

Review

# Analyzing Evidence of Sustainable Urban Water Management Systems: A Review through the Lenses of Sociotechnical Transitions

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**Abstract:** Sustainability concerns and multiple socio-environmental pressures have necessitated a shift towards Sustainable Urban Water Management (SUWM) systems. Viewing SUWM systems as sociotechnical, this paper departs from eight factors previously identified by transition research: *Pressures, Context, Purposes, Actors, Instruments, Processes, Outputs, and Outcomes* as a methodological framework for a structured review of 100 articles. The study seeks to analyze empirical cases of planning and implementing SUWM systems worldwide. A wide range of public actors—driven by social and environmental factors rather than by economic pressures—have initiated SUWM projects so as to locally fulfill defined social and environmental purposes. We provide evidence on the emergence of new actors, such as experts, users, and private developers, as well as on the diverse and innovative technical and societal instruments used to promote and implement SUWM systems. We also explore their contexts and institutional capacity to deal with pressures and to mobilize significant financial and human resources, which is in itself vital for the transition to SUWM. Planned or implemented SUWM outputs are divided into green (wet ponds, raingardens, and green roofs) and gray (rain barrels and porous pavements) measures. The outcomes of SUWM projects—in terms of societal and technical learning, and their institutional uptakes—are often implicit or lacking, which seemingly reduces the rate of desirable change.

**Keywords:** Blue–Green Infrastructure; low-impact development; sustainable urban drainage system; Water-Sensitive Urban Design; Water-Sensitive City; integrated urban water management; Sponge City; rainwater harvesting systems; planning; case study

## 1. Introduction

A wealth of socio-economic and environmental issues—in terms of resource scarcity and sinks, as well as climate change impacts—are placing a great amount of strain on conventional infrastructure systems, forcing them to overstep their sustainability limits [1–4]. Urban water systems, and particularly underground-piped drainage systems, have for decades received significant criticism for not being able to adequately respond to the rising pressures, thereby acknowledging the necessity for a transformative change towards innovative solutions [1–3,5,6]. Increasingly, open spatial systems mimicking natural principles are advocated as alternative system solutions that could restore natural hydrological flows. These systems could reverse the impacts of urbanization and alteration of engineering-based water flows, close the urban water cycle, enhance water security, and act as structural measures for urban climate change resilience [7–9]. As an overarching concept, the envisioned solutions are commonly referred to as Sustainable Urban Water Management (SUWM) [3,6,10]. These new systems encapsulate

hydrological principles of detention and conveyance, retention, and infiltration of rainwater and runoffs, integrated into designed nature-based facilities, such as ponds, wetlands, porous pavements, swales, trenches, open canals, green roofs and walls, and bio-retention systems [7,11–13]. SUWM systems promise to deliver a wide range of socioeconomic, environmental, and ecological benefits and services, thereby significantly contributing to urban sustainability [7,10,14,15]. Nevertheless, a transition towards SUWM systems has been relatively slow [3,16]. Existing urban drainage and, generally, urban water systems are viewed as sociotechnical systems that imply seamless interconnectivity of physical artefacts, economics, politics, actors, and structures, and are therefore resistant to radical change.

Intensified water challenges, such as the increased pollution of receiving water bodies, diminishing water resources, and the increased occurrences of floods and droughts has ignited a process of regime change. Accordingly, cities are increasingly turning to initiatives that seek to implement and promote SUWM solutions [6,17–23]. A diverse array of terms has evolved to describe these new system solutions designed to fit for various purposes in dealing with urban water challenges in different urban contexts [11,24,25]. Similarly, there has been an increase in the number of studies that focus on the transition towards SUWM and discuss a range of relevant technical and societal issues regarding the process of change (see [26] for a review). Factors that normatively and empirically hinder or facilitate desirable change include urban water *pressures* triggering change, *contexts* in which new solutions are sought, action *processes* for the transformation of urban water regimes, the *actors* involved, and the expected *outputs* and *outcomes* [26–31].

Despite the substantial body of academic work on the transition to sustainable policy approaches and the planning of urban drainage systems, the status of the knowledge available on the change required to cope with rising urban water issues and the impact of climate change is still in need of exploration. What lessons can be learned from worldwide empirical initiatives towards alternative solutions? Outlining the available knowledge in the relevant literature through a systematic review from the perspective of sociotechnical transition theory could serve to advance our understanding on the status and pace of change taking place in urban water systems and water drainage systems worldwide. Accordingly, this paper proposes a review of the literature on empirical evidence of the planning and governance of SUWM systems that have been advocated to complement and/or replace existing urban water systems.

