Nature's integration in cities' hydrologies, ecologies and societies

# D4.3 Transition pathways towards Nature's Integration in Cities' Hydrologies, Ecologies and Societies

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# 1 Summary

Deliverable 4.3 of the NICHES project explores transition pathways for integrating Nature-based Solutions (NBS) into urban water governance across three case study cities: Rotterdam, Berlin, and Barcelona. Recognizing the limitations of traditional grey infrastructure, the deliverable highlights how climate stressors such as increased rainfall and combined sewer overflows (CSOs) demand a shift towards sustainable, adaptive, and multifunctional urban water systems. The analysis is framed within the socio-ecological-technical systems (SETS) approach, emphasizing the interconnections between technological infrastructure, ecological resilience, and social equity.

This deliverable builds on the insights gathered from participatory workshops and literature reviews. It identifies current challenges in each city, including fragmented governance structures, insufficient public engagement, and limited integration of ecological considerations. Technological constraints such as reliance on outdated sewer systems and inconsistent standards further limit the implementation of NBS.

Innovative pathways for overcoming these challenges are proposed, highlighting the importance of participatory governance models, cross-sectoral collaboration, and regulatory reform. Technical innovations like digital monitoring platforms and decentralized stormwater solutions are emphasized, along with the need to integrate circular water management principles and expand blue-green infrastructure.

The deliverable underscores that while each city exhibits unique contextual challenges and opportunities, systemic integration of NBS requires comprehensive, inclusive strategies that address social, ecological, and technological dimensions. Transition pathways must prioritize co-produced governance frameworks, align local and regional policies, and foster public participation to ensure long-term resilience and equity in urban water management. The insights generated offer actionable guidance for policymakers, practitioners, and researchers seeking to create sustainable and adaptive urban water futures.

# 2 Introduction

Addressing the escalating challenges of stormwater management in urban areas demands not only technical innovation but also transformative governance approaches that can operate across socio-ecological-technical systems (SETS). Traditional grey infrastructure, long embedded in urban water governance, often lacks the flexibility to adapt to climate-induced intensification of combined sewer overflow (CSO) events (McPhearson et al., 2016) . In response, Nature-based Solutions (NBS) have emerged as ecologically restorative alternatives that promise multifunctional benefits (i.e., runoff mitigation, improved water quality, biodiversity enhancement and increased social equity) (Raymond et al., 2017). Yet, their effective deployment remains dependent on overcoming institutional fragmentation within current governance structures (Patterson et al., 2017).

The NICHES project considers this a central obstacle to the systemic integration of NBS. Particularly in the context of CSOs, governance challenges are embedded in how legitimate actors, knowledge systems, and infrastructural investments are prioritized, and many times excluded, from decision-making processes (Bush & Doyon, 2019). Transitioning from existing hard infrastructure toward integrated NBS-based urban water systems entails not only technical innovation but also a shift in values, policies, and institutional arrangements. Such a transition requires co-produced, inclusive processes to ensure legitimacy and effectiveness across diverse urban contexts (Bai et al., 2010; Frantzeskaki & Rok, 2018).

Delivery 4.3 focuses on the feasible transition pathways for integrating NBS into urban water management. In order to achieve this, dedicated co-creation workshops across three NICHES cities (Rotterdam, Barcelona and Berlin) were carried out to understand the current and desired states of water management systems, as well as the existing opportunities and challenges influencing its transitions. These pathways are aimed at overcoming sectoral silos and fostering synergies between urban water and green infrastructure governance, with potential for wider application in global urban contexts.

# 3 Theoretical framework

## 3.1 Socio-Ecological-Technical Systems framework

The Socio-Ecological-Technical Systems (SETS) framework examines the interconnected dynamics between urban components, including human activity, natural environments, technological systems infrastructure, and governance structures. Projects like NICHES apply this approach (Figure 1) to identify novel solutions for urban water management. By integrating urban planning and governance perspectives, the SETS framework facilitates a multidimensional understanding of NBS, encompassing technical (engineered structures, materials), ecological (climate, biodiversity, biophysical factors), and social (cultural, economic, governance) dimensions. Ecosystem services serve as a unifying concept, helping to harmonize SETS outcomes across different scales while addressing fragmented approaches in urban sustainability efforts (Cadenasso & Pickett, 2008; McPhearson et al., 2022).

