BASELINE REPORT – Living Labs

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Introduction

The INTERLAYER project focuses on water retention technologies that contribute to improve resilience, adaptation and mitigation to hydroclimatic extreme events while contributing to co-benefits, including increasing water availability and quality by balancing groundwater and surface water management practices. INTERLAYER explores groundwater and surface water availability and relates it to land use (including specific agricultural practices) and water quality from a synergetic perspective so that available Slow Hydrology (SH) techniques are anticipated to be used in future River Basin Management Plans. To do so, we set up four Living Labs (LL) in four contrasting European watersheds to include and compare different European edaphoclimatic regions with different geologic and geomorphological characteristics, see Fig. 1.

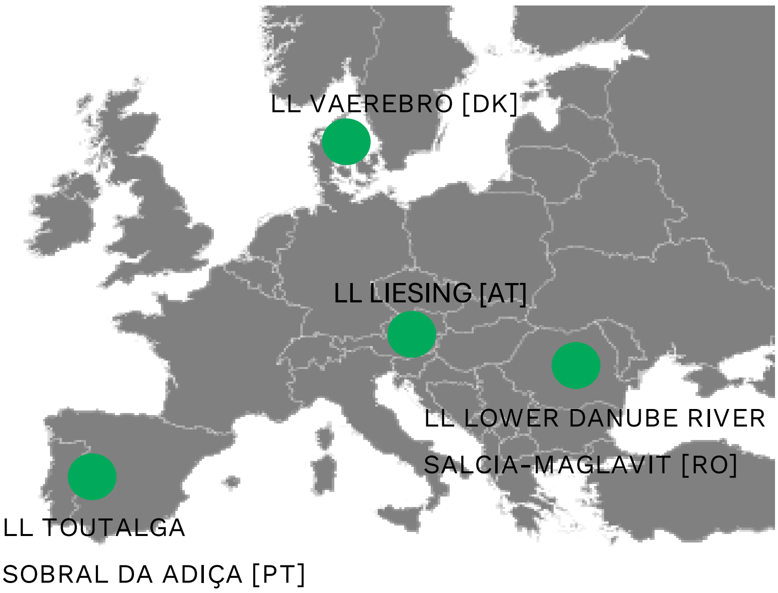

Fig. 1: INTERLAYERs four LLs, located in contrasting watersheds in different regions of Europe

Vaerebro River [DK] - The catchment of river Vaerebro is 153 km^2 and the river itself is 35 km long and one of the longest rivers in the capital region of Denmark, having its source in a biodiversity rich bog area, passing through mixed land use with small and medium sized villages, many spare-time farmers, often horse-hobby, and some agriculture, before discharging to Roskilde Fjord. This LL is set in a rural area within the peri-urban matrix in a regional context and allows a source-to-sea approach, in a region with a continental humid with warm summer climate. A mature formalized LL is established and ready for engagement.

Liesing River [AT] - The Liesing river is beside the Danube and the Wien river one of the main water courses in the city of Vienna. It flows 30 km through strongly populated regions in the south of Vienna. The catchment can be divided into a forest dominated area followed by an urban river section. This LL is set in a peri-urban and urban regional context, with high potential for replication due to stakeholder involvement rates (capitalized from other projects), in a region with a continental humid with warm summer climate.

Toutalga, Sobral da Adiça [PT] The Guadiana watershed has a total surface area of 66 800 km^2 and is shared between Spain (83%) and Portugal (17%). Guadiana river is 810 km long, with 260 km in Portugal and 110 km along the border between the two countries. This LL will be set up in an international river with hot summer Mediterranean climate, encompassing the biggest artificial lake in Europe (Alqueva reservoir), as well as smaller reservoirs, rivers and streams. Flash-flood events and temporary streams are characteristic of the system. The LL allows for source-to-sea approach. The Toutalga catchment is a sub-basin of Guadiana river located in the southeast of Portugal near the village of Safara and the city of Moura, covering 136 km^2. It is a rural sub-basin overlapping the Moura-Ficalho aquifer with two temporary rivers called São Pedro and Toutalga.

Lower Danube River (Salcia-Maglavit) [RO] - A stretch of the former floodplain of the Danube River, between Salcia and Maglavit villages consisting of 200 ha along the corridor at Salcia, with abandoned fish farm, arable land with mix uses, including planted forest and pasture. This LL is set up in a continental humid with a hot summer climate. The area has high potential for improvement of lateral connectivity through Nature-based solutions (NBS) implementation in order to re-connect the surface and groundwater to increase resilience and reduce the impact of drought.

The Baseline Report:

This report shares the findings of the first research, analysis, categorizations and calculations related to the four Interlayer Living Labs. It consists of a gathering of information, GIS analyses and climate projections. In a general characteristic the focus is put on the identification of geomorphological aspects (terrain, river network, geology, ...), land use classes, soil specific aspects, the hydrological system etc. The existing monitoring system in the living labs is described. In the context of slow hydrology primary objectives were defined and related ecosystem services were collected and ranked and compared.

For the climatic characterization of the sites D4.1 - Preliminary assessment of the expected evolution of climatic and derived variables was used (Ribalaygua Batalla, Gaitán Fernández, and Galiano Sánchez 2024). The results were interpreted, summed up for each Living Lab and compared across them.

From a hydrological point of view, the results of a GIS analysis regarding the detection of blue spots, that can retain surface water due to their topographical characteristics were included. The catchment (drainage basin) was demarcated from an analysis in ArcGIS Pro ver. 3.2 of a high-resolution hydro-conditioned LiDAR based DTM (digital terrain model). The hydro-conditioning is necessary to obtain the correct terrain levels to model flow directions on ground where streams underpasses infrastructure (roads and railroads). The catchment delineation included three sub-steps: A fill up of all landscape sinks, determination of flow directions, and identification of all upstream cells from the river's discharge point. Next, the DTM covering the catchment was investigated to identify landscape sinks and flow paths. The flow paths (= streamlines) originate where the landscape sinks are spilling over ('blue spots") at varying uniform rain events, assuming hortonian flow conditions (no soil infiltration included). The investigation used tools from the Arc-Malstrøm stormwater screening software developed by (Balstrøm and Crawford 2018) available for download from Model bluespots to map flood risk | Learn ArcGIS. The principle behind the screening is described in detail in Balstrøm et al. (2024). In short, the method detects local bluespots and their pour points when filled, their contributing watersheds, and streamlines originating at the bluespots pour points carrying the excess water downstream. The streamlines form a hierarchical, hydrologic network. So, assuming steady state conditions and adding uniform rain events in the range 30-100 mm in steps of 10 mm, an overview is produced

All results are put together and state the current situation in the four Living Labs before planned slow hydrology interventions. This information helps us to better understand the functioning of our Living Labs as well as the similarities and differences across them. Further on, it can be seen as first steps in the identification of areas, where slow hydrology interventions can take place.

Liesing River [AT]

General profiling

Area: The catchment covers 117 km^2 in the south of the city Vienna, It is split in an intermittent part, called Dürre Liesing with a catchment dominated by limestone, and a permanent flowing part originated in flysch area, Reiche Liesing. River Liesing inundates into River Schwechat.

Landuse:

- 23% artificial surface,
- 48% agricultural area
- 28% forests and seminatural area

Background and status: Liesing catchment has natural areas in upstream reaches and is strongly influenced by a growing urban environment in the middle course. Flood events show very fast peaks, while under dry weather conditions low flow aspects are relevant. In the urban area a sealed trapezoidal riverbed was installed in the 1970s. Since the year 2000 river stretches have been restored and are now well accepted as urban recreational areas. Restoration works are still going on.

Associated institutions: MA 45 (public agency City of Vienna)

Stakeholder: Public agencies, neighbors, farmers, ÖBF - Austrian Federal Forests, ...

Research questions:

- What are the aspects of slow hydrology in a watershed covering natural as well as highly urban areas?
- What are the results of already implemented NBS solutions in terms of ecosystem services along the river channel?
- What is the potential of slow hydrology techniques in the catchment based on an aerial approach?

Characteristics

The Liesing River has a catchment area of about 117 km^2, covering regions in Lower Austria and Vienna. The river inundates into the river Schwechat and is part of the bigger Danube catchment between Enns and March, see Fig. 2 . The catchment of River Liesing is divided into two sections: the upper and lower catchment. The upper catchment is further subdivided into four smaller basins (Reiche Liesing, Guetenbach, Laaberbach, Duerre Liesing), located in the Viennese Forests. This area is sparsely populated and retains a largely natural characteristic. In contrast, the lower catchment is highly urbanized, featuring densely populated areas and predominantly sealed surfaces, which prevent water infiltration into the ground. In this area the river is mostly disconnected from the groundwater. The lower catchment includes three retention basins as well as many inundations. Despite the urban dominance, some agricultural areas persist in the most downstream section of the lower catchment, providing a glimpse of the region's historical land use.

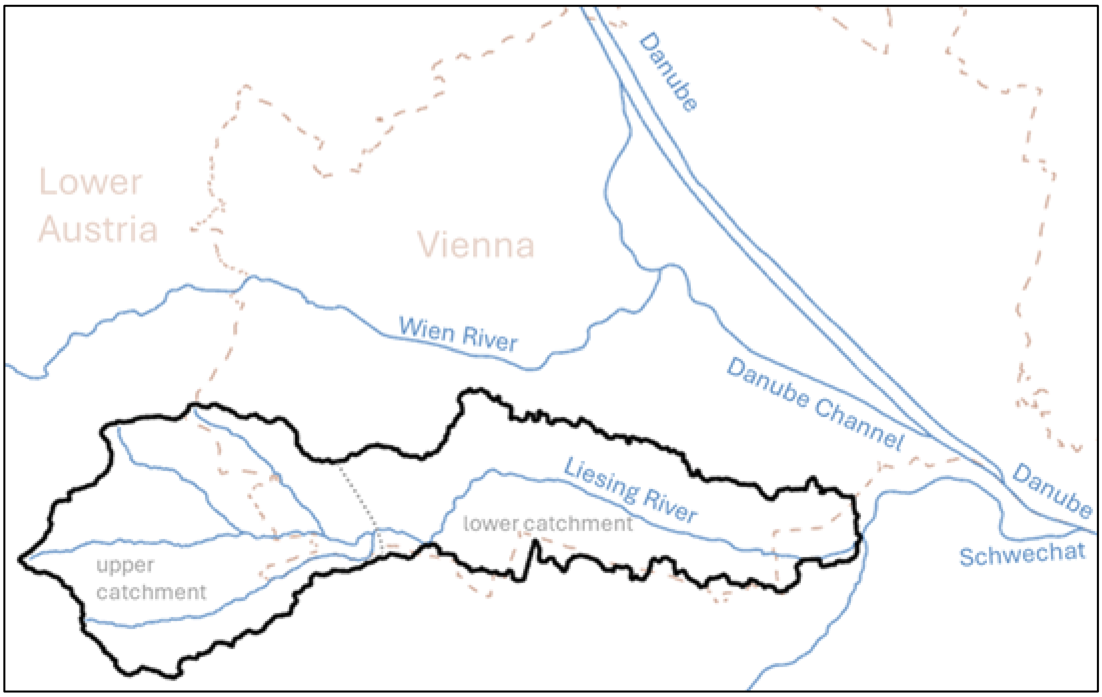

Fig. 2: Location of the LL Liesing in the South of Vienna, the given river system and the division in upper and lower catchment of Liesing River. Data: (Umweltbundesamt GmbH 2020)

A more detailed **analysis for the upper catchment** has been carried out separately for all for sub catchments based on the Hydrobod 50 m dataset (Land Niederösterreich 2022). All sub catchments show forest that stands on at least 50 % of their area. Guetenbach has a markable high share of forested area by 73 %, also the sub catchment associated with Reiche Liesing shows with 63 % large proportions of forests. The second dominant land cover category in the upper Liesing catchment is meadows. The subbasin Reiche Liesing has 12 % of its area appearing as meadows the lowest catchment. The other three exceed rates of 20% in this category.

Geological data indicates that the upper catchment is predominantly composed of marl and claystone, influencing soil permeability and runoff characteristics (Fig. 3). An exception is the Dürre Liesing sub-catchment, where limestone prevails, implicating different infiltration dynamics and hydrological behavior compared to the marl- and claystone-dominated areas of the other sub-catchments.

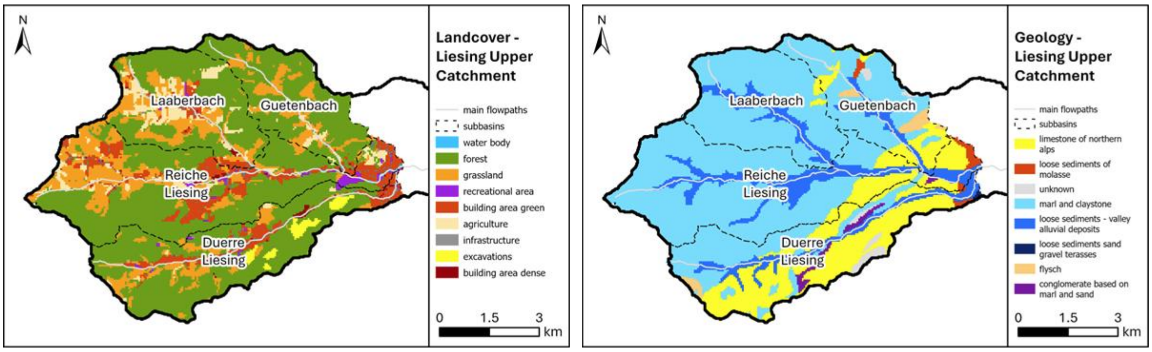

Fig. 3: Land cover in the upper Liesing catchment (left) and geology (right), based on the Hydrobod dataset (Land Niederösterreich 2022))

The soil water storage of the upper catchment shows volumes up to 375 mm. The highest capacity can be found in the Guetenbach sub-catchment, while Duerre Liesing shows the lowest value (see Fig. 4). This seems to be related to the limestone geology in this subbasin. The interception capacity of the vegetation cover in the upper catchment is divided into two classes: 2 mm and 5 mm. Mainly the forests show a high infiltration capacity. While settlements and agricultural areas are assigned to have an interception capacity of 2 mm.

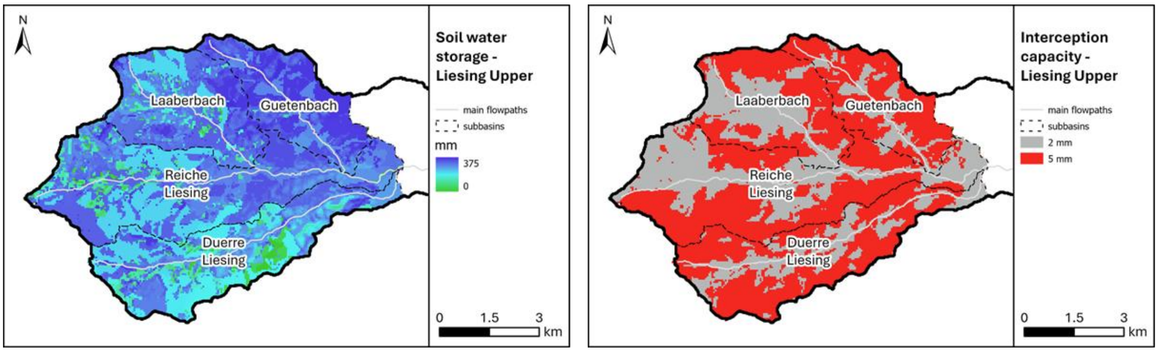

Fig. 4: Soil water storage of the upper Liesing catchment (left) and interception capacity (right), based on the Hydrobod dataset (Land Niederösterreich 2022)

Monitoring System

Within the whole catchment eight meteorological stations are distributed, they are supplemented by five further stations in the close neighborhood. At eight points groundwater table is measured, two times combined with water temperature. The middle and lower catchment share three gauges, while one is focused on discharge, the other two measure water level. Additionally, 13 water temperature loggers are installed within this part of the catchment. The period of data availability varies between all measuring stations and is plotted in Fig. 5.

