D1.2

Catalogue of innovative sponge solutions

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Lead beneficiary: UFZ

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1 Preface

SpongeBoost is a four-year EU Horizon project focusing on upscaling the natural sponge functions of freshwater ecosystems in Europe and to deliver multi-benefit Green Deal Solutions. The following report presents the outcomes of Task 1.2, which involved the evaluation of literature compiled in Task 1.1 to develop a comprehensive catalogue on best practice approaches and innovative solutions.

The main goal of the WP1 was to compile the best available and innovative knowledge about the sponge potential of ecosystems, available and improved solutions to enhance their sponge functioning, the connection and multifunctionality of soil, groundwater and surface water systems, potential economic costs and benefits as well as potential challenges, the failures or successes of implementing solutions from local to the European scale. In this context "innovative sponge solutions" are defined as nature-based measures and approaches, that enhance the natural water retention capacity of soils, wetlands, and landscapes by integrating ecological, technical, economic, and social innovations to increase the multifunctionality and strengthen climate resilience.

In order to achieve this goal, a systematic literature review was conducted. In Task 1.1 the literature was compiled by national and international literature review. In Task 1.2. this literature review was utilised to create a state-of-the-art knowledge catalogue, which will integrate existing knowledge on sponge functions from ecological, technical, social and economic points of view.

The definition of search string was suggested and used for a systematic literature review (see D1.1). It was applied to 7 languages including English, Czech, Dutch, Estonian, German, Portuguese and Spanish. Almost one thousand papers were captured by the search string in English alone. The highest number of papers in national languages was identified in Czech and Spanish.

2 Summary

In total, 1,938 papers were identified in all languages. Out of these, 417 were considered eligible for the project based on an analysis of the abstracts. Later, additional papers were removed after full read-throughs, resulting in 264 eligible papers. The majority of these thoroughly studied the sponge function, and its impacts and offered innovative solutions for the future. The highest number of (scientific) papers was identified in English, followed by Spanish, Dutch (including non-scientific literature such as grey literature, project reports or student theses).

The results show that sponge function is becoming a significant topic in science. An increasing trend has been identified in the number of eligible papers published each year. Most of the papers use applied research and quantitative methods, focus on natural sciences, engineering and technology, and social sciences. The analysis typically focuses on a national scale and rarely studies impacts across borders. Most of

the articles consider impacts in the rural environment, although there are also articles that focus on (sub)urban environment including the Sponge City concept.

3 Process of systematic literature review

The initial step of a systematic literature review was the definition of the search string (D1.1). Such a search string should ensure that all the relevant papers are captured in the search while maintaining a reasonable total number of papers. Several search strings were suggested by the UJEP team and the options were discussed during the SpongeBoost kick-off meeting in Leipzig in 2024. Simultaneously, a table for repository (storing the records) and the subsequent analysis was drafted and discussed. The individual steps are described in Figure 1.
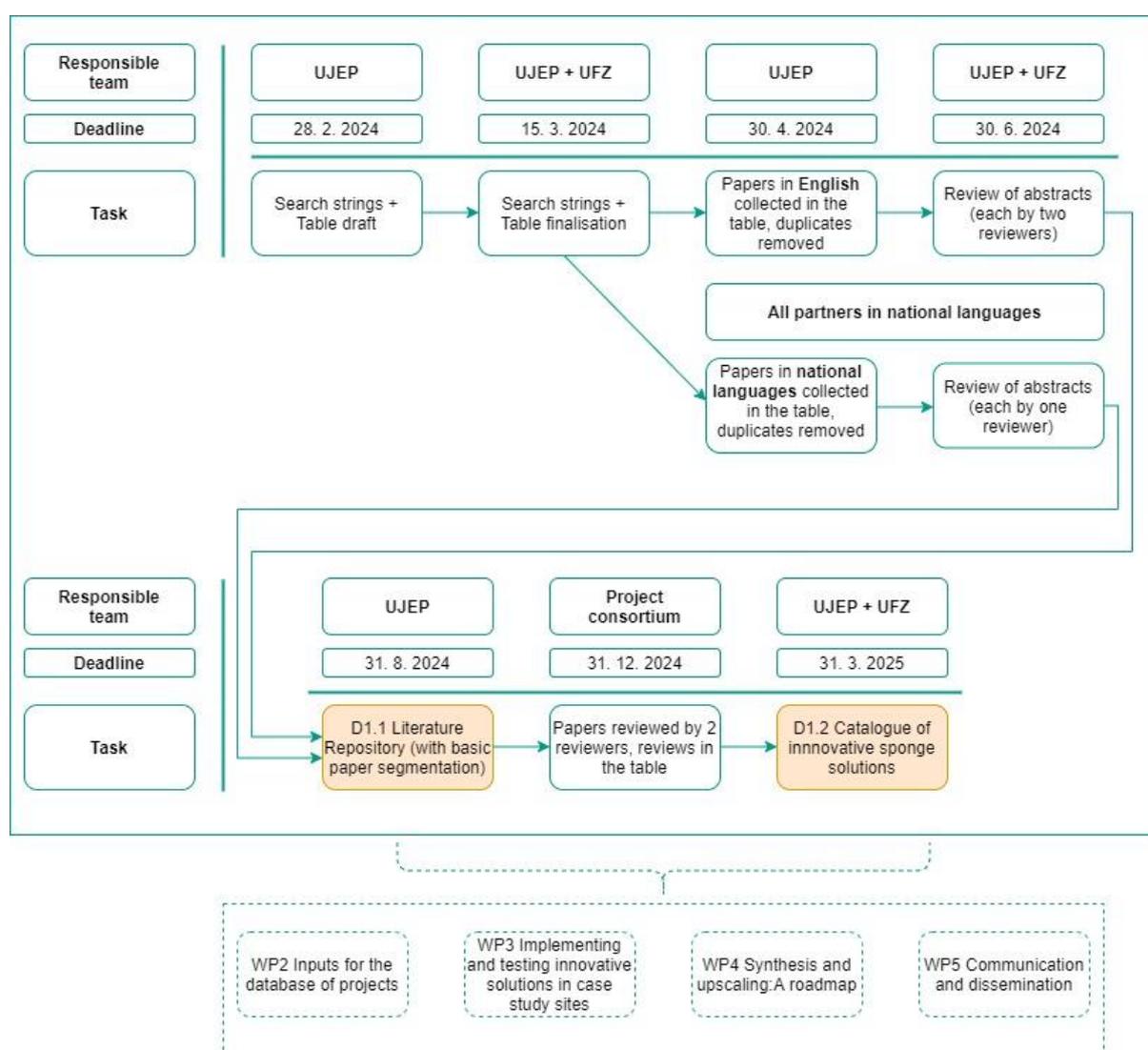