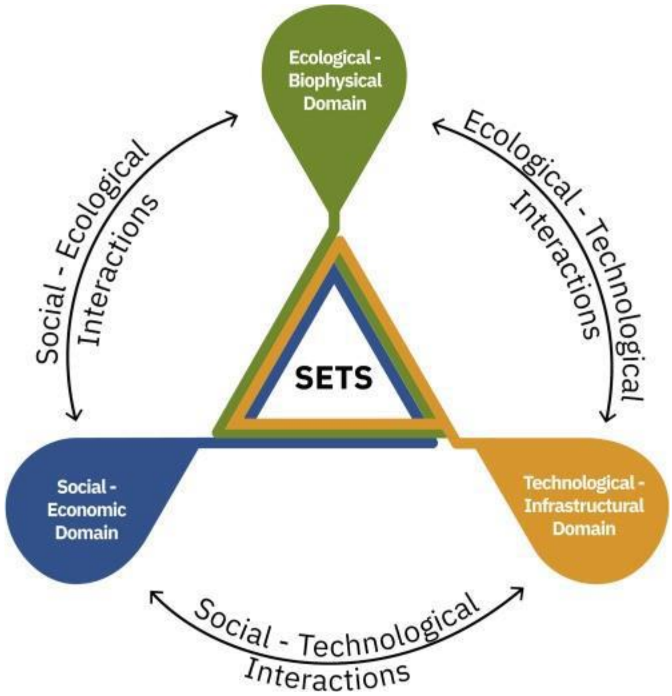


*Figure 1: Social-ecological-technological systems conceptual framework. Source: McPhearson et al. (2022)*

Unlike conventional interpretations of ecosystem services as purely ecological or socio-ecological processes, the SETS perspective emphasizes the necessity of technological systems, institutional frameworks, and governance mechanisms to ensure these services effectively benefit communities. Hybrid solutions such as bioswales and retention basins, for instance, require integrated social, ecological, and technical considerations during planning, implementation, and maintenance to optimize stormwater management benefits (McPhearson et al., 2022).

Furthermore, SETS reveals key interdependencies among ecosystem services. Some research suggests that in stormwater management, ecological and technical factors may outweigh social influences in low- to medium-density urban settings. The effectiveness of bioswales, for example, often depends more on engineered infrastructure and soil-plant interactions than on community involvement (McPhearson et al., 2022).

However, in densely populated areas, governance and social dynamics have become increasingly critical. Given that NICHES focuses on high-density cities, the social and political dimensions of SETS are likely central to the successful adoption and longevity of NBS in urban water systems.

While technical aspects are vital for initial green infrastructure deployment, governance and social engagement gain importance over time (McPhearson et al., 2022). Additionally, recent studies highlight how participatory governance models can support sustainable urban transitions, moving beyond technocratic approaches to incorporate broader societal co-benefits of NBS (Branny et al., 2022).

## 3.2 Transition pathways framework

In order to understand and guide transitions in urban water management, the Three Horizons framework (Sharpe et al., 2016) offers a valuable lens. It provides a structured way to engage with diverse temporal spaces and competing system dynamics.

The Three Horizons framework conceptualizes transformation as the interaction of three overlapping "horizons" of change. Rather than being viewed as rigid phases, these horizons represent different patterns of systems that coexist over time, allowing stakeholders to examine tensions, opportunities, and trajectories of systemic evolution.

- **Horizon 1 (H1)** reflects the dominant regime, the set of current institutional arrangements, infrastructures, and practices that define how urban water systems function today. While H1 may still deliver necessary services, its declining relevance in the face of climate change and CSO events signals the need for transformation.
- **Horizon 2 (H2)** captures emergent innovations and transitional practices. These are often hybrid forms that mix elements of the existing regime with more sustainable, adaptive approaches, such as pilot NBS projects, cross-sectoral collaborations, or new financing mechanisms. H2 actors often struggle to scale due to institutional inertia, yet they are critical enablers of system reconfiguration.
- **Horizon 3 (H3)** represents the vision of a transformed future system. It embodies new governance cultures, policy paradigms, and infrastructures aligned with long-term sustainability, resilience, and justice. In the context of NICHES, H3 envisions a cross-integrated water and green infrastructure system that is adaptive and equitable.

By articulating and connecting these horizons, the framework supports the co-production of pathways that link present realities to desired futures. Within the NICHES cities, this approach is particularly suited to reconciling short-term feasibility with long-term transformation actions in the integration of NBS.

# 4 Methodology

## 4.1 Case study cities

- Rotterdam, the Netherlands' second-largest city and home to Europe's largest seaport, sits largely below sea level and has long relied on advanced water infrastructure to manage flood risks. Its integrated system of canals, dams, and barriers reflects a tradition of technical excellence in water governance. However, growing pressures from climate change (i.e., rising sea levels, extreme rainfall, and drought) are pushing the city to pursue more adaptive and sustainable approaches. Rotterdam has begun to frame these challenges as opportunities to develop resilient pathways that integrate NBS alongside existing grey infrastructure.

