# Chapter 6
# Integrating the Grey, Green, and Blue in Cities: Nature-Based Solutions for Climate Change Adaptation and Risk Reduction

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**Abstract** Cities are high emitters of greenhouse gases and are drivers of environmental modification, often leading to degradation and fragmentation of ecosystems at local and regional scales. Linked to these trends is a growing threat experienced by urban areas: the risk from hydro-meteorological and climatological hazards, further accentuated by climate change. Ecosystems and their services, though often overlooked or degraded, can provide multiple hazard regulating functions such as coastal and surface flood regulation, temperature regulation and erosion control. Engineering or grey approaches often do not tackle the root causes of risk and can increase the vulnerability of populations over the long-term. However, evidence of alternative approaches such as the role of healthy, functioning ecosystems in disaster risk reduction are still scarce, contentious, and with limited applicability in the urban context. This chapter explores the role of grey, green, and blue infrastructure and in particular hybrid approaches for disaster risk reduction and climate change adaptation to shed light on available sustainable adaptation opportunities in cities and urban areas. We highlight the dependence of cities on ecosystems as a key component of climate resilience building through case studies and literature review. At the same time, we highlight the limitation and drawbacks in the adoption of merely grey or merely green infrastructures. We suggest that an intermediate 'hybrid' approach, which combines both blue, green and grey approaches, may be the most effective strategy for reducing risk to hazards in the urban context.

**Keywords** Urban areas • Disaster risk reduction • Climate change adaptation • Green infrastructures • Hybrid approaches

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## 6.1 Introduction

### *6.1.1 Challenges of Climate Change in Cities*

Levels of greenhouse gases emissions per person are particularly high in cities in North America – often 25–50 times higher than in cities in low-income nations (Satterthwaite 2006). Cities are therefore drivers of climate change and at the same time increasingly at risk from its effects. At the global scale, climate change is expected to lead to significant sea level rise and to changes in frequency, intensity and spatial patterns of temperature, precipitation and other meteorological factors (IPCC 2015). Over the coming century, climate change scenarios project that urban regions will have to cope with and adapt to increasing extreme events (Rosenzweig et al. 2011a). Furthermore, cities already face aggravated impacts due to the higher presence of sealed surfaces which increase the magnitude of heat risk via the urban heat island (UHI) (Tan et al. 2010). Similarly, reduced water infiltration in highly paved urban areas generates increased risk of surface flooding at the local scale and regional scale (see Depietri et al. 2011 for a review), especially given that cities are often located in exposed coastal areas and floodplains. Negative impacts of climate extremes are likely to affect human health, energy and critical infrastructures, such as transportation, and water supply (McCarthy et al. 2010; Rosenzweig et al. 2011a). Many of these impacts are already being felt, especially by coastal communities (Spalding et al. 2014).

So far, most efforts by cities to respond to climate change have focused on mitigation (i.e. reduction of greenhouse gases emissions) and much less on adaptation (i.e. long term strategies to reduce exposure, susceptibility and improve coping capacity of communities to hazards) as these strategies imply taking a precautionary and anticipatory approach (Castán Broto and Bulkeley 2013). However, the implementation of adaptation plans is urgent. Changes in global climate are already underway and social, infrastructural, and economic costs of inaction are high (Bosello et al. 2012).

In this chapter, we explore the role of grey, green, blue and hybrid infrastructures for climate change adaptation (CCA) in cities in order to shed light on the different resilience and sustainability opportunities available and their pros and cons for urban areas. We highlight the dependence of cities on healthy ecosystems and support the case for 'hybrid' approaches as a key component of urban disaster risk reduction (DRR) and CCA through literature review and using New York City (NYC) as a case study. Natural capital (or the stock of biophysical resources), along with technological or infrastructural capital, are considered together in order to look closely at the interdependency and feedbacks between biophysical and technological domains of complex urban systems (McPhearson et al. 2016a,b) which challenge decision-makers faced with advancing CCA and DRR agendas. In the following sections we review the risk caused by to climate change in cities and introduce the social-ecological-technological systems (SETs) framework as a way for researchers and practitioners to explore adaptation strategies, particularly hybrid approaches, that work across interacting SET domains of urban systems.

### *6.1.2 Risk and Vulnerability to People, Ecosystems and Infrastructures in Cities*

Cities, if exposed to hazards, are hotspots of vulnerability due to the concentration of people and infrastructures. It is increasingly acknowledged that the human vulnerability to natural hazards is the result of the socio-economic, physical and environmental processes that characterise a social-ecological system and is thus socially constructed (Oliver-Smith 1999). This view of hazards is even more relevant in urban areas where the environment is highly modified by physical infrastructures and socio-economic activities. Cities are centres of interchange of knowledge, cultures, innovations and goods. To facilitate exchanges, these are often located in the proximity of rivers and seas making them exposed to a number of hazards such as storms, flooding, cyclones, coastal erosion and sea level rise (Sherbinin et al. 2007). Urban sprawl can exacerbate impacts of hazards through "poor urban management, inadequate planning, high population density, inappropriate construction, ecological imbalances and infrastructure dependency" (Jacobs 2005). As a result, cities of developed countries may face the highest impacts in terms damages assets and economic losses (Dickson et al. 2012). In the US, catastrophic events have increased in the last 35 years according to MunichRe NatCatService.[1]