Figure 1: Steps of the systematic literature review

The final search string the project team agreed on and which was used for this systematic literature review was ("Nature-based solution" OR "Nature-based solutions" OR wetland* OR peatland* OR floodplain*) AND (spong* OR "water retention"). This means the search returned papers that focus on water retention (or directly the sponge function) in combination with either nature-based solutions or land types that cover wetlands, peatlands or floodplains. The search string was applied in English to two scientific databases: (i) Web of Science and (ii) Scopus. The same search string was also applied to other European languages (Czech, Dutch, Estonian, German, Spanish and Portuguese) however without results. Therefore, the decision was made to apply the search string in national languages more broadly, to include articles indexed on Google Scholar. Only scientific articles were eligible in English while a more relaxed approach was selected for the documents in national languages, where the database also contains grey literature and student theses. Such an approach allows to establish a database with basic information in national languages, which creates an educational opportunity also for non-experts in the given country. Additionally, project partners were encouraged to search for additional records that deal with the sponge boost function in their respective languages.

In the first round of reviews, all the duplicates were removed from the analysis. This was mainly in the case of English language papers as they originated from two partly overlapping sources. After establishing the initial database each English abstract was read by two independent reviewers (only one reviewer was considered necessary for the analysis in non-English language papers). In the case of a contradiction, a third reviewer read the abstract and decided whether the paper should be involved in the full read-through analysis. Papers were considered eligible if the following criteria were met:

- the sponge function was the main focus of the paper
- the paper evaluated the impacts (ecological, social, economic) of measures, sponge cities or water retention
- the paper presented innovative solutions for the future
- the paper dealt with multifunctionality of sponge measures and upscaling

Papers were excluded if they only presented overviews of existing measures, had a conceptual focus or described various strategies/plans, as well as papers that studied the accumulation of water rather than retention or focused on the historical development of sponge measures.

The analysis continued with reading full papers. One reviewer read each paper and filled in the needed information into the table described below. The criteria for eligibility were the same as in the previous round of abstract review.

The selected reviewed catalogue of innovative sponge solutions has been published at ZENODO (Macháč et al., 2025; see Annex).

4 Results

An overview of the identified papers is presented in Table 1. Almost one thousand papers were captured by the search string in English (excluding duplicates covered in both databases). In the first round of review of English language papers, 188 papers were considered eligible for the full-text review by both reviewers. The reviewers also agreed to reject 607 papers identified by the search string. In the remaining cases, reviewers disagreed on the eligibility and an additional reviewer evaluated the remaining 141 abstracts. Out of these, 64 were considered eligible, finalising the total number of eligible abstracts of papers in English at 252. The highest number of papers identified in other national languages was in Czech, Spanish and Dutch. A total of 252 selected English articles were read in full in the second step, during which a decision was made regarding their suitability for inclusion in the catalogue. Based on the evaluation, 166 papers were proposed for inclusion. After the same process was applied to national articles, a total of 264 papers were selected for the catalogue (see Annex).

Table 1: Summary of the papers identified in the systematic literature review

Language	Number of identified papers	Number of eligible papers after abstract review	Share of papers considered eligible from the total number of identified papers	Number of eligible papers after the full read through	Share of papers considered eligible from the total number of identified papers
Czech	480	38	7.9%	14	2.9%
Dutch	84	46	54.8%	26	31.0%
English	936	252	26.9%	166	17.7%
Estonian	5	2	40.0%	1	20%
German	32	13	40.6%	13	40.6%
Portuguese	3	0	0.0%	0	0%
Spanish	398	66	16.6%	44	11.1%

