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Sustainable Blue-Green Infrastructure: new international vision

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Abstract

Blue-Green Infrastructure (BGI) is an approach to urban flood resilience, recognised globally and in international literature, that capitalises on the benefits of working with urban green-spaces and naturalised water-flows. Literature reveals BGI's sustainable functioning and benefits-provision depend on the behaviour of those who use it, therefore local stewardship is often proposed to support maintenance. However, there is a gap in understanding the requirements and behaviours of users, as well as their potential for developing stewardship behaviours, that is not addressed through traditional analysis approaches based around demographics

Keywords: Climate Change, Extreme Events, Sustainability, Resilience, Blue-Green Infrastructure (BGI)

Infrastructure Bleue-Verte Durable : une nouvelle vision internationale

Résumé

L'infrastructure Bleue-Verte (TBV) est une approche de la résilience urbaine face aux inondations, reconnue mondialement et documentée dans la littérature internationale, qui tire parti des avantages des espaces verts urbains et des cours d'eau naturalisés. La littérature révèle que le fonctionnement durable de l'TBV et ses bénéfices dépendent du comportement de ses usagers ; c'est pourquoi une gestion locale est souvent proposée pour soutenir son entretien. Cependant, les approches analytiques traditionnelles, basées sur les données démographiques, ne permettent pas de comprendre pleinement les besoins et les comportements des usagers, ni leur potentiel à adopter des comportements responsables.

Mots clés : Changement climatique, événements extrêmes, durabilité, résilience, Infrastructures Bleues et Vertes

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1. INTRODUCTION

Without water, there is no agriculture, and a great deal of it is needed (approximately 3,000 liters per person per day – 90% of the total used by humans) to ensure our food supply. The issue of water is therefore essentially an agricultural/food issue, and vice versa. Three-quarters of this water is "green" water (rainwater used directly by rainfed crops), and one-quarter is "blue" water (water withdrawn for irrigated crops). Irrigation is of strategic importance: one irrigated hectare is on average three times more productive than one hectare of rainfed land, and irrigated crops account for 40% of global production. However, fresh water, whatever one might say, is a generally abundant resource since the total used for food production represents only 6% of the total resource.

Blue-Green Infrastructure (BGI) is a planned network of natural and semi-natural areas—combining vegetation ("green") and water bodies ("blue")—designed to manage urban water, reduce flood risks, and enhance biodiversity. It acts as a sustainable, nature-based alternative to traditional "grey" concrete infrastructure, providing climate resilience, cooling effect, and improved urban life quality.

Blue-Green Infrastructure (BGI) is regarded as a more nature-friendly means of managing urban flood-risk (particularly pluvial). The phrase 'blue-green' or 'green/blue' infrastructure emerged around the turn of the last decade (Gledhill and James, 2008, Selman, 2008) from a growing awareness of the need for a more integrated systems-approach to the management of Green and Blue Infrastructure. Ghofrani, Sposito, and Faggian (2017, 15) describe BGI as 'an interconnected network of natural and designed landscape components, including water bodies and green and open spaces'; a short list of examples could include green roofs, retention and detention ponds, re-naturalised and de-culverted rivers, swales and 'bioswales', or rain gardens (Abbott et al., 2013). BGI has been argued to offer multiple further benefits, such as improvements in air and water quality, aesthetics, biodiversity and amenity (Hoyer et al., 2011, Lawson et al., 2014). As a result, it is increasingly seen internationally as an effective way of managing flood risk and simultaneously improving the public realm (Alves et al., 2018, Hoyer et al., 2011, Jiang et al., 2018, Shandas et al., 2010, Wong and Eadie, 2000).

The Blue and Green Infrastructure (BGI) aims to combat the erosion of biodiversity caused by habitat fragmentation and destruction resulting from human activities (Alphandéry et al., 2012). Landscape fragmentation is characterized by both the fragmentation, isolation, and reduction of the surface area of natural habitats and by changes in connectivity between habitat patches (Janin, 2011). Landscape connectivity is understood as the degree to which landscape features facilitate or impede the movement of species between different habitats (Taylor et al., 1993). It therefore depends on both the structure and spatial organization of the habitat and how species interact with this environment (Calabrese and Fagan, 2004; Taylor et al., 1993). Landscape fragmentation hinders the movement of both animal and plant species (Ritchie, et al., 2009). It affects the ecological balance by disrupting the hunting and reproductive activities of species, but also by reducing interactions between individuals, which limits the genetic diversity of populations (Fahrig, 2011, Henkel, 2015).

n order to limit these effects, it is necessary to implement management measures to restore connectivity between habitats. Based on the principles of landscape ecology, the Blue and Green Infrastructure ((BGI)) aims to create a viable ecological network for species, made up of biodiversity reservoirs and terrestrial or aquatic corridors (Burel and Baudry, 1999, Bennet, 1991).

The first type of habitat is the areas where biodiversity is best represented and where species can complete all or part of their life cycle, i.e., feed, reproduce, and rest (Arnould et al., 2011; Linglart et al., 2016). These areas are linked by corridors that constitute "functional links" (Arnould et al., 2011), allowing the movement of species or groups of species between different habitats (Clergeau and Désiré, 1999). Biodiversity-based ecosystems (GBEs) have been developed and studied at the regional level through the development of Regional Ecological Coherence Schemes (SRCEs) (Amsallem et al., 2010).