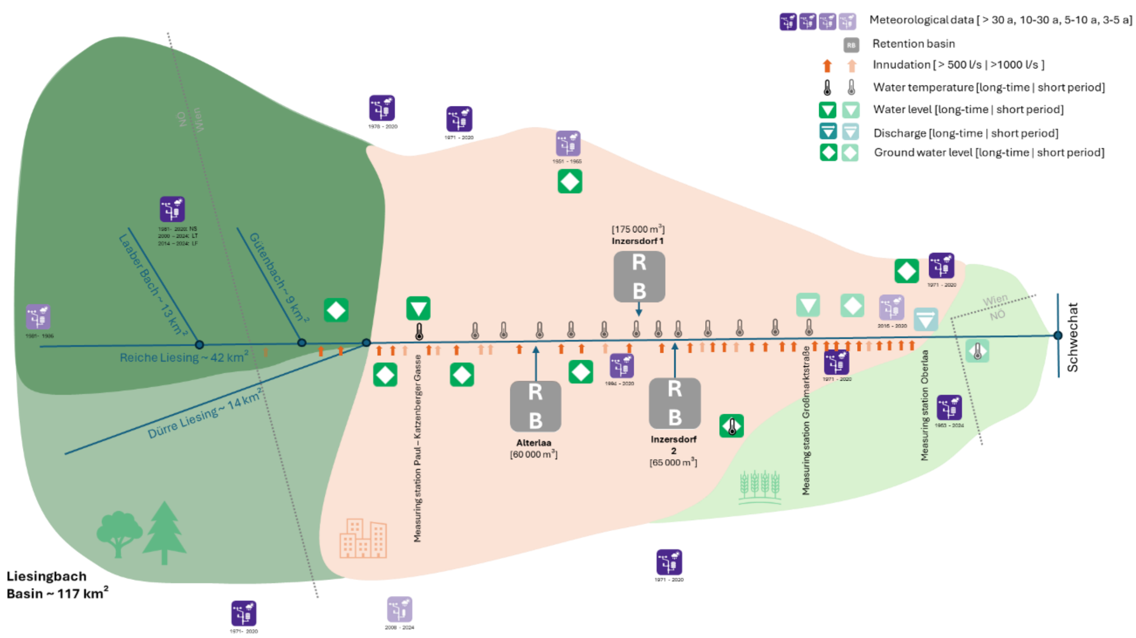

Fig. 5: Schematic sketch of LL Liesing, including the retention basins and the monitoring infrastructure

Bluespot screening

DTM data source:

- Digital Terrain Model Province of Lower Austria - 1m: https://geoshop.noel.gv.at/ , 1 m resolution, 2024.

- Raster data of the terrain model (DTM) of Vienna with a spatial resolution of 1 meter: http://www.wien.gv.at/stadtentwicklung/stadtvermessung/geodaten/dgm/index.html , 2015)

Modifications to the DTM: Merged both datasets, Hydro-conditioned for streams under passing roads.

Interpretation of results:

The drainage basin investigated covers 117 km2 located S-SW of Vienna city, see Fig. 6. It is a sub-basin pouring into the Danube River east of the town of Schwechat that has a W-E extent of approx. 25 km. The DTM reveals a mountainous 58 km2 large westerly sub-catchment for the Liesing River with elevations ranging from 250 to 643 m above sea level (asl). The sub-catchment is dominated by forests and extensive agricultural areas with a few smaller settlements, only, located along the streams' valleys. The easterly sub-catchment south of Vienna towards the Danube River is gently sloping with elevations ranging from 156-250 m asl.

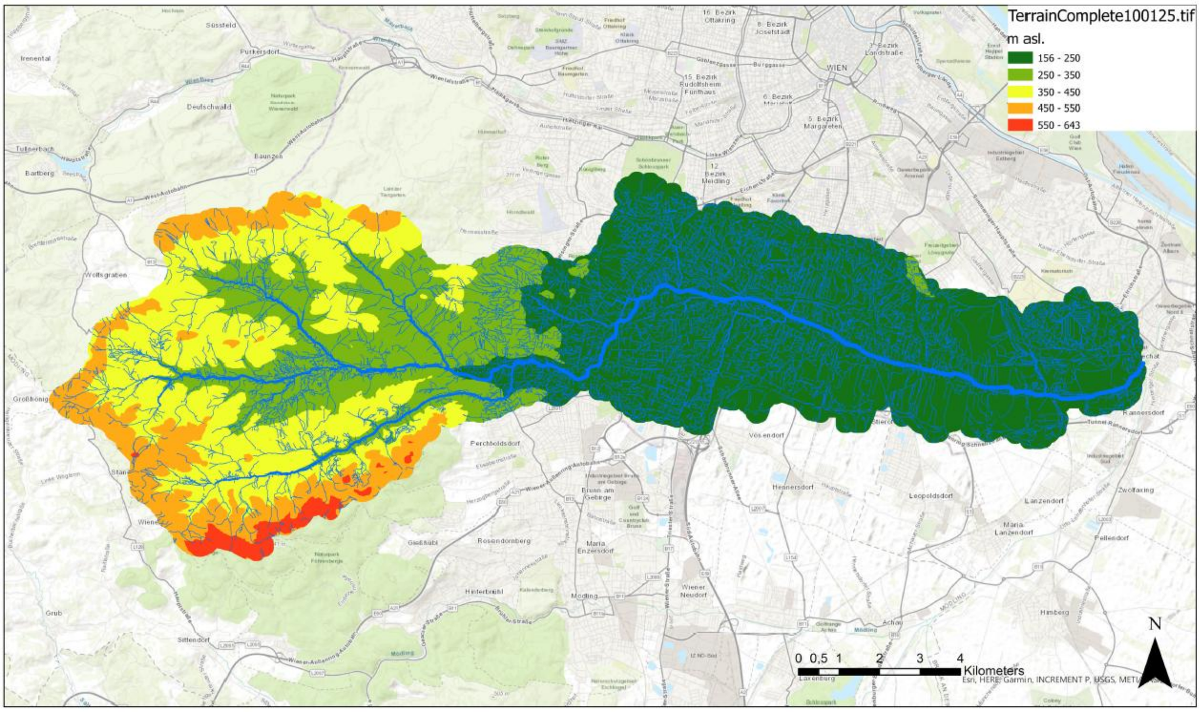

Fig. 6: LL Liesing - DTM hydroconditionned and calculated flow paths

Fig. 7: The bluespot screening reveals almost no bluespots (landscape depressions) in the western sub-catchment. Consequently, there are almost no natural retention basins in the region. As soils in the mountainous region are shallow, most of the runoff generated during stormwater events is quickly turned into surface runoff entering the streams. At the location where the major local streams converge and turn into a single major river flowing through residential areas south of Vienna, the accumulated runoff volume for a uniform 60 mm stormwater event is estimated to a stunning 3.3 mio. m^3. Such an event today is expected to occur every year as an event of 2 days duration and every 100 years as a 60 min event by 2020 (grid point 2871 – Hydrographischer Dienst, 2020, ehyd.gv.at), but under climate change these values are assumed to change. At the drainage basin's outlet, the stormwater volume is estimated to 5.4 mio. m^3 for a 60 mm stormwater event. This means that the urbanized region covering approx. 52 km^2 only generates approx. 2.2 mio. m^3, as several bluespots within this sub-catchment are detected can retain large precipitation volumes. Considering a 60 mm event the retention basins in the urban part of the catchment are not filled yet.

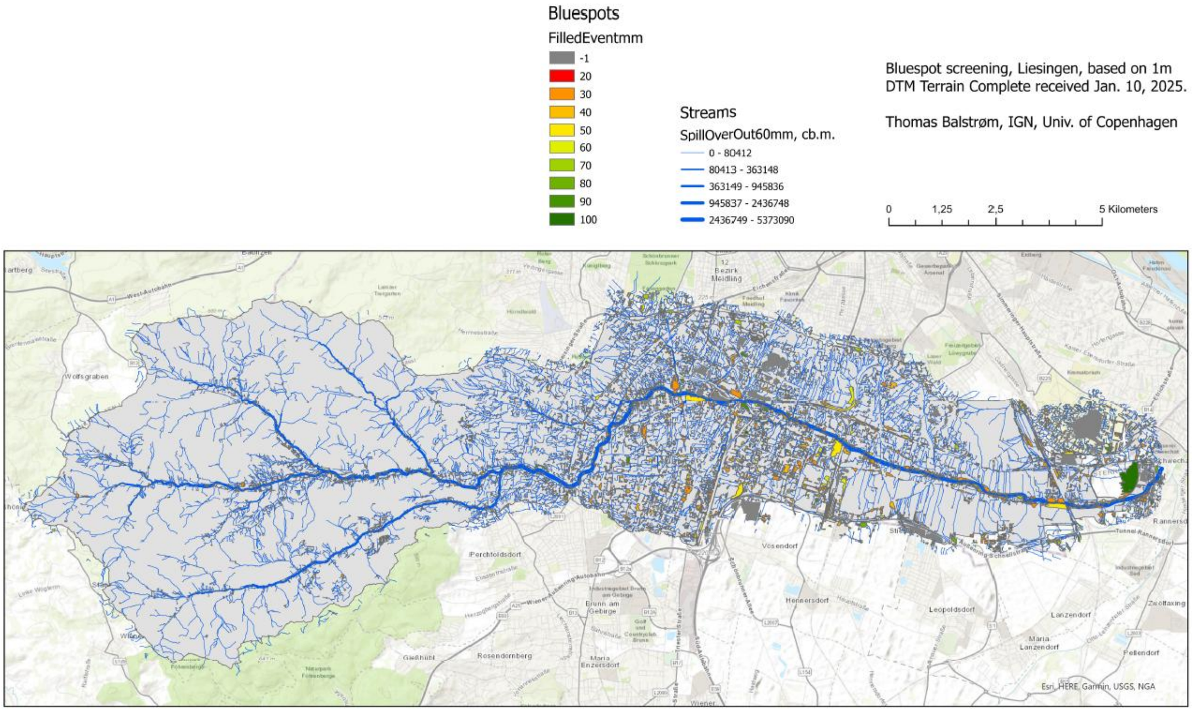

Fig. 7: LL Liesing – results bluespot screening 60 mm rainfall event

Summary of Key Climate Projections

Maximum temperatures are projected to increase by 1.9–2.3°C by mid-century and by 2.5–4.4°C by the end of the century under the SSP2-4.5 and SSP5-8.5 scenarios. The most intense warming is expected during summer and autumn. This warming trend is likely to intensify extreme weather events, especially heat waves, posing risks to wetland ecosystems. The number of heat wave events could triple in the most pessimistic scenarios by mid-century, although their average duration and intensity are expected to change only slightly.

The number of days exceeding the 95th percentile of historical maximum temperatures could increase significantly, from an average of 5 days to 20–26 days. The warmest months will experience the most dramatic increases, with maximum temperatures rising by 3.3–4.4°C under SSP2-4.5 and up to 7.8°C under SSP5-8.5. Mean and minimum annual temperatures are expected to rise similarly in absolute terms.

A substantial reduction in frost days is anticipated, with declines of 30–36 days by mid-century—effectively eliminating frost events. Tropical nights (Tmin > 22°C) will increase notably, from none in the historical period to 3–6 nights per year. Cold waves are expected to become slightly longer and more intense, although their frequency is projected to drop to zero by mid-century. Similarly, days with minimum temperatures below the 5th percentile will decrease from 7 to as few as 1 day annually.

Precipitation levels are not expected to change significantly by mid-century. However, annual reference evapotranspiration is projected to increase by 78–95 mm, largely due to rising temperatures. This will raise total evapotranspiration from 816.7 mm to as much as 912 mm, with increases most pronounced in summer and autumn.

The overall annual water balance will remain stable, but the summer water balance is expected to deteriorate considerably under high-emission scenarios, declining by 68.4 mm and exacerbating existing deficits (from –187.5 mm to –255.9 mm). No significant changes are expected in the annual water surplus or in the number of months with a positive water balance. Reductions in the annual water deficit are only expected by the end of the century.

No significant changes are expected in the aridity index by mid-century. Similarly, projections for the Thornthwaite humidity index show no relevant changes, either annually or seasonally. Drought intensity is not expected to increase significantly by mid-century. The SPI (based only on precipitation) does not show significant increases at mid-century, although such increases are projected for the end of the century. Minor, non-significant decreases are expected in the SPEI (which accounts for both precipitation and temperature).

Stakeholder

- Municipal Department 45 - Water Management Vienna:
  Authority in charge of river Liesing, ongoing restoration projects, flood protection, hydrological data ...
- Local residents: The area is densely populated, the riparian corridor functions as recreational area ...
- Österreichische Bundesforste AG – Austrian federal forests: major landowner of forest areas in the upper catchment
- Local farmers and landowners

Primary objective

Transformation of hydrological peaks (slow hydrology) in order to derive flood security and ecologically compatible low flow: Relevant processes for flood security keep water in the landscape and buffer run off from extreme events, while ecological low flow situations require a certain amount of flow as well as a certain standard of water quality (see Fig. 8).

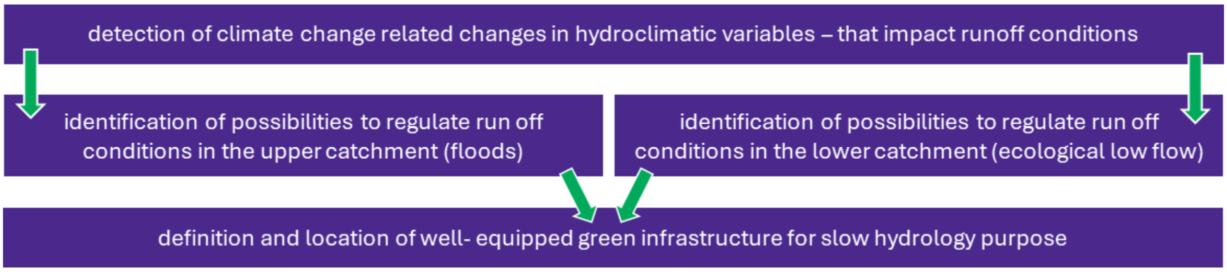

Fig. 8: Primary objective LL Liesing split in four subpoints

Ecosystem Services – Co benefits

<u>SUPPORTING</u>

- **hydrological cycle**
- **nutrient cycle**

<u>REGULATIVE</u>

- **retention of C, N and P**
- **global climate – C sequestration**
- **flood regulation**
- **low flow regulation**
- **drainage system (receiving water courses)**
- **cooling effects for running waters**
- **providing habitats**
- **air quality**
- **erosion protection**

<u>CULTURAL</u>

- **education**
- **science**
- **recreation**

The LL Liesing in pictures

Fig. 9: Liesing Living Lab in pictures: Heavily embanked riparian corridor, restoration work, recently restored areas, 10 – 20 years old restoration work, the Liesing corridor during a flood event.

Værebro River [DK]

General profiling

The Værebro catchment, located northwest of Copenhagen, covers approximately 150 km^2 with an elevation ranging from 0 to 60 meters. The Værebro River originates in a biologically diverse bog ecosystem and flows through a landscape characterized by mixed land use.

Land use:

- Agriculture: 52 %
- Urban: 20%
- Forest and nature: 20%
- Water bodies: 3%
- Others: 2%

Agriculture is the predominant land use, and most of the agricultural land is artificially drained through a network of drainage pipes and ditches. In addition to its agricultural character, the catchment is also peri-urban and includes several smaller towns and villages.

Background and status: This living lab is situated in a rural setting within a peri-urban mosaic, presenting challenges relating to downstream flooding of urban and agricultural land and ecological deterioration calling for a source-to-sea mitigation approach. The area is located in a region with a continental climate featuring warm summers, supporting a wide range of ecological and land use dynamics. The Ecological status of the stream is poor. It is tributary to Roskilde Fjord Natura2000 Area; Part of the river catchment is designated as nature conservation and recreational areas due to landscape and nature values.

Living Lab objectives:

- Mapping of potential Slow Hydrology intervention sites
- Site specific design and sizing of interventions
- Inspiration of local authorities and decision makers on Slow Hydrology as a new tool in strategies for nature protection, GHG emission mitigation and flood control
- Preparation of pilot testing for monitoring of resulting water balance (local recharge and temporal storage).

Associated institutions: *Most of the river catchment falls within the m*unicipalities of Egedal, Ballerup and Furesø. Novafos, a water utility company, serves most of the area.

Stakeholder: Farmers, municipalities, utility companies, local associations, landowners, culture institutions, and company owners in the area.

Research questions:

- Where in the landscape can Slow Hydrology interventions most efficiently be located in the landscape to retain or detain flowing water?
- How can interventions be designed to meet the primary site-specific hydrologic objective(s) and synergistically provide additional ecosystem services?
- What is the potential and feasibility of retrofitting the existing drainage systems to a dual-purpose system ensuring drainage of excess water and recharging of the rootzone? What is the potential of vegetated landscape belts designed to enhance infiltration and improve water quality, while providing additional ecosystem services (e.g. intercropping harvesting, bio-corridor connectivity, public accessibility, etc.)?
- How can the idea of Slow Hydrology be efficiently embedded in ongoing climate adaptations and ecological restorations at both project and strategic level?

Political context

The Danish Tripartite Agreement is a political agreement reached on June 2024, which aims to drastically change the land use in Denmark, to reduce GHG emissions, and decrease N leaching from the agricultural sector.

Among the key measures of the agreement there is the creation of a Green Land Fund to set aside around 15 % of agricultural land (390.000 ha) for afforestation, extensive agriculture, peatland rewetting, and biodiversity enhancement. The first 140.000 ha consisting of low-lying land will according to the plan be transformed to nature ultimo 2027, and the remaining 250.000 ha of high lying land by 2045.

Monitoring System

The Vaerebro River catchment is hydrologically monitored for discharge and groundwater levels, as indicated in Fig. 10, showing the type and position of observation points.