There were various reasons for rejecting papers after the abstract review. Almost one third of the papers were rejected because the paper was completely out of scope. To give an example, some papers focused on fossils, trees, sponge-named fauna, seed dispersal, seaweed, microplastics or even pottery. It should be noted that belonging to one of the following categories does not automatically mean that the paper was rejected. The main criterion was whether the paper deals with the impacts of the sponge function meaning that even papers that studied one of the following topics appear among the eligible papers. The second large group of rejected abstracts focused on the removal of nutrients, residues and other pollutants. The third significant group of

papers studied the chemical composition of soils and waters. Other significant topics that were consistently rejected were papers that focused on the following topics without a close relationship to the sponge function:

- historical aspects and the development of wetlands
- wastewater treatment in constructed wetlands
- modelling of hydrological properties
- water accumulation
- mapping of wetlands
- conceptual solutions and strategies
- description of non-innovative measures and projects
- sediments
- flora and fauna in wetlands and biodiversity
- carbon sequestration and storage
- valuation of ecosystem services
- effects of biochar
- papers about green and blue infrastructure and nature-based solutions not connected to the sponge function
- water quality
- technical solutions

In addition to that papers that were duplicates, not available, not scientific or written in a language other than English were also removed (or moved to a national language database). We have also removed papers that studied the sponge function but their main focus was elsewhere. The last group of rejected papers consisted of papers that were considered too descriptive and general. A similar process was used during the full read-through. Papers that did not focus on the main topics of the SpongeBoost project as much as reviewers thought were not selected.

During the read-throughs, the reviewers filled in sponge-related information contained in the papers into the designed table. The table consists of five sections. The first section was extracted automatically from the databases and includes basic characteristics of each papers, such as the title, author team, journal, DOI, keywords and abstract. The following characteristics were collected manually by the reviewers:

- Type of article (scientific paper, project report, conference paper, (chapter in) monography, opinion paper, thesis, policy brief)
- Type of research (applied, experimental, literature review)
- Frascati manual (natural sciences, engineering and technology, medical and health sciences, agricultural and veterinary sciences, social sciences, humanities and the arts)
- Main purpose of the article
- Type of societal challenge (flood risk, drought, water quality, water quantity, rainwater management, carbon sequestration, nature and well-being, biodiversity, food production, natural hazards (not specified))
- Type of effect studied (social, economic, technical, ecological)
- Methods used (quantitative, qualitative, combined)
- Example of practical implementation?

- Is there a connection to other projects?

The second section of the table covers the geographical characteristics of the papers:

- Scale of analysis (national, cross-border, continental (covering larger geographical regions such as continents), global, not relevant)
- Specific country and location
- Type of approach (renaturation, restoration, not relevant)
- Is the site in a protected area?
- Type of area (urban, suburban, rural, laboratory)
- Land cover (peatland, streams and floodplains, agriculture and forestry, urban area and infrastructure, other)

The third section covers the nature-based solutions in the papers:

- Type of a nature-based solution (coastal measures, floodplain retention and polders, peatlands, wetlands, river restoration, nature-based river dams, small retention ponds, pools and lakes, channel alternation and diverging flows, land use changes, improving soil conditions, spatial water retention in urban areas, urban water sensitive buildings)
- Description of the solution
- Scale of the solution (small scale, large scale)
- Positive impacts, weaknesses, strengths and barriers of the solution

The fourth section described the socio-economic aspects mentioned in the papers:

- Stakeholders involved (private landowners, farmers, local residents, public administration, decision makers on state/regional level, decision makers on local level, NGOs, universities and research institutes)
- Policy instruments applied (land use planning/consolidation, financing schemes for stormwater management, financial incentives for land use changes, flood risk pooling schemes, general subsidy/tax breaks, cap and trade schemes, other innovative payment schemes, voluntary agreements)
- Socio-economic conflicts
- Main source of financing (governmental subsidy, governmental compensation, public investor, private investor, payments for ecosystem services, public fundraiser)
- Economic costs and benefits
- Was cost-benefit analysis performed?

The fifth section is dedicated to environmental aspects:

- Is modelling involved?
- Is upstream/downstream relation studied?
- Studied environmental impacts (impact on surface waters, impact on ground waters, impact on soil, impact on disaster risk reduction, impact on carbon, impact on biodiversity)
- Were ecosystem services assessed?

The review of the article goal shows a clear concentration on hydrological retention and related processes: the most frequent lexical items are water, retention, water retention, soil and flood, reflecting the centrality of retention-related research questions across the recorded goals. Grouping of the goal texts identifies several substantive groups of studies with different emphases. The largest group (≈100 records) is framed explicitly around water-retention potential, measures and restoration: these papers typically quantify retention capacity, estimate potential retention gains from interventions, or assess restoration outcomes. A second large group (≈55 records) addresses soil and peatland hydraulic properties and material-level processes; these contributions focus on infiltration, storage characteristics, hydraulic conductivity and the role of soil/peat structure for water storage. A third cluster (≈49 records) is urban in orientation, addressing sponge-city concepts and urban green-infrastructure interventions; such studies commonly combine hydrological modelling with urban design or policy framing. Smaller but distinct groups examine flood retention and flood-risk reduction (≈30 records), programme-level or climate-adaptation perspectives and experience reports (≈19 records), and a small set emphasising peatland capacity and regional strategies (≈12 records).

