Low Impact Development practices in the context of United Nations Sustainable Development Goals: a new concept, lessons learned and challenges

Marina Batalini de Macedo[1], Marcus Nóbrega Gomes Júnior[2], Thalita Raquel Pereira de Oliveira[3], Marcio H. Giacomoni[4], Maryam Imani[5], Kefeng Zhang[6], César Ambrogi Ferreira do Lago[7], Eduardo Mario Mendiondo[8]

[1]Researcher, Hydraulic Engineering and Sanitation, University of Sao Paulo, Av. Trabalhador Saocarlense,400 CP 359 São Carlos, SP CEP 13566-590, Brazil, marinabatalini@usp.br (corresponding author)

[2]Researcher, Hydraulic Engineering and Sanitation, University of Sao Paulo, Av. Trabalhador Saocarlense,400 CP 359 São Carlos, SP CEP 13566-590, Brazil, and researcher at University of Texas at San Antonio, One UTSA Circle, San Antonio, TX, 78249, USA, marcusnobrega@usp.br

[3]Researcher, Hydraulic Engineering and Sanitation, University of Sao Paulo, Av. Trabalhador Saocarlense,400 CP 359 São Carlos, SP CEP 13566-590, Brazil, thalitaoliveira@usp.br

[4]Assistant Professor, Department of Civil and Environmental Engineering, University of Texas at San Antonio, One UTSA Circle, San Antonio, TX, 78249, USA, marcio.giacomoni@utsa.edu

[5]Senior Lecturer in Water Systems Engineering (Civil Engineering), Anglia Ruskin University, Chelmsford Campus, Bishop, Hall Lane, Essex, CM1 1SQ, United Kingdom, maryam.imani@anglia.ac.uk

[6]Senior Research Associate in Water Research Centre (WRC), School of Civil and Environmental Engineering, UNSW Sydney, Vallentine Annex (H22), Room 139, UNSW Kensington Campus, NSW 2052 Australia, kefeng.zhang@unsw.edu.au

[7]Researcher, Hydraulic Engineering and Sanitation, University of Sao Paulo, Av. Trabalhador Saocarlense, 400 CP 359 São Carlos, SP CEP 13566-590, Brazil and researcher at University of Texas at San Antonio, One UTSA Circle, San Antonio, TX, 78249, USA, cesar.dolago@utsa.edu

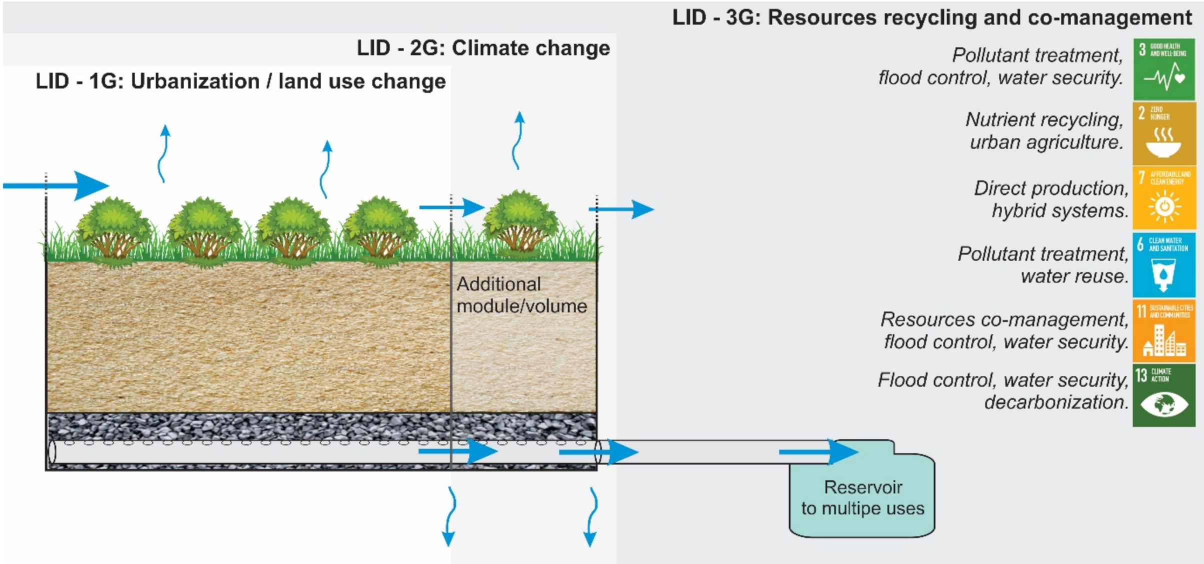
[8]Professor at University of Sao Paulo, Av. Trabalhador Saocarlense, 400 CP 359 São Carlos, SP CEP 3566-590, Brazil emm@sc.usp.br

Table of contents

Abstract

The increase in urbanization and climate change brings new challenges to the cities' sustainability and resilience, mainly related to flood and drought events. Among these challenges, it can be highlighted the physical and health damage to the population, interruption of water, energy and food supply services, damage to basic infrastructure, economic losses and contamination of urban rivers. To contribute to the increase of resilience in urban centers, LID practices have been used as a new approach of mitigation and adaptation within urban drainage systems, aiming at runoff retention, peak flow attenuation, pollutant removal and ecosystem services restoration (e.g.: resources recycling, carbon sequestration, thermal comfort and landscape integration). These different mitigation purposes and complementary benefits provided by LID practices can be related to the different Sustainable Development Goals (SDG) presented by the United Nations (UN), to achieve countries' systemic sustainability. The identification of local techniques that contribute to the different SDG helps to achieve their territorialization and application as public policy. Therefore, this paper presents a literature review, categorizing the studies into different generations based on their main application purpose and presents a linkage of the LID benefits to different SDG. Some challenges were identified requiring further investigation, such as the need to identify and quantify the energy demands for LID practices maintenance and their incorporation in the system final energy balance, identification of processes that contribute to carbon sequestration and emission, and risks of emerging pollutants for human health from water reuse and nutrient cycling for sustainable agriculture.

Graphical abstract



Keywords: Resilience. Stormwater Harvesting. Carbon sequestration. Climate Change. Water-energy-food nexus.

1. Introduction

Several cities worldwide experience problems related to hydrological extremes, e. g. flood events due to intense rainfall and high periods of droughts affecting local water security. On the one hand, the increasing urbanization, land use, and paving increases runoff generation and, combined with insufficient urban planning, intensify the frequency and magnitude of flood events (Lucas & Sample, 2015; Guan, Sillanpaa, & Koivusalo, 2015). Floods lead to significant economic losses and injury risks for households and commercial buildings in vulnerable areas such as river floodplains and hill slopes (Sun, Zhang, & Wang, 2017; Carter, et al., 2015; Douglas, et al., 2010). On the other hand, the high population density in the cities leads to high water demands, while longer droughts and urban river contamination by sewage disposal and diffuse pollution threaten the availability of reliable water resources (Fletcher, Andrieu, & Hamel, 2013).

Climate change scenarios projected by recent Intergovernmental Panel on Climate Change's (IPCC) reports indicate that the increase of global temperature will worsen both of drought and flood events (Rosinger, 2018; Mohor & Mendiondo, 2017; Kirchhoff et al., 2016; Ambrizzi & Magaña, 2016; Carter, et al., 2015). In this sense, the previous problems faced by the cities tend to be intensified.

Many approaches, techniques and policies have been presented to increase society and urban resilience and mitigate those problems. In 2015, the United Nations presented the Sustainable Development Goals (UN SDG) (UN, 2020) as an agenda to be met by countries until 2030 to move towards a resilient and prosperous global society. This agenda presents 17 goals that require urgent actions to ensure greater social welfare, health, education, reduce social inequalities and, at the same time, preserve natural resources and combat climate change.

The concept of alternative urban drainage systems emerges around the world to manage the flood and drought risks, as a strategy that facilitates implementation of flood resilience

(Fletcher, Andrieu, & Hamel, 2013). Different nomenclatures can be used for this strategy: Best Management Practices (BMP), Low Impact Development (LID), Green Infrastructure or Stormwater Control Measures (SCM) in the USA, Sustainable Urban Drainage Systems (SuDS) in Europe, Compensatory Techniques (CT) in France and Brazil, Water Sensitive Urban Design (WSUD) in Australia, and Sponge City in China (Eckart, McPhee, & Bolisetti, 2017; Jun, et al., 2017; Fletcher et al., 2015). Some authors present different concepts for each nomenclature, however, they have been used as synonyms in international academic papers (Fletcher et al., 2015). In this paper, the LID practice nomenclature will be adopted.

LID practices restore the natural hydrological cycle, or pre-urbanization cycle, focusing on water infiltration, groundwater recharge, runoff retention and improvement of water quality (The Prince George's County, 2007). Therefore, LID practices vary from non-structural measures, such as policies to reduce the runoff generation, and structural measures aiming at the induced infiltration and groundwater recharge, retention, (bio)filtration, runoff control at the source, urban landscape integration, and non-transference of the impacts downstream (Fletcher et al., 2015).

Due to the multiple purposes of these systems in flood control, water treatment, stormwater harvesting, carbon sequestration, among others, they can potentially cooperate for different UN SDG, such as SDG 2 – zero hunger, SDG 3 – good health and well-being (Chandrasena, Deletic, & McCarthy, 2016), SDG 6 – clean water and sanitation (Fletcher et al., 2008, Jing et al., 2017), SDG 7 – affordable and clean energy (Ramos et al., 2013; Nair et al., 2014), SDG 11 – sustainable cities and communities (Moore & Hunt, 2012), and SDG 13 – climate action (Brudler et al., 2016; Zahmatkseh et al., 2015), as well as to reduce flood frequency and increase water security.

This study aims to investigate the potentials of LID practices to contribute to different UN SDG and increase cities resilience, facing drivers of change in urbanization and climate.

Two strategies were adopted to this purpose: (1) to propose a new classification of LID practices generations, according to different purposes of mitigation, considering future scenarios with different drivers of change (such as urbanization and climate), and their potential contribution to the UN SDG; (2) to present a review of the literature of the studies already developed in each LID generation, identifying the gaps and potentials that still need to be explored. Finally, a method for evaluating the dynamic resilience of urban watersheds was presented to evaluate new studies.

2. New concept: 1st, 2nd and 3rd generation LIDs – changes in urbanization, climate change, resources security and co-management

Historically, LID practices have evolved with new paradigms and challenges, such as water quality improvement linked to flood mitigation, and recently water recycling and water security (Fletcher et al., 2015). Guides and manuals for LID practices design present several classical design purposes, for example, maintenance of recharge volume (for re-establishment of the water cycle), improvement of water quality (first flush treatment), channel protection, reduction of runoff volume to protect against channel overflow, and peak flows amortization (Waterways, 2005; The Prince George's County, 2007; Council, 2007; McAuley, 2009). Recently, stormwater harvesting, ecosystem services, and carbon sequestration are being considered as design purposes (Ge et al., 2016; Moore & Hunt, 2012).

However, designing these practices to meet different purposes do not ensure site resilience if the timescale is not considered. There are drivers of change in the cities affecting considerably the runoff and pollutant generation, such as changes in land use due to the increasing urbanization and climate change (Liu et al., 2016; Liu et al., 2017). Therefore, the timescale including the future scenarios should also be considered in their design.

A new classification of LID's generation is introduced in this paper (Figure 1) to integrate these new paradigms. The generations are differentiated according to the timescale, drivers of change, and resilience purpose. This classification aims to clarify that there is an advance in the problems related to flood management and the need to integrate recent studies and technologies with the UN SDG demands. Therefore, the adoption of LID practices from a new paradigm of resource recycling, stormwater harvesting, watershed life cycle and sustainable communities increases the resilience of a natural-social environment that cannot be afforded by other classic structural measures.

[Figure 1 near here]

Figure 1 presents a scheme to illustrate the generation's classification. T_0 is the base scenario, which is period prior to urbanization. In this scenario, any rain (P_1) that falls on the watershed is separated between infiltration (Ia_1), soil storage (S_1), runoff (Q_1) and evapotranspiration (ET). There is a reduction in both the maximum soil storage (S_2) and initial infiltration capacity (Ia_2) with changes in soil characteristics caused by urbanization (increased paving and change in slope), so that the same rainfall P_1 generates a larger volume of runoff (Q_2) relative to the base scenario (named as exceeding runoff $\Delta Q|_{urb}$, which causes flood problems) (Leopold, 1968; Konrad & Booth, 2005; Wong & Eadie, 2000; Stovin et al., 2013). In addition to higher runoff volumes, the urbanization also leads to pollution problems, so that waste and other pollutants present on the catchment are carried to the water bodies during rainfall events (named as exceeding load $\Delta L|_{urb}$, which is responsible for the urban rivers contamination) (EPA, 1983). Also, there is a reduction of total ET ($\Delta ET|_{urb}$) due to surface paving and reduction of vegetation. LID practices can help to increase back the ET fluxes.

Therefore, the stormwater quality and quantity issues caused by urbanization have led to the emerging of the first generation of LID (LID-1G).

However, nowadays the medium and long-term strategic planning, i.e. incorporating timescale, must also be considered to make cities more resilient. Therefore, the future scenarios must be addressed, considering all the drivers of change, such as urbanization and climatic patterns. Global climate change also becomes a regional and local problem, changing rainfall depth, intensity, and frequency of events, contributing to the increase of droughts and flood extremes (Gersonius et al., 2012; Arnone et al., 2013; Chou et al.; 2014). Therefore, there is an additional rainfall depth for a rain P_1 ($\Delta P|_{climate}$), which generates a new volume of exceeding runoff ($\Delta Q|_{climate}$). This additional volume must be considered to design LID structures regarding long-term flood mitigation. The $\Delta P|_{climate}$ will also lead to different process of pollutant build up and wash off, affecting the pollutant load in the runoff ($\Delta L|_{climate}$) (Liu et al., 2016; Liu et al., 2017; Lago, Macedo & Mendiondo, 2018). ET is also affected by the difference in precipitation and temperature regimes ($\Delta ET|_{climate}$). In this case, where both urbanization and climate are considered, the LID practices are called of 2nd generation (LID-2G).

Finally, changes in future scenarios threats natural resources availability and social environments. In terms of natural resources, one of the impacts of climate change is reducing water security. Simultaneously it also affects the security of other resources, such as energy and food (the link between these resources is presented by Hoff (2011), as the *water-energy-food nexus*). Measures that help fix carbon in the soil and biosphere also contribute to the environment sustainability. It is, therefore, necessary to think of new approaches that consider circular mitigation, where the exceeded runoff or pollution is seen not only to be eliminated, but as a possibility of resource to be reinserted into the watershed life cycle, moving toward sustainable and resilient communities. Therefore, for the last scenario, the exceeding runoff is reinserted in the watershed life cycle and can provide multiple benefits (e.g.: stormwater harvesting, nutrient recycling, carbon sequestration, thermal comfort). In this last scenario, the benefits of using LID practices can be linked to multiple sustainability purposes (proposed in the UN SDG), and they are classified as 3rd generation (LID-3G).