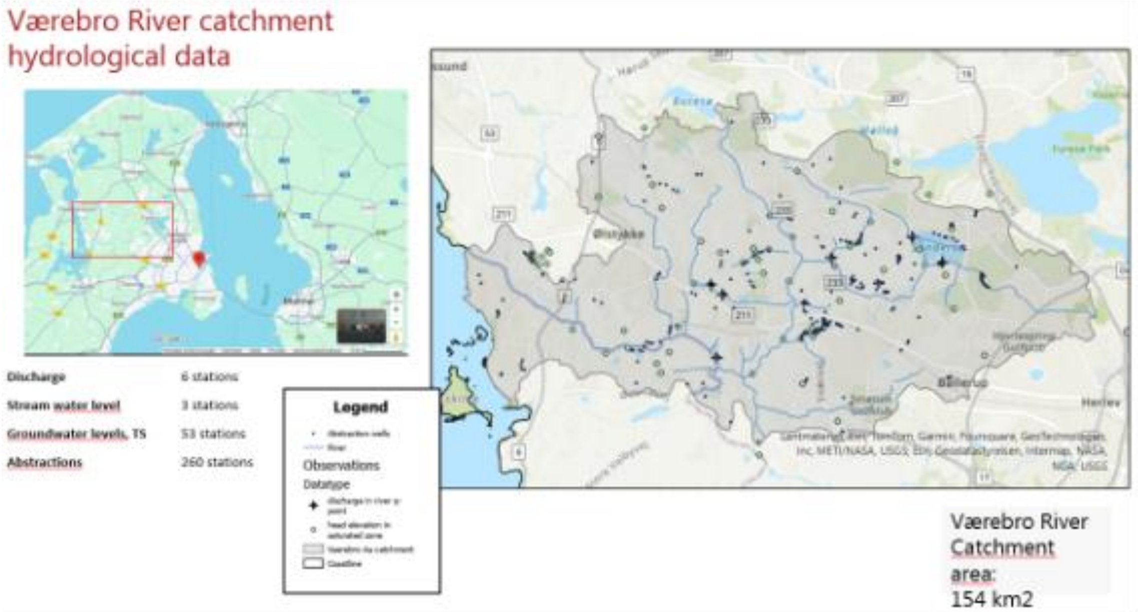

Fig. 10: Hydrological monitoring. The figure to the left shows the DK-LL in the Eastern part of Denmark The figure to the right shows abstraction wells (260), discharge stations (6), stream water level stations (3) and groundwater monitoring wells (53)

Bluespot screening

DTM data source: The Danish Agency for Climate Data, 0.4 m resolution, 2021, resampled to 1.2 m resolution.

Modifications to the DTM: Hydro-conditioned for viaducts and streams underpassing roads.

Interpretation of results:

The drainage basin investigated covers 149 km2 and is located in the Capital Region of Denmark centered approx. 30 km W-NW of Copenhagen, see Fig. 11. The basin flows directly into the ocean (Roskilde Fjord) near the town of Jyllinge. The basin is oriented W-E with the longest extent of approx. 15 km. The DTM reveals a landscape with max. elevations of approx. 60 m found along the basin's northern extent. Meanwhile, the landscape dips abruptly into low-lying flat valleys located 0-20 m above sea level (asl), and along a 20 km long stretch the deepest parts of the mainstream are located below 10 m asl.

The bluespot screening shows that the landscape is dominated by several bluespots where many of them have large water capacities (colored in grey with a filled event value of -1), see

Fig. 12. This means that when assuming Hortonian flow conditions, the bluespots do not produce any spillover even at a uniform 100 mm stormwater event. At a uniform 60 mm stormwater event occurring approx. every 15 years by 2025, but every 10-12 years by 2050, the accumulated runoff at the outlet into the ocean is approx. 3.2 mio. m3 (if no infiltration takes place/Hortonian flow). Almost half of this (1.4 mio. is generated in the basin’s central part consisting of a flat river valley, explaining the seasonal flooding frequently experienced here.

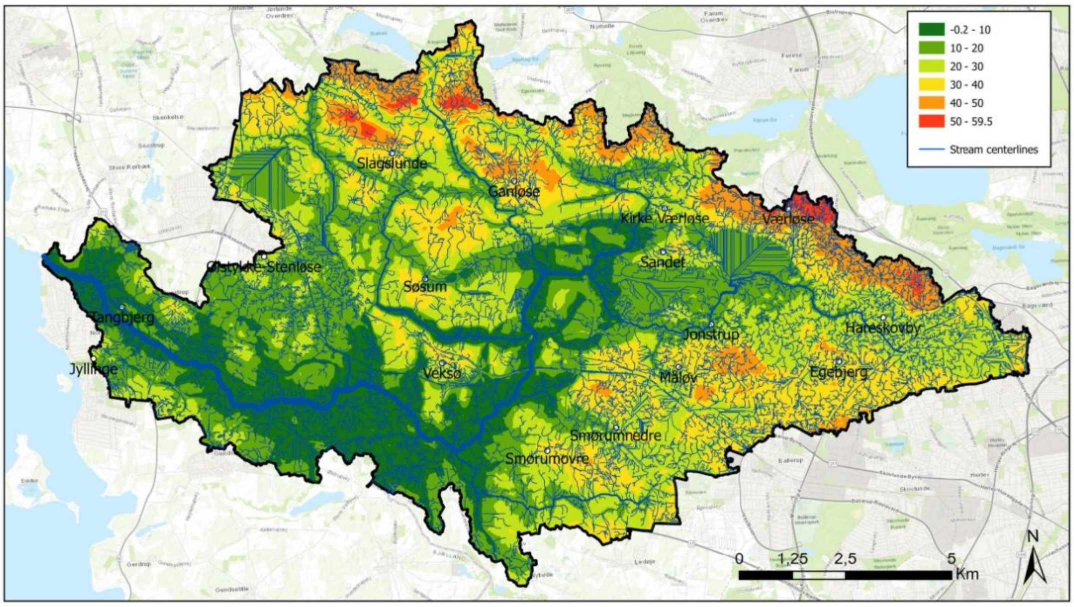

Fig. 11: LL Vaerebro - DTM hydroconditionned and calculated flow paths

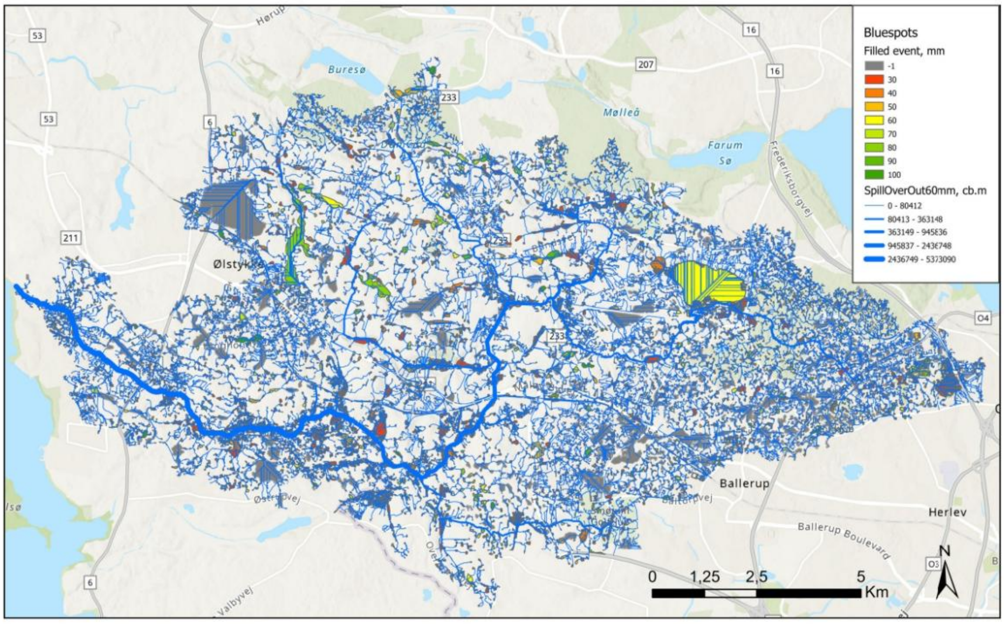

Fig. 12: LL Vaerebro – results bluespot screening 60 mm rainfall event

Summary of Key Climate Projections

According to the climate change local scenarios generated for this case study we can expect an increase in temperatures across all scenarios, time horizons, and periods of the year. However, no significant changes are expected in terms of precipitation by mid-century for any of the scenarios or periods of the year although there would be significant increases by the end of the century, especially during the summer and spring seasons.

Maximum temperature increases are expected to range from 2 to 2.4 degrees Celsius by mid-century and from 2.5 to 4.4 by the end of the century in the SSP2-4.5 and SSP5-8.5 respectively. This change would be especially significant in the summer and autumn months when the change would be up to 2.6 and 2.8 degrees respectively by mid-century in the most pessimistic scenario.

Additionally, the increase in temperatures will affect the occurrence of extreme weather events such as heat waves. Therefore, the length, intensity, and frequency of both heat waves and cold waves must be analysed to characterize these extreme weather events.

Regarding the heat waves, the main change is expected to occur in the annual number of events, which will increase significantly in every scenario and time horizon. The change in minimum temperatures will also lead to a significant increase in the occurrence of tropical nights (those with Tmin>22º). The temperatures of the coldest and warmest months are expected to increase for all time horizons and scenarios.

Slight significant changes are expected in terms of precipitation for any of the scenarios, and periods of the year by end-century. However, concerning the annual evapotranspiration, significant increases are expected for all time horizons and scenarios and almost all times of the year, mainly caused by the rise of temperatures. The annual reference evapotranspiration would increase 41.8 mm to 54.5 mm in the SSP2-4.5 and SSP5-8.5 scenarios respectively, so the absolute value would rise from 539.3 mm to 581.1 mm or 593.8 mm, by mid-century. This increase would be mainly distributed in the summer and autumn seasons.

Water balance, meaning, the difference between the accumulated precipitation minus the calculated evapotranspiration for each month, is not expected to change in general terms. Only summer water balance is expected to be slightly reduced in every scenario already by mid-century, this decrease will be 25.9 mm in the higher GHG emissions scenario by mid-century. In this case, the historically negative water balance is going to be reduced from –25.9 mm to –34.4 mm in this scenario.

Annual water surplus is expected to change in any scenario by the end of the century. However, some decreases are expected in the annual water deficit. Seasonally, this change would be mainly concentrated in the summer season. This indicates a potential increase in aridity during the summer season. Regarding the aridity index analysed, no significant changes are expected on it in general by mid-century.

Stakeholders involved

Since the start of the project, we have been in contact with the municipalities of Egedal, Ballerup and Furesø, as well as the water utility company Novafos. An overview of the meetings held, and the contact status can be found in the table below.

Tab. 1: List of stakeholder and the documentation of Meetings in the Vaerebro Living Lab

Stakeholders	Meetings and status
Municipality of Egedal	• Introduction meeting – Apr. 2024 • Participation in our Kick-Off meeting Vaerebro catchment visit – Apr.2024 • Acatchment visit where most of the DK-LL team participated has been completed on June 19 2025 and the outcomes of the field trip documented for planning further LL activities. • Further contact with the municipality is anticipated
Municipality of Ballerup	• Introduction meeting – Jun. 2024 • Follow-up meeting – Aug. 2024 • The contact is open
Municipality of Furesø	• Last contact – Jul. 2024 • Due to limited human resources, they were not able to engage with the project. • Aim to reestablish the contact in 2025.
Novafos (water utility company)	• Introduction meeting – Apr. 2024 • Follow-up meeting – Sep. 2024 • Status meeting – Nov. 2024 • Status meeting – Jan. 2024 • Status meeting – Feb. 2025

	• Status meeting – Mar. 2025 • The contact is open

Besides the above stakeholders other national and local actors with a role in water management and slow hydrology have been identified:

- Danish Ministry of Environment and Gender Equality
- Danish Environmental Agency
- Danish Ministry of Green Transition
- Danish Nature Agency
- Danish Ministry of Climate Energy and Utilities
- Danish Energy Agency
- DANVA (National NGO of water professionals)
- Danish Water Works (National NGO organizing water works)
- Danish Agriculture and Food Council (National NGO organizing Danish farmers)
- Local farmers and landowners
- Danish Society for Nature Conservation (National NGO with a focus on nature protection).

Primary objective

The primary objective is exploring the possibilities of shifting the water balance toward more retention through evaporation and infiltration, thereby obtaining less and slower runoff. Depending on the local situation, the goal is one or more of the following:

1. Reduce downstream flooding by retaining excess water further upstream
2. Improve water quality in the recipient sub area
3. Increase water flow during dry periods, mitigating drought
4. Increase groundwater recharge by infiltration of retained water, where possible

Further to consider **physical interventions in the landscape**, typically in the form of a basin. The design of such a basin can be adapted to provide additional value, such as improving nature quality or recreational opportunities.

By using **GIS modeling of water flow patterns**, potential intervention sites can be identified. This can be done in the following steps:

1. Delineation of the catchment area
2. Generation of flow paths (bluespot analyses)

3. Sorting of flow paths based on expected water flow (derived from the corresponding sub-catchment)
4. Overlaying of flow paths with maps of streams covered by the Water Framework Directive

The **potential intervention sites** are thus the **nodes where significant flow paths meet a stream**. Finally, a target must also be set for **how much water should be retained**, if relevant. This would have to be based on **hydrological models accounting for surface-groundwater interaction**.

Ecosystem Services – Co benefits

Tab. 2: Ecosystem Services and Co benefits in the Vaerebro Living Lab

Co-benefit	**Description**	**Main mechanism**
Regulating services		
1. Temperature	Cool the landscape to the benefit of aquatic and terrestrial life forms	shadowing from vegetation; conversion of sensible heat to latent heat through enhanced evapotranspiration;
2. Temperature	Cool downwind cities and mitigate UHI	Strategically positioned larger SH interventions – e.g. forests – can help cool down-wind cities,
3. Water quality	Prevent eutrophication of aquatic ecosystems (Roskilde Fjord, Wetlands along the river)	retaining of nutrients as well as suspended solids and contaminants in the fields
4. Erosion	Prevent soil loss	less runoff; slower runoff; in combination with enhanced vegetation for improved soil structure
Provisioning services		
5. Water supply	Groundwater recharging	Enhanced infiltration in general. Infiltration trenches can be positioned where land-use and geological conditions for groundwater recharging are optimal.
6. Farming	Higher harvest security during drought episodes	Increased amount of water in the root zone Reduced loss of nutrients and soil (Improved conditions for pollination and organic pest control in intervention increases vegetation cover)
7. Farming	Development of future/alternative cropping systems	The SH interventions will go well hand-in-hand with e.g. perma-culture, forest-farming, and intercropping systems
8. Forestry	Higher security by establishment of new forests	Flooding and drought resilience

9. Renewable energy	Allocation of land	Areas designated for SH intervention can double as solar panel parks, space for windmills and energy crops
Cultural services		
10. Aesthetic values	Aesthetic values of the landscape can be strengthened	A more variable landscape with more vegetation, supporting wildlife. Existing values, like viewpoints, landmarks, cultural heritage must be respected and new values shaped through the design of the system's elements.
11. Recreation and tourism	More options for nature tourism and sightseeing to the benefit of physical and mental health of visitors	The SH interventions can connect parts in the landscapes, e.g. forests, bogs and be connected to coherent paths, passing through interesting features in the landscape
12. Strengthen local communities	Enhance sense of belonging and counteract loneliness	Engaging stakeholders in taking care of their local landscape and in the prioritization of co-benefits and thus the specific designs of SH interventions may build a socially stronger community
13. Enhance value/attractiveness of rural areas	More people may want to settle in rural areas	Young farmers and other young families may want to settle in rural areas if they can have access to land and if there is a well-functioning community with schools, grocery shops etc. in the area.
Biodiversity support		
14. Improve ecological quality of streams and rivers	Combined effect of water quality improvement, temperature regulation and possibly re-meandering and other physical measures in the water course	Less nutrients and suspended solids are transported from the cropping fields to the streams and rivers. Erosion is controlled.
15. Improve ecological structure and diversity	Create new habitats Strengthen existing habitats	Enhance vegetation cover; Improve vegetation structure; Improve hydrological dynamics and other abiotic factors. Increase connectivity (biocorridors) Make a good management plan

The LL Værebro in pictures

Fig. 13: Vaerebro Living Lab in pictures

Toutalga, Sobral da Adiça [PT]

General profiling

The Toutalga catchment is a sub-basin of Guadiana river located in the southeast of Portugal near the village of Safara and the city of Moura, covering 136 km^2. It is a rural sub-basin overlapping the Moura-Ficalho aquifer with two temporary rivers called São Pedro and Toutalga. The geology of the area is characterized by shale and graywackes with some granite, gabbro, sandstone and claystone.

Fig. 14 shows the Land Use Land Cover of the catchment from COS2023 which is dominated by "Other agricultural areas (57%), followed by "Cork oak and holm oak" (20%), "Autumn/winter annual crops" (11%), "Spontaneous herbaceous vegetation" (7%), "Shrubland" (3%) and "Stone pine" (1%).