The establishment of a network of Green and Blue Infrastructure relies on several methodologies that presuppose a territorial assessment, but no universal method is proposed. Regions can therefore choose the method for identifying Green and Blue Infrastructure that best suits their needs (Vanpeene-Bhuier and Amsallem, 2014). However, the different approaches must take into account criteria defined at the national level, such as the integration of regulatory zoning, inventories, or elements of national importance (Vanpeene-Bhuier and Amsallem, 2014). Three main methods are commonly used to identify ecological corridors: visual interpretation analysis, analysis of permeability of the environment, and the use of a dilation-erosion treatment (Amsallem et al., 2010; Bernier and Théau, 2013), but these methods are rarely compared with one another (Vanpeene-Bhuier and Amsallem, 2014). These methods translate into two major types of approaches. The first relies on the study of habitats and their organization; this is known as the structural approach. The second focuses on species' responses to environments by using information on ecological functions through a functional approach (Fu, et al., 2010, Girardet, et al., 2013).

Green infrastructure refers to multifunctional green spaces that can be adopted in urban and rural landscapes, and that improve the quality of life and environmental benefits for communities. Green infrastructure facilitates ecosystem-based initiatives such as roof gardens, vertical gardens, open green spaces, public parks, etc. , that support climate change mitigation, disaster resilience, and community wellbeing. Blue infrastructure facilitates water-associated ecosystems for the same purpose above. This includes urban ponds, rain gardens, wetlands, canals, and other water-associated ecosystems. Under the nature- and ecosystems-based solutions for disaster risk reduction, green and blue infrastructure features are encouraged as an environmentally sustainable solutions for making communities resilient. However, understanding of policies concerning green and blue infrastructure and their support among decision-makers and practitioners needs to improve. In addressing this scope, this paper aims to understand the policy support for green and blue infrastructure implementation towards disaster risk reduction for better preparedness among local and national communities

Green infrastructure was developed as an alternative to legacy stormwater management systems, which are known in this context as gray infrastructure. Gray infrastructure takes its name from the fact that much of it is constructed from concrete and steel. It consists of a network of gutters, sewers, ditches, dams, sewage tunnels, permeable pavement, and pipes that divert stormwater away from inhabited areas and reroute it to natural bodies of water or to water treatment facilities. Gray infrastructure also collects and delivers household graywater to sewage treatment plants. The term "graywater" describes any type of wastewater not contaminated with human waste; it primarily includes drainage from fixtures and appliances like bathtubs, showers, dishwashers, and washing machines.

Gray infrastructure primarily uses a centralized approach to stormwater and wastewater management, capturing and collecting incoming water before strategically diverting it to a planned destination. It is designed to reproduce nature's ability to absorb and retain water but offers limited utility beyond its primary purpose. The gray infrastructure installed in many urban centers is also aging, having handled large volumes of stormwater and wastewater for decades.

Green infrastructure initially evolved as a complementary system to supplement existing gray infrastructure in need of upgrading or replacement. These coupled systems are sometimes referred to as green-gray infrastructure, and they are effective at reducing the heavy water volumes that erode gray infrastructure. Unlike gray infrastructure, green infrastructure is also capable of harvesting urban rainwater and utilizing it as part of a wider water resource management strategy, which serves as a key example of its broader set of case-uses.

Research into the economic benefits of coupled systems have found that they offer significant long-term cost savings. A study published in the academic journal Resources, Conservation & Recycling (Xu, Tang, Haifeng, and Xu, 2019) reported that green-gray infrastructure systems have the potential to cut lifecycle costs by as much as 94 percent when compared to gray-only infrastructure. The study recommended investing in the optimization of coupled systems and encouraged urban planners to make increased use of green infrastructure technologies in their municipal stormwater and wastewater management plans. The study reflects a growing sentiment among policymakers and urban planners to make more conscientious use of green and blue-green approaches to local development.

The notion of ecological resilience was first elab- orated by Holling in a seminal article published in 1973 (Holling, 1973). This perspective devel- oped from population and landscape ecology and applied resource management. Holling's insight incorporates three concepts of changes that oc- cur in an ecosystem over time. The first de- scribed the "persistence of relationships within a system" and the "ability of systems to absorb changes of state variables, driving variables, and parameters, and still persist" (Holling, 1973). The second concept recognized the occurrence of alternative and multiple states in a system as opposed to the assumption of a single equilib- rium and global stability; therefore, resilience is "the size of stability domain or the amount of dis- turbance a system could take before it shifted to an alternative configuration" (Holling, 1973). The third notion was the surprise and discontinuous nature of change.

Weather extremes (droughts and floods) are an accepted component of coupled human-environ- ment systems. There is a strong need for an anthropogenic modification of the environment in response to climate and weather over time and development of "sustainable" engineering solutions. BGI, as one of those solutions, provides a proven, sus- tainable, underpinning of development that pro- tects against floods and offers a range of other benefits with no down sides. The driver of cli- mate change and increased extreme weather means we need to implement systems like BGI if we wish to have sustainable and resilient settle- ments. There is no comprehensive synthesis of BGI, and given its growing importance, there is need for a review

2 BRIEF HISTORY BLUE-GREEN INFRASTRUCTURE (BGI)

Experts often characterize the concept of green infrastructure as an outgrowth of the modern environmental movement, which rose to national prominence in the United States during the late 1960s and became a major topic of sociopolitical concern in the 1980s and 1990s. Scholarly analysis of the history of green infrastructure notes the concept's interdisciplinary roots. Its underlying principles evolved over decades, leading to the first known usage of the term in 1994 when policymakers referenced "green infrastructure" in a land conservation report prepared for Florida's then-governor Lawton Chiles. The report highlighted the importance and effectiveness of natural systems as complements to human-made infrastructural assets, noting that gray infrastructure requires thorough long-term planning and positing that policymakers therefore have ample opportunity to incorporate green infrastructure into their wastewater management strategies.