In Figure 1, Ia_2 and S_2 were considered constant for the same land use scenario after a drought period, however it is important to state that they can vary along time according to the previous soil moisture condition. The previous soil moisture condition can be affected by the differences in rainfall pattern (long drought periods or more intense rainfall volumes) and recirculation of runoff in the watershed. Therefore, the variations in runoff due to changes in soil storage and infiltration capacity are also possible for LID-2G and LID-3G.

Figure 2 presents the LID generations classification according to evolution of LID practices presented by Fletcher et al. (2015). The origin of the urban drainage concept was thought only concerning flood mitigation, and it was later integrated to water quality, which is defined as LID-1G purposes. These purposes are also listed in the Bioretention Manual, developed in the USA by The Prince George's County, and in the WSUD Guidelines, developed in Australia by the South Eastern Councils (The Prince George's County, 2007, Waterways, 2005). Currently, most of the alternative systems applied serves to 1st generation purposes (LID-1G).

According to Fletcher et al. (2015), in 2013, aspects of 3rd generation were already involved in the LID systems design, such as urban harvesting (stormwater as resource), ecosystem ecology and resilience (along with microclimate), that is, integrating nature-based solutions, and targeting different sustainability purposes (UN SDG: clean water and sanitation, climate action, affordable and clean energy, good health and well-being). Despite the purpose of "resilience" for the design of new LID practices, Fletcher et al. (2015) does not present explicitly temporal scaling and future changes of the hydrological cycle that occurs by land use and climate changes, that characterizes 2nd generation LID. However, this timescale should be considered while planning or designing LID system. Therefore, in Figure 2, the urban drainage system evolution presented by Fletcher et al. (2015) has been adapted considering aspects of timescale and future scenarios of climate change and land use changes.

[Figure 2 near here]

Although there are already many studies addressing the new purposes of LID that meets the UN SDG, there is still no systematization of classification that incorporates these new approaches with the usual purposes of runoff retention and water quality improvement, i.e. the impact of non-stationary effects of climate change, modulation and integration with water-energy-food security, climate action and sustainable cities and communities. In addition, unlike usual studies that approach purposes based on static criteria, the classification of LID generations incorporates a temporal efficiency attribute allowing the maximization of the resilience of these systems over time. Therefore, the categorization of LID generations helps to visualize and compare different studies, discriminating and analyzing the different approaches. It also evidences the advances on flood management issues and a new resource cycling paradigm to increase mitigation and resilience to extremes.

In the further sections it is presented a review of papers that correspond to studies in LID-1G, LID-2G and LID-3G. This review exemplifies the studies developed for each generation purposes, stating the lessons learned, and identifying remaining challenges.

3. LID - 1G – Increase of urbanization

Studies involving applications of LID practices to mitigate urbanization can be separated into two types: static studies and time scale studies. In this section, it is first presented the static studies, as they are the most developed to date. Later, new perspectives to incorporate time scale in the evaluation of urbanization are presented.

3.1. Static evaluation of LID practices performance for urbanization impacts

One of the LID practices that have been extensively studied is bioretention, due to its ability to both mitigate floods and promote pollutant removal. Table 1 presents a summary of studies developed with 1st generation bioretention, both in relation to runoff retention, as well as water quality treatment.

Regarding flood control purposes, the results presented in Table 1 show different performance results for each practice evaluated but with a trend in the capacity of flood peaks mitigation and runoff volumes reduction. However, the variability of results indicates the complexity in the general assessment of LID structures, since local factors such as degree of urbanization, soil type, filtering media, as well as climatic characteristics (rainfall, drought time, and rainfall intensity) act jointly on the devices efficiency. This complexity of factors acting on the bioretention performance was evaluated by Macedo et al. (2019), for a subtropical climate locality. They found that antecedent soil moisture and runoff generation rate were the main environmental factors affecting the performance during the dry period, while the rainfall depth and intensity had the greatest influence on the rainy season.

The diversity of results by different studies shows that it is still necessary to better understand the influence of environmental, climatic, and constructive factors of LID practices on their performance. From this understanding, the design guidelines and manuals should be updated with recommendations for different combinations of factors. Most current guides address only temperate climate locations and consider constructive aspects without major variations, such as local soil, vegetation and filter media.

[Table 1 near here]

Regarding pollutant control, the results presented in Table 1 show that there is still a great variability in nutrient removal rates (nitrogen and phosphorus). Soil type, filter media, vegetation (Litern et al., 2011) and climate (Mangangka et al., 2015) are some of the main factors affecting this removal. Configurations including a vegetation layer and an anaerobic zone are recommended to optimize nutrient removal (Glaister et al., 2016; Sun, Zhang & Wang, 2017; Wan, Li & Shi, 2017). However, nutrient species responded differently to changes in inflow volume and dry weather antecedence. Therefore, nutrient removal optimization is still a challenge to be addressed (Glaister et al., 2016). It is also necessary to expand the studies to tropical and subtropical regions and evaluate the effect of the climate in nutrient removal. In tropical regions, it is common to have long drought periods, affecting the biological behavior inside the LID practices and the vegetation survivor. Once the vegetation and biological treatment plays an important role in the pollutant removal, it is necessary to evaluate how these long drought periods affect the pollutant control.

The removal of different metals in bioretention systems has also been widely studied (Table 1), due to the capacity of these systems to adsorb metals in their filtering media, often due to the cationic exchange capacity of the soil and plants assimilation capacity. Overall, studies show good metal removal capacity, ranging from 37% for Hg (Gilbreath et al., 2019) to 84% for Zn (Hatt, Fletcher & Deletic, 2009). However, in some places metal exports are observed, such as Cu and Fe (Chahal, Shi & Flury, 2016; Macedo, Lago & Mendiondo, 2019), concerning the presence of metals initially in the soil or filtering media, which are leached with the stormwater passing through the system.

A growing concern with the presence of pathogens in the stormwater runoff is also noted, mainly due to the increase of stormwater/rainwater harvesting to human reuse. *E. coli* is an usual indicator of faecal contamination and it presents a great persistence to disinfection treatments. The study of Chandrasena et al. (2019) and Liu et al. (2020) (Table 1) are recent examples of evaluating different configurations to increase the removal of pathogens using bioretention systems. Both studies evaluated different filtering media, so that the first focused more on different types of natural soil with different plants, and the second evaluated unconventional filter media such as biochar and zeolite to increase *E. coli* adsorption. The biochar (Liu et al., 2020) showed a greater removal capacity when compared to conventional medias (Chandrasena et al., 2019). However, Chandrasena et al. (2019) noted that, even with removal rates 67% of the times higher than the recommended by the Australian guideline for water reuse (NRMMC, 2009), the outflow concentration rarely reached values lower than the recommended 100 MPN/100mL, demonstrating the need for further studies on bioretention configuration to optimize *E. coli* removal.

In this sense, Shen et al. (2018) developed a process-based model for the removal of *E. coli* in bioretention systems containing a saturated zone, allowing to identify the key factors for treatment. However, this model requires values of adsorption constants for different filtering media, as well as other *E. coli* fate processes (such as die-off). In this sense, the study of Mei et al. (2020) identified the adsorption constants of different models (Langmuir and Freundlich) for different filtering media.

Another growing concern in terms of water quality is emerging pollutants, such as microplastics, aromatics, medicines, and pesticides. There are still few studies that have evaluated the ability to remove these pollutants in bioretention systems (Table 1) and in LID practices in general. Zhang et al. (2014) evaluated a micropollutants treatment in a field's bioretention system, obtaining removal rates from 6 to 99.6%, varying according to the pollutant and the presence of a saturated zone. These experimental results were later used to calibrate the process-based model MPiRe, developed by Randelovic et al. (2016). Gilbreath et al. (2019) also evaluated several emerging pollutants, including micro plastic and micro particles, obtaining 90% removal in a bioretention system. Lamont, Jenkins & Kavehei (2019), identified more than 8000 tons of plastic pollution generated and transported in the stormwater of Gold Coast city (Australia), therefore pointing to the need to start addressing micro plastic in LID practices.

3.2. New perspectives for time scale evaluation in LID practices for urbanization impacts

To ensure cities long-term resilience, it is necessary to incorporate drivers of changes in the assessment and design of the devices. New studies have been evaluating the efficiency for future scenarios through simulation and modeling.

Liu et al. (2016) evaluated the effect of land use change on the generation of runoff and pollutant loads for an urban catchment between 2001 and 2050, resulting in increases between 8% and 17.9% of the total runoff volume generated. Liu et al. (2017) achieved a 1% increase in the constant of infiltration for the Soil Conservation Service – Curve Number (SCS-CN) method for future urbanization scenarios (from 2001 to 2050), which led to a 1.2 to 17.5% increase in runoff volume in their study area.

Wang et al. (2016) evaluated the cost-effectiveness of bioretention practices under future urbanization scenarios (varied from the Shared Socio-economic reference Pathways – SSP). As a result, urbanization has more effect on surface runoff quality (total suspended solids – TSS loading) than on runoff peak. In addition, the major costs of bioretention are associated with maintenance and transportation activities.

To ensure LID practices efficiency and long-term resilience maintenance, it is necessary to incorporate timescale aspects right into the LID framework design step, which is still not considered in most of the guidelines and manuals. One of the possibilities to consider future urbanization scenarios into the classical designs is by modifying the constants of the infiltration methods that are used to runoff estimation, e.g., when using the infiltration method SCS-CN (Chow, Maidment & Mays, 1988) it is possible to include urbanization by updating the curve number (CN) (Liu et al., 2017), or when using the rational method, updating the runoff coefficient (C) (Chow, Maidment & Mays, 1988). This is a simple and easy-to-use way for pre-sizing and design of LID structures or continuous simulations.

In addition to urbanization, other factors to be considered in timescale assessments are the infrastructure aging and the need for maintenance over time. For infiltration and filtration systems, the main aging factor that must be considered is clogging, which occurs due to the entrainment of solids into the system. Coustumer et al. (2012) and Coustumer et al. (2009) studied the effect of clogging on bioretention systems and obtained drops in hydraulic conductivity in factors of 3.6 over a period of 72 weeks, varying according to the type of plants (that may favour greater infiltration due to the root system). However, despite the variability of hydraulic conductivity in different media due to clogging effect, little variation in treatment performance was observed, since most systems are large, and their ponding volume compensates for the reduction in conductivity of the filtering media.

Clogging must be considered to design the techniques and to plan the corrective maintenance time (changing the filter bed or backwashing for bioretention and porous pavements, for example). Macedo (2020) included the loss of hydraulic conductivity due to clogging as one of the parameters in the sensitivity analysis of different design methods of bioretention systems and obtained that, considering future scenarios, to adopt reduced hydraulic conductivity coefficients helps in maintaining efficiency throughout the time. However, the efficiency of the device was more sensitive to the constants of the infiltration methods, which varies according to the urbanization level.

4. LID - 2G – Adaptation measures to climate change

Besides urbanization, change in the future climate pattern should also be considered in timescale studies and design. In this section, it is presented studies that address the consequences of climate change in urban catchments and perspectives of their incorporation into design guidelines.

4.1. Climate impact mitigation through LID systems

Table 2 presents the results of studies that assessed the impacts of climate change on urban catchment and their drainage systems in different regions, as well as the mitigation capacity provided by LID practices. Impacts vary from regions, some of which has increased rainfall in the wet month (Carter et al., 2015), and there is a reduction in some (Liuzzo et al., 2015; Arnone et al., 2013; Lyra et al., 2018), but overall, climate change tends to increase rainfall intensity. As seen in the previous section, rainfall intensity is one of the factors that most affect the performance of LID practices in the rainy season. In addition, the decrease in total rainfall leads to reduced water availability, and the increased drought period leads to higher pollutant build up and wash off (Liu et al., 2016; Liu et al., 2017; Lago, Macedo & Mendiondo, 2018).

In watershed and city scale, Brudler et al. (2016) used a lifecycle approach to quantify the environmental impacts of climate change in the classic drainage system when compared to system integrated with LID practices, in the city of Copenhagen in Denmark. They have concluded that the classical systems have up to 5x more impacts on the environment than the adaptive measures using LID. The studies of Dudula and Randhir (2016) and Paola et al. (2015) evaluated the effectiveness of LID practices implantation from hydraulic and hydrological models. Common results show that exceeding runoff generated by climate change can be mitigated by using LID practices. In this same sense, Zahmatkseh et al. (2015) showed that, while average increase in historical annual runoff volume under climate change was of approximately 48%, the LID controls could provide an average reduction of 41% in annual runoff volume. Application of LID also reduced peak flow rates by an average of 8% to 13%. Recently, in their review study, Pour et al. (2020) found that LID practices had a great efficiency in mitigating flood peaks to small events, but they were not so effective for more intense events. Therefore, the mitigation of more frequent extremes posed by climate change is still a challenge.

[Table 2 near here]

4.2. New perspectives for incorporating climate change in LID design

The studies presented have evaluated the effects of climate changes in the LID practices efficiencies but did not propose adaptations in design methods. Many of the guidelines and manuals for design LID practices (Waterways, 2005; The Prince George's County, 2007; COUNCIL, 2007; McAuley, 2009) recommend the use of synthetic design storms obtained using the Intensity-Duration-Frequency (IDF) curves, with different return periods. Therefore, one of the options to incorporate the non-stationarity of climate in the design of LID practices is to update the IDF curves considering the climate change scenarios projected by the IPCC, generating, then, design storms more compatible with the future scenario (Madsen, Arnbjerg-Nielsen & Mikkelsen., 2009; Soro et al., 2010; Mailhot & Duchesne, 2009). The update of IDFs for drainage design and flood management has been recommended in several studies (He, Valeo & Bouchart, 2006; Wang, Hagen & Alizad., 2013; Madsen et al., 2014) and has already been adopted in guidelines of the New York State and Belgium (Willems, 2013; DeGaetano & Castellano, 2017).

Methods to IDF update are presented by Willems & Vrac (2011), Willems (2013), Wang Hagen & Alizad (2013) and Srivastav, Schardong & Simonovic (2014). These methods consist in performing spatial and temporal downscaling from Global Circulations Models (GCM) or Regional Climate Models (RCM), followed by bias correction. Climate change models have great uncertainties, and these should be considered in hydrological simulations and construction of new IDFs, even when performing downscaling and bias correction methods. Willems & Vrac (2011) propose that instead of quantifying statistical uncertainties it would be possible to deal with uncertainty scenarios, using various climate models, emission scenarios and applying different bias correction methods.

Macedo (2020) evaluated the updating of the IDFs considering climate change scenarios for the construction of design storms in projects of bioretention systems on a property, street and neighborhood scale for different design methods. Additionally, infiltration constants, such as C and CN, were also varied to assess the influence of future urbanization scenarios. In this study, they observed that the total rainfall volume used in the design has more influence than the rainfall intensity considering future climate scenarios.

