Water Europe

Technology & Innovation

OPPORTUNITIES FOR HYBRID GREY & GREEN INFRASTRUCTURE IN WATER MANAGEMENT: CHALLENGES AND WAYS FORWARD

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Prologue

Water Europe (WE) is the recognized voice and promotor of water-related innovation and RTD in Europe. WE is a value-based multi-stakeholder association that represents the whole diversity of the innovative water ecosystem. WE was initiated by the European Commission as a European Technology Platform in 2004.

All WE activities are guided by its Water Vision and the ambition to achieve a Water-Smart Society.

The Water Europe White Papers are aimed at informing readers about complex water-related topics in a concise and targeted way, and presenting WE's vision and philosophy on the matter. They present evidence-based opinions on multiple water-related challenges and on ways to overcome them.

WE White Papers are produced as part of the WE Collaboration Programme by the WE Vision Leadership Teams and the WE Working Groups. They target a wide variety of potential audiences, including the EU institutions, international organisations, the water industry, water users and water-related strategic stakeholders, the economic sectors, as well as media, analysts, regulatory and governing bodies, citizens and society at large.

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Water Europe Executive director

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Abstract

Hybrid grey and green water infrastructures (HGGI) are combinations of grey, smart and green infrastructures, aimed at producing (climate) resilient water systems, reliably controlling peak flows and/or delivering clean water, sustaining environmental flows, and providing ecosystem, economic and social services. They can therefore be seen as supplying multiple benefits simultaneously.

The implementation level (planning, designing, constructing and maintaining) of HGGI cannot be evaluated by a Technology Readiness Level (TRL) alone; it also needs a symbiosis of multiple dimensions, as distinguished in the Symbiosis Readiness Level (SRL) (Sommer, 2019). The SRL incorporates four dimensions: Technology, Business, Ecology and Management. The use of the SRL as an approach to evaluate priority actions for the further wide-scale implementation of HGGI has resulted in a list of actions per implementation level.

To outgrow the 'proof of concept' level, a Technological priority action could be to improve the performance of green infrastructure solutions through the use of artificial intelligence and real-time control, while an Ecological priority action would be to determine which parameters are to be monitored for environmental, social and economic impact assessment, and what tools (e.g., Life cycle analysis, multi-criteria assessment) are to be used to quantify these impacts, the circularity and the resilience. A priority action within the Business dimension could be to develop methods to effectively communicate the pros and cons in order to strengthen citizen support and engagement. In the Management dimension, match-making meetings could be organized to create initiatives on technological developments of hybrid solutions and demonstration projects.

Further growth on the implementation level, towards 'commercialisation', could be achieved by priority actions such as: Incentivize the peloton of water managers to make time for exploring and repeat testing new solutions and to learn from the experiences of the front runners. Demonstrate and quantify the costs, benefits and co-benefits of HGGI solutions in order to maximize ecosystemic benefits and minimize costs, spatial and other resource demands. And identify and remove legal and regulatory barriers keeping utilities or businesses from taking up new roles and responsibilities in urban water management.

Executive Summary

The audience of this white paper includes all stakeholder categories associated with water infrastructure, including policy developers in public and semi-public authorities, urban and landscape designers, construction companies, operation and maintenance staff, water utility owners and staff, asset managers, water and infrastructure researchers and students, European research funding authorities, investors and business analysts.

The present work aims to provide an overview of ***hybrid (grey-green) water infrastructure***, to inspire, inform, nudge and recommend, ambitioning to bridge the knowledge gap on green water infrastructure, raising awareness of their advantages and sustainable design in the community, and to stimulate the implementation of integrated grey-green and digital infrastructure, exploiting smart water technologies.

In order to address the impact of climate change and an aging water infrastructure, ambitious programmes are being initiated with the aim of improving the well-being of the growing population and responding to increasing societal demands. The pros and cons of grey and green water infrastructures are well known. However, the transition from grey to green infrastructure remains challenging, despite the benefits outlined in Water Europe's vision towards a Water-Smart Society, and the corresponding promotion by European and national policies. To overcome the implementation barriers, the concept of hybrid grey-green water infrastructure is proposed. Hybrid water infrastructure offers a resilient, sustainable, and reliable way of delivering water-related and other ecosystem services. However, more effort and greater collaboration is needed in the fields of technology, spatial development and governance, to enhance the integration of nature-based, blue-green solutions with solutions from traditional monitoring and control water technologies. The way to stimulate the development of hybrid infrastructure is to assess the developing technologies, using not only the Technology Readiness Level (TRL), but also an industrial Symbiosis Readiness Level (SRL). An SRL assessment will build trust in the market and guarantee more rapid implementation. Our joint TRL and SRL assessment of current hybrid infrastructure not only shows the level of immaturity it has today, it also gives direction to 'next step' actions to raise these levels. We have suggested the research advances required to make hybrid solutions 'take off'. R&D by a coalition of experts from the fields of water technology, green infrastructure and smart monitoring and control technology, as well as the establishment of relevant living labs for co-creating the solutions with stakeholders and demonstration sites, are necessary to provide success stories and lessons learned for the relevant stakeholders. At the same time, these living labs provide evidence on the achieved performance as monitored by Key Performance Indicators, and on the benefits and co-benefits of these solutions. Targeted investments in R&D and the inclusion of the technological subsidiary principle[1] in the regulatory framework are strongly recommended to facilitate this development.

The actions to be considered for research and innovation on hybrid infrastructure are organized in the four components of symbiosis readiness:

- Technology level: Integrate solutions from water technology in nature-based solutions and vice-versa; proof of concept validation in living labs.
- Ecology level: Assess benefits, co-benefits, reliability and sustainability; integrate hybrid solutions in surface and underground space while maximizing their added value.
- Management level: Match partners from the fields of water technology, green infrastructure and smart monitoring and control technology, in order to create innovative coalitions.
- Business level: Organize citizen and business engagement in the development, implementation and maintenance process; test the business model.

[1] IDefinitions of the technological subsidiarity principle, nature-based solutions and grey, green, natural and hybrid infrastructure can be found in Annex 1

Introduction

Objective

The objective of this white paper is to provide evidence that grey and green water infrastructures present a clear opportunity for improving water management by combining their joint benefits. The paper is intended to inspire, inform, nudge and recommend, ambitioning to bridge the gap between the 'green/nature-based water infrastructure community' and the 'grey water technology and infrastructure community'. It provides an overview of what ***hybrid*** grey and green/nature-based solutions are, shows their strong values, and outlines the priority steps to be taken, and the knowledge gaps that need to be filled, in order to accelerate the adoption of hybrid grey and green water infrastructure. The document is the product of a joint quest by Water Europe's Vision Leadership Team (VLT) Hybrid Grey and Green Infrastructure, and the Working Groups on Nature-based Solutions, Ecosystem Services and Water Distribution Infrastructure.

The target audience for this paper includes professionals working on the planning, design, construction and maintenance, management renewal and innovation of our water infrastructure; colleagues working on water technology as well as on blue-green, nature-based solutions, in particular those working on new, better solutions, aimed at solving the problems of today and tomorrow. It is also aimed at all those who steer and influence the related research and innovation programmes, at the level of the European Commission, national governments, utilities, businesses and investment funds.

Challenges faced by our existing water infrastructure

Europe formulated the Green Deal to create a sustainable society and a resource-efficient, competitive economy, while at the same time decarbonizing Europe, adapting the continent to climate change, cutting down pollution, strengthening environmental protection and enhancing biodiversity. It is seen as the way out of the climate crisis, mitigating sea-level rise and climate change, while empowering the European economy to become a global leader in related products and solutions. This ambition will have far-reaching effects on our work and even our lives.

Climate change will not only lead to extra water demand for nature, but also for agriculture and urban areas. Demand for drinking water and for irrigation water will increase, while water quality will be under pressure. Drought and groundwater extraction will enhance land subsidence. On the other hand, certain areas will be confronted with more and more intense rainfall events and hence with risk of flooding. And ongoing urbanization in Europe will aggravate these water problems.