In 1995, author Charles E. Little published the book Greenways for America, which experts credit with popularizing the term "greenways." The greenways movement, which gained momentum following the book's publication, seeks to establish and maintain landscaped spaces in urban, semiurban, and rural areas. Greenways are viewed as a means of encouraging outdoor recreation and linking a region's parks and nature preserves through an interconnected network of paths and trails. The greenways movement foretold the subsequent rise in interest surrounding green infrastructure by formally importing the concept of landscape ecology into urban and regional planning.

The EPA formally adopted the term "green infrastructure" in 2007, using it to describe a novel approach to low-impact stormwater management, which endeavors to apply natural hydrologic processes to engineered systems. During the 2000s, urban planners, civil engineers, and policymakers began to recognize the ecological and cost-efficiency potential of using ecological services to meet community-based needs. This touched off a concerted move toward scale planning that incorporated landscape and nature features into their designs at increasing rates. The trend reflected an underlying realization among localities that nature conservation and the restoration of natural landscapes were vitally important to building sustainable, healthier, and more livable communities.

In 2006, a landmark study examined the financial value of strategically using tree cover as a means of improving air quality and managing stormwater volumes. Its findings were jointly published by researchers Edward McMahon and Mark A. Benedict in their book Green Infrastructure: Linking Landscapes and Communities. The researchers concluded that tree cover held the potential to save U.S. municipalities as much as $400 billion in air quality mitigation, water treatment, biofilter, and stormwater pond investments.

Also in 2006, multiple agencies of the US federal government produced a report titled Ecological: An Ecosystem Approach to Developing Infrastructure Projects. Though the work mainly focused on sustainable transportation and road design practices, it signaled growing government recognition of eco-conscious infrastructure development. The Green Infrastructure Center, a Virginia-based nonprofit organization that helps communities make more environmentally conscious planning decisions, was also established that year. The Trust for Public Land, another eco-protection nonprofit group, has since financed and published multiple academic studies into green infrastructure. These studies examine the social and financial benefits of green spaces in urban planning, noting their multifaceted potential as effective ways to bridge access gaps to outdoor recreation opportunities while making better use of natural resources.

As the concepts of green and blue-green infrastructure have developed, they have been taken up by policymakers, urban planners, and stakeholders in many countries around the world. The European Commission (EC)the executive authority of the European Union (EU)now maintains an official green infrastructure strategy. East Asian countries including China and Japan continue to deepen their investments in green infrastructure, while the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia's national scientific agency, has created a "national agenda" for making increased use of green infrastructure principles and technologies in the nation's urban areas.

In 2019, US lawmakers passed the Water Infrastructure Improvement Act. The legislation formally incorporated the EPA's integrated planning (IP) principles into federal law, giving municipalities and regional governments new paths to planning and financing green infrastructure additions to their existing stormwater and wastewater management systems. Notably, the Water Infrastructure Improvement Act also contains a specific description of "green infrastructure," which now serves as the standard definition used by US federal agencies. It describes green infrastructure as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters."

3. OVERVIEW SUSTAINABLE BLUE-GREEN INFRASTRUCTURE

In the last three decades, several alternative ap- proaches have suggested different ways to ad- dress sustainability and sustainable development. The more traditional ap- proaches are anthropocentric (also referred to as "weak" approaches to sustainability). These consider nature as something external to hu- mans, a resource to be consumed and exploited, but with moderation to make it last. Instead, an eco-centric approach (or "strong" approach to sustainability) presents so- cial systems and nature as co-evolving in mutual, complicated interaction and, therefore, takes into consideration a balance of social require- ments, ecological restrictions, and quality of life.

The global water problem is not a problem of quantity but a problem of distribution, access, and the risk of cascading instabilities. It is indeed necessary to distinguish several types of regions (Figure 1).