- Barcelona, Spain's second-largest city, has been marked by droughts and water quality issues in the past. Growing climate pressures have also included flooding. Despite improvements in its sewer infrastructure and the implementation of large underground stormwater reservoirs, there still exists water management pressures that have led to increasing interest in decentralized and restorative approaches. Efforts to protect nearby ecosystems such as the Llobregat River and wetlands that are crucial both ecologically and for freshwater supply, have spurred adoption of Sustainable Urban Drainage Systems (SUDS) and other NBS. These initiatives reflect a broader governance shift toward multifunctional and climate-adapted urban water management.

- Berlin, Germany's capital and largest city, faces a dual water challenge: low annual precipitation combined with intensifying heavy rainfall events. These conditions strain its limited stormwater storage capacity and the risk of overflows in urban streams, threatening water quality and biodiversity. The establishment of a dedicated Rainwater Agency and the promotion of NBS for flood-prone areas reflect emerging governance practices focused on systemic adaptation and the socio-ecological integration of water infrastructure.

## 4.2 Participatory workshops

To explore how the three cities are addressing current water management challenges and to identify opportunities for incorporating restorative NBS into existing policies, the NICHES project organized workshops with key stakeholders. These sessions gathered expert insights on both the present state and future possibilities for urban water systems.

- Rotterdam

The session, organized by NIOO-KNAW on 13 March 2023, brought together 20 stakeholders representing municipal authorities, regional water boards, and the drinking water utility. These actors reflect key institutional nodes within the Rotterdam urban water governance landscape, and their participation ensured that a diversity of operational, regulatory, and infrastructural perspectives were represented.

The workshop combined IPBES's Nature Futures Framework (Pereira et al., 2023) and the Three Horizons model (Sharpe et al., 2016) to explore ecological, social, and technological transitions. Participants prepared by sharing their own photos representing water's value, sparking discussions on nature perspectives (e.g., "Nature for Nature" vs. "Nature for People").

Finally, using the Three Horizons framework, participants situated possible interventions within a temporal schema spanning current practices (H1) and emerging innovations (H2).

Notably, Rotterdam was the first city to conduct this type of assessment. Like the other cities, it used the Three Horizons framework to guide the participatory exercise. However, the framework's implementation differed in the next two cities, as lessons from Rotterdam's workshop informed adjustments to the questions and dynamics in subsequent sessions, while still addressing the same core aspects.

- Barcelona

Two workshops were held in Barcelona as part of the co-development of transition pathways for urban water governance. Led by ICTA-UAB, the first took place on March 6, 2023, and the second on November 13, 2024. Each session gathered public officials, academics, NGOs, and private sector representatives.

Both workshops employed the Three Horizons framework to support reflection on current system lock-ins, desirable future scenarios, and the innovations required for systemic transformation. The first workshop focused on Horizons 1 and 3, identifying the structural constraints of the Metropolitan Area of Barcelona's stormwater system and envisioning its sustainable future. During this workshop, the following questions were asked to participants to understand their points of view on the local water systems:

H1:

- *What are the main characteristics of the stormwater management system and the unified sanitation system? What aspects of these systems work and what do not?*
- *What are the likely effects for the future of these management systems if the current model is followed?*
- *What changes, both positive and negative, have you observed in the last 25 years in stormwater management and the sanitation system? What do you think should be maintained in the current urban rainwater system and sanitation system?*

H3:

- *What is the future you want for urban water systems? What would be their main characteristics?*
- *What are those other visions of the future that diverge from yours? Could you collaborate with their proponents because you share enough elements or are there inherently contradictory visions?*
- *What are the innovative niches that represent the desired future that already exists in the present? Give specific examples*
- *Looking back, what visions are these innovative niches built on? What history, values, and management models do they represent?*

The second centered on Horizon 2, guiding small-group discussions on the social, ecological, and technological barriers, enablers, and innovations shaping NBS implementation.

- Barriers: *What are the barriers that limit the development of SBNs to mitigate hydrological risks in the AMB?*
- Enablers: *What strategies, resources or technologies already available in the AMB can help increase the effectiveness of SBNs or facilitate their implementation?*
- Innovations: *What strategies, resources or technologies that are not yet available in the AMB could help increase the effectiveness of SBNs or facilitate their implementation?*