Enhancing or bridging knowledge gaps through literature reviews so as to assess the process of urban water system regime change has gained the attention of many scholars. Some studies have focused on reviewing the evolving paradigms and terms used to describe the core principles of the newly sought solutions [11,32]. The literature regarding the status of the implementation of sustainable initiatives, solutions, and challenges in particular geographic contexts [12], as well as recent trends on novel sustainable water systems [33], has also been reviewed. Other studies have centered around governance and management challenges to regime change [34], or the scope and type of barriers against the mainstreaming of alternative solutions [16]. Moreover, other studies have specialized on specific issues, such as the spatial allocation of new systems for concluding on strategies and optimization tools [35], the societal benefits of the new solutions, and management criteria to control water pollution [36]. In brief, departing from the observably slow pace of change, one can argue that these literature reviews sought to understand the factors facilitating or hindering the advocated change. However, these reviews tell us little on the status of available knowledge in relation to transition theory and prospects for change.

Through following a novel approach for our review, this paper contributes to the debate on the pace of transformation of existing systems in favor of sustainable approaches and practices regarding managing urban rainwater and runoffs. It does so by conducting a comprehensive systematic literature review of all of the factors considered significant for materializing regime change (Section 3). These factors—which form the methodological framework for the review process—are outlined from a previous study based on a literature review of relevant scholarly work on theoretical transition perspectives [26]. These factors are described, defined, and translated into questions that were applied

when reviewing the literature (Section 2). A key contribution of this paper is the analysis and discussion of the extent and ways in which the results (Section 3) are linked and relevant to the findings and conclusions of other studies in the field (Section 4). Finally, the paper draws conclusions (Section 5).

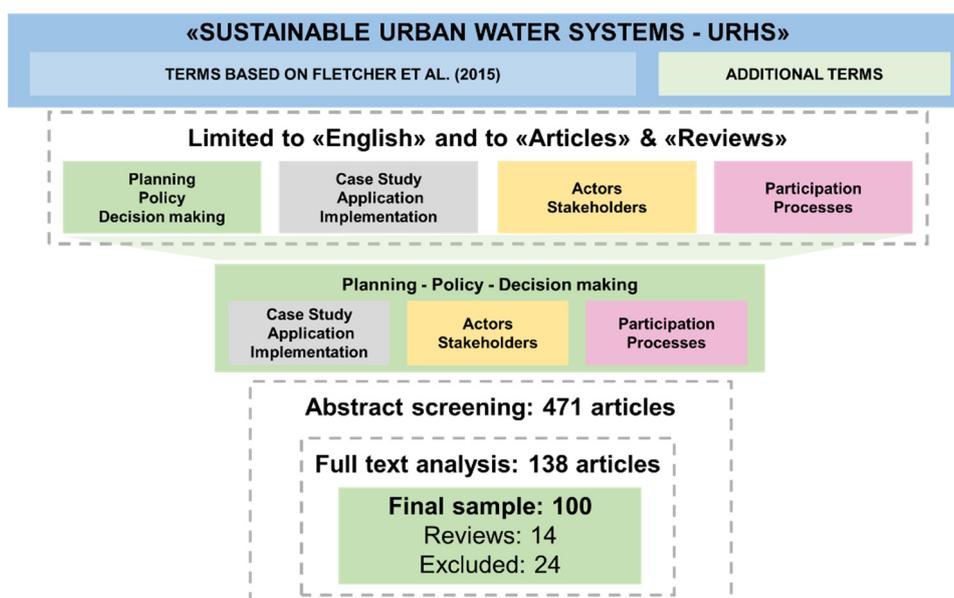
## 2. Materials and Methods

### 2.1. Selection of Articles: Keyword Search, Abstract Screening, and Text Analysis

The final sample of articles to be reviewed was identified through a four-stage selection process. In Stage 1, studies were selected through keyword searches (concluded on 3 May 2019) in the Web of Science v.5.32 (<https://webofknowledge.com>), while considering all databases from 1950 to 2019. Starting from the terminology reported in [11], the search included studies whose title, abstract, or keywords contained any of the terms used to indicate SUWM. The search keywords included terms such as *Stormwater Control Measures (SCMs)*, *Stormwater Quality Improvement Devices (SQIDs)*, *Best Management Practices (BMPs)*, *Sustainable Urban Drainage Systems (SUDS)*, *Alternative techniques*, *Source control*, *Water-Sensitive Urban Drainage Design (WSUD)*, *Low Impact Design*, *Integrated Urban Water Management (IUWM)*, *Water-Sensitive Cities*, and *Green Infrastructures (GI)* [11]. Other relevant concepts were added to these, such as *Sponge city*, *Nature-based Solutions (NBS)*, *Blue Infrastructure (BI)*, *Ecosystem Services (ES)*, *Urban Rainwater Harvest (URH)*, *Nature-close rainwater management*, *Open Storm/Rainwater Drainage or Management*, and *Blue–Green City* (see Table A1 in Appendix A). These terms were used as search keywords to identify relevant peer-reviewed scientific articles. The search resulted in a total of 7002 ‘articles’ and/or ‘reviews’ in the English language.

