Communities of the Roňava
River Basin for Climate Healing

HOLISTIC PLAN FOR CLIMATE RECOVERY IN THE ROŇAVA RIVER BASIN

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March 2026

Košice

Content

1. Introduction

The Roňava river basin is located in the southeastern part of Slovakia. 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 communities living in this area. The various types of flooding that occur lead to risks that have not been addressed for a long time. Due to its compact size and the way its forest-agricultural landscape is used for economic purposes, the river basin is not resilient to climate change. The region also faces 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.

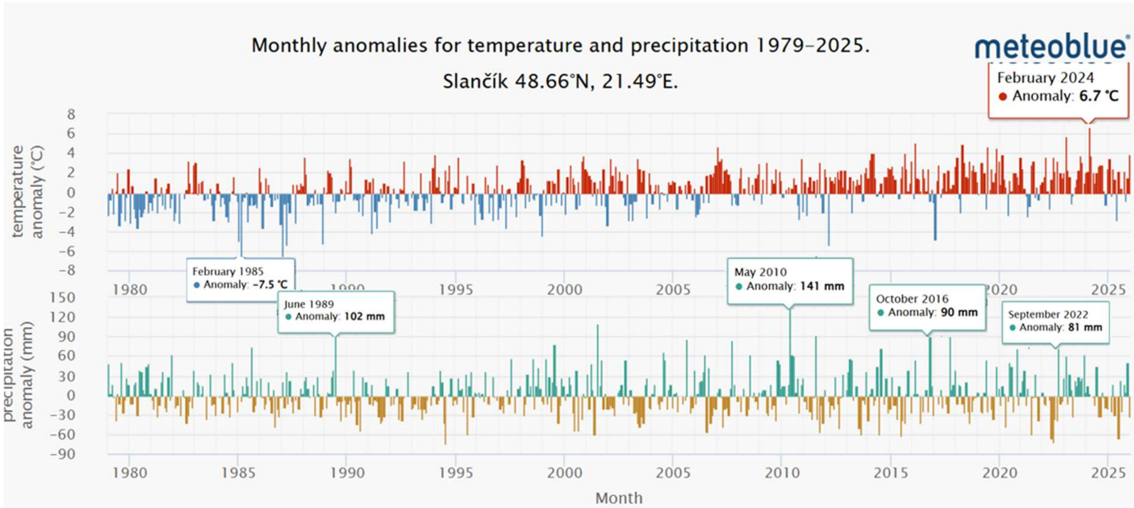
Challenges facing the region

Previous activities in the Roňava river basin, focused primarily on draining large volumes of water from the basin, were carried out with the aim of creating favourable conditions for very intensive crop production through industrial agriculture. However, this approach has led to a reduction in the climate resilience of the landscape to extreme weather events. The urgent need to increase resilience to climate change requires finding and offering solutions that prioritise slowing down rainwater runoff and strengthening the natural productive potential of the area so that the landscape can cope with adverse weather conditions and periods of drought.

2. Analysis of the current situation

The Roňava river basin, covering an area of 212 km^2 on the Slovak side, faces several long-standing serious environmental, climatic and, as a result, socio-economic problems. The more frequent occurrence of anomalous weather events in historical records confirms that, since 1980, there has been a trend of rising temperatures, with warm winters and hot summers marked by infrequent storm rains of low intensity, interrupted by episodes of intense rainfall.

There are 16 municipalities scattered across the Roňava river basin, covering an area of 192.82 km^2, with the remaining 9% of the basin area belonging to neighbouring cadastral areas, also dominated by agricultural land. The analyses we prepared in this area were based on the needs of individual administrative units, enabling public institutions to use the acquired knowledge in their decision-making during spatial planning.

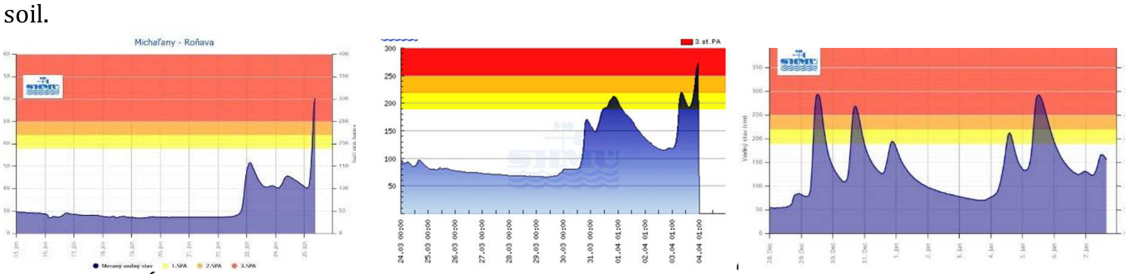


Source: www.meteoblue.com

The current use of forest-agricultural and urbanized land increases the risk of frequent flooding. Rainwater runoff through forest transport infrastructure, the management of industrialized agricultural land, supported by the drainage ditches and canalization of all roofed and paved areas, has caused very rapid rainwater runoff into the river system with very frequent flooding.

The result is the frequent occurrence of flood anomalies, which brings a new reality on two levels

Frequent flood threats are alternated with drought. The main cause of this unfavourable 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.



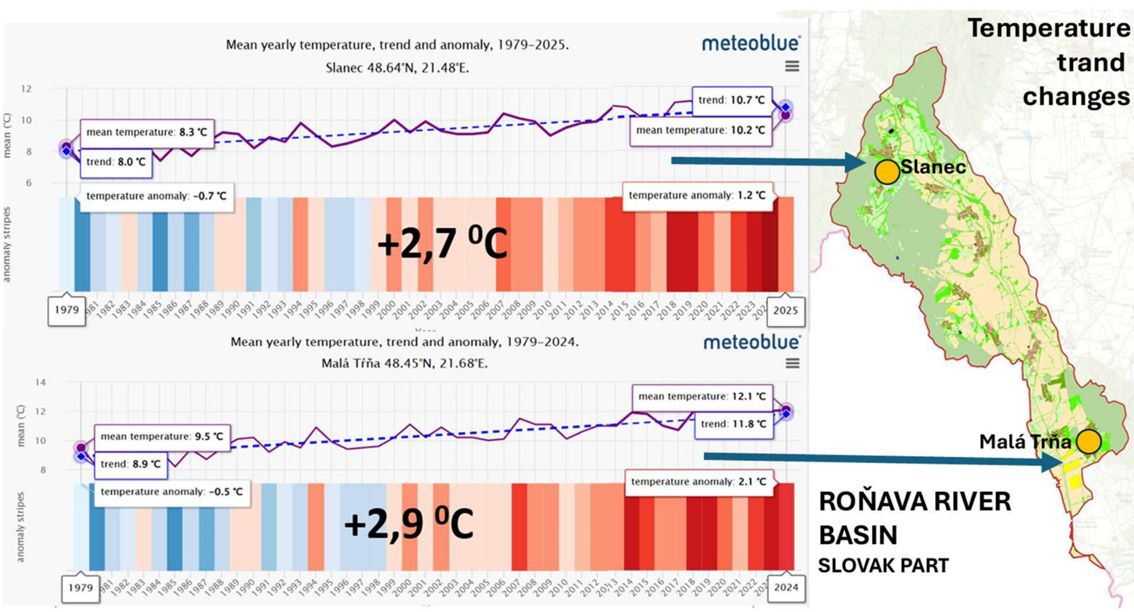
Source: SHMÚ www.shmu.sk

There are 16 communities in the Roňava river basin, 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 the municipalities. The basin is dominated by intensively cultivated agricultural land (35%), which, together with permanent grassland, accounts for more than 50% of the basin's total area. Forest ecosystems make up almost 20% of the landscape structure of the river basin, which is approximately half the percentage of forests in the whole of Slovakia.

Municipality	Arable land	Vineyard	Graden	Orchard	Permanent grassland	Forest land	Water area	Urban Area	Other Area	SUM (Ha)
Byšta	166.6	1	15	2.3	204.3	718.3	10.6	23.6	10.6	1 152.3
Čerhov	408.4	51.5	44.6	41	222.2	0	12.6	66.3	6.2	852.8
Kalša	136	0	26	4	199	40	9	44	4	462
Kazimír	666.9	1.4	48.9	0	160	24.8	15.1	58.4	17.3	992.7
Kuzmice	816.7	11.7	46.9	2.9	205.5	136.4	20.3	88.3	24.9	1 353.8
Lastovce	1 122.9	0	36.4	3.9	198.7	5.6	16.6	96	45.3	1 525.5
Luhyňa	351.5	1.3	33.4	63.3	148.4	23.3	5.4	45.3	11.5	683.5
Malá Tŕňa	146.5	323.4	30.8	119	146.8	150.4	4.4	48	11.3	980.7
Michaľany	545.9	0	49.7	0	113.6	1	10.5	88	6.5	815.2
Nový Salaš	0	0	12	3	282	772	6	11	16	1 102
Slivník	745.3	0	43.7	2.2	11.7	190.5	21.3	107.5	8.4	1 130.6
Slančík	118	0	13	0	135	25	1	22	16	330
Slanec	491	0	46	10	418	898	8	125	50	2 046
Slanská Huta	1	0	10	2	276	1 082	5	22	19	1 417
Slanské N. M.	821	0	20	11	184	1 852	12	83	43	3 026
Veľká Tŕňa	292.2	68.5	37.1	70	70.2	802.3	5	44.9	21.3	1 411.5
SUM (Ha)	6 829.9	458.8	513.5	334.6	2 975.4	6 721.6	162.8	973.3	311.3	19 281.6
Percentage %	35.42	2.38	2.66	1.74	15.43	34.86	0.84	5.5	1.61	100.00

The lower part of the river basin has favourable conditions for growing fruit and grapes. There are more than 450 hectares of vineyards and almost 850 hectares of orchards and gardens. The drying of the landscape is also influenced by reduced infiltration of rainwater into the soil profile, which also contributes to an increase in temperature. The increased temperature causes an increase in potential evaporation from the landscape. As evaporation increases, we observe that, according to SHMÚ sources, groundwater levels have declined in all monitored locations.

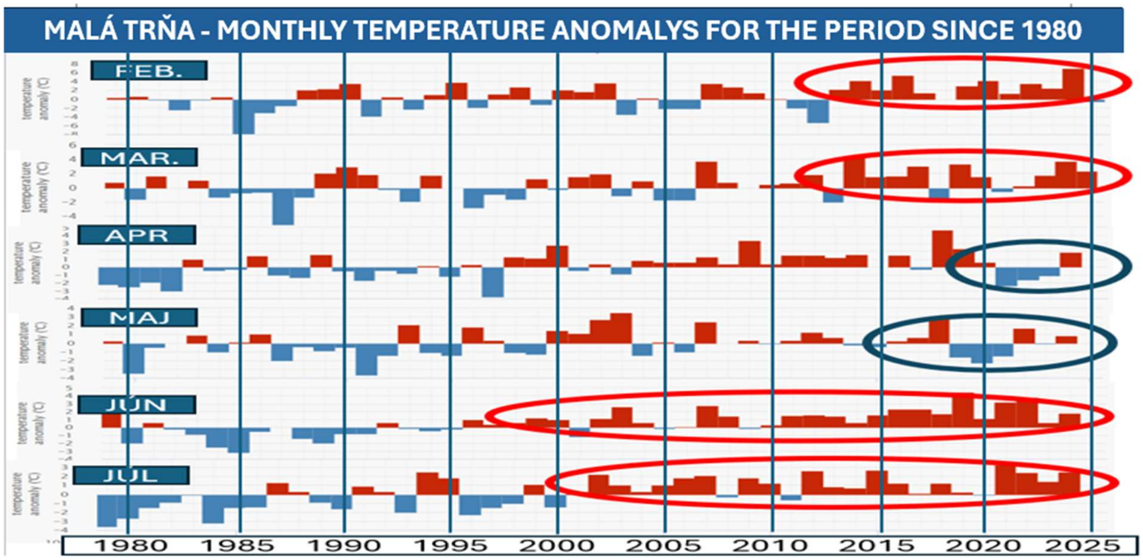
The long-term trend of rising temperatures is significant both in the mountainous forested part of the river basin and in the lowland part. In more forested areas, average annual temperatures have risen (in Slanec) by +2.7 °C. In more open agricultural landscapes, average temperatures have risen by 2.9 °C.



