11 090,01	Small check dams	10 800	270	pcs
Other areas	397 629	11 431,81	Contour trenches	11 500	4 600	lm
Total	4 892 990	81 114,18		81 128		

Micro-basin 4	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Built up areas	21 388	896,42	Rain Gardens	500	1 000	m^2
			Infiltration Areas	462	700	m^2
Gardens	97 506	1517,38				
Roads	23 913	726,87	Infiltration ditches along roads	375	250	lm
			Surface cross drains with soaking pits	420	60	pcs
Arable land	843 791	18 120,24	Contour trenches	17 500	7 000	lm
			Soaking pits	1 400	4	pcs
Permanent grass land	240 110	2 586,89	Contour trenches with tree line	2 750	1 100	lm
Forest areas	124 683	1 566,74	Small check dams	1 600	40	pcs
Other areas	402 048	11 558,85	Contour trenches	12 000	4 800	lm
Total	1 753 439	36 973,39		37 007		

Micro-basin 5	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Built up areas	3 910	163,88	Rain Gardens	80	160	m^2
			Infiltration Areas	86	130	m^2
Gardens	44 163	687,26				
Roads	36 562	1111,36	Infiltration ditches along roads	300	200	lm
			Surface cross drains with soaking pits	700	100	pcs
Arable land	3 934 759	84 498,13	Contour trenches	75 000	30 000	lm
			Soaking pits	10 500	30	pcs
Permanent grass land	885 416	9 539,26	Contour trenches with tree line	9 500	3 800	lm
Forest areas	273 947	3 442,36	Small check dams	3 200	80	pcs
Other areas	168 782	4 852,47	Contour trenches	5 000	2 000	lm
Total	5 347 539	104 294,72		104 286		

Micro-basin 6	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Built up areas	45 352	1900,81	Rain Gardens	1 000	2 000	m^2
			Infiltration Areas	990	1 500	m^2
Gardens	116 003	1805,23				
Roads	61 623	1873,12	Infiltration ditches along roads	675	450	lm
			Surface cross drains with soaking pits	840	120	pcs
Arable land	3 080 044	66 143,31	Contour trenches	60 000	24 000	lm
			Soaking pits	9 800	28	pcs
Permanent grass land	1 146 845	12 355,84	Contour trenches with tree line	12 500	5 000	lm
Forest areas	284 114	3 570,12	Small check dams	1 400	35	pcs
Other areas	221 121	6 357,21	Contour trenches	6 750	2 700	lm
Total	4 955 102	94 005,64		93 995		

Micro-basin 7	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Roads	23 615	717,81	Surface cross drains with soaking pits	700	100	pcs
Arable land	1 331 210	28 587,46	Contour trenches	30 000	12 000	lm
Permanent grass land	2 023 796	21 803,90	Contour trenches with tree line	23 250	9 300	lm
Forest areas	330 474	4 152,66	Small check dams	1 200	30	pcs
Total	3 709 095	55 261,83		55 150		

Micro-basin 8	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Roads	22 639	688,15	Surface cross drains with soaking pits	700	100	pcs
Arable land	1 131 980	24 309,04	Contour trenches	25 750	10 300	lm
Permanent grass land	1 138 417	12 265,04	Contour trenches with tree line	12 500	5 000	lm
Forest areas	164 971	2072,99	Small check dams	400	10	pcs
Total	2 458 007	39 335,22		39 350		

Micro-basin 9	Area [m^2]	Runoff volume [m^3]	Type of NbS	Volume of NbS [m^3]	Number of NbS	The dimension of NbS
Roads	1 496	45,47	Surface cross drains with soaking pits	42	6	pcs
Arable land	307 221	6 597,51	Contour trenches	7 250	2 900	lm
Permanent grass land	623 900	6 721,75	Contour trenches with tree line	7 050	2 820	lm
Forest areas	78 104	981,44				
Total	1 010 721	14 346,17		14 342		

Micro-basin 10	Area [m²]	Runoff volume [m³]	Type of NbS	Volume of NbS [m³]	Number of NbS	The dimension of NbS
Roads	9 987	303,57	Infiltration ditches along roads	165	110	lm
			Surface cross drains with soaking pits	140	20	pcs
Arable land	843 010	18 103,46	Contour trenches	16 250	6 500	lm
			Soaking pits	1 750	5	pcs
Permanent grass land	150 619	1 622,73	Contour trenches with tree line	1 750	700	lm
Forest areas	59 220	744,15	Small check dams	760	19	pcs
Total	1 062 836	20 773,91		20 815		

Micro-basin 11	Area [m²]	Runoff volume [m³]	Type of NbS	Volume of NbS [m³]	Number of NbS	The dimension of NbS
Built up areas	13 959	585,06	Rain Gardens	300	600	m²
			Infiltration Areas	297	450	m²
Gardens	62 075	966				
Roads	12 671	385,15	Infiltration ditches along roads	255	170	lm
			Surface cross drains with soaking pits	126	18	pcs
Arable land	534 227	11 472,41	Contour trenches	10 000	4 000	lm
			Soaking pits	2 800	8	pcs
Permanent grass land	392 543	4 229,17	Contour trenches with tree line	4 250	1 700	lm
Forest areas	89 650	1 126,52	Small check dams	720	18	pcs
Total	1 105 125	18 764,31		18 748		

18 748,00

Micro-basin 12	Area [m²]	Runoff volume [m³]	Type of NbS	Volume of NbS [m³]	Number of NbS	The dimension of NbS
Built up areas	8 306	348,12	Rain Gardens	200	400	m²
			Infiltration Areas	198	300	m²
Gardens	74 416	1 158,05				
Roads	10 866	330,29	Infiltration ditches along roads	375	250	lm
Arable land	125 338	2 691,61	Contour trenches	2 375	950	lm
			Soaking pits	700	2	pcs
Permanent grass land	301 985	3 253,51	Contour trenches with tree line	5 000	2 000	lm
Forest areas	581 601	7 308,27	Small check dams	6 400	160	pcs
Total	1 108 180	15 252,80		15 248	4 062	

Overview of water retention measures for individual drainage areas

In the spirit of the principles of sustainable development, integrated water resources management and climate protection, it is necessary to define the quantification of the reduction of surface runoff of rainwater and the increase of land retention. Captured rainwater in the land can be retained on suitable areas for its infiltration, to replenish soil and groundwater reserves, to allow vegetation and agricultural crops to transpirate it into the air and thus improve the microclimate and at the same time reduce surface runoff of rainwater, also as part of systemic flood prevention measures. Collected, slowed down and retained or directed rainwater into suitable terrains and water retention elements can be used for beneficial purposes, as a water supply for periods when there is a lack of precipitation.
Over the last 20 years, several techniques and technologies have been developed around the world to manage rainwater in landscapes to prevent flood risks, drought risks, and overheating of the landscape.

The basic principle of rainwater harvesting measures is to allow rainwater to infiltrate the soil to improve soil and groundwater supplies. Groundwater improves the yield conditions of springs and their potential for use.

Many of the measures already implemented can also be found in the publication:

44_kravcik-after-us-the-desert-and-the-deluge.pdf

5.1 Measures in forest landscapes

Forest ecosystems cover almost 12% of the DAIA basin. They contribute to almost 9% of flood waves. During an intense rainfall event of 60 mm, more than 45 000 m³ of water runs off from forest areas in the basin. To strengthen ecosystem services in the forests of the basin, it is necessary to build NbS capable of capturing and cyclically utilizing this volume (45 000 m³) of rainwater at once. In addition to ecosystem services, the implementation of NbS will also strengthen the economic performance of the forest, through increased biomass and thus also wood increments, and, above all, improve the protection of community.

Certain aspects of rainwater management in forests have long been underestimated. It is necessary to strengthen measures for rainwater retention in forests so that the retained water increases wood mass growth, and to find a balance between the economic use of forests and the need for ecosystem services. It is also necessary to change the approach to rainwater management in transport infrastructure, to protect forests from drying, to increase the yield of springs, to ensure fire protection and sufficient water for forest wildlife and support the development of local tourism.

Several successful projects have been implemented in Slovakia and can serve as examples of good practice (Restoration of the Tatra forests after windstorm, Hričov Waterway, Blue Alternative, and many other revitalization projects), which can serve as inspiration for the integrated restoration of degraded ecosystems in other regions.

We propose to implement a total of 882 individual types of dams in individual gorges and small streams.

- In the initial parts of the ravines and erosion grooves, which periodically dry out, we propose to build a cascade of wooden interleaved dams every 15-20 meters and a height of 0,5-1,0 m.

- In the middle sections of nameless streams, in which water permanently flows at a height of up to 5 cm at the time of dam construction, we propose a cascade of wooden interleaved dams with a height of 1– 1,5 m at distances of every 20 - 30 meters.

On average, the water retention volume of one dam will reach 40 m^3, with the visible volume of the water retention space being approximately 30 m^3, and 10 m^3 will be the contribution of each dam to the saturation of the surrounding environment, caused by the backflow of retained water. Based on the characteristics of the relief in the valleys and erosion grooves, the variability of the water retention space from 5 m^3 to 50 m^3 is allowed. It is possible that the real number of objects may not coincide with the proposed numbers. However, it is not the number of objects that is important, but the water retention volume. This must be observed during implementation. The number of objects will depend on the volume of water retention measures.