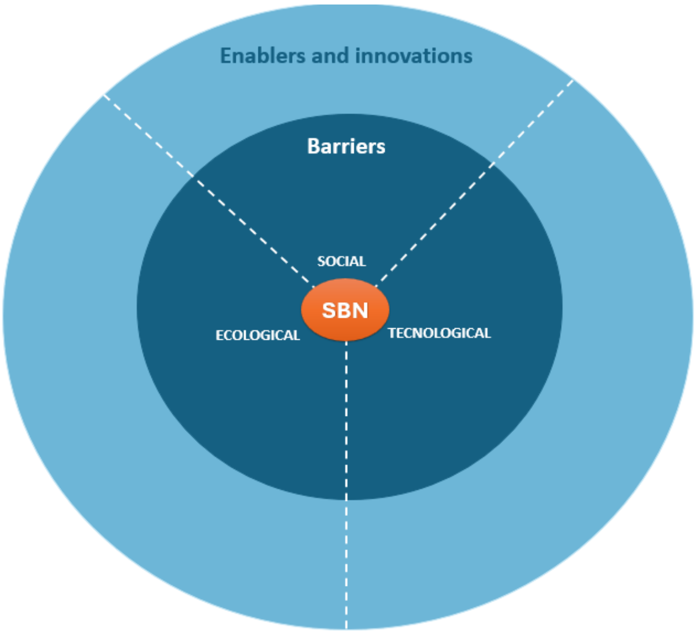


*Figure 2: Diagram employed for guiding the H2 discussion during the workshops of Barcelona and Berlin, where participants included their opinions and ideas using post its.*

- Berlin

A stakeholder workshop was held in Berlin on December 3, 2024, at Ecologic Institute, bringing together participants from municipal authorities, urban planning, academia, utilities, and civil society. The session was designed around the Three Horizons framework to facilitate co-learning about transition pathways for integrating NBS into urban stormwater governance.

The workshop started with presentations from keynote speakers and included an introduction to the previous work carried out by Ecologic in which it assessed the Horizon 1 (current state of the water management systems in the city), based on an online survey conducted in summer that year and literature review. Then, participants engaged in small-group discussions and plenary sessions. Employing the same questions and visual tools from the Barcelona workshop (see Figure 2), the workshop enabled participants to map the desirable future visions and transition pathways, and explore enabling innovations across ecological, social, and technological dimensions. The event formed a key step in co-producing actionable pathways for Berlin’s transition toward sponge city principles.

# 5 Results

## 5.1 Rotterdam

The Rotterdam workshop (see Fig. 3) focused primarily on assessing the current state (H1) and identifying transition pathways (H2) for urban water management, with results derived exclusively from stakeholder interventions.

- **Horizon 1: Current system characteristics**
    - Social: key issues include lack of public awareness of environmental issues, social inequities regarding water access, and insufficient engagement in decision-making processes. Additionally, concerns were raised about the need

for clearer communication and education efforts to align public understanding with sustainability goals.
    - Ecological: the ecological dimension of the current system reflects constraints in biodiversity protection, with urban environments limiting ecological connectivity and resilience. Participants highlighted degradation of natural habitats and the limited integration of green spaces into stormwater management.
    - Technical: technologically, the existing system is heavily reliant on grey infrastructure, with centralized sewer systems struggling to adapt to extreme rainfall. Limitations in adaptive capacity, outdated design standards, and lack of innovation were identified as barriers to sustainability and resilience.

- **Horizon 2: Innovations and transition enablers**
    - Social: stakeholders proposed a range of social strategies to facilitate transitions, including strengthening collaborative platforms, promoting environmental education in schools, and increasing public engagement through surveys and ownership-building initiatives. Institutional shifts, such as integrating environmental targets into urban planning policies, applying cost-benefit analyses, and enhancing training for administrators, were emphasized. Regulatory and policy-focused suggestions, such as integrating rainwater regulation into national climate adaptation strategies, banning polluting construction materials, taxing impermeable surfaces, and promoting car-free cities were also brought up.
    - Ecological: ecological considerations, while less frequent, highlighted the need for adaptive water management approaches that restore and enhance natural water systems and integrate ecological thinking into urban developments. These contributions emphasized the ecological connectivity and resilience of urban water systems.
    - Technical: technological contributions focused on the integration of innovative infrastructure solutions, including blue-green infrastructure in new developments and advancements in adaptive water management systems. Specific proposals included material innovations, such as banning the use of construction materials that leach pollutants.

*Figure 3. Rotterdam workshop carried out on 13 March 2023. Credit: NIOO-KNAW*

## 5.2 Berlin

The Berlin results were derived from a hybrid approach. H1 was developed through a literature review and a stakeholder survey conducted in summer 2024, summarizing pre-existing knowledge on Berlin's stormwater management system. During the December 3rd, 2024, workshop, participants focused only on H2 and H3 (see Fig. 4)

- **H1: Current system characteristics**
  - Social: the urban water system in Berlin faces challenges rooted in fragmented responsibilities and limited cooperation across institutions. Insufficient coordination between districts, sectors, and agencies hinders integrated planning, while public awareness of decentralized rainwater solutions remains low. Gaps in knowledge transfer and technical expertise further limit progress. The social benefits of NbS are often underappreciated in assessments, and there is a general lack of incentives for private actors to adopt sustainable practices. Despite some improvements, including decentralized rainwater management initiatives and supportive policies, the overall approach is fragmented and not fully aligned with long-term adaptation goals.