Continuous simulation with climate change scenarios has been used as an alternative in the LID practices design. Ghodsi et al. (2020) optimized the design, location and type of technique to be applied in an experimental catchment from continuous simulation in Storm Water Management Model - SWMM. As a result, they obtained an optimized total area of LID practices corresponding to 0.23% of the catchment area, which allowed a reduction of runoff volumes by up to 18%. However, continuous simulation is not yet adopted in the design guidelines because of the greater complexity.

Another challenge is the requirement of a great initial investment in the implementation of LID practices considering future scenarios, since structures tend to have larger area and volume. To overcome this adversity, Rosa (2016) and Loiola, Mary & da Silva (2018) propose a similar idea of modular design for LID systems. The LID devices are designed for future scenarios, but their implementation is made through modular expansion, so that its construction and hence costs are distributed over the years, for a better adaptation to changes and exceeding runoff and pollutant loads.

The idea of modular expansion is to make possible to predict future modules since the design, but to implement it in a future period. The land availability and the general basic infrastructure (e.g., disconnection from the conventional drainage network) necessary for future expansion are incorporated in the initial planning. Modular expansion can be easily performed in systems that do not require excavation, such as stormwater harvesting tanks, green roofs (as presented in Loiola, Mary & Silva, 2018), and unburied rain garden systems, such as the Metal Downspout Planters (Figure 3a) of the raincheck program (Philadelphia Water Department, 2020). In addition, there are already some other buried modulated filtration systems, such as the Stormwater Filter Screens (Figure 3b) developed by the Envirostream Solutions (Enviss, 2020), allowing you to add new modules in the future without structural damage. Although the Metal Downspout Planters and Stormwater Filter Screens systems were not initially conceived for future expansion, their designs and structures easily allow their use for this purpose.

In the case of buried LID practices, such as bioretention, wetlands, infiltration trenches, detention basins, there are additional challenges regarding modular expansion, such as soil stability, excavation, etc. Therefore, Rosa (2016) suggests that modular expansion should be done along pre-defined intervals of the system corrective maintenance, such as replacement of the filtering media due to clogging (Erickson, Weiss & Gulliver, 2013). For this type of LID practices, we suggest further studies incorporating new design and construction ideas that allow modulation, such as the ones presented in Figure 3, or future expansion without causing structural damages for the existing systems.

[Figure 3 near here]

5. LID - 3G – Contribution of LID practices in moving toward UN SDG

In addition to incorporating the timescale and drivers of change in LID projects, moving towards a more resilient society also requires a systematic and holistic view of stormwater management, integrating measures that help the whole of a balanced and fair environment. From this conception, LID practices can be used to meet the SDG.

Within the systematic view from which the SDG emerges, it is necessary to understand that the use of natural resources and its impacts on the environment are correlated with each other and have complex relationships of exchange and interdependence. It is from this systemic view that the *water-energy-food nexus* also emerges. This approach is based on the idea that the security of these resources and the system resilience can only be guaranteed by an integrated management, explaining all the relations and connections between the production, operation and distribution of water, energy and food resource among each other (Hoff, 2011). *Water-energy-food nexus* is already being used and widespread in the water and energy production sectors, with little insertion in stormwater management studies, despite its potential integration with alternative urban drainage measures.

Within the *water-energy-food nexus* approach, stormwater harvesting also reduces the energy demand of supply systems by producing water near the point of consumption and the systems can be used to cycle nutrients present in the stormwater for agricultural purposes. By reducing demands for energy and resource production, alternative drainage systems also have positive impacts on reducing greenhouse gas (GHG) emissions (Novotny, 2010). Moreover, in addition to the indirect contribution to GHG reduction, LIDs also have carbon sequestration capacity through the assimilation of organic matter into the filtering media and vegetation growth (Kavehei et al., 2018). Therefore, a new "carbon" component can also be incorporated into the nexus (Nair et al., 2014).

For a better presentation of the review, in this section, the contribution of LID practices to the water-energy-food security, carbon sequestration and ecosystem ecology are presented separately. However, it should be highlighted that the nexus and the SDG are systemic approaches, where their correlations are greater than the evaluation of each separate component. In addition, LID practices may contribute to other SDG than those presented in this review.

5.1. Contribution to water-energy-food security

In this section we review studies with direct contributions from different LID systems to increase water-energy-food security. Integration with water reuse (directly related to urban drainage) has been studied since 2008, evaluating the recovery of the LID practices outflow (which has a higher quality than the runoff) to later non-drinking water demands (Mitchel et al., 2008; Fletcher et al., 2008, Burns et al., 2015). The water recovery from the wet season can then be used to meet water demands during the dry season and increase the water security, therefore contributing to the SDG 6 (clean water and sanitation). The contribution to the water security in these systems depends on factors such as rainfall pattern, adequate water quality in the outflow, capacity of the storage reservoir, demand of the population (Karim, Bashar & Imteaz, 2015), length of rainfall record, inter-annual variability of seasonal demand, and storage surface type (Mitchel et al., 2008) which can affect their reliability.

In this sense, Karim, Bashar & Imteaz (2015) evaluated the reliability and economic saving of stormwater harvesting systems in Bangladesh megacity. Results indicated that 250 m^3 to 550 m^3 of rainwater can be harvest each year for catchment sizes varying from 140 m^2 to 200 m^2, with volumetric reliability about 15–25% under the wet climatic condition. Petit-Boix et al. (2018) estimated that cisterns were able to supply ~75% of the rainwater demand for laundry and toilet flushing. Clark et al. (2015) modeled the water demand reduction using rainwater harvesting, concluding that an annual demand equivalent to 12.8% of the catchment rainfall could be met with 99.5% of volumetric reliability. Macedo (2020) also evaluated a bioretention system with outflow storage to meet less restrictive non-drinking water demands for residences Sao Carlos, Brazil, and observed that the stormwater recovered was able to supply the non-potable demands over seven months.

One of the difficulties about implementing stormwater reuse is the lack of specific legislation establishing the limit values of water quality parameters, to be used for different reuse types (Fletcher et al., 2008). Therefore, countries should develop their own legislation, based on values already adopted elsewhere and adapting it to their environmental reality.

In Brazil, in the last three years, three standards were approved and updated regarding the management of alternative sources of water in buildings. The guideline "NBR 15.527/2019: stormwater – coverings utilization in urban areas for non-potable purposes - requirements" establishes limits for turbidity, *E. coli* and pH for the stormwater non-potable reuse.

Currently, the most developed countries regarding compliance with specific legislation for rainwater reuse are Australia and the United States. In 2008, the Australian Guidelines for Recycling Water document was prepared, which discusses principles of water recycling, including action policies, monitoring routine and systems operation (NRMMC, 2008). In this document, the same values from the Australian Drinking Water Guidelines are used, but with a greater discussion on pathogens, and other chemicals such as medicines and pesticides.

In the USA, the current standards for water reuse are given by the "2012 Guidelines for Water Reuse", produced by the Environmental Protection Agency – EPA, (EPA, 2012). One of the motivations for water reuse presented in this document is the advance of urbanization that increases water scarcity. With a guideline for water reuse, the EPA aims to meet the *water-energy nexus* to optimize the use of these two resources.

In the same direction of the EPA guidelines to meet the *water-energy nexus* from water reuse, Sapotka et al. (2016) and Arora et al. (2015) evaluated the benefits of LID practices in the urban infrastructure, where they can integrate hybrid water supply systems, from decentralized water supply and treatment of diffuse pollution and decentralized drainage systems. They observed a reduction in energy demands in centralized supply systems, increasing the integrated resilience of water and energy systems and contributing to SDG 7 (affordable and clean energy). Consequently, regarding the *water-energy-greenhouse gas nexus* (Nair et al., 2014), the reductions in energy demand in hybrid supply systems also contribute to the reduction of GHG emissions (Arora et al., 2015).

However, the use of hybrid water supply systems still presents some gaps and challenges. There is still a lack of knowledge concerning their long-term performance, their operation and maintenance costs, energy expenditure, and appropriate governance (Sapotka et al., 2015). Additionally, some challenges in how to operate these systems also arises: the stormwater reuse will increase the proportion between water supply and wastewater in the central system, since part of the water demands will be met by individual water tanks, reducing the demand but keeping the wastewater constant. Also, dual piping systems will be adopted to the different water supply systems, and in the water reuse piping the higher pollutant concentration can lead to problems such as blockage and corrosion (Sapotka et al., 2015).

Despite the possible reduction on energy demands by hybrid and decentralized water supply systems, the LID practices can also contribute to decrease energy demand by climate comfort when applied at source/property scale. Many studies have been developed to assess the contribution of green roofs to decrease energy demands for heating/cooling due to reduction of surface temperature and increase of thermal comfort (Hashemi, Mahmud & Ashraf, 2015; Shafique, Kim & Rafiq, 2018). In a recent review of green(blue) roofs, Shafique, Xuo & Luo

(2020) obtained a variation of energy savings by these systems of 0.6 to 70% when compared to conventional roofs.

A different approach has also explored energy production using hybrid photovoltaic green roofs. Hui & Chan (2011) and Chemisana & Lamnatou (2014) evaluated the synergy effects of power output in photovoltaic panels (PV) with planted roofs and obtained as result an increase of 8.3% and 1.29 to 3.33%, respectively, in the power production when compared to traditional PV systems. Additionally, the planted roofs were able to reduce the energy demands in the buildings.

Ramos et al. (2013) present the LID practices and flood control structures as hydropower opportunities, by integrating the pond capacity with energy converters for small heads. In this study, the authors integrated hydropower converter for open channel flows and small head differences (a tubular propeller with 5 blades) with the outflow pipe of retention ponds. A total of 210 MWh/year could be produced in the case study evaluated. They also noted that the higher the ponding height, the greater is the energy production. However, since the flood control and energy production are purposes that lead to different and opposite design optimization, they highlight that the focus of these systems is to prevent floods and the energy recovery is an additional benefit.

Although previous studies have assessed the energy savings provided by LID practices, it is important to emphasize that their long-term operation also demands energy for several activities, mainly related to maintenance. Vegetated systems, such as green (blue) roofs, need pruning and an irrigation system is necessary during the dry months. Infiltration systems need corrective maintenance from time to time to reverse the effects of clogging and re-establish infiltration rates, such as pressure washing (on pervious pavements), or changing of the filtering media (in bioretention) (Erickson, Weiss & Gulliver, 2013; Blecken et al., 2015), which demand energy.

Regarding the systems that aim to water reuse, it is also necessary to consider the demands related to the internal water pumping. To compare a central supply system with hybrid systems by applying LID practices, Gardner et al. (2006) raised their energy demands and found that decentralized systems have higher costs than those of central systems, due to the lower efficiency of smaller pumping systems and multiple start-ups throughout the day. Therefore, they suggest the integration of the hybrid local system with PV to help supply the additional energy demand.

It is possible to notice that the contribution to energy security through LID systems is not a direct implication and easy to assess. It is necessary to quantify the energy balance throughout its lifetime and make a comparison with traditional systems. To this end, life cycle analysis (LCA) methodologies can be used for different configurations and types of systems, in their different phases of construction, operation and maintenance (Petit-Boix et al., 2015; Petit-Boix et al., 2017; Shafique et al.; 2020).

Since some LID techniques are vegetated, and nutrients are one of the main pollutants in the runoff, new studies have explored the food production capacity on these systems, contributing to urban agriculture. The food cultivation allows nutrient recycling, which once free in water can lead to eutrophication processes, but when absorbed by plants, they contribute to their growth. Whittinghill et al. (2013) started feasibility studies for green roof agriculture, based on the evaluation of the production of tomatoes, beans, cucumber and herbs on green roofs of small scale. As a result, they obtained production of yields slightly smaller than those on ground, with minimal irrigation during the dry season and minimal fertilizer inputs.

The study by Richards et al. (2015) evaluated the food production in a bioretention practice, irrigated by runoff from a roof catchment. They obtained a food production capacity similar to a common irrigation system, additionally contributing to a reduction in the overflow frequency by more than 90%. The system proposed a sub-irrigation to reduce the direct contact between crops and pollutants, reducing contamination risks. Ng et al. (2018) also evaluated food production in bioretention systems, however, the presence of metals in the runoff makes this process tricky, due to their possible accumulation in the edible parts of the plants above the risk limits established by the World Health Organization (WHO). Tom, Fletcher & McCarthy (2014) also conducted a study evaluating the contamination by metals in plants irrigated with runoff water, obtaining similar results to those of Ng et al. (2018).

An alternative for nutrient cycling is the reuse of plant biomass as a biofertilizer in another location (Ge et al., 2016), which allows the management with a proper dosage so that there is no toxicity by metals to the plants or consumers. Also, Chandrasena, Deletic & McCarthy (2016) investigated the pathogens concentration (*E. coli* and *Campylobacter ssp.*) in bioretention effluent and have obtained removal rates that were able to meet the Australian stormwater harvesting guidelines for irrigation.

In this perspective, LID practices (vegetated or not) can contribute to urban and sustainable agriculture and to SDG 2 (zero hunger). Studies of LCA should be done to investigate the impacts of food production near the consumption and nutrient cycling in reducing the demands for artificial fertilizers and energy consumption.

5.2. Contribution to greenhouse gases sequestration and storage

Due to the presence of a vegetation layer in different types of LID practices (e.g. bioretention, green roof, wetlands etc.) and their potential to reduce energy demands, LID practices can also be exploited in their ability to carbon sequester as a mean of mitigating GHG emissions (Novotny, 2010; Nair et al., 2014) and contributing to climate action (SDG 13).

Kavehei et al. (2018) have made a systematic review of studies with carbon sequestration and LID practices. They were able to quantify the carbon footprint related to the life cycle of different LID practices and the carbon sequestration during their lifetime. The main contribution for the carbon footprint of these systems was found to be associated with the implementation phase. Also, the vegetated systems have more potential on amortizing the carbon footprint during their lifetime, e.g. bioretentions were able to mitigate approximately 70% of carbon emissions, while stormwater ponds only mitigate 8%.

Getter et al. (2009) evaluated experimentally the carbon sequestration capacity in green roofs by vegetation growth and incorporating plant litter into the soil. The green roofs stored in the range of 64 to 239gC/m^2 in aboveground biomass (plant tissue) and 37 to 185gC /m^2 in belowground biomass (plant litter). Bouchard et al. (2013) and Moore & Hunt (2012) have used a similar methodology of quantifying the accumulation of carbon in the soil of roadside vegetated filter strips, swales, constructed wetlands and ponds. As a result, the vegetated systems (filter strips and constructed wetlands) had more capacity to accumulate carbon. However, the authors state that the interpretation of the results is limited by the lack of long-term data and the carbon fluxes in inflow and outflow. Additionally, this methodology does not account for GHG emissions in the systems.