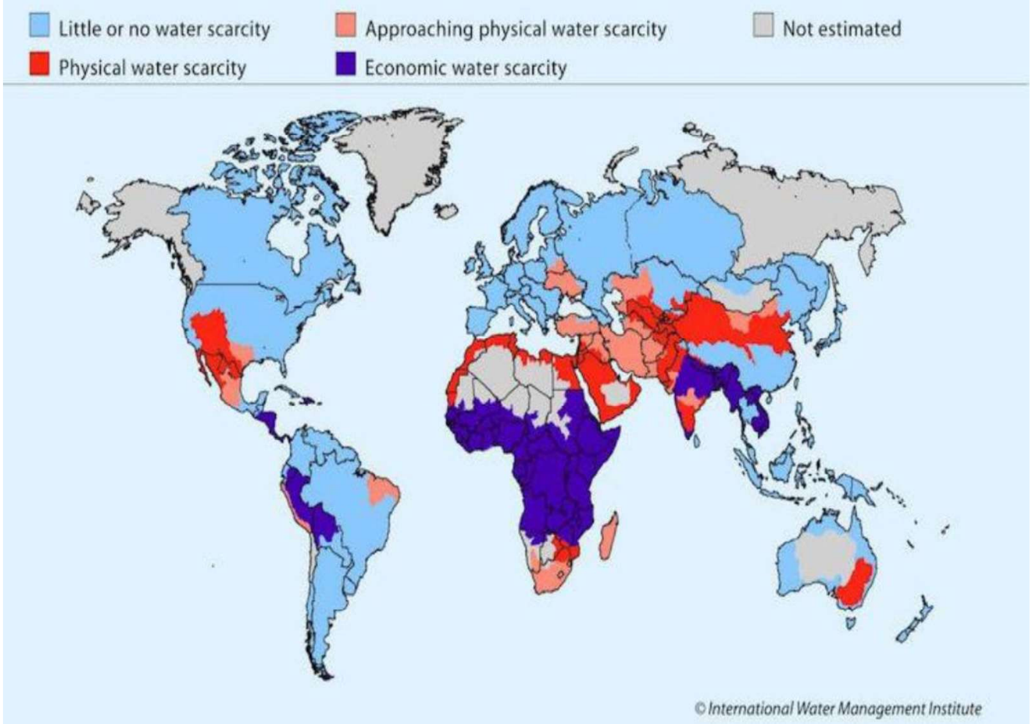


Figure 1. Global water problem in the world

In the Southern Mediterranean, from Morocco to Syria, there is a real problem of "physical scarcity" because demand already represents 105% of the resource (total runoff)!

In West Africa, however, scarcity is only "economic": due to a lack of investment, only 3% of the renewable resource is being utilized (13 out of 387 km³/year; Source: Sahara and Sahel Observatory, COP 21).

On the northern shore of the Mediterranean, from Portugal to Turkey, this rate is 13%, and in France, a country with numerous water towers, the total consumed (all uses) represents only 3% of annual runoff (5.35/175 km³/year). Our country, which is not sufficiently aware of this, is therefore very The situations in these three main types of regions (physical scarcity, economic scarcity, abundance) are therefore not at all the same.

One consequence of the poor geographical distribution of resources (land, water, institutional and financial capacity) is the very strong growth in food dependencies (Africa, the Middle East, Asia) and therefore in international trade. privileged.

The situations in these three main types of regions (physical scarcity, economic scarcity, abundance) are therefore not at all the same. One consequence of the poor geographical distribution of resources (land, water, institutional and financial capacity) is the very strong growth in food dependencies (Africa, the Middle East, Asia) and therefore in international trade.

The bad news is that South Asia (primarily due to a lack of land and sometimes water), North Africa and the Middle East (due to a lack of water), and sub-Saharan Africa (due to a lack of investment in water infrastructure and agricultural development) have become extraordinarily dependent on imports. Yet, Africa, which is only 14 km from Europe, will gain another billion inhabitants by 2050, and agricultural and food forecasts predict a risk of more than a tripling of production deficits! This is unprecedented. We must therefore expect an explosion in foreign trade (as resource-rich countries will have to produce more to secure supplies) and/or large-scale migration and instability.

The other bad news is that the EU, after regaining its food independence in the 1990s, thanks in particular to the CAP, has also been experiencing ever-increasing deficits ever since! France is somewhat of an exception because it exports the equivalent of 5 million hectares of cereals, which allows it to make a significant contribution to securing wheat imports for the Maghreb and Egypt, and therefore stability. But for how long can it do this, given that our country has lost 2 million hectares of excellent farmland in just 30 years, an area that corresponds exactly to the increase in developed land (largely due to urban sprawl)?

Experts are careful to note distinctions between green infrastructure and green building, as the terms are often confused and inaccurately used interchangeably. Green building refers to the certifications offered by organizations such as Leadership in Environment, Energy, and Design (LEED) for structures that conform to elevated energy efficiency standards. LEED ratings are endorsed by agencies such as the US Green Building Council, and now also extend to neighborhood development. As understood by the EPA, urban planners, and ecodevelopment professionals, green infrastructure refers exclusively to individual, municipal, and regional resource management systems for dealing specifically with stormwater and wastewater.

As the EPA notes, green infrastructure can exist across multiple scales, ranging from what it calls individualized “urban scales” to neighborhood scales and larger citywide or regional scales. At the individual level, green infrastructure includes basic interventions that have a long history of established use; examples include using barrels to collect rainwater for household use, adding trees to streets, and remediating abandoned or underused properties with landscaped elements. Green infrastructure at the neighborhood scale involves engineered solutions with community-level impacts, such as creating a multi-acre green space within an urban district, planting low-elevation rain gardens to absorb rainwater runoff from building roofs and graded properties, and creating artificial wetlands to serve subdivisions or housing complexes by harvesting rainwater resources and supporting localized biodiversity. Scaled up to the citywide or regional level, green infrastructure includes networked groups of localized projects that combine to improve air quality, boost the resilience of water resources, and protect against flooding while making outdoor recreation options more plentiful and accessible.

The EPA lists multiple technologies and systems that can be used in green infrastructure, which can be grouped into broad categories including stormwater management, construction and landscape architecture, building materials, and land use strategies. Each category contains interventions with applications at the urban, neighborhood, citywide, and regional levels. Stormwater management techniques comprise downspout disconnection, rainwater harvesting, rain gardens, and planter boxes. Major examples of construction and landscape architecture-based approaches to green infrastructure include bioswales, green parking areas, green roofs, and green streets. Permeable pavements represent a widely used green infrastructure building material, while land use strategies incorporate urban tree canopies and various land management policies and practices.

Downspout disconnection can be carried out at the homeowner level. It involves reconfiguring rooftop drainage systems to empty stormwater into storage vessels, gardens, or other permeable areas. When applied at the neighborhood or citywide level, it can dramatically reduce the amount of water handled by existing gray infrastructure, thus helping extend its lifespan and reduce maintenance and replacement costs.