In Stage 2, in order to refine the search and identify those articles reporting on case studies of SUWM planning and implementation, we defined four types of inclusion criteria based on keywords. The inclusion criteria are meant to ensure that the study: (i) Addresses either planning, decision-making, or policy-making, (ii) includes a case study of SUWM planning and/or implementation, (iii) involves actors and/or stakeholders, and (iv) refers to some form of participation process. In fact, we were aware from the beginning of the study that hindering or facilitating factors towards socio-technical transition are institutional rather than technical, and thus, we were interested in capturing the information on former factors. Appendix A.1 illustrates the additional keywords introduced to operationalize the four inclusion criteria. For example, we defined 23 keywords to represent the different types of actors, including inhabitants, activists, mayors, and investors. Similarly, we considered nine keywords as representing different levels of participation: From information to empowerment, or advocacy. Based on these four inclusion criteria, the sample of 7002 articles could be reduced to 4710, 5490, 2976, and 1094, respectively. Hence, in line with the research aim to be able to critically appraise and synthesize evidence on multitudinous factors that facilitate (or hinder) the transition towards SUWM, we identified a subset of articles as being particularly informative. We selected the articles that meet all four of the inclusion criteria, i.e., 471 articles out of 7002.

In Stage 3, after reading the title and abstract, the sample was further condensed to 138—the excluded articles not focusing on SUWM (e.g., concerning rural farming, strict biodiversity conservation, or forest management). Lastly, based on a content assessment conducted on all of the documents to check for relevance (i.e., to ascertain whether they actually report a case study of planning and/or implementing an SUWM system), the sample was further reduced to 100 articles (numbered in the Supplementary Materials) in Stage 4. This selection excluded 14 reviews whose main points were synthesized in the introduction, and 24 additional documents that were either irrelevant or unavailable. Figure 1 (and Table A1 in Appendix A) illustrates the selection process of the final sample of articles based on keyword searches, abstract screening, and full text analysis. While not exhaustive, we considered the sample of 100 articles to be sufficiently large as to gain useful insights into the empirical evidence on the planning and implementation of SUWM systems.



**Figure 1.** Selection of the final sample based on keyword searches, abstract screening, and full text analysis (see also Appendix A).

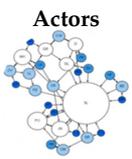
2.2. Review Framework

Despite the wealth of literature pertaining to transition processes, no broadly applicable analytical framework exists that captures the most significant factors for understanding transition trajectories—especially regarding socio-technical systems [37,38]. Building on work conducted by [26], we here apply the framework presented in Table 1. By distilling the relevant literature, the framework identifies eight factors that are significant for sustainability transitions in general, and sociotechnical and SUWM transitions in particular [26]. These factors are: Pressures, Context, Actors, Purposes, Instruments, Processes, Outputs, and Outcomes. In addition to these eight factors, Table 1 considers Location, Scale, and Terminology as complementary aspects that could enhance the proposed literature review. For each factor, Table 1 presents the guiding question(s) used to review the literature, explanatory notes on how to interpret said questions, and references.

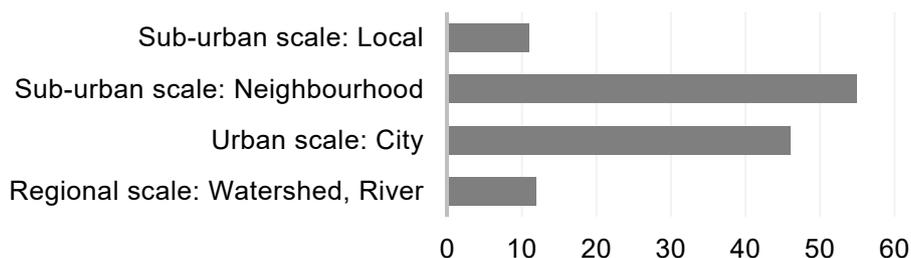
**Table 1.** The reviewing framework based on [26].

Factors	Questions	Interpretations	References
<b>Location</b>	What is the geographical region of the case study and publication year?	<ul style="list-style-type: none"> <li>Country and city in which the study area is located and year of publication.</li> </ul>	-
<b>Scale</b>	What is the extent of the analysis?	<ul style="list-style-type: none"> <li>Spatial extent of the study area in ha or km<sup>2</sup> and number of people.</li> </ul>	-
<b>Terminology</b>	What terms are used to refer to Sustainable Urban Water Management (SUWM)?	<ul style="list-style-type: none"> <li>List the terms mentioned in the article to refer to SUWM.</li> </ul>	[3,11,13]
<b>Pressures</b>	What are the main pressures on urban water systems?	<ul style="list-style-type: none"> <li>List all environmental, social, climatic, and economic pressures mentioned in general.</li> <li>List all environmental, social, climatic, and economic pressures in the case study.</li> </ul>	[39–43]

Table 1. Cont.

