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Original Research Article

Ecosystem-based water security and the Sustainable Development Goals (SDGs)

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A B S T R A C T

The economic development-environmental protection dichotomy is an out-dated construct. A 21st century approach to the world's water problems is progressively being developed by researchers and practitioners, who are combining traditional and ecosystem-based engineering systems to yield cost-effective solutions. Given the continuing and widespread loss of ecological services and functions, water security in a multi-generational, SDG context requires a meaningful, global commitment to redirect the current downward trajectory in both (i) the state of the world's ecosystems and the services they provide to society, and (ii)

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our collective level of stewardship of these important resources. Achieving sustainable water security will require overcoming strategic challenges related to protected areas, ecosystem-based solutions research, water observatories and expanded technical readiness. It also needs to address other limitations and demands related to water infrastructure, economies, human settlements and water quality, sanitation and health. Four globally significant actions can support the adoption of more efficient and sustainable water futures: green infrastructure watershed banks, an accelerated global research and solutions program, a new global water-ecosystem services observatory, and an improved technical capacity/workforce development initiative. Finally, the engagement of relevant stakeholders from academia, government, the private sector and civil society are needed to ensure that humankind will be able to meet its water security goals and commitments, including those expressed in the sustainable development agenda.

1. Introduction: an SDG-inspired vision of water security

Given the central role of water to human enterprise, the successful achievement of nearly all of the Sustainable Development Goals will depend on water. The integrity of the environment underpins a reliable water resource base, and well-managed environments offer essential and low-cost public goods and services. Thus, if these aquatic environments and their concomitant services are managed with a long time-horizon in mind – the essence of sustainability – they will provide a critical foundation to human well-being and economic development. IUCN (2018) defines *nature-based solutions* as actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits. It has also been a central focus of the 2018 World Water Assessment Program's 2018 report (WWAP/UN-Water, 2018). For the purposes of this article, we use *ecosystem-based solutions* interchangably with this other nomenclature.

The current, heavy reliance on modern, centralized engineering solutions to water problems typically ignores more cost-effective problem prevention and collaterally destroys environmental systems that produce renewable freshwater resources. These realities can be used to motivate a fundamental change in the way water security, in the sense of the collective definition articulated through the High Level Panel on Water focal points (see Section 3), could be effected through innovations in the arena of traditional engineering linked to the services provided by natural capital. Essential to any success in this domain will be a formal recognition of the role of environmental stewardship. Combining the realities of the day with aspirations for the future suggests a vision (Box 1), which we propose as a useful guidepost for formulating water-related policies and interventions during the execution phase of the SDGs. The remainder of this paper highlights the challenges and opportunities in realizing this vision.

2. The ecosystem services challenge

Fresh water serves many roles in the Earth system, sustaining our climate, biosphere, and human society. The availability of renewable and reliable water resources, the key to human water security, cannot be achieved on a truly sustainable basis without a well-functioning environment capable of supporting adequate resource quantity, quality, and timing. Ecological integrity, "the combination of the biodiversity and ecosystem processes that characterize an area at a given point in time" (Bridgewater et al., 2014),

Box 1. A vision for water security.

The year is 2030. The ever accelerating environmental and societal challenges of the rapidly developing world, particularly in the water sector, are today routinely met with novel solutions that have moved beyond the typical and unitary focus on engineering-based approaches of the past to embrace blended grey-green approaches to water management. These solutions were initiated within the first 5 years of the SDGs by early investments that stimulated innovation in water provision systems that rely on the conjunctive use of traditional engineering and environmental services. This has been particularly beneficial given now-universal recognition by member states of the criticality of water to support life on a planet experiencing growing human pressure. With the ever-rising costs of non-renewable energy, the benefits of water-related ecosystem services, combined with appropriately scaled grey infrastructure, have been harnessed for cost-effective and reliable water delivery. Conserving and managing well-functioning ecosystems today provides enormous cost savings that has freed-up investment capital to ensure universal access to clean drinking water and sanitation and has supported all 17 of the SDGs initiated back in 2015. Success can be verified by early investments (prior to 2020) in advanced environmental monitoring capabilities using state-of-the-art environmental sensing, data, and computer simulation systems, which have replaced fragmentary environmental surveillance systems and guesswork regarding water in the past. A skilled practitioner workforce is today in place, which can rapidly assimilate new knowledge from the water sciences and convert it into practical solutions.

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needs to also be viewed as an integral building block of the sustainable development agenda. Water-related ecosystem services include a broad array of benefits, such as the provision of clean water supplies, water for farming and food processing, fish protein, and greater resilience to climate extremes like flooding (Box 2). They also convey values in many parts of the world that are less visible, but are equally important in social, environmental, and economic realms (Díaz et al., 2018; Pascual et al., 2017).

Much has been written on the global water crisis with regard to scarcity, pollution, and lack of clean drinking water and sanitation available to large segments of the world's population (FAO, 2012; Hoekstra et al., 2012; WHO/UNICEF JMP, 2016; WWAP, 2015, 2016). Water scarcity already affects more than 40% of the global population, and water crises are now ranked as third in the top 10 global risks to the world economy (WEF, 2017). Water scarcity is projected to increase substantially well into the future (FAO, 2012; WWAP/UN-Water, 2018), with global demand for water services (from industry, agriculture and domestic use sectors) projected to rise by 20–30% in 2050 (Burek et al., 2016).

Many of these problems proliferate as a by-product of development, in the absence of adequate environmental management (Harrison et al., 2016; Vörösmarty et al., 2010). To achieve human water security, modern, centralized engineering-based solutions frequently have been promoted (Addams et al., 2009; Gleick, 2003; Hansjürgens et al., 2016; Tockner et al., 2016), in many cases ignoring more cost-effective problem prevention or mitigation achievable through improved management of natural infrastructure (Palmer et al., 2010, 2015). While traditional engineering approaches (hereafter referred to as *grey infrastructure*) without question convey immediate benefits in addressing a target water problem, they typically have been costly to install, often outstrip the technical capacity of many nations to operate and maintain, and in many cases impair environmental systems. This includes *green infrastructure*, natural and semi-natural ecosystems and other environmental features designed and managed to deliver a wide range of ecosystem services that serve as the foundation or source for renewable water supplies) (EC, 2013; Green et al., 2015; UNEP, 2014; Vörösmarty et al., 2013). Elements of these two categories of infrastructure are often combined, as with municipal water supplies relying on both protected watersheds as well as traditional water collection, treatment, and distribution systems (Dudley and Stolton 2003; Poustie et al., 2015; Kabisch et al., 2017).

Box 2. Key examples of water-related ecosystem services (after MEA, 2005; TEEB, 2010).

The justification for protecting goods and services produced from the environment, based on a utilitarian economic logic, is not new (Odum, 1973). More recent studies, quantifying the societal benefits of water-focused ecosystem services, like those given below, find that their importance has been typically underestimated, and the ultimate contribution of all ecosystem services to human well-being may exceed twice the value of global GDP (Costanza et al., 2014a,b).

Environmental services	Green infrastructure approaches	Examples
Drinking water for cities (water supply regulation)	Nearly one third of the world's 100 largest cities derive a significant proportion of their potable water from protected forests (Dudley and Stolton, 2003).	Cities such as Rio de Janeiro, Johannesburg, Tokyo, Melbourne, New York, and Jakarta depend on watersheds that are protected by forests to provide water for their residents (Dudley and Stolton, 2003).
Moderation of extreme events/ flood risk management (riverine flood control, urban stormwater runoff and coastal flood control)	Floodplains dampen the severity and duration of extreme river flows downstream (Blackwell and Maltby, 2006), while coastal wetlands and barrier islands reduce storm surge (Barbier et al., 2013). Green solutions include riparian buffers, forest conservation, green roofs, water harvesting, restored wetlands, mangroves, marshes and dunes (UNEP, 2014).	This has been especially important for cities such as Rotterdam and Lagos that depend on critical grey and green infrastructure approaches for their flood protection (Tessler et al., 2015).
Water quality regulation and waste-water treatment	Healthy ecosystems convey well-documented benefits in waste treatment (e.g., wetlands and other aquatic ecosystems remove human-generated pollution) and thereby act as natural water purification plants (de Groot et al., 2002; Russi et al., 2013).	A wetland in Kampala-Uganda purifies wastewater and removes pollutants entering Lake Victoria, saving Uganda up to US$1.75M in reduced waste-water treatment costs, much cheaper than traditional treatment systems (Emerton et al., 1998).
Habitat for biodiversity	Ecosystems naturally provide food, water, shelter, reproductive & nursery grounds, and thus abundant biodiversity. Lost biodiversity can reduce the efficiency of pollination, nutrient cycling, soil formation, water purification (Cardinale et al., 2012; Dicks et al., 2016).	An annual societal benefit of CA$263 per hectare is provided by the genetic pool of swamps and marshes in Canadian boreal ecosystems (Anielski and Wilson, 2003)
Recreation/tourism	Natural environments support a growing ecotourism sector within the US$1 trillion per year global tourism industry (Pratt, 2011).	Many iconic river systems benefit from increasing interest in ecotourism, such as in the Danube (Wetlands Restoration and Pollution Reduction Project, n.d.), Mekong (Khanal and Babar, 2007), and Amazon (Kirkby et al., 2010) Rivers.

In this context, four strategic challenges, if left unaddressed, will continue to entrench the status quo, making it increasingly difficult to move onto more sustainable water pathways for economic development:

(i) **Protected area shortfalls**. Even if protected areas have not been created to protect water supplies for humans per se, they often host valuable *green infrastructure* and deliver water and other types of ecosystem services to downstream users (Dudley et al., 2016). Even though there have been constant gains in protected area coverage in past years in some parts of the world (15.4% of terrestrial area and 8.4% of marine areas under national jurisdiction) (EC, 2017; Juffe-Bignoli et al., 2014), the global protected area coverage still falls short of meeting chief strategic targets set by the CBD (Lewis et al., 2017; Watson et al., 2014). Despite some progress towards achieving some of the CBD Aichi targets (especially target 1 on awareness, 11 on protected areas and 19 on knowledge), further efforts are needed to reduce pressures on biodiversity and ecosystem services (Tittensor et al., 2014; IPBES, 2018). For example, in the case of target 11, area coverage (where most progress has been reported) is only a component of this target and other essential aspects need to be fulfilled for the target to effectively be met. Some of these include the effective, equitable management of biodiversity, ecological representation of mixed ecosystems and the improvement of connectivity between sites (Barnes, 2015). There are important needs to be considered in the case of freshwater biodiversity and achieving this target. This target needs to account not only for area but also for the endemism of aquatic life forms, freshwater ecosystem processes, habitats, pressures and essential actions to maintain them (Juffe-Bignoli et al., 2016; Strayer and Dudgeon 2010). A baseline is required to report on national and global progress (Juffe-Bignoli et al., 2016). Furthermore, protected areas are often not effectively managed and do not sufficiently cover areas that are of special importance for biodiversity and ecosystem services, including those related to water provisioning services (Darwall et al., 2011; Holland et al., 2012; Harrison et al., 2016; Hermoso et al., 2016; Juffe-Bignoli et al., 2014).

Despite the recognized importance of green infrastructure (EPA, 2015; EC, 2016), protected areas remain grossly underfunded relative to traditional water engineering investments. Global investments in protected areas and their maintenance, which would otherwise help to reduce the cost of traditional water engineering services, is less than 3% of standard water sector expenditures, with US$10s of billions in annual shortfalls (Ashley and Cashman, 2006; McCarthy et al., 2012). Even when in place, protected areas are often positioned inside regions that are characterized by impaired environments or do not include headwater or recharge regions (Sáenz et al., 2016), limiting their value as natural capital (Fig. 1). Remarkably, watersheds purposefully managed for municipal water supplies – which should have as a preeminent concern their environmental protection – have instead shown progressive degradation that is evident worldwide (McDonald et al., 2016). These accumulated effects arise from population incursion, poor land management, nutrient and sediment pollution, and substantially raise the costs of providing an essential human water service (a ~50% modeled rise in capital and operational costs for one-third of cities recently analyzed).