  - Ecological: Berlin's water system struggles with increasing sealed surfaces, reduced groundwater recharge, and frequent combined sewer overflows that discharge untreated wastewater into rivers and lakes. Biodiversity is under pressure due to habitat fragmentation and water quality issues linked to nutrient-rich discharges and pollutants. Green infrastructure efforts, such as tree planting, green roofs, and infiltration basins, have been introduced but remain limited in scale and effectiveness. The system's capacity to adapt to climate-induced changes is constrained, and the ecological impacts of continued urban development require stronger integration into planning and management.

- Technical: Berlin's combined sewer system, while historically effective, lacks the flexibility to handle increased runoff from extreme rainfall events. Technical limitations include inadequate capacity, outdated design standards, and insufficient storage for stormwater. Infrastructure such as underground basins and canal control systems has not kept pace with rising demands. Regulatory frameworks exist to limit rainwater discharges from construction projects, but enforcement is inconsistent, and implementation of decentralized technical solutions is hampered by bureaucratic and institutional barriers. Progress on digital monitoring systems and adaptive control technologies is limited, leaving the system vulnerable to overload and pollution.

- **H2: Innovations and transition enablers**
  - Social: stakeholders emphasized the need for stronger communication, clear responsibilities, and legal frameworks to facilitate cooperation. They highlighted the importance of participatory platforms, inclusive decision-making, and transparent goal setting to build shared understanding. Initiatives such as advisory councils, civil society networks, and partnerships with local organizations were proposed to enhance engagement. Reducing regulatory complexity and aligning financial incentives with sustainable practices were identified as key social enablers. Education, knowledge-sharing, and capacity building were also considered critical for fostering a culture of collaboration and innovation.

  - Ecological: proposals focused on expanding blue-green infrastructure and promoting ecological functions in urban planning. Suggestions included scaling up unsealing efforts, integrating biodiversity targets, and creating multifunctional green spaces that support both water retention and ecological resilience. Emphasis was placed on enhancing ecosystem services through adaptive landscape design and leveraging natural processes like photodegradation and biodegradation to improve water quality. The integration of biodiversity considerations into urban management was seen as essential for long-term sustainability.

  - Technical: technical enablers included developing decentralized rainwater management solutions, adaptive drainage systems, and advanced digital monitoring platforms. Participants proposed harmonizing technical standards, piloting innovative materials and techniques, and expanding the use of sustainable construction practices. Examples included the introduction of infiltration basins with diverse plantings, decentralized storage systems, and smart control technologies for optimizing stormwater flows. Investment in research and development, as well as support for scaling up innovative pilot projects, were recognized as important for achieving technical transformation.

- **H3: Desired future**
  - Social: the envisioned future system is characterized by inclusive governance, transparent decision-making, and active participation from diverse stakeholders. Priorities include equitable access to clean and resilient water systems and clear legal mandates. A shift towards collaborative, multi-level governance structures is seen as essential, supported by long-term funding and a commitment to fairness and justice.

  - Ecological: it was highlighted the necessity for restored ecological integrity, with integrated blue-green networks supporting biodiversity, climate adaptation, and improved air and water quality. Large-scale unsealing, expansion of permeable surfaces, and the use of native vegetation were highlighted as essential components. Stakeholders called for a planning approach that fully integrates ecological processes and prioritizes natural solutions over hard infrastructure.

  - Technical: technological visions focus on a decentralized and adaptive system that leverages digital technologies, smart monitoring, and sustainable materials to manage stormwater effectively. Future infrastructure is expected to be flexible, resilient, and integrated with ecological systems. Investment in innovation and the scaling of experimental solutions are seen as vital to realizing this vision, ensuring that Berlin’s urban water system can withstand future climate challenges and support a sustainable urban environment.

*Figure 4. Berlin workshop carried out on December 3, 2024. Credit: Ecologic Institute*

## 5.3 Barcelona

The results for Barcelona were derived from two participatory workshops conducted in March 2023 and November 2024. In the first workshop, participants explored both the current state (H1) and desired future (H3) of the stormwater and wastewater management system in the Metropolitan Area of Barcelona. The second workshop focused specifically on defining transition pathways (H2) (see Fig. 5).

- **Horizon 1: Current system characteristics**
    - Social: the current stormwater management system in the Metropolitan Area of Barcelona shows some improvement in public engagement and inter-institutional collaboration. However, challenges persist, including limited public awareness and understanding of NbS and insufficient participation in decision-making processes. Disparities remain, with vulnerable communities often more exposed to the impacts of system failures, such as flooding and pollution. Institutional fragmentation and a lack of clear regulatory frameworks hinder effective governance, contributing to inefficient responses to urban water challenges.