In healthy environments, ecosystems do not strictly experience disaster in the same way that we consider disaster in the human context. When discussing risks to ecosystems, ecologists tend to discuss this in terms of disturbance (e.g. Attiwill 1994; Swetnam and Betancourt 2010). In fact, variation and extremes in weather and climate and other disturbances have always been part of the functioning of natural ecosystems and provide a wide range of benefits such as soil fertilization in floodplains in the case of floods or groundwater recharge in the case of intense precipitation events associated, for instance, with typhoons. However, major impacts on the ecosystem might occur if hazards affect a degraded and less diverse ecosystems, as is often the case in and around cities (Alberti 2005). This could translate to a temporary or even permanent decline or impairment in supplying necessary ecosystem services to urban and peri-urban areas. Mitigating and adapting to climate change in and around cities thus needs to take into account the interacting effects of the built infrastructure and climate change on the ecological or biophysical components of local and regional ecosystems. If we are to utilize nature-based solutions (NBS) for CCA and DRR, then the health and function of urban ecosystems is of primary importance for providing effective climate regulating services.

[1] https://www.munichre.com/en/reinsurance/business/non-life/natcatservice/index.html (Retrieved on 13th of October 2016).

### 6.1.3 The SETS Framework

Due to the multiple factors of risk, management in cities and urban regions needs to be based on a multi-disciplinary and integrated approach. A social-ecological-technological systems (SETs) approach (illustrated in Fig. 6.1) can be a useful framework to understand the dynamic interactions between social, ecological, and technical-infrastructural domains of urban systems. The SETs approach aims at overcoming the limitation of a purely socio-technological approach which tends to exclude ecological functions, or of a social-ecological approach inclined to overlook critical roles of technology and infrastructure as fundamental constituents, and drivers of urban system dynamics (McPhearson et al. 2016a).

As the SETs approach, can broaden the spectrum of the options available for intervention (Grimm et al. 2016), it is therefore a suitable framework to explore the range of options available and needed to adapt to climate impacts in the urban context. Using this framework, we investigate the pros and cons of adapting to climate change through grey infrastructures (i.e. hard or engineering approaches), 'green' and 'blue' approaches (i.e. the restoration of ecosystems, various types of

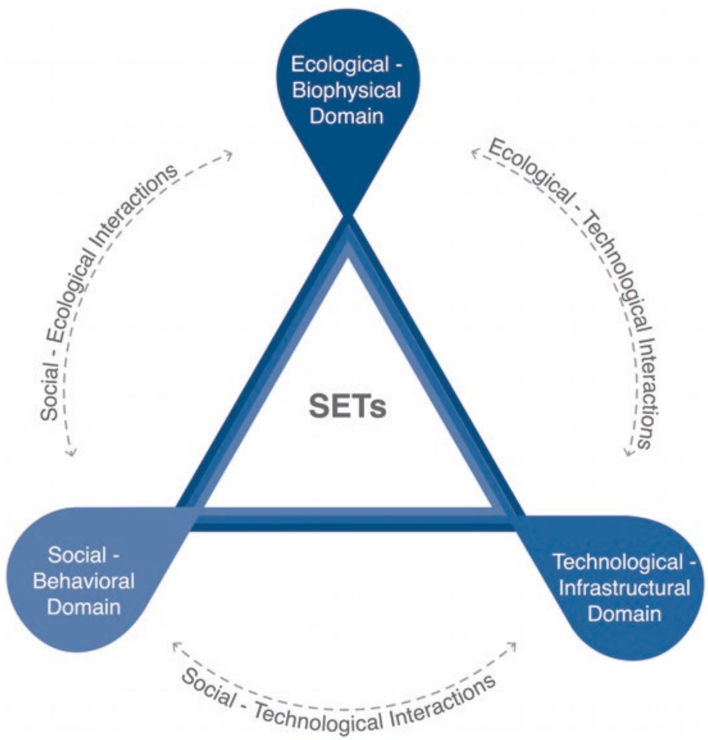


**Fig. 6.1** Conceptualizing urban systems as social-ecological-technical systems (SETs) with emphasis on the *interactions* between social, ecological, and technical-infrastructural domains of cities and urban areas (Source: own elaboration)

**Table 6.1** Flow of infrastructural adaptation options

| Grey | Hybrid or mixed approaches | Green and blue |
|---|---|---|
| Hard, engineering structures | Blend of biological-physical and engineering structures | Biophysical, Ecosystems and their services |
| Very limited role of ecosystem functions | Allows for some ecosystem functions mediated by technological solutions | Mainly relying on existing or restored ecosystem functions and water bodies |
| e.g. canals, pipes and tunnels of the drainage system; dikes; wastewater treatment plants; water filtration plants | e.g. bioswales; porous pavement; green roofs; rain gardens; constructed wetlands; Sustainable Urban Drainage Systems (SUDS) | e.g. wetlands restoration; installation of grass and riparian buffers; urban trees; stream restoration; rivers, lakes, ponds, oceans and seas |