(ii) **Lack of solutions-oriented research on composite grey-green infrastructure**. The idea of ecosystem-based water supply systems is not new; in fact, it is part of a broader set of integrated water resource management (IWRM) approaches (Bunn, 2016; Poff et al., 2015). The economic costs of relying solely on grey infrastructure is prohibitive for many countries and once built it often has unintended consequences (loss of life or surrounding buit capital, additional costs for repairs) due to partial or total failures. In the United States, nearly 14,000 dams have been classified as "high hazard" (ASCE, 2013). Combining grey with green infrastructure applied in the urban domain

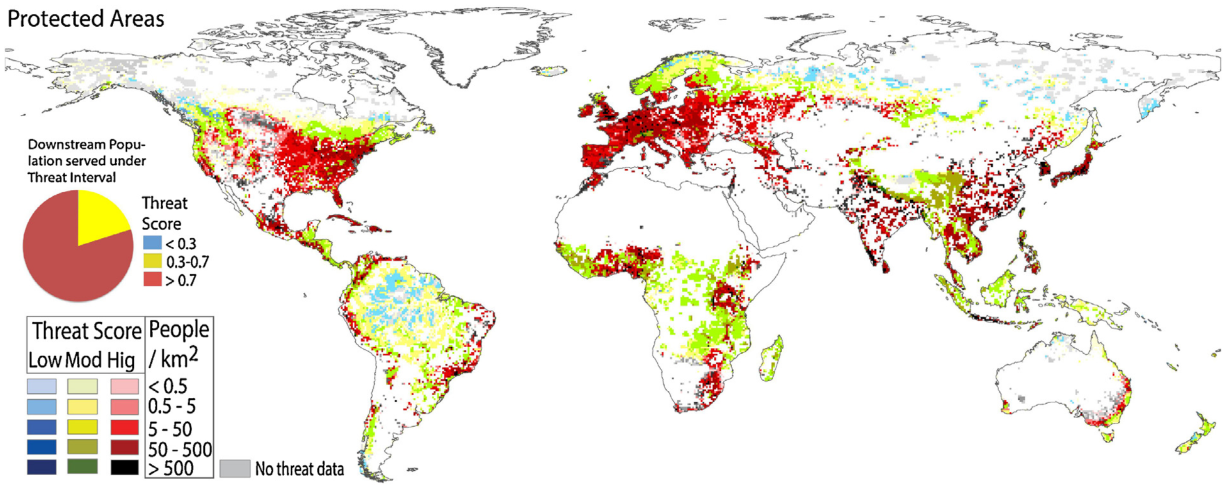

Fig. 1. The map below depicts the environmental performance of protected areas of the world, here co-located with freshwater provisioning source areas serving humankind. Although two thirds of the global population live downstream of protected areas, and the water services that they convey, nearly 80% of these people are served by water supplies drawn from protected areas under high levels of high environmental threat (red), especially in regions with dense population and agriculture. Costly remediation is needed to ensure water is safe and reliable (*Image:* Harrison et al., 2016). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

can increase resilience while providing other benefits (e.g., attenuating urban heat island impacts and saving energy via green roofs, providing natural habitats that buffer the impact of flood events) (Kabisch et al., 2017). However, there has been insufficient work on the design and context-dependency of performance for blending human-engineering with natural ecosystems (Hermoso et al., 2012, 2015); and application of methodologies on a scale required by the SDGs has yet to be formalized.

(iii) **Observatories in decline**. The application of SDGs to support water sustainability requires both a broad and deep knowledge of freshwater ecosystem function, and the dynamics of regional water use (Bhaduri et al., 2016). However, monitoring networks depicting the global water resource base and its supporting environments continue to deteriorate, particularly in response to reduced funding and operational support, thereby forcing researchers and practitioners to rely on *ad hoc* assemblages of data, simulation models, or best-guess approaches (GEO, 2014; WWAP, 2015). Yet, water resources managers cannot effectively plan or site grey infrastructure without detailed knowledge on the distribution and characteristics of existing infrastructure – both natural and grey. Such data limitations are a common problem in developing countries (Poustie et al., 2015). Monitoring networks need to help ensure that investments in protecting and restoring water resources are effective, which in turn can engender public confidence in the safety and reliability of their water supplies (Garrick et al., 2017). With further development space-based remote sensing could make a larger contribution to addressing these needs (GEO, 2014).

(iv) **Technical readiness in question**. Significant human and institutional capacity gaps limit the technical readiness of water professionals in many countries (UNESCO-IHE, 2013). Moreover, the additional knowledge needed to combine green with grey engineering for more cost-effective human water security remains in its infancy and requires a paradigm shift in engineering technology training, necessitating new interdisciplinary education programs worldwide. New programs to build technical capacity, especially in the global south, are needed. A recent example is a program funded by the United States Agency for International Development in partnership with the University of Utah and Mehran University in Pakistan that is creating a center for advanced studies in water in Pakistan (Burian et al., 2017); the project is aligned with attaining the SDGs for water.

Sustainability over a multi-generational timeframe, however, will be difficult without a meaningful, global commitment to addressing both the degradation of the world's drainage basins and their affiliated freshwater ecosystems, as well as the commitment to adequate collective stewardship of natural capital to maintain their ecosystem services into the future (Garrick et al., 2017).

3. Key interlinkages of ecosystem services with other sustainable development challenge domains

This document is in response to an official request made by the High Level Panel on Water (HLPW, 2016), which is co-convened by the UN Secretary General and the World Bank President and includes 11 heads of state and governments. A general inquiry was posted to the community of water experts in six sub-domains of the water security issue, on the themes of: *Water and the Environment*; *Water Infrastructure and Investment*; *Resilient Economies and Societies and Disaster Risk Reduction*; *Universal Access to Safe Water and Sanitation*; *Building Partnerships and International Cooperation*; and, *Sustainable Cities and Human Settlements*. We here deliver recommendations on the topic of *Water and Environment*, specifically focused on water-related ecosystem services and how they could be configured to support the sustainable development agenda (Box 3). Given the interconnected nature of these six themes, we were requested to explore the relationship of ecosystem services to these other high level challenges and to identify the co-benefits that would emerge should the themes be addressed together. These are discussed immediately below. In so doing we also hope to identify some specific objectives and actions that, as noted by others (Garrick et al., 2017), are necessary to address sustainable development of water resources (i.e., measurement, valuation, decision-making, and governance).

3.1. Water infrastructure

Our reliance on water engineering to provide secure freshwater resources extends to the earliest periods of human history (Vörösmarty et al., 2015), but today reflects a heavy dependence on *grey infrastructure* and some of the largest built systems on the planet. Grey infrastructure is sometimes overbuilt and its operation and maintenance costs are often ignored and not properly accounted for into water projects, resulting in less than optimal service (Palmer et al., 2015). Alternatively, as water and sewer services proliferate, wastewater treatment investments remain persistently underfunded (WWAP, 2015). It is reasonable to question the overwhelming emphasis on such systems in lieu of *green infrastructure* alternatives (i.e., the use of ecosystem services like floodplains for flood control or waste treatment), as they have been shown to provide an equivalent service. Such a debate is a rich one with strong arguments on both sides of the question. For instance, in the developing world with poor or non-existent water security, *grey infrastructure* is often seen as the only viable solution over an immediate timeframe (Muller et al., 2015). Further, where reliability must be high, green systems have not yet been fully justified. At the same time, grey systems are relatively inflexible, with much collateral and long-term potential damage to ecosystems (Palmer et al., 2015). Alternatives to an often overdesigned *grey infrastructure* include demand management or a reliance on small-scale systems, but these are seldom addressed in planning. Also, benefit-cost economics for *green infrastructure* is much less well developed relative to traditional engineering, thus limiting its attractiveness as an investment option.

If one accepts the importance of maintaining ecosystem services, their impairment represents water security threats with a substantial lost value to society, meriting rehabilitation. Post-hoc reparation is costly; for example

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Box 3. Water-related ecosystem services and the SDGs. Without ecosystem services managed for their long-term capacity to provide reliable, renewable sources of fresh water demanded by each sector of the economy, success in achieving each of the SDGs will arguably be placed into question.

1 NO POVERTY	Consistent access to clean water and impact buffering from costly water-related extremes like flooding from ecosystems are key to reducing poverty worldwide.	2 ZERO HUNGER	Agriculture depends on sustainable and efficient water use to support a growing human population.
3 GOOD HEALTH AND WELL-BEING	Well-functioning ecosystems support high levels of water quality, improving various aspects of quality of life, such as reduced exposure to water-borne diseases in addition to cultural and spiritual well-being.	4 QUALITY EDUCATION	Educating a next generation of environmental stewards focuses the education system on twenty-first century problem solutions.
5 GENDER EQUALITY	Improved water services can reduce gender inequality in household water collection and management, which in poor economies overwhelmingly fall to women and girls.	6 CLEAN WATER AND SANITATION	Upstream healthy ecosystems have an essential role in providing drinking water to downstream users.
7 AFFORDABLE AND CLEAN ENERGY	Efficient water use in both renewable and non-renewable energy systems reduces costs and improves the resilience of energy systems to climate change and its extremes.	8 DECENT WORK AND ECONOMIC GROWTH	Ecosystem-based water systems provide resource reliability supporting long-term economic growth; new investment in green and traditional engineering creates employment.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Innovation in water technology can lead to advances in efficiency and economic development.	10 REDUCED INEQUALITIES	Rectifying imbalances in water services and sanitation, now unequally distributed among rich and poor countries of the world, is a major step toward equality generally.
11 SUSTAINABLE CITIES AND COMMUNITIES	Water resources in cities can be redesigned to improve residents' health and well-being.	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Reducing water needs in production and consumption reduces threats to human water security and biodiversity.
13 CLIMATE ACTION	Water management and efficient use play a fundamental role worldwide in climate mitigation and adaptation.	14 LIFE BELOW WATER	Improving water quality will reduce ocean pollution and sustain many important fisheries that have life cycles dependent on both freshwater and marine ecosystems.
15 LIFE ON LAND	Water demand from urban users and businesses can stimulate upstream water source protection through forest conservation and restoration measures.	16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Well-managed watersheds can reduce the impact of asymmetries in water endowments within and across national borders.
17 PARTNERSHIPS FOR THE GOALS	Water's role in government, civil society, and the private sector means that co-beneficiary consortia can consolidate around all categories of ecosystem services in pursuit of the broader development agenda.	SUSTAINABLE DEVELOPMENT GOALS	

up to US$80 billion spent to rehabilitate the Yamatogawa River in Japan, a relatively small basin inhabited by only 2.1 million people (Tsuzuki and Yoneda, 2012). Even when investments are made, follow-up monitoring on the effectiveness of stream rehabilitation interventions is seldom attempted (Bernhardt et al., 2005), with the possibility that ineffective investment goes undetected or is even replicated in other regions. Additonally, this lack of monitoring and impact evaluation of rehabilitation and restoration means that the effectiveness of these processes may not be fully realized.