Source: www.meteoblue.com

This suggests that the decline in groundwater levels in the lower part of the river basin is probably even greater, as historically, the temperature increases are higher in agricultural and urbanized areas (see comparison of Slanec and Malá Tŕňa).

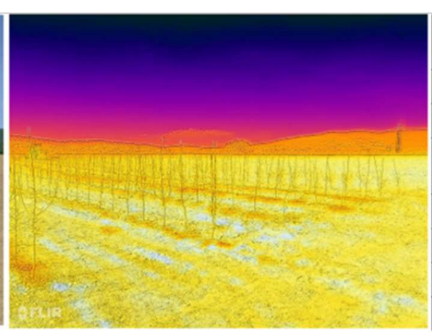
It is also very important to understand temperature anomalies throughout the year in order to recognise their relations with the agricultural industry, which is dominant here. Cultivated crops are sensitive to the temperature regime of the landscape, and in order for them to withstand dramatic weather 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.



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, 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.



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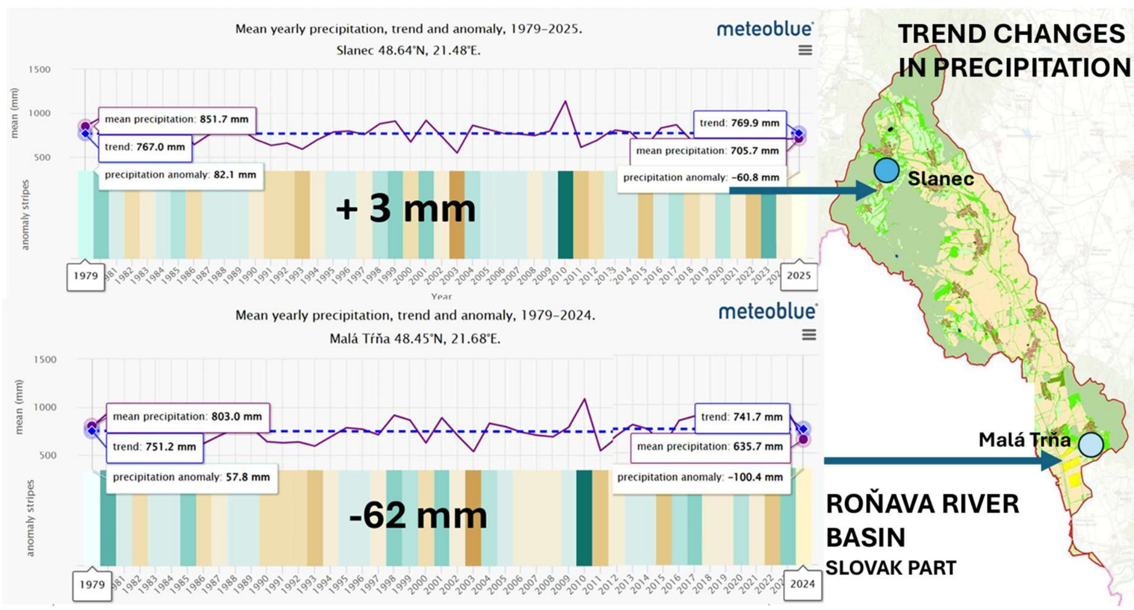
Date	1. 5. 2025 15:46
Latitude	48,45097
Longitude	21,67912
Palette	Železo
Emissivity	Matné
Max.	40,4 °C
Min.	-12,9 °C

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.

Economic use of the landscape in the recent past (1970-1990) promoted widespread drainage and subsequent drying of the landscape. This contributed to faster drying of agricultural land and subsequent overheating of the surrounding environment, and thus to a decrease in precipitation. 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.



Source: [*www.meteoblue.com*](http://www.meteoblue.com)

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 Roňava river basin:

1. Less frequent rainfall alternating with intense downpours and rapid runoff from intensively used land.
2. Landscape drying, declining groundwater levels, and loss of soil fertility.
3. Overheating of the land, increased sensible heat flux into the atmosphere, and rising ambient temperatures due to insufficient moisture.
4. The Roňava river has effectively become a canal that collects rainwater and drains it into the Bodrog, Tisa, and Danube river systems, thereby losing its function as a **stable water ecosystem.**

If no measures are taken, the Roňava river 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.

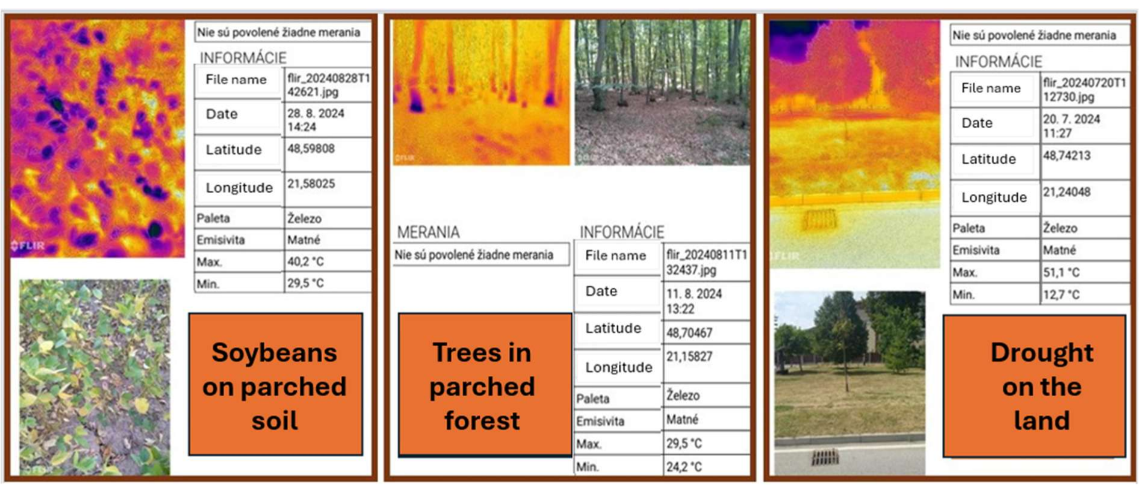
Climate change in the Roňava river basin manifests through negative effects such as reduced water availability, greater temperature extremes, alternating torrential floods and long periods of drought, and loss of soil fertility.

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.



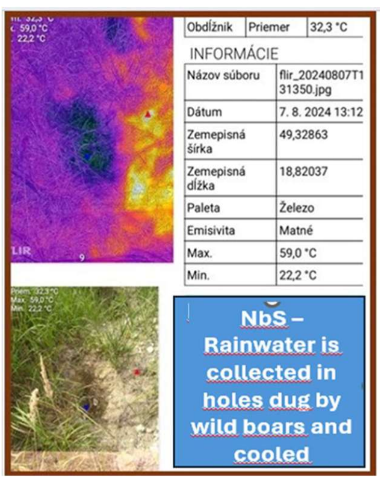
The temperature regime of forest trees clearly indicates drought, as the cooler parts of the ecosystem have tree trunks near the ground level. The upper parts of the tree trunks have a relatively high temperature, which confirms that the trees are suffering from a lack of water for their growth.

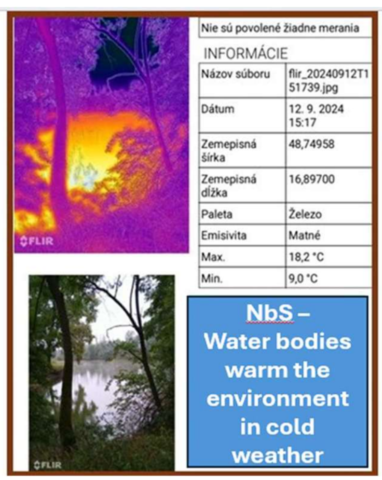
The thermal image was taken on 11 August, when the drought in Slovakia was at its peak after a previous long period without rain, which was also reflected in the dryness of the forests. Trees suffer from water deficit and therefore overheat quickly because they transpire less. This weakens photosynthesis 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.

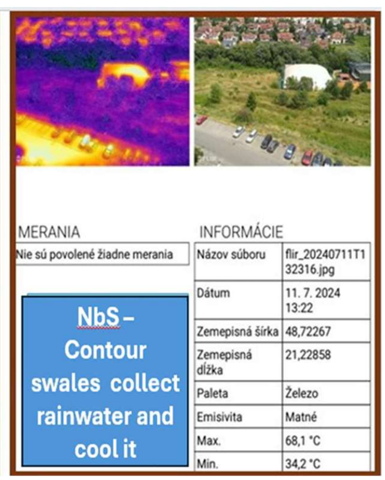
The third example of landscape temperature assessment comes from an urbanized city landscape. Here, the temperature difference between the atmosphere and the hot road surface exceeds 35 degrees. The coolest areas within tree vegetation reach temperatures of more than 45 °C, which confirms that dry grass and trees have a weak cooling effect because they lack water and, in this state, cannot contribute sufficiently to improving the climate. Unfortunately, rainwater management in the area is solved by drainage. By changing rainwater management, by collecting it in grassy vegetation and in the root zone of trees and shrubs, the climate of the ecosystem would be improved, and the temperature could drop by up to 10 °C compared to the current situation. This example highlights the potential for using rainwater in spatial planning to increase the climate resilience of ecosystems.

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. Quantification of the impact of rainwater harvesting through NbS provides the much-needed knowledge of the impact of landscape structure on climate in the LAND4CLIMATE project in a specific implementation in the Roňava river basin. The timeline from the site confirms the rapid regeneration of the ecosystem when sufficient rainwater is retained in the landscape.

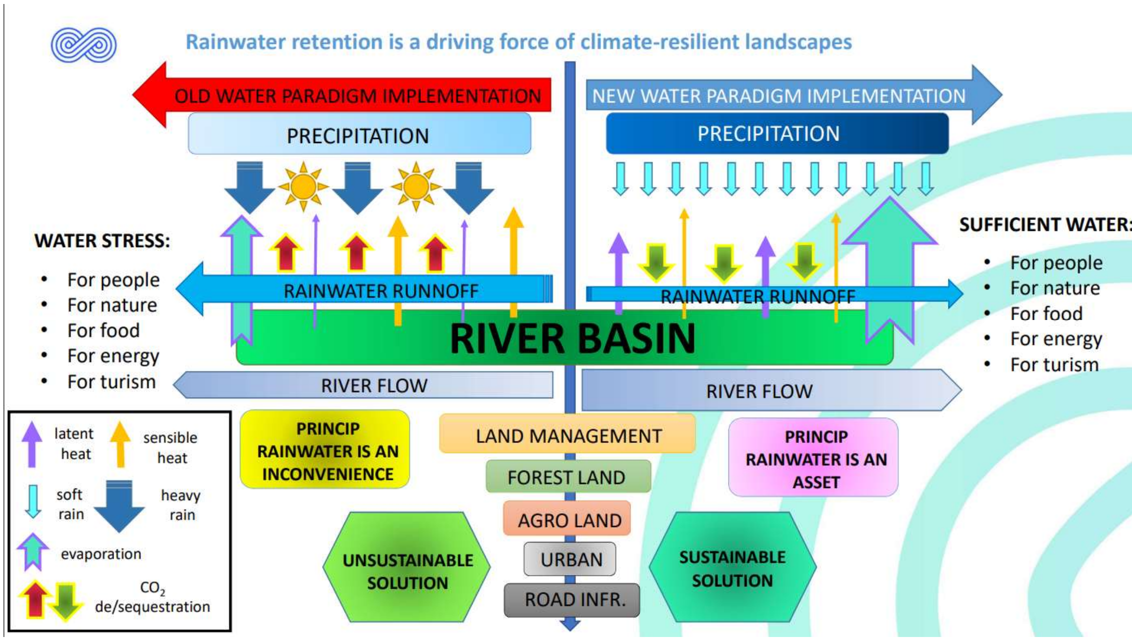
Transformation of degraded land through ecosystem rainwater retention

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. In the Roňava river basin, we selected six case study sites that are typical of the landscape structure and economic use of the land. These range from commercially managed forests, through agricultural land and orchards, to vineyards at the foot of the slopes between the Slanské hills and the lowlands, an area dominated by agricultural land.