Brushwood check dams

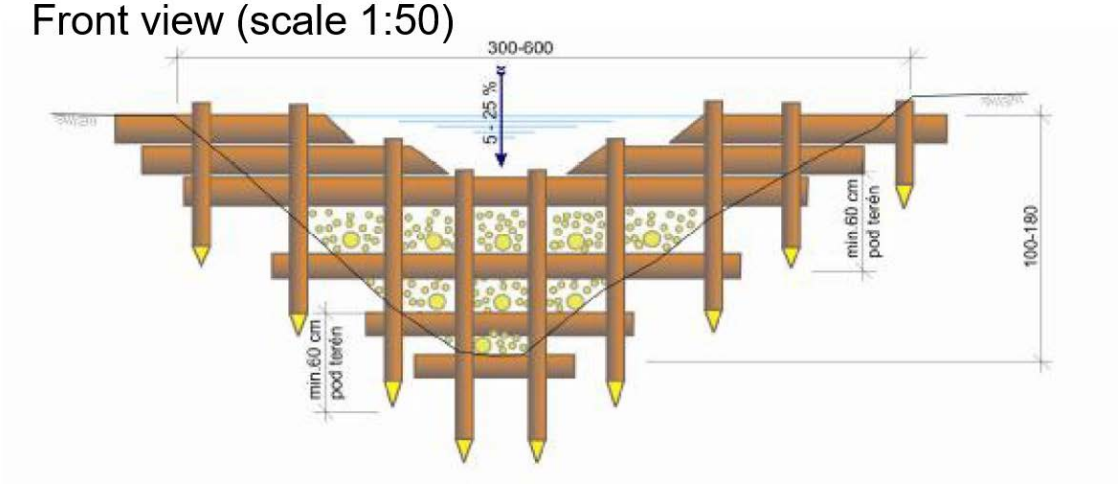
Due to forest landscape degradation, it is necessary to revitalize damaged areas, old potholes, and erosion gullies. In the headwater areas, we propose measures using local materials. The most suitable measures for these areas are brushwood dams made of branches and small-diameter wood, which is abundant in the ravines and surrounding areas. Waste wood from pruning can also be used.

The advantage of this solution is that the dams quickly become filled with sediment, and the wood preserved in the sediment will last for several decades. The dams thus create hydromorphic ecosystems that will retain rainwater during each rainfall and, at the same time, release water during droughts and protect small watercourses from drying out. A cascade arrangement of brushwood check dams stabilises erosion gullies and ravines. The bottom of the ravines will rise, protecting them from landslides and deepening them. Water reserves will form in the sediments, as these sediments will be fed by rainwater, which will accumulate. New vegetation will grow on the sediments of the dams, which will promote the restoration of vegetation and the gradual overgrowth of erosion gullies.

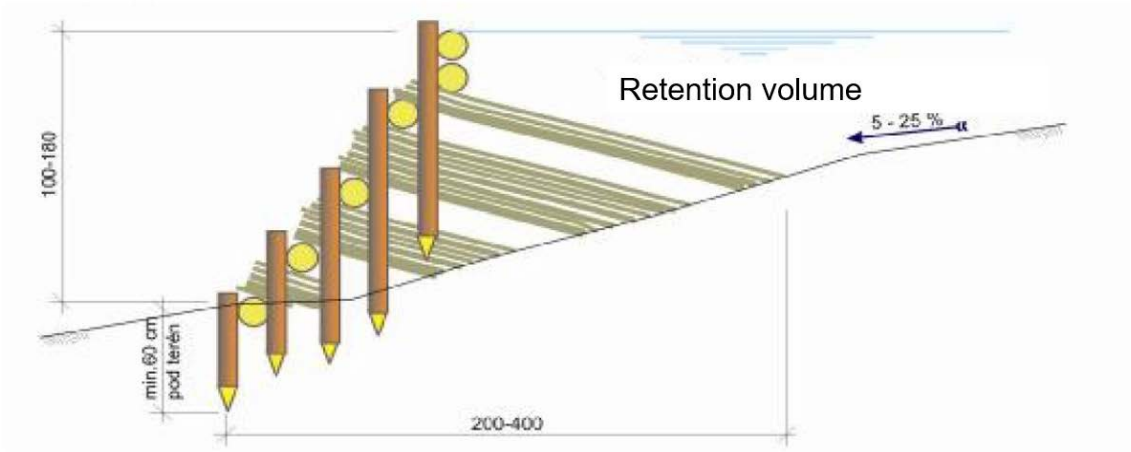


Impact of brushwood dams on the water regime of periodically drying small watercourses (Snežnica, Skalité, Oščadnica)

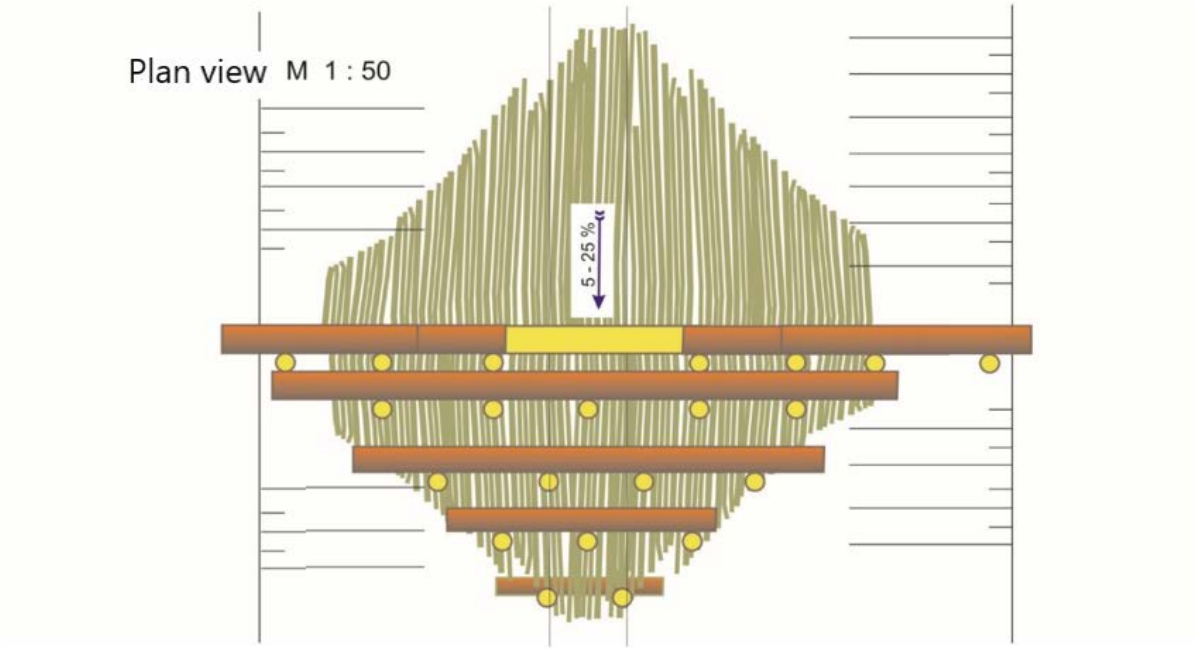
Front view (scale 1:50)



Side view (scale 1:50)



Plan view M 1 : 50







Stability and durability of check dams

The main element is its proper construction. The transverse wooden logs should be layered with branches and pulp (fascines) along the profile of the corridor.

It is important to reinforce the edges of the logs and fascines with stones and soil to ensure their stability.

The entire transverse and cross-sectional structure is stabilized by wooden stakes 8-12 cm in diameter which are hammered into the stream bed until they cannot be wedged.

These three elements are interconnected by nails of appropriate size or wire. If using coniferous timber, then it is vital to remove the bark from the logs and stakes. Use of on-site material. Natural material is in tune with nature protection and cultural heritage and customs. Placement of check dam in the narrowest profile of the stream bed and directly against the current while simultaneously ensuring that the retention area achieve its maximum size.



5.2 Measures on roads

Roads cover just 1,1% of the DAIA basin. They contribute to 1,9% of flood waves. During an intense rainfall event of 60 mm, almost 10 000 m³ of water runs off from roads in the basin.

It is necessary to strengthen measures for rainwater retention around roads so that the runoff water will no longer contribute to erosion process.

In built-up areas of the municipality and on larger roads that are commonly used for transportation with passenger vehicles, we propose Infiltration ditches along roads.

On unpaved roads in the DAIA valley that lead into the forest or onto agricultural land and are used mainly by heavy machinery, we suggest Surface cross drains with soaking pits.

In total, we propose to build 2 530 linear meters of Infiltration ditches along roads and 816 pcs of Surface cross drains with soaking pits.

Surface cross drains with soaking pits

We propose standardizing surface cross drains on roads so that surface cross drain is accompanied by a water soaking pit. The recommended types of surface cross drains are listed below. However, it is essential that rainwater from the surface cross drain is collected in infiltration pits, from which it will seep into the vegetation. The shape of the pit is not important—its volume is. We propose constructing an infiltration pit of approximately 7 m³ (5 m³ visible volume 2 m³ soil infiltration) for each cross drain, which in practice means that water bars must be installed every 40 m along forest roads and skid trails. Surface cross drains on forest and field on the way with they recommend plant at intervals of 40 m. On sloping slopes more as 12% is recommends spacing between 20m surface cross drain points to avoid damage roads. We recommend revitalizing skid trails immediately after logging. The spacing of water bars is not determined by the slope of the road, since the volume of runoff from compacted forest or agricultural roads is approximately the same. In this case, the key factor is not flow velocity but the total volume of runoff.



Water bars with infiltration pits

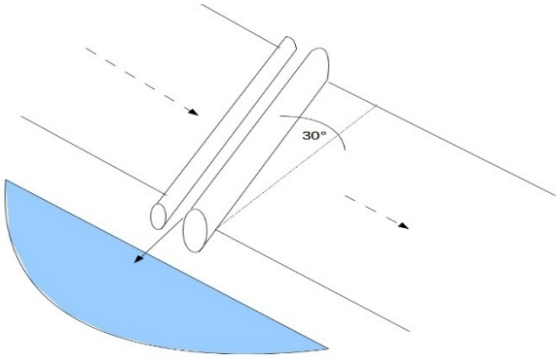
We recommend creating cross drain from a combination of materials, especially wood, depending on financial possibilities. The cross drain directs rainwater into the infiltration soaking pit, where it accumulates and gradually infiltrates into the subsoil. The infiltration area also reduces soil erosion, especially if it is lined with stone beneath the outlet of the water bar. Cross drain must be slightly sloped in the direction of water drainage to ensure maximum self-cleaning. Maintenance and cleaning are essential for the proper functioning of the cross-drain network.