More recently, D'Acunha & Johnson (2019) have quantified the dissolved organic carbon (DOC) and NO_3 concentrations in the effluent of a constructed wetland and their GHG emissions (carbon, methane and nitrous oxide). They concluded that the outflow still contained high values of DOC (latter decomposed and transformed in carbon emissions) and the water was supersaturated with carbon and methane, leading to evasion. These emissions must be considered when accounting LID practices contributions on carbon sequestration and climate action. Therefore, it is necessary to develop clearer methodologies to identify the carbon flux from the atmosphere to vegetation and soil, and from organic carbon to vegetation, soil and atmosphere. Already in 1999, Schlesinger (1999) stated that the carbon cycle in soils is the least well known of all the carbon cycles.

In addition to the direct effects on carbon sequestration, Pataki et al. (2006) and Shafique, Xue & Luo (2020) state the importance of the indirect effects of LID practices may in reducing GHG emissions, e.g.: green roofs increase thermal comfort and, thus, reduce energy demands with cooling and heating. However, these calculations were made from models with untested assumptions regarding urban vegetation and surface process and should be further explored.

5.3. Contribution to watershed ecology and sustainability

In 2005, Walsh, Fletcher & Ladson (2005) discussed the importance of considering stormwater management throughout the watershed area for the restoration of urban rivers in terms of their hydrological regime and ecosystem services. In this study, Walsh, Fletcher & Landson (2005) present the relationship between the level of areas effectively impermeable with different ecological indicators for the river, such as electrical conductivity, dissolved organic carbon (DOC), number of individuals from the Ephemeroptera, Plecoptera and Tricoptera families (EPT), and density of algae and diatom. In general, they observed a reduction of ecological indicators as the impermeable areas effectively connected to the river increased. Based on these results, they discuss that the restoration of ecosystem ecology requires to disconnect the impermeable areas of the central drainage system, through decentralized techniques such as LID practices. Walsh, Fletcher & Burns (2012) also argue that the use of decentralized LID systems in cities contribute to additional social benefits such as provision of water for human use.

In this same sense, Krivtsov et al. (2019) assessed the benefits to resilience and biodiversity provided by a stormwater pond associated with a rain garden in the city of Edinburgh. The benefits for ecology and biodiversity were also assessed using the quality indicators of the number of individuals from the EPT families and density of algae and diatoms, and the increase in bird diversity at the site. The reduction in peak flows, the increase in the residence time of runoff in the pond and the increase in biodiversity demonstrated that the combined use of the stormwater pond and the rain garden contributed to the increase in urban resilience and local ecosystem services.

Moore & Hunt (2012) evaluated the contribution to ecosystem services of 40 different stormwater ponds and constructed stormwater wetlands (CSW) devices. They incorporated indicators corresponding to regulation services (carbon sequestration, improvement of air quality and thermal comfort) provisioning services (food and raw material) and cultural services (recreation, education, and aesthetic). Both types of measures have contributed to increasing macroinvertebrate diversity and increasing habitat equally, but CSWs have demonstrated greater capacity to provide carbon sequestration, vegetation diversity and cultural services.

On the other hand, Li et al. (2019), Zhang & Chui (2019) and Mao, Jia & Yu (2017) evaluate the ecological benefits provided by LID practices from a different perspective, using the runoff retention volume, pollutants removal and water reuse (which are already widely used in the evaluation of LID systems), and landscape promotion as the main indicators for evaluating the restoration of ecosystem services. Zhang & Chui (2019) also present as bio-ecological benefits the increase of vegetation and its effects on hydrology, increased biodiversity, diversification of microhabitats, carbon sequestration, protection against erosion and thermal comfort.

Most design guides and algorithms for spatial distribution of LID practices consider only constructive aspects such as soil hydraulic conductivity, infiltration capacity, soil type, slope, and do not incorporate aspects of watershed ecology. To overcome this lack, Kaykhosravi et al. (2019) developed a primary index to determine the LID demand map, composed by the secondary hydrological-hydraulic index, socioeconomic index, and environmental index. The environmental index considers criteria of air pollution, biodiversity, water quality and soil contamination.

Based on the different mechanisms in which LID practices operate, they contribute to increase biodiversity and other ecological functions, contributing to SDG 3 – Good health and well-being and SDG 11 – Sustainable cities and communities.

5.4. Comparative analysis of LID practices to different SDG

Currently, there are several types of LID practices employed in sustainable urban drainage, according to the different mitigation purposes aimed by the decision makers and physical limitations of the catchment (Jia et al., 2013; Pour et al., 2020). These practices can be divided into vegetated (bioretention systems, rain garden, green roof) or non-vegetated (porous pavement, sand filter, detention ponds), infiltration-based (swales, infiltration trenchs, sand filter, rain garden) and retention-based (green roofs, detention ponds, rain barrel) (Erickson, Weiss & Gulliver, 2013; Eckart, McPhee & Bolisetti, 2017). Due to the different mechanisms employed by each of them and the main benefits provided, they have different levels of contribution to the multiple SDGs.

An overview on the most used LID practices and their limitations in terms of spatial application and their contribution to the different SDG is presented in Table 3. The contributions to each SDG were classified as low to high according to the characteristics of each technique in terms of treatment mechanisms for runoff and water quality, main mitigation purposes and scale. E.g. vegetated techniques have potential for carbon sequestration and nutrient cycling, therefore with medium to high potential in contribute to climate action and zero hunger; techniques with water storage or that can be coupled to reservoirs have the ability to reuse water, and therefore medium to high contribution to clean water and sanitation; techniques that have greater treatment capacity can contribute to clean water and sanitation and good health and well being; techniques capable of runoff retention/detention contribute to reduce flood events and can contribute medium to high for climate action and sustainable cities and communities; techniques with the possibility of landscape integration contribute medium to high for good health and well being; techniques with the production of local resources or that assist in thermal comfort contribute to reduce energy demands, and can be classified as medium to high for affordable and clean energy. In addition, the potential for use already explored in the studies reviewed in this paper was considered for the classification.

[Table 3 near here]

5.5. Future perspectives

Despite all the studies in how the LID practices can be used to LID-3G purposes, literature still lacks integration and knowledge on how to address all the purposes together. Table 4 presents the lessons learned in previous studies and the challenges that remain to LID-3G development. Clear metrics to quantify the fluxes of resources in LID practices still needs to be stated, allowing the evaluation of their contribution to the SDG and the impact on local resilience.

[Table 4 near here]

Also, increasing the application of LID practices focusing on 3G purposes requires clear guidance of how to incorporate these aspects into design of these practices. The studies did not present design guidelines that incorporate nutrient cycling, energy production or reduced energy demand, and carbon sequestration. Further studies should focus on responding to these gaps.

In addition, further studies are needed to assess the systems long-term behavior, providing data to a more precise life cycle analysis. To help with continuous long-term monitoring, studies have focus on creating low-cost real-time monitoring systems (RTM) (BoSL, 2020). The implementation of RTM is used to the development of real-time control (RTC) systems, which allows active and dynamic control of the flow regulation structures to optimize the mitigation objectives such as runoff retention, pollutant removal and water reuse (Brasil et al., 2020). Studies with RTC show promising results: Shishegar et al. (2021) and Shishegar, Duchesne & Pelletier (2019) compared a stormwater pond coupled with dynamic control in real time and obtained an average increase in peak reductions of 54% and from 73 to 95%, respectively.

Another important issue for the LID practices implementation and integration with the SDG is the population acceptance. The users need to be included in the stormwater management decision-making process. Souza et al. (2019) present the socio-hydrological observatories as a facilitator to include the population both in data acquisition (from citizen science) and in the decision process from opinion surveys and information on alternative urban drainage systems. New studies to address the acceptance and participation of the population in the management of stormwater must be developed.

6. Quantification of LID practices contribution to cities resilience

A way to evaluate LID systems is from their contribution to increase on-site resilience. The concept of resilience is linked to the ability of a system, population or society to return to initial conditions prior to a disturbance (Meerow, Newell, & Stults, 2016). The effort has been to develop ways of measuring the resilience level of a system. Several authors have proposed static resilience index as a form of quantification (Hashimoto, Stedinger, & Loucks, 1982; Kjeldsen & Rosbjerg, 2004). Simonovic & Peck (2013) and Simonovic (2017) criticize the time-independence static resilience measure because it is an abstract attribute, which does not describe the behavior and state of the system after stress, being inefficient for planning actions. Therefore, Simonovic & Peck (2013) propose a space-time dynamic resilience measure (STDRM), based on the concepts of system performance level and adaptive capacity, over time (Figure 4).

The disturbance events can generate different impacts (e.g. physical, social, economic, health, among others), which not always has the same unit. Therefore, the system performance needs to be measured for each impact in the correspondent impact unit. The dynamic resilience is then presented as a uniform unit measure representing the loss of system performance, i.e. graphically represented as the area under the system performance level between the beginning of the disturbance and the end of the system recovery (Figure 4a and equation 1) and is also variant in time and space. For resilience to be presented in a uniform unit for different impacts, the loss of system performance is normalized dividing it by maximum performance (equation 2). The integrated spatial-time dynamic resilience over all impacts is calculated according to equation 3.

$$\rho^i(t,s) = \int_{t_o}^{t} [P_0^i - P^i(t,s)]dt, \quad where\ t \in [t_0, t_r] \tag{1}$$

$$r^i(t,s) = 1 - \left(\frac{\rho^i(t,s)}{P_0^i \cdot (t-t_0)}\right) \tag{2}$$

$$R(t,s) = \left\{\prod_{i=1}^{M} r^i(t,s)\right\}^{\frac{1}{M}} \tag{3}$$

where: M is the total number of impacts; P_0^i is the maximum system performance level for impact i (at time t_0); $P^i(t, s)$ is the system performance level, at time t and space s; $r^i(t, s)$ is the resilience to impact i, at time t and space s; R(t, s) is the integrated system resilience, in time t and space s; s is the space variable; t is the time variable; t_0 is the disturbing initial time; t_r is the end of the recovery time; $\rho^i(t, s)$ is the loss of system performance to impact i, at time t and space s. Equations obtained from Simonovic and Peck (2013).

[Figure 4 near here]

Therefore, the first step in quantifying the dynamic resilience is to determine how much the system performs over time. For the assessment of LID-3G, focusing on water-energy-food security, disturbances are considered as flood events and drought periods (Figure 4b) and performance evaluation measures are proposed in equations 4 and 5 as metric examples. As proposed by Simonovic & Arunkumar (2016), the resilience for each system performance curve can be integrated into a single curve to quantify the overall system resilience (Figure 4b).

$$System\ performance_{runoff\ retention} = \frac{V_{in}(t) - V_{out}(t)}{V_{in}(t)} \quad (4)$$

$$System\ performance_{water\ reuse} = 1 - \left(\frac{WC(t) - \pi_{rec,W:E:F}(t)}{WC(t)}\right) \quad (5)$$

Where: V_{in} is the total runoff volume that enters the LID practice, V_{out} is the total water volume that exits the systems and return to the catchment as runoff (directly to rivers or to the conventional drainage systems), WC is the water consumption per household; $\pi_{rec,W:E:F}$ is the volume of water recovered/stored to future reuse for the water-energy-food security. All variables are time dependent.

To obtain a good resilience analysis, according to the STDRM methodology proposed by Simonovic & Peck (2013), it is necessary that the measures for assessing the system's performance are representative of the adaptation measure and its purpose. Furthermore, unified metrics are needed, describing the same behavior for different systems and application areas, so that they can be easily compared, allowing valid comparative conclusions.

The importance of unified metrics for assessing different measures, whether structural or political, was also identified by the UN for assessing progress of SDG in different countries. Therefore, in 2016 the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs) presented 231 global indicators to monitor the progress of countries and locations in reaching the different SDG, which were adopted in 2017 by the UN Statistical Commission (UNSTATS) and updated in 2020 (UNSTATS, 2020). The indicators adopted by UNSTATS present evaluations on larger spatial scales, usually at the country level. Therefore, it is also recommended that during the SDG territorialization stage, local indicators are proposed.

We presented just a few examples of indicators and metrics that can be developed to assess the contribution of conventional and hybrid urban drainage systems to the SDG and, therefore, 3G purposes. However, it is still necessary to develop new metrics to assess resource recycling, carbon storage, energy demand reductions, and other different SDG, identifying their correlations with global indicators. All these indicators are made up of time-dependent variables and will be affected in different ways by extreme events. Therefore, performance curves regarding each of the proposed indicators can be constructed by continuous simulation accounting for different infrastructure configuration.

7. Conclusion

The classification of LID practices in generations shows how their benefits and complexity evolves according to their purposes. For only runoff control and water quality improvement considering the urbanization impacts, they are classified as LID-1G. When considering non-stationary effects of climate change to future planning, they are classified as LID-2G. Finally, these practices can incorporate the *water-energy-food-GHG nexus* approach to help increasing the resilience in urban centers, aiming at different UN SDG, and are classified as LID-3G. Grouping them according to these characteristics will help researchers, urban designers, and stakeholders to identify the key factors to be consider in their design and their contribution to urban resilience. In addition, this new proposed terminology can also be used as an advertisement to promote implementation of higher generation LIDs.

Several research have already been developed observing these potentialities of the LID practices. Here we present the main lessons and challenges that remain to move toward their integration with the UN SDG:

- Future scenarios of urbanization and climate change need to be considered in the planning and design stage of LID practices. Studies showed increases up to 20% of runoff generation due to the increase of urbanization and climate change, together.
- Changes in infiltration coefficients and update IDF curves with climate change predictions are suggestions of how to include future scenarios on design guidelines. However, GCMs and RCMs, and hydrological models, present numerous uncertainties that need to be quantified and included in decision-making analysis of public managers.
- New designs that allow an optimization of urban harvesting in LID practices (integrating runoff reuse with nutrient cycling, and energy production and saving) are still incipient. There is still a need of a clear methodology to state the co-relations between these resources among each other and the catchment area.
- Methodologies for quantifying soil, vegetation and atmosphere carbon fluxes and life cycle analysis studies in the watershed, considering GHG emissions, need to be established to study the capacity of LID practices in decarbonization.
- Well-established metrics to identify and quantify the contribution of LID systems to the increase of urban resilience and the achievement of UN SDG.
- Studies for long-term monitoring data for LID practices should be developed, for real assessment of the benefits and challenges of LID practices incorporating timescale and future scenarios. To this end, low-cost RTM systems can assist in data acquisition.

Word count: 9997

Acknowledgments

This study was supported by CAPES grant n. 88887.091743/2014-01 (ProAlertas CEPED/USP), CNPq grant n. 465501/2014-1 and FAPESP grant n. 2014/50848-9 INCT-II (Climate Change, Water Security), CNPq grant n. PQ 312056/2016-8 (EESC-USP/CEMADEN/MCTIC) and CAPES PROEX (PPGSHS EESC USP), FAPESP grant n. 2015/20979-7 "Optimization of operation and maintenance of LID practices in subtropical climates", FAPESP grant n. 2017/15614-5 "Decentralized Urban Runoff Recycling Facility addressing the security of the Water-Energy-Food Nexus".