Adapted from Grimm et al. (2016)

ecosystem-based adaptation -EbA strategies, or NBS) and more mixed or 'hybrid' approaches, based on ecosystem functions complemented by engineered infrastructures in urban areas. The contrast between these three different strategies is described in Table 6.1 and illustrated in Fig. 6.2. Table 6.1 defines grey, hybrid, green and blue infrastructures as a continuum from grey infrastructures, to hybrid, to green and blue where hybrid approaches make use of engineering and ecosystem functions together. In Fig. 6.2 we use an example illustrating a range from green, to grey, to hybrid options for managing challenges of precipitation and stormwater in the urban context.

Soft, organizational or institutional and economic approaches (such as early warning systems, insurance or risk transfer, evacuation plans or improvements in public health and insurance system) are of primary importance for DRR and CCA, though it is beyond the scope of this chapter. The social component of the SETS framework described below is thus not explored.

## 6.2 Approaches to Reducing Risk and Overall Effects of Urban Climate Change

Adaptation strategies to climate change can be evaluated in multiple ways, including: success in implementation of no-regret measures; in terms of favouring reversibility; flexibility; cost-effectiveness and feasibility; or long-term sustainability. Next, we review relevant literature to summarize key arguments for the three main (grey, green and blue as well as hybrid) approaches in DRR and CCA in cities. We conclude with a summary of the three main approaches across all evaluative factors in the discussion section (see also Table 6.2).

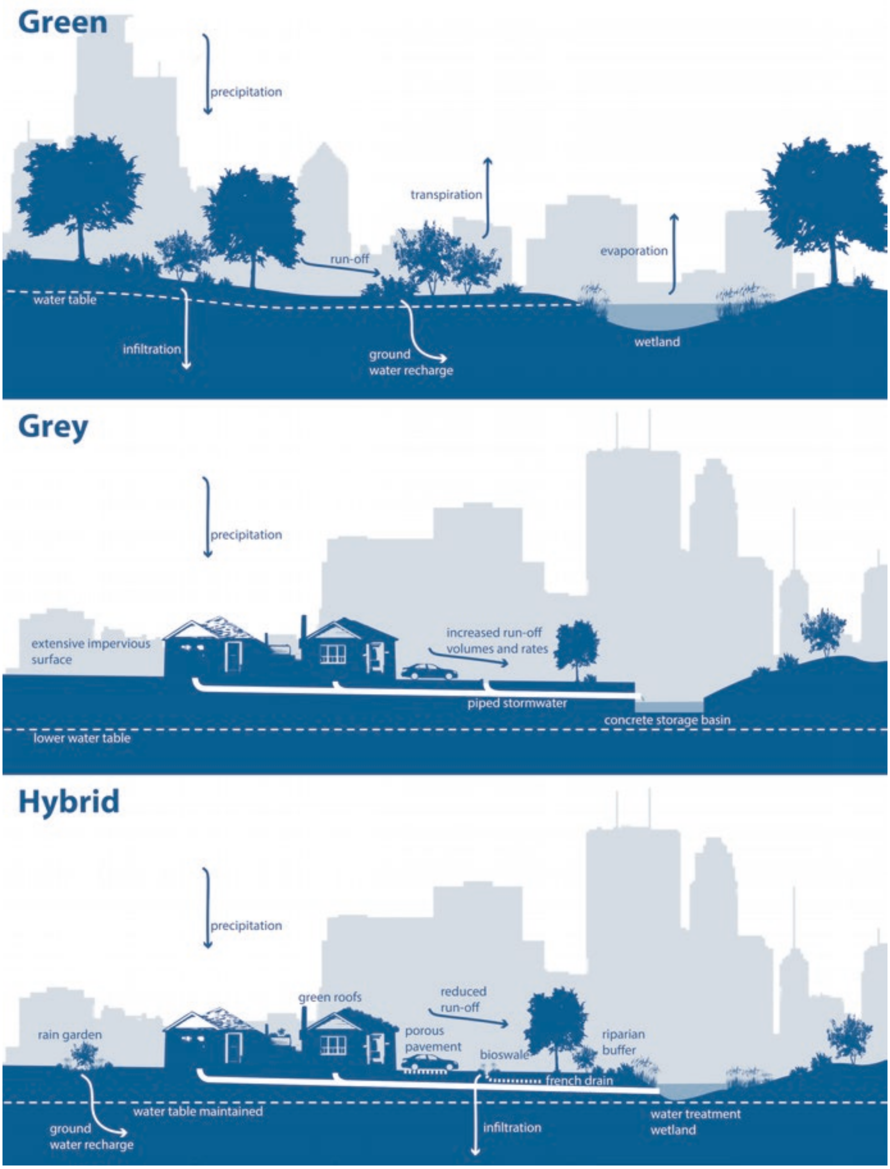


**Fig. 6.2** Three contrasting approaches, green and blue only, grey only, and hybrid for dealing with urban water, in particular significant precipitation events and other stormwater challenges that cities face. Hybrid approaches illustrated in the *bottom panel* combine grey and green approaches to maximize water absorption and infiltration and limit costs of green infrastructure while providing potential co-benefits (Source: own elaboration)