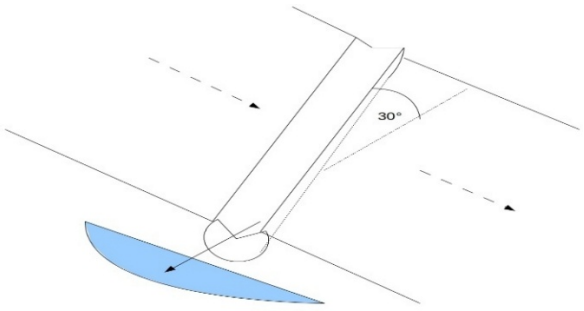
















Infiltration ditches along roads

In total, it is necessary to build 2 530 linear meters of infiltration ditches along the roads. We propose to implement these infiltration ditches in two ways.

In the newly built ditches, we propose runoff retarders by building a cascade of small dams with a height of up to 0,5 m depending on the depth, with the upper edge of the dam being at least 10 cm below the road surface.

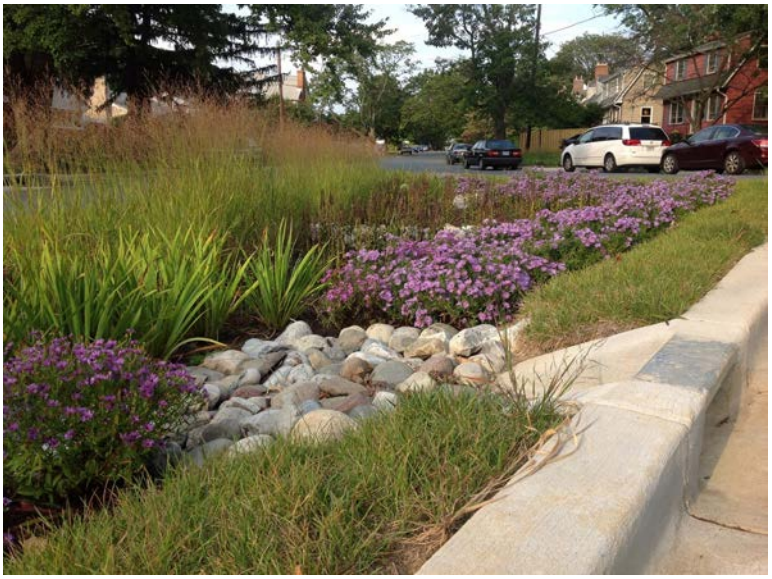
In sections where rainwater flows directly into the stream, we propose shallow intermittent infiltration strips with a depth of up to 0,5 m along the entire length so that all rainwater is collected in them and seeps into the soil.





International studies confirm that this system is also very effective in reducing the amount of contaminants such as total suspended solids, metals, oil and grease. A well-designed project and subsequent implementation with appropriate maintenance and filtration systems can dramatically reduce runoff intensity, replenish groundwater, improve its quality, as these artificially created ecosystems quickly become overgrown and function as biofilters.



Different types of Infiltration ditch schemes along the road, examples of application and rainwater collection in gutters (USA, Austria)

Logistics during construction, construction methods, and prevention of erosion and subsequent sedimentation are key to ensuring long-term functionality. An example from Austria shows how rainwater is collected from roads and subsequently infiltrates and evaporates.





Collecting rainwater from transport infrastructure and parking lots in reservoirs (example from Austria)

5.3 Measures in land management in agricultural landscapes

Agricultural land cover more than 80% (Arable land 47,4% and Permanent grass land 33,3%) of the DAIA basin. They contribute to 80% of flood waves (Arable land 59,2% and Permanent grass land 20,8%). During an intense rainfall event of 60 mm, more than 410 000 m³ of water runs off from agricultural land in the basin (Arable land 303 428 m³ and Permanent grass land 106 888 m³).

To strengthen ecosystem services in the agricultural land of the basin, it is necessary to build NbS capable of capturing and cyclically utilizing this volume (410 000 m³) of rainwater at once. In addition to ecosystem services, the implementation of NbS will also strengthen the economic performance of the fields, through increased biomass and thus also crop increments, and, above all, improve the protection of community.

Certain aspects of rainwater management in agricultural land have long been underestimated. It is necessary to strengthen measures for rainwater retention in agricultural land so that the retained water increases crop production and avoid erosion process, and to find a balance between the economic use of fields and the need for ecosystem services.

On agricultural land, we propose to create Contour trenches supplemented with Soaking pits. On permanent grasslands, we propose to supplement contour trenches with planting fruit trees in a line at 5 m intervals.

We propose to build Contour tranches in other areas where the erosion process has already progressed significantly.

In total we propose to implement 111 375 linear meters of Contour trenches and 106 pcs of Soaking pits on Arable land. On Permanent grass land we propose to implement 44 770 linear meters Contour trenches with tree line and on Other areas 14 100 linear meters of Contour trenches.

Contour tranches

According to the European Agricultural Policy, it is necessary to leave at least 5% of agricultural land for non-productive functions of the agricultural landscape. Therefore, we propose a type of measure that will ensure this through buffer strips on the permanent grass land and by restoring the boundaries of arable land by leaving strips 2,5 meters wide.

On permanent grassland and arable land, we recommend contour infiltration strips. On permanent grasslands, we propose to supplement contour trenches with planting fruit trees in a line at 5 m intervals.



Infiltration strips in an agricultural landscape

We always create trench along the contour lines. Recommendation of interrupting them so that there is there no leakage collected rain waters to their lowest points, so that the opposite effect does notes happen. Trenches are necessary to interrupt in distances of 15-20 meters. It is advisable to build them at a distance of every 20 meters to prevent the collected rainwater from running off. Recommended depth trench is up to 1,2 meters. We recommend spacing the individual trenches on average every 50 meters copying the contour lines of the landscape. Trenches are suitable implement on interface agricultural landscape and forest. Like this solution, will be detained rainwater irrigate root zone forest ecosystems. In permanent grass land along the trenches on the bottom side, it is convenient to plant trees with a spacing within 5 meters. Native fruit tree species are recommended.

This one type of measure causes small revolution in agriculture the country, because forces farmers plowing along the contour and not along the slope. This proposed solution fundamental way will support maintenance nutrients and creation humus in the soil agricultural countries. Greenery attractive country creates enough escape area.

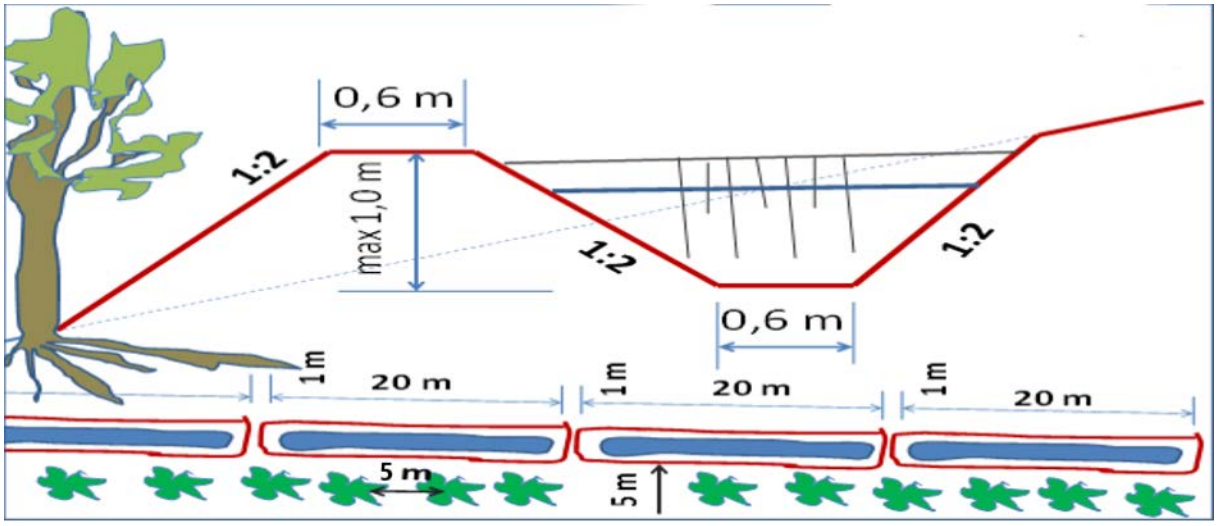









Photo:Ladislav Sisák (Spišské Dravce)





Soaking pits

Significant revitalizing element in the rural country they are soaking pits which they collect rainwater. Of them with gradually they create wetlands and buffering free zones living animals. They are Eco stabilizing elements in the country, contributing to the increase supplies underground water. Increased vapor water from soaking pits gradually heal microclimate. These measures significantly contribute also to the formation of dew in the land, which is dry periods significant benefit for maintenance moisture in the country. This measure is also preventive measure against drought, from which they arise risks fire.

Soaking pits we recommend implement with maximum depth into two meters with water retention with a volume of 350 m^3.

From soaking, with gradually they create wetland ecosystems that with they will become included complex prevention flood protection. They will significant ecostabilizing element of landscape with significant benefit for conservation biodiversity. Selection locations on building up soaking drink is necessary carefully consider, so that it corresponds to the total strategic intention

They will be eco-stabilizing elements in the agricultural landscape, contributing to increasing groundwater reserves. The increased evaporation of water from wetlands will gradually improve the microclimate. These measures will also significantly contribute, for example, to the formation of dew in the landscape, which has a significant benefit for maintaining moisture in the agricultural landscape in dry periods. This measure is also a preventive measure against drought, which creates fire risks.





Soaking pits in agricultural land are important because they also serve as watering places for livestock as part of a pasture system (also suitable for waterfowl breeding).

The placement of all these measures directly in the field will be incorporated into municipal/city zoning plan, with motivational support from the local government for all stakeholders.



5.4 Measures in built-up areas

A rainwater management system in urbanized areas can be implemented through structures based on the principle of water recycling in the environment where precipitation falls. These "structures" are based on a natural system with functions created by vegetation and soil mechanisms.