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.

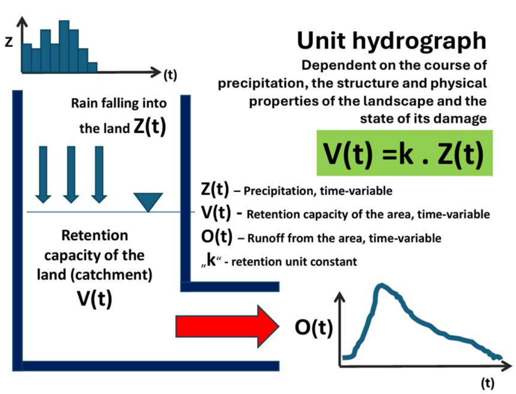
[1] Kravčík, M., Mulkerin, Z., Kravčíková, D. (2025). Climate Resiliency Through Restoration Using New Water Paradigm Methods. In: Leal Filho, W., Nagy, G.J., Ayal, D.Y. (eds) Handbook of Nature-Based Solutions to Mitigation and Adaptation to Climate Change. Springer, Cham. https://doi.org/10.1007/978-3-030-98067-2_94-1



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



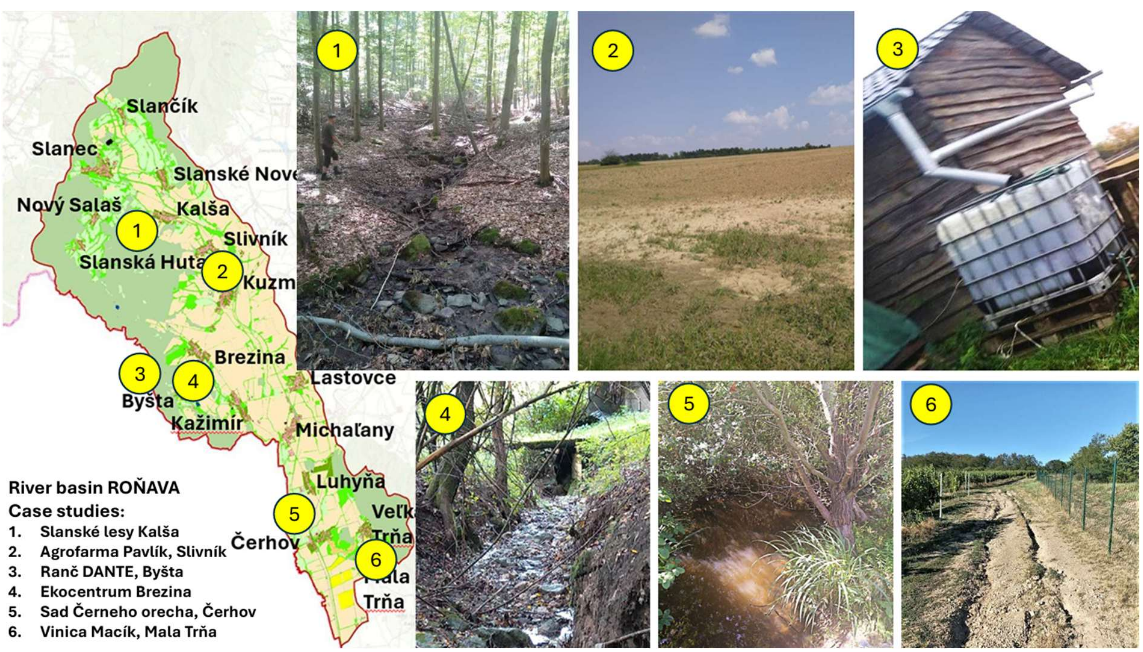
Principle of a unit diagram of rainwater runoff slowing through water retention measures in a degraded landscape

3. Case studies in the Roňava river basin

We have applied the above principles to case studies that form the backbone of model solutions that can be replicated throughout the Roňava River Basin and beyond. The following case studies were selected:

1. Slanec forests Kalša
2. Agrofarm Pavlík, Slivník
3. Ranch DANTE, Byšta
4. Brezina Eco-centre
5. Black walnut orchard, Čerhov
6. Macík Vineyard, Mala Tŕňa

These are marked on the map of the Roňava River basin along with their basic land-use characteristics.



3.1 Case study Slanec forests, Kalša

The forests are managed by the State Forests enterprise (Štátne lesy). The area was selected for the LAND4CLIMATE project to serve as a model solution for the necessary restoration of forests so that their degraded condition does not contribute to flooding, so that water remains in the forests instead of draining away without benefit, and, at the same time, provides ecosystem services in the area during ongoing climate change.

The character of the area and the extent of the damage highlight the need to manage the landscape in such a way that rainwater remains in forest ecosystems, does not contribute to flooding, and also protects the water resources used by the municipality of Kalša, which experiences flooding during periods of heavy rainfall, as rainwater quickly drains away and fails to replenish groundwater reserves.

Field research has shown that small watercourses are dry during periods without rain, and the infrastructure of forest roads, approximately 7.7 km long, according to rough estimates, also contributes to the drying of the area. The extent of erosion on roads, skidding trails, and extraction lines is documented by photographs.

Case study Slanec Forest Precipitation: 60 mm Soil: B	Unpaved road	Forest land	Total
Area [m²]	31 136	1 525 659	1 556 795
CN	82	60	93 407,70
A	55.76	169,33	934.08
H	22.81	3.49	6.47
Runoff volume [m³]	710.26	5 330.58	**6 041 m³**

Proposed water retention measures:

Considering the nature of the area in question and the problems of local flooding, we propose implementing preventive flood control measures based on Nature-based Solutions (NbS). The proposed types of solutions can utilize extreme torrential rainwater to regenerate natural resources. This chapter proposes types of measures for the area in question and the full scope of water retention measures. **The proposed measures were designed for average volumes of water retention measures and result in the following revitalization measures:**

- Small check dams with an average retention volume of 50 m^3 per unit
- Road water bars with infiltration pits (12 m^3 per unit)

Area in question	Area in m^2	Runoff volume in m^3	Types of measures in the micro-basin	Volume of measures	Number of measures
Forest land	1 525 659	5 330.58	Small check dams	5 400	108
Unpaved road	31 136	710.26	Road water bars with infiltration pits	648	54
Total	**1 556 795**	**6 040.84**		**6 048.00**	**108**

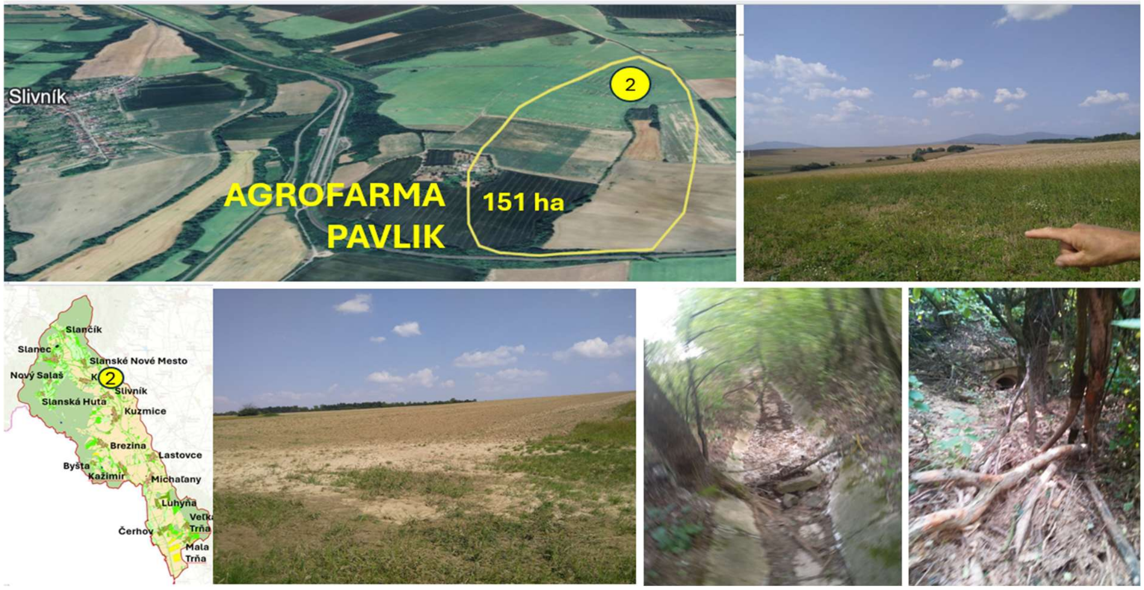
We defined the area size, the volume of runoff, the volume of the water source, the amount of water that will evaporate, increase in the increment of wood mass and total biomass, decrease in the production of sensible heat and increase in the production of latent heat, the effect on the temperature regime of the area, volume of carbon stored in the biomass.

SLANSKÉ LESY – BENEFITS of implementation	Forest	Forest roads	Total
Area (m^2)	1 525 659	31 136	1 556 795
Runoff volume (m^3)	5 331	710	6 041
Water source obtained (l/s)	1.1	0.1	1.2
Increased evaporation (m^3)	3 554	474	4 027
Estimated increased crop yield (€)	3 051	N/A	3 051
Reduction in sensible heat (GWh)	2.49	0.33	2.82
Reduction in current summer temperature (°C)	-0.08	-0.54	-0.09
Carbon sequestration (t)	427.18	8.72	435.90

3.2 Agrofarm Pavlík, Slivník

The average annual precipitation in this area is currently 720 mm. Of this amount of rainwater, around 500 mm remains in the soil and 220 mm runs off. Approximately half of it runs off the surface and contributes to water erosion in the landscape and flooding on the Roňava River. Since the potential evaporation in the area reaches around 980 mm, this means that the landscape suffers from a moisture deficit. It is therefore necessary to strengthen the retention capacity of this agricultural landscape and its water resources.

The character of the area and the degree of degradation indicate the need to address the landscape comprehensively so that rainwater remains directly in the agricultural landscape, does not contribute to flooding, and so that soil fertility and water resources are protected, more water evaporates from the landscape and returns to small water cycles, and thus thermoregulate the surrounding landscape. It is also desirable to promote more intense dew formation, especially during summer heat waves, which contributes to moisture replenishment during prolonged droughts when there is a water deficit, to enhance the growth of crops.



We observe that in the monitored area, small watercourses dry up completely during prolonged droughts, and increasing the water retention of the landscape would have a positive effect on their flow and the way agricultural land is managed. The current state of the small watercourse on the farm can be seen in the photo documentation from August 2024. A week before this, there were heavy rains that caused flooding and the stream to overflow its banks. At the time this photo was taken, the flow was almost zero (28 August 2024).

The character of the 151-hectare micro-basin was artificially altered by the construction of an embankment for the railway line. Drainage ditches were built along the embankment to collect rainwater from both the embankment and agricultural land into the valley, where flood flows are diverted through a 30-meter-long culvert under the embankment.