Factors	Questions	Interpretations	References
<b>Context</b> 	What has been the response to the pressures in the case study? How are the pressures in the case study articulated?	<ul style="list-style-type: none"> <li>Extract the information concerning the context described in the articles (often provided as a justification for the selection of the case study in the article).</li> </ul>	[29,31,42,44–47]
<b>Purposes</b> 	What purposes are considered in the planning, implementation, and/or assessment of the SUWM in the case study?	<ul style="list-style-type: none"> <li>List the environmental, social, and economic purposes considered in the planning, implementation, and/or assessment of the SUWM in the case study.</li> </ul>	[43]
<b>Actors</b> 	What actors are mentioned as important and/or discussed in the articles? Which actors are actually involved in the study?	<ul style="list-style-type: none"> <li>List the different types of actors (i.e., institutions, experts, users, businesses) that are mentioned as important stakeholders in relation to the SUWM.</li> <li>List the different types of actors that are actually involved in the study (e.g., through interviews, action-research, etc.).</li> </ul>	[1,15,28,29,48–52]
<b>Instruments</b> 	What instruments are used to promote and implement SUWM?	<ul style="list-style-type: none"> <li>List the different types of instruments used to promote the planning and implementation of SUWM in the study.</li> <li>Examples of instruments are Decision support tools; Planning instruments; Policy, governance, and management instruments; Funding Schemes and Incentive Programs; Participatory implementation instruments.</li> </ul>	[28,44,52–55]
<b>Processes</b> 	Which stages of a generalized planning and implementation cycle does the case study article address?	<ul style="list-style-type: none"> <li>Identify the stages of the planning and implementation cycle that could be (hypothetically) addressed by the study.</li> <li>Here, the generalized planning and implementation cycle consists of: (A) Problem analysis, (B) Analysis, (C) Planning, (D) System design/Analysis, (E) Implementation, (F) Monitoring, (G) Evaluation/Assessment.</li> </ul>	[54,56–58]
<b>Outputs</b> 	What green and/or gray measures are planned or implemented in the case study?	<ul style="list-style-type: none"> <li>List the types of green (e.g., wet ponds, rain gardens, and swales) and gray (e.g., rain barrels, permeable pavements) measures that are planned and/or implemented.</li> </ul>	[43,59–64]
<b>Outcomes</b> 	What outcomes are achieved concerning technical and social learning and mainstreaming?	<ul style="list-style-type: none"> <li>Technical learning outcomes in terms of building knowledge capacity.</li> <li>Social learning outcomes in terms of: (i) Actor involvement and organizational design, (ii) altered decision-making and governance structure, and (iii) readjustment in institutions.</li> <li>Outcomes in terms of replication, upscaling, and knowledge transfer.</li> </ul>	[16,28,45,49,51,52,56,65,66]