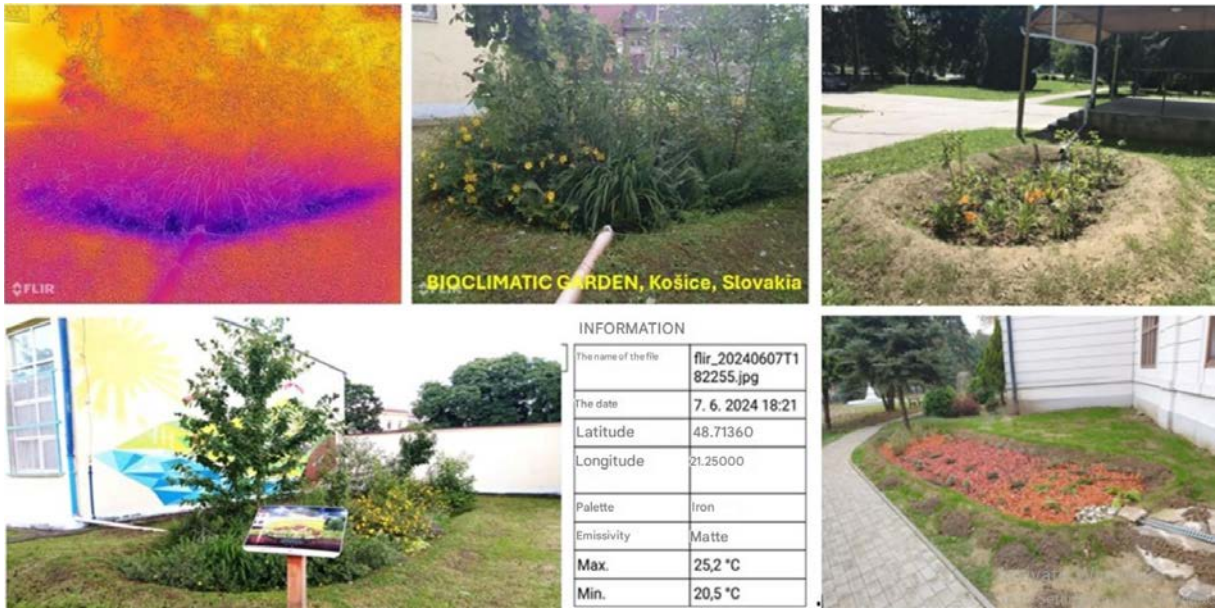
When designing and implementing in urban zones, private ownership is a big problem and there are few areas where the municipality could implement NbS. For the DAIA municipality, we selected Rain Gardens and various types of infiltration zones, more sophisticated measures do not fit well with the local traditional architectural style.

Bioclimatic Rain gardens

A rain garden (also called bioclimatic) is a shallow excavated depression planted with specially selected natural vegetation capable of modifying and capturing runoff.

Rain gardens can be integrated into sites with a high degree of flexibility and can be nicely combined with other building management systems, such as porous asphalt parking lots or infiltration ditches.

The vegetation in rain gardens provides filtration (water quality) and transpiration (water quantity) of runoff; root systems improve infiltration. Plants absorb foreign substances, the soil medium also captures them – filtering water, the bed provides additional volume control. Properly designed bioretention methods mimic the natural forest ecosystem in terms of species diversity, vegetation density and distribution, and the use of native species, resulting in a system that is resistant to insects, diseases, foreign substances, and climatic stress.



Bioclimatic rain gardens gardens - collecting rainwater from buildings into greenery

A rain garden is an attractive depression, usually on a grassy area, for collecting rainwater from impervious surfaces such as roofs, sidewalks, parking lots, driveways. In the municipality of DAIA, we propose to build a total of 5,460 m^2 of rain gardens. The size of the rain garden depends on the area of the building being drained, but its size should not exceed 100 m^2. The average water retention capacity of a rain garden is 0,5 m^3 per m^2.

The benefits of rain gardens are diverse. They can perform the following functions:

1. They help keep the water in our streams clean by filtering rainwater before it enters the local stream.

2. They help alleviate the problems of flooding.

3. They increase the attractiveness of garden architecture in cities and towns.

4. They provide refuge and a food chain for wildlife.

5. They replenish groundwater supplies.

6. They improve the microclimate of the environment by increasing evaporation.

A rain garden is not only a significant aesthetic component in the revitalization of urban areas of municipalities, offering suitable spaces for relaxation, but also an important element in protecting the quality of water resources. Rain gardens are not ponds. If a rain garden is well designed, water should remain in it for a maximum of 48 hours. The life cycle of mosquitoes is 7-12 days. A well-designed rain garden must not create conditions for stagnant water for so long that mosquito larvae have the opportunity to complete their life cycle. Rain gardens also have the advantage of attracting dragonflies, which are mosquito predators. Native plants for a given location in a rain garden create beautiful flower beds and therefore do not require special care or fertilization.

Location for a rain garden

A rain garden can be located on a lawn near a building, collecting rainwater from the roof and other paved areas of the property. The largest sources of water are from the roof, paved areas and compacted soils. The distance between the rain garden and the building should not be less than 3 meters to prevent the impact of water seepage under the structure. The garden should also not be in the area of an existing sewer or ditch. The most suitable place for a rain garden is a sunny place integrated into the entire garden by design, preferably not under large trees or in the area of large root structures.

Rain garden size

A rain garden can be any size. It is ideal to create a rain garden that will absorb all the rain that normally flows off the property.

The size of a rain garden depends on these factors:

1. Depth of the garden.

2. Volume of rainwater runoff from roofs and paved areas.

3. Type of soil in the garden.

Rain gardens were first used in Maryland (USA) in 1990 as a technology to reduce the risk of water pollution. The gardens were developed with the aim of achieving the best practice of rainwater bioretention, as a tool to collect water in depressions and slow down the runoff from intense rainstorms. All this in an effort to protect streams from pollution and at the same time reduce the amount of rainwater drainage fees for homeowners.

For more detailed instructions on how to make a rain garden, see Appendix 1.



Infiltration Areas

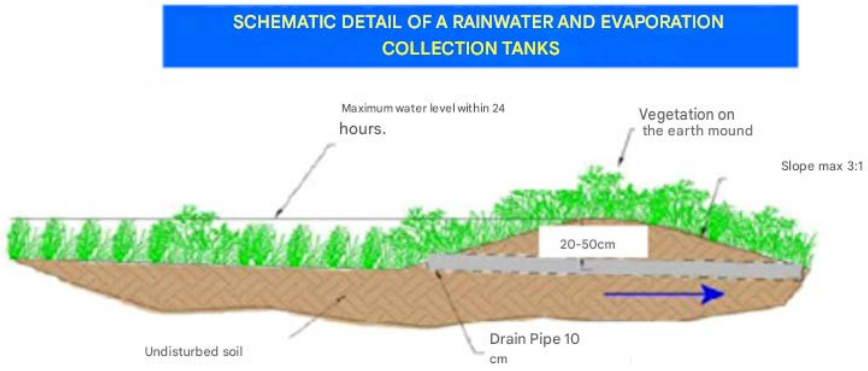
In the municipality of DAIA, a total of 4,030 m^2 of infiltration areas are designed. However, since this is mostly private property, the implementation of such measures is only possible if the municipality properly motivates its residents. We present several different types of water and infiltration areas as an example. This is a technical measure that requires separate project documentation and an adequate approval process.

Soaking pool

A soaking pool is a shallow dam reservoir in which rainwater located on a level, undisturbed area with relatively permeable soils is collected and infiltrated.

Soaking pools are shallow, water-retaining areas designed to temporarily store collected rainwater. Their size and shape can vary from one large basin to several smaller basins distributed throughout the site. soaking pool should be integrated into the existing terrain and surroundings in a subtle, barely noticeable way.

soaking pools that do not have vegetation and require excavation can be planted with vegetation. Planting plants on the infiltration area improves water quality and transpiration by evaporation and stimulates infiltration. Plants suitable for greening can include the whole range: from meadow mixtures to more significant forest species. The planting plan should sensitively consider the hydrological variability expected in the basin, as well as more specific issues related to the native vegetation of the habitats, the aesthetics of the site and other planting objectives. Access by heavy machinery or other vehicles of any type should be excluded to avoid compaction of the soil in the infiltration area.

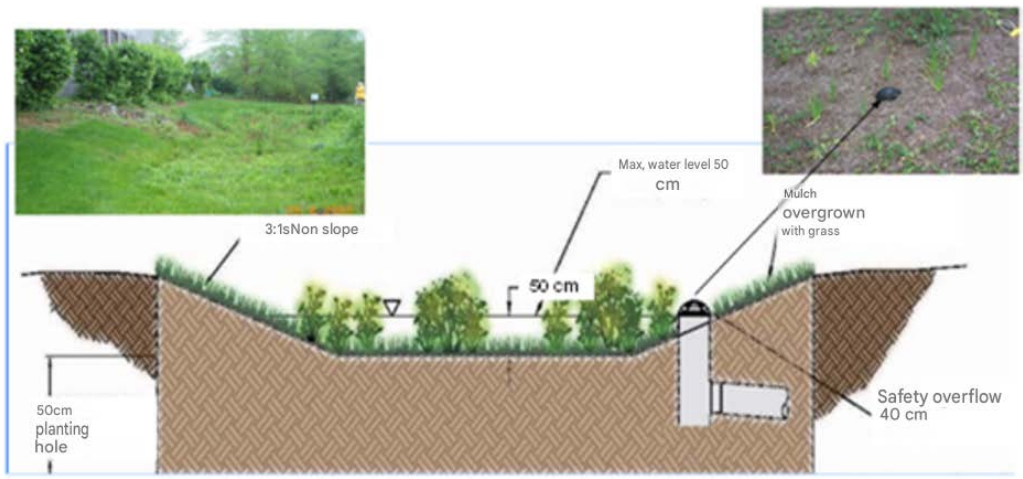


In soils with low infiltration capacity, soil infiltration can be supported by spreading a layer of sand or gravel (20 cm) on the bottom of the infiltration basin. This can be modified to improve the surface permeability of the basin.

soaking pools can be incorporated into new development on the site. Ideally, the vegetation that was already there should be preserved and used as part of the infiltration area. Runoff from adjacent buildings and impermeable surfaces can be directed to this area, which will irrigate the vegetation, which will not only increase infiltration but also increase transpiration by evaporation and improve the climate.

Existing grassed areas can be converted into soaking pools. If the soil and infiltration capacity are found to be suitable, then the basin can be closed and rainwater collection can be redirected without excavation.