The urgency to address these challenges increases with the aging of our existing infrastructure assets. The lifetime of many water infrastructure assets is coming to an end. In many places, the water supply and drainage networks, and flood protection facilities, date back to early last century. Their replacement requires decisions that will have an impact over many decades to come.

These traditional infrastructure assets are often referred to as **'grey'**, because of the concrete, steel and plastic that is used for reservoirs, pipes and other elements. To replace these is a challenge. New infrastructure has to meet new demands related to sustainability, resilience, circularity, while taking into account ongoing urbanization, densification, industrialization, digitalization, robotization, and climate change. New or renewed water infrastructures are expected to address several of these demands simultaneously. Investments in the water supply and sanitation sector have substantially improved utility performance (Saltiel, 2020), but the key question is: Are the distribution sectors and collection networks ready to deal with the expected changes in the coming decades? The water utilities tend to focus on a specific part of the urban water cycle – drinking water production and distribution and/or wastewater collection and treatment – while their involvement with other elements of the urban water system, such as stormwater runoff, urban surface water and urban groundwater, is generally limited. Europe is facing a decline in investments in its water infrastructure. For water and sanitation, investment needs are estimated at 160 billion Euros (Zachariadis, 2018). While much attention goes to transport and digital infrastructure, excellent infrastructure for water supply, drainage, treatment, and flood protection is a precondition for a flourishing European economy and society.

Services of grey solutions

Although traditional grey infrastructure is struggling to address present and upcoming challenges, the solutions it offers provides several benefits. Grey infrastructure systems are by design physical structures, long-lasting, and comprise engineered processes often controlled by digital systems. Grey infrastructure involves well-known practices regarding their design, construction, operation and maintenance. Their effectiveness and efficiency have been optimized over many decades; billions of Euros have been invested in water technology to achieve the best performance. Related infrastructure costs are well-documented and mastered. Grey systems are widely used by cities for various services (clean water, sanitation, stormwater management, etc.). Organizational structure, responsibilities and financing are well-organized; the regulatory framework, communication lines, knowledge and skills are available and operational. Over the last decades, these systems have proven their reliability and robustness. Indeed, engineered solutions inspire trust.

Garden of the Nutshuis, The Hague, the Netherlands

A transition to greener infrastructure

A fundamental shift is slowly taking place in urban drainage, water management and even in (drinking) water supply. Over the past 40 years, new solutions have been introduced, primarily to improve water quality and reduce peak runoff from the urban environment. Nature-based processes like retention, settling and infiltration are used to achieve these goals. Rather than using grey reservoirs, pipes and flood walls, Sustainable (urban) Drainage Systems (SuDS) are used to create low-impact development or water-sensitive urban design. ***Green, blue-green or nature-based*** solutions are other terms that are often used for these SuDS, as most of them are characterised by visible water and a diverse vegetation, thus providing many ecosystem services in addition to their drainage function (Raymond et al., 2017).

Terminology in this sector is still developing; only minor differences can be found between terms such as nature-based solutions, blue-green or green infrastructure, Sustainable (urban) Drainage Systems (SuDS), and the like (Fletcher et al., 2014). In this paper we also use the term ***green infrastructure*** for blue solutions like wetlands, ponds, bioswales, and ***grey-green infrastructure*** for hybrid solutions.

The European Commission promotes the use and integration of green infrastructure in other EU policy areas such as land use, water and the marine environment. In particular, the EU Biodiversity Strategy for 2030 aims to secure healthy, resilient, biodiversity-rich ecosystems that deliver the range of services essential to the prosperity and well-being of citizens as a pivotal part of the European Green Deal. Nature-based Solutions – with healthy and biodiverse ecosystems at their core – are central to achieving the objectives of this strategy and sustainably tackling wider societal, economic and environmental challenges. Nevertheless, the Biodiversity and Nature-based Solutions Report (European Commission, 2020a) points to research gaps; for example, concerning the costs and multiple benefits generated by different types and scales of Nature Based Solutions (NBS) and hybrid solutions (combining grey and natural elements) which are aimed at protecting biodiversity as a primary objective, or concerning ways of improving and streamlining the approaches and indicators for measuring these contributions to biodiversity and other objectives.

Water Europe's Vision, 'The Value of Water' (Water Europe, 2017), indicates that a rethinking and redesigning of water distribution and water service systems into a high-tech, human-built water infrastructure, integrated into a nature-based ecosystem, is the way forward to achieve a 'Water-Smart Society'. This combines centralised and decentralised water treatments, leading to reduced water loss, increased water reuse, optimised exploitation of alternative water sources in a circular economy, and strengthened resilience against climate change events, especially droughts and floods.

Green infrastructures are generally appreciated by the public because of the many services and co-benefits they deliver, their use of natural materials and their zero/low energy demand – that is, for their positive sustainability character. Some of these solutions even harvest water or thermal energy, contributing to the circularity of these resources and the reduction of demand for precious drinking water. Developers of green infrastructures are still improving their expertise on the detailed design, vegetation types and maintenance strategies, to provide the best performance under the local conditions at hand.

The visual attractiveness and proven performance of green infrastructures, in terms of water retention and water quality improvement, have prompted urban drainage practice to start shifting from grey to (blue-)green. Some municipalities have started implementing these solutions on a wide scale, while others have been more reluctant. The reasons for this reluctance are manifold. Some do not trust the infrastructures' reliability, such as their performance under different weather conditions, e.g., extreme cold, snow, drought, or with different kinds of vegetation. Others are uncertain about how to construct or operate and maintain these facilities properly – guidelines, regulations and policies are often immature (Vollaers et al., 2021). Questions arise, such as: Who is to fund these solutions and who is responsible? Despite scientific evidence of their benefits in terms of health, biodiversity, quality of streetscape, property value and so on, some stakeholders see problems with equity and justice. What is a fair distribution of the costs and benefits?

The result of these developments in both grey and green infrastructure is a very diverse mix of solutions. Some areas use grey solutions, while others resort to blue-green ones. But **hybrid** solutions, using both blue-green and grey technologies, are rare.

Services of green infrastructures

Green infrastructure (nature-based solutions) is often presented as the better alternatives to grey solutions, competing in terms of cost effectiveness and biodiversity impact (European Commission, 2020). Statements like ***'integrated valuations of NBS for water purification and flood protection show they can outperform grey infrastructure alternatives'*** are not uncommon (Liquete et al. 2016 in European Commission, 2020b). Additionally, green infrastructure solutions often originate or are closely linked to ecosystems and the services they provide for human well-being. Ecosystem services can be defined as the benefits people obtain from ecosystems (Millennium Ecosystem Assessment, 2005).

Ecosystem services are typically classified as either being 'provisioning', 'regulating' or 'cultural' services (European Environment Agency, 2020; Millennium Ecosystem Assessment, 2005). These services significantly contribute to both ecological and human well-being, as illustrated in Figure 1 below.