Across these thematic groups the stated objectives are dominated by two types of inquiry: (1) quantification and performance assessment focused on measuring or estimating retention volumes, runoff reduction, peak-flow attenuation or related service metrics; and (2) modelling and mapping focused on development or application of hydrological, hydraulic or GIS-based models to represent retention functions or to map potential. Laboratory and field characterisations of material behaviour (soil, peat) are also common, particularly in the soil/peatland cluster. Taken together, the goal descriptions indicate a mixed evidence base: modelling studies, lab experiments and field monitoring coexist in the catalogue, so the set of identified papers should be expected to contain heterogeneous methods and reporting formats.

The following tables and figures below represent the final results of the full read-through analysis.

Table 2: Type of research

Language	Applied research	Experimental research	Literature review	Other
Czech	13	1	0	0
Dutch	19	0	7	0
English	134	26	6	0
Estonian	1	0	0	0
German	11	0	1	1
Portuguese	0	0	0	0
Spanish	16	12	8	8

The majority of the articles can be classified as applied research (Table 2). There was a significant share of experimental research among the English and Spanish articles and some literature reviews were conducted in English, Dutch and Spanish.

Table 3: Frascati manual

Language	Agriculture and veterinary sciences	Engineering and technology	Humanities and the arts	Medical and Health sciences	Natural sciences	Social sciences
Czech	0	4	0	0	12	2
Dutch	3	11	0	0	26	8
English	8	79	0	0	135	28
Estonian	0	1	0	0	1	1
German	0	9	0	0	12	3
Portuguese	0	0	0	0	0	0
Spanish	7	30	0	0	11	2

Table 3 shows that the majority of eligible papers can be classified as belonging to either Engineering and technology or the Natural sciences. However, there were also papers that focused on Agricultural and veterinary sciences and on Social sciences. Some of the papers were classified in multiple categories, thus the sums may not equal to the number of eligible papers.
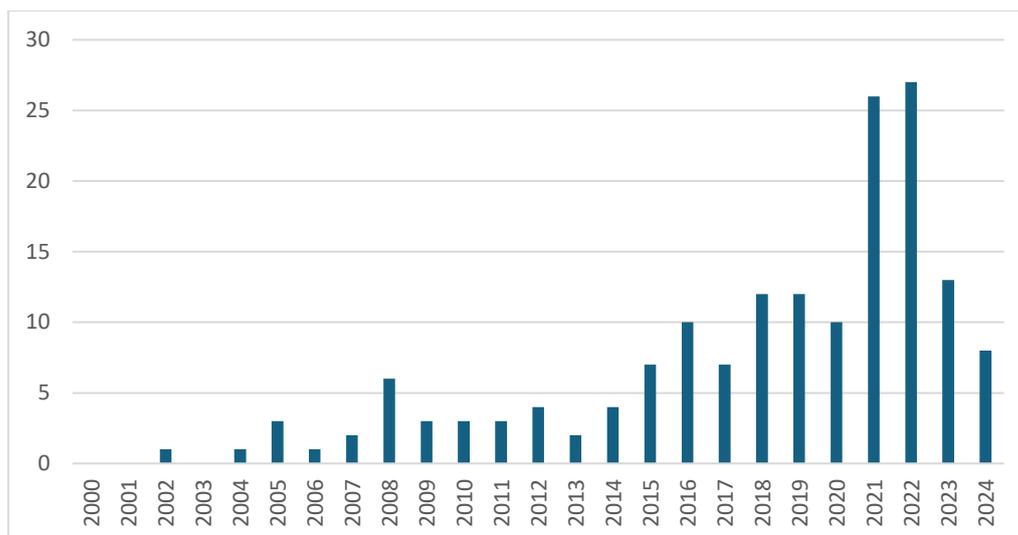
Figure 2: Distribution of English language papers by publication year

Figure 2 clearly shows that the sponge function has become a significant topic that is being discussed in scientific literature. The number of published papers has been rising over the past 20 years, showing how significant sponge functions have become. This is confirmed on the country level in Figure 3, which depicts the histogram of eligible papers in national languages.
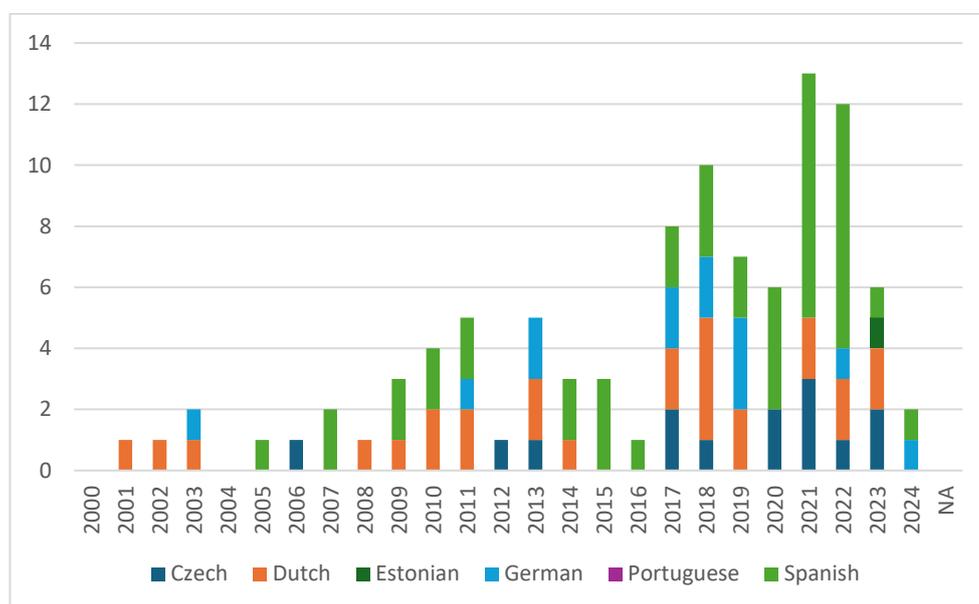