The size of the soaking pool is designed according to the amount of rainwater that is directed into it. The recommended infiltration period (the time for the bed to receive rainwater and provide infiltration) is 72 hours.



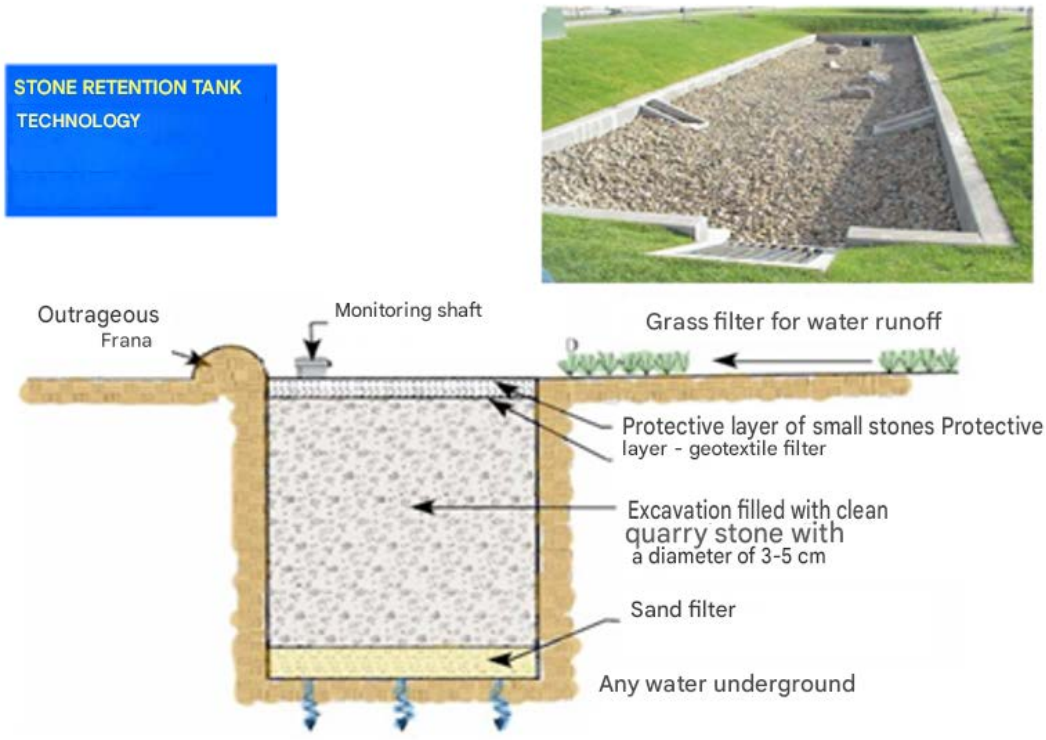
Stone retention tank

Stone retention tank or dry well is a combination of infiltration system designed for temporary accumulation and infiltration of rainwater runoff from roofs and other paved surfaces. The volume of a dry well is defined as the volume of the inflow. The volume of one dry well can be up to 75 m^3. This is a technical measure that requires separate project documentation and an adequate approval process.

A retention tank is a subsurface accumulation device that temporarily collects, stores and infiltrates rainwater. When collecting rainwater from roofs, roof gutters are directly connected to a dry well, which can be either a dug pit filled with structured aggregate of 3-5 cm fraction stored in geotextile. Dry wells discharge the accumulated rainwater by infiltration into the surroundings.

For the needs of connecting a dry well with a safety overflow to maintain a safety level, the design can be designed to connect the safety overflow by connecting it to, for example, a larger infiltration area, etc., which ensures that additional runoff is drained by gravity. By capturing runoff directly at the source, dry wells can dramatically reduce the increased volume of rainwater from building roofs and paved areas.

By reducing the volume of stormwater runoff, dry wells can also reduce the velocity of these runoffs and improve water quality. As with all infiltration methods, dry wells may not be suitable for problem areas or other areas where high pollutant or sediment loads are expected. We recommend that dry wells be built at a certain specified distance from buildings, at least 10 m.



5.5 Measures in spatial planning documentation in rural areas

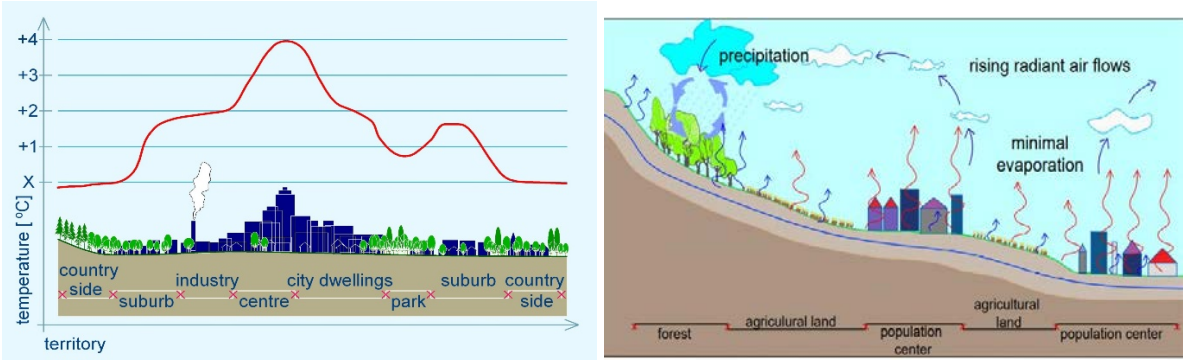
The construction of buildings, roads, parking lots, houses, or buildings is based on the principle of draining rainwater into the nearest watercourse. From all paved and covered parts of towns and villages, rainwater that used to soak into the soil and evaporate now runs off the surface, through ditches, or channels into watercourses.

As a result, built-up areas heat up the most and groundwater levels decline most rapidly. This results not only in the creation of heat islands, but also in a subsequent reduction in precipitation and the drying of wells.

This knowledge is crucial for spatial planning in order to make better and more competent decisions regarding spatial development and revitalization, not only in forest-agricultural areas, but also in urbanized areas. However, measures in urbanized areas are more technologically and financially demanding than in rural areas.

Therefore, it is necessary to incorporate these principles into spatial plans so that urbanisation does not increase the drying and overheating of built-up areas. Spatial plans underestimate the drying of built-up areas and the impact on climate change. Spatial planning requires support from public policies.

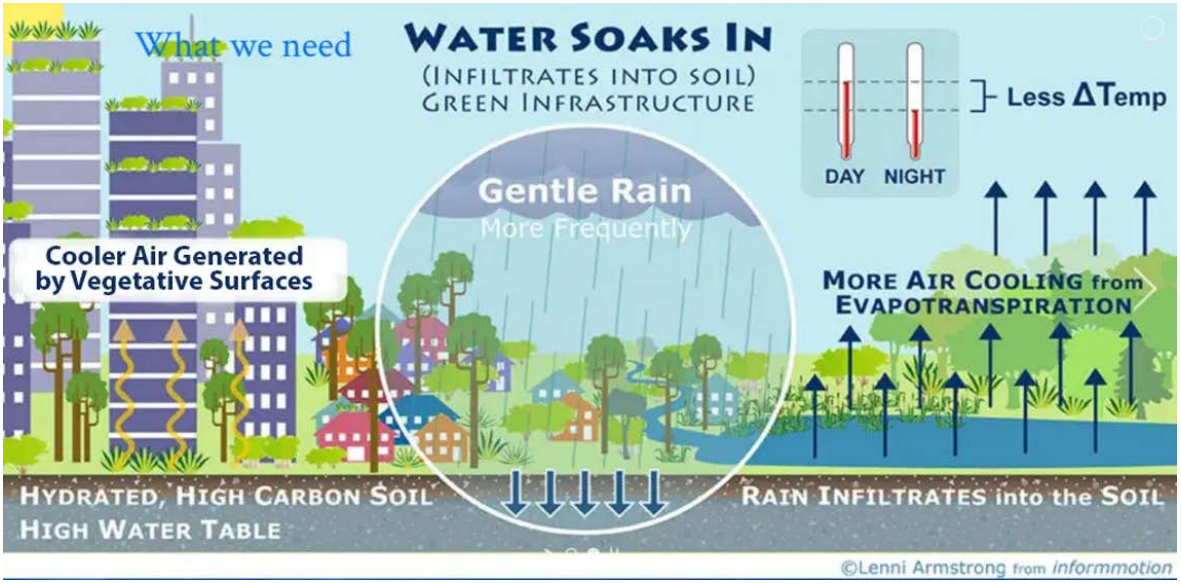
Spatial planning and construction, spatial plans define the spatial organisation and functional use of the land, determine its principles, and propose the material and temporal coordination of activities affecting the environment, ecological stability, cultural and historical values of the territory, territorial development and landscape formation according to sustainable development principles.



Heat island above urbanized environment and heat displacement from dried-up areas (decrease in precipitation) to cooler environments (increase in precipitation)

According to spatial planning, the conditions are created for the permanent harmony of all activities with special regard to environmental protection, the achievement of ecological balance and the assurance of sustainable development, the careful use of natural resources and the

preservation of natural, civilizational and cultural values. It defines the principles for the use of natural resources, conditions of the territory and the entire environment so that activities do not exceed the acceptable load on the territory[7], and ecological stability is created[8].



That means that spatial planning should create the conditions for the permanent harmony of activities that do not damage the environment, ecosystem functions, and ecological stability.

This interpretation implies that the spatial plan should include a binding section that ensures the sustainable protection and regeneration of natural resources so that they are permanently regenerated and not damaged. **Unfortunately, this is not the case in reality. The hydrological regime is constantly being damaged, thereby reducing the landscape's resilience to climate change.**

For this reason, it is necessary to define a separate chapter in the spatial plan dedicated to the sustainable preservation of natural resources and reducing civilizational impacts to zero. The fact that there is a negative change in the natural environment is evidenced by degradation of water resources, extreme weather, temporal and spatial changes in precipitation distribution, temperature extremes, loss of biodiversity, and declining soil fertility.