Rainwater harvesting takes a broader, upscaled approach to stormwater collection. In addition to the localized techniques that apply to downspout disconnection, rainwater harvesting also includes constructing pits and aquifers capable of storing large fluid volumes. Some systems also use nets and other technologies to capture and extract moisture from fog and dew.

Rain gardens, also known as bioretention cells, are small, localized plant collections created in low-lying areas that are surrounded by graded slopes or other drainage systems. They route stormwater into the garden, hydrating plants and helping prevent water from pooling on driveways, sidewalks, and other surfaces. When rain gardens are situated in densely developed urban areas and surrounded by vertical walls, they are called planter boxes.

Bioswales are features built into road infrastructure, such as gutters, curbs, and parking lots. They use dense volumes of plants and/or mulch, which reduce the speed at which stormwater can flow while also filtering incoming water. Bioswales reduce gray infrastructure workloads and help prevent systems from becoming inundated when major storms occur. Green parking strategies incorporate bioswales, rain gardens, planter boxes, and other green infrastructure technologies into surface parking lots, creating walkability improvements while mitigating the so-called "heat island effect" that links human activity with higher localized ambient temperatures.

Green roofs continue to emerge as an increasingly prominent feature of urban spaces. These architectural features reimagine conventional rooftops as green spaces, covering them with vegetation that supports the evapotranspiration of collected stormwater and the infiltration of incoming rainwater. Green roofs can also be configured as produce-yielding gardens, and they have become particularly popular in major metropolitan centers where the cost of remediating damage caused by excess stormwater is likely to be very high. Similar concepts can be applied in cities at ground level, creating what are widely known as green streets.

Permeable pavement represents a critically important green infrastructure material, as it has mass-scale applications. It includes any type of concrete, asphalt, or interlocking bricks capable of allowing water to pass through, and can be used to finish any flat surface in a developed area. Urban planners make extensive use of permeable pavement materials in high-value areas where flooding, ice, and meltwater volumes pose significant property damage risks.

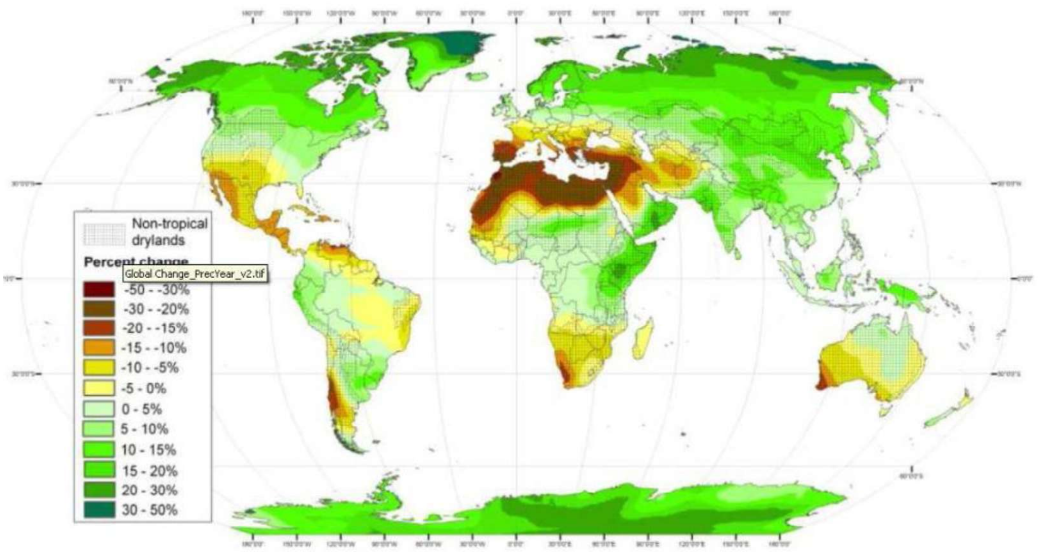
Developers can engineer urban tree canopies to improve localized vegetation density and dramatically accelerate the surrounding environment's ability to absorb rainwater in their branches and leaves. Because trees filter carbon dioxide and other impurities out of the air, they can also yield significant air quality improvements when constructed on a mass scale. Conservationist approaches to land management and urban development have similar impacts, especially in cities surrounded by hills, natural wetlands, flood plains, and streambanks.

Blue-Green Infrastructure extends the concept of green infrastructure to engineered systems that connect with natural landscapes and bodies of water. It can also include artificially constructed supplementary resources such as canals and water treatment facilities to create a municipal water management system that closely replicates the structure and function of natural water cycles. Blue-green infrastructure represents a more complete and integrated approach and holds the potential to improve ecosystem service delivery beyond what green infrastructure or green-gray infrastructure could achieve independently. Its potential benefits include natural reductions in localized air pollution, turnkey irrigation systems for parks and outdoor recreation areas, and more plentiful and resilient access to drinking water supplies.

Cities in the United States and around the world are adopting green and blue-green infrastructure strategies at increasing rates. US municipalities with major green and blue-green infrastructure developments include San Francisco, New York, and Los Angeles. Internationally, ten EU cities launched a joint blue-green infrastructure pilot project in 2021, with municipalities in Belgium, Germany, the Netherlands, Norway, Sweden, and the United Kingdom launching a combined thirty-four programs with a total financial value estimated at €347 million (US $392 million).