Figure 3: Distribution of papers by publication year (national languages)

Table 4: Methods used

Language	Combined	Qualitative	Quan-titative
Czech	4	4	6
Dutch	11	11	4
English	21	19	126
Estonian	0	1	0
German	11	2	0
Portuguese	0	0	0
Spanish	9	18	17

The English articles mostly utilised quantitative methods, sometimes combining them with a qualitative approach, as shown in Table 4. Only 11 % of the articles used exclusively qualitative methods. The methods used in the eligible articles in national languages were quite evenly distributed and often the qualitative and quantitative approach was combined.

Table 5: Scale of analysis

Language	National	Cross-border	Conti-nental	Global	Not rel-evant
Czech	13	0	0	0	1
Dutch	24	1	0	0	1
English	136	11	4	1	14
Estonian	1	0	0	0	0
German	12	1	0	0	0
Portuguese	0	0	0	0	0
Spanish	37	3	1	0	3

The vast majority of articles focused on a single nation, often only on a specific location such as a basin or a municipality. There were only a handful of articles covering cross-border issues or issues covering larger geographical regions such as continents. In a few cases the scale was not relevant, e.g., if the research was performed in laboratory conditions (Table 5).

Figure 4: Studied countries

Figure 4 shows the specific countries mentioned in the analysis. China was the most frequently studied country, followed by Germany, Poland and USA. Other frequently studied countries include Canada, Italy and Czechia. These results only cover the scientific literature in English. Papers in national languages usually focus on their respective countries.

Table 6: Type of area

Language	Laboratory	Rural	Suburban	Urban
Czech	1	11	2	1
Dutch	0	22	13	16
English	19	120	10	48
Estonian	0	1	1	1
German	0	12	0	1
Portuguese	0	0	0	0
Spanish	3	29	3	12

Table 6 shows significantly more papers focusing on rural environments than on suburban and urban environments, although in national languages there were quite a few papers that studied the sponge function also outside the rural environment. There were many papers that study Sponge City policies and strategies from China, but they were excluded because they focused more on town planning strategies than applied measures.

Table 7: Renaturation/restoration

Language	Renaturation	Restoration	Not relevant
Czech	2	8	4
Dutch	3	18	5
English	46	40	80
Estonian	1	0	0
German	7	4	2
Portuguese	0	0	0
Spanish	7	14	23

It is apparent in Table 7 that a significant share of the English papers did not focus on either renaturation or restoration. The remaining papers are quite evenly distributed between renaturation (construction of a new measure) and restoration (reconstruction/upgrade of an existing measure).

Table 8: Type of land cover

Language	Peatland	Streams and floodplains	Agriculture and forestry	Urban area and infrastructure	Other/not relevant
Czech	3	4	9	2	1
Dutch	9	15	14	11	0
English	45	60	44	50	17
Estonian	0	1	0	1	0
German	1	8	7	2	0
Portuguese	0	0	0	0	0
Spanish	13	9	20	12	1

The highest number of land cover type studied in the papers shown in Table 8 is "streams and floodplains" (96) closely followed by "agriculture and forestry" (93). However, there are also many papers that describe sponge solutions in urban areas (78) and in peatlands (71). Other land covers were mentioned infrequently.

Table 9. Type of nature-based solution studied

NBS	Czech	Dutch	English	Estonian	German	Portuguese	Spanish
Coastal measures	0	2	4	1	0	0	0
Floodplain retention and polders	2	12	27	1	7	0	3
Peatlands	6	8	44	0	0	0	7
Wetlands	2	9	37	0	0	0	8
River restoration	2	14	11	0	4	0	0
Nature-based river dams	1	0	5	0	1	0	2
Floodplain and wetland forests	0	2	4	0	5	0	0
Agroforestry	0	0	3	0	0	0	0
Small retention ponds, pools, lakes	4	7	18	0	2	0	2
Channel alternation and diverging flows	0	3	5	0	2	0	1
Land use changes	3	10	17	0	3	0	13
Improving soil conditions	1	8	17	0	1	0	1
Other agricultural measures (baulks, terraces, tree lines, etc.)	1	0	3	0	0	0	0
Spatial water retention in urban areas	1	9	29	1	1	0	7
Urban water sensitive buildings	1	2	17	1	1	0	4

NBS	Czech	Dutch	Eng-lish	Esto-nian	Ger-man	Portu-guese	Span-ish
Infiltration, filtration and biofiltration in urban areas	0	1	8	0	0	0	0
Trees and shrubs in urban areas	0	0	2	0	0	0	0

A whole range of different nature-based solutions was studied in the collected papers (see Table 9). Peatlands, Wetlands, Floodplain retention and polders, Spatial water retention in urban areas and land use changes were studied the most often. Slightly less frequently were mentioned Small retention ponds, pools and lakes, River restoration, improving soil conditions, Urban water sensitive buildings. The remaining nature-based solutions were mentioned only sporadically, although all of the categories defined during the initial project stages were used at least twice. The captured description of the specific measures is described in the following paragraphs.