Where a nation's ability to invest in traditional water engineering solutions, create local technical capacity, and maintain workforce readiness is limited, *green infrastructure* solutions can provide cost-effective alternatives to *grey engineering* with additional environmental, economic, and social benefits. Based on existing scientific knowledge (Elsevier, 2016; Green et al., 2015), many management options are available, including combinations of grey and green approaches (Garrick et al., 2017; WWAP/UN-Water, 2018), with specific choices determined by budget constraints and the existence of natural capital assets (Young, 2000). Riparian vegetation (acting as green infrastructure) is increasingly considered valuable for safeguarding water services, especially in Latin America (Grieg-Gran and Porras, 2012; Veiga and Gavaldão, 2012). Properly designed *green infrastructure* (e.g., natural areas delivering urban water supplies or urban rainfall gardens) provides a less costly service for flash flood reduction compared to replacing or upgrading sewer mains (EPA,

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2015). More generally, cities may be the ideal proving ground for new grey-green infrastructure, especially where the reliability of traditional systems can be combined with the inherent environmental protection of green systems (Palmer et al., 2015; Vollmer et al., 2016). Such solutions can also generate a significant number of jobs, thereby contributing to sustainable social and economic development (WWAP, 2016). A new paradigm for developing countries and the SDGs that embeds the economic valuation of ecosystem services and green infrastructure into traditional benefit-cost analysis could stimulate new "blended engineering" approaches to water security (Elsevier, 2016; Poff et al., 2015).

There is growing concern that for many parts of the world, including the USA, the aging of infrastructure threatens to decrease water management efficiencies and lead to catastrophic failures in times of floods. The replacement of these dated grey water infrastructure facilities with green infrastructure alternatives could provide capital savings to support a broader green infrastructure upgrade. Important initiatives with "hybrid systems' are available at local scales. For example, engineering and biological measures (sedimentation-biofiltration) can be used for the treatment of stormwater (Jurczak et al., 2018). However, a broader scale perspective is required to address the challenge of establishing human water security (Green et al., 2015; Harrison et al., 2016; Valderrama et al., 2017).

3.2. Resilient economies

An important byproduct of blending grey-green water engineering would be a fundamentally new approach regarding the use of natural assets to help attain SDG-6 and universal water security. This greater water security would, in turn, support many other goals, such as SDG-2 on food, and SDG-15 on conservation, restoration and sustainable use of freshwater ecosystems and their services (see Box 3). If natural capital is viewed as a building block of resilient water engineering systems, then its state and stewardship should become an intrinsic part of the planning process (Bennett et al., 2016). This perspective would have the practical impact of expanding the decision trade-off "space" for acceptable water allocations to industry, energy, and food versus other essential societal needs like public water supply or safeguarding the environment (Garrick et al., 2017). Investing in natural capital and its water-related ecosystem services, will be especially significant for sectors heavily dependent on water (e.g., 95% of jobs in the agriculture sector, 30% of jobs in the industry sector, and 10% of jobs in the services sector) (WWAP, 2016). The emergence of new business models, based on verifiable, science-based metrics that support sustainable impact investment choices by recognizing good corporate practices can represent an important turning point in how society values ecological integrity in the broader economy (Vörösmarty et al., 2018). Such models would seek structural market changes and practices that account for and value natural capital based on data and analytics that allow companies to objectively evaluate costs and benefits (Vogl et al., 2017).

3.3. Human settlements

Global population is forecast to expand during the period of the SDGs and through mid-century to 9–10 billion people (Lutz et al., 2014). After 2025, all of this growth will be in the world's cities, as global rural populations begin to decline (UN, 2014). With urban growth will come increasing demands for energy, materials, and infrastructure, yet this growth already outpaces the capacity of governments to build essential infrastructure, creating "informal settlements" or slums, often along rivers and riparian areas (Lutz et al., 2014). There may be more than 200,000 world communities that can be classified as slums, and the UN suggests that today these are where 1-in-3 urban dwellers reside (UN-HABITAT, 2010; WHO and UN-HABITAT, 2010). UN-Water (WWAP, 2015) highlights both the challenges and potential solutions for water: The world's slum population, which is expected to reach nearly 900 million by 2020, is both underserved with respect to basic water needs, and also more vulnerable to the impacts of extreme weather events. It is however possible to improve performance of urban water supply systems while continuing to expand the system and addressing the needs of the poor.

Under the specter of climate change these development deficiencies turn into "adaptation deficits" (Satterthwaite et al., 2007). The challenge of supplying adequate freshwater under uncertain future climate is exacerbated in xeric, coastal and riverine cities. Approximately 34% of the global urban population lives in arid regions (McGranahan et al., 2005) and more than 150 million people today are dependent on urban water supplies that show perennial shortage, with forecasts for that number to rise to 1 billion by mid-century (McDonald et al., 2011). Further, more than 50% of the world's urban population lives along coastlines or rivers (McGranahan et al., 2005). In these locations, the most vulnerable are typically the urban poor, in part because they often live in hazardous locations, such as floodplains.

In these contexts, protected watersheds and their associated ecosystem services can play an important role in managing the global transformation to an urbanized planet. For example, cities can rely on the protective role of ecosystem services by using natural lowlands as "relief valves" to allow dense settlements to escape the impact of river floods, as is current practice by The Netherlands Room for the River programme (Roth and Warner, 2007) or in the Mississippi River Basin (USACE-IWR, 2000). For example, The Netherlands programme recognized the flood risk reduction benefits of giving more space to rivers to increase their discharge capacity instead of building higher dikes in the face of increasing impacts of extreme flood events, which are likely to be exacerbated by climate change. This was done by constructing a bypass channel, an island in the river Waal and bridges to improve the connectivity of the area. Both the bypass channel and the island form a river park that provides recreational,

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ecological and aesthetic benefits besides flood risk protection (van Herk et al., 2015; WLA, 2017).

Another example is low impact development (LID) design and technologies within cities that focus on a range of stormwater management outcomes, from restoring water quality to flood prevention and rainwater harvesting. LID design includes hydrologic analysis in site planning, integrated management of erosion and sediment control as well as public outreach. LID technologies include, green roofs, rain gardens, permeable pavement, retention cells and treatment swales. LID has been implemented in the USA, Europe, Australia, New Zealand and China (Chang et al., 2018). A study of community demand in Jakarta also showed that the public would be willing to pay for freshwater ecosystem protection and rehabilitation that result in increased water security (Vollmer et al., 2016). This includes park space along the river and conservation of forests in the upper part of the catchment outside of the city, and possibly also support for a widened channel for flood risk mitigation. The key will be to create solution frameworks to more sensibly manage the inevitable trade-offs between urban water provision and urban infrastructure protection, while simultaneously preserving water flows for aquatic ecosystem health and biodiversity.

3.4. Water quality, sanitation and health

Significant, direct health impacts occur when ecosystem services are no longer able to meet human water security needs. Healthy ecosystems are highly effective at improving water quality and quantity (Russi et al., 2013; TEEB, 2010), removing pathogenic microbes, sequestering and converting inorganic ions, and transforming persistent organic pollutants (TEEB, 2010). Impairing or degrading ecosystems, especially those directly linked to the freshwater supply (Fig. 1), yields significant consequences for sanitation and hygiene. Even in places like the U.S.A. nearly 50 million people have used public water systems containing concentrations of chemicals and bacteria that exceed regulatory limits (Duhigg, 2009). The recent *Transboundary Waters Assessment Programme* (*TWAP*) synthesis report tabulated 1.4 billion people, half the population living in transboundary basins, facing serious and increasing risks due to pollution (UNEP-DHI and UNEP, 2016).

These realities are not inconsequential to the basic water goals (SDG-6) of the sustainable development agenda, insofar as inland aquatic ecosystems convey 80% of sustainable water supply to humans, yet are broadly degraded (Vörösmarty et al., 2010). This has already elevated costs for remediation to the level of US$100s of billions worldwide (Ashley and Cashman, 2006; Vörösmarty et al., 2010); if left unchecked, such degraded aquatic ecosystems produce substantial risks to human health. One of countless examples occurred in 2014 in Toledo, Ohio (USA), which had to temporarily cease drinking water operations due to the presence of cyanotoxins produced by blue-green algae in Lake Erie, a result of poor management of point and non-point source pollution across contributing landscapes. What was once considered a sporadic phenomenon, such harmful algal blooms have proliferated both in the U.S. and globally over only the last 30 years (WHOI, 2016).

4. Brief overview of the current landscape of the challenge

4.1. Diagnosing the challenge

While there is no shortage of individual challenges associated with ecosystem services that support water in the context of the SDGs (Box 3), these can be synthesized into a small number of urgent concerns. Seven such challenges areas are presented below, ranging from benchmarking the current state of affairs with respect to water-related ecosystem services to the impact of their loss, their surveillance, and approaches to coping with ongoing water stress.

4.1.1. Ecosystems in decline

Maintaining healthy ecosystems in light of ongoing economic development remains a persistent challenge, with a global disappearance of "the wild" in the contemporary world (Sanderson et al., 2002). In a turn-of-the-century benchmark study, the Millennium Ecosystem Assessment (MEA, 2005) demonstrated that all but one of 13 major ecosystem classes was in decline. Since this time, numerous studies have shown a deterioration of these ecosystems and their services, today and into the future – Living Planet Index (WWF, 2016), UNEP GEO-5 (UNEP, 2012), and Human Ecological Footprint (Mancini et al., 2016). Four recently launched landmark assessment reports of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) – with 129 member governments across four world regions: the Americas, Asia and the Pacific, Africa, as well as Europe and Central Asia – show alarming trends of declining biodiversity and ecosystem services (IPBES, n.d.). In the Americas, 65 per cent of biodiversity and ecosystem conditions that are important for human well-being are declining with 21 per cent declining strongly. Wetlands have been highly transformed across large areas of the American continent (IPBES, 2018). This loss of healthy ecosystems translates to a pandemic loss of effective support systems for a number of watershed ecosystem services of direct benefit to society – safe drinking water, wastewater processing and dilution, river bank stabilization, erosion control, and disaster risk reduction to downstream populations (Medeiros et al., 2011; TEEB, 2010; IPBES, 2018).

4.1.2. Biodiversity implications

Degraded freshwater ecosystems, vital for species diversity, are also a critical focal point of global species loss; at least 126,000 described species rely directly on freshwater habitats, including many diverse plants, invertebrates and vertebrates (Balian et al., 2008; IUCN, 2016). This number, while based on the most comprehensive global analysis thus far, is certainly an underestimate, and is likely to grow to over 1 million species if currently undescribed species are included (IUCN, 2016). Of the 28,000 freshwater-dependent species that have been assessed for the IUCN Red List of Threatened Species (www.iucnredlist.org) thus far, approximately one third are threatened with extinction (Carrizo et al., 2017). Some estimates place the per area rates of imperilment and extinction for freshwater species likely to be 100s if not 1000s of times more rapid than in land or ocean (Strayer and Dudgeon, 2010). The acceleration of biogeochemical cycles (e.g., erosion, N_2 fixation) due to human activities affect riverborne material and its transfer across river systems (Meybeck and Vörösmarty, 2005). When natural filters (like wetlands or soil-vegetation layers) are removed or impaired (e.g., fields drained for agriculture) there is a consequential loss of their natural functionality (Meybeck and Vörösmarty, 2005).

Conserving or rehabilitating environmental flows (i.e., "quantity, timing and quality of water flows required to sustain freshwater ecosystems and the human livelihood and well-being that depend on these ecosystems") (Riversymposium, 2017) is necessary to balance human modifications to river flows that can result in the loss of freshwater biodiversity and impairment of ecological processes in rivers (Arthington, 2015; Riversymposium, 2017; Pittock et al., 2015; Poff et al., 2010; Poff and Matthews, 2013). While certainly water engineering works such as dams and reservoirs are sometimes necessary to address water security, the challenge is how to manage the negative effects these produce on natural flows, and freshwater and riparian biodiversity, relating to the physical, chemical and biological impacts they confer. Emphasis on renewable energy under the Paris Agreement is likely to stimulate investment in hydropower (IHA, 2016), with severe negative impacts on aquatic biodiversity (Strayer and Dudgeon, 2010). In certain parts of the world, environmental flow protection is intimately connected with issues of the social and associated cultural values of water (Morgan, 2012). One example is the National Cultural Flows Research Project in Australia that aims to align indigenous water allocations in Australia's water planning and management efforts, ensuring appropriate delivery and maintenance of the cultural, social, and spiritual benefits in systems like the Murray-Darling Basin (National Cultural Flows Research Project, 2018).