In front of the embankment, there is a large amount of collected biomass, which accumulates during rainwater runoff and gets caught in bushes and trees, creating uncontrollable barriers in which lakes form and become the source of breakthrough flood waves. There are even exposed cables in front of the inlets to the culverts under the embankment, which probably belong to the railway infrastructure and pose a risk of accident. The railway embankment is also at risk from flash floods. Rainwater accumulates in front of the inlets under the embankment, posing a further risk to the safety of the railway embankment.

Based on the criteria defined above, we calculated the volume of rainwater runoff for the drainage area and its landscape structure in the event of extreme torrential rainfall of 60 mm. The entire area is arable land, and for the soil and relief characteristics with the given landscape structure, the result for an extreme rainfall of 60 mm, which contributes to the formation of a flood wave, is **20,453 m³** of water.

Calculation of runoff volume with a probability of occurrence once a year using the CN curve method	**PAVLÍK Family Agrofarm, Slivník,**
Area of type B arable land [Ha]	**151.26 Ha**
CN	74
A	89.24
H	13.52
Rainwater runoff volume from intense precipitation of 60 mm [m^3]	**20 453 m^3**

Based on the character of the area and the problems of erosion and rainwater runoff, we propose implementing Nature-based Solutions in the form of soft (revitalization) measures – NbS. These soft measures require a zoning decision on land use. This combination offers multiple benefits. This chapter proposes types of measures for the area and the full scope of water retention measures. **The proposed measures were designed for average volumes of water retention measures and include the following revitalization measures:**

1. Contour infiltration strips with tree planting
2. Check dams with an average water retention volume of 100 m^3/piece
3. Roadside water retention infiltration pits: 12 m^3/piece

Area covered	Area in Ha/m´	Runoff volume in m^3	Types of measures in the micro-basin	Volume of measures m^3	Number of measures
Agricultural arable land	151.67 Ha	15 000 m^3	Contour infiltration strips	15 000	5 360 m´
Periodic high stream	1 200 m´	2 200 m^3	Small check dams	2 200	22 pcs
Roads	1300 m´	3 000 m^3	MVN/Wetlands	3 000	3 pcs
		312 m^3	Bars/infiltration pits	312	26 pcs
Total	**151.67**	**20 453** m^3		**20 512** m^3	

Ecosystem-based rainwater retention in economically utilized landscapes contributes to improving soil fertility. This is reflected in increased crop production and has a positive impact on ecosystem services (biodiversity, climate). The fundamental requirement is to quantify the impact of ecosystem retention of rainwater in agricultural land on soil fertility, increased carbon sequestration, and the restoration of water resources, with the possible quantification of landscape thermoregulation through increased evaporation through vegetation of water that previously ran off the land without benefit.

Water resources and ecosystem services can be restored by retaining surface runoff from precipitation where it falls or nearby, which is a basic prerequisite for success. Retaining rainwater in the soil or ecosystems stimulates economic growth through photosynthesis, which directly affects carbon storage in the soil. Retaining water in the landscape also increases its evaporation, resulting in higher latent heat production and its removal by evaporated water through vegetation into higher, cooler layers of the atmosphere.

Based on this framework, an analysis and quantification of the volume of rainwater runoff was carried out for the area, and measures to retain this runoff were subsequently proposed. The benefits of implementing these measures were also quantified. The following table shows the results according to the methodological procedure of the SIM4NEXUS scientific research project.

The table shows: the area of the territory, the volume of runoff, the volume of the water source created the volume of water that evaporates through vegetation, how much biomass is produced in connection with crop yield, how sensible heat production is reduced and latent heat production is increased, how this affects the temperature regime of the area, and how much carbon is stored in biomass.

PAVLIK FARM BENEFITS	Agricul. land	Roads	Total
Area in Ha	151.15	0.52	151.67
Runoff volume (m^3)	20 000	453	20 453
Estimated volume of rainwater retained per year (m^3)	151 000	3 100	154 100
Estimated water source obtained (l/s)	3.2	0.1	3.3
Increased evaporation (m^3)	51 000	1 000	5 2000
Estimated increased CO_2 sequestration into the soil	214	4.5	218.5
Reduction in sensible heat (GWh)	70	0,7	70,7
Reduction in current summer temperature (°C)	-0.6	-0.04	-0.61

3.3 DANTE Ranch Byšta

The ranch is owned and managed by the Raček family. The area was selected for the LAND4CLIMATE project because it could serve as a model solution for the revitalization of agricultural land and, at the same time, as an educational centre for disseminating information to demonstrate water management on the land to improve the water balance so that retained rainwater does not contribute to flooding on the Roňava River but provides ecosystem services on the ranch.

This area receives an average of 730 mm of rainfall per year. Of this annual precipitation, an average of 180 mm runs off. We estimate that the land consumes an average of 550 mm per year for vegetation growth and evaporation. Calculations show that during extreme precipitation of 60 mm with a short duration, 1087 m^3 of rainwater will drain from this location. There are several types of precipitation in which rainwater drains from the surface of the area.

This means that 1,088 m^3 of rainwater drains from the ranch area with 60 mm of precipitation, which is heavy rainfall with an annual probability of occurrence. This amount of water is not sufficient to cover the moisture deficit for the optimal functioning of the area, so we propose to increase the volume of the proposed NbS to 4 050 m^3.

Dante Ranch Precipitation 60 mm Soil: loamy	Arable land	Forest land	Permanent grassland	Total
Area [m²]	71 945	12 532	6 614	91 091
CN	74	60	71	
A	89.24	169.33	103.75	
H	13.52	3.49	10.77	
Runoff volume [m³]	**972.85**	**43.79**	**71.26**	**1 088 m³**

This means that 1,088 m³ of rainwater drains from the ranch area with 60 mm of precipitation, which is heavy rainfall with an annual probability of occurrence. This amount of water is not sufficient to cover the moisture deficit for the optimal functioning of the area, so we propose to increase the volume of the proposed NbS to 4,050 m³.

Based on the characteristics of the area and the problems of erosion and rainwater runoff, we propose implementing Nature-based Solutions based on soft (revitalization) measures – NbS. This chapter proposes types of measures for the full scope of water retention measures. **The proposed measures were designed for average volumes of water retention measures, which means the following revitalization measures:**

1. Contour infiltration strips with tree planting 2.5 m³/m´
2. Check dams with an average water retention volume of 100 m³/piece
3. Infiltration pit: 600 m³/piece
4. Wetlands: 300 m³/piece

Area under consideration	Types of measures in the micro-basin	Volume of measures [m³]	Number of measures	Extension of measures
Agricultural land	Contour infiltration strips	1 250	500	m´
Forest cover	Check dams (interlaced)	700	7	pcs
	Infiltration pit	600	1	pcs
Permanent grassland	Wetlands	1 500	5	pcs
Total		**4 050**		

Area of land, volume of water collected, volume of water source created, volume of water evaporated through vegetation, amount of biomass produced in connection with crop yield, reduction in sensible heat production, increase in latent heat production, impact on the temperature regime of the area, attractiveness of the environment, and amount of carbon stored in biomass.

DANTE RANCH – BENEFITS	Arable land	PGL	Forest cover	Total
Area (m²)	71 945	6 614	12 532	91 091
Volume of water retained (m³)	1 250	1 500	1 300	4 050
NbS investment €	7 500	9 000	7 800	24 300
Water source obtained (l/s)	0.25	0.30	0.26	0.81
Increased evaporation (m³)	833	1 000	867	2 700
Estimated increased crop yield (€)	288	26	25	339
Reduction in sensible heat (GWh)	0.58	0.70	0.61	1.89
Reduction in current summer temperature (°C)	-0.41	-5.33	-2.44	-1.05
Carbon sequestration (t)	20.14	1.85	3.51	25.51

3.4 BREZINA Eco-Centre

In the village of Brezina, Veronika Volachová established an eco-farm on her own land with a historic farmhouse and 0.55 ha of agricultural land. The owner's ambition is to build a rural eco-centre to provide environmental education for primary school pupils in the region.

The farmstead is located in a contact zone with a local stream that dries out seasonally. During flood conditions caused by intense rainfall, water overflows from the stream onto the land. The local stream collects rainwater from a forest and agricultural landscape covering an area of almost 93 hectares. Therefore, support for this initiative is only meaningful if cooperation with neighbours (owners of real estate, agricultural land, and forests) is ensured.

Flood flows deepen the bottom of the streambed. According to the owner of the property, the bed of the periodically drying stream has lowered by about one meter over the past 10 years. Erosion damage to the banks with frequent landslides occurs during almost every flood and contributes to the transport of mud, stones, and branches from the forests, which causes the risk of clogging historically built footbridges and private bridges. Therefore, some owners, threatened by the clogging of these built structures, are building new ones with higher permeability. A culvert has been built near the owner's property, which is frequently clogged during floods, creating a flood lake and thus threatening the property. Flood flows, combined with accumulated wood blocking the culvert, endanger the surrounding environment. This situation leads to frequent conflicts and misunderstandings when addressing these issues.

The entire area of 92.57 hectares, dominated by forests, creates a flood wave with a volume of more than 11,000 m^3 (during extreme rainfall of 60 mm). This flood wave causes all the problems encountered by owners, administrators, and the municipality itself. We calculated the volume of runoff from extreme rainfall using the CN curve method[2,3].

We assumed that by retaining rainwater that currently runs off without benefit during periods of intense rainfall, we can restore ecosystem services. Strengthening water reserves in the area is a

[2] Model solution for surface runoff from agriculturally used land (Nemetova_Zuzana_Vasekova_Barbora-Modelove_riesenie_povrchoveho_odtoku_z_polnohospodarsky_vyuzivaneho_uzemia.pdf

[3] COMPUTER APPLICATIONSINHYDRAULIC ENGINEERING (www.1library.net/article/nrcs-scs-curve-number-method-caihe-pdf.z32ew8eq)

prerequisite for both increasing biomass production through more intensive photosynthesis and enhancing CO_2 uptake from the atmosphere.

Brezina Eco-Farm Precipitation 60 mm Soil: clay loam	Forest land	Permanent grassland	Total
Area [m²]	745 289	180 444	925 733
CN	73	71	55 543.98
A	93.95	103.75	555.44
H	12.57	10.77	20.36
Runoff volume [m³]	**9 365.14**	**1 944.06**	**11 309 m³**

We assumed that by retaining rainwater that currently runs off without benefit during periods of intense rainfall, we can restore ecosystem services. Strengthening water reserves in the area is a prerequisite for both increasing biomass production through more intensive photosynthesis and enhancing CO_2 uptake from the atmosphere.

If rainwater that runs off without benefit were to be used to stop erosion and prevent droughts and floods, it would be a significant private initiative. The condition and degradation of the area show the need to address the landscape in a comprehensive manner so that more rainwater remains directly in the country's ecosystems, does not contribute to flooding on the Roňava River, and also to strengthen private interests alongside public ones. Private interest is reflected in increased biomass production and soil fertility, while public interest is reflected in the strengthening of ecosystem services.

The recommended proposal for measures for average water retention volumes includes:

1. Contour infiltration strips with tree planting
2. Check dams with an average water retention volume of 100 m³/unit
3. Water area: 600 m³/unit
4. Wetlands: 300 m³/unit

Area covered	Area in Ha/m´	Types of measures in the micro-basin	Volume of measures m³	Number of measures
Permanent grassland	18.04 Ha	Contour infiltration strips	1 944	970 m´
Periodically high streams	400 m´	Check da (interlaced)	6 865	70 pcs
Forest Land	500 m´	Water area	500	1 pcs
		Wetlands	1 450	15 pcs
Settlement	1,15 Ha	Rain gardens	50	3 pcs
		Water area on the eco-farm	500	1 pcs
Total			**11 309**	

The developed concept of ecosystem restoration of natural resources in economically utilised landscapes brings benefits for the economic recovery of damaged landscapes and also for economic growth. It also brings environmental, social, and climate benefits, enabling the Eco-centre to profit in the public interest.