Constructed wetlands and treatment-wetland cells are regularly described as multifunctional elements combining temporary water storage with vegetation-mediated processes. Descriptions commonly specify wetland configuration (e.g., surface-flow or subsurface flow cells), vegetation types, inlet/outlet arrangements and overflow handling. In many entries the wetland is framed both as a retention volume and as a biogeochemical treatment element, with explicit mention of sediment trapping and nutrient removal alongside storage function.

Retention and infiltration basins, ponds and engineered depressions appear frequently. Descriptions emphasise storage depth and area, engineered layers (e.g., gravel or engineered media to support infiltration), connections to conveyance systems and design features that control residence time and overflow. Small retention ponds are often described as distributed elements within a network of measures rather than as isolated structures.

Peatland restoration and rewetting show up as a clearly articulated category in a number of records. Phrases used in this context include ditch-blocking, raising groundwater table, rewetting of degraded peat, and re-establishment of wetland vegetation. These entries tend to tie hydrological change to wider ecosystem services such as carbon sequestration and biodiversity enhancement, and they describe relatively large spatial and long-term interventions.

Small, distributed retention measures are described in many local-scale implementations. Typical elements named include swales, infiltration trenches, soakaways, infiltration strips, roadside ditches and micro-ponds. These entries characterise measures as physically small but numerous and often emphasise their role in decentralised management of runoff and in reducing immediate peak flows at the plot or street scale.

Urban green-infrastructure packages are frequently represented under umbrella terms such as "sponge-city interventions," "green infrastructure package" or "integrated SUDFs" (sustainable urban drainage features). Entries in this group list combinations of green roofs, permeable pavements, infiltration planters, vegetated swales and street trees, and often describe systemic placement (streets, plazas, roofs) and interactions with grey drainage. Several records describe retrofit applications where multiple urban measures are combined to achieve distributed storage and delay.

Soil and material interventions appear as a distinct strand of solutions. Descriptions include addition of organic matter, engineered substrates or amendments to increase field capacity and infiltration, alteration of soil profiles to increase storage, and use of specific materials (e.g., biochar, engineered soil mixes) to alter hydraulic behaviour. These entries frequently detail the material change and the intended hydrological effect (increased infiltration, increased water holding) rather than presenting a built structure.

Landscape-scale and hybrid approaches are also present. These descriptions combine river-floodplain reconnection, constructed wetlands, re-meandering, and land-use change (e.g., conversion of arable land to grassland or woodland) to increase catchment retention. Many records explicitly present solutions as "packages" or "systems" where spatial configuration and sequencing of elements are integral to the design.

Reports include a number of programme-level or governance-oriented solutions. Where the "sponge city" term is used, it often denotes an urban planning package incorporating technical measures, policies and management arrangements. Entries in this sub-set refer to demonstration projects, city-scale planning domains and institutional measures (maintenance regimes, decentralised management responsibilities).

Innovation themes also emerge qualitatively. Several entries describe modular or prefabricated elements, engineered substrates for improved retention, hybrid grey-green connectivity solutions, and adaptation of nature-based elements to constrained urban sites. Implementation detail often includes vegetation choice, substrate layers and overflow configurations, indicating that the literature places importance on constructability and maintenance considerations as part of the solution description.

Table 10. Type of impact of the sponge solution

Language	Local impact	Regional/na-tional impact
Czech	14	0
Dutch	16	10
English	114	52
Estonian	1	0
German	6	7
Portuguese	0	0
Spanish	38	6

Table 10 shows that most of the identified articles focused on small scale solutions that have only a local impact. That means about two thirds of English papers studied local impacts. The share is more lopsided towards local impact in the case of Spanish papers while it is even slightly in favour of regional/national impact in the case of German papers.

Table 11: Overview of other indicators

Language	Modelling in-volved (% yes)	Cost-benefit analysis per-formed (% yes)	Upstream-down-stream relation assessed (% yes)	Ecosystem services as-sessed (% yes)
Czech	21	7	7	21
Dutch	27	12	38	42
English	54	7	20	22
Estonian	100	0	0	0
German	23	0	15	8
Portuguese	0	0	0	0
Spanish	18	11	16	25

As can be seen in Table 11, more than half of the English papers included modelling.

The range of models is wide, covering both hydrological simulation tools and soil/plant process models. Several categories can be distinguished:

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- **Hydrological and hydraulic simulation models**: These include frequently used tools such as **HEC-HMS**, **SWMM**, **SWAT+**, and **MODFLOW**, as well as 1D and 2D hydraulic models. Such models are applied to simulate rainfall–run-off processes, surface water routing, infiltration and groundwater dynamics. They are often used in case studies evaluating sponge solutions under different rainfall or land-use scenarios.

- **Soil and hydraulic parameterisation models**: The **van Genuchten model** and related formulations (e.g. RETC) are applied in studies focusing on soil water retention, hydraulic conductivity and infiltration. These are especially present in research on peatland and soil amendments, where understanding the water-holding capacity of substrates is crucial.

- **GIS-based and topographic models**: **Digital Elevation Models (DEM)** are frequently referenced as inputs for hydrological assessment, mapping retention potential and delineating catchments. DEMs often underpin more complex modelling frameworks.