The TWAP (UNEP-DHI and UNEP, 2016) noted that extinction risk to freshwater biodiversity is moderate to very high in 70% of the area of transboundary river basins – indicating a strong need for international cooperation to address this issue. Important international agreements promote the effective transboundary management of aquatic systems within countries but also across boundaries. For example, the Convention on Wetlands, Ramsar, provides a framework for national and international action towards the conservation and adequate use of wetlands and their resources (Ramsar et al., 2014). The Convention on Migratory Species (CMS) is also focused on the protection of species that migrate across or outside national jurisdictional boundaries (https://www.cms.int/en/convention-text). Hogan (2011) identified ca. 30 species of freshwater fishes that meet all the criteria for CMS listing, and a further ca. 10 species that might benefit from a listing. There are 29 freshwater 'megafauna species' – which represent flagships for the conservation of freshwater ecosystems – currently listed by CMS (Carrizo et al, 2017).

4.1.3. Lost ecosystem services mean rising economic costs

The supporting environment is rapidly losing its ability to deliver services (Day et al., 2014), with wetlands – of particular value to water security in terms of pollution abatement, fisheries, and flood control – particularly in decline. Overall declines represent an economic loss of US$4.3-20.2 trillion in ecosystem services between 1997 and 2011 (Costanza et al., 2014a). Nevertheless, in most countries funding for ecosystem protection for water services and infrastructure is neither sufficient nor sustainable (WWAP, 2015), despite high return-on-investment ratios (e.g., 3-to-1 recognized in China [China Water Risk, 2016]). For protected areas (that are designed to convey ecosystem services of many types), less than 6% of countries reporting to CBD indicated adequate resources for the management of such areas (Watson et al., 2014), yet a recent study showed that staff and budget capacity were the strongest predictor of the conservation impact of protected areas (Gill et al., 2017). A survey of protected areas in the Southeast USA showed that most protected areas have fewer resources dedicated to freshwater conservation and management than to other activities, and some completely lack the necessary resources (McDonald et al., 2016; Thieme et al., 2012). This is further evident in many populated parts of the world, where protected areas face increasing threats due to their proximity to poorly managed watersheds and other external stressors (Harrison et al., 2016; Thieme et al., 2012), which raises the cost of protected area management (see Fig. 1).

4.1.4. Funding of protected ecosystems and their Services

Despite the fundamental role of ecosystem-based solutions in biodiversity conservation and provision of ecosystem services, investment in these solutions remains well below 1% of total investment in water resources management infrastructure (WWAP/UN-Water, 2018). Governments, businesses, and donors invested only US$ 25 billion in 2015 on payments for green infrastructure for water directed at rehabilitating and/or protecting 487 million ha under watershed management (Bennett and Ruef, 2016). Such investments included public subsidies (e.g., government-based payment for watershed services), user-driven watershed investments (e.g., payments from water users such as water utilities or companies to conserve, restore or create green infrastructure), water quality trading and offsets, and water markets that trade water rights (Bennett and Ruef, 2016).

These interventions relied primarily on public subsidies, but also collective actions such as water trust funds. The potential for success of payment for watershed services schemes is regionally highly variable (Harrison et al., 2016), but has been shown to be successful in some areas (Abell et al., 2017). A new initiative under development is the Cloud Forest Blue Energy Mechanism that aims to mobilize domestic commercial finance to reforest and conserve cloud forests that provide crucial benefits to the hydropower industry in Latin America. It is based on a "pay for success" financing model where hydropower plants pay for the ecosystem benefits provided by restored cloud forests (The Lab, 2018).

In some parts of the world, especially in developing countries, there is a severe underfunding of protected areas (McCarthy et al., 2012; Watson et al., 2014), and an additional area of 2.2 million km^2 of land and inland waters is needed to be effectively managed and sufficiently cover areas that are of special importance for biodiversity and ecosystem services (Juffe-Bignoli et al., 2014). Preserving and effectively managing all terrestrial sites for global taxa protection was estimated to cost US$76.1 billion annually (McCarthy et al., 2012). To put this in perspective, more than US$1 trillion will be needed by the traditional water services sector alone by year 2030 (Ashley and Cashman, 2006).

4.1.5. Tracking metrics

Observational networks and monitoring systems (through remote sensing, *in situ* sampling, ground truthing, surveys) to evaluate the ways in which humans control, degrade, or possibly enhance water services – and thus define the collective significance of these changes – remains an urgent global need (Gardner et al., 2015; Turak et al., 2017; Garrick et al., 2017; WWAP/UN-Water, 2018). Consistent and objective information on the state of water resources, including their use and management, is frequently missing, inadequate, or unavailable, with the situation for water quality data even more severe (FAO, 2006; WWAP, 2015). Currently, water observation networks over most parts of the world provide only partial or unreliable data on surface and groundwater quantity and quality, with a similar paucity of information with respect to wastewater related services (GEO, 2014; WWAP, 2009). Furthermore, several studies show only static snapshots of the state of water services at a particular time and place, failing to include a more comprehensive view of water challenge trends over time and across different regions in the world. For example, inability to measure all of the implications of an extreme precipitation event for erosion and pollution mobilization reflects our inability to undertake fully integrated monitoring programs. This has an obvious and direct practical implication for water system planning and decision-making (WWAP, 2015). The situation is particularly severe in the least developed countries, where long-term sustainability clearly hinges on reliable water data. In addition, the potential for using remote sensing data to help address these monitoring needs should be further explored.

Water indicators of a systematic and dynamic nature (e.g., near real time) from the earth system sciences can provide long-term annual and sub-annual tracking of water availability (FAO, 2006), which can be combined with coincident socio-economic changes to compute water vulnerability indicators (Vollmer et al., 2016). Such a capability would be an important step forward in creating an operational and dynamic monitoring capability. This is critical as hydrologic change keeps pace (or not) with climate change (Milly et al., 2008; NRC-COHS, 2011). This would be a necessary precursor for a sustained and comprehensive global water assessment procedure.

4.1.6. Capacity building for water-related SDG support

Achieving long-term, positive environmental benefits is an especially important outcome of capacity development, particularly if they can be used to train a next generation of practitioners and decision makers in strengthening policies, strategies and legal frameworks that support the sustainable use of water-related ecosystem services (UNESCO-IHE, 2013; Wyborn et al., 2016). However, this has not been well implemented; in terms of capacity, only 14 of 108 surveyed nations were capable of instituting the Johannesburg target on integrated water resource management (IWRM) (WWAP, 2006). In addition to traditional water engineering and technology training, current and future professionals need to be trained to bettter understand and then use water-related ecosystem services datasets and tools with blended engineering approaches (Future Earth, 2016; SIWI, 2016; START, 2016; SWFP, 2016; UNESCO-IHE, 2013; UN-Water, 2015). This includes accounting of the benefits of water-related ecosystem services to improve quality of life as well as to evaluate ecosystem states and trajectories. In addition, an appreciation of the cross-linkages among the SDGs will be essential; a general framework for mapping these interactions has been proposed (Nilsson et al., 2016) and a logical next step is to apply this more specificially to the SDG Targets that are relevant to freshwater (Bhaduri et al., 2016). Major investments are needed in water education and capacity building, particularly in Africa where the gap between needs and reality is highest.

4.2. Key actors and activities

Existing mechanisms are in place to address many of the challenges highlighted in this document, advanced by a community that recognizes a high demand for water-related ecosystem services and an opportunity to implement cost-effective actions towards watershed protection, restoration and sustainable management (Rodríguez Osuna, 2015; TEEB, 2010). Such mechanisms include: payments for watershed services (PWS) or water quality/quantity; trading markets; and, reciprocal or in-kind agreements (water funds); support for research and applications. There is also a ready-made community of actors contributing to water-related ecosystem services protection or capacity development that could jointly be mobilized for protection and management efforts in the context of the SDGs (Table 1).

For example, UNESCO's International Hydrological Programme (IHP) is the intergovernmental program of the UN system devoted to water research, water resources management, education and capacity building. Since its foundation in 1975, IHP has evolved from an international hydrological research program into an institution with a broader agenda to facilitate education and capacity building and improve water resources management and governance. This program has been implemented in six-year stages and is in its eight implementation phase (2014–2021). This current phase focuses on six thematic areas: (1) Water-related disaster and hydrological changes; (2) Groundwater in a changing environment; (3) Addressing water scarcity and quality; (4) Water and

Table 1
Examples of key mechanisms, tools and data portals, and institutions related to water-related environmental services.

Name of the initiative	Objective	Actors	Outcomes	Scale
TNC Protecting Water for People and Nature/Water Program and NatureVest	To conserve freshwater through scientific and strategic partnerships in: Sustainable Hydropower, Source Water Protection, Agriculture & Water, Water Markets, and Floodplain Restoration	NGOs, private sector, local governments	Water funds and system-scale planning facilities set up in several regions (Latin America, US, Africa, Australia)	Local, regional, global
The World Bank-Wealth Accounting and the Valuation of Ecosystem Services-WAVES	To promote sustainable development by ensuring that natural resources are mainstreamed in development and national economic planning	World Bank and 8 partner countries	Accounting methods, case studies, tools and publications	Select national
UNESCO-IHE Institute for Water Education; a large international educational and research facility	To train professionals in the fields of water, the environment and infrastructure in developing countries and countries in transition	Academia, UN Institute	Graduate education; technical courses; new knowledge to address key water-related development challenges	Regional, global
Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)	To provide policy relevant knowledge on biodiversity and ecosystem services to inform decision making	UN body formed with 124 Country members, a Secretariat and an Expert Panel	Study TEEB Reports (e.g., TEEB for Water and Wetlands)	Global, regional, local
The Economics of Ecosystems and Biodiversity for Water and Wetlands (TEEB)	To execute global-scale analysis on the importance of valuing ecosystem services in the policy arena	Government of Germany, European Commission, academia	Dataset of publicly available corporate water information; CDP Global Water Reports	Global
The Carbon Disclosure Project-CDP Water Program	To guide companies and investors to better understand how their portfolio companies and suppliers are disclosing water associated risks	Private sector (investors network)	Reports, maps, country rankings	Global
The Aqueduct Water Risk Atlas (Aqueduct)-World Resources Institute	To inform companies, investors, and other audiences about geographic exposure to water-related risks	NGOs, private sector	Reports on exposure to water risks at various levels	Global
World Wide Fund for Nature-WWF: The Water Risk Filter	A tool for companies to raise awareness and an understanding of their water risks, as well as mitigation activities	Private sector, NGOs	Baseline reports and maps; future scenario assessments; water governance analysis; monitor progress in meeting SDG 6	Local, regional
Freshwater Health Initiative	To measure the overall condition of freshwater ecosystems and their ability to support healthy and economically-sustainable populations.	Basin organizations; local, provincial, national governments; NGOs; industries		Basin (local to regional)
Global Wetland Observing System (GWOS) and Satellite-based Wetland Observation Service (SWOS)	To monitor the status of the world's wetlands and their ecosystem services	Univ. of Bonn, Wetlands Int'l, Ramsar Secretariat, and GEO BON/GEO Water/ GEO-Wetlands	Data set and reports on the status of the world's wetlands	Global, Regional
The 2030 Water Resources Group	To facilitate dialogue processes for water resources reform in water stressed countries and in developing economies	Bilateral agencies, private companies, development banks, civil society	Reports, newsletters, case studies	Global, Regional
IUCN World Commission on Protected Areas, Freshwater Task Force	To assimilate information about legal, institutional and social factors addressing protected area and water security management	Voluntary body of experts, coordinated via IUCN	Reports and case studies on successes	Global, Regional
Sustainable Water Future Programme and Solutions Lab	To address science, engineering, governance and management issues to drive change and stimulate water solutions	Academia, industry	Scientific reports, proofs-of concept, case studies	Global

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human settlements of the future; (5) Ecohydrology, engineering harmony for a sustainable world and (6) Water education, key to water security (UNESCO, 2018).