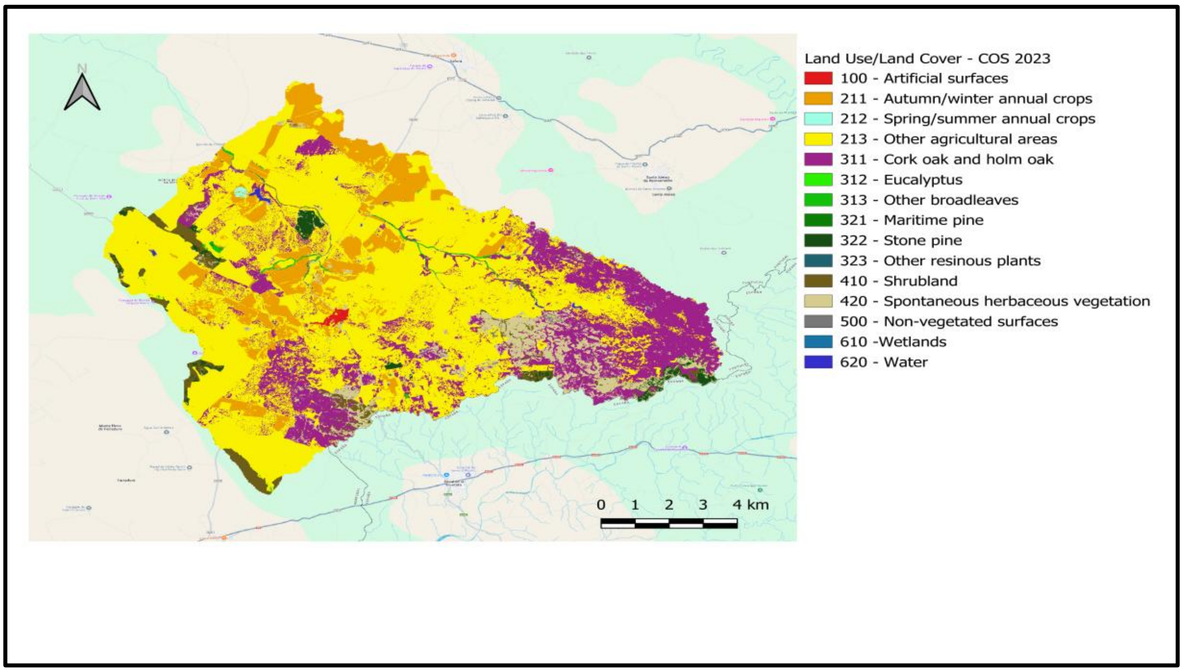

Fig. 14: The Land Use Land Cover (LULC) of the catchment. Data from COS2023.

The Digital Elevation Model (DEM) of the catchment was obtained by the DGT (Portuguese Territory Authority), with 0.5 m resolution, and reveals a landscape with maximum elevations of approx. 480 m found on the edges of the basin's nevertheless, the catchment is dominated by flat valleys with elevations between 180 and 280 m where the two main streams, São Pedro and Toutalga rivers, are located, see Fig. 15.

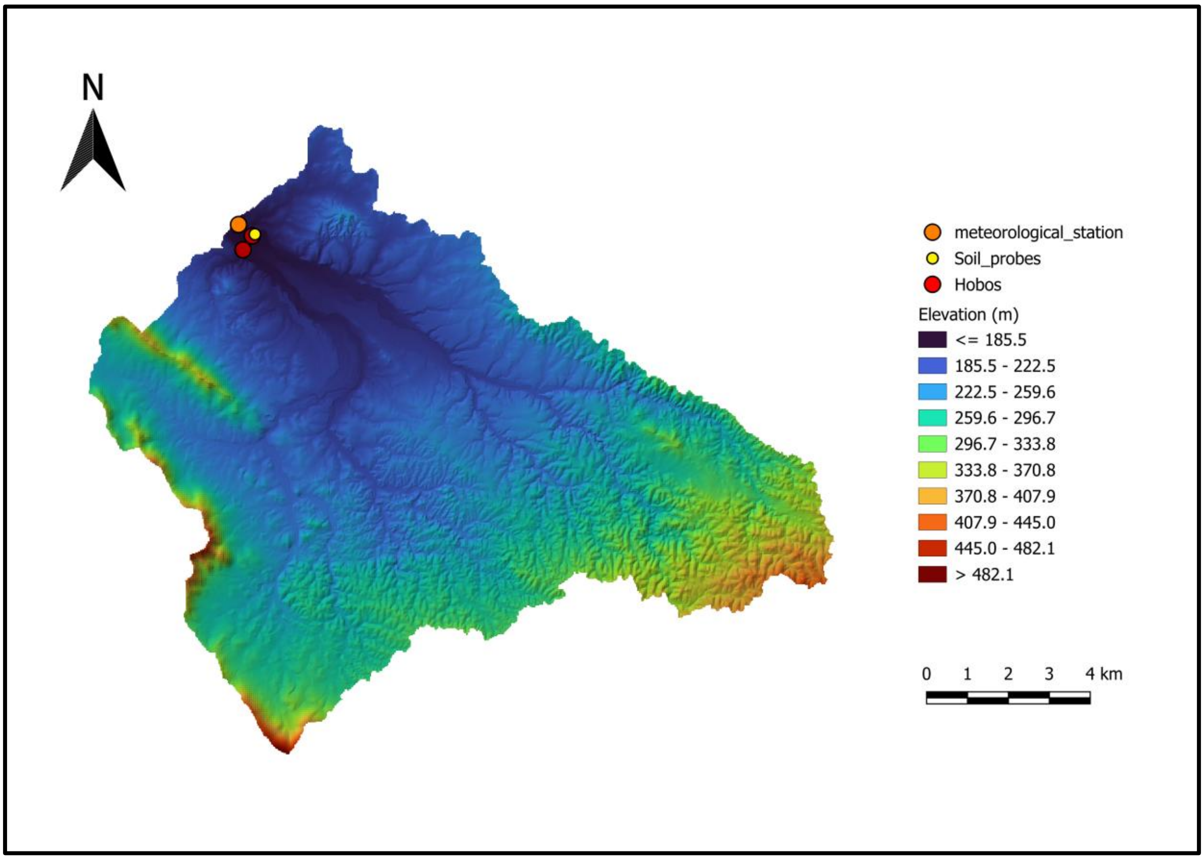

Fig. 15: The Digital Elevation Model (DEM) of the catchment with the location of the meteorological station, soil moisture probes and water level sensors (Hobos). Data from DGT (Portuguese Territory Authority) with 0.5 m resolution.

In Fig. 16 the Moura-Ficalho aquifer is shown and the Toutalga catchment where the overlapping area in the western part of the catchment is visible. The main streams and the protected rivers according to the Portuguese Environment Agency (APA).

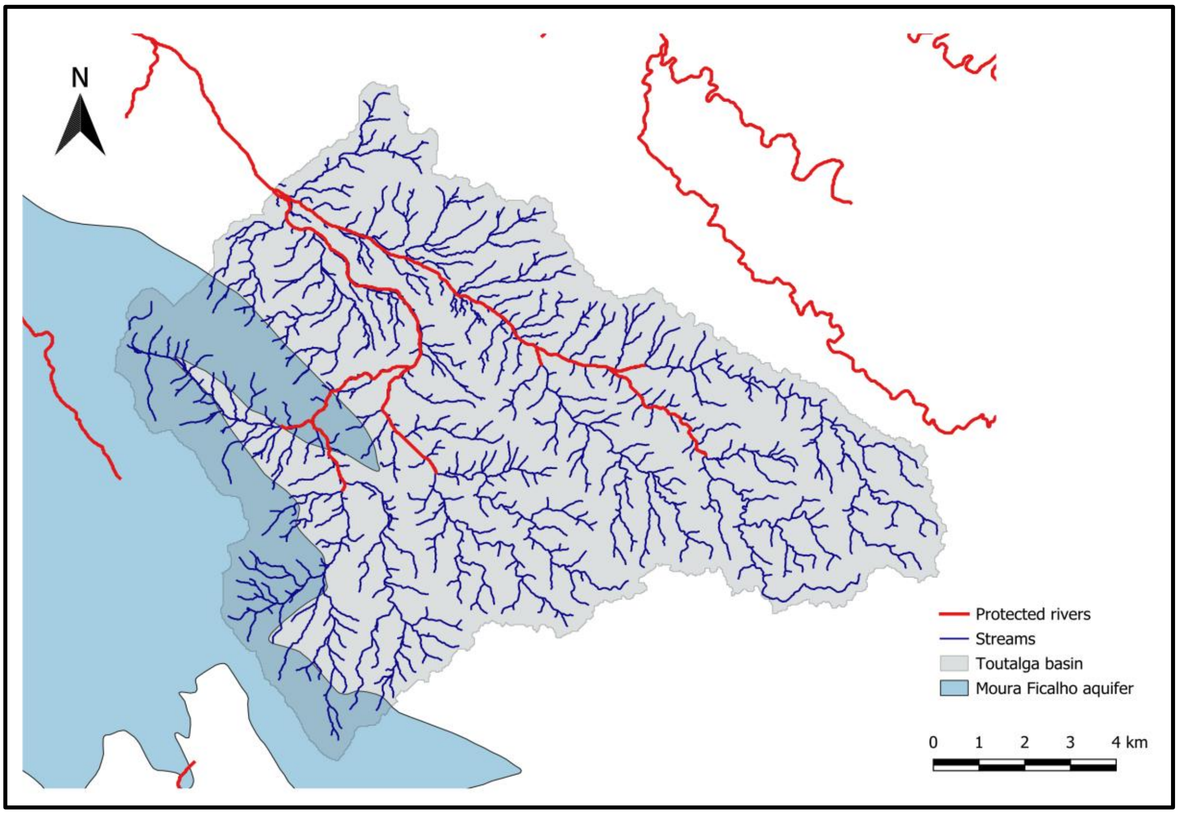

Fig. 16: The Moura-Ficalho aquifer in blue contour and the Toutalga catchment in grey contour (with the overlapping area), the streams in blue and the protected rivers in red.

Background and status:

The Toutalga sub-basin has no historical NBS interventions, however a single intervention was carried out for river regularization for flood protection (channeling and covering) on the Toutalga stream, in the municipality of Moura, over a length of 493 meters (APA 2015).

The Toutalga intermittent river was stated has "excellent" for the biological quality element Phytobenthos according to the Portuguese Environmental Agency (APA) on two campaigns realized in 2019 and 2021 in the station: Monte da Coroada (station code: 25N/50; lat: 38.074444; -7.293778).

Living Lab objectives:

- Biodiversity conservation
- Water quality
- Water retention and infiltration
- Creating possible favorable conditions for future NBS implementation

Associated institutions:

- Portuguese Environment Agency (APA)

- Empresa de Desenvolvimento e Infra-estruturas do Alqueva, S.A. (EDIA)

Stakeholders:

- Public agencies
- Municipalities
- Farmers and landowners
- Non-Governmental Organizations (NGOs)

Monitoring System

The monitoring design in place comprises the assessment of two reaches in S.Pedro and Toutalga streams, including meteorological, hydrological, hydromorphoplogical, physico-chemical and biological parameters. Meteorological parameters, water level, water temperature, soil moisture and vertebrates are assessed continuously. Physico-chemical and the remaining biological parameters are sampled monthly during the flowing phase and more frequently during the dry-phase. Hydromorphological assessment, based on the River Habitat Survey methodology is carried out once per season.

In detail, the methods for each parameter are as follows: i) soil moisture at three levels with EC-5 and ZL6 sensors from Zentra, water level and temperature with a HOBO® U20L Water Level Loggers in each stream; ii) *in situ* physico-chemical parameters, as temperature, dissolved oxygen, conductivity, turbidity, pH, ORP, resistivity and density, using a multiparametric Aqua TROLL 500 probe; iii) water physico-chemical analysis, carried out in the laboratory, following standard methods (APHA 2022), including Hardness (mg/l), Nitrate (mg/l), Nitrite (mg/l), Ammonium (mg/l), Ammonia (mg/l), Total Nitrogen (mg/l), Phosphates (mg/l), Total Phosphorus (mg/l), Sulphate (mg/l), Silica, Biochemical Oxygen Demand (mg/l), Total Organic Carbon (mg/l), Total Suspended Solids (mg/l), Sulphate (mg/l), Silica (mg/l); iv) Aquatic biological communities (i.e., microalgae and invertebrates), following standard methods during the flowing phase (e.g. AFNOR 2003, European Committee for Standardization 2003, INAG 2008 for diatoms), during the dry-phase, independent samples will be collected in each pool; v) terrestrial biological communities (e.g. vertebrates), by placing 2 camera traps (1 in each stream) to monitor the vertebrate fauna and their interrelation with the water availability; v) Hydromorphological assessment, based on the River Habitat Survey methodology, assessing a stretch of 500 m in each stream; vi) eDNA analysis – Biodiversity analysis using DNA barcode sequencing with minION from Oxford Nanopore; vii) meteorological data are retrieved from an automatic weather station installed in the living lab, a Vaisala Weather Transmitter WXT520 and an Tipping

Bucket Raingauge ARG100 from Campbell Scientific, the variables under monitoring are air temperature (ºC), relative humidity (%), wind speed (m/s) and direction (º), barometric pressure (hPa), precipitation (mm), global solar radiation (W/m^2), details found in: https://www.newclima.cge.uevora.pt/toutalga.php.

Soil Erosion Risk Assessment

The Revised Universal Soil Loss Equation model (RUSLE) was applied based on the integration of datasets for rainfall erosivity, soil erodibility, topographic slope and length, land cover, and erosion control practices (Benavidez et al. 2018). Its main goal is to estimate long-term average annual soil loss from sheet and rill erosion, helping guide land use planning, water management and conservational efforts (Renard et al. 1997).

The spatial variability of the potential risk of soil erosion in the Toutalga basin was obtained with values grouped into four classes, ranging from under 10 t ha^{-1} yr^{-1} in low-risk areas to over 25 t ha^{-1} yr^{-1} in the most vulnerable zones. The results indicate that the highest erosion rates are concentrated mainly in the western and northwestern sectors, where steep slopes and low vegetation cover coincide. This pattern aligns with expectations based on terrain and land use characteristics, as well as the slope profiles and drainage density patterns.

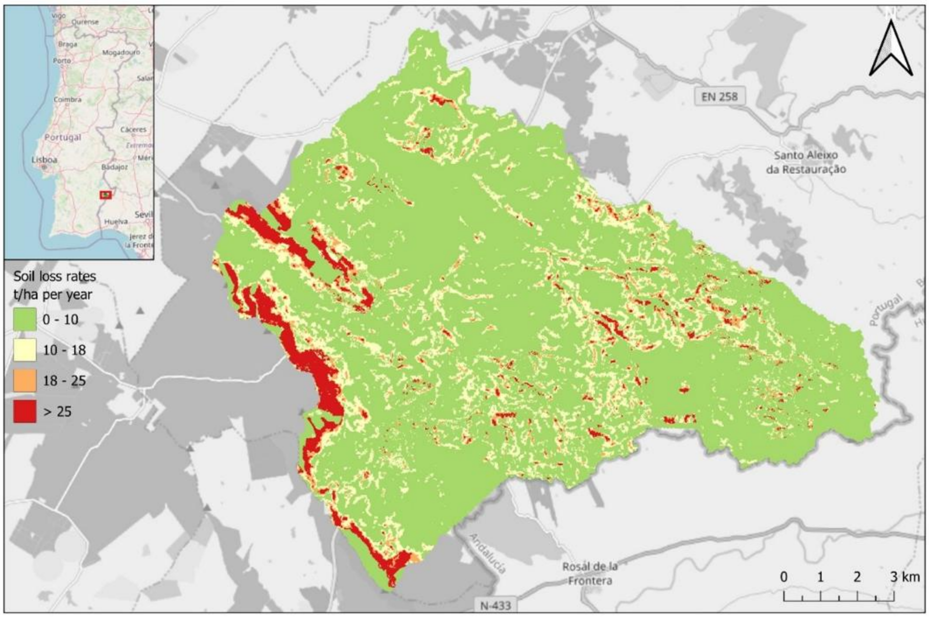

Fig. 17: Soil erosion risk map for the Toutalga Basin, calculated using the RUSLE model.

The model offers a reliable approximation of soil erosion risk at the basin scale. It highlights specific areas where soil conservation efforts and land and water management interventions would be most beneficial, helping to achieve part of the broad benefits of “Slow Hydrology”.

Bluespot screening

DTM data source: Direção Geral do Território (DGT), 0.5 m resolution, 2024.

Modifications to the DTM: None.

Interpretation of results:

The Toutalga drainage basin under study covers an area of 136 km^2 and is located in the south of Portugal, namely in the Alentejo region, close to the border with Spain, see Fig. 17 . From the DEM, the mountainous areas are distributed along the southwest and southeast margins of the basin, with a ridge of elevation evident in the northwestern area. The elevations vary between 144 and 523 m.a.s.l., with the predominant drainage direction in the basin being from southeast to northwest (SE-NW). According to the analysis of the hypsometric curve, 90% of the basin's areas are below the elevation of 324 m.a.s.l. and the river network within the drainage basin forms a dendritic pattern, a common pattern in river basins in the south of Portugal, such as those in Alentejo.

For the 60 mm rainfall event in Toutalga, the analysis reveals only a few small “bluespots”, natural depressions in the basin, with the maximum overflow occurring in a 50 mm bluespot according to its contributing drainage area, see Fig. 18. None of them had the full capacity to retain the volume of stormwater, for this particular extreme stormwater event, without overflowing (grey color with a filled event value of -1). These natural depressions in the soil can act as important water buffers, acting as small retention basins for irrigation and animal watering in the dry seasons, especially in this region, although their accumulated capacity is small. However, in some lower parts of the landscape, which are dominated by loosely compacted soils with gravel overlying the rock, the runoff accumulated in these streams was high and spatially concentrated.