Tables and figures with caption

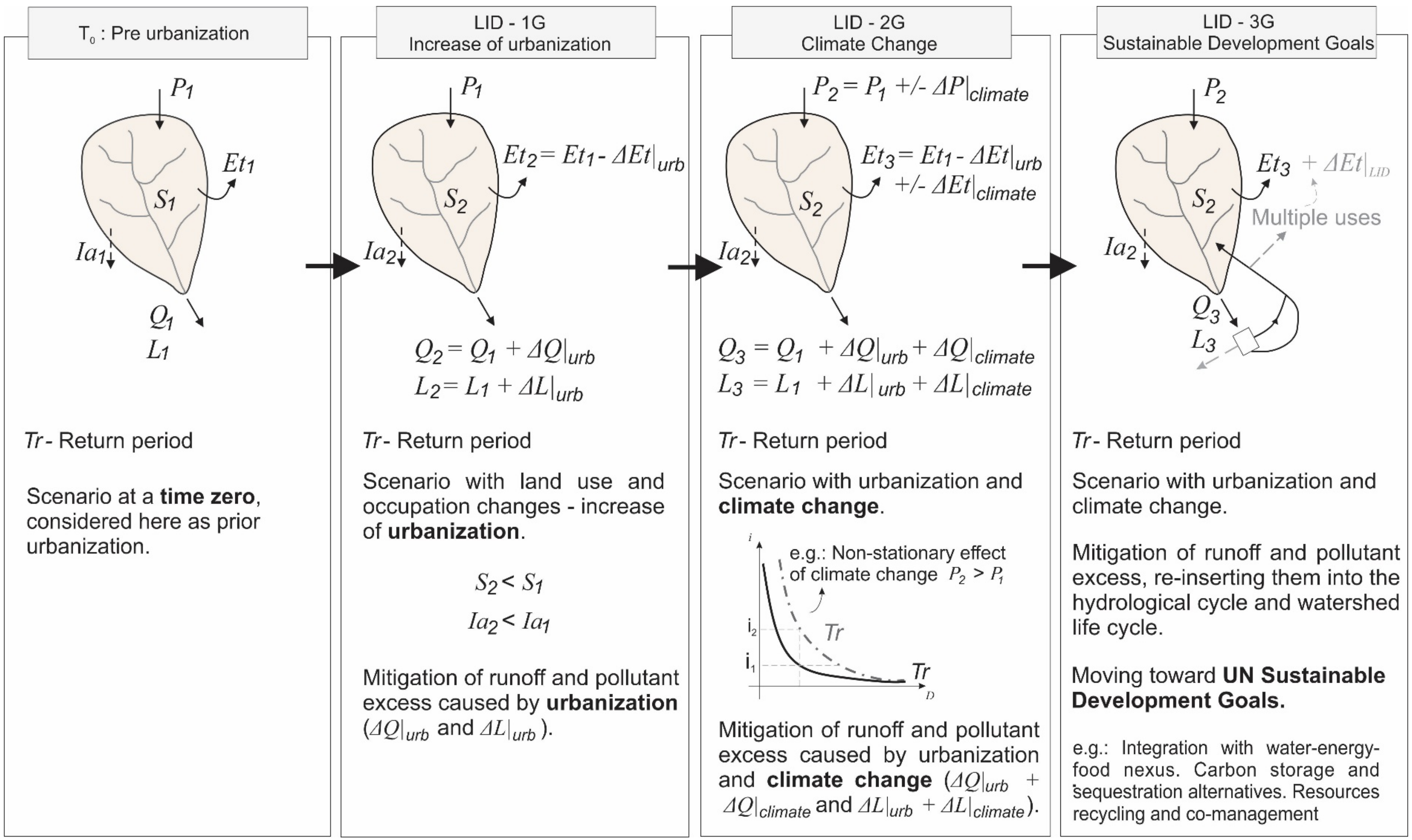


Figure 1 – Concept and evolution of LID practices generations in terms of water balance variables and mitigation purpose. In the figure, P_1, Et_1, Q_1, L_1, S_1, Ia_1 and Tr represent, respectively, rainfall, evapotranspiration, runoff, pollutant load, soil storage capacity, infiltration and return period to base scenario of pre-urbanization (adapted from Macedo et al., 2017).

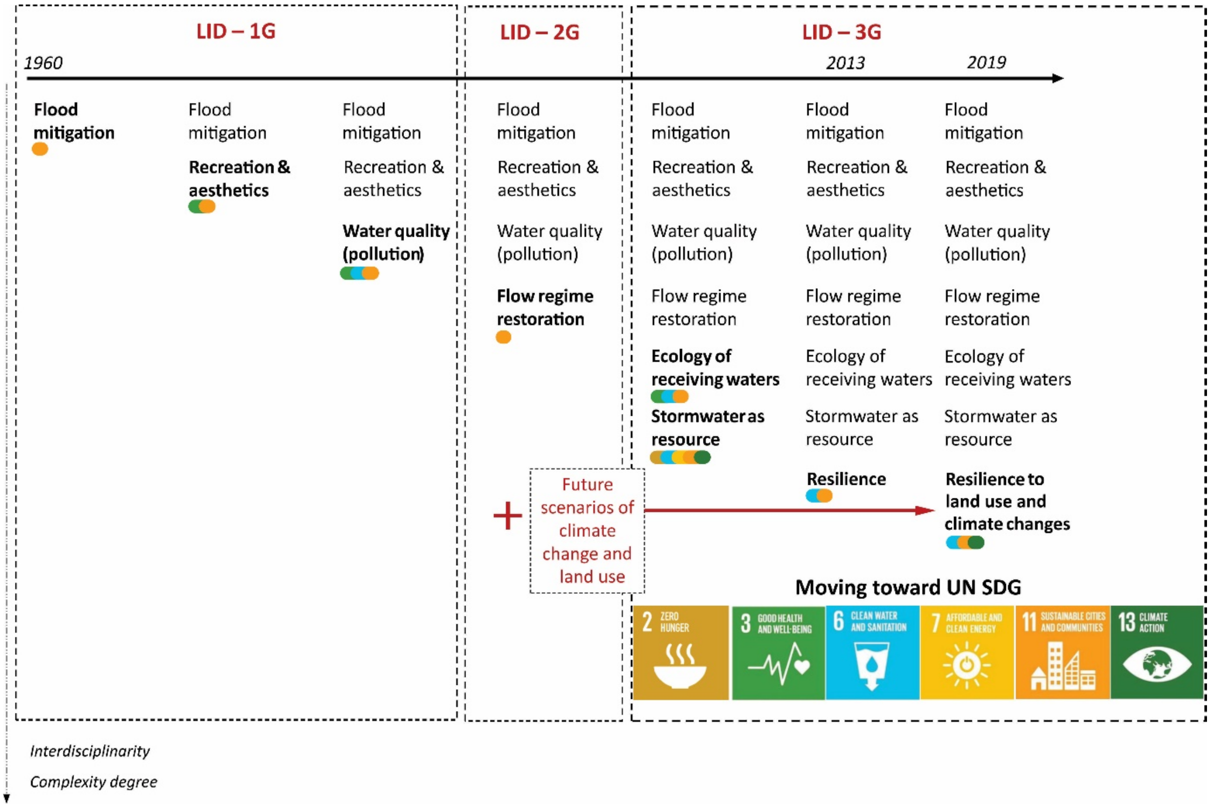
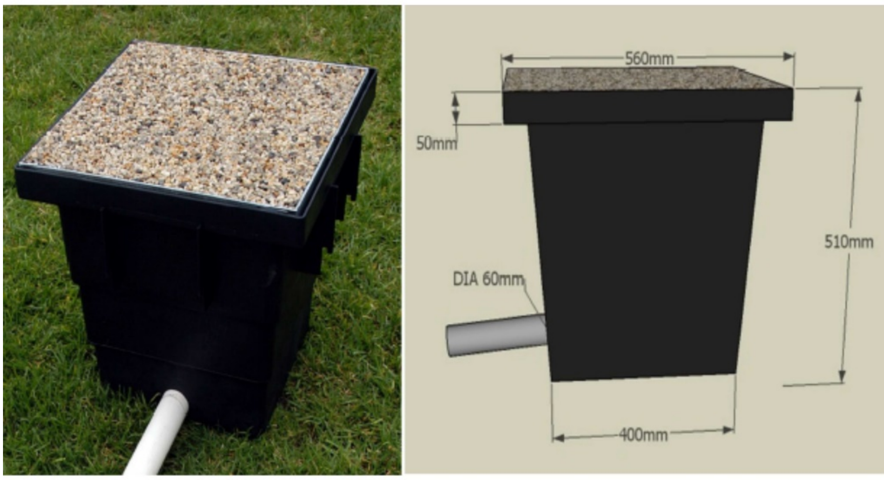


Figure 2 – New concept: Incorporation of aspects of the hydrological cycle, water quality and watershed ecohydrology into the urban drainage concept over time and its evolution within the concept of LID generations. Adapted from Fletcher et al. (2015).

(a) Metal Downspout Planters - Raincheck program



(b) Stormwater Filter Screen - Envirostreams Solutions

Figure 3 – Example of commercial LID systems that allow modulation for future scenarios or urbanization and climate: (a) Metal Downspout Planter from Raincheck program, which is similar to a lined bioretention system (Philadelphia Water Department, 2020) and (b) Stormwater Filter Screen from Envirostreams Solutions, which represent a buried filtration system (Enviss, 2020).

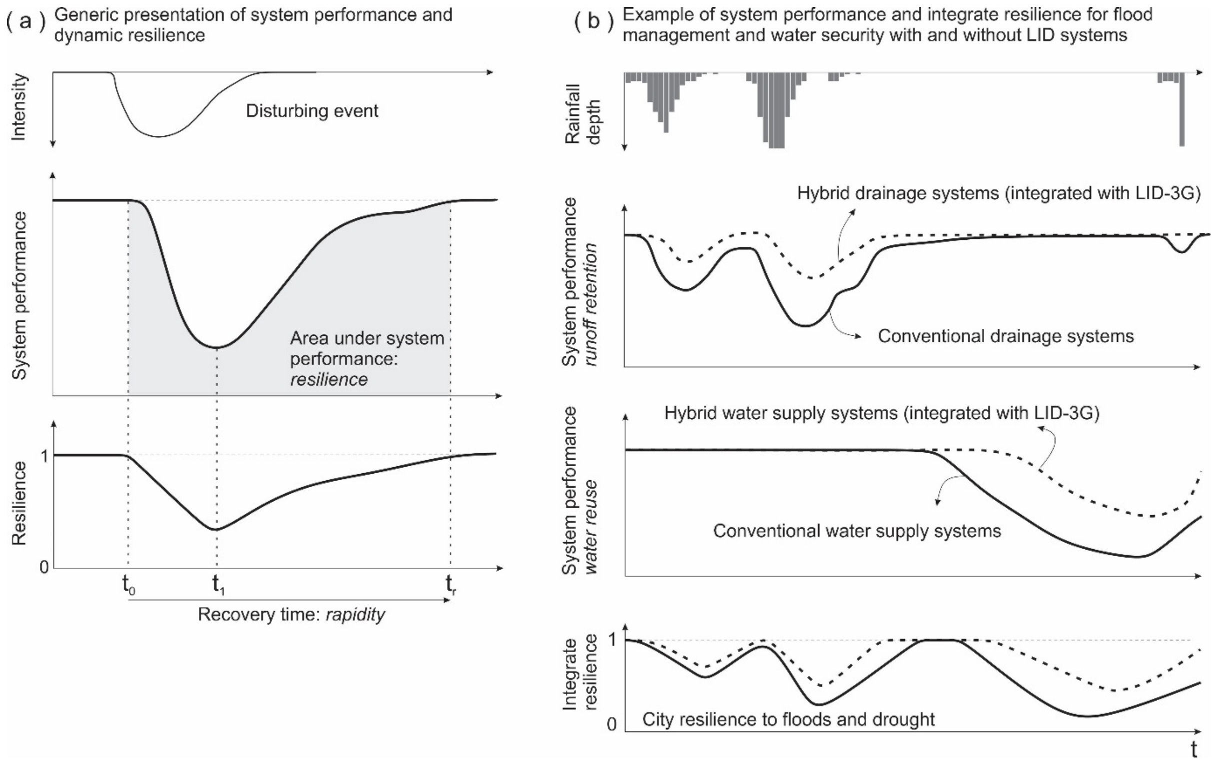


Figure 4 – (a) Generic presentation of a system performance and dynamic resilience under an extreme rainfall event (disturbing event). Adapted from Simonovic & Peck (2013), (b) Generic presentation of an urban drainage and water supply system performance with and without integration with LID practices and the respective integrate dynamic resilience curve.