There is scientific evidence of the role of land use (changes in landscape structure in the distribution of solar energy, the water cycle, temperature dynamics, local and regional weather,

[7] **Section 5 of Act No. 17/1992 Coll.**: The sustainable load of an area is the load imposed on the area by human activity that does not cause damage to the environment, in particular its components, ecosystem functions, or ecological stability.

[8] **Section 4 of Act No. 17/1992 Coll.**: Ecological stability is the ability of an ecosystem to compensate for changes caused by external factors and to maintain its natural properties and functions.

and carbon sequestration) (PIELKE, 2005[9]; PIELKE et al., 2011[10]). SHEIL (2018)[11] examined links between vegetation cover and rainfall, emphasizing the importance of studying evaporation biology, aerosols, air mass movement, as well as the processes that determine rainfall and daily cycles.

This is described by the theory of biotic pumps, which explains how it is possible to maintain the temperature regime of the landscape and the distribution of precipitation without changes in functional vegetation and water cycles. The loss of vegetation and forests and the drainage of the landscape cause a transition from a healthy, climate-resistant landscape to a landscape with more frequent and extreme weather anomalies[12].

There are many unknowns in this area and little scientific knowledge based on long-term monitoring. Solving this problem and improving our understanding of the relationship between water, vegetation, and climate requires further research and developing integrated solutions that will increase the resilience of the landscape to dramatic climate change. Regenerating natural resources through ecosystem rainwater retention and NbS are the first step towards systemic change.

Increased evaporation from the landscape balances air temperature and pressure potentials both vertically and horizontally. Reduced evaporation causes heat to accumulate in the troposphere and, with cooler air in the surrounding area, increases the dynamics of the exchange of warm and cold air masses and reinforces anomalies in the atmosphere (POKORNÝ 2019)[13]. Satellite images allow for an accurate assessment of land cover and related temperature changes dating back to the 1980s[14].

Restoring degraded landscapes through ecosystem-based rainwater retention provides an opportunity for any city/municipality to develop its community in a way that also restores the landscape's resilience to climate change. The principles of land use in spatial planning based on the principle of "zero runoff from the surface" should be one of the key conditions for sustainable landscape resilience (for any type of landscape structure).

The mechanism of ecosystem-based rainwater retention in degraded ecosystems is one of the key ways in which we can restore vegetation, increase carbon sequestration, improve soil quality, restore water resources, increase spring yield, improve air quality, and use solar energy to cool any type of landscape. Most importantly, we need to reduce the production of sensible heat. Ideally,

[9] PIELKE Sr., R.A. (2005) 'Land use and climate change', *Science*, Vol. 5754, No. 310, pp.1625-1626.
[10] PIELKE Sr., R.A.et al. (2011): Land use/land cover changes and climate: modeling analysis and observational evidence. WIREs Clim Change 2, p. 828–850.
[11] SHIEL, D 2018 Forests, atmospheric water and an uncertain future: the new biology of the global water cycle *Forest Ecosystems* volume 5, Article number: 19 (2018)
[12] KRAVČÍK M., Pokorný J., Kohutiar J., Kováč M., Tóth E., New Water Paradigm – Water for the Recovery of the Climate, 2007 (http://www.waterparadigm.org/download/Water_for_the_Recovery_of_the_Climate_A_New_Water_Paradigm.pdf)
[13] POKORMÝ, J., (2019): Evapotranspiration.In:Fath,B.D.(editor in chief) Encyclopedia of Ecology,2nd edition,vol.2, pp. 292–303. Oxford: Elsevier.
[14] (https://landsat.gsfc.nasa.gov/)

we should use rainwater that causes damage during floods; instead, we can benefit from it if we retain it in the landscape.

Ecosystem-based retention of rainwater in the area has multiple benefits for water, landscape temperature, biodiversity, and landscape recovery processes. Importantly, when water evaporates during the day and solar energy is consumed in evaporation, when dew forms, that energy is released into the air and warms it[15]. This is a very important phenomenon of balancing the temperature between day and night. An example of this is dew formation. Another highly underestimated factor that influences the landscape structure is cloud formation. The more water evaporates from the land, the more horizontally scattered clouds are in the sky, which reduce the solar radiation reaching the earth's surface with more frequent occurrences of soft rain[16].

This functional model should not only be described in strategic documents and monitored and evaluated through research but also translated into legislative instruments and implemented through municipal spatial planning.

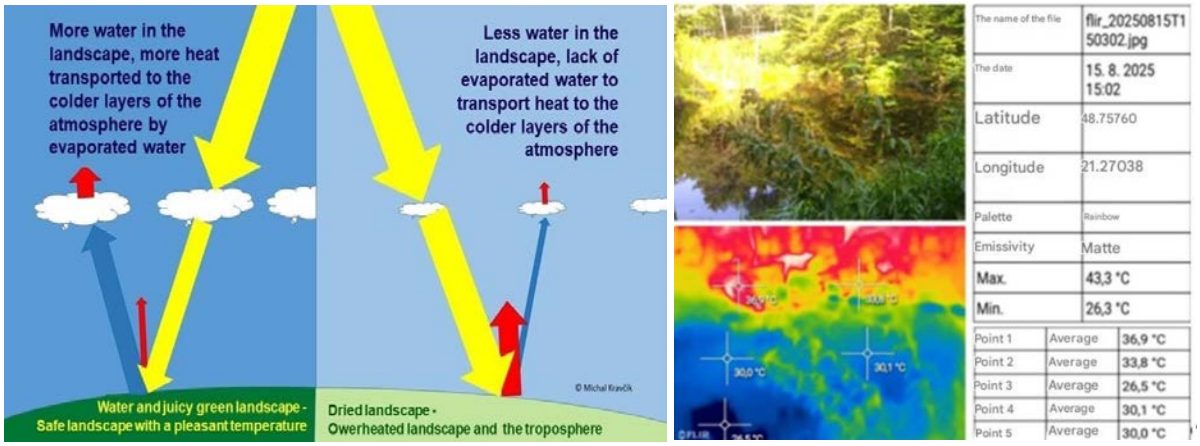
The Spatial Planning Act fully allows for this shift in rainwater management, even with the current form of legislative instruments. We need to understand that rainwater is a life-giving fluid and not waste, revitalizing ecosystems, determining the conditions for photosynthesis, i.e., vegetation growth, regulating the temperature of landscape, stimulating biological and chemical processes of life in the soil, and influencing cloud formation and rainfall[17].

Therefore, the common denominator of ecosystem restoration, atmospheric CO_2 reduction, and landscape thermoregulation is rainwater, which currently flows uselessly out of the cadastral area and contributes to local flooding. It flows into rivers and oceans, where it contributes to rising sea levels, leaving less water in the ecosystems where it is most needed. Taking measures to retain rainwater in the degraded landscape structure is exactly what we need to incorporate into spatial planning through local regulations (see diagram).

15 MITSH WJ, HERNANDEZ MI (2013) Landscape and climate change threats to wetlands of North and Central America. Aquat Sci 75: 133 – 149

16 MAKARIEVA A M, Gorshkov V G, Sheil D, Nobre A D, Bunyard P, Li B-L, 2014: Why Does Air Passage over Forest Yield More Rain? Examining the Coupling between Rainfall, Pressure, and Atmospheric Moisture Content*. Journal of Hydrometeorology, 15(1): 411-426. DOI: 10.1175/JHM-D-12-0190.1

17 HESSLEROVÁ, P., Pokorný, J., Huryna, H., Harper, D., 2019, Wetlands and Forests Regulate Climate via Evapotranspiration In: S.An, J.T.A. Verhoeven (eds.) Wetlands: Ecosystem Services, Restoration and Wise Use, Ecological Studies 238, pp 63 – 93, Springer Nature Switzerland AG



Transformation of solar energy in wet and dry landscapes. (A) More water in the landscape, more solar heat consumed by evaporation and conversion of solar energy into latent heat, and less heat released into the troposphere. (B) Less water in the landscape, less solar energy consumed for water evaporation, and more heat released into the troposphere

Increasing the capacity to retain rainwater in degraded landscapes increases the fertility of soil and groundwater reserves and supports water consumption for photosynthesis. This causes higher biomass production and its accumulation in moist soil. Carbon is stored in growing vegetation and in the soil. During photosynthesis, water evaporates (transpiration), which increases the conversion of solar energy into latent heat. This heat is then carried away by evaporated water to cooler layers of the atmosphere, where clouds form, and the amount of solar energy entering the ecosystem is reduced.

Sensible heat production decreases, the surface temperature of the land remains moderate, and the air cools (air temperature is measured at a height of 2 m = meteorological/thermodynamic temperature). This represents a practical way, based on current knowledge, to incorporate a new layer into the spatial plan that is missing from the mosaic of spatial planning.

Reflecting this need in land use through legislative norms is an appropriate form at both the national and local levels. At the local level, it is advisable to adopt generally binding regulations that set conditions for the use of land in the outer landscape (forest-agricultural landscape) and the inner landscape (built-up areas of towns and municipalities). This should be supported by national legislation.

6. Good practice

Based on the principles of ecosystemic rainwater retention through Nature-based Solutions, it is very important that each NbS can quantify how much rainwater it can retain and translate into strengthening ecosystem services. In Slovakia, more than 100,000 such water retention measures have been implemented since 2010. These measures were implemented thanks to the Landscape Revitalization and Integrated River Basin Management Program, adopted by the Government of the Slovak Republic on 28 October 2010. In 18 months between 2010 and 2012, more than 100,000 water retention measures were built in 488 municipalities with a retention capacity of 10 million

m3 at the time of implementation. This represents approximately 4% of the total planned implementation of water retention measures throughout Slovakia.

More than 11 000 people worked on the Program, which also had a social dimension. More than 7 800 long-term unemployed people participated in the implementation of NbS. The Program was coordinated by the Office of the Government of the Slovak Republic. In 2012, we documented this in the book "Po nás púšť a potopa?" (After Us, the Desert and the Deluge?)[18] . Most of these measures are still in place and fulfilling their purpose, partly because local governments were contractually obliged to implement these measures for at least 20 years.

With the support of the EU's HORIZON EUROPE program, research is being conducted on the impact of NbS on improving the hydrology of small watercourses as part of the DALIA project (www.dalia-danube.eu). The preliminary results are very promising and are suitable for replication in the DAIA river project.