- **Analytical and stochastic approaches**: Some papers report the use of analytical stochastic models or simplified rainfall–runoff models for estimating average effects of retention measures. These are less common but indicate efforts to capture variability and uncertainty.

- **Specialised or local modelling frameworks**: Individual entries mention specific hydrodynamic or integrated models (e.g., Floris2000, Hydro_AS-2D, Waterisk). These tend to appear in single papers and reflect either local traditions or project-specific tools.

In qualitative terms, the modelling column illustrates the dual orientation of the literature: a strong reliance on widely established hydrological software for catchment-scale assessment, and a parallel strand of soil physics models for detailed material-level characterisation. Together they show that quantitative modelling is a dominant method for evaluating sponge solutions, whether at the plot, site or basin scale. Advanced modelling and monitoring capabilities enable accurate predictions, faster computations, and integration with remote sensing technologies. The use of GIS, MODIS imagery, and artificial neural network models significantly enhances the ability to monitor and analyse hydrological dynamics. These techniques not only improve accuracy but also allow for large-scale assessments of ecosystem conditions.

Table 11 also shows that ecosystem services and upstream vs. downstream relations were mentioned in nearly a quarter of the English papers. Cost-benefit analysis was used in only 7% of the English papers, and in the other national documents, it was also mentioned sporadically.

Information about stakeholder involvement is relatively limited due the inclusion of papers covering other different disciplines besides Social sciences (Engineering and technology, Natural sciences and Agricultural and veterinary sciences). In the English-language literature, 22 papers identified relevant information. The most frequently mentioned stakeholders fall into two main categories: decision-makers at the state,

regional, or local levels, followed by private landowners. Other stakeholder groups were mentioned less frequently. Spanish literature also mentioned universities and research institutions quite often. Dutch literature focuses also on local residents and farmers but less on public administration.

The situation is limited also when it comes to policy instruments. Only 33 English papers identified a relevant instrument. Land use planning/consolidation is the most frequent one. Other instruments such as voluntary agreements, financial schemes for stormwater management and financial incentives for land use changes are mentioned sporadically. The national literature informs about policy instruments more often. The Dutch literature mentioned financial incentives for land use changes and general subsidies or tax breaks more frequently. German and Spanish literature also focused on land use planning/consolidation.

Only a small fraction provides substantive descriptions of socio-economic conflicts. Where conflicts are mentioned, they reveal recurring themes:

- **Land-use competition**: Several records highlight tensions between agriculture, forestry, flood control and conservation. The conflicts are framed around difficulties in reconciling productive land uses with the space and management practices required for sponge measures.

- **Economic risks for land managers**: Some descriptions note the economic burden on farmers adapting to new practices, such as foregone agricultural income or increased costs associated with implementing retention measures.

- **Perceptual and cultural framings**: One record refers to conflicting perspectives on floodplains: as profitable land, as dangerous territory, as controllable systems, or as ordinary landscape. This reflects not only material conflicts but also divergent values and cultural understandings.

- **Governance and planning trade-offs**: Although less explicitly detailed, several entries imply that optimal floodplain management is complicated by overlapping and sometimes contradictory demands from different sectors and stakeholders.

The analysis also focused on positive impacts, weaknesses, strengths and barriers of sponge solutions and their implementation. This part was limited to the scientific articles in English. Not all articles identified these categories. However, the following paragraphs categorise the findings in more detail.

Positive Impacts of sponge solutions

Sponge solutions offer significant benefits across various environmental and economic dimensions. One of their most notable advantages is enhanced water retention and hydrological stability. By implementing techniques such as conservation tillage, controlled flooding, and organic amendments, these solutions contribute to stabilizing water tables and reducing fluctuations. This improved moisture retention is essential for

sustaining vegetation and maintaining ecological balance. Additionally, sponge solutions are highly effective in flood mitigation and risk reduction, as they help lower flood peaks, decrease inundation areas, and reduce overall flood damage. Both natural interventions, such as wetland and floodplain restoration, and engineered measures, such as permeable pavements and green roofs, play a crucial role in achieving these outcomes.

Another key advantage of sponge solutions is their contribution to ecological restoration and biodiversity enhancement. By improving water retention, these solutions create favourable conditions for habitat restoration and species diversity. Similarly, they aid in carbon storage and climate regulation by increasing soil organic carbon through afforestation, wetland restoration, and improved soil management. Sponge solutions also support agricultural resilience by improving soil quality, reducing bulk density, and enhancing nutrient cycling, which collectively leads to higher crop yields. In urban settings, they facilitate sustainable infrastructure through stormwater management, pollution reduction, and urban cooling effects.

From an economic perspective, sponge solutions offer cost savings by reducing flood damage and enabling more efficient water management. Additional ecosystem and social benefits include improved water quality, enhanced recreational spaces, and overall environmental stability.

Weaknesses

Despite their advantages, sponge solutions exhibit several limitations that affect their overall effectiveness. One of the most significant weaknesses is their limited water retention capacity, with some techniques only increasing retention by a few millimetres. Certain soil types, such as sandy-loamy sediments, allow for significant seepage, thereby reducing long-term retention. Additionally, green infrastructure elements like rain gardens and wetlands often provide limited flood prevention capacity. Furthermore, their performance can be inconsistent, as they are highly dependent on seasonal variations, topographical factors, and differences in vegetation cover. Additionally, sponge solutions can sometimes lead to unintended ecological consequences, such as biodiversity loss, increased methane emissions in wetlands, and negative impacts on aquatic ecosystems due to sedimentation and nutrient loading.