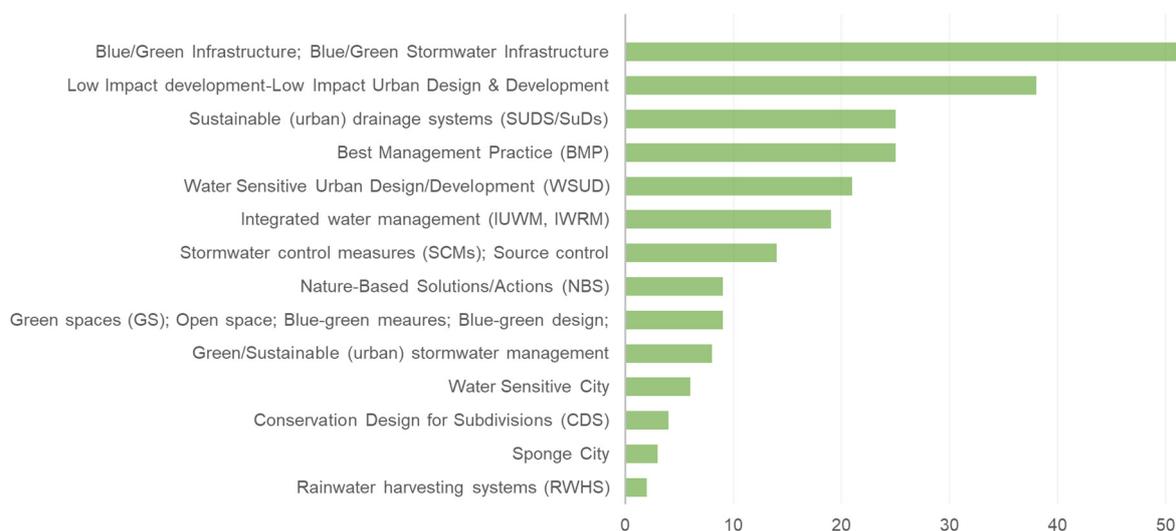


**Figure 4.** Spatial scale of the case studies reported in the reviewed articles.

The 100 reviewed articles were published in 53 journals. *Landscape and Urban Planning* (eight articles) and *Journal of Environmental Management* (seven articles) were the two journals with the highest number of articles. *Environmental Science and Policy* and *Water Science and Technology* each contained six articles, followed by *Sustainability*, *Water*, and *Water Resource Management* with four articles each. *Environmental Modelling and Software*, *Journal of Green Building*, *Journal of Hydrology*, and *Urban Water Journal* contained three articles each. Regarding authorship, the majority of the articles (76) were co-authored by between two and five researchers, followed by articles with 6–7 co-authors (10), then articles with a sole author (6), and, finally, a cluster of articles had between 8 and 25 co-authors (8); see details in the Supplementary Materials.

### 3.2. Terminology

Overall, the reviewed articles used 63 different terms to refer to SUWM. This variety of terms was grouped into 14 main clusters, including *Blue/Green (Stormwater) Infrastructures* and *Low-Impact Development/Low-Impact Urban Design and Development*. Figure 5 shows the frequency with which the terms in each cluster were used to refer to SUWM. In addition, Table A2 (in Appendix B) shows the frequency of mention of each of the 63 terms in the reviewed articles, as well as their grouping into 14 clusters.

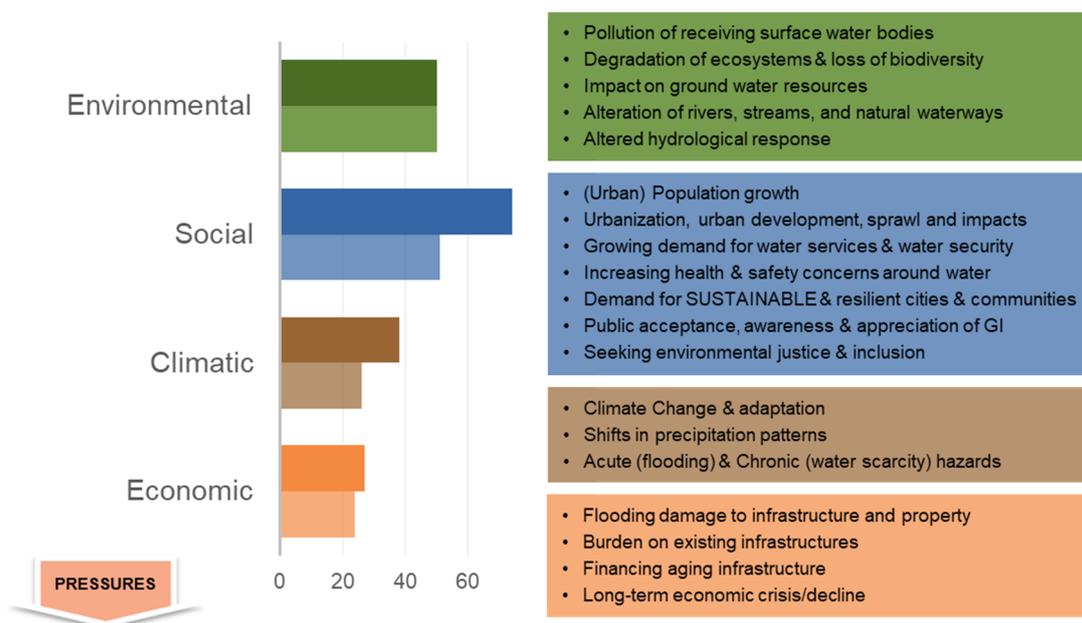


**Figure 5.** Frequency of the terms used in the reviewed articles to refer to SUWM.

### 3.3. Pressures

A considerable number of pressures were reported in the reviewed articles. These were described both in general terms (supported by references) and, more specifically, with respect to the case studies analyzed in the articles. Through an iterative process, we grouped the pressures into four categories: Environmental, social, climatic, and economic (adapted from [43]). Figure 6 presents the frequency of different types of pressures mentioned in the reviewed articles. The figure also specifies the different

types of pressures by category. Indeed, the most frequently mentioned types of pressures were social and environmental, followed by climatic and economic. Table A3 (in Appendix B) illustrates the variety of pressures along with examples from the reviewed articles.



**Figure 6.** Type and frequency of pressures mentioned in the reviewed articles. Lighter colors represent pressures mentioned in general, while darker colors refer to pressures in specific case studies.