Table 1 – Summary of the results obtained for hydrological and pollutant removal performance on bioretention studies worldwide

Control target	Control efficiency (%)	Obs.	Reference
TSS	99	Laboratory	
TP	81	Filter media: Soil, sand, gravel with none vegetation	Bratieres et al. (2008)
TN	-204		
Cu	-260 to 60	Laboratory	Chahal, Shi & Flury (2016)
$NO_{2,3}$	-53 to -1100	Filter media: Sand and compost	
Peak attenuation	44 to 63		
Runoff retention	55 to 70		
Cu	57		
Pb	83		
Zn	62	Field	Davis (2007 and 2008)
TSS	47		
TP	76		
$NO_{2,3}$	83		
Peak attenuation	37 to 96		
Runoff retention	15 to 83		
Cu	67		
Pb	80	Field	Hatt, Fletcher & Deletic (2009)
Zn	84		
TSS	76		
NH_4	64		
TP	96 to 99.8	Laboratory	Liu et al. (2014)
Peak attenuation	79.5 to 93.6		
Runoff retention	32.7 to 84.3		
TSS	-1295 to 100	Field	Lucke & Nichols (2015)
TP	-8820 to 100		
TN	-426 to 100		
Runoff retention	70		
Zn	76.2		
PO_4	61.1	Field	Macedo, Lago & Mendiondo (2019)
NH_4	67.7	Dry period	
$NO_{2,3}$	69.5		
Runoff retention	12 to 38/22 to 90		
TSS	41.8/80.8		
TP	36.4/75.3		
PO_4	37.8/73.4	Simulation	Mangangka et al. (2015)
TN	38.7/47.9	Wet period/dry period	
NH_4	49.3/82.2		
$NO_{2,3}$	23.2/65.0		
Peak attenuation	86 to 96		
Runoff retention	48 to 96		
TSS	93		Shrestha et al. (2018)
TP	-35 to -285	Field	
TN	-24 to 67		
$NO_{2,3}$	-272 to 77		
TN	83	Laboratory	Wan, Li & Shi (2017)
$NO_{2,3}$	81	Filter media: Layered with wood chips	
TN	-123 to 84.2	Laboratory	Wang et al. (2017)
TSS	25.3/50.4	Filter media: Stepped with *Medicago sativa* , *Vetiveria zizanoides* and others	
TP	-38.4/3.2		
TN	40.2/47.6	Field	Winston, Luell & Hunt (2011)
NH_4	23.5/54.8	Undersized/Full sized	
$NO_{2,3}$	62.6/75.6		
TPHs	99.6 to 98.9/99.6 to 98.9		
Glyphosate	91.6 to 96.0/95.9 to 96.0		
Atrazine	46.9 to 70.5/13.8 to 70.5		
Simazine	44.6 to 80.3/6.0 to 83.0		
Prometryn	71.2 to 88.2/41.3 to 88.2	Field	
DBP	97.8 to 98.4/97.2 to 98.6	Filter media: Loamy sand with no submerged zone/Sand with submerged	Zhang et al. (2014)
DEHP	96.6 to 98.3/96.8 to 98.3	zone	
Chloroform	40.5 to 61.5/26.9 to 61.5		
Pyrene	93.3/93.9		
Naphtalene	89.3/87.1		
PCP	87.5/61.7		
Phenol	89.3/78.2		
SSC	94		
PCB	96		
Cu	68	Field	Gilbreath et al. (2019)
Hg	37	Filter media: Sandy loam, clay and organic matter with *Juncus patens*	
MeHg	49	*Festuca californica* and *Verbena lilacina*	
Micro plastic	90		
E. coli	0 to 3 log reduction	Laboratory Filter media: Five configuration with submerged zone - washed sand, loamy *sand with Carex appressa* , *Lesptospermum continentale* and Palmetto buff	Chandrasena et al. (2019)
E. coli	0.2 to 3.5 log reduction	Laboratory Filter media: biochar, quartz sand, anthracite and zeolite with submerged zone	Liu et al. (2020)

Cu - Copper; Pb - Lead; Cd - Cadmium; Zn - Zinc; TSS - Total suspended solids; TP - Total phosporus; PO_4 - Phosphate; TN - Total nitrogen; NH3 - Amonium - NO2,3 - Nitrite and nitrate; TPH - Total petroleum hyrocarbons; DBP - Dibutyl phthalate; DEHP - Bis-(2-ethylhexyl)phthalate; PCP - Pentachlorophenol ; SSC - Suspended sediment concentration; PCB - Polyclorinated biphenyls; Hg - Mercury ; MeHg - Methylmercury

Table 2 – Climate change studies over the world: Impacts on climate patterns, hydrology, and LID systems

Region	Evaluation scale	Main results	Reference
United Kingdom	Watershed	Increase of flood risks to 1.2 million people	Houston, Werritty & Basset (2011)
United Kingdon	Climate patterns and watershed	Drier summers / wetter winters Increase of 31% total rainfall Increase of flood events	Carter et al. (2015)
USA / Oklahoma	Watershed	Climate change affects more the watershed dynamics then land use changes	Pumo et al. (2017)
USA / Indiana	Watershed	Climate change reduced runoff and pollutant loads Urbanization increased runoff and pollutant loads	Liu et al. (2016)
USA / Indiana	Watershed	Climate change and urbanization increased runoff and pollutant generation Annual costs needed to reduce extremes: 2.1 million dollar/year	Liu et al. (2017)
USA	LID	Increase in overflow frequency and magnitude in LID systems LID systems need to be increased to supply runoff increase	Hathaway et al. (2014)
USA	LID	Increase in runoff of 48% LID were able to reduce 41% in annual runoff LID practices are able to mitigate the effects of climate change	Zahmatskih et al. (2015)
Brazil	Climate patterns and watershed	Rainfall reduction during summer Increase of extreme rainfall events	Chou et al. (2014) and Lyra et al. (2018)
Brazil	LID	Water retention efficiency in bioretention will be maintained over the years Increase in pollutant concentrations Increase in pollutant removal efficiency	Lago, Macedo & Mendiondo (2018)
Sweden	Watershed	Climate change and urbanization increase peak flows and runoff volumes	Semadeni-Davies et al. (2008)
Netherlands	Watershed	Decrease of total rainfall volumes Increase of extremes	Gersonius et al. (2012)
Denmark	LID	Climate change has up to 5x more impacts on classical systems when compared with systems integrated with LID practices	Brudler et al. (2016)
Italy	Watershed	Reduction on surface and groundwater resource Increase of water resource stress Increase on heavy-torrential precipitation	Arnone et al. (2013)
Italy	Climate patterns and watershed	Negative trends to total rainfall depth	Liuzzo et al. (2015)
Australia	LID	Drier future and longer dry periods Minimum difference in LID performance for runoff retention and pollutant removal efficiency	Zhang et al. (2019)
Tanzania	LID	LID helps to reduce peak flow discharge in watersheds affected by climate change	Paola et al. (2015)
Iran	LID	Combination of LID practices can help to reduce runoff volumes in up to 18%, for optimezed scenarios where total LID implementation areas correspond to 0.23% of the watershed area	Ghodsi et al. (2020)

Table 3 – Description of commonly used LID practices, limitations to their spatial application and benchmark selection to multiple SDG

LID practice	Description	Limitations	Contribution to SDGs					
			SDG 2 *Zero hunger*	**SDG 3** *Good health and well-being*	**SDG 6** *Clean water and sanitation*	**SDG 7** *Affordable and clean energy*	**SDG 11** *Sustainable cities and communities*	**SDG 13** *Climate action*
Green(blue) roof	Roofs covered with a vegetated layer	Small to medium catchment areas and small to medium storms. Regular inspection	Medium	High	High	High	High	Medium to high
Porous pavement	Permeable surface used in roads and pathways that allow subinfiltration	Strongly dependent on hydraulic conductivity, soil infiltration and slope. Small to medium storms	Low	Medium	Medium	Low	Medium	Low
Bioretention / Rain gardens	Vegetated concave filled with a filtering media designed to store, infiltrate and treat stormwater	Strongly dependent on hydraulic conductivity and slope. Small to medium storms. Regular inspection	High	High	High	Medium to high	High	Medium to high
Sand filter	Concave divided in two layers, one of sand and one of gravel to allow infiltration and runoff treatment. They can be vegetated or not.	Strongly dependent on hydraulic conductivity and slope. Small to medium storms	Low	Medium	Medium	Low	Medium	Low
Constructed wetlands	An artificial wetland to treat stormwater	Require soils with low infiltration rate. Annual maintenance	Low	High	Medium to high	Low	Medium to high	Medium to high
Infiltration trenchs	Chanel made of gravel to allow storage and infiltration and can be covered by soil and vegetation	Strongly dependent on hydraulic conductivity and slope. Small to medium storms. Regular cuttings if vegetated.	Low	Medium to high	Medium	Low	Medium	Low to medium
Stormwater detention ponds	An artificial depression in the soil to store stormwater/runoff for a longer period	Does not allow infiltration and can increase disease dissemination	Low	Medium	Low to medium	Low to medium	Medium to high	Low
Rain barrel / Rainwater tank	Surface tanks to store rainwater from rooftops	Small to medium catchment areas and small to medium storms. Does not allow infiltration	Low to medium	Medium to high	Medium to high	Medium to high	Medium to high	Medium
Swales	Shallow open channels grassed of vegetated with mild side slopes and flat bottom	Strongly dependent on slope. Small to medium storms. Regular cuttings.	Low	Medium	Medium	Low	Medium	Low to medium

Table 4 - How LID practices can contribute to UN SDG? Suggestions and challenges

SDG	How LID contribute to this UN SDG?	Suggestions in LID design	Spatial scale	Time scale	Challenges	Main references
SDG 2 - Zero hunger	Production of food directly in the surface of vegetated practices	Sub-irrigation system	Individual	Short-term	Metals, pathogens and other contaminants in plant tissues; seasonality and dry periods	Richards et al. (2015); Ng et al. (2018)
	To plant biomass as biofertilizer in another location	-	Catchment/City	Mid and long-term	Metals, pathogens and other contaminants in the water that may be transferead to the plants	Ge at al. (2016)
	Reuse of water as irrigation for agricultural purposes	-	Catchment/City	Mid-term	Metals, pathogens and other contaminants in the water that may be transferead to the plants	Chandrasena, Deletic & McCarthy (2016)
SDG 3 - Good health and well-being	Runoff volume retention	Design storms for higher return periods	Catchment	Short-term	Need to incorporate changes in urbanization and climate in design guides and manuals; quantification of maintenance costs	Davis (2008); Winston, Dorsey & Hunt (2016)
	Peak flow reduction (decrease flood risks)	Design storms for higher return periods		Short and mid-term		
	Pollutant removal from runoff (decrease risks of urban rivers contamination)	Anaerobic zone to denitrification (increase nutrient removal)	Catchment	Short and mid-term	Results in nutrient removal still present great ranges variation; micropollutants and pathogens removal studies are still incipients	Davis (2007); Hatt, Fletcher & Deletic (2009); Glaister et al. (2016)
	Stormwater harvesting and water reuse (decrease risks of water scarcity)	Underdrain to collect treated water and storage tanks to future reuse	Individual/Catchment	Short and mid-term	Lack of standards to water reuse; estimate of operation costs; need of additional treatment (e.g. pathogens removal)	Fletcher et al. (2008); Karim, Bashar & Imteaz (2015); Chandrasena, Deletic & McCarthy (2016)
SDG 6 - Clean water and sanitation	LID systems allow runoff treatment and less pollutant loads in urban rivers (one of the main causes of urban river contamination)	Anaerobic zone to denitrification (increase nutrient removal)	City	Mid-term	Results in nutrient removal still present great ranges variation; micropollutants and pathogens removal studies are still incipients	Davis (2007); Hatt, Fletcher & Deletic (2009); Glaister et al. (2016)
	Groundwater recharge	Permeable walls and bottom to allow exfiltration	Catchment	Mid-term	Avoid groundwater contamination	-
SDG 7 - Affordable and clean energy	Energy saving by cooling and heating	Green/blue roofs and walls	Individual	Mid-term	Need of methodology to quantification; energy demands to maintenance of the systems	Hashemi, Mahmud & Ashraf (2015); Shafique, Kim & Rafiq (2018)
	Energy production	Integration of turbines with retention ponds. Allow higher water level (available head to turbines). Integration of photovoltaic panels in green roofs	Catchment	Short-term	Develpment of new technologies to other LID practices types; integration with city energy grid	Hui & Chan (2011); Ramos et al. (2013); Chemisana & Lamnatou (2014)
	Recycling resources (construction materials, biomass as fertilizers)	-	City	Long-term	Lack of guidelines and standards to resource recycling	-
	Reduction of energy expenditures with water and food transportation	Implementation close to housing	City	Long-term	Need of methodology to quantification; energy demands to maintenance of the systems	-

Table 4 - continuation

SDG 11 - Sustainable cities and	Local water, energy and food production (increase water-energy-food security)	Implementation close to housing; For food production: Vegetable practices (e.g. bioretention) and soil with high capacity of metal sorption	Individual/Catchment	Mid-term	For food production: metals and other contaminants in plant tissues;	Richards et al. (2015); Ge et al. (2016); Ng et al. (2018)
	Urban resilience to rainfall and drought extremes under changing scenarios of urbanization and climate	-	City	Mid and long-term	New metrics to system performance linked with UN SDG	Simonovic and Peck (2013)
SDG 13 - Climate action	Decarbonization	Vegetable practices	Not possible to restrict scale (gas emission)	Long-term	Need of methodology to quantification of carbon fluxes (sequestration and emission)	Kavehei et al. (2018)
	Secondary reduction in carbon emissions (water-energy-greenhouse gases nexus)	Allow resources recycling at the source (e.g. rainwater/stormwater harvesting, cooling effect by green roofs)	Individual/Catchment	Mid and long-term	Need of methodology to quantification	Nair et al. (2014); Shafique, Xue & Luo (2020)

References

1. Ambrizzi, T., & Magaña, V. (2016). Mudanças Climáticas e Projeções Futuras de Eventos Extremos. [Climate change and future projections of extreme events]. In *Desastres - Múltiplas Abordagens e Desafios*. 1st edition. Elsevier. (in Portuguese)

2. Arnone, E., Pumo, D., Viola, F., Noto, L., & La Loggia, G. (2013). Rainfall statistics changes in Sicily. *Hydrology and Earth System Sciences*, 17(7), 2449 - 2458.

3. Arora, M., Malano, H., Davidson, B., Nelson, R., & George, B. (2015). Interactions between centralized and decentralized water systems in urban context: A review. Wiley Interdisciplinary Reviews: *Water*, 2(6), 623-634.

4. Blecken, G. T., Hunt III, W. F., Al-Rubaei, A. M., Viklander, M., & Lord, W. G. (2015). Stormwater control measure (SCM) maintenance considerations to ensure designed functionality. *Urban Water Journal*, 14(3), 278-290.

5. BoSL (2020). *BoSL develops low cost sensors and control options for monitoring water systems*. Available in: < http://www.bosl.com.au/>. Access in: Dec 2020.

6. Bouchard, N., Osmond, D., Winston, R., & Hunt, W. (2013). The capacity of roadside vegetated filter strips and swales to sequester carbon. *Ecological Engineering*, 54, 227-232.

7. Brasil, J. A. T.; Macedo, M. B.; Oliveira, T. R. P.; Oliveira, T. H.; Gomes Junior, M. N.; Lago, C. A. F.; Mendiondo, E. M. (2020). Nature-based solutions and Real-time control: Challenges and opportunities. *Proceeding of 5th International Electronic Conference on Water Sciences*, online.

8. Bratieres, K., Fletcher, T., Deletic, A., Alcazar, L., Coustumer, L., & McCarthy, D. (2008). Removal of nutrients, heavy metals and pathogens by stormwater biofilters. *Proceeding of 11th International Conference on Urban Drainage*. Porto Alegre, Brazil.

9. Brudler, S., Ambierg-Nielsen, K., Hauschlid, M., & Rygaard, M. (2016). Life cycle assessment of stormwater management in the context of climate change adaptation. *Water research*, 106, 394-404.

10. Burns, S., Arnbjerg-Nielsen, K., Hauschild, M., & Rygaard, M. (2015). The performance of rainwater tanks for stormwater retention and water supply at the household scale: An empirical study. *Hydrological Processes*, 29(1), 152-160.

11. Carter, J., Cavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). Climate change and the city: building capacity for urban adaptation. *Progress in Planning*, 95, 1-66.

12. Chahal, M., Shi, Z., & Flury, M. (2016). Nutrient leaching and copper speciation in compost-amended bioretention systems. *Science of the Total Environment*, 556, 302 - 309.

13. Chandrasena, G., Deletic, A., & McCarthy, D. (2016). Biofiltration for stormwater harvesting: comparison of Campylobacter spp. and Escherichia coli removal under normal and challenging operational conditions. *Journal of Hydrology*, 537, 248-259.