An affiliated UNESCO European Regional Center for Ecohydrology links the understanding of relationships between hydrological and biological processes at different scales to improve human water security, enhance biodiversity and other opportunities for sustainable development. Ecohydrology views ecosystem processes as management tools to achieve sustainability by stating multidimensional objectives to manage catchments – WBSRC (Water, Biodiversity, Ecosystem Services for Society, Resilience to climatic changes and Cultural heritage) (Zalewski, 2000; Zalewski et al., 2017). The WBSRC strategy aims at gaining synergies between ecosystem-based solutions and the circular economy (Zalewski et al., 2017).

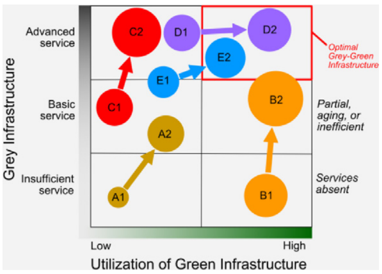
Box 4. Blended grey-green infrastructure approaches to water security in three key ecosystem service domains.

Environmental service	Actions to create optimal composite grey-green infrastructure
Drinking water for cities	Green: Increase areas under watershed protection (especially upstream sustaining ecosystems) through riparian forest protection, re/afforestation of upstream ecosystems Grey: Modernize drinking water treatment facilities; increase levels of treatment in sanitation systems (for receiving water integrity, which is often used as water supply downstream); minimize/avoid water losses (e.g. leaking pipes)
Water quality/pollution mitigation	Green: Develop and expand wetland areas, bioswales, and other natural infrastructure Grey: Modernize wastewater treatment plants to improve levels of treatment and efficiency gains
Flood risk control	Green: Restrict human settlement in vulnerable lowlands; expand and restore wetlands; identify and use natural and managed landscapes as "relief valves" during extreme precipitation and river discharge extremes; execute benefit-cost studies on value of green infrastructure Grey: Optimize conjunctive management of flood mitigation at the basin scale; revise future plans for hard infrastructure (e.g., levees & check reservoirs)

Each of the actions described above represents a way in which cities and countries could utilize the best in both grey and green infrastructure to meet SDG goals. While the optimal scenario of high adoption rates for green infrastructure (e.g., abundant wetlands for water quality purification) coupled with advanced, modern grey infrastructure systems (e.g., highly efficient water delivery systems) may not be achievable universally, cities in U.N. member states could nonetheless move toward a more efficient and sustainable water pathway, reflecting all major constraints (e.g., no remaining natural lands) or opportunities (e.g., existing grey infrastructure, retrofitted to adopt green components). Developing an individualized plan for each state/city would allow each to foster innovations in water security, which may be transferrable elsewhere.

Within the short term (2018-2020), an inventory and analysis of water sector approaches in each of the world's top 100 cities could be identified, with an eye toward identifying arenas of potential improvement to grey-green water infra-structure. Over the medium term (2020-2030), an initial ten cities could begin improvements toward achieving optimal or improved water environmental services, with additional cities to be added to this target list (e.g., 10 additional cities per year). The long-term goal (2030 and beyond) would be for all 100 cities to have significantly moved along their individual pathways to sustainable human water security, a situation augmented by new cities on an ongoing basis.

Below are five example scenarios of how different nations/cities could move from their present-day water security (current status denoted by "1" in each circle) to a more sustainable water future able to meet the needs of its expanding urban population (e.g., larger circles denote increased demands in the future). The scenarios would use the best possible combination of grey-green infrastructure for that city (2030 and beyond scenarios denoted by "2").



A1/A2: Currently very limited grey infrastructure to meet city's needs, together with limited use of green infrastructure. Due to these constraints, can only capitalize on modest gains in grey-green infrastructure. *Example: Kabul, Afghanistan.*

B1/B2: Currently has abundant availability of green infrastructure, but no efficient or available grey infrastructure. Future improvements by modernizing grey infrastructure for gains in efficiency. *Example: Kinshasa, DRC.*

C1/C2: Today has sufficient grey infrastructure to meet demand, but limited availability of green infrastructure due to abundant land use in surrounding areas. Future benefits can only be achieved by rehabilitation of land for green infrastructure coupled with improvements to grey infrastructure efficiency. *Example: Beijing, China.*

D1/D2: Currently has moderate use of green infrastructure, coupled with advanced/efficient grey infrastructure. Future system improvements by increasing amount of green infrastructure used for water services. *Example: New York City, USA.*

E1/E2: Currently has basic grey infrastructure with low-to-moderate use of green infrastructure. Future benefits can be achieved through modest improvements in both grey and green infrastructure (e.g., reducing leaks in pipes, expanding green areas for water quality improvements). *Example: Rio de Janeiro, Brazil.*

5. Call-to-action: managing supplies, quality, and risk

The economic development-environmental protection dichotomy is an out-dated construct, and a 21st century approach to the water crisis (Young, 2000) is progressively being developed by researchers and practitioners, in which they combine traditional and ecosystem-based engineering solutions. A major strategic initiative is proposed here. Four strategic, globally-significant supporting actions are shown here as opportunities to counterbalance trends in the deterioration of water-related ecosystem services, as well as in the erosion of the capacity of SDG signatory states to address four main strategic water challenges as outlined in Section 2.

- *Green infrastructure watershed "banks"* comprising natural ecosystem-based assets that would be identified and employed in water delivery systems designed for long-term, cost-effective human use;
- *An accelerated global research and solutions program* on coupled human–environment engineered systems, based on cost-benefit analyses that explicitly evaluate green infrastructure, to attain universal, human water security through well-functioning, integral environments;
- *A new global water-ecosystem services observatory* to assess progress or backsliding in sustainable management of water assets, combining state-of-the-art Earth observations, survey data, and simulation models depicting conditions from worldwide to local scales and with near real-time, operational coverage, and;
- *An expanded capacity/workforce development initiative* to create universal readiness among UN member states to produce a next generation of environmental planners and water practitioners.

The supporting initiatives are presented here as durable actions to the development agenda during the full SDG timeframe but also post-2030. A brief, annotated description is offered in Box 4. A diverse set of stakeholders from academia, government, the private sector and civil society would need to be engaged to ensure success. A global inventory of *watershed banks* would help to identify candidate natural assets to be combined ultimately with grey approaches. *Research*, of both a basic and applied nature, would need to include the scientific community and engineers, supported by public funding agencies, but also through innovation grants from foundations and private sector research and development (R&D). *Observatory and monitoring components* of such a program would involve a similar set of actors. To expand *technical capacity*, international research societies, technical schools and universities, UN and other development-oriented educational programs, and private sector internal training programs would need to be engaged.

6. Conclusion

A growing and rapidly urbanizing population and its associated production and consumption of energy and materials will impact fresh water systems for the foreseeable future. Yet, these drivers and their impacts have not been sufficiently controlled by current conservation and mitigation measures (Garrick et al., 2017; Green et al., 2015; Harrison et al., 2016), rendering improved environmental management for water security a persistent societal imperative over the entire SDG execution period. If one accepts the premise that durable water security requires well-functioning ecosystems, a central tenet of SDG-6 expressed through target 6.6, then this improvement we speak of becomes critical, as the biocapacity or carrying capacity of ecosystems, catchments and the biosphere at large to provide water services to humankind is likely to otherwise continue its long-term decline (Global Footprint Network, 2016) and compromise the very water security that SDG-6 seeks.

In the context of sustainability, new solutions become apparent – at once recognizing the need to raise the level of human economic well-being, while at the same time preserving the underlying benefits of natural capital in water provisioning. Innovation in the evolving 21st century water sector will be central to such a transformation, and a critical part of this innovation will be a deeper understanding of ecosystem services and appreciation of how these can be used productively and in tandem with traditionally engineered systems (Palmer et al., 2015).

One could argue that the degree to which we have, thus far, been successful (or not) in meeting the water challenge is predicated on our more-or-less unitary focus on traditional engineering to address society's growing water challenges. An expanded approach, that includes an admittedly more complex and unwieldy set of multiple perspectives that embody ecology, engineering, economics, governance, ethics and culture, will undoubtedly be a challenge for researchers and practitioners to achieve. The broad scale absence of integrated water resource management benefits (Vörösmarty et al., 2010), themselves multidimensional, is a testament to this challenge ahead. In this context, it is important to recognize that the community is in the early stages of a much needed, but much longer-term dialogue, on this subject.

The proposals made in this article are admittedly but a starting point and but one way forward, yet they hopefully provide a small enough set of practical guideposts around which policymakers and practitioners could begin to unite. Formulating international policies on climate mitigation and adaption suggests that overcoming water challenges will not be an easy task, but one that will bear no less critical impacts on human well-being and environmental integrity for many decades to come.

Conflict of interest

None declared.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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References

Abell, R., Asquith, N., Boccaletti, G., Bremer, L., Chapin, E., Erickson-Quiroz, A., Higgins, J., Johnson, J., Kang, S., Karres, N., Lehner, B., Mcdonald, R., Raepple, J., Shemie, D., Simmons, E., Sridhar, A., Vigerstøl, K., Vogl, A., Wood, S., et al., 2017. Beyond the Source: The Environmental, Economic and Community Benefits of Source Water. The Nature Conservancy; Arlington, VA. Retrieved fromhttps://www.cbd.int/financial/2017docs/tnc-water-source.pdf.

Addams, L., Boccaletti, G., Kerlin, M., Stuchtey, M., 2009. Charting Our Water Future. Economic Frameworks to Inform Decision-Making. 2030 Water Resources Group. The Barilla Group, The Coca-Cola Company, The International Finance Corporation, McKinsey & Company, Nestlé S.A., New Holland Agriculture, SABMiller plc, Standard Chartered Bank, and Syngenta AG.

Anielski, M., Wilson, S.J., 2003. Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems. Retrieved from-Canadian Boreal Initiativehttp://files/193/Boreal_FINAL.pdf.

Arthington, A.H., 2015. Environmental flows: a scientific resource and policy framework for river conservation and restoration. Aquat. Conserv. Mar. Freshw. Ecosyst. 25 (2), 155–161.

ASCE, 2013. 2013 Report Card for America's Infrasructure. American Society of Civil Engineers, Reston VA 74 pp.

Ashley, R., Cashman, A., 2006. The impacts of change on the long-term future demand for water sector infrastructure. In: OECD (Eds.), Infrastructure to 2030: Telecom, Land Transport, Water, and Electricity. OECD Publishing, Paris, France, pp. 241–349.

Balian, E.V., Segers, H.H., Lévèque, C., Martens, K., 2008. The freshwater animal diversity assessment: an overview of the results. Hydrobiologia 595 (1), 627–637.

Barbier, E.B., Georgiou, I.Y., Enchelmeyer, B., Reed, D.J., 2013. The value of wetlands in protecting Southeast Louisiana from hurricane storm surges. PLoS ONE 8 (3), e58715.

Barnes, M., 2015. Protect biodiversity, not just area. Nature 526 (7572), 195.

Bennett, G., Ruef, F., 2016. Alliances for Green Infrastructure: State of Watershed Investment 2016. Retrieved fromForest Trends, Washington, DChttps://www.forest-trends.org/wp-content/uploads/2017/03/doc_5463.pdf.

Bennett, G., Cassin, J., Carroll, N., 2016. Natural infrastructure investment and implications for the nexus: a global overview. Ecosyst. Serv. 17, 293–297.

Bernhardt, E.S., Palmer, M., Allan, J.D., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson, R., Katz, S., Kondolf, G.M., Lake, P.S., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Powell, B., Sudduth, E., 2005. Synthesizing U.S. river restoration efforts. Science 308 (5722), 636–637.