**Table 6.2** Summary table for comparison of the three approaches based on their suggested low-medium-high performance with respect to a list of factors identified in the literature

| Aspect | Grey infrastructures | Green infrastructures | Hybrid approaches |
|---|---|---|---|
| Feasibility in the urban context | High<br><br>(occupies a reduced area) | Low<br><br>(But highly important and feasible in peri- and regional urban areas) | High |
| Reliability | Medium<br><br>These measures do not completely eliminate risk<br><br>Mixed success has been reported | Medium<br><br>Role has been proven but some studies lead to contradictory results due to the multiple factors that play a role in determining the magnitude of a hazard<br><br>Highly depends on the type of hazard | High |
| No-regret strategy | Often high regret measure | Low regret measure | Medium |
| Long-term durability or resilience | Durable, but can be maladaptive. | Medium<br><br>Can be affected by hazards and ecosystems in and around cities are generally highly transformed and often degraded | Medium-high |
| Reversibility and flexibility | Little or not reversible | Medium<br><br>Can be high or low reversibility depending on the type | Medium |
| Cost-effectiveness | Low.<br><br>High building costs<br><br>Depreciate in value over time | High<br><br>Investments in green infrastructure can be much less expensive in short and long run than those in grey infrastructure | Medium to High |
| Biodiversity conservation | None | High<br><br>Green infrastructures provide natural habitat for species | Medium |
| Other co-benefits | Low<br><br>(but some examples of medium to high exist such as water and energy supply provided by riverine dikes initially designed for flood control) | High<br><br>Vegetation provides local communities with critical ecosystem services such as those improving livelihoods, food security and recreation and that may enhance their resilience to extreme events in the long-term<br><br>Broadly applicable | Medium<br><br>Contributes to providing other services, such as pollution control and recreation, but will depend on the green infrastructure component of the hybrid approach |

(Source: own elaboration)

### *6.2.1 Grey Strategies*

Response to exposure of communities to natural hazards has traditionally relied on grey infrastructures (Jones et al. 2012). Grey infrastructures are built up, engineered and physical structure, often made of concrete or other long-lasting materials, that mediate between the human, built up system and the variability of the meteorological and climatic system. These include dikes, floodgates, levees, embankments, sea walls and breakwaters for riverine and coastal flood protection, drainage systems for storm water management such as storm sewers, pipes, detention basins, and air conditioning or cooling centers to cope with extreme heat. Engineering approaches largely ignore or supplant the functions of biophysical systems. Through the SETs lens these approaches tend to be located fully within the technological domain with little input from ecological domains. Grey infrastructures provide an important means of adapting to biophysical challenges including hazards and climate driven extreme events, but are often costly to install and maintain, have long-term effects on ecosystems, tend to have low flexibility, and when they fail can generate catastrophic impacts on social and ecological domains of urban SETs.

Despite this, in some cases grey infrastructures might still be needed. For instance, Khazai et al. (2007) reviewed the role and effectiveness of coastal structures in reducing damage to coastal communities from tsunamis and storm surges caused by cyclones, hurricanes and typhoons, finding that concrete seawalls are the most durable protection against various types of storm surges.

Still the he SETs framework helps elucidate the need to recognize that grey infrastructures are not isolated systems but embedded in and affect social and ecological components of the urban system. In urban systems, habitat loss is often a direct consequence of the hardening of coastal and inland water systems. Grey infrastructures for coastal defence have also been criticized for inhibiting normal coastal processes (Khazai et al. 2007). Social and ecological systems are co-evolutionary (Norgaard 1994; Kallis 2007) in the sense that they evolve while influencing eachother thus creating sharp contrast with fixed, long-lasting grey infrastructures that lack flexibility to be. For these and other reasons tied to the long term impacts engineered infrastructures, such as sea walls or wastewater treatment plants, have on neighbouring social communities, these projects increasingly encounter high resistance by residents especially those concerned with the environment, health and sustainability.

Though engineered systems can have enormous benefits (clean water, sanitation, etc.) they can also lead to undesirable system lock-ins and path dependency which make their negative impacts, and even the infrastructure itself, difficult to reverse (Dawson 2007). Expanding cities increasingly rely on grey infrastructures for their protection with sprawling areas and informal settlements are often located in hazard-prone areas. A false sense of security generated by these protective infrastructures can in fact lead populations to further expand in unsafe areas increasing their exposure to hazards and further aggravating risk (Mitchell 2003).