    - Ecological: the system's ecological performance is constrained by high levels of surface sealing, habitat fragmentation, and limited integration of NBS into urban environments. CSOs continue to affect aquatic ecosystems, exacerbating water quality issues in rivers and beaches. While initiatives like the Natura 2030 Plan and the inclusion of green roofs have been introduced, these remain limited in scale. The ecological functions of urban water management are often underprioritized, with insufficient attention to restoring biodiversity and ecological connectivity.

    - Technical: the combined sewer system performs adequately under normal conditions, with rapid activation during rainfall and effective water purification before discharge. However, extreme weather events expose its limitations, leading to overflows and sediment accumulation. Some municipalities have implemented separate stormwater and wastewater networks, but these practices are not widespread. Existing infrastructure often lacks flexibility, with insufficient storage capacity and outdated design standards, making it ill-suited to handle the increasing intensity and frequency of rainfall events linked to climate change.

- **Horizon 2: Innovations and transition enablers**
    - Social: participants highlighted the need to strengthen public participation, enhance education and awareness campaigns, and leverage community organizations to support NBS implementation. Enablers include existing citizen associations, participatory platforms like DECIDIM BCN, and environmental programs that create opportunities for engagement. Recommendations included developing collaborative governance models, aligning local and regional policies, and promoting public-private partnerships

to mobilize resources. Stakeholders emphasized the importance of integrating social equity into planning, ensuring that vulnerable populations benefit from NBS investments and improvements.

- Ecological: proposed ecological enablers focused on scaling up blue-green infrastructure, enhancing biodiversity, and creating multifunctional green spaces that combine ecological and water management functions. Examples included unsealing impermeable surfaces, integrating green corridors, and employing xeriscaping (i.e., the process of landscaping, or gardening, that reduces or eliminates the need for irrigation) techniques. The use of biodiversity indicators and the promotion of ecosystem services were seen as crucial steps to support a more resilient and ecologically functional urban landscape.

- Technical: technological innovations included the integration of digital monitoring platforms, adoption of advanced materials and design standards, and development of methodologies to optimize the multifunctionality of NBS. The use of GIS and artificial intelligence tools to model and plan NBS solutions was highlighted as a key enabler, alongside leveraging financial incentives such as tax benefits and subsidies. Stakeholders also proposed the development of general catalogs and standards for NBS, investment in research and development of bio-based construction materials, and the expansion of SUDS through technical guidance and support frameworks.

- **Horizon 3: Desired future**
    - Social: the envisioned future system for the AMB emphasizes inclusive, participatory governance with active citizen involvement and transparent decision-making processes. Priorities include embedding social justice and equity into water management strategies, enhancing education and awareness, and ensuring that all communities benefit from NBS adoption. Stronger inter-institutional collaboration and alignment of local, regional, and international policies were identified as necessary to support this vision.

    - Ecological: the desired ecological future integrates large-scale blue-green infrastructure that restores natural hydrological cycles, enhances biodiversity, and improves urban resilience to climate impacts. A focus on deconstructing impermeable surfaces, reconnecting ecological corridors, and adopting holistic landscape approaches was seen as essential for achieving long-term sustainability.

    - Technical: a technically advanced and adaptive system is envisioned, combining decentralized stormwater solutions with cutting-edge digital technologies. This includes real-time monitoring and management platforms, widespread use of innovative materials and construction practices, and integration of circular water management principles such as reuse and recycling at local levels. Participants emphasized the need for harmonized technical standards and continuous innovation to ensure resilience to climate-induced challenges.

*Figure 5. Barcelona workshop nº 2, carried out on November 13th, 2024. Credit: ICTA-UAB*

## 5.4 Cross-city Analysis

This section presents a cross-city analysis of the transition pathways identified in Rotterdam, Berlin, and Barcelona, highlighting both shared challenges and city-specific approaches to climate-resilient urban water management. To visually capture the thematic emphasis of workshop discussions, word clouds are presented for each horizon and dimension. These visualizations synthesize the most frequently mentioned concepts from across the cities (see Fig. 6).

- **H1: Present system characteristics**
    - **Social:** A consistent challenge across the three cities is fragmented governance, limited public participation, and a lack of transparent decision-making structures. Rotterdam's approach is shaped by its port-centric, risk-management focus, which prioritizes technical control but has limited emphasis on participatory engagement. Berlin shows gaps in institutional cooperation and public engagement, with social innovation initiatives often localized and lacking systemic support. Barcelona, despite stronger participatory platforms, struggles with effectively integrating ecological considerations into governance, and engagement efforts remain uneven across neighbourhoods.