Bhaduri, A., Bogardi, J., Afreen, S., Voigt, H., Vörösmarty, C., Pahl-Wostl, C., Bunn, S.E., Shrivastava, P., Lawford, R., Foster, S., Kremer, H., Renaud, F.G., Bruns, A., Rodríguez Osuna, V., 2016. Achieving sustainable development goals from a Water perspective. Front. Environ. Sci. 4 (64), 1–13.

Blackwell, M.S.A., Maltby, E., 2006. How to Use Floodplains for Flood Risk Reduction. Ecofllod Guidelines. European Commission. Directorate-General for Research, Sustainable Development, Global Change and Ecosystems, Luxembourg.

Bridgewater, P., Kim, R.E., Bosselmann, K., 2014. Ecological integrity: a relevant concept for International Environmental Law in the anthropocene? Yearb. Int. Environ. Law 25 (1), 61–78.

Bunn, S.E., 2016. Grand challenge for the future of freshwater ecosystems. Front. Environ. Sci. 4 (21), 1–4.

Burek, P., Satoh, Y., Fischer, G., Kahil, M.T., Nava Jimenez, S., Scherzer, A., Tramberend, S., Wada, Y., Eisner, S., Flörke, M., Hanasaki, N., Magnusziewski, P., Cosgrove, W., Wiberg, B., 2016. Water Futures and Solution-Fast Track Initiative (Final Report). IIASA Working Paper. Laxenburg: Retrieved from Institutional Institute for Applied Systems Analysis (IIASA)http://pure.iiasa.ac.at/id/eprint/13008/1/WP-16-006.pdf.

Burian, S.J., Ward, M., Banuri, T.J., Ahmad, S., Mahar, R.B., VanDerslice, J.A., et al., 2017. Higher education capacity building in water resources engineering and management to support achieving the sustainable development goal for water in Pakistan. ASEE Annual Conference and Exposition, Conference Proceedings, vol. 2017. , Retrieved from https://utah.pure.elsevier.com/en/publications/higher-education-capacity-building-in-water-resources-engineering.

Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S., Naeem, S., 2012. Biodiversity loss and its impact on humanity. Nature 486 (7401), 59–67.

Carrizo, S.F., Jähnig, S.C., Bremerich, V., Freyhof, J., Harrison, I., He, F., Langhans, S.D., Tockner, K., Zarfl, C., Darwall, W., 2017. Freshwater megafauna: flagships for freshwater biodiversity under threat. BioScience 67 (10), 919–927.

Chang, N.-B., Lu, J.-W., Chui, T.F.M., Hartshorn, N., 2018. Global policy analysis of low impact development for stormwater management in urban regions. Land Use Policy 70, 368–383.

China Water Risk, 2016. New "Water Ten Plan" to Safeguard China's Waters. Retrieved fromhttp://chinawaterrisk.org/notices/new-water-ten-plan-to-safeguard-chinas-waters/.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014a. Changes in the global value of ecosystem services. Glob. Environ. Change 26, 152–158.

Costanza, R., Kubiszweski, I., Giovannini, E., Lovins, H., McGlade, J., Pickett, K.E., 2014b. Development: time to leave GDP behind. Nature 505, 283–285.

Darwall, W.R.T., Smith, K.G., Allen, D.J., Holland, R., Harrison, I.J., Brooks, E.G.E., 2011. The Diversity of Life in African Freshwaters: Under Water, Under Reat. An Analysis of the Status and Distribution of Freshwater Species Throughout Mainland Africa. International Union for Conservation of Nature (IUCN), Gland, Switzerland and Cambridge, UK.

Day, J.W., Moerschbaecher, M., Pimentel, D., Hall, C., Yáñez-Arancibia, A., 2014. Sustainability and place: how emerging mega-trends of the 21st century will affect humans and nature at the landscape level. Ecol. Eng. 65, 33–48.

de Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol. Econ. 41 (3), 393–408.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., van Oudenhoven, A.P.E., van der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindle, S., Shirayama, Y., 2018. Assessing nature's contributions to people. Science 359 (6373), 270–272.

Dicks, L.V., Viana, B., Bommarco, R., Brosi, B., Arizmendi, M., del, C., Cunningham, S.A., Galetto, L., Hill, R., Lopes, A.V., Pires, C., Taki, H., Potts, S.G., 2016. Ten policies for pollinators. Science 354 (6315) .

Dudley, N., Harrison, I.J., Kettunen, M., Madgwick, J., Mauerhofer, V., 2016. Natural solutions for water management of the future: freshwater protected areas at the 6th world parks congress. Aquat. Conserv. Mar. Freshw. Ecosyst. 26 (S1), 121–132.

Dudley, N., Stolton, S., 2003. Running Pure: The Importance of Forest Protected Areas to Drinking Water. Retrieved fromWorld Bank/WWF Alliance for Forest Conservation and Sustainable Usehttps://openknowledge.worldbank.org/handle/10986/15006.

Duhigg, C., 2009. Millions in U.S. Drink contaminated water, records show. The New York Times, Retrieved fromhttp://www.nytimes.com/2009/12/08/business/energy-environment/08water.html.

EC, 2013. Technical Information on Green Infrastructure – Enhancing Europe's Natural Capital. Retrieved fromEuropean Commission, Brusselshttp://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013SC0155&from=EN.

EC, 2016. Background on Green Infrastructure. Retrieved fromEuropean Commissionhttp://ec.europa.eu/environment/nature/ecosystems/background.htm.

EC, 2017. Natura 2000. European Commission Retrieved from http://ec.europa.eu/environment/nature/natura2000/index_en.htm.

Elsevier, 2016. Ecological Engineering (Journal). Retrieved fromhttp://www.journals.elsevier.com/ecological-engineering.

Emerton, L., Iyango, L., Luwum, P., Malinga, A., 1998. The Present Economic Value of Nakivubo Urban Wetland, Uganda. IUCN — The World Conservation Union, Eastern Africa Regional Office, Nairobi and National Wetlands Programme, Wetlands Inspectorate Division, Ministry of Water, Land and Enviornment, Kampala.

EPA, 2015. EPA Science Matters Newsletter: From Gray to Green – Helping Communities Adopt Green Infrastructure Water Research. Retrieved fromEnvironmental Protection Agencyhttps://www.epa.gov/water-research/epa-science-matters-newsletter-gray-green-helping-communities-adopt-green.

FAO, 2006. Water Monitoring: Mapping Existing Global Systems & Initatives. Background Document, Prepared by FAO on Behalf of the UN-

Water Task Force on Monitoring. Food and Agriculture Organization of the United Nations, Rome.
FAO, 2012. Coping With Water Scarcity an Action Framework for Agriculture and Food Security. Rome.
Future Earth, 2016. Future Earth: Research for Global Sustainability Retrieved from http://www.futureearth.org.
Gardner, R.C., Barchiesi, S., Beltrame, C., Finlayson, C.M., Galewski, T., Harrison, I., Paganini, M., Perennou, C., Pritchard, D., Rosenqvist, A., Walpole, M., 2015. State of the World's Wetlands and Their Services to People: A Compilation of Recent Analyses. Ramsar Convention Secretariat, Gland, Switzerland.
Garrick, D.E., Hall, J.W., Dobson, A., Damania, R., Grafton, R.Q., Hope, R., Hepburn, C., Bark, R., Boltz, F.K., De Stefano, L., O'donnell, E., Matthews, N., Money, A., 2017. Valuing water for sustainable development. Measurement and governance must advance together. Science 358 (6366), 1003–1005.
GEO, 2014. The GEOSS water strategy: From observations to decisions. In: Lawford, R., Boisvert, A.-A. (Eds.), Group on Earth Observations. Japan Aerospace Exploration Agency, Geneva and Tokyo, Retrieved from ftp://ftp.earthobservations.org/TEMP/Water/GEOSS_WSR_Full_Report.pdf.
Gill, D.A., Mascia, M.B., Ahmadia, G.N., Glew, L., Lester, S.E., Barnes, M., Craigie, I., Darling, E.S., Free, C.M., Geldmann, J., Holst, S., Jensen, O.P., White, A.T., Basurto, X., Coad, L., Gates, R.D., Guannel, G., Mumby, P.J., Thomas, H., Whitmee, S., Woodley, S., Fox, H.E., 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature 543 (7647), 665–669.
Gleick, P.H., 2003. Global freshwater resources: soft-path solutions for the 21st century. Science 302 (5650), 1524–1528.
Global Footprint Network, 2016. National Footprint Accounts, 2016 Edition Retrieved from https://www.footprintnetwork.org.
Green, P.A., Vörösmarty, C.J., Harrison, I., Farrell, T., Sáenz, L., Fekete, B.M., 2015. Freshwater ecosystem services supporting humans: pivoting from water crisis to water solutions. Glob. Environ. Change 34, 108–118.
Grieg-Gran, M., Porras, I., 2012. Paying for Watershed Services: An Effective Tool in the Developing World. IIED Briefing Papers. IIED (International Institute for Environment and Development), London, UK.
Hansjürgens, B., Droste, N., Tockner, K., 2016. Neglected values of major water engineering projects: ecosystem services, social impacts, and economic valuation. In: Hüttl, R.F., Bens, O., Bismuth, C., Hoechstetter, S. (Eds.), Society–Water–Technology: A Critical Appraisal of Major Water Engineering Projects. Springer International Publishing, Cham, pp. 65–78.
Harrison, I.J., Green, P.A., Farrell, T.A., Juffe-Bignoli, D., Sáenz, L., Vörösmarty, C.J., 2016. Protected areas and freshwater provisioning: a global assessment of freshwater provision, threats and management strategies to support human water security. Aquat. Conserv. Mar. Freshw. Ecosyst. 26 (S1), 103–120.
Hermoso, V., Pantus, F., Olley, J., Linke, S., Mugodo, J., Lea, P., 2012. Systematic planning for river rehabilitation: integrating multiple ecological and economic objectives in complex decisions: freshwater systematic rehabilitation planning. Freshw. Biol. 57 (1), 1–9.
Hermoso, V., Pantus, F., Olley, J., Linke, S., Mugodo, J., Lea, P., 2015. Prioritising catchment rehabilitation for multi objective management: an application from se-queensland, Australia. Ecol. Model. 316, 168–175.
Hermoso, V., Abell, R., Linke, S., Boon, P., 2016. The role of protected areas for freshwater biodiversity conservation: challenges and opportunities in a rapidly changing world. Aquat. Conserv. Mar. Freshw. Ecosyst. 26 (S1), 3–11.
HLPW, 2016. Mobilizing Action Towards a Water Secure World for All. High Level Panel on Water. Retrieved fromWorld Bank & United Nationshttps://sustainabledevelopment.un.org/content/documents/11284HLPW_Summary_DEF_11-1.pdf.
Hoekstra, A.Y., Mekonnen, M.M., Chapagain, A.K., Mathews, R.E., Richter, B.D., 2012. Global monthly water scarcity: blue water footprints versus blue water availability. PLoS ONE 7 (2), e32688.
Hogan, Z., 2011. Review of migratory freshwater fish. Convention on migratory speciesIn: Tenth Meeting of the Conference of the Parties. Bergen, 20–25 November 2011 Agenda Item 19. , https://www.cms.int/sites/default/files/document/inf_33_freshwater_fish_eonly_0.pdf.
Holland, R.A., Darwall, W.R.T., Smith, K.G., 2012. Conservation priorities for freshwater biodiversity: the key biodiversity area approach refined and tested for continental Africa. Biol. Conserv. 148 (1), 167–179.
IHA, 2016. What Will the Paris Agreement Mean for Hydropower Development? Inernational Hydropower Association. Retrieved from http://www.hydropower.org/blog/what-will-the-paris-agreement-mean-for-hydropower-development.
IPBES. (n.d.) Deliverable 2(B): Regional/subregional Assessments on Biodiversity and Ecosystem Services. Bonn, Germany: IPBES Secretariat. Retrieved from https://www.ipbes.net/deliverables/2b-regional-assessments.
IPBES, 2018. In: Rice, J., Seixas, C.S., Zaccagnini, M.E., Bedoya-Gaitán, M., Valderrama, N., Anderson, C.B., Arroyo, M.T.K., Bustamante, M., Cavender-Bares, J., Diaz-de-Leon, A., Fennessy, S., García Márquez, J.R., Garcia, K., Helmer, E.H., Herrera, B., Klatt, B., Ometo, J.P., Rodríguez Osuna, V., Scarano, F.R., Schill, S., Farinaci, J.S. (Eds.), Summary for Policymakers of the Regional Assessment Report on Biodiversity and Ecosystem Services for the Americas of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat, Bonn, Germany. Retrieved from https://www.ipbes.net/assessment-reports/americas.
IUCN, 2016. Freshwater Biodiversity. Retrieved fromInternational Union for Conservation of NatureIn: http://www.iucn.org/theme/species/our-work-ssc/our-work/freshwater-biodiversity.
IUCN, 2018. Nature-Based Solutions. In: https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions, retrieved (24.01.18).
Juffe-Bignoli, D., Burgess, N.D., Bingham, H., Belle, E.M.S., de Lima, M.G., Deguignet, M., Bertzky, B., Milam, A., Martinez-Lopez, J., Lewis, E., Eassom, A., WIcander, S., Geldmann, J., van Soesbergen, A., Arnell, A.P., O'Connor, B., Park, S., Shi, Y., Danks, F.S., MacSharry, B., Kingston, N., 2014. Protected Planet Report 2014. UNEP-WCMC, Cambridge, UK.
Juffe-Bignoli, D., Harrison, I., Butchart, S.H., Flitcroft, R., Hermoso, V., Jonas, H., Lukasiewicz, A., Thieme, M., Turak, E., Bingham, H., Dalton, J., Darwall, W., Deguignet, M., Dudley, N., Gardner, R., Higgins, J., Kumar, R., Linke, S., Milton, G.R., Pittock, J., Smith, K.G., van Soesbergen, A., 2016. Achieving aichi biodiversity target 11 to improve the performance of protected areas and conserve freshwater biodiversity. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 133–151.
Jurczak, T., Wagner, I., Kaczkowski, Z., Szklarek, S., Zalewski, M., 2018. Hybrid system for the purification of street stormwater runoff supplying urban recreation reservoirs. Ecol. Eng. 110, 67–77.
Kabisch, N., Korn, H., Stadler, J., Bonn, A., 2017. Nature-Based Solutions to Climate Change Adaptation in Urban Areas – Linkages Between Science, Policy and Practice. Springer, Cham.
Khanal, B.R., Babar, J.T., 2007. Community based ecotourism for sustainable tourism development in the mekong region. Policy Brief. 1, 2007., Retrieved fromIn: http://www.cuts-international.org/HRC/pdf/PB-1-07.pdf.
Kirkby, C.A., Giudice-Granados, R., Day, B., Turner, K., Velarde-Andrade, L.M., Dueñas-Dueñas, A., Lara-Rivas, J.C., Yu, D.W., 2010. The market triumph of ecotourism: an economic investigation of the private and social benefits of competing land uses in the Peruvian amazon. PLoS ONE 5 (9), e13015.
Lewis, E., MacSharry, B., Juffe-Bignoli, D., Harris, N., Burrows, G., Kingston, N., Burgess, N.D., 2017. Dynamics in the global protected-area estate since 2004. Conserv. Biol..
Lutz, W., Butz, W.P., KC, S., 2014. World Population and Human Capital in the Twenty-First Century. Oxford University Press, http://dx.doi.org/10.1093/acprof:oso/9780198703167.001.0001.
Mancini, M.S., Galli, A., Niccolucci, V., Lin, D., Bastianoni, S., Wackernagel, M., Marchettini, N., 2016. Ecological footprint: refining the carbon footprint calculation. Ecol. Indic. 61, 390–403.
McCarthy, D.P., Donald, P.F., Scharlemann, J.P.W., Buchanan, G.M., Balmford, A., Green, J.M.H., Bennun, L.A., Burgess, N.D., Fishpool, L.D.C., Garnett, S.T., Leonard, D.L., Maloney, R.F., Morling, P., Schaefer, H.M., Symes, A., Wiedenfeld, D.A., Butchart, S.H.M., 2012. Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. Science 338 (6109), 946–949.
McDonald, R.I., Green, P.A., Balk, D., Fekete, B.M., Revenga, C., Todd, M., Montgomery, M., 2011. Urban growth, climate change, and freshwater availability. Proc. Natl. Acad. Sci. 108 (15), 6312–6317.
McDonald, R.I., Weber, K.F., Padowski, J., Boucher, T., Shemie, D., 2016. Estimating watershed degradation over the last century and its impact on water-treatment costs for the world's large cities. Proc. Natl. Acad. Sci. U. S. A. 113 (32), 9117–9122.
McGranahan, G., Marcotullio, P.J., Bai, X., Balk, D., Braga, T., Douglas, I., Elmqvist, T., Rees, W., Satterthwaite, D., Songsore, J., Zlotnik, H., 2005. Chapter 27: Urban Systems. In Millennium Ecosystem Assessment, Current State and Trends: Findings of the Condition and Trends Working Group. Ecosystems and Human Well-Being, Volume 1. Island Press, Washington, DC, pp. 795–825.
MEA, 2005.In: Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Island Press, Washington DC.