Grey infrastructures can fail, especially when confronted with climate driven extreme events. Ready examples include the devastating effects of Hurricane Katrina in New Orleans in 2005 and Hurricane Sandy in New York City in 2012. These types of weather-related hazards overtopped levees, sea walls, and storm barriers engineered to protect people and ecosystems from hurricanes and storm surges, and ultimately failed with disastrous consequences.

Climate change creates uncertainty and system non-stationarity. Thus future risk is not easily taken into account in planning and building of infrastructures (Hallegatte 2009). For example, a levee designed to accommodate a certain future level storm surge is useless if climate change causes extreme events that surpass the original infrastructure target. Grey infrastructures might not be able to respond and accommodate the uncertain future ahead of us. Huge flood defence works, in the Thames river in the UK or the MOSES project in Venice (Italy), have shown to have quite long time lags of implementation, about 30 years, which is also true in the case changes in urban planning (Hallegatte 2009). Maladaptation to climate change can also occur through the installation of energy-intensive machines or infrastructures (such as pumped drainage or desalination plants) (Dawson 2007). These usually do not meet climate mitigation objectives since they are often powered by climate polluting energy sources, and can also fail as was the case of overconsumption and power outages illustrated by the summer blackout in the U.S. Northeast in 2003 (Andersson et al. 2005). Especially in the case of CCA, construction costs can be extremely high (Bosello et al. 2012) while maintenance and restructuring (e.g. digging in sand for riverine dikes) can also be financially demanding.

There is however a wide variability among factors important to consider in the case of the implementation and maintenance of grey infrastructures. These factors also depend on the type of hazard under consideration. For some hazards, structural measures with highly sophisticated early warning and evacuation plans might be needed. Seawalls are for instance particularly effective in the case of tsunamis, even if these might be costly (Khazai et al. 2007). Additionally, to adapt to rising temperatures and heat-waves, air conditioning and cooling centers, will continue to be important for adaptation and reduction of risk. Grey infrastructures tend to require limited amounts of land, are replicable, can be monitored, and to some extent controlled (The Nature Conservancy 2013), all of which are characteristics that remain particularly suitable to the urban context in a fast changing climate.

### *6.2.2 Green and Blue Infrastructures*

The vulnerability of social-ecological-technological systems can be expressed also through the type and the quality of the dependence of communities on ecosystems (Adger 2000; Renaud et al. 2010). Anthropogenic environmental change, by affecting the functioning of ecosystems and their services through land use and climate changes, is one of the main drivers of the increasing impacts of a number of natural hazards (Kaly et al. 2004). Healthy ecosystems play a significant role in buffering communities from climatological and hydro-meteorological hazards at different scales (McPhearson et al. forthcoming). However, despite the recognition of green approaches as “low regret” measures for DRR and CCA, also at the global level (UNISDR 2005, 2015; IPCC 2012), ecosystems approaches remain the most disregarded component of plans and strategies (Renaud et al. 2013; Matthews et al. 2015).

Green infrastructures are principally constituted by well-functioning biophysical systems to which some management and restoration may apply. They are represented, by healthy oyster reefs, coastal salt marshes, mangroves, coral reefs, sea grasses, sand beaches and dunes in the coast environment and mainly by forests, parks, street trees, and grasslands inland. Blue infrastructures include all bodies of waters, including ponds, wetlands, rivers, lakes and streams, as well as estuaries, seas and oceans. Since water and land come together in multiple ways, including riparian areas, beaches, wetlands, and more, combining green and blue infrastructure is gaining attention in both research and practice for CCA and DRR. Green and blue infrastructures, as we use the terms here, rely primarily on healthy, functioning ecosystems and allow for little or no technological/infrastructure intervention, thus situating them fully within the ecological domain of the SETs framework.

Initial research and practice has shown that well managed ecosystems and their regulating services can contribute to the reduction of risk and are very often cost-effective, multifunctional and win-win solutions especially in the long run (Renaud et al. 2013; Sudmeier-Rieux 2013). In addition, to be useful strategies for CCA and DRR, green and blue infrastructures provide multiple co-benefits such as recreation, psychological well-being and pollution-control opportunities (Gomez-Baggethun et al. 2013). These are also often flexible and applicable in a variety of settings (Jones et al. 2012).