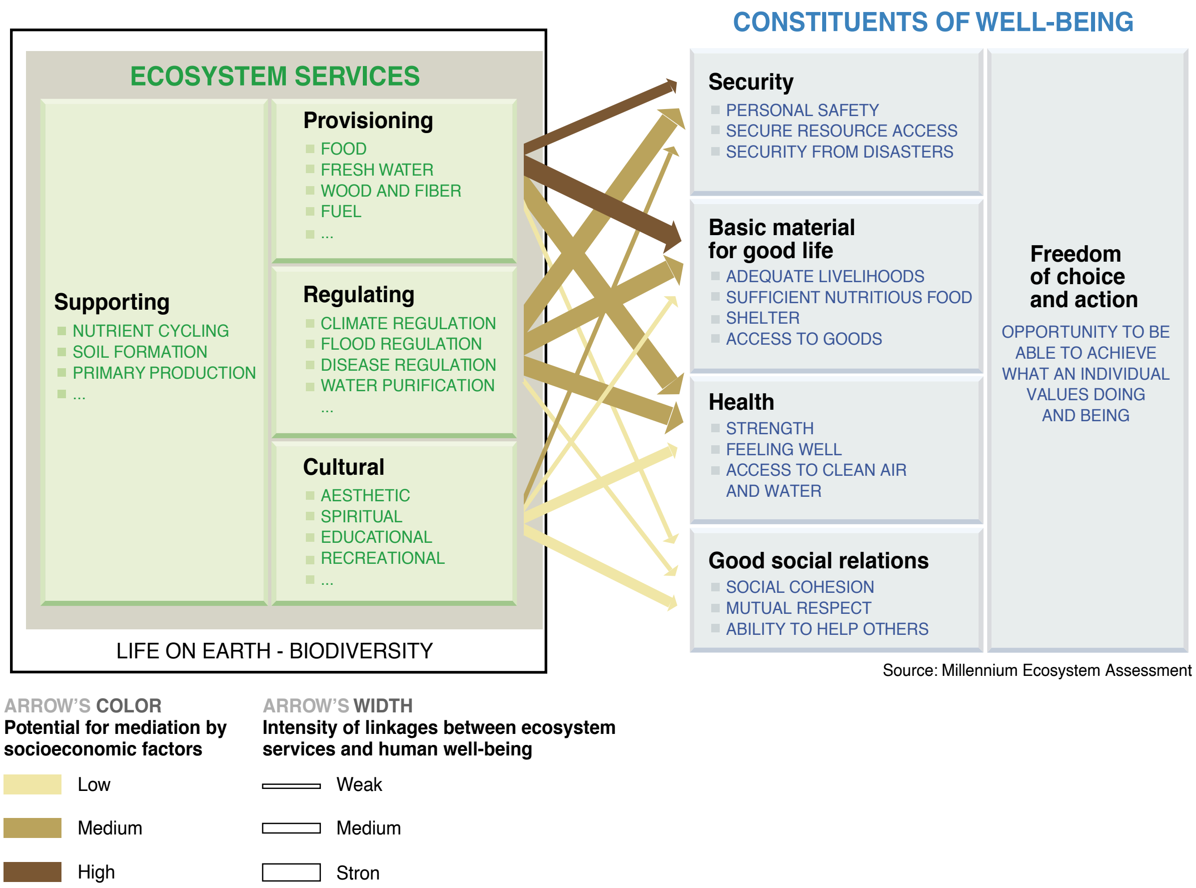


Figure 1. Relationship between ecosystem services and human well-being (Millennium Ecosystem Assessment, 2005).

Ecosystem services provided by green infrastructure not only relate to water treatment and water regulation, such as the timing and magnitude of flood runoff (Millennium Ecosystem Assessment, 2005), but also to the legibility of the landscape, the identity of an urban environment, the connectivity in the ecological network, to food production in urban agriculture, to social cohesion, physical and mental wellbeing, and so on. Green infrastructure allows nature and natural features and processes into urban and rural areas, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions, and provides cost-effective solutions. It simultaneously provides environmental, social and economic resilience (Wild et al. 2017; European Commission, 2020a; IUCN, 2020; Dumitru and Wendling, 2021).

Green infrastructure however also has its limitations. For example, its performance depends on the climatic/weather conditions. Biodegradation of pollution slows as temperature drops; and drought can damage the vegetation and affect the infrastructure's performance. Green infrastructure also requires space – above-ground or subsurface – in urban environments where space is scarce. Moreover, the introduction of green infrastructure often requires new arrangements within or between organizations for the monitoring, maintenance and financing of these structures, as well as new knowledge and skills for those who have to design, construct and take care of them.

Hybrid Grey and Green Infrastructure

Hybrid water infrastructure

Hybrid grey-green water infrastructure is defined here as a ***combination of grey***, ***smart*** and ***green*** infrastructures, aimed at producing (climate) resilient water systems, reliably controlling peak flows and/or delivering clean water, sustaining environmental flows, and providing ecosystem, economic and social services.

This definition of hybrid grey and green water infrastructure builds on the those given by Brockbank et al. (2017) and Naylor et al. (2017), as quoted in the Annex, but adds 'smart' as a component. This addition is made because a more sustainable, effective and resilient water management can be achieved by combining the strengths of grey and green solutions with smart control, in the form of artificial intelligence for instance.

Examples of hybrid water management solutions

As hybrid solutions are yet to be developed, their examples obviously remain rare and incomplete. Nevertheless, some cases can be found that integrate grey, green and smart technologies, with the aim of improving a facility's performance and services. An example of a hybrid solution is managed aquifer recharge, which takes advantage of the provisioning service of groundwater. This infrastructure exploits natural purification processes, enhancing the groundwater provision and benefiting future human consumption (Dillon et al., 2020). In other examples, the Puridrain enhances the natural purification process by modifying the soil around subsurface drains, while the Polderroof reduces peak flows from roof surfaces by temporarily retaining water.

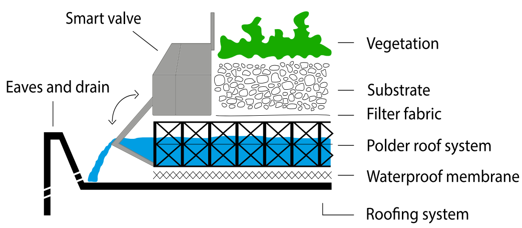
Examples of hybrid urban water management solutions:

- Polderroof is a green roof concept with a smartly controlled outlet, in which water is retained on the roof for periods of drought and to reduce peak flows.
- Puridrain involves the removal of phosphate by electro-coagulation and the addition of wood chips to a filter; nitrate is captured, avoiding eutrophication problems downstream.
- Constructed wetlands for wastewater treatment effluent polishing.
- Urban Water Buffer, Spangen. Stormwater runoff is treated in a biofiltration cell, stored in an aquifer and then used to irrigate a soccer field.
- Bioretention systems for stormwater treatment and retention.
- Smartly controlled combination of nature-based solutions for integrated urban drainage (green roof, permeable pavement and stormwater filter), at the Urban Hydraulic Park experimental site of the Hydraulics and Hydrology Laboratory of the University of Calabria in Rende, Italy (Pearlmutter et al., 2019).