Strengths

Sponge solutions demonstrate adaptability and rapid restoration potential. Many techniques can be implemented almost immediately after environmental disturbances, minimizing negative impacts on hydrology. Additionally, their multifunctionality ensures that they address both water retention and water quality issues, making them highly beneficial for long-term environmental planning. Their effectiveness in flood mitigation and hydrological performance is another core strength, as sponge solutions often outperform traditional engineering measures by lowering flood peaks and improving water storage capacity. Furthermore, sponge solutions contribute to ecosystem services by

enhancing biodiversity, supporting carbon sequestration, and promoting recreational and urban benefits.

Sponge solutions are characterized by several strengths that make them a viable option for sustainable water management. Another major strength is cost-effectiveness and operational efficiency, as some sponge solutions, such as acrotelm transplanting and small dams, offer relatively low financial and maintenance demands compared to traditional engineering approaches.

Barriers to implement sponge solutions

Several barriers hinder the widespread adoption of sponge solutions. One of the primary mentioned challenges is the lack of sufficient knowledge and data regarding soil properties, groundwater dynamics, and site-specific hydrological conditions. Many hydrological responses remain poorly understood, and data collection is often costly and time-consuming. Technical and environmental challenges also pose obstacles, as sediment heterogeneity and variable hydraulic conductivity can lead to uneven water retention. Additionally, external factors such as climate variability, oxidation, and high evapotranspiration rates further complicate sustainability. Additionally, changing river flow regimes, urban expansion, and external land-use pressures threaten the effectiveness of these solutions.

Another major challenge is the difficulty of large-scale implementation due to legal uncertainties, cross-border coordination issues, and the requirement for extensive land areas, particularly in urban settings. Technical and scientific limitations further impede effectiveness, with concerns over data accuracy, measurement errors, and limited validation of hydrological models.

Economic, administrative, and governance barriers are also prevalent. High costs associated with engineering structures, rewetting efforts, and long-term maintenance make sponge solutions financially challenging. Legal and administrative hurdles, such as conflicting regulations and lengthy approval processes, further slowdown implementation. Scaling up these solutions remains difficult due to site-specific limitations, particularly in dense urban areas where green space is scarce. Social and stakeholder issues further limit their feasibility, as conflicts with landowners, lack of public trust, and cultural barriers to land-use changes reduce acceptance. Addressing these barriers will require enhanced data collection, improved technical approaches, and stronger governance frameworks to ensure long-term viability and successful implementation.

5 Conclusion

In conclusion, Deliverable 1.2 presents the results of an extensive literature review. The report starts by outlining the approach taken for the literature review, which was developed as part of the Deliverable 1.1. It then presents a quantitative analysis of the data and concludes with an assessment of the benefits of sponge measures, as well as the key factors contributing to its success or failure. The findings have been compiled into a comprehensive catalogue of innovative solutions aimed at securing and improving water retention, ecosystem resilience, and sustainability. This catalogue serves as a crucial input for WP3, where selected innovative solutions will be tested under diverse environmental, economic, and social conditions in the case study sites. Furthermore, it will contribute to WP4, facilitating the upscaling of results from the local to the European level and informing the design of a prototype roadmap (D4.4). Additionally, the catalogue will support WP5 by providing valuable content for dissemination and exploitation activities, ensuring that best practices and innovative solutions reach relevant stakeholders and policymakers. With this, Task 1.2 has been successfully completed, providing a solid foundation for the subsequent phases of the project. This database has aggregated research articles from a range of sources, covering multiple languages as well as regions within Europe and whole world. **This repository will serve as the foundation to continue with the in-depth analysis as described in the task 1.2** and successfully deliver the outputs of Work Package 1 in a timely manner. In further activities within the project, we will therefore build on the catalog and basic quantitative analysis presented here.

This work has played a critical role in supporting the achievement of the project goals and provides the basis for a long-term sustainable database for researchers and other interested people to use. **In subsequent work packages, more in-depth, qualitatively focused analyses will be carried out on relevant articles from the catalog on sub-topics such as the provision of ecosystem services, experience to date with the use of policy instruments, etc.**

It is apparent that most of the scientific literature exists in English and that the number of articles that study sponge function increases in time. The research is usually applied and focuses on qualitative methods. Also, most of the articles studied only local impacts in rural environments (except for the Sponge City concept) within national borders. The highest share of articles studies areas such as floodplains or agricultural (forest) environments, but there is also a significant number of papers that focus on urban environments. The research has also identified many positive impacts, weaknesses, strengths and barriers of sponge solutions. There is, however, scarcity of papers that also focus on involvement of stakeholders in sponge solutions, on financing these solutions and on policy instrument.

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Annex

Dataset containing all selected papers is available at:

Macháč, J., Brabec, J., Zaňková, L., Hekrle, M., Schmid, S., Lindner, M., Marhuenda, A., Vieweg, M., Scholz, M. (2025). SpongeBoost D1.2 Catalogue of innovative sponge solutions - dataset. ZENODO. doi.org/10.5281/zenodo.15095307