### 3.4. Contexts

We acknowledged a receptive and adaptive context as a key factor for transitions. Table 2 presents some selected extracts from the reviewed articles, which could indicate a receptive and adaptive context in the case study. The selected examples are meant to demonstrate the broad variety of adaptive contexts. However, it is worth bearing in mind that a more in-depth analysis of each case study would have been required so as to assess the actual receptivity of the contexts in question.

**Table 2.** Examples of receptive and adaptive contexts in the reviewed articles.

Short Description of Contexts	References
Kiruna city has an ambitious planning strategy and a conducive political climate.	[67]
Fort Collins is a progressive city with a Sustainability Services Department; it has adopted sustainability and climate action plans. The local community has a history of innovation and investment in its future focused on ecological and social values.	[68]
Since 2013, China has been promoting the planning and construction of the Sponge City, and has strengthened implementation of a CO <sub>2</sub> emission reduction plan and a green economy strategy.	[69]
Chesapeake Bay’s natural resources add over 678 billion USD to the economy. Multiple legislative approaches through the 1972 Clean Water Act and later legislative amendments allowed effective monitoring, policy development, and regulation of discharges. In 2009, President Obama enacted Executive Order 13508 to renew efforts to protect Chesapeake Bay.	[70]
History of discrimination—Rochester Heights is the first African American neighborhood built partly within the Walnut Creek floodplain. In the mid-1990s, community leaders and advocates formed the Partners for Environmental Justice (PEJ), whose goal was to promote the growth and quality of life of Southeast Raleigh.	[71]

Table 2. Cont.

Short Description of Contexts	References
Portland is a leading city in its pursuit of Blue–Green Infrastructure (BGI). In 1999, the city adopted a Stormwater Management Manual (SWMM), and then initiated a Green Streets Policy in 2007.	[72]
Common resilience activities involving the built environment are often government-led, have limited public participation, and are dominated by interest groups/elite groups. Vulnerable communities in the USA have less voice with which to influence these types of actions, despite their facing the highest risk from environmental change and disasters. The disparities are deeply entrenched.	[73]
Chicago is working to comply with National Pollutant Discharge Elimination System Phase II requirements. It has been successful at implementing structural and non-structural Best Management Practices (BMPs) to treat stormwater runoff, and at utilizing Green Infrastructure’s (GI’s) broad appeal (the Stormwater Ordinance, the Green Roof Initiative, and the Green Alleys Program).	[20]
Australian Intergovernmental Agreement on a National Water Initiative incorporated the concepts of Water-Sensitive Urban Drainage Design (WSUD) into its urban water reform agenda, and defined WSUD as: ‘The integration of urban planning with the management, protection, and conservation of the urban water cycle that ensures urban water management is sensitive to natural hydrological and ecological processes’. In South Australia, the former Department of Planning and Local Government developed the ‘Water-Sensitive Urban Design Technical Manual’.	[74,75]
Melbourne is considered a world leader in Integrated Urban Water Management (IUWM) and, since 2009, has had a significant number of decentralized recycled sewage and stormwater harvesting reuse schemes planned. Five strategies were conducted over the 1997–2007 drought.	[76]
Daybreak, the largest built GI community in semi-arid Utah, USA. Daybreak is a master-planned community development in South Jordan, Utah, and one of the ‘Top 500’ urban sites in the US. A demonstration community of comprehensive sustainable design, Daybreak’s extensive parks and open space are integrated with stormwater management, and are enlivened by social and recreational programming. Daybreak is a project assessed in the 2011 Landscape Architecture Foundation Case Study Investigation program.	[77]
Water-sensitive urban design in Melbourne. In 2006, the state government of Victoria released a plan to improve the quality of the Yarra River. A total of 20 million dollars was allocated under the four-year plan to invest in stormwater-related WSUD and associated capacity building of 38 municipal councils across the region.	[78]
Prince George’s County has been a pioneer in promoting and implementing innovative and practical stormwater BMP and Low-Impact Development (LID) techniques, and has developed a number of tools to support analysis and decision-making.	[79]
The UK government strongly encourages local authorities to implement Sustainable Urban Drainage Systems (SUDS) for future development and regeneration sites. The ‘Glasgow Surface Water Management Project’ is a Community Initiative established in 2000 by the Commission of European Communities.	[80]

### 3.5. Actors

Overall, a diverse range of actors were involved in the reviewed case studies. As shown in Figure 7, they include institutions (e.g., water utilities and municipal departments), different experts (e.g., water engineers, landscape planners, and social scientists), users (e.g., residents, marginalized groups, and non-governmental organizations (NGOs)), and businesses (e.g., developers). Interestingly, the majority of the studies involved or highlighted the key role of users (also referred to as consumers, landowners, and residents, among others), municipal decision-makers, as well as NGOs and other pressure groups. More specifically, Table A4 (Appendix B) provides examples of each category of actors from the reviewed articles.