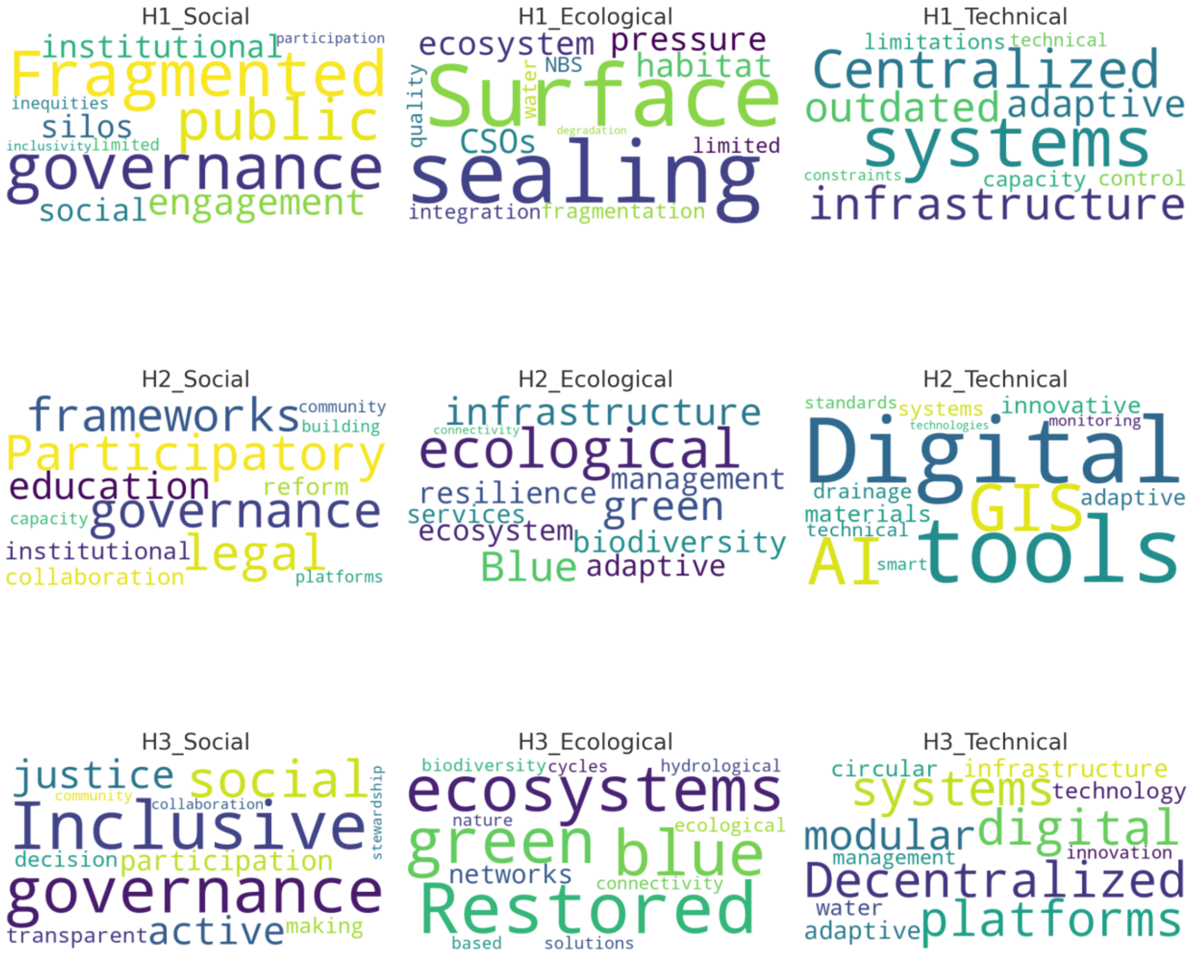


*Figure 6. Word cloud synthesizing the most frequently mentioned concepts from across the cities for each horizon and each dimension. H3 only considers Barcelona and Berlin results, since Rotterdam did not assess this horizon during its workshops.*

- **Ecological:** All three cities experience ecological pressures linked to surface sealing, degraded ecosystems, and CSOs that harm water quality. Rotterdam's robust canal and flood protection systems have yet to fully integrate NBS to address these pressures. Berlin faces severe biodiversity fragmentation and water quality degradation exacerbated by pollutant discharges and habitat loss. Barcelona's urban ecosystems are under strain from urbanization and limited ecological connectivity. Despite localized green initiatives, systemic integration of nature-based approaches into water management remains limited.

- **Technical:** These **c**enter on reliance on outdated grey infrastructure across all cities. Rotterdam, while possessing advanced water control systems, lacks significant integration of NBS with its technical solutions. Berlin's stormwater system struggles with capacity constraints and has not fully adopted adaptive or decentralized technologies. Barcelona has made advances in decentralized stormwater management, but infrastructure remains uneven, with technical standards and monitoring systems lagging behind ambitions for resilience. Collectively, these cities reveal a shared need for modernization but demonstrate varied levels of readiness and integration between grey and green infrastructure.