Medeiros, R., Young, C.E.F., Pavese, H.B., Araújo, F.F.S., 2011. Contribuição das unidades de conservação brasileiras para a economia nacional. UNEP-WCMC, Brasilia-DF.

Meybeck, M., Vörösmarty, C., 2005. Fluvial filtering of land-to-ocean fluxes: from natural holocene variations to anthropocene. Comp. R. Geosci. 337 (1–2), 107–123.

Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., Stouffer, R.J., 2008. Stationarity is dead: whither water management? Science 319, 573–574.

Morgan, M., 2012. Cultural flows: asserting indigenous rights and interests in the waters of the murray-darling River system, Australia. In: Johnston, B.R., Hiwasaki, L., Klaver, I.J., Ramos Castillo, A., Strang, V. (Eds.), Water, Cultural Diversity, and Global Environmental Change: Emerging Trends, Sustainable Futures? United Nations Educatioal, Scientific and Cultural Organization (UNESCO), Heidelberg, London, New York, pp. 453–466.

Muller, M., Biswas, A., Martin-Hurtado, R., Tortajada, C., 2015. Built infrastructure is essential. Science 349 (6248), 585–586.

National Cultural Flows Research Project, 2018. Indigenous People and Water. Retrieved fromIn: http://culturalflows.com.au/.

Nilsson, M., Griggs, D., Visbeck, M., 2016. Policy: map the interactions between sustainable development goals. Nature 534 (7607), 320–322.

NRC-COHS, 2011. Global Change and Extreme Hydrology: Testing Conventional Wisdom. National Research Council National Research Council. Committee on Hydrologic Science, Washington, DC.

Odum, H.T., 1973. Energy, ecology, and economics. Ambio 2, 220–227.

Palmer, M.A., Liu, J., Matthews, J.H., Mumba, M., D'Odorico, P., Liu, J., Ortloff, C., Critchley, W., Negi, G., Brommer, M., Rockström, J., Luo, S., Stive, M.J., Ziv, G., Baran, E., Nam, S., Rodríguez-Iturbe, I., Levin, S.A., Galizia, M.C., Schilis-Gallego, C., Cabra, M., Stakhiv, E.Z., Ansar, A., Flyvbjerg, B., Budzier, A., Lunn, D., Heine, R.A., Pinter, N., Russi, D., Moberg, F., Ronnback, P., Koch, B., Febria, C.M., Gevrey, M., Wainger, L.A., Palmer, M.A., Talberth, J., Troy, T.J., Pavao-Zuckerman, M., Evans, T.P., Roa-García, M.C., Brown, S., Schreier, H., Lavkulich, L.M., Lawrence, D., Vandecar, K., Bonan, G.B., 2015. Water security: gray or green? Manage water in a green way. Science 349 (6248), 584–585.

Palmer, M.A., Menninger, H.L., Bernhardt, E., 2010. River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? Freshw. Biol. 55, 205–222.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R.T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S.M., Wittmer, H., Adlan, A., Ahn, S.E., Al-Hafedh, Y.S., Amankwah, E., Asah, S.T., Berry, P., Bilgin, A., Breslow, S.J., Bullock, C., Cáceres, D., Daly-Hassen, H., Figueroa, E., Golden, C.D., Gómez-Baggethun, E., González-Jiménez, D., Houdet, J., Keune, H., Kumar, R., Ma, K., May, P.H., Mead, A., O'Farrell, P., Pandit, R., Pengue, W., Pichis-Madruga, R., Popa, F., Preston, S., Pacheco-Balanza, D., Saarikoski, H., Strassburg, B.B., van den Belt, M., Verma, M., Wickson, F., Yagi, N., 2017. Valuing nature's contributions to people: the IPBES approach. Curr. Opin. Environ. Sustain. 26–27, 7–16.

Pittock, J., Finlayson, M., Arthington, A.H., Roux, D., Matthews, J.H., Biggs, H., Blom, E., Flitcroft, R., Froend, R., Harrison, I., Hermoso, V., Junk, W., Kumar, R., Linke, S., Nel, J., Nunes da Cunha, C., Pattnaik, A., Pollard, S., Rast, W., Thieme, M.L., Turak, E., Turpie, T., van Niekerk, L., Willems, D., Viers, J., 2015. Managing freshwater, river, wetland and estuarine protected areas. In: Worboys, G.L., Lockwood, M., Kothari, A., Feary, S., Pulsford, I. (Eds.), Protected Area Governance and Management. ANU Press, Canberra, Australia, pp. 569–608.

Poff, N.L., Brown, C.M., Grantham, T.E., Matthews, J.H., Palmer, M.A., Spence, C.M., Wilby, R.L., Haasnoot, M., Mendoza, G.F., Dominique, K.C., Baeza, A., 2015. Sustainable water management under future uncertainty with eco-engineering decision scaling. Nat. Clim. Change 6 (1), 25–34.

Poff, N.L., Matthews, J.H., 2013. Environmental flows in the anthropocence: past progress and future prospects. Curr. Opin. Environ. Sustain. 5 (6), 667–675.

Poff, N.L., Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G., Merritt, D.M., O'Keefe, J.H., Olden, J.D., Rogers, K., Tharme, R.E., Warner, A., 2010. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards: ecological limits of hydrologic alteration. Freshw. Biol. 55 (1), 147–170.

Poustie, M.S., Deletic, A., Brown, R.R., Wong, T., de Haan, F.J., Skinner, R., 2015. Sustainable urban water futures in developing countries: the centralised, decentralised or hybrid dilemma. Urban Water J. 12 (7), 543–558.

Pratt, L., 2011. Tourism: Investing in Energy and Resource Efficiency. United Nations Environment Programme. Retrieved fromIn: http://files/957/greeneconomy_tourism.pdf.

Ramsar, 2014. About Ramsar. Gland, Switzerland: The Ramsar Convention Secretariat. Retrieved fromIn: https://www.ramsar.org.

Riversymposium, 2017. The Brisbane declaration - 2007. International RiverFoundation, Retrieved fromIn: http://riversymposium.com/about/brisbane-declaration-2007/.

Rodríguez Osuna, V., 2015. Targeting watershed protection in the guapiaçu-macacu region of the Atlantic Forest, Brazil: an environmental and economic assessment of the potential for a payment for ecosystem services scheme. Cologne J. Eng. Nat. Sci. Res.. Band. 1. Cologne Open. Sci..

Roth, D., Warner, J., 2007. Flood risk, uncertainty and changing river protection policy in the Netherlands: the case of calamity polders. Tijdschrift Voor Economische En Sociale Geografie 98 (4), 519–525.