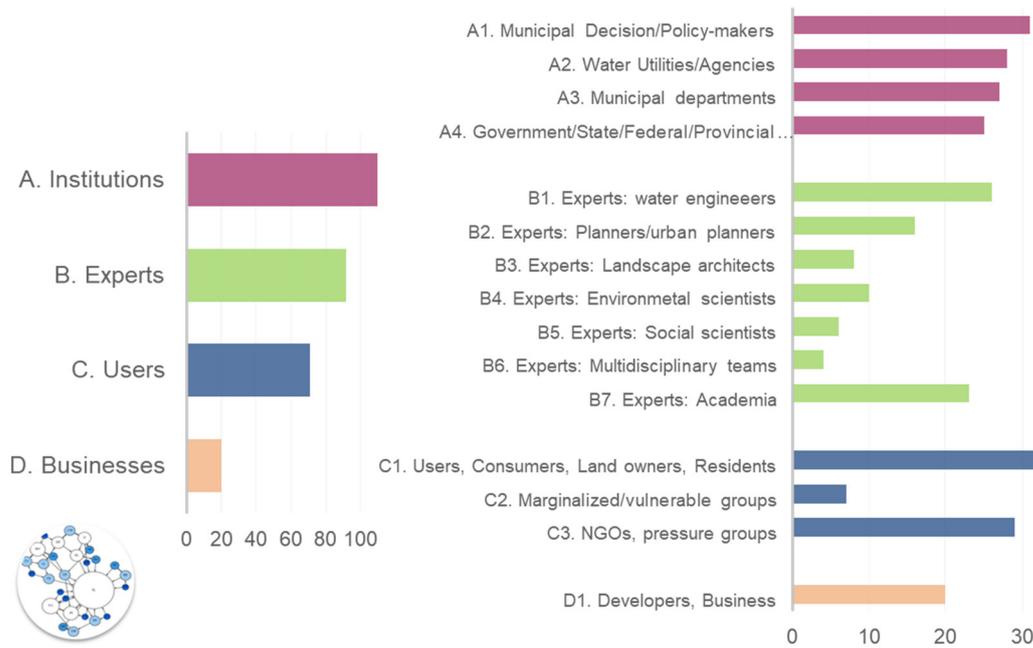


Figure 7. Type and frequency of different types of actors mentioned or involved in the reviewed articles.

3.6. Purposes

Different types of purposes were considered in the planning and implementation of SUWM systems. Following a classification proposed by [43], the purposes were here classified into environmental and ecological, social, and economic categories. As shown in Figure 8, the most frequently mentioned purposes were again social (e.g., flood mitigation, education and outreach, and recreation), followed by environmental (e.g., water quality of receiving bodies, biodiversity, and ecology), and economic (e.g., cost effectiveness and flexible implementation, green jobs, and investments).

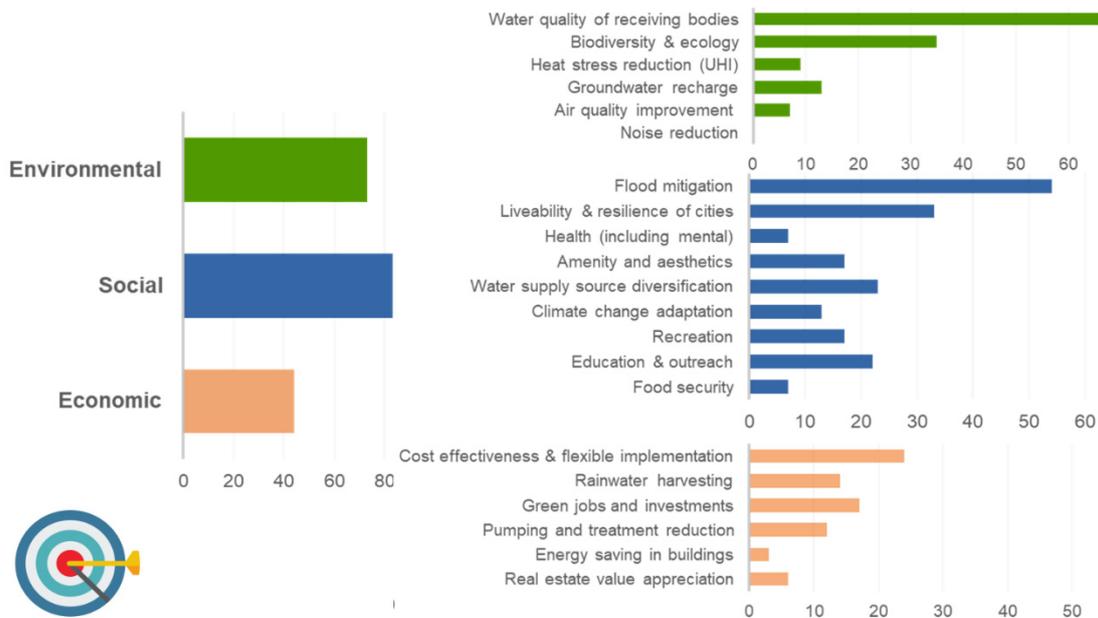


Figure 8. Type and frequency of different purposes associated with SUWM in the reviewed articles.