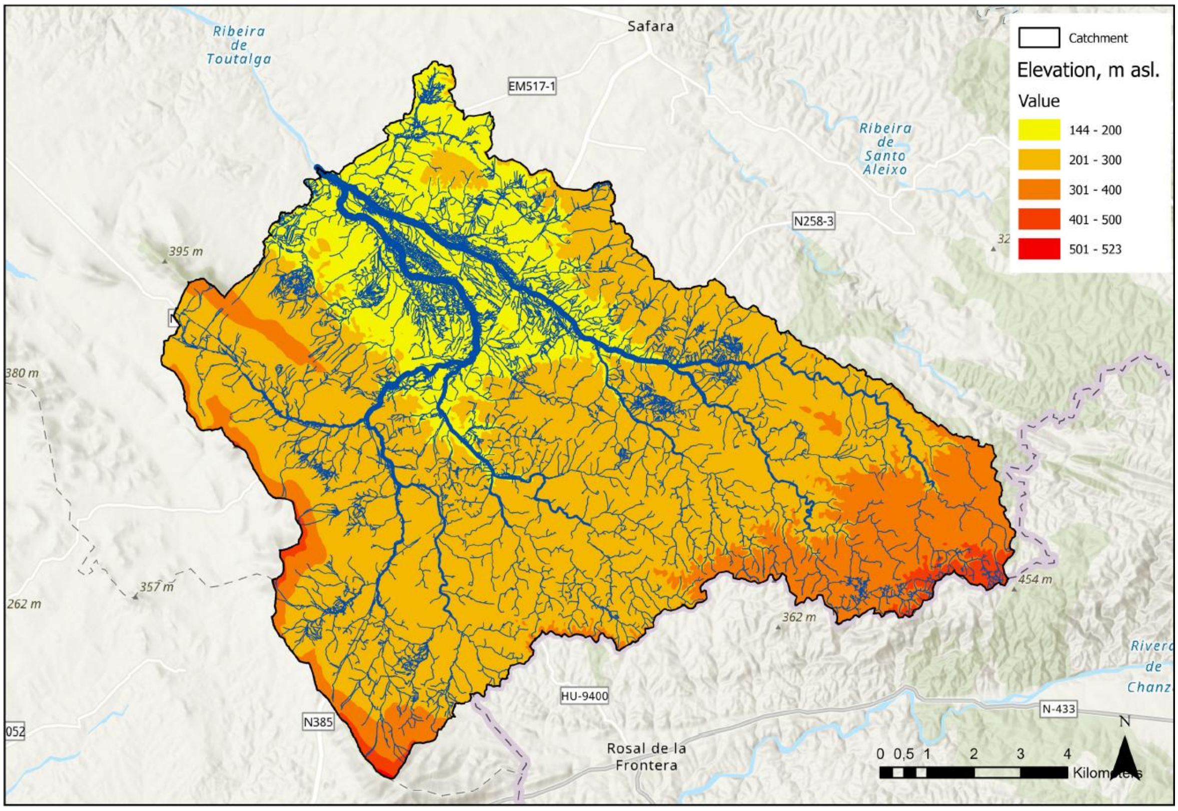

Fig. 17: LL Toutalga, Sobral da Adiça- DTM and calculated flow paths

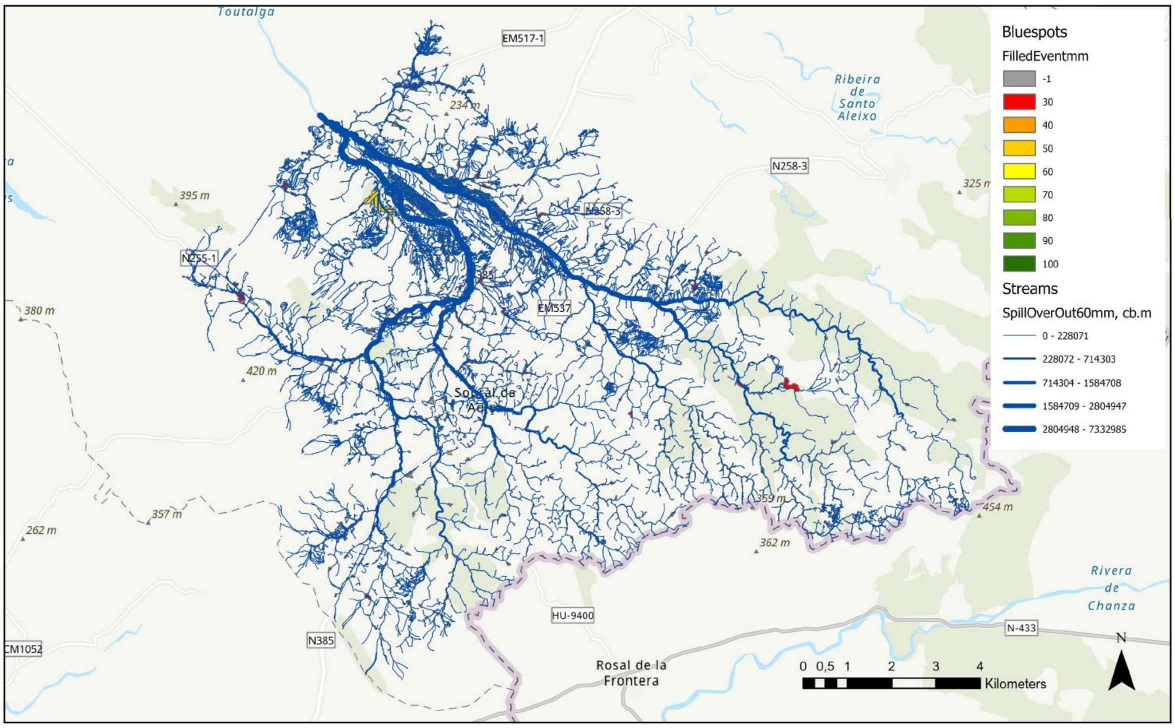

Fig. 18: LL Toutalga, Sobral da Adiça – results bluespot screening 60 mm rainfall event

According to historical annual maxima daily precipitation data, an extreme rainfall event of 60 mm occurs approximately once every 75 years (empirical return period). Thus, this uniform

60 mm stormwater event, assuming Hortonian flow conditions, generate an accumulated runoff at the outlet estimated in7.3 mio m^3.

Summary of Key Climate Projections

Maximum temperatures are projected to increase by 2.2–2.7°C by mid-century and 3.2–5.7°C by the end of the century under SSP2-4.5 and SSP5-8.5 scenarios. These increases will be especially significant during summer and autumn. Such warming is expected to intensify extreme weather events, particularly heat waves, which could pose a major threat to wetland ecosystems. The frequency of heat waves may double under optimistic scenarios and quadruple under pessimistic ones by mid-century, though their duration and intensity are not expected to change significantly.

The number of days exceeding the 95th percentile of historical maximum temperatures could rise from 5 to 20–27 days by mid-century. Warmest month temperatures will also increase across all time horizons and scenarios. Mean and minimum annual temperatures will rise slightly less than maximum temperatures, increasing by 2.0–2.5°C and 1.9–2.3°C, respectively, by mid-century.

Frost days will decline sharply—from 26 days historically to only 14–16 days—nearly eliminating frost occurrences. Tropical nights (Tmin > 22°C) will increase from none to 5–8 nights per year by mid-century. Cold wave behaviour is not expected to change significantly; average durations will remain around 4 days, with only slight increases in intensity. Their frequency will decrease from 1 to 0 events annually.

Days with extremely low minimum temperatures (below the 5th percentile) will drop from 8 to 2 or 1 day annually. Coldest month temperatures will increase across all scenarios and timeframes. No significant changes are projected for the annual temperature range.

Annual precipitation is not expected to change significantly by mid-century. However, rising temperatures will lead to substantial increases in annual evapotranspiration: by 129.8–171.3 mm, raising total values from 1556.5 mm to 1686.3 mm or 1727.8 mm. These increases will occur primarily during summer and autumn.

Annual water surplus will remain largely unchanged. However, the annual water deficit is projected to worsen—from –1208.6 mm historically to –1391.6 mm in the most pessimistic scenario by mid-century. This trend will be most pronounced during summer and autumn, indicating a likely increase in summer aridity. The number of months with a positive water balance is not expected to change.

No significant changes are projected in the general aridity index, nor in the Martonne, Lang, or Thornthwaite humidity indices by mid-century. However, drought intensity is expected to decrease significantly on an annual basis and during spring and winter. By the end of the century, this reduction will extend to all seasons except autumn. The SPI (precipitation-only index) is not expected to change, while the SPEI (which includes temperature) will decrease significantly, especially toward the end of the century.

Stakeholders

At the beginning of the project, on the 15th April 2024, we have contacted and presented INTERLAYER project to the Regional Hydrographic Region Administration (*Administração da Região Hidrográfica do Alentejo, ARH-APA*), the regional water management authority. We have discussed a suitable place to settle the pilot Living Lab within the Guadiana basin according to the objectives of the project. Further, contacts have been established with the owner of the farm where the pilot area is located, in order to have permission to set up the monitoring program and also to know more about the region.

Besides the above stakeholders, other national and local actors with a role in water management have been identified:

- Farmers and landowners in the Toutalga catchment, especially in the areas surrounding the S. Pedro and Toutalga monitoring stations - to address the effect of cropping systems and selected species in water holding capacity of the soil and resilience, according to the expected future climate;
- Public water managers, such as Águas Públicas do Alentejo and Empresa de Desenvolvimento e Infraestruturas do Alqueva, S.A. (EDIA), the latter being the company that manages the Alqueva Multipurpose Reservoir;
- Sobral da Adiça Parish and Moura municipality, to discuss the possibility of the implementation of a water retention basin upstream of Sobral da Adiça village to ensure resilience towards flooding;
- Local communities of neighboring villages (e.g. Sobral da Adiça, Safara and Santo Amador), with whom it is envisaged to discuss the identification of the best water retention technologies for the Toutalga river basin; as well as the identification of the best strategies to develop a representative range of cropping systems and urban areas

and ecosystem protective measures taking in consideration impacts on water quality and biodiversity;

- Conservation and Environmental Organizations, as the national nature and forests conservation institute (Instituto de Conservação da Natureza e das Florestas), to discuss the possibility to implement a water retention basin to store water during the dry-phase to be available for biodiversity conservation. Further, it is an important stakeholder because the Toutalga catchment is partially included in a protected area (i.e., integrates Natura 2000 network, the Zona de Proteção Especial de Mourão/ Moura/ Barrancos);
- Non-governmental organizations (NGOs), e.g., the Sociedade Portuguesa para o Estudo das Aves (SPEA), QUERCUS - Associação Nacional de Conservação da Natureza, FAPAS - Associação Portuguesa para a Conservação da Biodiversidade. The contact with these NGOs aims at the discussion of the development of strategies for a range of cropping systems and ecosystem protective measures taking into consideration impacts on water quantity, quality and biodiversity, especially important in Toutalga catchment;
- Apart from the regional hydrographic region authority (ARH Alentejo), further contacts can also be established with the Portuguese Environmental Agency, to discuss possible policy recommendations.

Primary objective

The potential of slow hydrology within a natural watershed dominated by intermittent rivers and ephemeral streams (IRES)is assessed by considering specific objectives adapted within the main dimensions of support:

Ecological Services and Biodiversity

I. Encourage the maintenance and creation of natural habitats for protected wild fauna and flora species in areas classified as Natura 2000;

    Action: Promoting surface storage of water volumes generated by flash floods, using the topography of the terrain, existent natural drainage systems and Nature Based Solutions (NBS)

II. Preserve the functions of riparian wetlands and the biodiversity associated with slower and more stable hydrological regimes;

    Action: Establish protective barriers as dikes and using Nature-Based Solutions (NBS) to slow down water velocity, as well as ditches and diversion channels to temporarily store excess rainwater.

Cultural and Social Impacts

I. Increase community and stakeholders engagement within sustainable water management practices and principles.

    Action: Raise awareness of water-related issues by conducting public education campaigns through workshops, social media, and school activities, but also by providing regular updates on ongoing water related projects using digital information systems with interactive and understandable GIS maps and platforms.

II. Improve water availability and quality during periods of drought, considering water needs for agricultural and livestock activities.

Action: Promoting surface storage of water volumes generated by flash floods, using the topography of the terrain, existent natural drainage systems and Nature Based Solutions (NBS)

III. Increase urban flood protection of citizens and properties against extreme precipitation events that are becoming more frequent in southern Portugal

Action: Promoting surface storage of water volumes generated by flash floods, using the topography of the terrain, existent natural drainage systems and Nature Based Solutions (NBS).

Hydrological Resilience

I. Increase the system's capacity to absorb shocks and recover, taking advantage of the synergistic interrelationship between surface water and groundwater, in order to improve its ability to cope with extreme hydrological events, which are particularly relevant in areas experiencing a rapid decline in groundwater levels.

Action: Promote processes such as infiltration and deep percolation through the use of managed aquifer recharge (MAR) practices by implementing infiltration ponds.

II. Control soil degradation and depletion to ensure its sustainable use for agricultural production, nutrient cycling and carbon storage

Action: Development of risk-based erosion maps to identify areas most vulnerable to soil erosion, enabling the implementation of measures to control and reduce surface runoff rates, increase vegetation cover, and promote rooting in the soil structure.

Ecosystem Services – Co benefits

SUPPORTING

- **morphology + ecology**
- **hydrological cycle**
- **nutrient cycle**
- **soil genesis**

REGULATIVE

- **retention of C, N and P**
- **flood regulation**
- **low flow regulation**
- **drainage system (receiving water courses)**
- **sediment regulation**
- **cooling effects for running waters**

- **cooling effects for soil**
- **providing habitats**
- **erosion protection**
- **natural hazard protection**
- **drought resilience**
- **water infiltration**

<u>CULTURAL</u>

- **natural + cultural heritage**
- **education**
- **science**

<u>PROVISIONING</u>

- **forage crops**
- **drinking water (groundwater)**
- **water for industry + agriculture**
- **water for sustaining biodiversity**

The LL Toutalga, Sobral da Adiça in pictures

Fig. 19: Living Lab Toutalga, Sobral da Adiça in pictures

Lower Danube River (Salcia-Maglavit) [RO]

General profiling

Area:

The Salcia–Maglavit area covers 77 km^2 along a former Danube River floodplain in southwestern Romania. It features a mix of arable land, wetlands, pastures, and forest, with ecological value recognized through Natura 2000 and nearby RAMSAR designations. The site lies in a low-elevation, humid continental zone, with soils and geology typical of floodplain systems.

Background and current status:

Situated in southwestern Romania, the Salcia–Maglavit area forms part of the historical Danube floodplain, once shaped by natural inundation cycles. Over time, human interventions, such as land drainage, agriculture expansion, and fish farming altered its hydrological function. The region includes a patchwork of land uses, from cropland and pastures to forest plantations and wetland remnants. Its environmental importance is recognized through designations like Natura 2000 and nearby protected areas under the RAMSAR Convention.

Despite its potential, the area faces challenges such as drainage, water overabstraction, deforestation, and drought. Reconnecting the Danube through Nature-Based Solutions offers a clear opportunity to restore hydrological function, enhance biodiversity, and support climate resilience.

Pilot outcomes:

- Initial testing of slow hydrology measures for local water retention and delayed runoff
- Identification of conditions suitable for implementing NBS
- Monitoring surface water presence
- Evaluation of vegetation trends
- Mapping of fire frequency as an indicator of landscape disturbance and vulnerability
- Stakeholder engagement to support management actions
- In-situ monitoring of groundwater levels and weather variables

Associated institutions: The Executive Agency for Higher Education, Research and Innovation Funding (UEFISCDI).

Stakeholder: local authorities, local farmers, Romanian Waters National Administration, local community members

Research questions:

- How can hydrological connectivity between the Danube River and the Salcia–Maglavit floodplain be effectively restored?
- What are the most suitable NBS for enhancing slow hydrology and floodplain retention in this region?

- How do land use patterns (e.g. agriculture, pastures, abandoned fish ponds) affect water retention and ecological function in the floodplain?
- What is the impact of current and future climate conditions (e.g. increased temperature, evapotranspiration) on water balance and drought risk in the area?
- How does vegetation stability respond to changes in hydrology, land management, and seasonal variability?
- What role can remote sensing tools (e.g. Sentinel-1, Sentinel-2, MODIS) play in monitoring water dynamics, vegetation health, and disturbance events over time?
- Which zones within the landscape offer the highest potential for seasonal flooding, storage, and wetland reactivation?

Characteristics

Located along a 77 km² stretch of the former floodplain of the Danube River in Romania (Fig. 20) between the villages of Salcia and Maglavit, this site presents a rich mosaic of agricultural lands, wetlands, and peri-urban areas, with an elevation under 100 meters. The landscape includes mixed-use arable land, planted forest, pasture, and an abandoned fish farm, making it an ideal location for both ecological restoration and sustainable agricultural development. It experiences a continental humid climate with hot summers, adding to the complexity of managing water resources and land use.