Improvements in the well-being and security specifically of urban populations through green infrastructures have been reviewed by various authors (e.g. Gill et al. 2007; Foster et al. 2011; Depietri et al. 2011) and we do not attempt a comprehensive review here. An example of the benefits of the ecosystem-based approach to DRR is the case of flood regulation policies in The Netherlands. Investments in alternative flood control policies, such as land use changes and floodplain restoration, were found to be justified when additional ecological and socio-economic benefits in a long-term perspective were included (Brouwer and van Ek 2004). In the US, the case of the Boston's Charles River Basin is exemplary in this aspect too. The city was threatened by disastrous floods since urban expansion and industrial development converted land in large parts of the floodplain during the 1950s-1960s (Platt 2006). By 1983 the Army Corps of Engineers acquired the Charles River Natural Valley Storage areas, a total of about 32.8 km$^2$, and, after a decade of improvements and ecosystem restoration, the Charles River Water Association (CRWA) could measure significant benefits in terms of flood reduction, and improvements in water quality, and recreation opportunities (Platt 2006). Another example of the role of green and blue infrastructures is in Sheffield, UK where the temperature above the river crossing the city was found to be 1.5 °C lower compared to the neighbouring areas in the spring. Of course, the high heat capacity of water which helps maintain cooler temperatures during high heat events also has built in drawbacks due a capacity for thermal inertia, and so may have other consequences on urban SETs.

Ecosystem-based strategies can be cost-effective. In Portland, Oregon, USA, an increase in street trees has been estimated to be 3–6 times more effective in managing storm-water per US$1000 invested than conventional drainage systems. These estimates induced the city to invest US$8 million in green infrastructure in order to save US$250 million in hard infrastructure costs (Foster et al. 2011). Guadagno et al. (2013) gathered and reviewed a wide range of case studies worldwide demonstrating the effectiveness of promoting ecosystem management for DRR in urban areas, and not least for its reduced economic costs.

However, research on the role of ecosystems in mitigating hazards has led so far to contradictory results or has been overemphasized in some cases (Renaud et al. 2013). The available evidence is still scarce and in some cases contentious (Balmford et al. 2008). The lack of evidence of the direct role of ecosystems for human health and well-being may be one additional obstacle that helps to explain the lack of implementation of NBS for hazard mitigation in general, but also in Europe (Sudmeier-Rieux 2013) and in cities worldwide (Guadagno et al. 2013).

Few studies have analysed the way green infrastructures actually meet the demand for hazard related services in urban areas. A study in Cologne, Germany highlighted that ecosystem services might be effective in terms of microclimate regulation but much less in terms of air purification which has implications for risk to extreme heat (Depietri et al. 2013). Urban cooling by green spaces can be significant. In Singapore cooling by vegetation was estimated at 3.07 °C as a mean value by Wong and Yu (2005) while the urban heat island of the city reaches 7 °C (Chow and Roth 2006). The effectiveness of the removal of air pollutants by trees in NYC was estimated between 0.001% and 0.4% depending on the air pollutant (Nowak et al. 2006), which remains low. These cases express limitation in the possibility to rely merely on green infrastructures in the urban context for CCA and DRR. Also, green infrastructures generally require large amounts of land to deliver the service, which is often in short supply in many built up urban areas.

Another drawback is that trees and green areas in cities are generally distributed unevenly, are not always in locations where they are most needed (See Andersson et al., Chap. 4, this volume). Tree canopy cover is often concentrated in wealthier neighbourhoods as is the case in Phoenix, Arizona (Harlan et al. 2006; Jenerette et al. 2011). Plans for the implementation of green infrastructures across the urban fabric should then take into account concerns of social justice and equity lest new green infrastructure investment exacerbate existing inequalities in access to benefits of urban green space (see Chap. 13 by A. Haase in this issue). In short, more research is needed but literature so far shows that ecosystem-based approaches vary in their ability to mediate and mitigate climate threats, but can have a potentially much stronger role in DRR if appropriately managed, protected and better located where they are most needed (McPhearson et al. forthcoming).

### *6.2.3 Hybrid, Green-Grey Approaches*

Hybrid, green-grey approaches utilize combined grey and green infrastructures. An example is when wetlands restoration is coupled with engineering measures such as small levees for coastal flood protection. Other examples are bioswales, rain gardens, green roofs, street trees installed in sidewalk tree pits, and other engineered ecosystem approaches to CCA and DRR. Hybrid approaches thus combine engineering and properly ecosystem functions and are situated at the intersection of the ecological and technological components of the SETs framework. It is important to note that in the literature, the term green infrastructure often tends to encompass what we defined here as hybrid approaches. However, we make a distinction between a system which relies merely on ecosystem functions (green or blue infrastructures) or where a technological or built infrastructure complement the service delivered by a green or blue infrastructure (= hybrid infrastructure).

There is increasing evidence that hybrid approaches provide cost-effective hazard protection solutions. Hamilton City, California, USA and in its surrounding rural areas are regularly exposed to floods. The option of setback levees, facilitating the natural functioning of the floodplain, was estimated to be a more cost effective strategy when compared to upgrading existing levees (The Nature Conservancy, n.d.). Biotechnologies or hybrid approaches like these are especially suitable in the urban context where relying solely on green infrastructures rarely meets demands in risk reduction but where urban planners have traditionally relied only on solely built structures. Hybrid approaches are intended to reduce reliance of the urban system on grey infrastructures and the drawbacks that these involve and improve sustainability of cities and the well-being of their inhabitants through co-benefits.