Green blue infrastructure enhancements do not have to be limited to buildings or solid infrastructure. There can be a significant return on investment when these efforts are turned to urban water sources. For example, many urban areas have rivers and lakes within their confines, as well as wetlands and engineered greening. When projects are undertaken to improve water quality, availability, and biodiversity, human populations benefit from the increased green spaces and reduced waterborne diseases. These projects can also reduce ever-rising heat indexes in cities that are increasingly making urban areas less habitable. The most efficient air cooling projects of this type include botanical gardens, wetlands, green walls, street trees, and vegetated balconies.

However, the very bad news is that climate change poses a serious threat to agriculture and food security, especially since many agricultural systems are already degraded by erosion or threatened by the overexploitation of groundwater (significant locally in India, Iran, Mexico, the Southern and Eastern Mediterranean, and the Western United States), by salinization, or by rural poverty. The most threatened regions (South Asia, Africa, the Southern Mediterranean, and the Middle East) are precisely those where the food trade deficit is already the largest! West Africa and the Southern Mediterranean are in an even more critical situation, as sharp declines in rainfall and runoff (up to 30 or 40% over a century) are predicted (and have already been partially observed), and rising temperatures are changing the agricultural landscape (land is losing its agricultural potential and is only suitable for livestock production) and having a very negative impact on yields (Figure 2).



Relative change of mean annual precipitation 1980/1999 to 2080/2099, scenario A1b, average of 21 GCMs (compiled by GIS Unit ICARDA, based on partial maps in Christensen et al., 2007)

Figure 2. Climate change: Relative change in mean annual precipitation (1980/1999 to 2080/2099)

With droughts, declining agricultural productivity, lack of access to irrigation water, and population growth, the risk is therefore that of failed states and large-scale migration and instability. International reports also warn of the risk of a sharp increase in the number of undernourished people worldwide (600 million more than the 800 million already recorded). The issue of the water/land/agriculture relationship and that of rural development are therefore of paramount geopolitical importance.

The essential challenge facing the world today is to better manage resources and achieve sustainable agricultural intensification to ensure both food and water security, adaptation, and mitigation. This involves securing production systems, transitioning to sustainable systems everywhere, increasing production, particularly to secure the rapidly growing supplies of countries lacking water and/or land, and improving access and incomes for the most vulnerable (small-scale farmers).

The good news is that by managing water and soil better, it is often possible to simultaneously: i) improve production and income (by improving water productivity), ii) achieve successful adaptation, and iii) make a decisive contribution to mitigation. Thanks to photosynthesis, we can transform our fields into much better "carbon pumps," meaning we can absorb some of the excess carbon in the atmosphere as CO2 and simultaneously store carbon in the soil as organic matter, while also producing more and better crops.

This is the crux of agroecology and the "4 per 1000: Soils for Food Security and Climate" initiative, launched at COP 21. The figure "4/1000" represents the increase in carbon stocks in topsoil that would offset all anthropogenic CO2 emissions. The IPCC's work shows that the technical potential is high and that restoring degraded land must become a true global priority.

Sustainable Blue-Green Infrastructure (BGI) is an integrated planning approach that combines natural, semi-natural, and engineered systems to manage urban water, enhance ecological resilience, and improve human well-being. It pairs "blue" elements (water bodies, wetlands) with "green" spaces (parks, green roofs) to provide multifunctional solutions Reducing vulnerability and exposure to present climate variability is the first step towards adaptation to future climate change. Flooding and extreme events will become more prevalent under climate change, and only sustainable approaches such as Blue-Green Infrastructure (BGI) will save us from ourselves. Strategies such as BGI that include actions with co-benefits for other objectives can increase resilience across a range of possible future climates while helping to improve human health, social and economic wellbeing, environmental quality, and livelihoods

4. BLUE-GREEN INFRASTRUCTURE AS A SOLUTION UNDERPINNING SUSTAINABLE DEVELOPMENT

Blue-Green Infrastructure (BGI), as an umbrella notion, is closely related to the concept of "green infrastructure" - a landscape planning concept that is allied to otherplanning concepts such as green-ways (ahern, 1995; fábos and ryan, 2006) and ecological networks (jongman and pungetti, 2004). Since 2000, green infrastructure has primarily been introduced to design and promote urban green bodies as a coherent environmental planning system (sandström, 2002; thomas and littlewood, 2010). it can be considered to include all artificial, natural, and semi-natural components of multifunctional environmental systems around, within, and between urban areas. the increasing popularity of green infrastructure applicationsin various regions of the world underscores its multitude of benefits (benedict and mcmahon, 2006; gill et al., 2007; mell, 2008; tzoulas et al., 2007). green infrastructure highlights the quantity and quality of regional, periurban, and urban green bodies; their multifunctional impact; and the significance of connections between habitats (ryn and cowan, 2013). it has also been argued that the ecosystem services offered by green infrastructure can secure healthy environments and health improvements, including physical and mental health, to the people residing within or in close proximity to it (tzoulas et al., 2007). encompassing all these aspects, the comprehensive definition put forward by benedict and mcmahon (benedict and mcmahon, 2002) is: "green infrastructure is an interconnected network of waterways, wetlands, wildlife habitats, and other natural areas; greenways, parks, and other conservation lands; working farms, ranches, and forests; and wilderness and other open spaces that support species, maintain natural ecological processes, sustain air and water resources, and contribute to the health and quality of life for (american) communities and people" (mell, 2008). Furthermore, the contribution of (blue-) green infrastructure to climate change adaptation has begun to be documented (gill et al., 2007; Kazmierczak and carter, 2010), yet there are few studies that have so far systematically focused on this aspect.