Brezina ECO CENTER	Area
Area	92.57 ha
Runoff volume (m³)	11 309 m³
Estimated volume of rainwater retained per year	45 000 m³
Estimated water source obtained (l/s)	0.94 l/s
Increased evaporation (m³)	30 000 m³
Volume of increased biomass production (tons)	45.9 ton
Estimated increased CO_2 sequestration into the soil	64.3 ton
Reduction in sensible heat (GWh)	21 GWh
Reduction in current summer temperature (°C)	-0.51

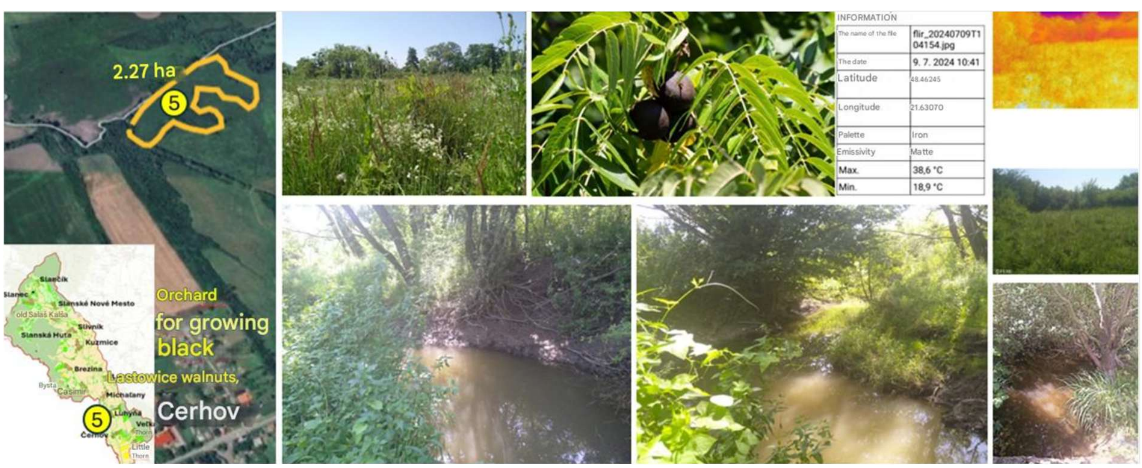
Ecosystem retention of rainwater for carbon sequestration, restoration of water resources, with the possibility of thermoregulation of the landscape through increased evaporation, can significantly improve the attractiveness of the environment and bring benefits for the functioning of the Eco-centre.

The volume of rainwater collected, the volume of water resources created, volume of water retained in the soil, volume of water evaporated, biomass production, reduction of sensible heat, and increase in heat extraction through evaporation, as well as changes in the temperature regime of the area with CO_2 consumption into biomass and soil, are shown in the following table.

3.5 Black walnut orchard in Čerhov

The site is located in the floodplain of the Roňava river in the cadastral area of Čerhov. This area is periodically flooded during flood conditions when water levels rise. The frequency of flooding is very irregular; over the past 15 years, the site has been flooded 38 times.

When water levels in the Roňava river drop, water from the flooded area drains away. We estimate that flood overflows from the Roňava river contribute approximately 100 mm to the site annually, which means an annual contribution of approximately 2,270 m³ of water to the 2.27-hectare site.



In terms of precipitation, this area has a significant moisture deficit, as the landscape consumes almost 960 mm of water annually. This is the potential evaporation that can evaporate from the land annually. Analyses of changes in precipitation distribution show that the water deficit in Zemplín region will increase. A 10-15% decrease in precipitation is expected, which will increase the risks to agricultural production potential. Although the site is in the contact zone with the Roňava river, this area is without rain during the summer months, with a deepening deficit. The planted trees were therefore unable to withstand the lack of water and dried up. Thermal images show that the temperature on the site is approximately 6 °C higher than in the surrounding area, which impairs the optimal growth of vegetation that is sensitive to water availability.

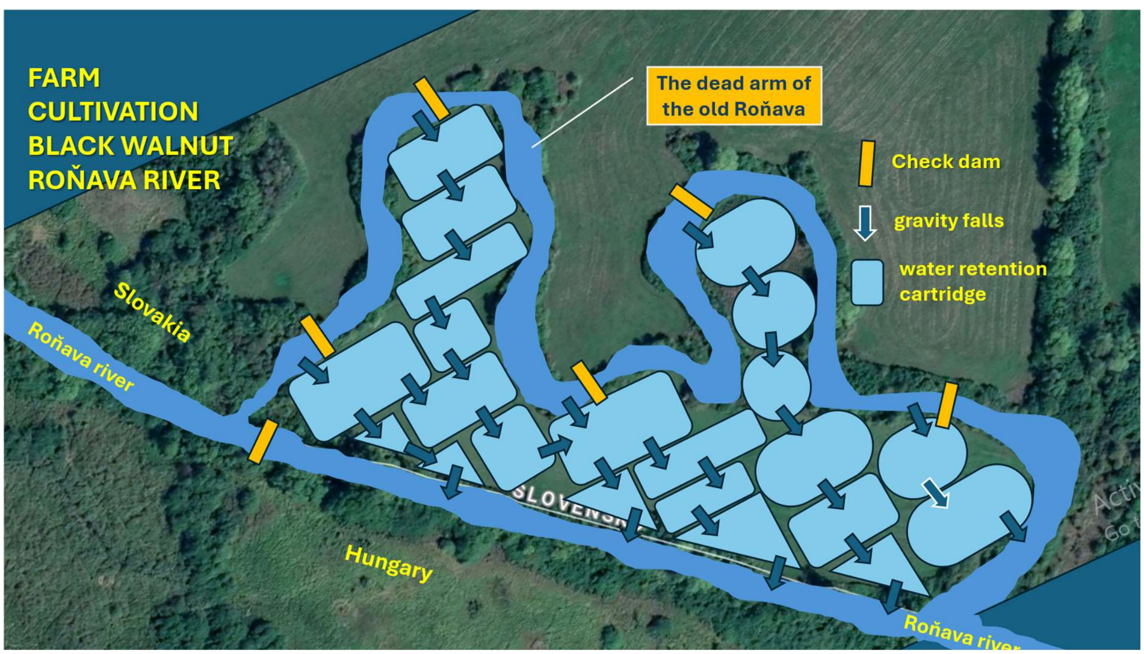
The area is interesting for a model solution not only for the Roňava river basin, but also for the entire Danube river basin, for several reasons, provided that the potential of the proximity of the Roňava river and the dried-up meandering system of the old Roňava river is utilized. We propose to implement technical solutions in the location that can ensure sufficient water for the ecosystem for optimal black walnut growth.

The technical solution consists of a comprehensive increase in water reserves in the location so that the annual water balance is increased by 950 mm (950 litres/m^2). The orchard receives an average of 573 mm of precipitation per year. We estimate that during flood waves, the volume of water flowing out of the Roňava river will increase the water balance in the area by approximately 100 mm. Nevertheless, this amount of water is not sufficient to cover the deficit in the area for the cultivation of black walnut, which requires approximately 1000 mm per year. Therefore, we propose to create conditions in the area that will increase water reserves by an additional approx. 300 mm per year, which is 7,000 m^3 in terms of volume.

By increasing the water balance in the area, it will be possible to create suitable conditions for the growth of moisture-loving trees. These are direct benefits for farmers, who will have sufficient water for optimal fruit growth. The increase in the water balance in the area will increase biomass production. As a result of this solution, the periodic spilling of water into the area will increase biomass and thus also walnut production. The estimated increase in biomass production in the area will be approximately 10 tons.

We estimate that the temperature in this area during the summer will be over 5 °C lower, as the accumulated sensible heat, which was originally accumulated in the troposphere when the sun's rays hit the earth's surface, will be transported to cooler layers in the atmosphere, both vertically and horizontally, by increased evaporation.

The solution lies in the creation of cartridges in which the spilled water will be retained, along with the revitalisation of the original Roňava riverbed. We intend to turn this into a pilot model of a bioclimatic park, which will serve the economic interests of farmers and, at the same time, as a model solution for learning about green solutions that will contribute to public interests in addressing climate change.



The foundation of the solution is to create cartridge water retention measures that will be regularly replenished during more frequent periodic floods. The site slopes downstream toward the regulated Roňava River. The objective is to restore the old, dead arm (former meander) of the Roňava, where a permanent water level would be maintained. A cascade of wooden check dams would be constructed within the restored channel to regulate and stabilize the water level in the system so that the water flows into the cartridges and remains there until it soaks into the soil to irrigate the roots of the trees. We propose to make the cartridge dams from locally sourced soil; their height should not exceed 0.5 meters.

3.6 Macík vineyard in Kráľová in Malá Tŕňa

The locality of Kráľova, in the cadastral area of Malá Tŕňa, is situated in the eastern part of the village at the foot of a forest with a southwestern exposure of the slope and covers an area of approximately 25 hectares.

During intense rainfall, rainwater runs off relatively quickly from the vineyard, causing a flood risk for the built-up area of the village. Forest roads above the vineyard also contribute to local flooding. In the upper part of the area, there is a vineyard planted with grapevines with relatively stable rainwater runoff from the site.

The soil structure is poor in organic matter, so when rainwater hits the soil, it easily crumbles and breaks up. This effect is further intensified by the long runoff line, which is around 250 m. With a slope of 12%, the rainwater gains kinetic energy and causes soil erosion. Consequently, not only does rainwater run off the area, but part of the topsoil and nutrients are also washed away.

Given the nature of the soil, when establishing vineyards, it is necessary to focus on enhancing photosynthesis in vine cultivation. Experience from organic farming shows that natural soil fertilisation through enhanced photosynthesis enriches the soil with organic matter.

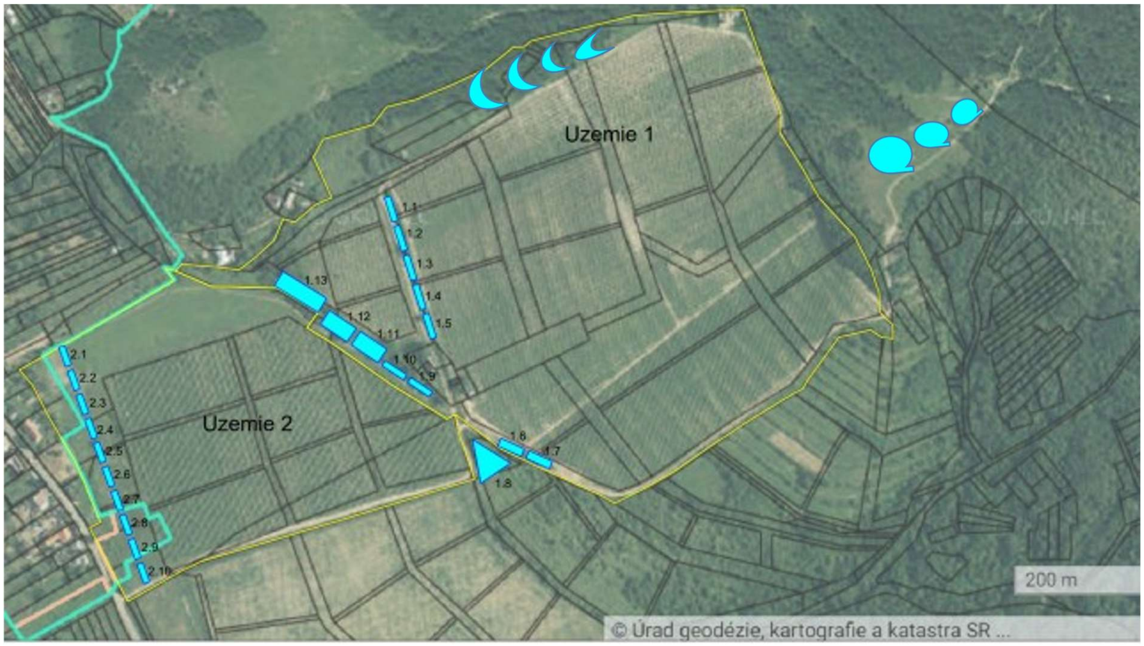
Rainwater runoff volume calculations at two locations. The upper location has an area of 17.7 ha. The total runoff volume from the upper location during extreme precipitation of 60 mm reaches 5,125 m³. For more details, see the table.