Some types of water retention measures at the Kysucký Lieskovec pilot site

Nature-based Solutions (NbS) in the Kysuca river basin can also be replicated for the DAIA basin and potentially for other areas in Romania too, which are very affected by drought. The DAIA basin project can be a model for the transfer of experience to the whole of Romania.

In the Kysuca river basin, nine runoff areas (micro-catchments) were selected as pilot demonstration sites, in which the impact of NbS on flood prevention, drought and the creation of new water resources are monitored. In the example of the DAIA project, this can be enriched by

[18] www.ludiaavoda.sk/data/files/44_kravcik-after-us-the-desert-and-the-deluge.pdf

monitoring the development of the local economy, increasing the production potential of the drying land, increasing climate resilience and restoring biodiversity.

The monitored system of NbS impact at selected sites in the Kysuca river basin in the DALIA project may also be useful in the DAIA river basin within the framework of creating a living laboratory for Romania. For inspiration, we present solutions that were implemented in Kysuce with the possibility of replication in the DAIA project.



Monitoring facility for observing flows, precipitation, and water retention facilities filled with collected rainwater during heavy rainfall

We used this knowledge when designing NbS in case studies, with the possibility of replicating suitable solutions throughout the DAIA basin.



Cascade of water retention measures on periodically drying small watercourses

The basic principle is to collect rainwater in NbS and strengthen ecosystem services. All rainwater that NbS can consume for ecosystem services does not contribute to flood risks, increases the replenishment of soil and groundwater recharge, and enhances photosynthesis in the landscape. Water evaporation through vegetation cools the surrounding environment and also returns water to small water cycles. In the DALIA project, a monitoring system has been built at nine locations to monitor precipitation and flow rates.

The relationship between the implemented NbS and the rest of the DAIA basin lies in the fact that the processes occurring in the monitored spring area of the river basin influence the dynamics of the hydrological regime in the network of watercourses, streams-downstream. This means that if NbS strengthen any degraded part of the river basin in the source areas and rainwater remains in the landscape during precipitation, this also has a positive effect on the water level and flow

regime of streams and improves water resources. The same applies to low flows. This effect is cumulative; the further downstream we go, the more pronounced the impact.



Water measuring stations for measuring flows with online data transmission

If we leave the damaged landscape in its current state, the drought will be prolonged and intensified, as will the increased flow anomaly manifested in the form of more frequent and extreme floods. If the springs and small watercourses in the headwaters of the DAIA basin dry up, it will result in an increase in hydrological anomalies on the river itself and thus more frequent and extreme floods on the DAIA. The knowledge gained will therefore be very valuable for the needs of agroforestry policy recommendations and spatial planning for all types of landscapes and communities in the DAIA basin. Communities can act as innovators, addressing their own challenges, while showing solidarity and inspiration to all communities in and downstream of the DAIA basin.

The plan presented for expert and public discussion proposes to increase climate resilience by redirecting rainwater, which currently contributes to flood risks, into NbS to mitigate the risk of drought, thereby reducing climate anomalies. It is expected that a substantial portion of the rainwater will evaporate, thereby cooling the ground layers of the atmosphere. It is expected that the case studies will serve as model solutions for entire cadastral areas at least in the Transylvania region.

For a better understanding, we give an example from Košice, where the Water Holistic team operates. Here in 2005, several examples of water retention measures were implemented base on the Košice Water Protocol, which was approved by the Košice Parliament in February 2005. The implemented example clearly demonstrates that ecosystems are changing due to ecosystemic rainwater retention. Over 20 years, the previously degraded ecosystem has been fully regenerated by retaining all rainwater. It should be noted that multiple precipitation episodes during the year may occur with greater frequency when the water retention system is already full. Under such circumstances, it is possible to expect the risk of flooding with a clear transformation of flood waves anywhere, including in the DAIA basin.

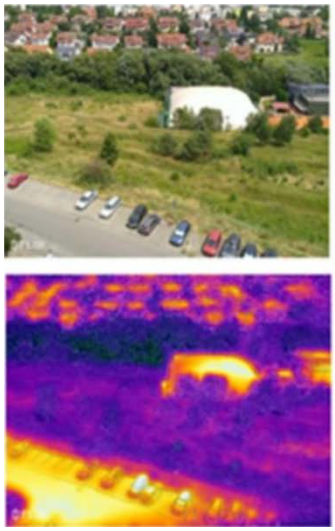
Unfortunately, the current trend in neglecting landscape care is the opposite. The result is that rainless periods are getting longer and are alternating with intense heavy rains. Where a dried landscape is revitalized, the vegetation is healthier and more abundant with a well-developed root system. This means that ecosystems can be even more resilient to climate risks. Such areas are less prone to floods and droughts. These ecosystems also warm up more slowly and subsequently cool down more gradually.

The transformation of dried-out ecosystems into areas with lush vegetation is achievable. A project in Košice (2005) confirms that NbS water retention systems can restore ecosystems very quickly if rainwater is retained on site.



Ecosystemic rainwater retention turns a degraded ecosystem into a vibrant ecosystem. Project implemented in 2005

We assume that these solutions will inspire initiatives by local governments to foster genuine partnership cooperation between public institutions, professional institutions for the protection of forests, nature, water, agricultural land, forest and agricultural landowners, as well as civic initiatives, so that all stakeholders contribute to improving water resources throughout the DAIA basin and ensure long-term sustainability and at the same time to inspire other municipalities in Romania.



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The date	11. 7. 2024 13:22
Latitude	48.72267
Longitude	21.22858
Palette	Iron
Emissivity	Matte
Max.	68,1 °C
Min.	34,2 °C



Example of water retention measures in an urban environment in Košice. Area of 3 Ha, cost €8 000. Restoration of a damaged ecosystem by collecting rainwater. In addition to vegetation restoration and a significant drop in temperature, species that were in decline (pedunculate oak) are reappearing.

For implementation of these solutions, it is essential to understand the real condition of the landscape and the extent of its degradation, and how these influences runoff conditions in specific territories. Determining the volume of rainwater that runs off without benefit is key to defining the potential for its utilization.

The foundation of water management planning, water resource protection, and flood and drought prevention is a three-step approach:

1. first capture rainwater at the place/space where it falls
2. then retain/accumulate/infiltrate rainwater into the soil
3. and finally drain the part of the rainwater that the river basin/area/landscape has not previously absorbed

This procedure also determines the main focus and priorities for comprehensive solutions: retaining rainwater in the landscape, slowing down its runoff and allowing infiltration, revitalizing and restoring degraded landscapes/territories/entire cadastral areas.

We propose preventive measures to increase the effectiveness of the existing direct technical flood protection infrastructure, health, lives, private and public property, cultural assets, and other assets of a material or non-material nature, and to protect them from direct damage caused by torrential waters and destructive floods.

One of the fundamental steps in effective flood prevention will be the restoration of the ecosystem functions of the cadastral areas of 3 communities which, thanks to its natural properties, will retain rainwater, allow it to infiltrate into the subsoil, improve soil quality, and, as part of the spatial optimization of functions, needs, and human use of the landscape, ensure its ecological stability and support biodiversity.

Climate adaptation is not only about funding

It is about rules, planning and about water. In Košice, the industrial park owner CTP made a simple but powerful decision: rainwater from transport infrastructure was redirected into the centre of a roundabout instead of the sewer system. Within one year, a dry and overheated traffic island transformed into a green oasis.



Rainwater from transport infrastructure was redirected into the centre of a roundabout (CTP industrial park, Košice)

The photos show something very important: When water stays in the landscape, climate improves. This example opens three important dimensions for municipalities and planners:

1 Technical dimension – measurable climate impact

- 100 m³ of rainwater retained per roundabout annually
- Evaporation through vegetation cools the surroundings
- Reduction of sensible heat up to 70 000 kWh per year
- Lower burden on drainage infrastructure

2 Policy dimension – spatial planning as a climate tool. Municipalities do not need to finance every climate solution. But they can define standards in zoning and spatial plans:

- Water retention is not decoration. It is decentralized climate regulation.
- Rainwater must be retained on site
- Transport infrastructure integrates retention
- Industrial and commercial zones contribute to local water cycles
- When water retention becomes a planning standard, private investment automatically aligns with public climate interest. Urban planning is climate policy.

3 Economic dimension – reducing future costs. Every cubic meter of rainwater that flows into sewers increases infrastructure pressure. Every cubic meter retained in the landscape reduces:

- Flood risks
- Urban overheating
- Long-term adaptation costs
- Energy demand for cooling

Small distributed solutions prevent large centralized expenses. This is not about chasing public subsidies. This is about creating rules that make climate-positive investment the default option. If 1,000 roundabouts per year across Europe retained 100 m³ each, we would return 100 000 m³ of water annually into local water cycles. In 10 years: 1 million m³. No new dams. No mega-projects. Just smarter standards. Water is not waste. Water is climate infrastructure.

The transformation visible in these photos proves that restoring the small water cycle is possible — quickly, affordably, and systemically. Now the question for municipalities and partners across Europe — including Germany — is simple: Will spatial planning continue to drain rainwater away? Or will it start restoring climate through water?