14. Chandrasena, G. I., Deletic, A., Hathaway, J. M., Lintern, A., Henry, R., & McCarthy, D. T. (2019). Enhancing Escherichia coli removal in stormwater biofilters with a submerged zone: balancing the impact of vegetation, filter media and extended dry weather periods. *Urban Water Journal*, 16(6), 460-468.

15. Chemisana, D., & Lamnatou, C. (2014). Photovoltaic-green roofs: An experimental evaluation of system performance. *Applied Energy*, 119, 246-256.

16. Chou, S., Lyra, A., Mourao, C., Derecynski, C., Pilotto, I., Gomes, J., . . . Campos, D. (2014). Assessment of climate change over South America under RCP 4.5 and 8.5 downscaling scenarios. *American Journal of Climate Change*, 3(5), 5121 - 525.

17. Chow, V. T; Maidment, D. R.; Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill Science, 1ed.

18. Clark, R., Gonzalez, D., Dillon, O., Charles, S., Cresswell, D., & Naumann, B. (2015). Reliability of water supply from stormwater harvesting and managed aquifer recharge with a brackish aquifer in an urbanising catchment and changing climate. *Environmental Modelling & Software*, 72, 117-125.

19. Council, G. C. (2007). *Water Sensitive Urban Design Guidelines*. Gold Coast City Council, Queensland.

20. Coustumer, S., Fletcher, T. D., Deletic, A., Barraud, S., & Lewis, J. F. (2009). Hydraulic performance of biofilter systems for stormwater management: Influences of design and operation. *Journal of Hydrology*, 376(1-2), 16-23.

21. Coustumer, S., Fletcher, T. D., Deletic, A., Barraud, S., & Poelsma, P. (2012). The influence of design parameters on clogging of stormwater biofilters: A large-scale column study. *Water Research*, 46(20), 6743-6752.

22. D'Acunha, B., & Johnson, M. (2019). Water quality and greenhouse gas fluxes for stormwater detained in a constructed wetland. *Journal of Environmental Management*, 231, 1232-1240.

23. Davis, A. P. (2007). Field performance of bioretention: Water quality. *Environmental Engineering Science*, 24(8), 1048-1064.

24. Davis, A. (2008). Field performance of bioretention: Hydrology impacts. *Journal of Hydrologic Engineering*, 13(2), 90-95.

25. DeGaetano, A., & Castellano, C. (2017). Future projections of extreme precipitation intensity-duration-frequency curves for climate adaptation planning in New York State. *Climate Services*, 5, 23-35.

26. Douglas, I., Garvin, S., Lawson, N., Richards, J., Tippett, J., & White, I. (2010). Urban pluvial flooding: a qualitative case study of cause, effect and nonstructural mitigation. *Journal of Flood Risk Management*, 3(2), 112 - 125.

27. Dudula, J., & Randhir, T. (2016). Modeling the influence of climate change on watershed systems: adaptation through targeted practices. *Journal of Hydrology*, 541, 703-713.

28. Eckart, K., McPhee, Z., & Bolisetti, T. (2017). Performance and implementation of low impact development–a review. *Science of the Total Environment*, 607, 413-432.

29. Enviss (2020). Stormwater Filtration Screens. Available in: <https://www.enviss.com.au/stormwater-filter-screens/ >. Access in: Dec 2020.

30. EPA, E. P. (1983). *Results of the National wide urban runoff program: Volume 1 – Final Report*. Washington, DC.: Water Planning Division, U.S. EPA.

31. EPA. (2012). *2012 Guidelines for Water Reuse*. Washington, D. C.: U. S. Environmental Protection Agency, Office of Wastewater Management, Office of Water.

32. Erickson, A., Weiss, P., & Gulliver, J. (2013). *Optimizing stormwater treatment practices: a handbook of assessment and maintenance*. New York: Springer.

33. Fletcher, T., Deletic, A., Mitchell, V., & Hatt, B. (2008). Reuse of urban runoff in Australia: a review of recent advances and remaining challenges. *Journal of Environmental Quality*, 37(5), s-116 - s127.

34. Fletcher, T., Andrieu, H., & Hamel, P. (2013). Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. *Advances in Water Resources*, 51, 261-279.

35. Fletcher, T., Shuster, W., Hunt, W., Ashley, R., Butler, D., Arthur, S., . . . Mikkelsen, P. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12(7), 525-542.

36. Gardner, E. A., Millar, G. E., Christiansen, C., Vieritz, A. M., & Chapman, H. (2006). Energy and water use at a WSUD subdivision in Brisbane, Australia. *Australasian Journal of Water Resources*, 10(3), 283-291.

37. Ge, Z., Feng, C., Wang, X., & Zhang, J. (2016). Seasonal applicability of three vegetation constructed floating treatment wetlands for nutrient removal and harvesting strategy in urban stormwater retention ponds. *International Biodeterioration & Biodegradation*, 112, 80-87.

38. Gersonius, B., Nasruddin, F., Ashley, R., Jeuken, A., Pathirana, A., & Zevenbergen, C. (2012). Developing the evidence base for mainstreaming adaptation of stormwater systems to climate change. *Water research*, 46(20), 6824 - 6835.

39. Getter, K., Rowe, D., Robertson, G., Cregg, B., & Andresen, J. (2009). Carbon sequestration potential of extensive green roofs. *Environmental Science & Technology*, 43(19), 7564-7570.

40. Ghodsi, S. H., Zahmatkesh, Z., Goharian, E., Kerachian, R., & Zhu, Z. (2020). Optimal design of low impact development practices in response to climate change. *Journal of Hydrology*, 580, 124266.

41. Gilbreath, A., McKee, L., Shimabuku, I., Lin, D., Werbowski, L. M., Zhu, X., ... & Rochman, C. (2019). Multiyear water quality performance and mass accumulation of PCBs, Mercury, Methylmercury, Copper, and Microplastics in a bioretention rain garden. *Journal of Sustainable Water in the Built Environment*, 5(4), 04019004.

42. Glaister, B., Fletcher, T., Cook, P., & Hatt, B. (2016). Intra-event nutrient removal dynamics in stormwater biofilters: the influence of system design. Traitement de la pollution/Pollution treatment. *Proceeding of 9th Novatech*. Lyon, France.

43. Guan, M., Sillanpaa, N., & Koivusalo, H. (2015). Modelling and assessment of hydrological changes in a developing urban catchment. *Hydrological Process*, 29(13), 2880-2894.

44. Hashemi, S., Mahmud, H., & Ashraf, M. (2015). Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: a review. *Renewable and Sustainable Energy Reviews*, 52, 669-679.

45. Hashimoto, T., Stedinger, J., & Loucks, D. (1982). Reliability, resiliency, and vulnerability criteria for water resources system performance evaluation. *Water Resources Research*, 18, 14-20.

46. Hathaway, J., Brown, R., Fu, J., & Hunt, W. (2014). Bioretention function under climate change scenarios in North Carolina, USA. *Journal of Hydrology*, 519, 503-511.

47. Hatt, B., Fletcher, T., & Deletic, A. (2009). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology*, 365(3), 310 - 321.

48. He, J., Valeo, C., & Bouchart, F. (2006). Enhancing urban infrastructure investment planning practices for a changing climate. *Water Science and Technology*, 53(10), 13-20.

49. Hoff, H. (2011). Understanding the nexus: background paper for the Bonn2011. *Nexus Conference*.

50. Houston, D., Werritty, A., & Bassett, D. (2011). *Pluvial (rain-related) Flooding in Urban Areas: the Invisible Hazard*. Joseph Rowntree Foundation.

51. Hui, S. C., & Chan, S. C. (2011). Integration of green roof and solar photovoltaic systems. *Proceedings of Joint Symposium 2011: Integrated Building Design in the New Era of Sustainability.* Kowloon, Hong Kong.

52. Jing, X., Zhang, S., Zhang, J., Wang, Y., & Wang, Y. (2017). Assessing efficiency and economic viability of rainwater harvesting systems for meeting non-potable water demands in four climatic zones of China. *Resources, Conservation and Recycling*, 126, 74-85.

53. Jun, X., Yong, Z., LiHua, X., Shan, H., LongFeng, W., & ZhongBo, Y. (2017). Opportunities and challenges of the Sponge City construction related to urban water issues in China. *Science China Earth Sciences*, 60(4), 652.

54. Karim, M., Bashar, M., & Imteaz, M. (2015). Reliability and economic analysis of urban rainwater harvesting in a megacity in Bangladesh. *Resources, Conservation and Recycling*, 104, 61-67.

55. Kavehei, E., Jenkins, G., Adame, M., & Lemckert, C. (2018). Carbon sequestration potential for mitigating the carbon footprint of green stormwater infrastructure. *Renewable and Sustainable Energy Reviews*, 94, 1179-1191.

56. Kaykhosravi, S., Abogadil, K., Khan, U. T., & Jadidi, M. A. (2019). The Low-Impact Development demand index: A new approach to identifying locations for LID. *Water*, 11(11), 2341.

57. Kirchhoff, C. J., Lara-Valencia, F., Brugger, J., Mussetta, P., & Pineda-Pablos, N. (2016). Towards joint consideration of adaptive capacity and water security: lessons from the arid Americas. *Current Opinion in Environmental Sustainability*, 21, 22-28.

58. Kjeldsen, T., & Rosbjerg, D. (2004). Choice of reliability, resilience and vulnerability estimators for risk assessment of water resources systems. *Hydrologic Sciences Journal*, 49(5), 755-797.

59. Konrad, C., & Booth, D. (2005). Hydrologic changes in urban streams and their cological significance. *American Fisheries Society Simposium*, 47, 157 - 177.

60. Krivtsov, V., Birkinshaw, S., Arthur, S., Knott, D., Monfries, R., Wilson, K., ... & Buckman, J. (2020). Flood resilience, amenity and biodiversity benefits of an historic urban pond. *Philosophical Transactions of the Royal Society A*, 378(2168), 20190389.

61. Lago, C., Macedo, M., & Mendiondo, E. (2018). Modelling climate changes impacts in a subtropical urban drainage. *Proceedings 11th International Conference on Urban Drainage Modelling*. Palermo, Italy.

62. Lamont, B., Jenkins, G., & Kavehei, E. (2019). Generation and transport of plastic in an urban stormwater system. *Proceeding of Novatech 2019*. Lyon, France.

63. Leopold, L. (1968). *Hydrology for urban land planning: A guidebook on the hydrological effects of urban land use*. Circ. No. 554. Washington, DC: Geological Survey.

64. Li, Q., Wang, F., Yu, Y., Huang, Z., Li, M., & Guan, Y. (2019). Comprehensive performance evaluation of LID practices for the sponge city construction: a case study in Guangxi, China. *Journal of Environmental Management*, 231, 10-20.

65. Litern, A., Daly, E., Duncan, H., Hatt, B., Fletcher, T., & Deletic, A. (2011). Key design characteristics that influence the performance of stormwater biofilters. *Proceeding 12th International Conference on Urban Drainage*. Porto Alegre, Brazil.

66. Liu, J., Sample, D., Owen, J., & Evanylo, G. (2014). Assessment of selected bioretention blends for nutrient retention using mesocosm experiments. *Journal of Environmental Quality*, 43(5), 1754 - 1763.

67. Liu, Y., Theller, L., Pijanowski, B., & Engel, B. (2016). Optimal selection and placement of green infrastructure to reduce impacts of land use change and climate change on hydrology and water quality: An application to the Trail Creek Watershed, Indiana. *Science of the Total Environment*, 553, 149-163.

68. Liu, Y., Engel, B., Collingsworth, P., & Pijanowski, B. (2017). Optimal implementation of green infrastructure practices to minimize influences of land use change and climate change on hydrology and water quality: case study in Spy Run Creek watershed, Indiana. *Science of the Total Environment*, 601, 1400 - 1411.

69. Liu, J., Yue, P., He, Y., & Zhao, M. (2020). Removal of E. coli from stormwater by bioretention system: parameter optimization and mechanism. *Water Science and Technology*, 81(6), 1170–1179.

70. Liuzzo, L., Noto, L., Arnone, E., Caracciolo, D., & La Loggia, G. (2015). Modifications in water resources availability under climate changes: a case study in a Sicilian Basin. *Water Resources Management*, 29(4), 1117-1135.

71. Loiola, C., Mary, W., & da Silva, L. (2018). Hydrological performance of modular-tray green roof systems for increasing the resilience of mega-cities to climate change. *Journal of Hydrology*, 573, 1057-1066.

72. Lucas, W. C., & Sample, D. J. (2015). Reducing combined sewer overflows by using outlet controls for Green Stormwater Infrastructure: Case study in Richmond, Virginia. *Journal of Hydrology*, 520, 473 - 488.

73. Lucke, T., & Nichols, P. (2015). The pollution removal and stormwater reduction performance of street-side bioretention basins after ten years in operation. *Science of the Total Environment*, 536, 784 - 792.

74. Lyra, A., Tavares, P., Chou, S., Sueiro, G., Dereczynski, C., Sondermann, M., . . . Giarolla, A. (2018). Climate change projections over three metropolitan regions in Southeast Brazil using the non-hydrostatic Eta regional climate model at 5-km resolution. *Theoretical and Applied Climatology*, 132(1-2), 663 - 682.

75. Macedo, M., Lago, C., Rosa, A., & Mendiondo, E. (2017). Técnicas compensatórias de bioretenção para cidades resilientes: integração com nexus–água, energia, alimento. [Low Impact Development practices of bioretention to resilient cities: integration with the water-energy-food nexus]. *Proceedings of XXII Simposio Brasileiro de Recursos Hidricos*. Florianopolis, Brazil. (in Portuguese).

76. Macedo, M., Lago, C., & Mendiondo, E. (2019). Stormwater volume reduction and water quality improvement by bioretention: Potentials and challenges for water security in a subtropical catchment. *Science of the Total Environment*, 647, 923-931.

77. Macedo, M., Lago, C., Mendiondo, E., & Giacomoni, M. (2019). Bioretention performance under different rainfall regimes in subtropical. *Journal of Environmental Management*, 248, 109266.

78. Macedo, M. B. (2020). *Técnicas Descentralizadas Para Reciclagem De Águas De Drenagem Urbana Visando A Segurança Hídrica-Energética-Alimentar. [Decentralized LID practices for Recycling Urban Runoff for Water-Energy-Food Security].* Thesis. Escola de Engenharia de São Carlos – Universidade de Sao Paulo, Sao Carlos. In Portuguese

79. Madsen, H., Arnbjerg-Nielsen, K., & Mikkelsen, P. (2009). Updated of regional intensity–duration–frequency curves in Denmark: tendency towards increased storm intensities. *Atmospheric Research*, 92(3), 343 - 349.