Russi, D., Ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., Kumar, R., Davidson, N., 2013. The Economics of Ecosystems and Biodiversity for Water and Wetlands. The Institute for European Environmental Policy (IEEP); London, Brussels. Retrieved fromIn: http://www.ramsar.org/sites/default/files/documents/library/teeb_waterwetlands_report_2013.pdf.

Sáenz, L., Farrell, T., Olsson, A., Turner, W., Mulligan, M., Acero, N., Neugarten, R., Wright, M., McKinnon, M., Ruiz, C., Guerrero, J., 2016. Mapping potential freshwater services, and their representation within protected areas (PAs), under conditions of sparse data. Pilot implementation for Cambodia. Glob. Ecol. Conserv. 7, 107–121.

Sanderson, E.W., Jaiteh, M., Levy, Ma., Redford, K.H., Wannebo, A.V., Woolmer, G., 2002. The human footprint and the last of the wild. BioScience 52 (10), 891.

Satterthwaite, D., Huq, S., Pelling, M., Reid, H., Romero Lankao, P., 2007. Adapting to Climate Change in Urban Areas: The Possibilities and Constraints in Low- and Middle-Income Nations. International Institute for Environment and Development, London.

SIWI, 2016. Stockholm International Water Institute. Retrieved fromIn: http://www.siwi.org.

START, 2016. Biennial Report 2014-2015. Scientific Leadership for Sustainability. Retrieved fromSTART International IncIn: http://www.start.org.

Strayer, D.L., Dudgeon, D., 2010. Freshwater biodiversity conservation: recent progress and future challenges. J. N. Am. Benthol. Soc. 29 (1), 344–358.

SWFP, 2016. Sustainable Water Future Programme (SWFP). Retrieved fromIn: http://www.water-future.org.

TEEB, 2010. Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB. The Economics of Ecosystems and Biodiversity, Malta.

Tessler, Z.D., Vörösmarty, C.J., Grossberg, M., Gladkova, I., Aizenman, H., Syvitski, J.P.M., Foufoula-Georgiou, E., 2015. Profiling risk and sustainability in coastal deltas of the world. Science 349 (6248), 638–643.

The Lab, 2018. Cloud Forest Blue Energy Mechanism – The Lab: Driving Sustainable Investment. Retrieved January 29, 2018, fromIn: https://www.climatefinancelab.org/project/cloud-forest-blue-energy-mechanism/.

Thieme, M.L., Rudulph, J., Higgins, J., Takats, J.A., 2012. Protected areas and freshwater conservation: a survey of protected area managers in the Tennessee and Cumberland River basins, USA. J. Environ. Manage. 109, 189–199.

Tittensor, D.P., Walpole, M., Hill, S.L.L., Boyce, D.G., Britten, G.L., Burgess, N.D., Butchart, S.H.M., Leadley, P.W., Regan, E.C., Alkemade, R., Baumung, R., Bellard, C., Bouwman, L., Bowles-Newark, N.J., Chenery, A.M., Cheung, W.W.L., Christensen, V., Cooper, H.D., Crowther, A.R., Dixon, M.J.R., Galli, A., Gaveau, V., Gregory, R.D., Gutierrez, N.L., Hirsch, T.L., Höft, R., Januchowski-Hartley, S.R., Karmann, M., Krug, C.B., Leverington, F.J., Loh, J., Lojenga, R.K., Malsch, K., Marques, A., Morgan, D.H.W., Mumby, P.J., Newbold, T., Noonan-Mooney, K., Pagad, S.N., Parks, B.C., Pereira, H.M., Robertson, T., Rondinini, C., Santini, L., Scharlemann, J.P.W., Schindler, S., Sumaila, U.R., Teh, L.S.L., van Kolck, J., Visconti, P., Ye, Y., 2014. A mid-term analysis of progress toward international biodiversity targets. Science 346 (6206), 241–244.

Tockner, K., Bernhardt, E.S., Koska, A., Zarfl, C., 2016. A global view on future major water engineering projects. In: Hüttl, R.F., Bens, O., Bismuth, C., Hoechstetter, S. (Eds.), Society–Water–Technology: A Critical Appraisal of Major Water Engineering Projects. Springer International Publishing, Cham, pp. 47–64.

Tsuzuki, Y., Yoneda, M., 2012. Benefit-cost of river water environment and investments related to water environment in the river basin. Soc. Sci. Res. Netw., Retrieved fromIn: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2167853.

Turak, E., Harrison, I., Dudgeon, D., Abell, R., Bush, A., Darwall, W., Finlayson, C.M., Ferrier, S., Freyhof, J., Hermoso, V., Juffe-Bignoli, D., Linke, S., Nel, J., Patricio, H.C., Pittock, J., Raghavan, R., Revenga, C., Simaika, J.P., De Wever, A., 2017. Essential biodiversity variables for measuring change in global freshwater biodiversity. Biol. Conserv. 213 (Part B), 272–279.

UN, 2014. World Urbanization Prospects: The 2014 Revision. Department of Economic and Social Affairs, Population Division, United Nations.

UN-HABITAT, 2010. State of the World's Cities 2010/2011 - Cities for All: Bridging the Urban Divide. United Nations Human Settlements Programme (UN-HABITAT)/Earthscan.

UN-Water, 2015. Annual Report 2014. Retrieved fromUN-Water, Geneva, SwitzerlandIn: http://www.unwater.org.

UNEP, 2012. GEO 5. Global Environmental Outlook. Retrieved fromUnited Nations Environment Programme, MaltaIn: http://www.unep.org/geo/GEO5_ebook/index.html.

UNEP, 2014. Green Infrastructure Guide for Water Management: Ecosystem-Based Management Approaches for Water-Related Infrastructure Projects. United Nations Environment Programme.

UNEP-DHI, UNEP, 2016. Transboundary River Basins: Status and Trends. United Nations Environment Programme (UNEP), Nairobi.

UNESCO, 2018. Hydrology (IHP). Retrieved January 24, 2018, fromIn: https://en.unesco.org/themes/water-security/hydrology.

UNESCO-IHE, 2013. Capacity Development Key to Meeting a Water-Related SDG. Delft, The Netherlands. Retrieved fromIn: http://files/738/UNESCO_IHE_2013.pdf.

USACE-IWR, 2000. Civil Works Floodplain Management Initiatives: Value to the Nation. U.S. Army Corps of Engineers, Institute for Water Resources.

Valderrama, A., Lochner, J., Koval, M., 2017. Catalyzing Green Infrastructure on Private Property: Recommendations for a Green, Equitable, and Sustainable New York City. Center for Sustainable Business, NYU Stern School of Business Natural Resources Defense Council, New York, NY.

van Herk, S., Rijke, J., Zevenbergen, C., Ashley, R., 2015. Understanding the transition to integrated flood risk management in the Netherlands. Environ. Innov. Soc. Transit. 15, 84–100.

Veiga, F., Gavaldão, M., 2012. Iniciativas de PSA de conservação dos recursos hídricos na Mata atlântica. In: Guedes, F.B., Seehusen, S.E., Cunha, A.A. (Eds.), Pagamentos Por Serviços Ambientais Na Mata Atlântica: Lições Aprendidas E Desafios (2a. Ed. Re) Ministério do Meio Ambiente, Secretaria de Biodiversidade e Florestas, Departamento de Conservação da Biodiversidade, Brasília, DF, pp. 123–182.

Vogl, A.L., Goldstein, J.H., Daily, G.C., Vira, B., Bremer, L., McDonald, R.I., Shemie, D., Tellman, B., Cassin, J., 2017. Mainstreaming investments in watershed services to enhance water security: barriers and opportunities. Environ. Sci. Policy 75, 19–27.

Vollmer, D., Regan, H.M., Andelman, S.J., 2016. Assessing the sustainability of freshwater systems: a critical review of composite indicators. Ambio 45 (7), 765–780.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., Davies, P.M., 2010. Global threats to human water security and river biodiversity. Nature 467 (7315), 555–561.

Vörösmarty, C.J., Meybeck, M., Pastore, C.L., 2015. Impair-then-Repair: a brief history & global-scale hypothesis regarding human-water interactions in the anthropocene. Daedalus 144 (3), 94–109.

Vörösmarty, C.J., Pahl-Wostl, C., Bhaduri, A., 2013. Water in the anthropocene: New perspectives for global sustainability. Curr. Opin. Environ. Sustain. 5 (6), 535–538.

Vörösmarty, C.J., Rodríguez Osuna, V., Koehler, D.A., Spengler, J.D., Buonocore, J.J., Cak, A.D., Tessler, Z.D., Corsi, F., Green, P.A., Sánchez, R., 2018. Scientifically assess impacts of sustainable investments. Science 359 (6375) .

Watson, J.E.M., Dudley, N., Segan, D.B., Hockings, M., 2014. The performance and potential of protected areas. Nature 515 (7525), 67–73.

WEF, 2017. The Global Risks Report 2017, 12th ed. World Economic Forum, Geneva.

Wetlands Restoration and Pollution Reduction Project (n.d.) Danube River Wetlands Ecotourism Destination: Action Plan for Ecotourism Destination. Ecotourism Naturally in Bulgaria. Sofia, Bulgaria: Biodiversity Conservation and Economic Growth Project II. Retrieved from http://files/1006/ecotourism Wetlands Eng.pdf.

WHO/UNICEF JMP, 2016. Joint Monitoring Programme for Water Supply and Sanitation. Retrieved fromWorld Health Organization. UNICEFIn: http://www.wssinfo.org/.

WHO and UN-HABITAT, 2010. 2010 Hidden Cities: Unmasking and Overcoming Health Inequalities in Urban Settings. World Health Organization, Geneva.

WHOI, 2016. Recent Trends: National Changes. National Office for Harmful Algal Blooms. Retrieved fromWoods Hole Oceanographic Institution.In: https://www.whoi.edu/redtide/regions/us/recent-trends.

WLA, 2017. Room for the River | Nijmegen, The Netherlands | H+N+S Landscape Architects. Retrieved fromIn: http://worldlandscapearchitect.com/room-for-the-river-nijmegen-the-netherlands-hns-landscape-architects/#.WmjaqZM-dR5.

WWAP, 2006. The United Nations World Water Development Report 2: Water: A Shared Responsibility. UNESCO. United Nations World Water Assessment Programme, Paris.

WWAP, 2009. The United Nations World Water Development Report 3: Water in a Changing World. UNESCO, and London: Earthscan. United Nations World Water Assessment Programme, Paris.

WWAP, 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. UNESCO. United Nations World Water Assessment Programme, Paris.

WWAP, 2016. Water and Jobs. UNESCO. United Nations World Water Assessment Programme, Paris.

WWAP/UN-Water, 2018. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. UNESCO. United Nations World Water Assessment Programme, Paris.

WWF, 2016. The Living Planet Report 2016. Risk and resilience in a new era. Switzerland.

Wyborn, C., van Kerkhoff, L., Dunlop, M., Dudley, N., Guevara, O., 2016. Future oriented conservation: knowledge governance, uncertainty and learning. Biodivers. Conserv. 25 (7), 1401–1408.

Young, S.C., 2000. The Emergence of Ecological Modernisation: Integrating the Environment and the Economy? Routledge, London.

Zalewski, M., 2000. Ecohydrology – the scientific background to use ecosystem properties as management tools toward sustainability of water resources. Ecol. Eng. 16 (1), 1–8.

Zalewski, M., Arduino, G., Bidoglio, G., Cullmann, J., Uhlenbrook, S., Guo, J., Garcia de Leaniz, C., Galizia Tundisi, J., Chicharo, L., 2017. Integration of Circular Economy, Nature-Based Solutions and Ecohydrology towards Sustainable and Responsible Science. International Symposium-Ecohydrology for the Circular economy and Nature-based solutions towards mitigation/adaptation to Climate change. European Regional Center for Ecohydrology of the Polish Academy of Sciences, Lodz.