BGI can exist at various geographic levels (e.g. re- gion, city-region, urban, river basin/ catch- ment/watershed, and site) and functions across jurisdictional boundaries. Therefore, BGI is not limited to urban spaces, and its planning can be considered at multiple levels and in various planning contexts such as urban, peri-urban, regional, and rural planning. BGI is significantly different from conventional "hard" built infrastructures such as roads, sewerage and drainage systems, and utility lines. Connectivity is a key concept for BGI, since many of the bene- fits of BGI can only be truly realized by an inter- connected network of its constituting compo- nents (Faggian and Sposito, 2009; Faggian et al., 2012).

BGI is an important means of dealing with flood- ing/extreme weather since it can consist of a net- work of interconnected water reservoirs, wet- lands, and their associated (natural) open spaces developed along rivers, which serve several in- terrelated purposes including: (i) water storage, especially for agriculture's irrigation and indus- try use; (ii) regulators of the river system, partic- ularly the prevention of floods during extreme rainfall events; (iii) habitat for plants and animal wild life (nature conservation); (iv) a cleaning system of polluted water, particularly absorbing fertilizers that are often washed away from farmland and which tend to cause algae blooms in rivers and lakes; (v) areas for the growth of wetland crops, such as reed, for second genera- tion biofuel production; and (vi) zones for the pursuit of suitable recreational activities (Benedict and McMahon, 2006; Kazmierczak and Carter, 2010; Koomen et al., 2012; Mell, 2008).

The number of BGI projects that have been suc- cessfully carried out or are still under develop- ment is relatively small, but this number will in- crease in the future. Despite its great promise, there are a number of obstacles preventing the wide-scale uptake of the BGI concept. While it is costly to implement BGI, the expense is quickly recovered through avoided damage at the first flood and easily justified through the multiple benefits that accrue. In some parts of the world, such as in The Netherlands, BGI is well accepted; but the concept has not been as widely imple- mented elsewhere due to a general lack of awareness (Thorne et al., 2015).

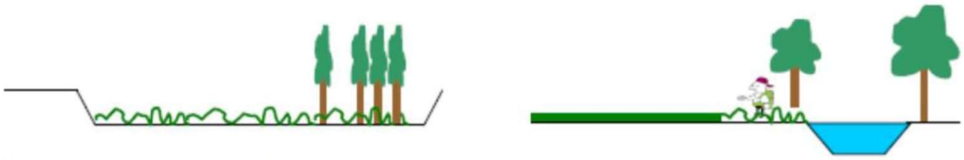
The most important antecedent to BGI is the ex- tensive spatial planning work and research un- dertaken in The Netherlands over many decades. In particular, climate change impacts on flooding are especially relevant in the Netherlands where about 25% of the land is below mean sea level and over 50% of the country is being protected from flooding by embankments (Koomen et al., 2012; Snepvangers et al., 2011; Sposito et al., 2014; Verburg et al., 2012). More broadly, it has been argued that:

"Drastic changes are expected in land-use pat- terns as a result of socioeconomic developments and climate change. Biodiversity and other land- use functions require larger areas for adaptation to changes in climatic conditions and thus in- crease competition for available space. This requires a different, more multi-functional type of land-use planning and more efficient manage- ment of resources" (Koomen et al., 2012).

Practical examples from The Netherlands of var- ious possible components of BGI that promote functional synergies are illustrated in Figure 3 (Snepvangers et al., 2011).

(a) Long and flat water reservoir

(b) Long water reservoir combined with shadowing



(c) Flat water reservoir combined with biodiversity (high landscape element)

(d) Combination of shading with recreation paths

Figure 3: Practical examples from the netherlands of various possible components of bgi (snepvangers et al., 2011**)**

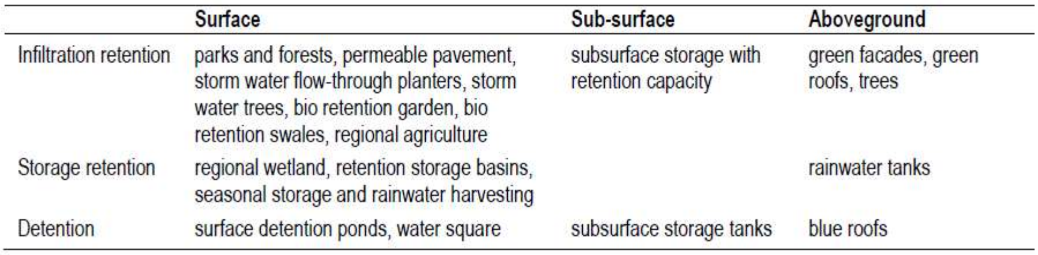
Figure 3 (a) shows a long and flat reservoir, which allows for a highly flexible system to store water at different levels. This BGI component can be ecologically managed to develop a large natural area along the watercourse, so improvements in water quality can be secured. The larger area has the capacity to soak up much more of the nutrient and sediment load than the animals and plants in the stream channel, which can be over- whelmed at the time of heavy rainfalls. There- fore, it can improve the water quality. Moreover, wetlands take a while to fill and empty during a flood, so they help decrease the size of floods for downstream areas (Snepvangers et al., 2011).

Figure 3 (b) shows a long water reservoir com- bined with shadowing along the river banks. If the banks are designed with attention to dy- namic changes, water quality improvements can be secured. For instance, dynamic changes can be obtained by planting suitable trees (river trees) that project shadows to the watercourse. Shadows aid significantly in keeping water- course temperature cool. Catchment organisms desire their watercourse to be shaded. Warmer water can't carry as much dissolved oxygen, and this will lead to water quality decline and death for some organisms that can't survive in these situations. Tree planting also helps to stabilize the bank and reduce erosion and reinstate the natural habitat. It also prevents excess soil and nutrients from getting into the watershed and will improve the quality of the water.