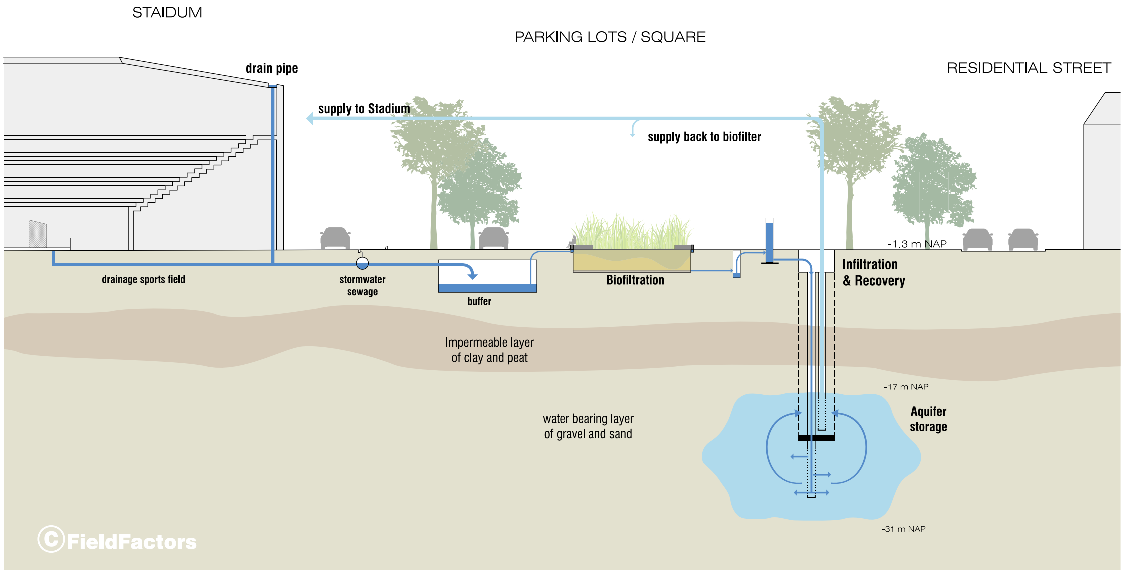
Puridrain N and P removal

Polderroof; green roof with controlled discharge

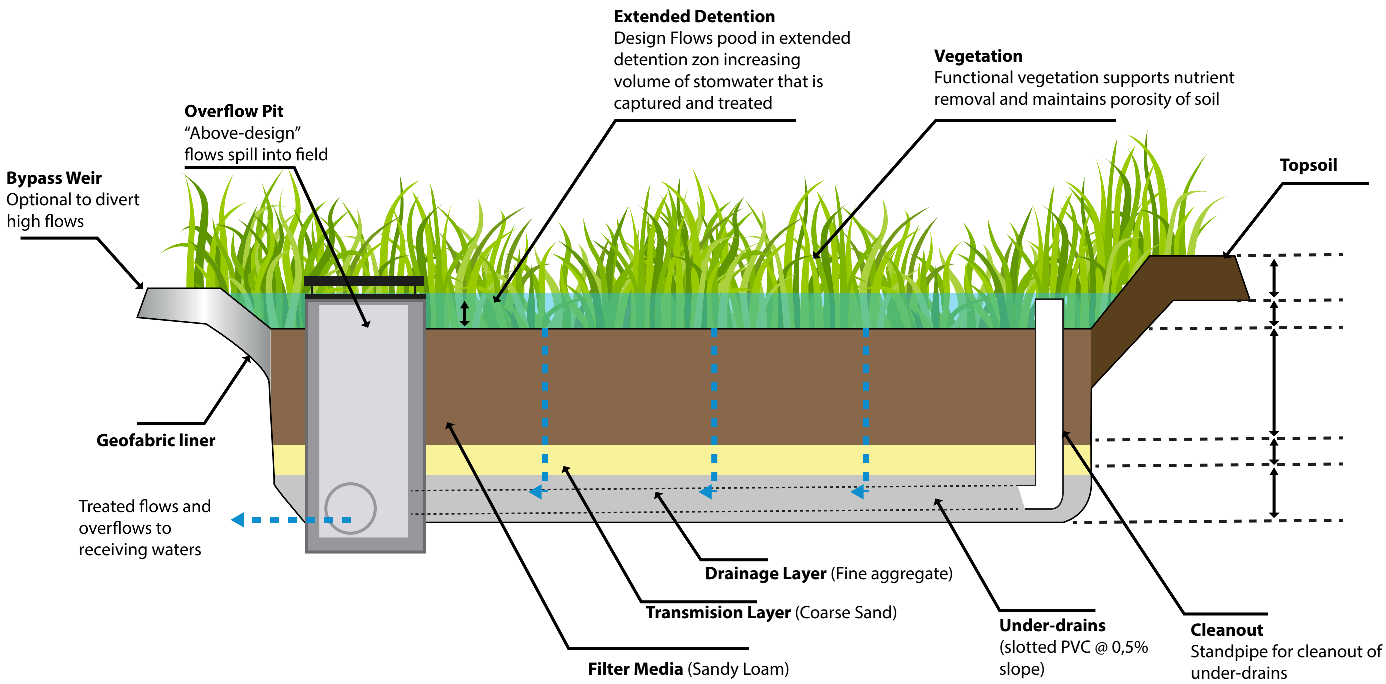
Wetland and lake restoration.
Nanobubbles, ozone, H-peroxide



Cross-section of the polderroof with control-gate



Urban Water Buffer, Spangen



Bioretention system

Benefits of hybrid water management solutions

Hybrid, grey-green approaches utilize combined grey and green infrastructure features as presented in Table 1. Hybrid solutions can therefore provide a whole range of water management services, from water provision to flood protection, from drought resilience and heat-stress reduction to ecological health and urban liveability, from land subsidence reduction to urban landscaping, creating landmarks and recreational and educational purposes. Reducing monofunctional land use, risks and costs is combined with maximizing benefits. The incorporation of green infrastructure creates new technical options for service delivery to complement, substitute, or safeguard grey infrastructure.

As shown in Table 1, hybrid systems strategically integrate the best of both grey and green solutions to provide services and thus fulfil sustainable development goals. Design of hybrid systems offers opportunities to technology developers and service providers to target different contaminants for challenging sites. As they combine the features of grey and green infrastructure, hybrid systems have the potential to provide water, food, and energy to growing populations, lift communities out of poverty, and strengthen public health (European Commission, 2020a; IUCN, 2020; Dumitru and Wendling, 2021).

Grey	Hybrid systems and approaches	Blue-Green
Engineered systems made of long-lasting materials.	Mix of engineered and green, nature-based solutions.	Biophysical systems, ecosystems and their services.
Poor ecosystems functions.	Nature and natural ecosystems features are mediated by engineered systems.	Ecosystems functions and water bodies are essential.
Conventional infrastructures such as: pipes, stormwater pipes and tunnels, reservoirs, water and wastewater treatment plants.	Include solutions, when applicable, such as: smart green roofs, rainwater use facilities, spongy porous pavements, bioswales+, bioretention+, enhanced constructed wetlands.	Systems such as: green roofs, trees, vegetation, wetlands, rain barrel, ponds, canals, lakes, rivers.

Table 1. Grey, blue-green and hybrid system features (adapted from Depietri & McPhearson, 2017 and Grimm et al. 2016).

Highlighting grey and green infrastructure from the perspective of the ecosystem service concept, indicates that the smart coupling of grey water infrastructure with green urban infrastructure offers a high potential to increase human well-being: conventional sewer-based drainage and wastewater systems, combined with infrastructure to increase decentralised infiltration and evapotranspiration, create sustainable urban drainage designs; measures like de-paving, rain gardens, tree-trenches, vegetated intensive roofs and others, embedded and linked to urban ecosystems like (restored) river courses and interlinked with biodiversity hotspots, such as parks with new avenue trees. This is vital for the rapidly growing urban communities worldwide and presents a conceptual challenge for the retrofitting of existing urban areas that have aging water infrastructure. Climate change adds to the risk of insufficient urban water infrastructure capacity, calling for new ways of urban water management, under the umbrella of hybrid grey-green infrastructure concepts embedded in urban ecosystems. Smart city planning may generate true social benefits in this regard, by retrofitting city quarters that have low quality of life, for example, due to dense population, high levels of concrete/pavements, little decentralised water use, low urban green, channelized urban streams, or a high percentage of combined sewers.

The demand from society for more sustainable, healthy and attractive solutions to enhance the well-being of urban dwellers drives the social willingness to accept new solutions, as long as the direct interests of persons, businesses and nature are protected. This receptivity of large parts of the population to green solutions creates a window of opportunity for researchers and innovative businesses to test new solutions. The time to test, improve and demonstrate hybrid solutions has come, so that the benefits of integrating blue-green, grey and smart technologies can be evaluated, improved and demonstrated. Society as a whole will become interested in applying ***hybrid*** solutions only if we can put convincing practical examples and positive business cases in the spotlights.

Three dimensions of hybrid infrastructure implementation challenge

By implementing hybrid grey-green water infrastructure one can combine the advantages of both these segments, but the challenges involved must also be considered. These include aspects such as the technological, spatial and governance (including the economic and social) dimensions of implementation (Sugano and Lu, 2019).

Technological dimension

In order to sustainably achieve a continuous, reliable performance as a water resource and ecosystem services provider, in terms of water quantity and quality, hybrid grey and green water infrastructure makes use of natural subsurface processes, plants and (micro-)organisms, in combination with technological solutions, grey materials, and smart monitoring and control.

Numerous developments are taking place in green infrastructure solutions. Designs, construction and maintenance of these solutions is being improved and standardized, based on research results and lessons learned from their application in practice all over the world. Meanwhile, new water treatment methods are being developed and introduced in water technology (e.g., SHARON®, Anammox®, Nereda®, Crystalactor®) and water resources management (e.g., MAR, ATES), combined with smart monitoring and controllers.