- **H2: Transition enablers and innovations**
  - **Social:**
    All cities recognize the importance of participatory governance, capacity building, and institutional reform to advance NBS. However, mechanisms vary: Rotterdam focuses on regulatory reforms and top-down policy adjustments, including stricter building codes and compensation requirements for impervious surfaces. Berlin prioritizes expanding participatory platforms and knowledge-sharing networks, emphasizing social learning and institutional coordination. Barcelona leverages financial incentives, community organizations, and collaborative governance models that integrate diverse stakeholder voices, albeit with varying levels of local effectiveness. These distinct approaches reveal each city's strategic emphasis on social transformation.

  - **Ecological:**
    A shared focus on scaling up blue-green infrastructure and restoring ecological functions is remarked. Rotterdam integrates blue-green measures within its extensive grey infrastructure system but leans toward incremental adaptation. Berlin is driving an expansion of NBS within its sponge city strategy, emphasizing connectivity and biodiversity enhancement. Barcelona's ecological focus extends to reconnecting hydrological cycles, scaling up green corridors, and emphasizing ecosystem service provision. While all cities value ecological resilience, their strategies reflect different priorities and operational approaches.

  - **Technical:**
    Technological innovations are recognized as critical across cities, yet their readiness and focus diverge. Rotterdam emphasizes stricter construction material standards and incremental adoption of innovative technologies, maintaining integration with existing systems. Berlin advances adaptive drainage solutions, enhanced digital monitoring, and smart control technologies, leaning towards a more technical modernization. Barcelona prioritizes integrated circular water management, digital platforms, and piloting bio-based construction materials.

- **H3: Desired future systems**
  Note: H3 was not assessed for the city of Rotterdam, but only for Berlin and Barcelona

  **For H3, the city of Rotterdam did not**
  - **Social:**
    Berlin envisions a highly participatory governance model anchored in expanded advisory councils, community co-management initiatives, and transparent decision-making processes. This proactive approach focuses on institutional reform, ensuring that public participation is embedded within formal structures. Barcelona, in contrast, leans towards embedding NBS and

water governance, emphasizing community empowerment through bottom-up initiatives, including neighborhood-scale NBS projects and educational programs. While both cities value inclusivity and participation, Berlin's focus is on institutionalized collaboration, whereas Barcelona champions grassroots and socio-ecological integration.

- **Ecological:**
  Both cities share a vision of restored and interconnected ecosystems supported by expansive blue-green networks. Berlin's future centres on creating continuous biodiversity corridors and integrating ecological considerations into urban design standards. In contrast, Barcelona emphasizes large-scale unsealing of impermeable surfaces, restoration of hydrological cycles, and maximizing multifunctionality of green spaces to address both ecological and social needs.

- **Technical:**
  Technologically, Berlin aims to lead with adaptive infrastructure featuring real-time monitoring, advanced data integration, and modular drainage systems that can flexibly respond to climate variability. Barcelona envisions a technically robust system integrating circular water management, extensive use of digital platforms for decision-making, and innovative materials and construction practices that support both environmental and social goals. While both cities share aspirations for high-tech, resilient water systems, Berlin's focus leans toward operational adaptability and monitoring, whereas Barcelona emphasizes holistic integration of sustainability principles and circularity.

## 5.5 Conclusion

This delivery has explored transition pathways for integrating NBS into urban water governance across three NICHES cities (Rotterdam, Berlin, and Barcelona). The analysis was guided by the three horizons methodology, and operationalized through a combination of stakeholder workshops and cross-city comparisons. The findings highlight both shared challenges and unique opportunities, emphasizing the importance of systemic, cross-scalar integration of social, ecological, and technical dimensions in stormwater management.

In all cities, fragmented governance structures and outdated technical infrastructures were identified as major barriers to effective NBS adoption, particularly in the face of climate-induced stressors such as flooding and drought. However, the workshops also revealed significant potential for innovation, from participatory platforms and regulatory reforms to the expansion of blue-green infrastructure and the adoption of advanced monitoring and circular water systems.

The cross-city analysis underscores the necessity of contextual strategies and confirming that there are no one size fits all solutions. Transitioning towards integrated urban water management requires not only technical innovation but also shifts in governance culture, policy frameworks, and societal engagement.

Finally, the Three Horizons framework offered a useful structure for untangling the complexities of water management planning and the ambitions to transform these systems into more sustainable and resilient ones. Additionally, it enabled a comparison between different cities, revealing both similarities and differences in their approaches to developing these systems under varying urban conditions.

By documenting these transition pathways, this deliverable contributes to the broader understanding of how cities can navigate complex socio-ecological-technological challenges. The insights gained offer actionable guidance for policymakers, practitioners, and researchers working to foster just, resilient, and sustainable urban water futures.

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