Upper location **Precipitation 60 mm** **Soil: clay**	**Vineyard**	**Garden**	**Permanent grassland**	**Forest land**	**Built-up area and courtyard**	**Other areas**	**Total**
Area [m²]	141 351	684	3 867	18 171	358	9 938	174 369
CN	87.00	62.00	79.00	77.00	86.00	94.00	10 462.14
A	37.95	155,68	67.52	75.87	41.35	16.21	104.62
H	30.40	4.51	18.96	16.65	28.75	44.15	48.98
Runoff volume [m³]	**4 297**	**3**	**73**	**303**	**10**	**439**	**5 125 m³**

Lower location **Precipitation 60 mm** **Soil: clay**	**Arable land**	**Permanent grassland**	**Total**
Area [m²]	70 221	7 163	77 384
CN	89.00	85.00	4 643.04
A	31.39	44.82	46.43
H	33.91	27.17	55.47
Runoff volume [m³]	**2 381**	**195**	**2 576 m³**

According to our calculations, 7,220 m³ of water flows out of the vineyard during a torrential rainfall of 60 mm. Based on the characteristics of the runoff areas and the impact on the formation of local floods, we propose water retention measures (see diagram) using water collection measures that will retain rainwater directly in the vineyard and collect it cyclically, contributing to the improvement of water reserves in the area, as well as strengthening the formation of horizontal precipitation and ensuring sufficient water for optimal vine growth. This will also contribute to carbon storage in biomass and soil, and contribute to soil fertilization. We recommend the following four types of measures for this location:

1. Wetlands and water bodies above the vineyard (prevention of rainwater runoff from the forest)
2. On the right side of the vineyard, below the apiary, strengthening hydromorphism as part of ecological biodiversity
3. Strengthening water retention directly in the vineyard
4. Preventing rainwater runoff from the vineyard



Implementing water retention measures in the vineyard will significantly reduce flood risks in the village and, at the same time, stop the drying out of the area, increase water reserves, increase the fertility of the vineyard, strengthen biodiversity, and make the vineyard and its surroundings more attractive. In the near future, environmental security and competitiveness will depend on sufficient water for people, food production, nature, and a healthy climate.

4. Proposed NbS solutions for case studies

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 m^3 at the time of implementation. This represents approximately 4% of the total planned implementation of water retention measures throughout Slovakia.

Political misunderstandings and a change in political course in Slovakia in 2012 caused the termination of the entire Program. This was also one of the reasons why parts of the scientific community in Slovakia were hesitant to conduct a comprehensive research evaluation of its impacts. 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?)[4]. 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.

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

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 LAND4CLIMATE 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 Roňava river basin and potentially for other areas in the LAND4CLIMATE project.

In the Kysuca river basin, nine runoff areas (micro-catchments) were selected as pilot demonstration sites. Water retention measures such as check dams, diversion bars with infiltration pits, contour infiltration strips, etc, were implemented in five of them. In the remaining four micro-catchments, no NbS were implemented. These serve as control sites, enabling comparison and assessment of how NbS influence spring yields and the increase of minimum flows during dry periods.

The monitored system of NbS impact at selected sites in the Kysuca river basin in the DALIA project may also be useful in the Roňava river basin within the LAND4CLIMATE project. For inspiration, we present solutions that were implemented in Kysuce with the possibility of replication in the LAND4CLIMATE 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 Roňava river 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 Roňava river 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, and rivers 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 degraded 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 Roňava river 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 Roňava. 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 Roňava river basin. Communities can act as innovators, addressing their own challenges, while showing solidarity and inspiration to all communities in and outside the Roňava river basin.

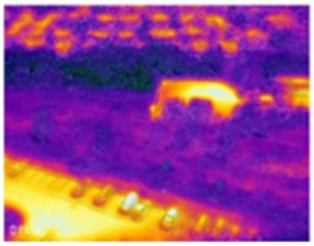
The plan presented for expert and public discussion proposes to increase climate resilience by redirecting rainwater, which currently contributes to flood risks, into NbS to mitigate the risk of drought, thereby reducing climate anomalies. It is expected that a substantial portion of the rainwater will 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.

This recommendation is also supported by the water retention system that was implemented in Košice in 2005. 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 Roňava river basin.

Unfortunately, the current trend is the opposite. Rainless periods are getting longer and are alternating with intense heavy rains. Where a degraded 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 (2004) confirms that NbS water retention systems can restore ecosystems very quickly if rainwater is retained on site.

We assume that these solutions will encourage initiatives by local governments 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 Roňava river basin and ensure long-term sustainability.



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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 area*, 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.

5. Restoration of ecosystem services in the Roňava river basin

Roňava river basin – an example of successful restoration of degraded landscape

Based on the hydrological analysis of the specific area in the Roňava river basin, it is possible to determine the total volume of rainwater running off the area, creating flood risks during periods of heavy rainfall. 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 water, 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.

Municipality	Arable land	Gardens	Grasslands	Forest land	Urbanized lands	Other lands	Total m^3
Byšta	19 409	1 532	11 575	25 097	5 384	968	63 965
Čerhov	47 579	11 477	12 589	0	15 124	566	87 335
Kalša	15 844	2 511	11 275	1 398	10 037	365	41 430
Kažimír	77 694	4 211	9 065	867	13 322	1 580	106 739
Kuzmice	95 146	5 148	11 643	4 766	20 143	2 275	139 121
Lastovce	133 818	3 374	11 258	196	21 899	4 138	174 683
Luhyňa	40 950	8 204	8 408	814	10 334	1 051	69 761
Malá Tŕňa	17 067	39 613	8 317	5 255	10 950	1 032	82 234
Michaľany	63 598	4 161	6 439	35	20 074	596	94 903
Nový Salaš	0	1 256	15 977	26 973	2 509	1 462	48 177
Slivník	86 828	3 842	663	23	24 522	767	116 645
Slančík	13 747	1 088	7 649	873	5 019	1 462	29 838
Slanec	57 202	4 688	23 683	31 376	28 514	4 568	150 031
Slanská Huta	117	1 005	15 637	37 805	5 019	1 739	61 322
Slanské N. M.	95 647	2 595	19 425	84 708	18 934	1 328	222 637
Veľká Tŕňa	34 031	14 700	3 977	28 032	10 242	1 946	92 928
Runoff total m^3	798 677	109 405	177 580	248 218	222 026	25 843	1 581 749
Percentage %	50.5	9.26	2.26	7.26	14.0	46174	100.0

A total of 1.582 million 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 river basin, the surface runoff reaches 8.2 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. This means that at least 3 million m^3 of rainwater flows out of the river basin every year, which, if the water retention capacity were increased, would activate ecosystem services.

The rainwater runoff balances are also very interesting. The dominant runoff is from an agricultural landscape (66%). It is worth noting the share of urbanized areas (built-up areas of municipalities), which account for 5% of the territory but contribute to 14% of flood formation. Forests cover less than 20% of the catchment area and contribute to 16% of flood wave formation. This is important mainly because public opinion during floods often focuses on the impact of damaged forests on the flood situation, but their share is approximately equal to the impact of soil sealing, roofing, and urbanization of the surface in built-up areas of cities and municipalities. The public seems to be completely unaware of this. The impact of the urbanized environment on desertification is even more pronounced. This is because surface runoff from precipitation on sealed surfaces occurs when precipitation exceeds 10 mm. In an agricultural landscape, it generally occurs when precipitation is approximately three times higher.

This suggests potential opportunities to use runoff rainwater from the catchment area to restore ecosystem services. 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 projected case studies onto all cadastral areas in the Roňava river basin. The results of the runoff analysis are presented below.

The objective is to retain rainwater that runs off without benefit in the forest-agricultural and urbanized landscape in the 212 km² Roňava river basin in all cadastral areas of the municipalities of Košice Vidiek and Trebišov in order to contribute to the regeneration of natural resources and increase the resilience of the landscape to climate. Under the current conditions of the cadastral areas, 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 Roňava river basin, *water 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 in the drainage areas so that they are economically efficient with an expected yield once a year.

5.1 Restoration of degraded landscapes

The revitalization of the entire territory of the Roňava river basin is a comprehensive objective of the strategic plan for economic growth in the region, 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 Slovakia and the environmental and climate security needs of the Košice region.
To this end, it is necessary to improve the ecosystem-based rainwater retention techniques in:

1. forest landscapes
2. agricultural landscapes
3. urbanized 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.

5.2 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[5].

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[6] 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.

6. 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), municipal spatial plans, 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 municipal 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. The Appendix provides proposals for water retention volumes that need to be implemented in the cadastral areas of each municipality, as well as recommendations for forests, various types of agricultural land, and urbanized areas.

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.

6.1 Benefits of water retention measures

The Plan is structured so that it can be implemented at various levels. The plan can be implemented by any owner or manager of an entire forest-agricultural landscape or part of an urbanized area with real estate. The Plan can also be initiated by a public figure who perceives the need to promote or activate public ecosystem-based services beneficial to the public. The aim is to improve the climate in

[5] Agenda 21
[6] www.vodnaparadigma.sk

the environment where such stakeholder operates or has impact on decision-making in public policies for forestry, agriculture, water management, regional development, nature conservation, biodiversity, and climate in favour of sustainable development.

ROŇAVA RIVER BASIN	Arable land	Gardens	Permanent grassland	Forest land	Urbanized lands	Other lands	Total
Area [Ha]	6 829.9	1 306.9	2 975.4	6 721.6	973.3	311.3	19 118.4
Created water retention volume [m^3]	798 677	109 405	177 580	248 218	222 026	25 843	1 581 749
Estimated volume of rainwater retained [m^3/year]	1 836 957	153 167	266 370	322 683	1 998 234	180 901	4 758 313
Estimated investment costs [€]	9 584 124	1 312 860	2 130 960	2 978 616	8 881 040	775 290	25 662 890
New water source acquired [m^3/year]	600 000	63 000	95 000	95 000	662 000	63 000	1 577 000
Increased water evaporation from the land [m^3]	1 224 638	102 111	177 580	215 122	1 332 156	120 601	3 172 208
Increased moisture formation [m^3]	3 414 950	653 450	1 487 700	3 360 800	486 650	155 650	9 559 200
Increased water supply in ecosystems [m^3]	4 639 588	755 561	1 665 280	3 575 922	1 818 806	276 251	12 731 408
Estimated increased biomass production [ton/year]	9 279	1 511	3 331	7 152	3 638	553	25 463
Reduction in sensible heat [GWh/y]	3 247 712	528 893	1 165 696	2 503 146	1 273 164	193 375	8 911 986
Reduction in average annual temperature [°C]	-1.20	-1.02	-0.99	-0.94	-3.30	-1.57	-1.17
Carbon sequestration [ton/year]	12 991	2 116	4 663	10 013	5 093	774	35 648
Carbon credit [€/year - at price 77.53 €/t]	1 007 180	164 020	361 506	776 276	394 834	59 970	2 763 785
Return on investment on carbon credit [years]	10	8	6	4	22	13	9

Estimated quantification of benefits after implementation of the Plan in the entire Roňava river basin

The proposed plan has a relatively high return on investment. With an investment of €25.66 million in carbon credits, the money invested would be recovered within nine years. The proposed solution has other significant benefits. In addition to minimizing damage from natural disasters, the water regime in the country will be stabilized with the creation of water sources with a yield of 50 litres per second. In annual volume, this is more than 1.5 million m^3 of new water resources in the area, which would improve the region’s economy. The plan also provides solutions for the restoration of forest ecosystems. Biomass growth in ecosystems would increase by approximately 25,000 tons, which would result in an increase in annual wood increment of 8,000 tons/m^3, which would improve the economic performance of commercially exploited forests and also provide sufficient food and water to sustain wildlife. The plan will have a significant impact on the climate. Estimates show that average summer temperatures could drop by almost 1.2 °C.