Although there is a wide array of emerging literature related to green infrastructures for climate change adaptation in urban areas (e.g. review in McPhearson et al. forthcoming), literature remains thin on hybrid, green and grey approaches with an often confusing use of terminology. We suggest that hybrid approaches are of primary importance in urban areas where purely green approaches may be insufficient to meet the rising impacts of climate change, where space is limited, and cost effectiveness is critical not only in a context of climate uncertainty, but also economic uncertainty.

Coastal and riverine urban areas, exploring how dunes, wetlands, and forest restoration contribute to adaptation to climate change in and around cities are examples of how green infrastructure can be a first step in the planning process for CCA and DRR. However, complementary infrastructures such as small levees, embankments, bioswales, rain gardens, green roofs, porous pavements, and even more traditional grey infrastructures could be implemented simultaneously to utilize a more hybrid approach to maximize ability to provide safety during climate driven extreme events. Hybrid approaches can also benefit from a stronger local support as environmentalists generally generate opposition to engineering approaches sometimes forcing abandonment of grey infrastructure projects (e.g. the case of Napa River also in California, The Nature Conservancy, n.d.).

## 6.3 Focusing on Key Urban Climate Challenges

### *6.3.1 New York City and Climate Change*

Most adaptation strategies in the US are still at the initial stage of drafting and implementation (Bierbaum et al. 2012). In this section we briefly highlight New York City as a case study and examine the planned and potential opportunities for the implementation of integrated green and grey approaches to climate change adaptation, focusing on surface and coastal floods.

NYC is the largest city in the USA with about 8.3 million people in 2010 according to U.S. census bureau and the largest also in terms of economic activity. In the city live approximately 1.4 million elderly (age 65 and older), which constitute 17% of the population and an example of one of the many vulnerable populations to climate extremes along with low-income, minority, and children among other indicators of climate vulnerability. The elderly proportion is projected to increase in the next 20 years (Goldman et al. 2014) creating significant challenges for the city to prepare for and build resilience to predicted climate extremes including heat waves, coastal flooding, and risk of major storms. Additionally, rising sea level poses increasing risk to city infrastructure and residents. NYC is built around a networks of rivers, estuaries and islands with much of the Metropolitan region less than 5 m above mean sea level (MSL) (Colle et al. 2008). New York City climate is already changing with higher temperatures and heavy downpours increasingly frequent (Rosenzweig and Solecki 2015). With these changes hazards such as urban flooding and coastal storms are also projected to increase.

### *6.3.2 Surface and Coastal Flooding in NYC*

Combined sewer overflows, occurring when sewage and storm water are discharged from sewer pipes without treatment, are frequent in NYC and are a significant source of environmental pollution (Rosenzweig et al. 2006; McPhearson et al. 2014). Precipitation has increased at a rate of approximately 20.3 mm per decade from 1900 to 2013 in Central Park and this trend is likely to continue according to climate projections (Horton et al. 2015). Even relatively small precipitation events (over 4.4 cm) can overwhelm the combined sewage system causing raw sewage to be discharged into adjacent waterways.

NYC is low-lying with nearly 15% of the its area within the 100-year flood zone (Maantay and Maroko 2009). It is one of the top ten cities in the world in terms of assets exposed to coastal floods aggravated by climate change (Nicholls et al. 2008). The most frequent coastal storms affecting NYC are tropical storms and Nor'easters (cyclones occurring along the upper East Coast of the United States and Atlantic Canada). In NYC, even moderate Nor'eastern events can cause significant flooding (Colle et al. 2008) and are often associated with extended periods of high winds and high water (Rosenzweig et al. 2011b). Hurricanes affect the city infrequently. Five major hurricanes of category 3 have affected the New York area between 1851 and 2010, most in the month of September (Blake et al. 2011), but generally leading to large damages (Rosenzweig et al. 2011b). Hurricane Sandy which made landfall in 2012 caused 43 deaths in New York City of which nearly half were adults ages 65 or older (Kinney et al. 2015). Yet infrastructural and other damage resulted in US$67 billion of total economic losses in the country (NOAA 2015).

In 2010 the city committed to a hybrid infrastructure plan for storm water management, investing US$ 5.3 billion over 20 years to absorb 10% of the first inch (25.4 mm) of rainfall to reduce unwanted storm water run-off (NYC 2010). Of this, US$2.4 billion is targeted for green infrastructure investments which were shown in cost-benefit analysis to have significant savings compared to a scenario of traditional pipe and tanks improvements (NYC 2010). The city Green Infrastructure Plan (NYC 2010) is a clear example of how the SETs approach can be implemented for DRR and CCA in cities (note: In this plan green infrastructure means both ecosystem-based and hybrid approaches). Overall, NYC's 2010 Green Infrastructure Plan aims to reduce the city's sewer management costs by US$2.4 billion over 20 years (Foster et al. 2011). The plan estimates that every approx. 4000 $m^2$ of green infrastructure would provide total annual benefits of US$8522 in reduced energy demand, US$166 in reduced $CO_2$ emissions, US$1044 in improved air quality, and US$4725 in increased property value. It also estimates that the city can reduce combined sewage overflow volumes by 2 billion gallons by 2030, using vegetated areas at a total cost of US$1.5 billion less than traditional methods (Foster et al. 2011).