Digital innovation and transition are providing new solutions, such as artificial intelligence (AI) and digital twin technologies, which offer a new vision of the water system and build bridges between grey and green expertise for the optimal management of complex systems. To improve the understanding of grey/green infrastructures and their interaction, equation-based models are being created, with solutions based on big data and AI producing complementary insights. A new generation of such software is being developed for water system modelling, or for planning, design and construction support (e.g., HYETOS, Delft3D, Adaptation Support Toolbox, XPSite3D, Serious Games) (Aubert et al., 2018).

However, these developments are for the most part taking place in separated silos. Combinations of the grey, green and smart fields of expertise are rare. The two communities seem to be working in different worlds. Green infrastructure often makes use of the soil and subsurface to host treatment and storage processes, while conventional water technologies seem to rely more on surface waters and constructed systems such as water tanks, piped systems and treatment plants.

Although circularity is topical in both communities as a way to realize sustainable solutions, it is approached differently. Green infrastructure tries to make use of circular materials and resources, while water technology focuses on producing products that can be (re)used, thus avoiding waste generation.

Spatial dimension

Striking differences between the two communities also occur in the spatial dimension. While green infrastructure is scattered and embedded in the urban landscape, grey infrastructure tends to be invisible, underground, behind fences and gates or in inaccessible buildings, and located at the fringe or outside of the urban environment. Green infrastructure however requires space, is located *within* the urban environment, and tends to be much more multi-functional. Green infrastructures can vitalize degraded and underused urban spaces by introducing new functionality (Breuste et al., 2015; Dagenais et al., 2016). Grey water infrastructure is often limited to large central facilities and networks for water supply or sanitation. Hybridity, for its part, has a much wider meaning, encompassing blue, grey, green and smart solutions at all spatial scales.

Infrastructure ought to contribute to the properties of the urban landscape, namely: legibility, connectivity and visibility. Legibility means that people can recognize the coherence and role of elements in a (water) system, elements that should help them recognize 'where they are'. The elements should contribute to the 'sense of place'. Connectivity refers to the interconnectedness of the elements which should be visible to the observer. This connectivity concerns the water infrastructure, but also the green and red (building) elements in the urban environment. The current grey infrastructure is often not seen to contribute to the quality of the urban landscape, while this functionality is key to green infrastructures.

Governance dimension

The governance regimes under which grey and green infrastructures are developed are very different. The regulatory framework for utilities responsible for water supply, drainage and treatment cannot be compared to that applied to green infrastructure, nor can the ownership and management profiles. From a historical perspective, water supply, wastewater treatment, stormwater drainage, flood/drought protection and spatial planning have developed more or less independently, resulting in separate legal, financial and institutional settings (Van der Woud, 2010). These different governance contexts create important barriers to the development and implementation of ***hybrid*** grey and green infrastructure, namely:

- Solutions from the green infrastructure community are unknown to the community of water technology developers, and vice versa; and smart control and related monitoring technology is relatively new to the sector, in particular in green infrastructure solutions. Increasing awareness and establishing relations for the sake of knowledge exchange would constitute important first steps towards enhancing receptivity to novel solutions.
- Existing standards and regulations prevent the authorisation of other solutions.
- The know-how for the design and implementation of hybrid solutions is missing.
- The capacity to operate and maintain the hybrid system is not there (yet).
- The existing organizational and financing structure hinders making budgets and capacity available at the right place at the right time.

Other relevant governance issues in the application of hybrid solutions are the societal implications, such as inclusiveness, equity and justice (Toxopeus et al., 2020). How fair is it to invest public money in solutions that only the residents of one district can enjoy? Are these hybrid solutions gender-age- ethnicity-neutral? What is their effect on marginalized or vulnerable groups? Are there any cultural, social or educational co-benefits?

Financing is a crucial part of governance. Financing the implementation and maintenance of hybrid solutions depends on the infrastructure's owner and on the beneficiaries. Decision making on the use of specific solutions depends on the financial structure of each stakeholder and the legal context. The business model of a homeowner or private company is quite a different matter than the financial strategies of public organizations. Justice requires a fair distribution of the costs among those who benefit, but existing organizational and financial structures and regulations can be obstacles in making the best choice for the residents and the environment. For example, regulations can hinder spending public money on solutions built on private property, such as smart green roofs, raingardens or bioswales. Or sewerage fees cannot be used to cover the costs of maintenance of green infrastructure. And the costs of disconnecting paved surfaces from the sewer system often land in the lap of the municipality, while the benefits go to the water authority that is responsible for wastewater treatment and the local and regional surface water quality.

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How to develop hybrid grey-green infrastructure

Industrial symbiosis

In order to develop new, hybrid grey-green infrastructure solutions and to realize their implementation, an ***industrial symbiosis*** has to be created (European Commission, 2020b). Businesses, knowledge institutions, government and civil society organizations, need to cooperate closely to achieve synergy. Symbiosis not only allows for the development of innovative solutions, it has the power to create testbeds, pilot applications, demonstration sites, and to change standards and regulations, and reorganize governance and financing. However, an effective symbiosis is unfortunately not easy to achieve. Businesses, knowledge institutions, government and civil society organizations are highly diverse. Government ranges from local to European, business from industrial manufacturers to insurance companies. Utilities are often owned or partially owned by government, but are run as non-profit organizations. Knowledge institutions range from academic to applied science and civil society organizations, and include a multitude of non-governmental organizations (NGOs), associations, groups and networks, each with its own objectives, stakes and priorities.

The organization of industrial symbiosis therefore constitutes a major challenge, but it remains the only way to develop new technologies and successfully introduce them in society. The measure normally used in this context is the Technology Readiness Level (TRL). However, a high TRL alone is no guarantee for a successful implementation. A high score in the Symbiosis Readiness Level (SRL), is a better guarantee (Sommer, 2019). The SRL table is presented in Figure 2 alongside the TRLs. Hybrid grey-green infrastructure needs to climb both the technology and symbiosis readiness ladders.

Symbiosis readiness level	Technology	Business	Ecology	Management
9	Commercialisation	Business case continuously controlled, reported and shared	Sustainability benefits proven	Resilient partnership
8	Extended operation	Finalise legal framework	Benefits routinely monitored and reported	Practical operation and management starts
7	Demonstration	Partners committed	Monitoring and reporting begins	Senior management is involved and supports industrial symbiosis case
6	Prototype demonstration 'looks like'	Business case with all details	Permits applied for	Concept for joint management is developed
5	Breadboard demonstration 'acts like'	Evaluate competitiveness	Sustainability assessment finalised	Partners start joint evaluation of industrial symbiosis. potential
4	Proof of concept validation	Check resources and criteria	Sustainability assessment in progress	Partners indicate interest
3	Proof of concept research (bench scale)	Check fit with strategies of partners	Thorough data collection	First contact with partners
2	Academic research	Develop concept	Rough estimate	Potential partners (*) identified
1	Initial ideas			

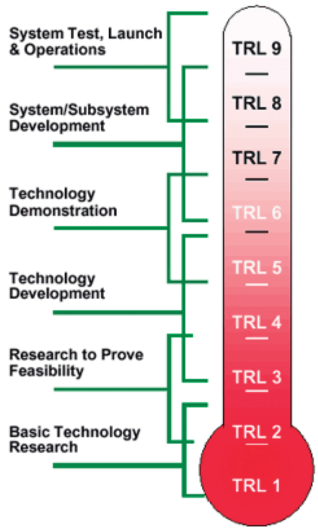

Figure 2. (a) Symbiosis Readiness Levels and their technological and organizational characteristics (Sommer, 2019). The term 'Breadboard demonstration' (SLR5), in our context, is to be read as experimenting in pilot test sites in living labs. (b) Technology Readiness Levels (TRLs) (Wikipedia).