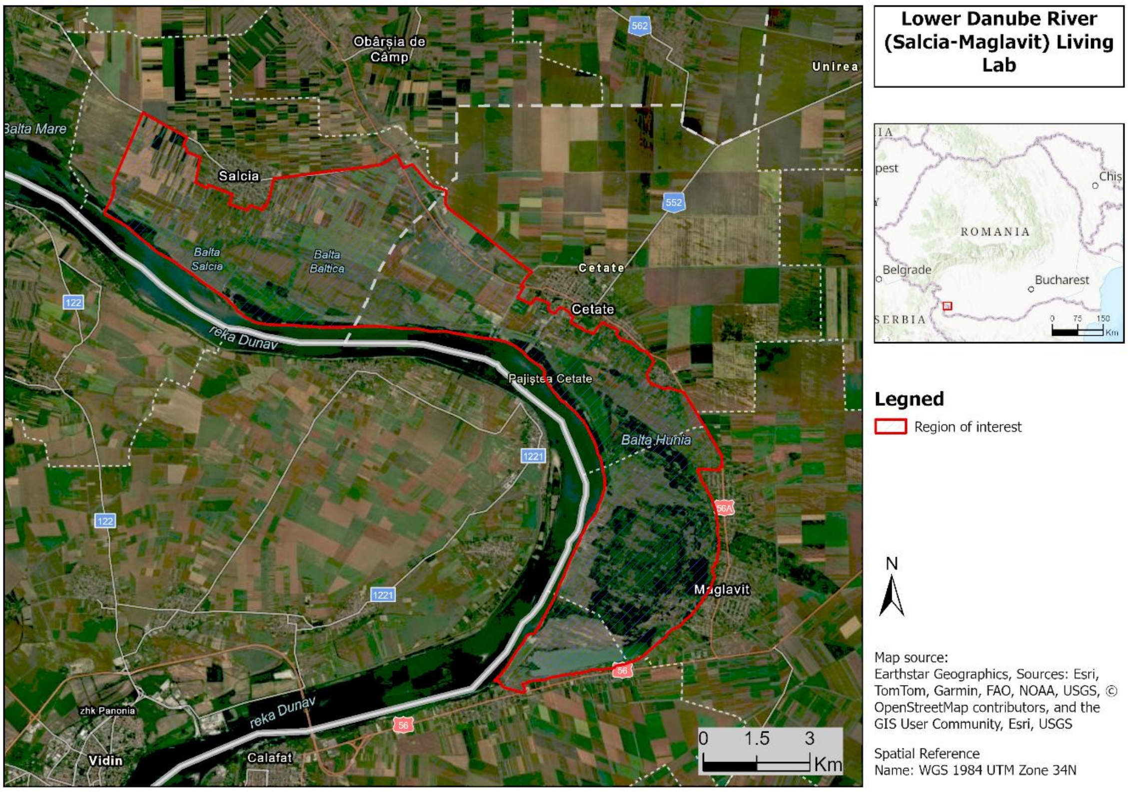

Fig. 20: Location and extent of the Lower Danube River (Salcia–Maglavit) Living Lab

The site holds significant ecological value, with several formal protection statuses, including the Natura 2000 site Maglavit and the Pajiștea Cetate nature reserve, part of the Danube Floodplain. It is also in close proximity to the Gârla Mare Natura 2000 site and the Calafat – Ciuperceni – Dunăre RAMSAR site, further highlighting its importance for biodiversity conservation and habitat connectivity.

Geologically, the site is situated in the southwestern part of the Oltenia Plain within the Romanian Plain, characterized by layers of gravel, sand, and loess from the Quaternary period. The dominant soil types are luvisol, podzoluvisol, and planosol, which are typical of floodplain environments and influence both agricultural productivity and water management strategies.

Despite its ecological importance, the site faces several critical water and environmental challenges. The drainage of agricultural and urban areas has disrupted natural hydrological cycles, while water abstraction and urban development have further strained local water resources. Deforestation and rising temperatures compound these issues, increasing the risk of drought and environmental degradation. Given these challenges, the site has significant potential for intervention through NBS. Enhancing lateral connectivity to re-establish surface and groundwater interactions could improve ecological resilience, restore wetland functionality, and reduce the impacts of climate change.

The CORINE Land Cover 2018 data for the Danube River site between Salcia and Maglavit shows a mix of land uses, combining agriculture, natural areas, and water features typical of a floodplain (Fig. 21). The largest land use type is **non-irrigated arable land**, covering **34.3%** of the area. This suggests that farming is a primary activity in the region. **Pastures** make up **20.4%**, showing the presence of open grasslands used for grazing. **Broad-leaved forests** cover **13.1%**, contributing to natural vegetation along the floodplain. Smaller areas include **agriculture mixed with natural vegetation** (7.2%) and **complex cultivation patterns** (5.8%), reflecting a combination of different land uses. **Vineyards** account for **6.5%**, adding to the agricultural diversity. **Transitional woodland-shrub** covers **3.5%**, often found in areas that are changing from open land to forest. Water features are present in the form of **water bodies** (8.2%) and **water courses** (0.1%), supporting the site's floodplain character. **Discontinuous urban fabric** is very limited, at only **0.1%**, showing that built-up areas are minimal. Overall, the land cover data shows a predominantly rural landscape with a mix of farming, grassland, forest, and water areas, offering varied conditions for land and water management.

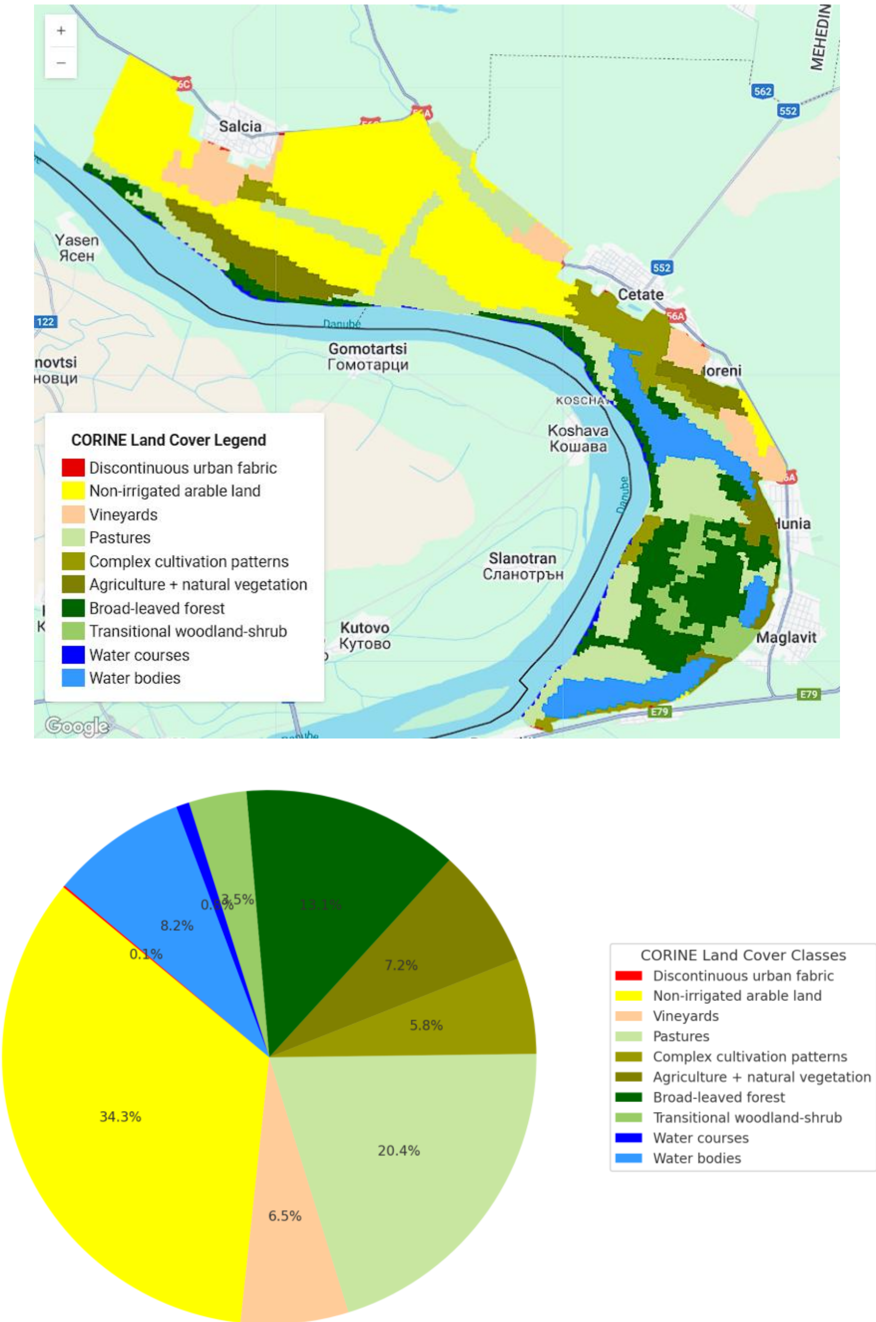

Fig. 21: Land cover distribution in the Living Lab area based on CORINE Land Cover 2018.

Monitoring System

In-situ Monitoring in the Danube River (Fig. 22**)**

- Water discharge measurements using ADCP (Acoustic Doppler Current Profiler)
- Bathymetric surveys conducted with a single-beam echo sounder
- Water quality parameters monitored on site

Fig. 22: In-situ measurements and field monitoring activities.

In-situ Monitoring in the Living Lab Area (Fig. 23)**:**

Five Sensoterra multi-depth soil moisture sensors have been installed at the Romanian site to ensure precise monitoring and data collection. These devices provide continuous measurements of soil moisture at various depths, along with soil temperature. This data is essential for understanding water infiltration, retention capacity, and the behaviour of the soil under a changing climate.

In addition to soil monitoring, a Decentlab weather station has been deployed to collect a wide array of environmental variables. These include solar radiation, precipitation (including cumulative totals and electrical conductivity), air temperature, relative humidity, vapor pressure, barometric pressure, wind speed and direction, maximum wind speed, and lightning strike data (count and average distance). This dataset supports a holistic analysis of local climatic and hydrological conditions.

All sensor data is transmitted in real time via LoRaWAN (Long Range Wide Area Network), which offers low-power and long-range communication.

The collected data will inform models and simulations, guide the design of nature-based solutions, and support decision-making aimed at increasing water retention, improving drought resilience, preserving water quality, and enhancing biodiversity. The Romanian Living Lab contributes to a larger European effort to build adaptive, climate-resilient water management strategies tailored to regional needs and conditions.

Fig. 23: Gateway (left), soil moisture sensor (middle), weather station (right).

Remote Sensing-Based Monitoring

Satellite data from the Sentinel-1 mission is used to monitor surface water dynamics in the Danube River floodplain (Fig. 24). The analysis relies on radar imagery (2510 images) (SAR) from Sentinel-1 collected over multiple years (2015–2024), with both VV and VH polarizations selected for detailed water detection. The instrument mode used is IW (Interferometric Wide swath), which is standard for land monitoring applications.

The image displayed represents a surface water map derived using a water index threshold (swiThreshold = -0.16). The darker blue tones in the image indicate areas of persistent or significant surface water, while lighter areas are less water-affected or dry. This allows for the detection of both permanent and temporary water bodies, such as channels, ponds, and floodplains.

The approach is suitable for observing changes in water extent over time, identifying flooding patterns, and supporting decisions on water management and ecosystem restoration.

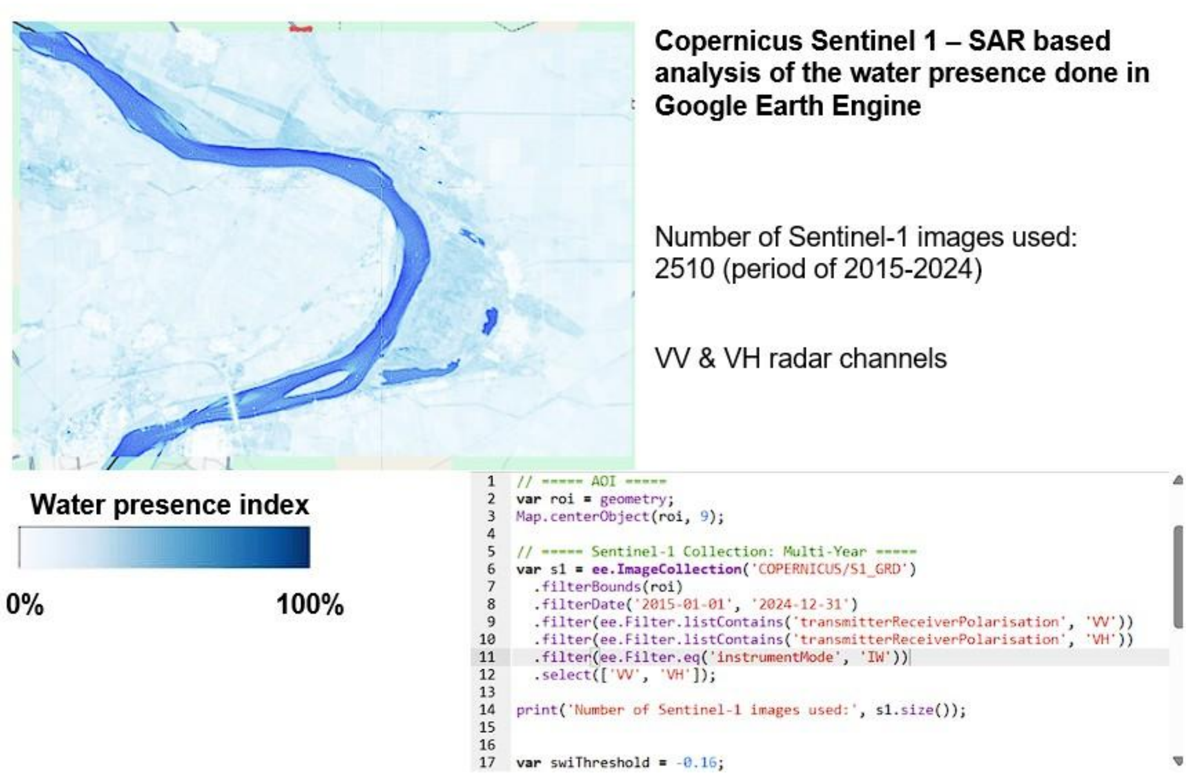

Fig. 24: Water presence analysis using Sentinel-1 SAR data (2015–2024).

Vegetation presence and stability in the Danube River Living Lab are monitored using Sentinel-2 optical satellite data (Fig. 25). A total of **781 images** from the period **2015–2024** were analyzed using the **Normalized Difference Vegetation Index (NDVI)**, calculated as: **NDVI = (NIR - RED) / (NIR + RED)**.

The map shows a vegetation stability index, where areas in green indicate stable and dense vegetation (closer to 100%), while red areas represent low or no vegetation cover (closer to 0%). This approach helps identify land cover types, seasonal vegetation patterns, and changes due to land use or hydrological variability.

By filtering for low cloud cover (less than 20%), and using NIR (Band 8) and RED (Band 4) spectral bands, the method produces a consistent time series of vegetation health and coverage. This data supports ecosystem monitoring, agricultural planning, and the evaluation of restoration outcomes.

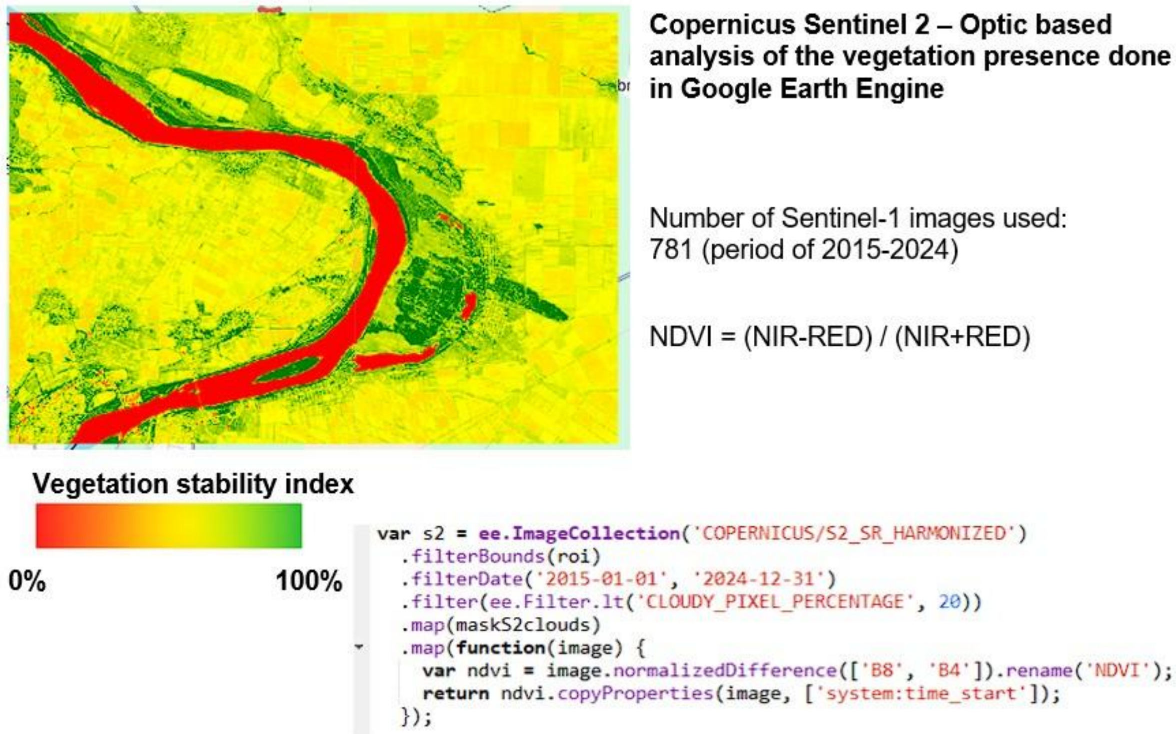

Fig. 25: Vegetation presence and stability analysis using Sentinel-2 optical data (2015–2024).