## 6.4 Discussion

### *6.4.1 Embrace Both Green and Grey Approaches*

Research is beginning to demonstrate the importance of preserving well-functioning ecosystems in and around urban areas for DRR and to protect and enhance human well-being (see Depietri et al. 2011 for a review; Depietri et al. 2013; Andersson et al., Chap. 4, this volume). Green, blue and grey protection systems in combination may provide some of the most effective and broadly beneficial solutions against hurricane, cyclone, typhoon and storm surges in urban areas. Hybrid approaches, like all approaches, have pros and cons. Based on our literature review, we derived the main factors through which the three approaches (grey, green and blue, and hybrid) have been so far described and evaluated. These factors are analysed and listed in the first column of Table 6.2 as hypotheses, which need to be examined empirically to better understand the effectiveness of hybrid approaches for DRR and CCA. We assigned classes of low to medium to high performance to the three main strategies with respect to the factors identified in the literature, with particular considerations of the urban context.

Grey infrastructures for DRR provide a wide array of drawbacks under most factors we consider (Table 6.2), but are, on the other hand, easily adaptable to the urban context. Green infrastructures, on the other hand, are flexible, no-regret measures and provide a wide range of benefits and co-benefits, which go beyond the mere protective or buffering functions. However, in the urban context these are often difficult to implement. Hybrid approaches fit well to the already hybrid nature of urban areas while providing solid solutions including many, if not all, of the co-benefits that more traditional green or blue approaches. Thus, at the very local scale, hybrid approaches are suggested as the way forward for DRR and CCA solutions in cities and urbanized regions.

### *6.4.2 Urban SETS and Importance of Bringing Together Engineering and Ecological Approaches*

Built and technical infrastructures continue to be viewed by local policy makers as the most important line of defense against hazards and disasters in cities. In much of the developed world, however, urban infrastructure is aging and proving inadequate for protecting city populations (for the US see ASCE 2013). And in much of the developing, rapidly urbanizing world, new infrastructure is being constructed at breath-taking pace, often without the benefit of ecologically based design (McHale et al. 2015; McPhearson et al. 2016b). Urban infrastructure mediates the relationships between human activities and ecosystem processes and may exacerbate or reduce human impact depending on its approach (McPhearson et al. 2016c). We suggest that a fundamental rethinking is urgently needed of what makes both grey and green built infrastructures – as well as human communities with their social, ecological, and technological couplings – resilient to environmental hazards and climate extremes. We argue that urban decision makers need to move beyond traditional engineering approaches and compliment stand-alone ecological interventions to consider how to utilize combined green-grey or hybrid approaches to advance CCA and DRR. Hybrid approaches are fundamentally ecosystem-based and take advantage of ecosystem functions together with the efficacy of more engineered systems to deliver the needed level of service. Examples such as using vegetation, porous surfaces, and temporary water storage in a combined hybrid approach to limit combined sewage overflows in New York City is a useful benchmark on how cities can transmit less water through the grey infrastructure drainage system to often overloaded wastewater treatment plants.

Additionally, we suggest that viewing cities as interactive urban SETs can help to keep in mind the need for more combined approaches to dealing with climate driven hazards and improve urban sustainability. The SETs framework offers the fundamental concept that urban systems and all urban services have a combination of all three domains (social, ecological, and technical-infrastructural) as part of their production, dynamics, and efficacy.

## 6.5 Conclusion

### *6.5.1 Critical Opportunities for Working with Hybrid Approaches in Cities for CCA and DRR*

Local, state and national governments are developing a range of adaptation plans to climate change. We reviewed grey, green and blue, and hybrid infrastructures approaches to CCA and DRR as a way to suggest avenues for future research and for guidance on urban development strategies. The future is ultimately uncertain with inherent challenges, in part due to climate change, and therefore difficult to make clear predictions to guide safe, secure, and urban sustainable development practices. Development and implementation strategies that are flexible, adaptive and can accommodate change are important in an era of non-stationarity and uncertainty. In this context, grey infrastructures tend to have problematic risks, and are often not cost-effective, nor fit easily into long-term sustainability goals. On the other hand, the implementation of purely green infrastructures at the urban level for CCA, though offering short and long-term benefits, might not be sufficient to meet the scale of predicted future climate hazards. Additionally, they often encounter resistance in city planning departments due to institutional path dependency form a history of utilizing grey infrastructures to meet city needs for hazard mitigation.

We suggest that cities should rely on a mix of grey, green and blue infrastructure solutions, which balance traditional built infrastructures with more nature-based solutions, especially to improve the management of urban water, heat, and other climate driven threats. Instead of turning to grey infrastructures as the default solution, town and regional planners should assess and investigate opportunities for restoring and expanding ecosystems to provide hybrid, more flexible and sustainable approaches to CCA and DRR.

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