7. Restoration of ecosystem services in the DAIA basin

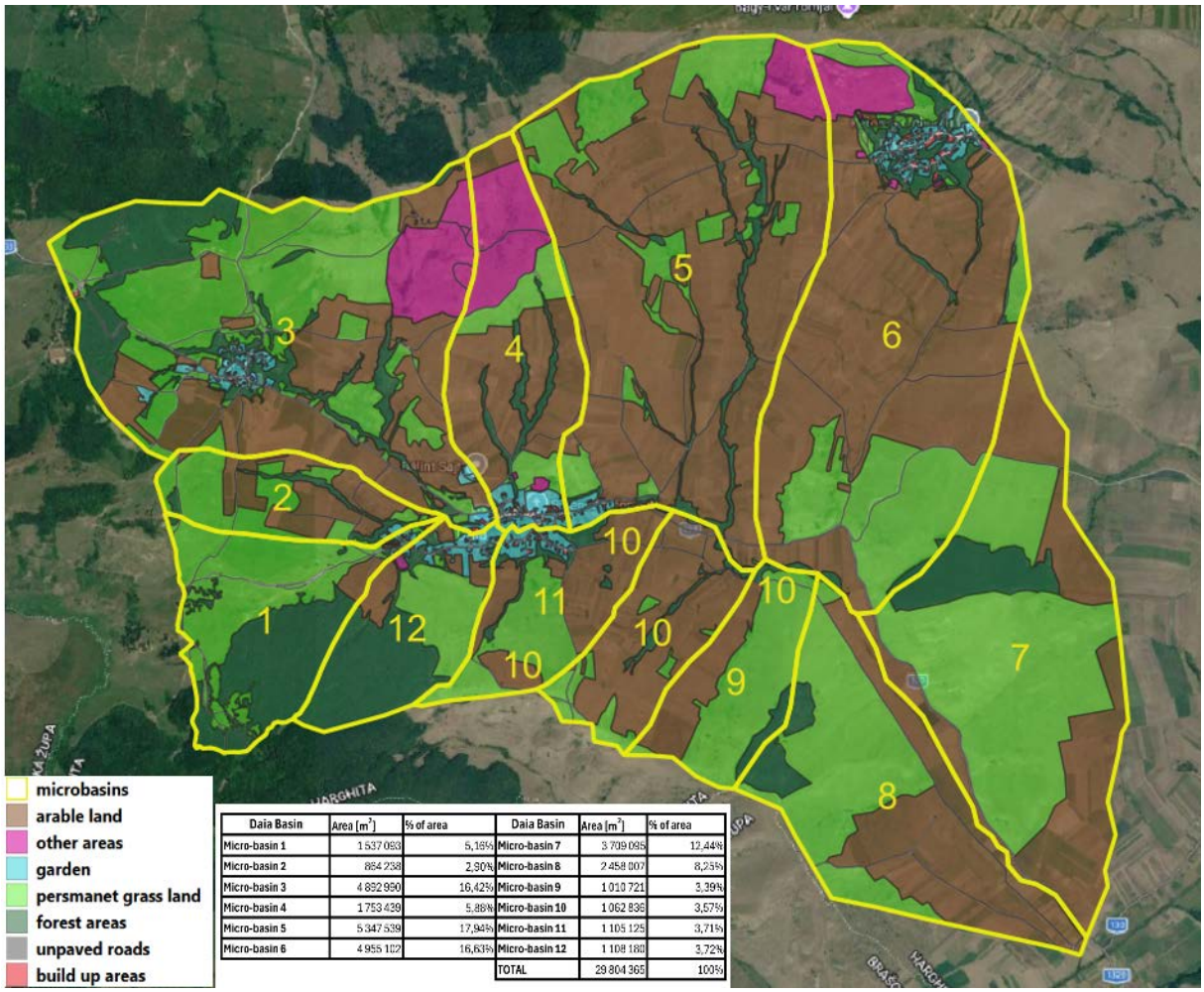
DAIA basin – an example of successful restoration of degraded landscape in Romania

Based on the hydrological analysis of the specific area in the DAIA basin, it is possible to determine the total volume of rainwater running off the area, creating flood risks during periods of heavy rainfall and at the same time contributes to drought. At the same time, the analysis offers a solution for using this useless runoff water as a source for creating water reserves in the basin, increasing soil fertility, increasing evaporation, and cooling the lower layers of the atmosphere, as defined in the SIM4NEXUS model. In other words, what is currently perceived as a problem can be transformed into a benefit. Problematic rainwater, which creates flood waves that endanger people and cause damage, must be turned into a useful resource with a multiplying positive effect.

Using the Curve Number (CN) method to calculate the volume of rainwater runoff from areas in case studies, we were able to obtain quite realistic volumes of rainwater runoff that form during short-duration intense rainfall of 60 mm.

A total of 513 000 m^3 of rainwater flows from the landscape into the river network. This volume creates a flood wave during a short, intense rainfall of 60 mm. If we look at the area of the basin, the surface runoff reaches 17,2 mm, which is not much. However, this rainwater is a unique source for landscape regeneration, provided that we are able to increase the water retention capacity of the river basin in an ecosystem-based way. Over the past 20 years (since 2005), there have been more than 40 precipitation episodes in the area, resulting in significant surface runoff of rainwater. During this same period, there were 7 episodes of precipitation activity with precipitation greater

than 60 mm. This means that at least 1,28 million m³ of rainwater flows out of the river basin every year, which, if the water retention capacity were increased, would activate ecosystem services.



Daia Basin	Area [m²]	% of area	Daia Basin	Area [m²]	% of area
Micro-basin 1	1 537 093	5,16%	Micro-basin 7	3 709 095	12,44%
Micro-basin 2	864 238	2,90%	Micro-basin 8	2 458 007	8,25%
Micro-basin 3	4 892 950	16,42%	Micro-basin 9	1 010 721	3,39%
Micro-basin 4	1 753 439	5,88%	Micro-basin 10	1 062 836	3,57%
Micro-basin 5	5 347 539	17,94%	Micro-basin 11	1 105 125	3,71%
Micro-basin 6	4 955 102	16,63%	Micro-basin 12	1 108 180	3,72%
			TOTAL	29 804 365	100%

Proposal of volumes of ecosystem-based water retention measures for individual micro-basins in the DAIA basin. The necessary plan achieves the construction of 513 thousand m³ of water retention measures

The rainwater runoff balances are also very interesting. The dominant runoff is from an agricultural landscape (59%). Forests cover 8.8% of the catchment area and contribute to 12% of flood wave formation, which is not a major impact. The state of the forest's points to their damage and thus their gradual drying out. The impact of the urbanized and transport infrastructure on desertification also has an impact. 1,4% of roofed and asphalted areas (urban areas of municipalities and transport infrastructure) contribute 3% to flood wave formation, but up to 8,8% to desertification. This is because surface runoff from precipitation on sealed surfaces occurs when precipitation exceeds 5 mm. In an agricultural landscape, it generally occurs when precipitation is approximately 4 times higher.

This suggests potential needs to use runoff rainwater from the catchment area to restore ecosystem services even in urban areas. Such an approach supports the reduction of flood risks

and drought risks and also improves the economic use of forest and agricultural land by supporting soil fertility, biodiversity protection, and increased resilience of the area to weather extremes. For this reason, we have methodically entered the DAIA basin.

The objective is to retain rainwater that runs off without benefit in the forest-agricultural and urbanized landscape in DAIA basin (2 980 ha) in order to contribute to the regeneration of natural resources and increase the resilience of the landscape to climate. Under the current conditions, rainwater runoff is artificially accelerated.

The specific objective is to create and build water-retaining landscape and terrain features in forest, agricultural and urbanized landscapes in the cadastral areas of the municipalities of the DAIA basin, rainwater retention systems, facilities, and technical solutions (NbS) with a total cyclical rainwater retention capacity that can absorb all rainfall that falls in the area with a yield of up to 60 mm.

Subsequently, these water retention systems/facilities should be operated responsibly, their functionality maintained, and their maintenance and servicing carried out. This will be a continuous, cyclical process. The specified cyclical water retention capacity is based on an analysis of precipitation-runoff conditions so that they are economically efficient with an expected yield once a year.

7.1 Restoration of degraded landscapes

The revitalization of the entire territory of the DAIA basin is a comprehensive objective of the strategic plan for economic growth on the communities, including the enhancement of food security in the context of ongoing climate change. The plan is to implement measures of ecosystem-based retention of rainwater that runs off the area without benefit and to start restoring ecosystems to renew natural resources for economic growth, while protecting the community from floods and other climate change risks. By revitalizing the landscape, taking appropriate measures and making terrain adjustments, and changing the approach to the economic use of forest-agricultural land, ensure the minimization of floodwater runoff and also reduce the production of heat islands over intensively farmed land and urbanized environments.

Extensive ecosystem-based retention of rainwater will allow this rainwater in ecosystems to develop its beneficial functions, which are essential for the long-term economic development of this part of Romania and the environmental and climate security needs of the DAIA community and inspire their neighbours.

To this end, it is necessary to improve the ecosystem-based rainwater retention techniques with the active participation of stakeholders:

1) forest landscapes

2) agricultural landscapes

3) urbanized and road landscapes.

Implementation of the Plan through the application, expansion, and refinement of various techniques, ranging from ecological revitalization of the cadastral area, through technologies for infiltrating rainwater into soil structures, to small technical measures in the area and the application of their appropriate combinations, will ensure ecosystem rainwater retention to the extent necessary for the beneficial and necessary revitalization of cadastral areas, as well as for effective and necessary preventive protection of the area against floods, droughts, and other risks of sudden natural disasters.

7.2 Necessary change in the approach to community development

The philosophy of the Plan is focused primarily on changing the approach to rainwater and the landscape, on understanding their mutual interaction and complex interconnection. The Plan is a tool for understanding the multifunctionality of rainwater in the landscape and for realizing its effective and strategically usable potential for economic growth and environmental quality.

The objective of the Plan, from this philosophical perspective, requires an understanding of the necessity to reduce the runoff of rainwater, which, instead of potentially benefiting and contributing to economic growth in the cadastral area, causes damage during periods of increased precipitation and torrential rains, when it causes floods.

The implementation of the Plan will effectively promote optimal spatial water management in the landscape, especially in agricultural and forest areas, as well as in built-up areas within the spatial planning framework. The Plan supports the restoration, revitalization, and creation of renewable natural resources (water, soil, vegetation, forest resources, etc.) and meets the demanding requirements for sustainable development formulated in Agenda 21[19].

It is a methodological approach to developing the concept of ecosystem-based restoration of water in degraded landscape structures in order to support the regeneration of degraded landscapes that will be more resistant to extreme weather conditions. To understand these relationships, we use a landscape regeneration model that promotes ecosystem-based services through the implementation of a new water paradigm[20] and can comprehensively address the need for sufficient water for people, nature, food, energy, and tourism, with the necessary need to restore the climate. It is essential to calculate the volume of rainwater runoff from extreme precipitation.

[19] Agenda 21
[20] www.vodnaparadigma.sk

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