The four SRL components of Technology, Business, Ecology and Management show a strong relation with the three dimensions of hybridity, namely, the technological, spatial and governance dimensions. Technology is evidently a shared element, while Ecology is related to hybridity's spatial dimension, and Management to its governance dimension. New in the SRL are the business levels, as these are related to the alliances between partners and between producers and clients/society. This combination of aspects makes the SRL ladder a suitable evaluation framework for the assessment of the synergy that is required to develop and bring hybrid solutions to the market. Building on this assessment, next steps can be defined to stimulate their progress.

Given that the communities of water technology, green infrastructure and smart monitoring and control technology are not yet allied, we consider the SRL levels for hybrid grey and green infrastructure to be 1-2 rather than 3, because potential partners are as yet not eagerly interested and proofs of concept in various contexts are barely available. Partnerships need to be created between different types of businesses and knowledge institutions, aimed at product development and at creating the spatial and governance bases for these new solutions – from testbed to wide-scale application. Governments and civil society organizations can stimulate partnership creation through match-making, subsidies, promotional and image-building activities and other means.

Providing grants, subsidies and targeted investments in hybrid solutions is anticipated or assumed to be attractive for governments, because of the substantial social and ecological benefits they create. Such public investments can moreover be leveraged by cost sharing, pooling investment across project beneficiaries, issuing green bonds for green infrastructure, and engaging insurance companies (Browder et al., 2019). Moreover, governments are in the unique position to require such innovative solutions in their legislation, regulations, spatial planning and contracting, and to become launching customers.

The initiative for innovations in technology normally rests with businesses and knowledge providers. Development of hybrid grey-green infrastructure is therefore first of all a responsibility of the communities of water technology, green infrastructure and monitoring and control technology. The three have to join forces, develop technologies and become providers of these hybrid technologies and related services. In particular, they have to invest in the expertise and capacities needed to develop, deploy, implement, operate and maintain this next generation infrastructure solutions.

Match-making between the communities of water technology, green infrastructure and smart monitoring and control technology will need strong stimulation from other parties, such as governments and civil society organizations. The cultural differences between the grey, the green and the smart communities are substantial. Whereas ecological recovery and growing a balanced and biodiverse ecosystem can take a decade or more, industrial process adaptations – and their required return on investment – are characterized by time horizons in the order of 2-5 years. While water utilities and the related industry are accustomed to deploying technologies in closed compounds, the designers and implementers of green solutions are used to working at the heart of the city, exposed to its residents; stakeholder engagement and community buy-in are key to the success of their projects. Parties like governments and civil society organizations can nevertheless help bring these communities together, initiate their dialogue and bridge their cultural gaps.

Water utilities, related business partners, universities and other knowledge developers can advance the market for hybrid grey-green infrastructure in this early stage of innovation by investing in knowledge in three ways. First, they can build capacity with their own organizations to understand the potential of grey-green infrastructure solutions. Next, they can utilize grey-green assessment tools and approaches in their internal processes. Finally, they can help overcome knowledge gaps that are barriers to scaling up such infrastructure, by investing in performance monitoring and in widely communicating results and real-world experience (Browder et al., 2019). This can best be achieved in coalitions with a clear long-term research and development agenda.

Research and development needs

A shared R&D agenda for the partners is essential in order to raise the SLR level from 1-2 to 8-9. The collaborative development of this agenda is one of the first things that needs to be done.

New ideas for hybrid solutions can emerge from collaborative development teams through co-creative workshops. The key objective of these workshops would be to merge the rationale for the application of either grey or green into a single integrated urban water management system. Resulting ideas and designs would then be tested, first in the lab and then in the field, to determine their effectiveness and how they might be operationalized.

To date, available tools for training and design have been focused either on grey infrastructure or on green infrastructure. There is therefore a need for hybrid tools, for purposes of design, maintenance or rehabilitation. The development of such training and design support tools can build on the extensive experience of designing grey and green infrastructure services.

Demonstration sites are key to building confidence and demonstrating the benefits of hybrid solutions. Fortunately, many municipalities, utilities and water organizations are willing to test innovative solutions and share their experience, thereby providing opportunities to learn from each other. Green infrastructure facilities require a time scale of 2 years to become mature and fully deliver their potential, so such living lab sites should be developed for a period of many years. Benchmarking of pilot projects through Europe and creating a community of practice to share lessons learned are necessary to raise both the TRL and symbiosis level. By 2030, hybrid grey-green infrastructure should no longer be seen as pilots or demonstrations: they should constitute the new standard.

Monitoring remains a key to unlocking and demonstrating the potential of these technologies. Given the wide range of services delivered, the first step is to develop indicators, protocols and means/technologies to efficiently measure the overall performance of such hybrid systems, and not only the 'water' related services. Monitoring challenges are related to the complexity of the natural environment and to the long-time scales needed for performance evaluations, which integrate seasonal and climate variations, and the evolution of soil physical/biological/chemical characteristics. Observations should lead to a transdisciplinary performance assessment, involving costs and benefits, both for the city and its dwellers, and for the natural environment. Shifting from centralised grey systems to a hybrid combination of centralised and decentralised systems requires a new monitoring strategy, in order to decrease the costs and to increase EU benchmarking quality. Benchmarking is based on an efficient monitoring framework, shared among stakeholders and countries. Monitoring is also required to support the long-term operation, management and maintenance of hybrid grey-green infrastructures, in order to target accurately the actions needed.

Reflections on action priorities

Our environment, in particular the built environment, is in fact already a hybrid system in which grey water technologies support natural processes, but in a compartmentalized and unintentional way. Our challenge is to create hybrid solutions that truly integrate grey, green and smart technologies. The key question is how to optimize the synergy between green infrastructure, water technology and artificial intelligence, and monitoring and control technology, to make the water systems as a whole perform better. How can we optimize the operation and maintenance of hybrid infrastructure, in a context of seasonal and climate fluctuations, in order to maintain performance and extend lifespan? How can we maximize the added values of these systems, while minimizing their energy demand and waste flows? And what type of optimization is required to maximize their benefits while minimizing costs, resources use and (fossil)energy consumption?

Where do we start delivering? Action priorities

Investments are needed in research and innovation in the field of hybrid grey-green infrastructure. These investments should target the development of technologies, tools and methods, to increase their TRL, as well as match-making initiatives between experts in a range of disciplines, companies in the field of green infrastructure design and construction, water technology, monitoring technology, artificial intelligence and control technology, to increase their SRL. Symbiosis business models need to be developed and operationalized in practice. Entrepreneurship in this field has to be stimulated. More specifically:

- Living labs need to be identified and budget made available for the implementation and monitoring/evaluation of new hybrid solutions, as well as for communicating the results. Living labs are an effective way to experiment, demonstrate and promote hybrid grey-green infrastructure solutions. The labs also provide powerful communication tools for decision makers and investors.
- 'Learning by doing' and 'sharing lessons learned' are essential in such a complex innovation process. Testing, repeating, demonstrating and communicating through different media to different audiences – including the general public – are needed to inspire end-users and to overcome implementation barriers.
- Transparency in performance is essential to build trust in new technologies; performance assessment therefore needs to be made mandatory. An assessment framework needs to be developed for evaluating the performance of hybrid grey-green infrastructure.
- Inclusion of a 'technological subsidiarity principle[2]' in the legal and regulatory framework around urban water management is recommended. This principle states that: only if green infrastructure facilities cannot provide sufficient and continuous reliability of the required water system services, grey solutions can be added to – and preferably integrated with – the green ones, to provide a sufficient water quantity and quality for all the functions that are to be sustained.

Actions to realize the above need to be formulated.

[2] See Annex 1 for definitions

Potential actions on Research and Innovation

In order to define the necessary steps for closing the research and innovation gaps, the structure of the SRL ladder will be used, combined with the related TRL levels. So far, only a few examples of hybrid solutions have been developed and tested, so practice is currently more or less at SRL 1-2 and TRL 1-2. In order to reach SRL 4 (with TRL 4-5), research and innovation activities need to be undertaken, or at least stimulated in the four SRL components.

Technology level: proof of concept validation

- Integration of grey and green infrastructure and smart technology for adaptable and resilient solutions and improved performance.
- Use artificial intelligence, real-time control and related monitoring techniques to improve the performance of green infrastructure solutions.