When additional benefits are included—such as the creation of new water resources and increased timber and agricultural production—the total annual benefits are estimated to exceed €4 million. In such a case, the investment could be recovered in less than 7 years. We therefore 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 the economic benefits, the public interest (protection of water resources, climate, wellbeing, and safety of the population) is to ensure sustainable prosperity in rural areas for decades to come.

Appendix 1 lists the benefits, by individual cadastral areas and structures, that revitalization will have on water resources, biomass increment, changes in temperature regime, and carbon sequestration. The plan can also be implemented in stages, and we recommend applying it in cooperation with local governments, foresters, farmers, water managers, fishermen, and conservationists.

The tables also quantify the contribution of landscape revitalization to annual CO_2 storage through photosynthesis. Municipalities can, at their own discretion, offer emission allowance holders the opportunity to invest their allowances in the land registry, thereby giving the municipalities in the river basin a competitive advantage.

In addition to creating new water sources, soil fertilization, increasing timber production, and improving the temperature regime of the landscape, NbS also contribute to the protection of biodiversity.

Proposed 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.***

6.2 Measures in forest landscapes

Forest ecosystems cover almost 20% of the Roňava river basin. They contribute to almost 16% of flood waves. During an intense rainfall event of 60 mm, nearly 250,000 m^3 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 (250,000 m^3)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 communities in the Roňava river valley.

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.

Brushwood check dams in ravines

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)

Wooden check dams

In locations where brushwood dams are not suitable, wooden check dams of various types are proposed, depending on local conditions and materials available. They are particularly suitable for upper sections of erosion gullies. Their design and construction depend entirely on local conditions. They can be made of waste wood, arranged in a cascade in damaged areas where the depth does not exceed 2 meters.

New wooden check dams on the stream have slowed down the water and stabilised the riverbed

The result of volunteer-built check dams in a dry erosion gully after 30 years

Log check dams

Log check dams are recommended for dry gullies, positioned upstream of stone check dams in sequence. The dams can also be built from waste wood. We recommend using local wood directly from the site where the dams will be built.

Log and stone dams (Matysová, 2012)

Stone check dams

In locations where there is an abundance of local stone, we propose building stone dams up to 1 meter in height. If higher dams are required, we recommend using quarry stone with a diameter of 30-80 cm. These types of measures are suitable in the valley parts of gorges with a maximum height of up to two meters. Lower dams up to 1.5 meters will be installed at the end of the valley before the confluence with the main stream of the micro-basin. In cases where only small local stone with a fraction of 5–30 cm is available, we propose levelling the dam with wooden beams to ensure structural interlocking between wood and stone.

Stone dams with the creation of wetlands by earthen dams

Gabion check dams

Gabions are suitable in the lower parts of the basin/gully/runoff area as the last check dam on small streams before infrastructure elements. For example, along a road, to prevent residual sediments from flooding the road. They are suitable for periodically drying ravines and small, insignificant watercourses.

Trench baskets are suitable for use in small watercourses. They should be placed in straight sections of the stream, not in bends or immediately after bends. Trench baskets must not exceed 1 meter in height.

Image: Impact of gabions on sedimentation in water retention areas

Water bars on unpaved roads with infiltration pits

We propose standardizing water bars on roads so that each water bar is accompanied by a water retention pit. The recommended types of water bars are listed below. However, it is essential that rainwater from the water bar 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 10 m^3 for each water bar, which in practice means that water bars must be installed every 40 m along forest roads and skid trails. 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.

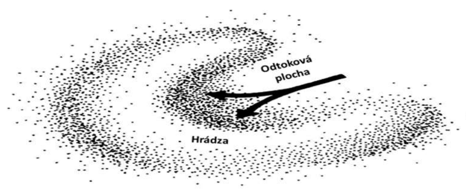
Water bars with infiltration pits

We recommend creating water bars from a combination of materials, especially wood, depending on financial possibilities. The water bar directs rainwater into the infiltration 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. Water bars 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 water bar network.

6.3 Measures in land management in agricultural landscapes

Micro-reservoirs and wetlands

Micro-reservoirs are suitable for use in gently sloping or nearly flat terrain with low runoff capacity, such as along pathways, in landscaped areas, parks, along parking spaces, etc. They can also be used in areas with higher water concentration if they are arranged in series with overflows from one to another. Micro-reservoirs are generally unsuitable for alluvial deposits/gullies and other locations with heavy runoff. Each site is unique; the appropriate range of methods of rainwater retention must be based on the specific environmental conditions. Micro-reservoirs gradually create wetlands and buffer zones for wildlife.



Schematic diagram of micro-reservoirs and wetlands in agricultural landscapes

Contour infiltration strips

On permanent grassland and arable land, we recommend contour infiltration strips planted with fruit trees. The recommended spacing between strips is, on average, approximately 50 meters. It is advisable to build them at a distance of every 20 meters to prevent the collected rainwater from running off.

Infiltration strips in an agricultural landscape

Small water reservoirs

Within cadastral areas, we also recommend constructing small water reservoirs that can serve as basic infrastructure for recreational water bodies with potential fish farming. Small water reservoirs have a constant water level and storage capacity to retain part of the flood wave. They will be eco-stabilizing elements in the agricultural landscape, contributing to the increase of groundwater reserves. Increased evaporation of water from small water reservoirs will gradually improve the microclimate. These measures will also contribute significantly, for example, to the formation of dew in the countryside, which is important for maintaining moisture in agricultural land during dry periods. This measure is also a preventive measure against drought, which creates a risk of fire. Small water reservoirs should be constructed with an outlet structure.

Small water reservoirs

Small water reservoirs 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 the land consolidation plan, forest management plan, and also the municipal/city zoning plan, with motivational support from the local government for all stakeholders.

6.4 Measures in spatial planning documentation in rural areas

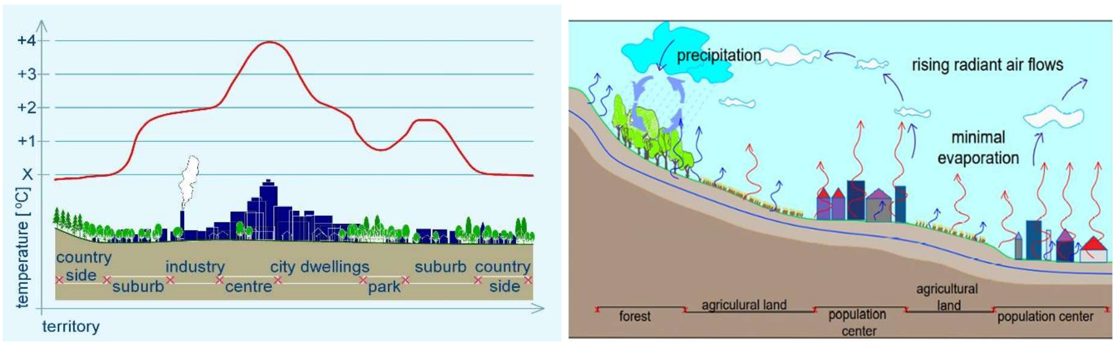
The construction of buildings, roads, parking lots, houses, or buildings is based on the principle of draining rainwater into the nearest watercourse. From all paved and covered parts of towns and villages, rainwater that used to soak into the soil and evaporate now runs off the surface, through ditches, or channels into watercourses. In the Roňava river basin, urbanization (built-up areas and transport infrastructure) covers 5% of the area, but accounts for up to 14% of the runoff from the basin. In terms of volume, this is 222,000 m3 of rainwater that flows from built-up areas in the basin, causing them to overheat quickly.

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.

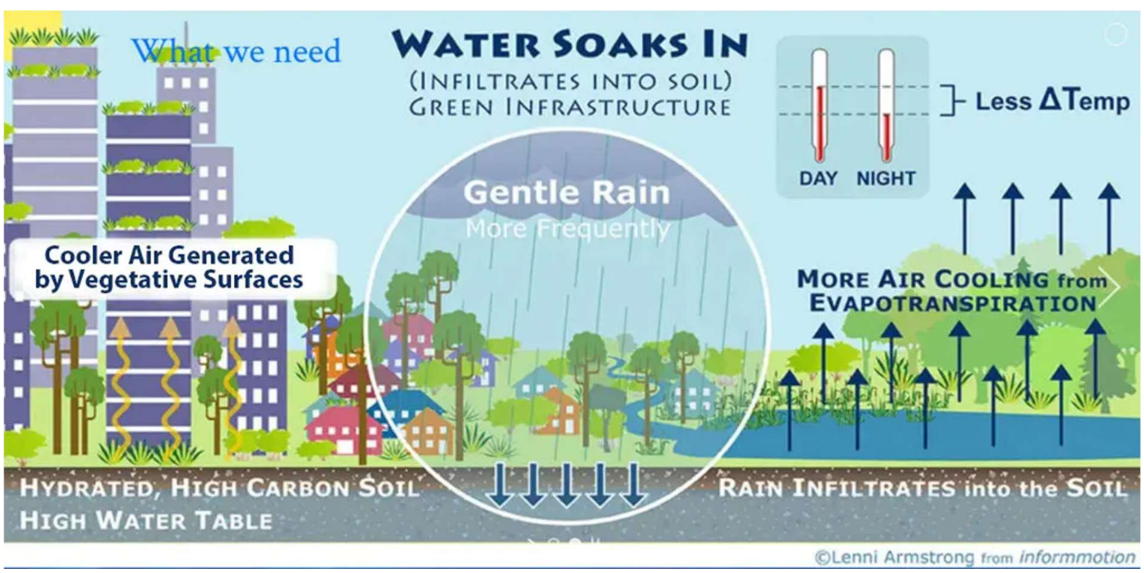
Therefore, it is necessary to incorporate these principles into spatial plans so that urbanisation does not increase the drying and overheating of built-up areas. Spatial plans in Slovakia underestimate the drying of built-up areas and the impact on climate change. Spatial planning requires support from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

According to Slovak laws on 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

[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.

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

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[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.

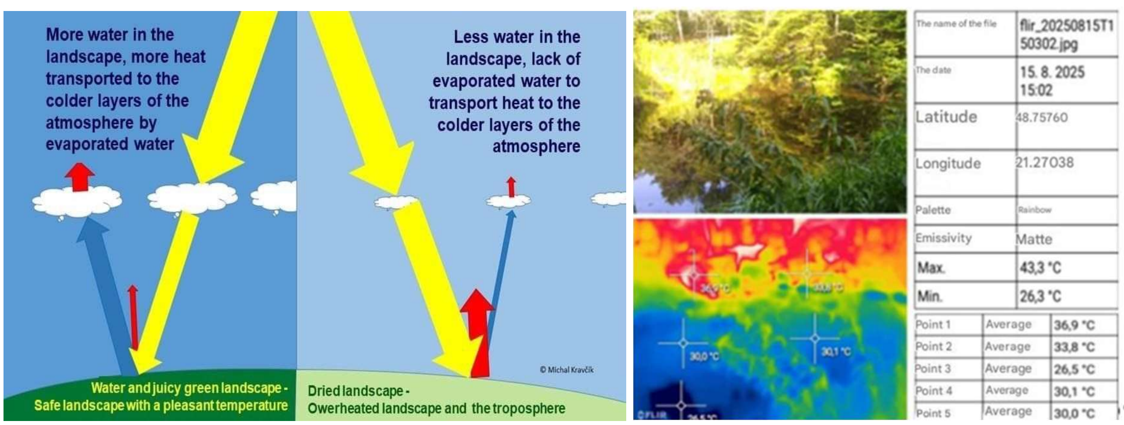
[14] (https://landsat.gsfc.nasa.gov/)

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).