Figure 3(c) shows the combination of a flat-water reservoir that can be enhanced by marshy forests (wet- lands) and a rich plant growth at a low level to attract birds and animal species.

Figure 3 (d) shows shading that has been secured through high landscape elements (trees) along a water- course, which adds variety as well as interesting resting places for people pursuing recreational activities (Snepvangers et al., 2011).
A sample of the first two classifications of BGI components is summarized in table 1 (Cruijsen, 2015).

Table 1 Classification of bgi components based on their contribution to flooding mitigation and their position (Cruijsen, 2015)



	Surface	Sub-surface	Aboveground
Infiltration retention	parks and forests, permeable pavement, storm water flow-through planters, storm water trees, bio retention garden, bio retention swales, regional agriculture	subsurface storage with retention capacity	green facades, green roofs, trees
Storage retention	regional wetland, retention storage basins, seasonal storage and rainwater harvesting		rainwater tanks
Detention	surface detention ponds, water square	subsurface storage tanks	blue roofs

CONCLUSION

To address the immense challenges ahead, solutions exist and two major new trends are emerging internationally.

The first trend is the growing awareness of the new strategic importance of water storage and irrigation, and the renewed interest in agricultural water management. This represents a reversal of the trend, because since the 1980s, in developed countries of the Global North (Spain being an exception), agricultural water management had a bad reputation, to the point that major international donors were no longer willing to finance investments in the Global South. This reversal is particularly evident in sub-Saharan Africa, as the continent has water resources, and the current low irrigation rate (5%) exacerbates its vulnerability and prevents it from meeting the dual challenge of food security and climate change.

Moreover, in many cases, the development of irrigation has given young people new opportunities, lifted them out of poverty, and halted emigration. It thus contributes to preserving major balances, particularly the urban-rural balance. Recent statements from donors confirm this trend.

Climate change is also a factor. Warming has the effect of significantly increasing potential evapotranspiration (already +15 to 20% in France), resulting in longer and more severe low-water periods and increased water needs for agriculture. The latest IPCC report (2014) therefore estimated that $225 billion in investments in storage and irrigation will be needed by 2030 simply to maintain the services currently provided by water in 200 countries. Its chapter on Europe shows that the relationship between water and agriculture will become a central concern for the continent. It calls for the creation of new hydraulic infrastructure to meet the new low-water needs and prevent conflicts.

The second fundamental trend is to improve water productivity through more efficient resource management and agronomic innovation. Significant progress has already been achieved in terms of efficiency (reduced losses in transport and at the plot level), thanks in particular to precision irrigation. While further progress is still possible, including in arid regions (see ICARDA's work), it should not be overestimated. What is new and important for the future is a return to agronomy, a holistic approach to water and soil (landscapes), and a commitment to the agro-ecological transition. By changing agronomic practices, utilizing crop rotations, and revitalizing soils, we can indeed reduce evaporation losses and significantly improve water productivity in rainfed and irrigated crops, but also: i) increase water retention in soils and the stock of organic carbon, ii) improve infiltration and groundwater recharge, and iii) reduce runoff losses and therefore also the risk of flooding.

Farmers, provided they have access to water and commit to agroecology, can therefore become key players in sustainable development. This is particularly crucial for rainfed crops, which are often overlooked in development efforts, despite the fact that they constitute the majority of agricultural land and support the farming population, and that their development can lead to significant environmental and socio-economic gains, including for the benefit of water resources and their downstream users.

We must therefore learn to think in terms of the "blue water - green water continuum" and seek ways to create synergy that intelligently combines productivity, ecosystems, and sustainability.

What ultimately emerges is the new strategic importance of "water storage"within a broader vision, that of a continuum that can draw on various options including: large and small dams, reservoirs, and cisterns; artificial recharge of aquifers; water storage/retention in soils (agroecology); and storage through proper preservation, creation, and management of wetlands. It is up to each region to develop the appropriate planning and management solution.

Success requires acting on all levers simultaneously (not pitting solutions against each other). It calls for both an evolution in the relationship between agriculture, water, and soil, and also an evolution in society's perceptions of water, agriculture, and the environment, as well as in policies, planning, and management.

The mistake would be to focus solely on agroecology and efficiency and neglect agricultural hydraulics, and vice versa. While climate change threatens stability, the worst thing would be to remain entrenched in dogmatic and rigid positions that will prevent us from anticipating and addressing local and global challenges related to adaptation/mitigation, food security, and employment.

If agriculture must commit to the agro-ecological transition, society must understand the new strategic importance of agriculture/food and water and carbon storage. Water policies, too often focused solely on supply (in the Global South) or, conversely, solely on demand (in the Global North), will therefore have to learn to combine supply and demand to take into account climate and food challenges and respond to the new needs of low water levels (agriculture and ecosystems).

Agriculture is not an economic activity like any other, and it cannot remain a mere variable for adjusting environmental policies or urban development. The right to food is a universal right that must be guaranteed if we are to maintain stability. Water and agricultural policies must therefore become genuine sustainable development policies.

Since each context is different, it is up to each territory to define and develop its own project, taking into account not only local issues but also global ones (climate and food security). More than ever, we therefore need to learn to think and act together, "locally" and "globally".

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