Fire occurrence across the Living Lab area was analyzed using the **MODIS MCD64A1 Burned Area dataset**, covering the period **2000 to May 2025 (**Fig. 26**).** This dataset provides monthly global maps of burned areas at 500m resolution. Burned pixels were identified and summed to calculate the **fire frequency**, or the number of times each location burned during the 25-year period.

The resulting map shows a clear spatial pattern:

- **Yellow areas** burned once between 2000 and 2025.
- **Orange areas** experienced **2–3 fires**.
- No areas within the AOI show higher fire frequencies (4+ times), suggesting **low to moderate fire recurrence** overall.

Most fires occurred in the **northern part of the site**, especially near Salcia and Cetate, where arable and grassland areas dominate. The southern and central floodplain areas near the Danube, especially zones with denser vegetation or permanent water, show **little to no fire activity.**

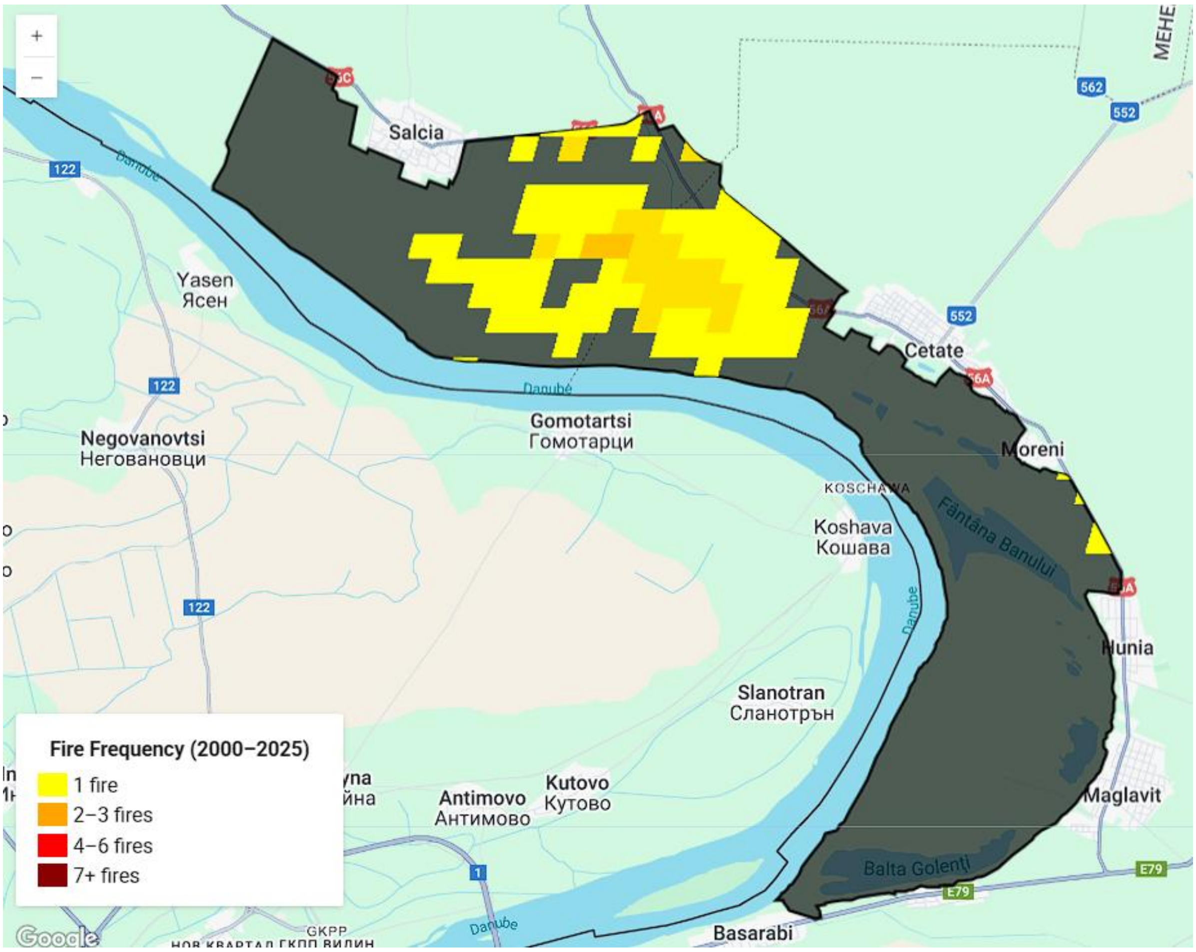

Fig. 26: Fire frequency map based on MODIS burned area data (2000–2025).

Bluespot screening

DTM data source: Continental Europe Digital Terrain Model (OpenTopography - Continental Europe Digital Terrain Model), 30 m resolution, 2000-2018.

Modifications to the DTM: None.

Interpretation of results:

The Living Lab (LL) is located at Salcia and Maglavit vis-a-vis the Lower Danube River. A thorough bluespot screening of the LL has not been carried out as a high-resolution DTM is not available for the region. Meanwhile, as several stormwater induced floods in the past have caused severe damage to Salcia and more towns within the 932 km^2 sub-catchment to the Danube River located N-NW of the LL, a screening of that region was issued. It shows a region with elevations ranging from 27 to 348 m asl. and a major N-S going river, Paraul Drincea.

The bluespot screening shows that numerous bluespots with large capacities are present (colored in grey with a filled event value of -1), especially in the SW part of the drainage basin, see Fig. 27. That said, very few of those bluespots are filled at a 60 mm uniform stormwater scenario which is projected to occur more frequently by 2050 due to climate change impacts on precipitation patterns. Thus, no spillover is produced from the runoff generated in this part of the drainage basin. However, as bluespots in the northern and eastern parts of the basin are sparse, the runoff generated there accumulates quickly, so the estimated potential runoff at the basin's outlet is estimated to be approx. 31.0 mio m^3.

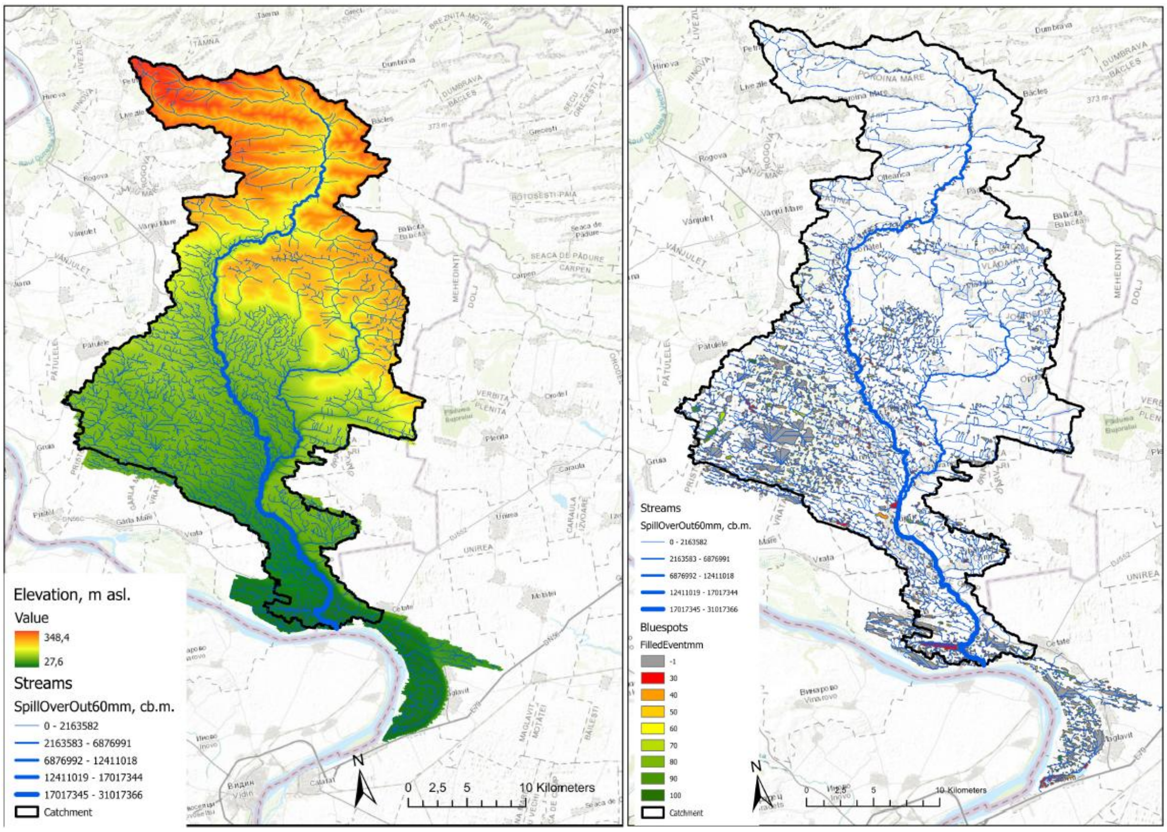

Fig. 27: LL Danube River (Salcia-Maglavit) DTM (left) and calculated flow paths and results of the bluespot screening 60 mm rainfall event (right)

Summary of Key Climate Projections

Maximum temperatures are projected to increase by 2.7–3.3°C by mid-century and by 3.8–6.6°C by the end of the century under SSP2-4.5 and SSP5-8.5 scenarios. This rise will be particularly pronounced in the summer and autumn seasons. The increase in temperature is expected to intensify extreme weather events, particularly heat waves, which could pose risks to wetland ecosystems. The number of heat wave events is projected to rise significantly, from 1 event to 3–4 events by mid-century, though no major changes in their average duration or intensity are expected.

Days with maximum temperatures exceeding the 95th percentile of the warmest months are expected to increase sharply—from 4 to 25–33 days by mid-century. Warmest month temperatures are projected to increase across all scenarios and timeframes.

Mean and minimum annual temperatures will also increase, although slightly less than maximum temperatures, rising by 2.5–3.1°C and 2.2–2.8°C respectively. The most notable increases will occur during spring and winter. Frost days are projected to decline substantially—from 79 historically to 44–50 days fewer by mid-century—effectively nearing their disappearance. Tropical nights ($T_{min} > 22$°C) will increase from none in the reference period to 15–23 nights annually by mid-century.

Cold wave characteristics are not expected to change significantly; average durations will remain at 4–5 days per year, with only slight increases in intensity. The number of days with minimum temperatures below the 5th percentile of the coldest months will decrease from 7 to 2 or 1 day annually. No significant changes are projected in the annual temperature range.

Annual precipitation levels are not expected to change significantly across any scenario by mid-century. In contrast, annual reference evapotranspiration will increase substantially due to higher temperatures, by 123.3 mm under SSP2-4.5 and 152.1 mm under SSP5-8.5. This raises total values from 1081.6 mm to 1204.9 mm or 1233.7 mm, with the largest increases in summer and autumn.

Although the overall water balance is expected to remain relatively stable by mid-century, a slight decline is anticipated toward the end of the century. Annual water surplus will remain unchanged, but the annual water deficit is projected to increase significantly—from –657.3 mm to –796.3 mm in the worst-case scenario. The most severe seasonal deterioration is expected in summer. The number of months with a positive water balance will remain stable.

No significant changes are projected in the general aridity index or the Martonne, Lang, and Thornthwaite indices by mid-century, maintaining current climate classifications. However, drought intensity is expected to decrease significantly on an annual basis and during spring and winter across all scenarios. The SPI (precipitation-only) is not expected to change significantly, while the SPEI (which accounts for temperature and precipitation) is projected to decrease substantially, especially by the end of the century.

Stakeholders

On November 18, 2024, GeoEcoMar hosted the first workshop (Fig. 28) dedicated to the INTERLAYER Project and the Romanian Living Lab in the picturesque town of Cetate, located in Dolj County.

The workshop brought together an impressive range of stakeholders, including representatives from the local administrations of Salcia, Cetate and Maglavit, as well as officials from the Jiu River Bazinal Administration, the Jiu Corridor Directorate (under the Dolj County Council) and the Romanian Water Administration.

Key Topics and Discussions

The workshop explored several key themes centred on innovative approaches to water management:

1. **Nature-Based Solutions (NBS):**
   Participants explored the implementation of NBS to support the emerging concept of "slow hydrology." This approach emphasizes natural water flow moderation, aiming to mitigate the impact of extreme weather events and support ecosystem health.
2. **Monitoring Wetland Areas:**
   A significant focus was placed on monitoring strategies for the wetland region in Salcia-Maglavit, designated as the Romanian Living Lab for the project. Ideas were shared on effective ways to measure the ecological and hydrological benefits of this area.

The event sparked a dynamic exchange between participants, who brought together complementary experiences and lessons learned from other case studies, further expanding the collective understanding of sustainable water management practices.

Fig. 28: First workshop on the Romanian Living Lab, held in Cetate on November 18, 2024.

Primary objective

The **core goal of this Living Lab is to restore hydrological connectivity** between the Danube River and its adjacent former floodplain. This makes the site particularly well-suited for implementing **slow hydrology strategies**—approaches that intentionally delay and retain water in the landscape to mimic natural processes.

Why the Potential is High:

Floodplain morphology: The area includes low-lying land under 100 meters in elevation, historically connected to the Danube and shaped by its flows. This natural topography is ideal for reactivating water retention and seasonal flooding.

Disconnected hydrology: Due to past **drainage for agriculture**, **urban development**, and **deforestation**, water currently bypasses the floodplain. Slow hydrology measures can reverse this by **slowing, spreading, and storing** water across the landscape.

Land use mix: A large portion of the area is **non-irrigated arable land, pastures, and transitional vegetation**, offering space and flexibility for interventions like:

- Controlled flooding of abandoned fish farms
- Seasonal wetland reactivation
- Swales, retention basins, and buffer zones

Ecosystem Services – Co benefits

1. Water Regulation

- **Drought buffering**: Enhanced groundwater recharge and moisture retention maintain water availability during dry periods.
- **Water purification**: Wetlands and restored floodplains filter nutrients, sediments, and pollutants.

2. Biodiversity and Habitat Provision

- **Habitat restoration:** Reconnected water flows support wetland, aquatic, and riparian ecosystems.
- **Species support:** Improved conditions benefit birds, fish, amphibians, and invertebrates, including those in Natura 2000 and RAMSAR sites.

3. Climate Regulation

- **Microclimate moderation:** Increased evapotranspiration and vegetation cover reduce heat stress and local temperature extremes.

4. Soil and Land Productivity

- **Soil fertility:** Natural flooding deposits nutrients, supporting more resilient agriculture.
- **Erosion control:** Vegetated areas stabilize soil and reduce runoff.

5. Cultural and Recreational Values

- **Nature-based tourism and education:** A restored landscape supports ecotourism, birdwatching, and environmental education.
- **Cultural heritage:** Reconnecting the river supports traditional land uses and cultural ties to the floodplain.

6. Socio-economic Resilience

- **Sustainable land use:** Diversified income sources through eco-agriculture, grazing, and conservation.
- **Risk reduction:** Lower vulnerability to floods and droughts reduces long-term economic and social risks.

The LL Lower Danube River (Salcia-Maglavit) in pictures

Fig. 29: Living Lab Lower Danube River (Salcia-Maglavit) in pictures

Comparison and conclusions

As the LLs are located in different and contrasting European regions, they show different processes and settings in the landscape as well as various microclimatic, hydrological and geological characteristics. It is a great chance to observe four different watersheds. Nevertheless, it is also a challenging process to find common characteristics and methodologies fitting to all four LLs in order to generate comparable results and thereby to support replication and upscaling of NBS interventions.

The size of all four Living Labs varies between 77 and 153 km^2. The outlines are marked by the Lower Danube River (Salcia-Maglavit) with 77 km^2 and Vaerebro River (153 km^2). The other Labs fit in between, see Fig. 30. Regarding the height differences within the single areas LL Liesing has the highest gradient of 487 m, stretching from 156 to 643 masl. It is followed by the Portuguese site showing a height difference of 380 m, and the Romanian Lab with 320 m difference from 28 – 348 masl. The Danish Living Lab starts from sea level and rises until an altitude of 60 masl.