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

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

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[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

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.

6.5 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.

Several innovative solutions have been proposed for urban environments. These have not been widely used in Slovakia, but are common practice in rainwater management in urban environments around the world. We have selected several “BEST PRACTICES” solutions for rainwater management. These systems are referred to internationally as BMPs (Best Management Practices). Many systems can also be implemented through alternative solutions.

Reducing flood runoff by retaining rainwater in reservoirs of transport infrastructure

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)

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.

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 m^3 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 m^3 each, we would return 100,000 m^3 of water annually into local water cycles. In 10 years: 1 million m^3. 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?

Infiltration basin, wetlands

An infiltration basin is a shallow embanked reservoir that collects and infiltrates rainwater. It is used on level, undisturbed areas with relatively permeable soils. Infiltration basins are shallow water retention areas designed for the temporary collection and infiltration of collected rainwater. Their size and shape can vary – from one large basin to several smaller basins distributed throughout the site. They should be integrated into the terrain and surroundings as sensitively and unobtrusively as possible.

Image: Collecting rainwater from urbanized areas and transport infrastructure in depressions

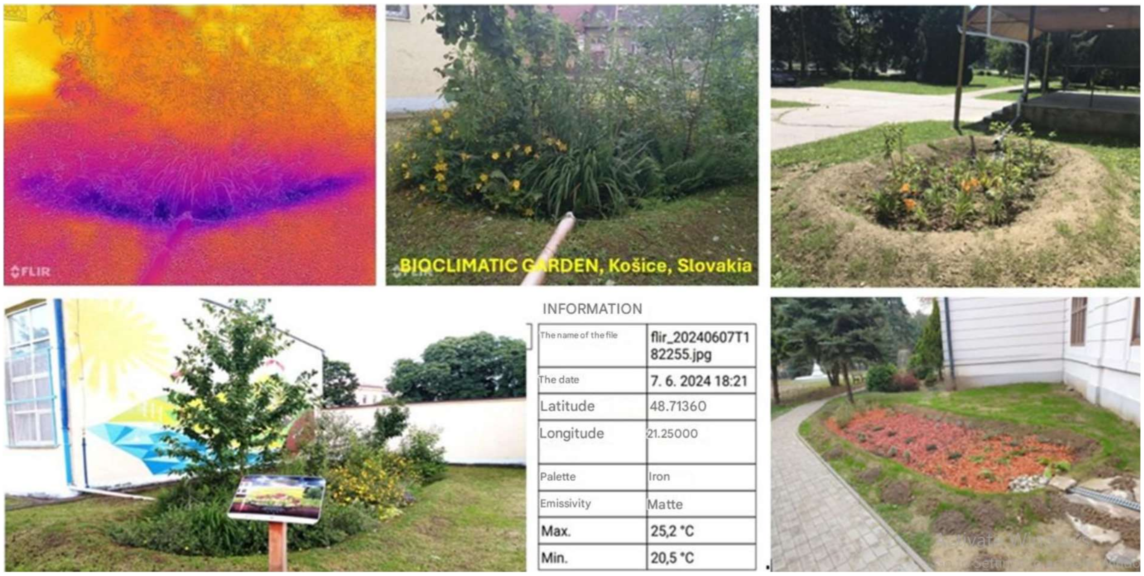
Wetland depressions are essentially basic linear wetland units. Their design often includes shallow permanent ponds or marsh conditions that sustain wetland vegetation, which effectively removes contaminants. High groundwater levels or poorly drained soils are a prerequisite for wetland depressions. A disadvantage of wetland depressions, at least in residential and commercial areas, is the potential for mosquito breeding.

Bioclimatic gardens

A rain garden (also called bioretention) 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 gardens - collecting rainwater from buildings into greenery

Rainwater from roads can also be used to irrigate existing roadside vegetation. This is a method of rainwater management that captures runoff rainwater and creates a shallow dam in a hollowed-out mulching area around a tree or shrub.

Examples of rainwater collection in the root zone of trees

<u>Bioretention in parking lots without curbs</u> - The rain garden is located right next to the parking area without curbs, allowing rainwater to flow widely into the rain garden. Shallow steps regulate inflow speed; this design can be used in combination with depressions to control the amount of rainwater.

It is important not to confuse bioretention areas with constructed wetlands or ponds that permanently retain water. Bioretention is best suited for areas with at least moderate infiltration rates (greater than 0.3 cm per hour).

In extreme situations, where permeability is less than 0.3 cm/hour, special variants can be applied, including those combined with interconnected underground drainage systems or even constructed wetlands.

Green roofs and walls

Rainwater harvesting is nothing new or revolutionary, whether around the world or in our country. Modern technology is so advanced that with properly designed family homes, residential houses, or industrial buildings, we can capture and use almost all the rainwater that falls on the roof or the surrounding land of the building through a suitable combination of different technologies. Proper and precise architectural design benefits both the environment and people by saving money and also aesthetically enhances the building and its surroundings.

At the same time, both experts and the general public recognise the issue of collecting rainwater flowing from roofs. The reason is simple and very practical. There is growing pressure from water management companies, which are calling for rainwater to be drained into sewers and for a fee to be charged for its disposal.

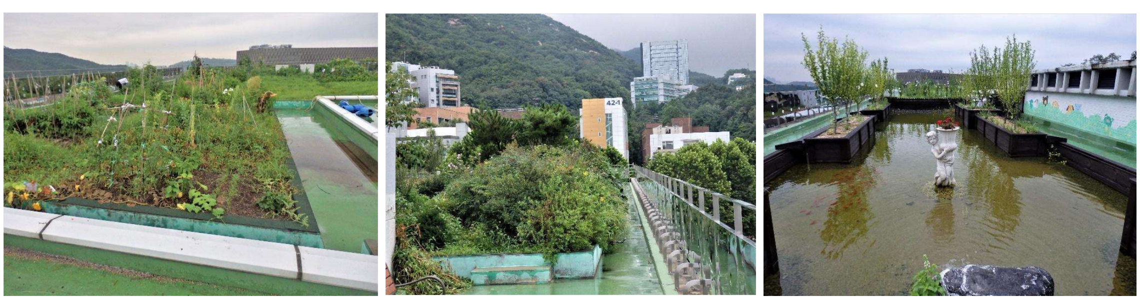
Such practices already exist in some EU countries and are becoming increasingly realistic in our legislation as well. On the other hand, society is beginning to realize not only the economic value of drinking and utility water. In connection with the impending climate changes, voices are also growing louder that water is the missing element that can be used to combat overheating and rising temperatures, even in large cities.

Green roofs were already common in antiquity. In Rome, roof gardens were an almost natural part of most patrician houses and palaces. By the 11th century, green roofs had spread across Italy, France, and other European countries. Green roofs have a long tradition, especially in Scandinavia, but also in Canada, Iceland, Guatemala, and Tanzania, mainly due to their high thermal insulation capacity. In Germany and neighbouring Czechia, green roofs began to be constructed in the mid-19th century. A greater boom occurred at the beginning of the 20th century.[18]

This type of roof is one way to restore the natural appearance of built-up areas, partially revitalize them, and thus reduce the impression of buildings being “torn” from nature. Architects who take into account people’s relationship with the environment focus on such projects. It seems that such buildings will be one of the key priorities of future-oriented architecture, as the demand for greenery in cities is growing.

Some types of green roofs can also serve as roof gardens, especially in suburban and urban areas, where they have two important functions. On the one hand, they provide additional green space, and on the other, they contribute to better water retention, thus improving the drainage system of the area. In addition, they have a positive effect on the microclimate of cities and also benefit the residents of buildings with such roofs. They reduce environmental pollution and increase energy savings for heating during the winter and air conditioning during hot summer days. They have also been proven reduce the penetration of high-frequency electromagnetic waves. Considering their overall lifespan, they are also more economical than conventional roofs.[19]

A green roof is a natural form of low-maintenance vegetation that develops and regenerates mostly on its own. The vegetation consists mainly of succulents (xerophilous plant species), mosses, herbs, and grasses. These are hardy, low-growing plants that spread across the surface, tolerate extreme conditions, and are able to survive periods of prolonged heat, drought, and frost. On the other hand, they can also cope with larger amounts of water.



Green roof at Seoul National University with vegetable cultivation

[18] http://www.linia.sk/L10_04/kralovna.htm

[19] http://exterier.hyperbyvanie.sk/vonkajsie-rastliny/252-zelene-strechy-sa-vracaju-na-vyslnie/

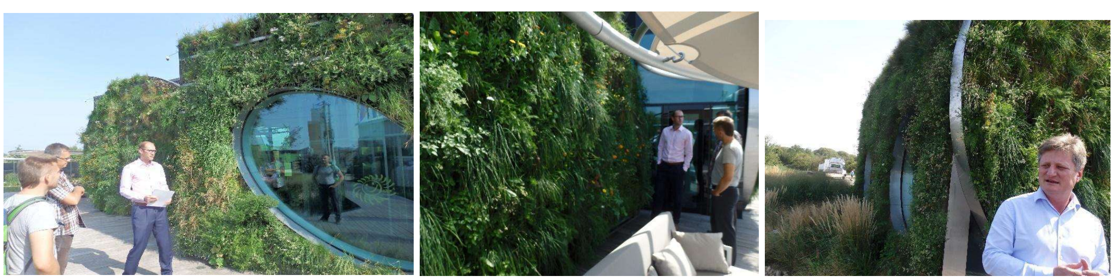
Benefits of green roofs:

1. *They have a natural air conditioning effect*
2. *They absorb noise*
3. *They contribute to fire resistance*
4. *They have a shading effect*
5. *They protect against electromagnetic smog*
6. *They produce oxygen and retain CO_2, dust, and other pollutants*
7. *They absorb pollutants from the air, filter dust particles, and prevent dust from swirling*
8. *They reduce temperature fluctuations between day and night*
9. *They mitigate fluctuations in air humidity*
10. *They create a living environment for insects*
11. *They spread fragrance*
12. *They have a very aesthetic effect in terms of recreation and relaxation*
13. *They can also be designed as gardens for growing flowers and vegetables*

Green cities also include green walls

System solutions for the construction of vertical vegetation walls offer the possibility of creating diverse, aesthetically pleasing, and architecturally interesting areas that are permanently covered with vegetation.

The vertical garden system consists of prefabricated aluminium panels (also known as cassettes or facade baskets), which are filled with substrate during production. Plants are then planted directly on site. The panels are attached to hanging profiles screwed to the wall or facade. The irrigation system is placed in horizontal cavities between the panels and is connected to the roof drainage systems. Vertical gardens are an effective way to utilize walls and facades. They are an architectural and ecological element that, in addition to increasing the aesthetic value of a building, can have a positive impact on human health, such as noise reduction thanks to the reduced sound reflectivity of vegetation areas, improvement of the microclimate in and around the building, protection of the building against overheating of the facade in summer and excessive cooling in winter, air humidification, protection against smog, capturing dust and pollutants from the air, binding CO_2 and producing oxygen, capturing rainwater and reducing runoff into the sewer system, increasing the diversity of plant species in the city, and protecting the facade against graffiti. The diffusive open-facade system allows almost all types of plants to be grown on the facade.



Green building, Likos, Slavkov u Brna[20]

[20] www.liko-s.cz

Photos - Archive MVO People and Water

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