Business level: check resources and criteria

- Interactions of the hybrid water solutions with energy, food and nutrients (the WENF nexus), as well as with land, labour and capital, need to be studied and developed as a market opportunity.
- Citizen support and engagement is essential, in particular for implementing decentralised grey-green infrastructure. Methods are needed to effectively communicate the pros and cons, do's and don'ts of the solution; effective community (social) learning procedures to this end are to be developed and tested.

Ecology level: sustainability assessment in progress

- Integration of the hybrid solutions in surface space and underground space is an essential point of research, as solutions are to be developed both for dense urban environments and for low-density, peri-urban and rural environments.
- Quantifying the benefits and co-benefits of hybrid solutions requires a truly multi- and interdisciplinary approach, as the nature of these benefits is extremely diverse – including physical, health, economic, ecological, social, psychological and other effects. This new way of assessing the benefits will also allow us to enrich our views on the value of water.
- Monitoring performance is a separate challenge. How to set up a monitoring network and collect data in such a way that the effects are reliably observed? Which parameters are to be monitored for environmental, social and economic impact assessment? What tools (e.g., Life cycle analysis, multi-criteria assessment) can be used to quantify these impacts, the circularity and resilience?
- Space for experiments is to be created, though with keen eye on people's safety and the protection of rare species and ecosystems.

Management level: partners show interest

- As a first step, match-making meetings are to be organized to create initiatives on technological developments of hybrid solutions. Cases provided by potential clients could be used to trigger development of hybrid grey-green infrastructure solutions.
- Investigate institutional, governance and spatial barriers for the implementation of hybrid grey-green infrastructure; develop adaptation policy pathways to overcome such barriers.
- The question of how best to incentivize development of hybrid solutions at the European, national and local level is a research topic of its own. Legal, financial and communicative instruments are to be explored and used to the most effective mix.
- A research and innovation budget is to be made available at the European and national level to stimulate initiatives and explore opportunities in the field of hybrid grey-green infrastructure development.
- Set standards and principles at European and national level demanding grey-green infrastructure.

To achieve SRL8-9 the following activities are to be stimulated or engaged in:

Technology level: Commercialisation

- Maintenance and operation practices for hybrid grey-green infrastructure are to be developed and optimized to guarantee the long-term performance of these assets.
- Incentivize front runners in the EU to share their experiences, so that others can learn from the lessons they have learned.
- Incentivize the peloton of water managers to make time for the exploration and repeat testing of new solutions, and to learn from the experiences of the front runners.

Business level: Business case controlled and shared

- Demonstrate and quantify the costs, benefits and co-benefits generated by different types and scales of green and hybrid infrastructure. How can the approaches and indicators for measuring these contributions towards ecosystem services, biodiversity and other objectives be improved and streamlined (European Commission, 2020)? And how does this performance compare to that of traditional grey solutions?
- Fair cost-sharing and financing mechanisms are to be developed and tested for the new technologies
- How to set up a monitoring network and collect data in such a way that the effects are reliably observed? Assessment of the environmental, social and economic performance, life cycle analysis
- Hybrid solutions could benefit from a new organizational and financing structure for urban water management. Develop business cases and test these in practice

Ecology level: Sustainability benefits proven

- Maintenance and operation practices are to be developed toward differentiated management of green spaces in order to maximize ecosystemic benefits and minimize costs, spatial and other resource demands.
- Assessment of environmental, economic and social benefits through case studies. Impacts on ecosystems, reduction of emissions, minimisation of costs, job creation, social acceptance among other potential benefits need to be demonstrated.

Management level: Resilient partnerships

- Interactions of the hybrid water solutions with energy, food and nutrients (the WENF nexus) as well as with land, labour and capital need to be studied and further optimized.
- Citizen support and engagement is essential for implementing decentralised grey-green infrastructure. Methods are needed to effectively communicate the pros and cons, do's and don'ts of the solution; effective community (social) learning procedures to this end are to be implemented.
- Legal and regulatory barriers hindering implementation of the solutions, or keeping utilities or businesses from taking up new roles and responsibilities in urban water management, are to be identified and removed.
- Pathways to a new organizational structure are to be developed. Management responsibilities are currently siloed in different organizations, each taking care of a specific element, sometimes privately organized and sometimes part of the public organizational structure.

Conclusions

Green infrastructure (nature-based solutions) is often presented as the better alternatives to grey solutions, competing in terms of cost effectiveness and biodiversity impact (European Commission, 2020). Statements like ***'integrated valuations of NBS for water purification and flood protection show they can outperform grey infrastructure alternatives'*** are not uncommon (Liquete et al. 2016 in European Commission, 2020b). And grey infrastructure for water management and water supply is under pressure, despite their good performance and track-record. Aging, climate change, ongoing urbanization, new demands from society and poor adaptability create a demand for their often monofunctional, centralized, invisible services. Hybrid solutions of grey and green infrastructure can provide an attractive alternative.

- Hybrid solutions do better since they outperform the green and the grey technologies integrated in the solution: water availability and quality can be improved, urban water circularity enhanced, and more economic, social and ecosystem services can be provided. Moreover, the resilience of our (urban) environment can be strengthened by combining the power of green infrastructure with smart monitoring and control systems and water technologies.
- Hybrid solutions can be centralised and decentralised. A combination of centralised and decentralised elements for water supply, drainage and treatment of polluted water seems most attractive; an appropriate mix depends on many different local factors.
- Hybrid solutions bring a more multifunctional and adaptable use of space by providing climate resilience and improving water quality; this is an answer to the social demand for sustainable solutions and an attractive, healthy and liveable environment in which to live and work.
- Investing in hybrid solutions seems attractive for investors, governments and NGOs; they can become launching customers of attractive innovative solutions, to emphasize their green credentials and to build public support.
- Harvesting these benefits requires new roles for the existing players in the field of (urban) drainage and water management, such as utilities for water supply and wastewater treatment, but also for urban planners, project developers, builders and others. New organizational and financial arrangements are needed to facilitate implementation.
- Implementation of hybrid solutions requires new spatial and governance arrangements. Existing policies and regulations can hinder implementation; capacity and skills development is essential for the appropriate installation, operation and maintenance of these systems. The use of the hybrid facilities sets requirements for accessibility, connectivity and legibility.
- Development of hybrid solutions is a complex innovation process, in which 'learning by doing' and 'learning from others' are essential strategies. Testing, repeating, demonstrating and communicating through different media to different audiences are needed to inspire end-users and to overcome implementation barriers.
- Europe has a strong position in both water technology and in green infrastructure. Hybrid, smart infrastructure solutions are however rare. Developments of these hybrid solutions will open new global markets for European industries. But local changes are needed to open global opportunities. By introducing a Technological Subsidiarity principle, Europe could stimulate its internal market to produce, widely apply and benefit from its ***hybrid*** grey and green infrastructure solutions.

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New water treatment and water resources management technologies mentioned in this white paper as examples:

SHARON®,	Single reactor system for High activity Ammonium Removal Over Nitrite https://en.wikipedia.org/wiki/SHARON_Wastewater_Treatment
Anammox®,	Anaerobic Ammonium Oxidation https://en.wikipedia.org/wiki/Anammox
Nereda®,	Innovative biological wastewater treatment technology https://en.wikipedia.org/wiki/Nereda
Crystalactor®	fluidized bed crystallization reactor for drinking water and waste water treatment https://iwaponline.com/ebooks/book/725/chapter-abstract/1378527/The-CrystalactorR-at-the-WWTP-Geestmerambacht-The?redirectedFrom=fulltext
MAR	Managed Aquifer Recharge https://research.csiro.au/mar/
ATES	Aquifer Thermal Energy Storage https://en.wikipedia.org/wiki/Aquifer_thermal_energy_storage

New software for water system modelling and planning and design support mentioned in this white paper as examples

HYETOS	A computer program for SUDS design http://www.cditech.fr/index.php/logiciel-c-a-o/
Delft3D	Open source modelling suite for hydrodynamics, sediment and water quality https://oss.deltares.nl/web/delft3d
	Adaptation Support Tool Planning support for climate adaptation using nature -based solutions https://crctool.org/en/
XPSite3D	Road design support tool https://www.innovyze.com/en-us/products/xpsite3d

ANNEX 1. Terminology and definitions

As we are facing an ongoing, fundamental development in the field of urban water management, water supply and sanitation, the terminology that is used in literature is diverse. We have tried to collect relevant definitions, aware of the fact that many more exist, each with slightly different emphasis and boundaries. Although we realize the importance of well-defined terms, this white paper accepts this diversity as a natural way towards a shared, common understanding and definition of components.

