

Leveraging synergies between asset management of stormwater systems and natural areas to increase resilience to climate change

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Urban regions are dynamic and complex systems, highly sensitive to disruptions, requiring coordination among diverse stakeholders due to the interdependence of their strategic services and assets. Climate change (CC) exacerbates existing challenges and introduces new hazards such as intense rainfall, droughts, and heat waves, affecting strategic services and their infrastructure, populations, ecosystems, and economies. Water, green spaces, and biodiversity are deeply interconnected. The increasing interdependence between ecosystems and human societies underscores the need for building resilience across all systems (UNDRR, 2023). Enhancing urban systems resilience to CC and other pressures is vital to ensure sustainability and reduce risks to human and natural systems.

Natural areas (NA), including both native ecosystems and constructed blue-green infrastructure, play a critical role in addressing CC. Natural and semi-natural systems, regardless of scale, help mitigate CC impacts. These systems contribute to urban heat island mitigation and effective stormwater (SW) management, as highlighted in various studies. The latest IPCC reports stress nature-based solutions (NBS) as essential for climate adaptation and mitigation, leveraging nature to enhance resilience and reduce risks. This underscores the importance of integrating natural systems into planning to face climate challenges effectively.

NBS include actions like reforestation, wetland restoration, sustainable agriculture, and urban greening, crucial for climate mitigation and adaptation by reducing greenhouse gas emissions, increasing resilience to climate impacts, supporting biodiversity, enhancing carbon storage, managing SW, and offering flood protection. They also provide co-benefits for communities and ecosystems while addressing climate challenges. However, poorly designed NBS can lead to maladaptation and exacerbate stress in SW systems. Proper planning and implementation are essential to maximize their potential.

NBS can significantly enhance sustainable urban water management by leveraging natural processes to manage SW effectively and increase climate resilience. Key contributions include increasing infiltration, evapotranspiration, and pollutant removal; creating storage areas to delay and control flood peaks, reducing direct runoff into drainage systems; storing SW and grey water for reuse, such as irrigating green areas or meeting off-site water needs, thereby conserving freshwater resources. International literature points out the advantages of implementing NBS for SW management adaptively, progressively, and taking advantage of investment opportunities for systems' expansion or rehabilitation (Kapetas and Fenner, 2020), for long-term sustainability. Therefore, it is crucial to incorporate these aspects in asset management (AM) of these systems recognizing the NBS interdependencies with other services, to ensure their adequate management. Leveraging synergies between SW systems and NA contributes to increasing resilience to CC.

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The holistic Resilience Assessment Framework (RAF) from the RESCCUE and ICARIA European projects (<https://toolkit.resccue.eu>, <https://www.icaria-project.eu>), integrates, among other, SW and NA as strategic services in a city or region. This paper presents how NBS and SW management relate to each other in the RAF, highlighting the opportunities to integrate resilience improvement in AM practice, taking advantage of the interactions between them, and pointing out new challenges. The *functional* resilience dimension considers ensuring NA are well-planned, managed, autonomous, and prepared for CC challenges. NA’s services are assessed as ecosystem services, e.g. health and well-being, biodiversity, aesthetical and recreational activities, groundwater recharge, air quality, enhanced infiltration, water retention and evapotranspiration (Brito et al., 2024). The relation to the SW service is evident for groundwater recharge and enhanced infiltration, water retention and evapotranspiration.

Incorporating NBS in SW AM requires ensuring proper governance of these services and addressing issues related to their boundary, as they are relevant for assigning responsibilities and defining mechanisms for financing and controlling the service provision. The RAF *functional* dimension considers service planning and risk management, its reliability, flexibility, autonomy and interdependencies, and its preparedness to respond, endure and build back from stressful CC events (Brito et al., 2024). When considering NBS, all these points of view require strong alignment and integration between SW and NA AM, as they are closely related. The metrics should be aligned for e.g. *Cascading impacts*, *Critical services dependence on the service according to CC scenarios*, *Impacts on other services in the last relevant climate-related event*. The link between the two services is also significant for the NA assessment metrics, e.g., *Groundwater recharge* or *Estimated water retention enhancement*. From the infrastructure perspective, the RAF *physical* dimension considers whether the assets are safe, robust, and prepared for CC, namely how autonomous, flexible, and redundant they are. NBS are assets with a significant role in the urban water cycle. This means that AM practices for SW and NA must be aligned and integrated as, for example, is depicted in the metrics *Capacity for zero floods*, *GHG emission target*, and *Implemented design solutions to address CC mitigation and adaptation*. Additionally, the relation between both services is significant for the NA assessment related to the metrics *Ecosystem services provided last year* or *Water self-sufficiency*.

Implementation of AM practices is essential to ensure sustainability of the strategic services, as SW and NA services. To increase resilience of these services to CC, it is fundamental to leverage synergies between their management. The RAF offers a valuable tool for evaluating their resilience to CC, providing insights that inform AM decisions. This includes contextual characterisation, diagnosis, identification of improvement opportunities and assessment of progress.

Key words: asset management; climate change; natural areas; resilience; stormwater services

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