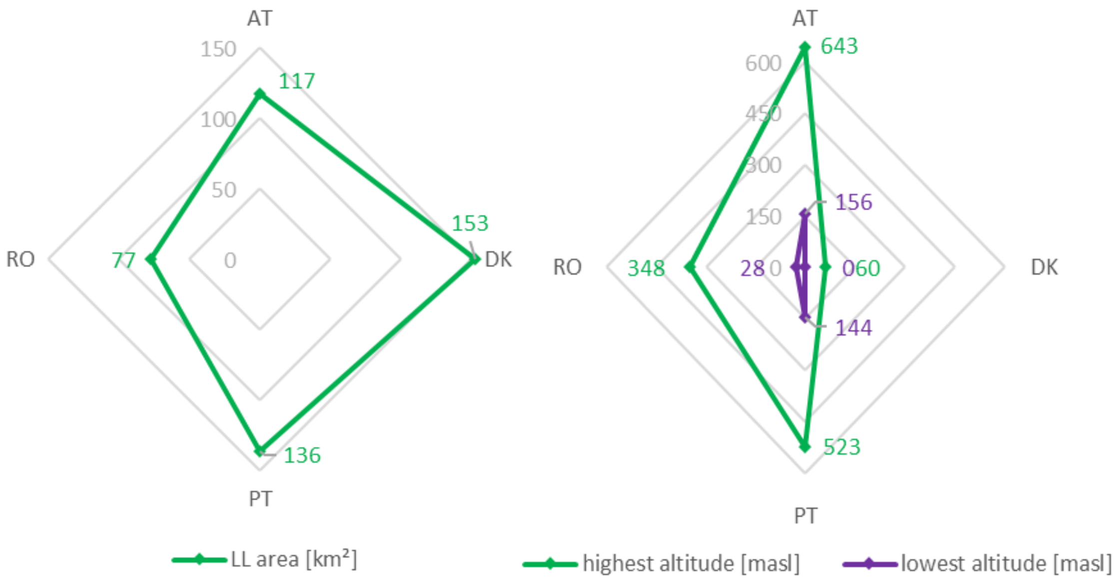

Fig. 30: Area of the Living Labs covering 77 km^2 to 153 km^2 (left). Spectrum of altitude in the single Living Labs in masl (right).

These labs represent a variety of environments, from semi-urban and agricultural to rural and peri-urban systems. The ecological status varies across the labs. The Austrian lab has a moderate to bad status, while the Danish lab exhibits varying conditions, mostly moderate to bad. The Romanian lab has a poor ecological status, and the Portuguese lab shows moderate to good status. Protection measures include Natura 2000 areas, nature reserves, and RAMSAR sites, particularly in Denmark, Romania, and the Portugal/Spain lab.

Common hydrological challenges include urban stormwater floods, low flow during dry periods, and backland flooding. At the Austrian site flood protection basins, stormwater retention, and riparian restoration play a role. In the Danish living lab canal gates to prevent storm surges, field drainage systems, and conventional separation of combined sewers are of interest. The Romanian research focuses on drainage, water abstraction, and urban development, while the Portugal/Spain focuses on dams and water abstraction.

For each of the LLs the local INTERLAYER research teams have identifed potential ecosystem services to target through slow hydrology interventions. Ecosystem services associated with these labs include recreational areas, heat island mitigation, and biodiversity in Austria; water storage, drought and flood mitigation, and food production in Denmark; drought and flood mitigation, food production, and leisure in Romania; and water abstraction for public supply, irrigation, electricity production, and biodiversity in the Portuguese lab. All labs emphasize the importance of biodiversity and recreational values.

Monitoring efforts across the labs include flora, fauna, (ground and surface) water level, discharge, water quality, and meteorological data. The Austrian lab focuses on surface water temperature modelling, while Denmark integrates groundwater and surface water flow modelling. The Romanian lab employs metabarcoding and disaster risk reduction strategies for flooding, drought, and fire. The Portuguese lab uses a comprehensive approach, including surface water temperature, water level, groundwater level, and biogeochemistry.

Restoration efforts are ongoing in all labs. In the Austrian lab they are in progress since 2000.

Overall Living Labs agricultural area is dominant. While the Austrian and the Denish Lab have shares about 50 %, the other two Living Labs show values around 70 %. In general, we can observe similar patterns and dimensions for LL Liesing and LL Vaerebro. The Portuguese and the Romanian sites are similar in their pattern but varying in the scales. Artificial surface including urban fabric, settlements, infrastructure and industry was only detected in the Austrian and Danish LL. The categories derived from the single LL related landcover analysis can be summed up into the categories: water body, artificial surface, forests and shrubland, agricultural area and other. For Details see Fig. 31 and the related chapters in the sections above.

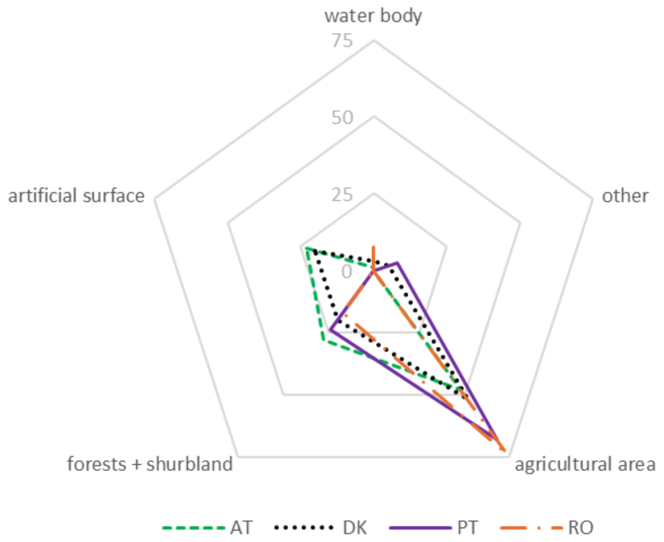

Fig. 31: Landcover analysis summarized in the classes water body, artificial surface, forests + shrubland, agricultural area and other across all four Living Labs.

Ecosystem services

32 ecosystem services were assessed across four Living Labs, categorized into the well documented groups: basic, regulative, provisioning, and cultural (Millennium Ecosystem Assessment 2005). Each service was evaluated through a three-tier relevance ranking: not relevant, relevant, and highly relevant. The single services are listed in Tab. 3 and were selected on based on literature (Millennium Ecosystem Assessment 2005; Podschun et al. 2018) and stakeholder information, assuming to be relevant ecosystem services related to hydrological and riparian systems.

Overall, regulative ecosystem services were identified as the most relevant across all Living Labs, followed by basic services, see Fig. 32. The Danish Living Lab exhibited a balanced relevance across all four service categories, while the Austrian Living Lab emphasized regulative and cultural ecosystem services. Notably, the Austrian and Romanian Living Labs showed similar patterns in the ranking of cultural ecosystem services, indicating aligned regional priorities or ecosystem functions. Meanwhile, the Romanian and Portuguese Living Labs presented comparable relevance assessments for regulative services.

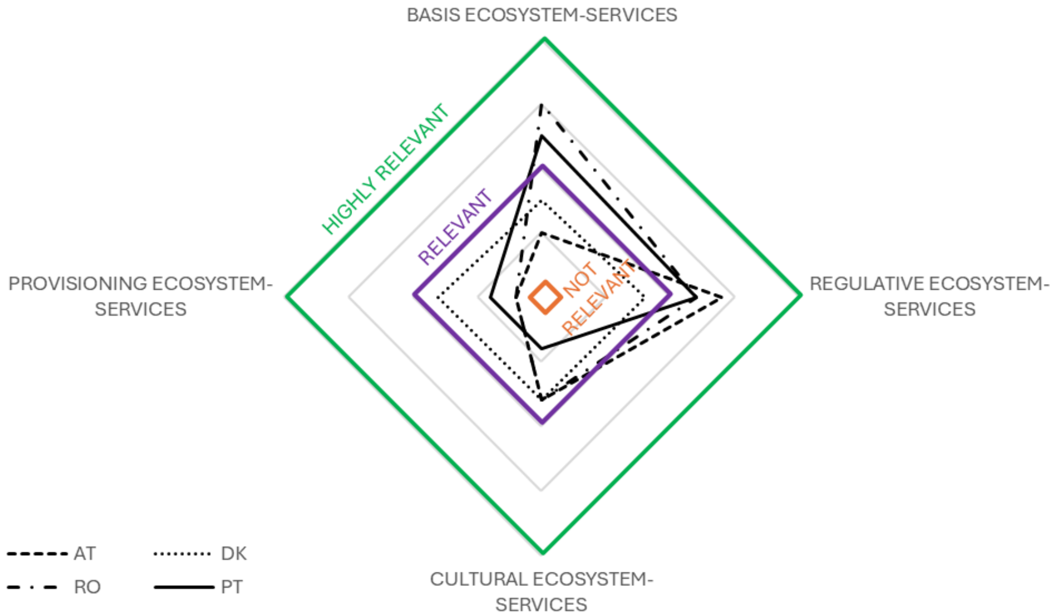

Fig. 32: Relevance of different categories of ecosystem services: basis, regulating, provisioning and cultural services for each Living Lab. The input data referes to Tab. 3.

The highest ranking across all Living Labs were reached by three regulative services: flood regulation, low flow regulation and drainage system (to water course recipients). All of them are assigned as highly relevant in three Living Labs and as relevant in one Lab. On the other end of the scale two cultural and three provisioning ecosystem services were considered as least relevant, being ranked with the category not relevant over all Living Labs: water related activities (leisure), tourism, drinking water (surface), plant based resources for further processing and plant based resources for energy production.

Tab. 3: Ecosystemservices used for the analysis across the four Living Labs in the categories basis, regulative, cultural and provisioning. Ranking: 🟠 not relevant, 🟣 relevant, 🟢 highly relevant

BASIS ECOSYSTEM SERVICES	AT	DK	PT	RO
Morphology + ecology	🟠	🟣	🟢	🟢
hydrological cycle	🟣	🟢	🟣	🟢
nutrient cycle	🟣	🟠	🟣	🟣
soil genesis	🟠	🟠	🟣	🟣

REGULATIVE ECOSYSTEM SERVICES	AT	DK	PT	RO
retention of C, N and P	🟣	🟣	🟣	🟣
global climate – C sequestration	🟣	🟣	🟠	🟠
flood regulation	🟢	🟢	🟢	🟣
low flow regulation	🟢	🟢	🟢	🟣
drainage system (receiving water courses)	🟢	🟣	🟢	🟢
sediment regulation	🟠	🟠	🟣	🟣

	AT	DK	PT	RO
cooling effects of running waters	🟢	🟠	🟣	🟠
cooling effects for soil	🟣	🟠	🟣	🟣
providing habitats	🟢	🟣	🟢	🟣
air quality	🟢	🟠	🟠	🟣
erosion protection	🟢	🟠	🟢	🟠
natural hazard protection	🟣	🟣	🟣	🟣
drought resilience		🟢	🟢	🟣
water infiltration (incl. Groundwater recharge)		🟣	🟣	🟢

CULTURAL ECOSYSTEM SERVICES	AT	DK	PT	RO
landscape scenery	🟣	🟣	🟠	🟣
natural + cultural heritage	🟠	🟣	🟣	🟠
education	🟣	🟣	🟣	🟣
science	🟣	🟣	🟣	🟢
water related activities (leisure)	🟠	🟠	🟠	🟠
recreation	🟢	🟣	🟠	🟣
tourism	🟠	🟠	🟠	🟠

PROVISIONING ECOSYSTEM SERVICES	AT	DK	PT	RO
food (crops, fish, game)	🟠	🟣	🟠	🟠
forage crops	🟠	🟠	🟣	🟠
drinking water (surface)	🟠	🟠	🟠	🟠
drinking water (groundwater)	🟠	🟠	🟢	🟠
water for industry + agriculture	🟠	🟢	🟢	🟣
plant based resources for further processing	🟠	🟠	🟠	🟠
plant based resources for energy production	🟠	🟠	🟠	🟠
water for biodiversity	🟣	🟣	🟢	🟣

Bluespot screening

A comparative hydrological analysis was conducted across four Living Labs under a uniform 60 mm stormwater event scenario. The Lower Danube River basin in Romania exhibits numerous large-capacity bluespots in its southwest ramaininge remain largely unfilled, yet there is a high runoff accumulation (31.0 mio. m^3) from sparsely buffered northern and eastern areas. In Portugal's Toutalga basin, few small bluespots act as minor retention zones, offering limited natural retention capacity, with accumulated runoff estimated at 7.3 mio. m^3. Liesing, Austria, shows minimal natural retention in its western sub-catchment due to shallow soils and steep terrain. In the western part of the catchment urban bluespots mitigate runoff moderately, with summed up 5.4 mio. m^3 estimated at the outlet. Conversely, Denmark's Værebro River basin benefits from extensive high-capacity bluespots that effectively prevent overflow even at 100 mm events. Under 60 mm conditions, it generates 3.2 million m^3 of runoff, largely from a central flat valley.

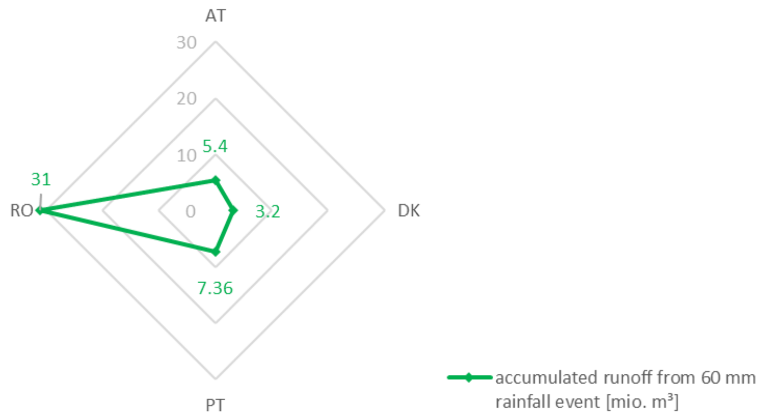

Fig. 33: Comparision of accumulated runoff volumes from a 60 mm rainfall event in mio. m^3 across all four LL

Key climate projections

The four living labs exhibit shared trends in climate projections, with regional variations in magnitude and seasonal impacts. Across all sites, maximum temperatures are expected to rise significantly by mid-century, ranging from 1.9–3.3°C, and even more by the end of the century, with increases of 2.5–6.6°C under SSP2-4.5 and SSP5-8.5 scenarios. The most intense warming is projected during summer and autumn, amplifying extreme weather events such as heat waves. Heat wave frequency is expected to increase substantially at all sites, with the most dramatic rises in Toutalga and the Lower Danube. Tropical nights (Tmin > 22°C) will emerge in all regions, ranging from 3–23 nights annually by mid-century. Frost days will decline sharply across all labs, with near elimination in Liesing and the Lower Danube.

Precipitation levels are projected to remain relatively stable by mid-century, though slight increases are expected in Vaerebro and Toutalga by the end of the century, particularly in summer and spring. Rising temperatures will drive significant increases in evapotranspiration across all sites, particularly in summer and autumn, exacerbating water deficits. The summer water balance is expected to deteriorate most severely in Liesing and Toutalga, indicating heightened seasonal aridity. Vaerebro and the Lower Danube are also expected to experience worsening summer water deficits, though to a lesser extent.

While annual water surplus and aridity indices remain stable across the labs, drought intensity is expected to decrease in Toutalga and the Lower Danube. However, the SPEI, which accounts for both temperature and precipitation, shows significant declines in all regions by the end of the century, underscoring the growing impact of warming on water availability and ecosystem health. These projections highlight the need for region-specific adaptation strategies to mitigate the impacts of climate change.

Objectives

All four Living Labs aim to **implement Slow Hydrology** as a novel water management approach including strategies that delay, retain, or redistribute water within the landscape to overall enhance resilience under climate variability, and simultaneously fortify targeted ecosystem services. This shared goal is tied to reducing flood risks, improving water availability, and sustaining ecosystem services.

Key Divergences:

- **Austria (Liesing)** addresses urban and peri-urban hydrology, aiming to transform peak flows to ensure both flood protection and ecological low flows. It focuses on environmental flow and related water quality needs with the clear boundary condition of flood security. The focus is on prioritizing runoff buffering and water quality maintenance in a densely settled landscape. Interventions in both upper and lower parts of the catchment are considered?
- **Denmark (Værebro)** takes a landscape planning and water balance-focused approach. The emphasis is on spatial optimization of interventions, retrofitting drainage systems, and embedding Slow Hydrology into strategic climate adaptation and ecological restoration. There's also a strong interest in co-benefits like biodiversity and improving nature value and mitigating nature degradation by obtaining a good balance in assigning land for agriculture and nature (Tripartite Agreement in Denmark).
- **Portugal (Toutalga)** focuses on balancing flood mitigation and water retention for dry periods. Objectives emphasize using natural topography to increase infiltration, slow water velocity, and ensure ecosystem health in a transboundary context. There's a strong focus on dual benefits for biodiversity and agricultural resilience.

- **Romania (Lower Danube)** is primarily concerned with restoring hydrological connectivity between the Danube and former floodplains. The lab uses Slow Hydrology to mimic natural floodplain functions, with a core focus on large-scale retention and reconnection for both flood mitigation and ecosystem restoration.

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