Grey infrastructure

Grey infrastructure: also, commonly known as traditional/conventional infrastructure or hard engineering, refers to the man-made engineered components of a system. These components often involve the use or manufacture of "hard materials" such as concrete, plastic and metal. Channels, culverts, pipes and storage tanks are common grey infrastructure components used in stormwater systems to collect and convey runoff to a centralised treatment system or directly to a receiving waterway. (Brockbank et al., 2017)

Gray infrastructure is built structures and mechanical equipment, such as reservoirs, embankments, pipes, pumps, water treatment plants, and canals. These engineered solutions are embedded within watersheds or coastal ecosystems whose hydrological and environmental attributes profoundly affect the performance of the gray infrastructure. (Browder et al., 2019).

Green infrastructure

Green infrastructure: an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations. Green infrastructure is the ecological framework needed for environmental, social and economic sustainability – our nation's natural life support system'. (Benedict & McMahon, 2002 cited by Brockbank et al., 2017)

Green infrastructure (also sometimes called natural infrastructure, or engineering with nature) intentionally and strategically preserves, enhances, or restores elements of a natural system, such as forests, agricultural land, floodplains, riparian areas, coastal forests (such as mangroves), among others, and combines them with gray infrastructure to produce more resilient and lower-cost services. (Browder et al., 2019)

Green infrastructure generally refers to projects designed and built in urban areas. Typically, urban areas are more degraded and, as such, green infrastructure projects require a more engineered solution, such as a bioswale, permeable pavement, or a green roof. (Conti et al., 2019)

Green infrastructure: "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (European Commission, 2013 cited by Cohen-Shacham et al. 2016)

Green building materials are raw and processed nature-based materials used in the construction of the built environment. (Pearlmutter et al., 2019)

Green building systems in this context are systems for the greening of buildings, and include components such as green roofs, façade greenery and living walls, house trees, and even building integrated constructed wetlands. (Pearlmutter et al., 2019)

Green building sites may be open spaces directly adjacent to buildings, typically within in the same property, or land parcels of small and medium scale (pocket parks, urban plazas, small community parks, elevated urban green promenades) that have a role in the blue-green (i.e. water and vegetation-based) network of the city. (Pearlmutter et al., 2019).

Natural infrastructure

Natural infrastructure generally refers to projects that incorporate existing or restored natural landscapes, such as floodplains, wetlands, and forests. Typically, natural infrastructure projects involve a strategically managed landscape, such as a forest or wetland, to provide a set of desired benefits, such as carbon sequestration, flood control, or water filtration. (Conti et al., 2019)

A natural infrastructure approach could be seen to be restoring structure, function and composition of ecosystems to deliver ecosystem services, whereas a green infrastructure approach would enhance these aspects of ecosystems, to deliver these services. Furthermore, while a green infrastructure approach is used at both an urban and a landscape scale, a natural infrastructure approach is used only at only a landscape scale. (Cohen-Shacham et al. 2016).

Nature-based solutions

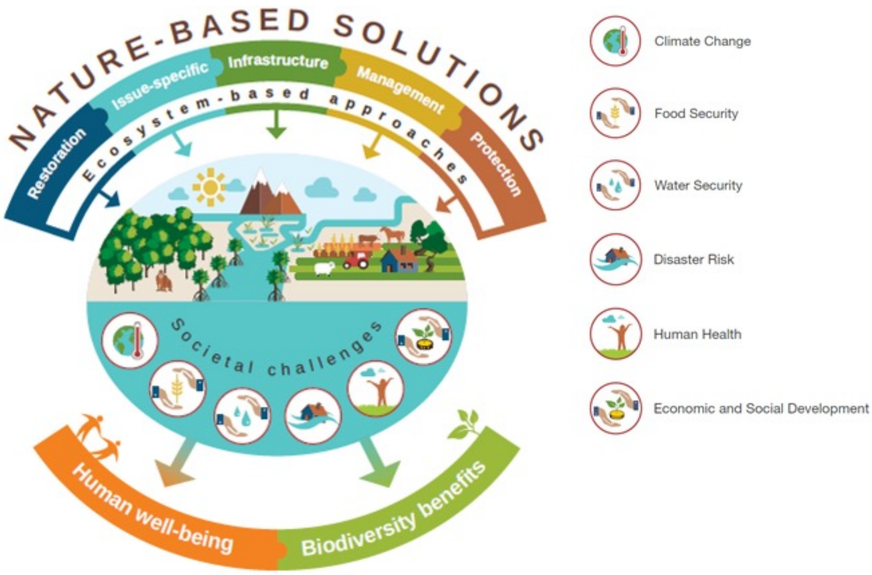
Nature-based solutions (NBS) is the broadest term referring to project solutions that are motivated and supported by nature and that may also offer environmental, economic, and social benefits, while increasing resiliency. NS include both green and natural infrastructure, but may also include other non-infrastructure solutions, such as ecosystem-based management (e.g., forest carbon projects and conservation). (Conti et al., 2019)

Nature-based solutions (NBS): actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits. (Cohen-Shacham et al. 2016).

Nature-based Solutions to societal challenges are solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions. Nature-based Solutions must benefit biodiversity and support the delivery of a range of ecosystem services. (Naumann et al., 2020).

Nature-based solutions (NBS) are concepts that bring nature into cities – and in many cases this includes ideas for urban design that are inspired or derived from nature. (Langergraber et al., 2019 cited by Pearlmutter et al., 2019).

Even within cities, NBS contribute to global objectives such as climate change mitigation and adaptation, and they have the potential to enhance human wellbeing biodiversity and resource recovery. (Pearlmutter et al., 2019).



Cohen-Shacham et al. 2016

Hybrid system

Hybrid system: integrated treatment approach that blends innovative engineered stormwater management technologies with more traditional land-based water-sensitive design practices and/or conventional landscaped areas to overcome the space and cost constraints. This hybrid approach is effectively a 'treatment train' (Brockbank et al., 2017).

Integrated greening of grey infrastructure (IGGI) is a new conservation strategy that involves biodiversity enhancement of hard infrastructure that cannot be replaced with green solutions (Naylor et al., 2017 cited by Firth et al., 2020).

Hybrid green & grey water infrastructure is a combination of green infrastructure solutions – also called nature-based or blue-green infra -, smart and grey infrastructure, aimed at producing (climate) resilient water systems, reliably controlling peak flows and/or delivering clean water, sustaining environmental flows, and providing other ecosystem, economic and social services. (This white paper)

Technological Subsidiarity Principle

Technological Subsidiarity Principle: Only if nature-based solutions cannot provide sufficient and continuous reliability of the required water system services grey solutions can be added to - and preferably integrated with - the green ones to provide a sufficient water quantity and quality for all the functions that are to be sustained. (This white paper).

Colophon

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Pictures:

- **Nutshuis:** F. van de Ven
- **Polderroof:** Dakdokters
- **Puridrain:** Deltares
- **Nanobubbles:** Solitude Lake management
- **Urban Water Buffer:** Field Factors
- **Bioretention system:** Healthy Waterways Ltd.

This white paper has been written for the purpose of stimulating discussion on how to improve water management. The paper does not reflect any formal standpoints, neither of the authors nor of the organizations where they work.

Notes

Notes

Water Europe
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OPPORTUNITIES FOR HYBRID GREY & GREEN INFRASTRUCTURE IN WATER MANAGEMENT: CHALLENGES AND WAYS FORWARD

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