80. Madsen, H., Lawrence, D., Lang, M., Martinkova, M., & Kjeldsen, T. (2014). Review of trend analysis and climate change projections of extreme precipitation and floods in Europe. *Journal of Hydrology*, 519, 3634 - 3650.

81. Mailhot, A., & Duchesne, S. (2009). Design criteria of urban drainage infrastructures under climate change. *Journal of Water Resources Planning and Management*, 136(2), 201-208.

82. Mangangka, I., Liu, A., Egodawatta, P., & Goonetilleke, A. (2015). Performance characterization of a stormwater treatment bioretention basin. *Journal of Environment Management*, 150, 173 - 178.

83. Mao, X., Jia, H., & Shaw, L. Y. (2017). Assessing the ecological benefits of aggregate LID-BMPs through modelling. *Ecological Modelling*, 353, 139-149.

84. McAuley, A. (2009). *Technical Design Guidelines*. Nothern Territory Department of Planning and Infrastructure.

85. Meerow, S., Newell, J., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning*, 147, 38-49.

86. Mei, Y., Zhou, H., Zhu, X. H., Zhang, P., Li, X. F., Zuo, Y. M., ... & Bao, J. J. (2020). Isothermal adsorption characteristics of bioretention media for fecal Escherichia coli. *Thermal Science*, 24(4), 2427-2436.

87. Mitchell, V. G., McCarthy, D. T., Deletic, A., & Fletcher, T. D. (2008). Urban stormwater harvesting–sensitivity of a storage behavior model. *Environmental Modelling & Software*, 23(6), 782-793.

88. Mohor, G., & Mendiondo, E. (2017). Economic indicators of hydrologic drought insurance under water demand and climate change scenarios in a Brazilian context. *Ecological Economics*, 140, 66-78.

89. Moore, T., & Hunt, W. (2012). Ecosystem service provision by stormwater wetlands and ponds–A means for evaluation? *Water Research*, 46(20), 6811-6823.

90. Nair, S., George, B., Malano, H., Arora, M., & Nawarathna, B. (2014). Water–energy–greenhouse gas nexus of urban water systems: Review of concepts, state-of-art and methods. *Resources, Conservation and Recycling*, 89, 1-10.

91. Ng, K., Herrero, P., Hatt, B., Farrelly, M., & McCarthy, D. (2018). Biofilters for urban agriculture: Metal uptake of vegetables irrigated with stormwater. *Ecological Engineering*, 122, 177-186.

92. Novotny, V. (2010). Urban Water and Energy Use from Current US Use to Cities of the Future. *Proceedings of the Water Environment Federation*, 2010(2), 118-140.

93. NRMMC, E. (2008). *AHMC, Australian guidelines for water recycling: managing health and environmental risks (Phase 2): Augmentation of drinking water supplies*, Environment Protection and Heritage Council, National Health and Medical Research Council. Canberra: Natural Resource Management Ministerial Council.

94. Paola, F., Galdiero, E., Giugni, M., & Pugliese, F. (2015). Sustainable development of storm-water systems in African cities considering climate change. *Procedia Engineering*, 119, 1181-1191.

95. Pataki, D., Alig, R., Fung, A., Golubiewski, N., Kennedy, C., McPherson, E., . . . Romero-Lamkaoss, P. (2006). Urban ecosystems and the North American carbon cycle. *Global Change Biology*, 12, 1-11.

96. Petit-Boix, A., Sevigné-Itoiz, E., Rojas-Gutierrez, L. A., Barbassa, A. P., Josa, A., Rieradevall, J., & Gabarrell, X. (2015). Environmental and economic assessment of a pilot stormwater infiltration system for flood prevention in Brazil. *Ecological Engineering*, 84, 194-201.

97. Petit-Boix, A., Sevigné-Itoiz, E., Rojas-Gutierrez, L. A., Barbassa, A. P., Josa, A., Rieradevall, J., & Gabarrell, X. (2017). Floods and consequential life cycle assessment: Integrating flood damage into the environmental assessment of stormwater Best Management Practices. *Journal of Cleaner Production*, 162, 601-608.

98. Petit-Boix, A., Deykota, J., Phillips, R., VargasParra, M., Josa, A., Gabarrell, X., . . . Apul, D. (2018). Life cycle and hydrologic modeling of rainwater harvesting in urban neighborhoods: implications of urban form and water demand patterns in the US and Spain. *Science of the Total Environment*, 621, 434-443.

99. Philadelphia Water Department. (2020). *Metal Downspout Planters*. Available in: < https://www.pwdraincheck.org/en/stormwater-tools/metal-downspout-planters>. Access in: Dec 2020.

100. Pour, S. H., Abd Wahab, A. K., Shahid, S., & Dewan, A. (2020). Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: current trends, issues and challenges. *Sustainable Cities and Society*, 102373.

101. Pumo, D., Arnone, E., Francipane, A., Caracciolo, D., & Noto, L. (2017). Potential implications of climate change and urbanization on watershed hydrology. *Journal of Hydrology*, 554, 80-99.

102. Ramos, H., Teyssier, C., Samora, I., & Schleiss, A. (2013). Energy recovery in SUDS towards smart water grids: A case study. *Energy policy*, 62, 463-472.

103. Randelovic, A., Zhang, K., Jacimovic, N., McCarthy, D., & Deletic, A. (2016). Stormwater biofilter treatment model (MPiRe) for selected micro-pollutants. *Water Research*, 89, 180-191.

104. Richards, P., Farrell, C., Tom, M., Williams, N., & Fletcher, T. (2015). Vegetable raingardens can produce food and reduce stormwater runoff. *Urban Forestry & Urban Greening*, 14(3), 646-654.

105. Rosa, A. (2016). *Bioretention for diffuse pollution control in SUDS using experimental-adaptive approaches of ecohydrology*. Sao Carlos: Thesis. Sao Carlos School of Engineering, University of Sao Paulo.

106. Rosinger, A. (2018). Household water insecurity after a historic flood: diarrhea and dehydration in the Bolivian Amazon. *Social Science & Medicine*, 197, 192-202.

107. Sapkota, M., Arora, M., Malano, H., Moglia, M., Sharma, A., George, B., & Pamminger, F. (2015). An overview of hybrid water supply systems in the context of urban water management: Challenges and opportunities. *Water*, 7(1), 153-174.

108. Sapkota, M., Arora, M., Malano, H., Moglia, M., Sharma, A., George, B., & Pamminger, F. (2016). An integrated framework for assessment of hybrid water supply systems. *Water*, 8(1), 4.

109. Schlesinger, W. H. (1999). Carbon sequestration in soils. *Science*, 284, 725-730.

110. Semadeni-Davies, A., Hernebring, C., Svensson, G., & Gustafsson, L. (2008). The impacts of climate change and urbanization on drainage in Helsingborg, Sweden: Suburban stormwater. *Journal of Hydrology*, 350(1-2), 114-125.

111. Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges–A review. *Renewable and Sustainable Energy Reviews*, 90, 757-773.

112. Shafique, M., Xue, X., & Luo, X. (2020). An overview of carbon sequestration of green roofs in urban areas. *Urban Forestry & Urban Greening*, 47, 126515.

113. Shafique, M., Azam, A., Rafiq, M., Ateeq, M., & Luo, X. (2020). An overview of life cycle assessment of green roofs. *Journal of Cleaner Production*, 250, 119471.

114. Shen, P., Deletic, A., Urich, C., Chandrasena, G. I., & McCarthy, D. T. (2018). Stormwater biofilter treatment model for faecal microorganisms. *Science of the Total Environment*, 630, 992-1002.

115. Shishegar, S., Duchesne, S., & Pelletier, G. (2019). An integrated optimization and rule-based approach for predictive real time control of urban stormwater management systems. *Journal of Hydrology*, 577, 124000.

116. Shishegar, S., Duchesne, S., Pelletier, G., & Ghorbani, R. (2021). A smart predictive framework for system-level stormwater management optimization. *Journal of Environmental Management*, 278, 111505.

117. Shrestha, A., Babel, M., Weesakul, S., & Vojinovic, Z. (2017). Developing Intensity–Duration–Frequency (IDF) curves under climate change uncertainty: the case of Bangkok, Thailand. *Water*, 9(2), 145.

118. Simonovic, S., & Peck, A. (2013). Dynamic resilience to climate change caused natural disasters in coastal megacities quantification framework. *International Journal of Environment and Climate Change*, 378 - 401.

119. Simonovic, S., & Arunkumar, R. (2016). Comparison of static and dynamic resilience for a multipurpose reservoir operation. *Water Resources Research*, 52(11), 8630-8649.

120. Simonovic, S. (2017). Adapting to Climate Change: a Web Based Intensity-Duration-Frequency (IDF) Tool. *Geotechnical News*, 35(3), 40-42.

121. Soro, G., Goula-Bi, T., Kouassi, F., & Srohourou, B. (2010). Update of intensity duration frequency curves for precipitation of short durations in tropical area of west Africa (Côte D'ivoire). *Journal of Apllied Sciences*, 10(9), 704-715.

122. Souza, F. A. A. ; Mendiondo, E. M. ; Bhattacharya-Mis, N. ; Fava, M. C. ; Buarque, A. C. S. ; Restrepo, C.E.E. ; Abreu, F. G. ; Tafarello, D. ; Abe, N. ; Gomes Junior, M. N. ; Macedo, M. B. ; Belini, J. P. C. ; Andrade, S. C. ; Delbem, A. C. B. (2019). Informações

voluntárias na produção de conhecimento científico e gestão de desastres. [Voluntary information in the production of scientific knowledge and disaster management] In: Yoshizaki, H. T. Y.; Rodriguez, C. A. M.; Ciccotti, L.. (Org.). *Riscos e Desastres: Caminhos para o Desenvolvimento Sustentável. [Risks and Disasters: Paths to Sustainable Development.]* 1ed.Sao Carlos: RiMa Editora, 2019, v, p. 155-183. In Portuguese.

123. Srivastav, R., Schardong, A., & Simonovic, S. (2014). Equidistance quantile matching method for updating IDF Curves under climate change. *Water Resources Management*, 28(9), 2539-2562.

124. Stovin, V., Moore, S., Wall, M., & Ashley, R. (2013). The potential to retrofit sustainable drainage systems to address combined sewer overflow discharges in the Thames tideway catchment. *Water and Environment Journal*, 27(2), 216-228.

125. Sun, Y., Zhang, D., & Wang, Z. (2017). The potential of using biological nitrogen removal technique for stormwater treatment. *Ecological Engineering*, 106, 482 - 495.

126. The Prince George's County. (2007). *Bioretention Manual*. Environmental Services Division, Department of Environmental Resources.

127. Tom, M., Fletcher, T., & McCarthy, D. (2014). Heavy metal contamination of vegetables irrigated by urban stormwater: a matter of time?. *PloS one*, 9(11), e112441.

128. UN – United Nations. (2020). *The 17 Goals.* Available in: < https://sdgs.un.org/goals>. Acess in: Oct 2020.

129. UNSTATS. (2020). *Global indicator framework adopted by the General Assembly (A/RES/71/313), annual refinements contained in E/CN.3/2018/2 (Annex II), E/CN.3/2019/2 (Annex II), and 2020 Comprehensive Review changes (Annex II) and annual refinements (Annex III) contained in E/CN.3/2020/2.* Available in: <https://unstats.un.org/sdgs/indicators/indicators-list/>. Access in: Oct 2020.

130. Walsh, C. J., Fletcher, T. D., & Ladson, A. R. (2009). Retention capacity: a metric to link stream ecology and storm-water management. *Journal of Hydrologic Engineering*, 14(4), 399-406.

131. Walsh, C. J., Fletcher, T. D., & Burns, M. J. (2012). Urban stormwater runoff: a new class of environmental flow problem. *PLOS one*, 7(9), e45814.

132. Wan, Z., Li, T., & Shi, Z. (2017). A layered bioretention system for inhibiting nitrate and organic matters leaching. *Ecological Engineering*, 107, 233-238.

133. Wang, D., Hagen, S., & Alizad, K. (2013). Climate change impact and uncertainty analysis of extreme rainfall events in the Apalachicola River basin, Florida. *Journal of Hydrology*, 480, 125 - 135.

134. Wang, M., Zhang, D., Adhitvan, A., Ng, W., Dong, J., & Tan, S. K. (2016). Assessing cost-effectiveness of bioretention on stormwater in response to climate change and urbanization for future scenarios. *Journal of Hydrology*, 543, 423-432.

135. Wang, S., Lin, X., Yu, H., Wang, Z., Xia, H., An, J., & Fan, G. (2017). Nitrogen removal from urban stormwater runoff by stepped bioretention systems. *Ecological Engineering*, 106, 340-348.

136. Waterways, M. (2005). *Water sensitive urban design: technical design guidelines for South East Queensland*. Moreton Bay Waterways and Catchment Partnership.

137. Whittinghill, L. J., Rowe, D. B., & Cregg, B. M. (2013). Evaluation of vegetable production on extensive green roofs. *Agroecology and Sustainable Food Systems*, 37(4), 465-484.

138. Willems, P., & Vrac, M. (2011). Statistical precipitation downscaling for small-scale hydrological impact investigations of climate change. *Journal of Hydrology*, 402(3-4), 193-205.

139. Willens, P. (2013). Revision of urban drainage design rules after assessment of climate change impacts on precipitation extremes at Uccle, Belgium. *Journal of Hydrology*, 496, 166-177.

140. Winston, R., Luell, S., & Hunt, W. (2011). Evaluation of undersized bioretention stormwater control measures for treatment of highway bridge deck runoff. *Water Science and Technology*, 64(4), 974-979.

141. Winston, R., Dorsey, J., & Hunt, W. (2016). Quantifying volume reduction and peak flow mitigation for three bioretention cells in clay soils in northeast Ohio. *Science of the Total Environment*, 553, 83 - 95.

142. Wong, T., & Eadie, M. (200). Water Sensitive Urban Design —a paradigm shift in urban design. *Proceedings of the Xth World Water Congress*, 12 - 16.

143. Zahmatkesh, Z., Burian, S., Karamouz, M., Tavakol-Davani, H., & Goharian, E. (2015). Low-impact development practices to mitigate climate change effects on urban stormwater runoff: Case study of New York City. *Journal of Irrigation and Drainage Engineering*, 141(1), 04014043.

144. Zhang, K., Randelovic, A., Page, D., McCarthy, D., & Deletic, A. (2014). The validation of stormwater biofilters for micropollutant removal using in-situ challenge tests. *Ecological Engineering*, 67(1), 1e10.

145. Zhang, K., & Chui, T. F. M. (2019). Linking hydrological and bioecological benefits of green infrastructures across spatial scales–A literature review. *Science of the Total Environment*, 646, 1219-1231.

146. Zhang, K., Manuelpillai, D., Raut, B., Deletic, A., & Bach, P. (2019). Evaluating the reliability of stormwater treatment systems under various future climate conditions. *Journal of Hydrology*, 568, 57-66.