### 3.7. Instruments

Figure 9 presents the range of instruments employed to support the planning and implementation of SUWM in the case studies. The different instruments are classified into five typologies. Decision support—the most frequently employed instrument type—includes hydrologic–hydraulic, water quality modeling, scenario development, and cost–benefit analysis. Planning instruments ranged from visions and strategies, through comprehensive plans, and up to the level of detailed designs and guidelines. Several studies also highlighted the application of instruments related to Policy, Governance, and Management, as well as Funding Schemes and Incentive Programs. Finally, one common instrument was Participatory Implementation, which took place through various forms of stakeholder engagement—often involving some piloting or experimentation schemes. Table A5 (Appendix B) shows a detailed example of the tools as mentioned in the reviewed articles.

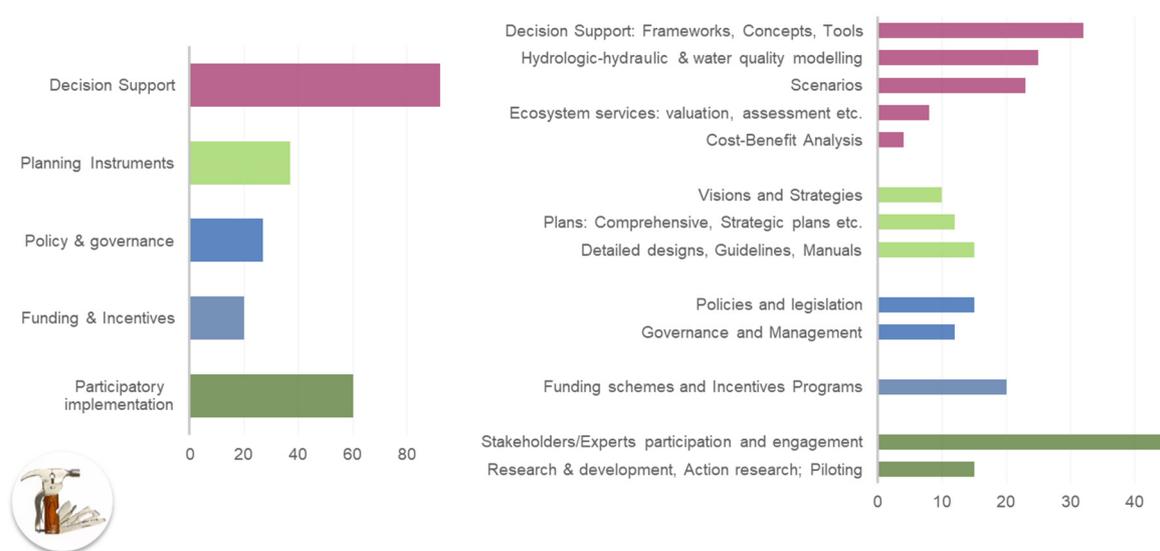


Figure 9. Type and frequency of instruments for implementing SUWM mentioned in the reviewed articles.

### 3.8. Processes

In our analysis, the reviewed cases were tentatively associated with one or more stages of a generalized planning and implementation cycle. Figure 10 illustrates the number of articles that could hypothetically be linked to the different stages. Accordingly, a significant number of studies (over 35) could be linked to the stages of Analysis (B), Evaluation/Assessment (G), and Problem Analysis (A). We found Monitoring (F) to be the least frequent stage of the process.

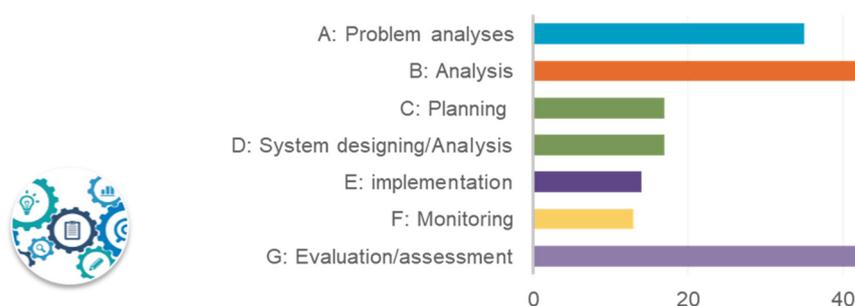


Figure 10. Different stages of generalized planning and implementation cycles addressed in the articles.

### 3.9. Outputs and Outcomes

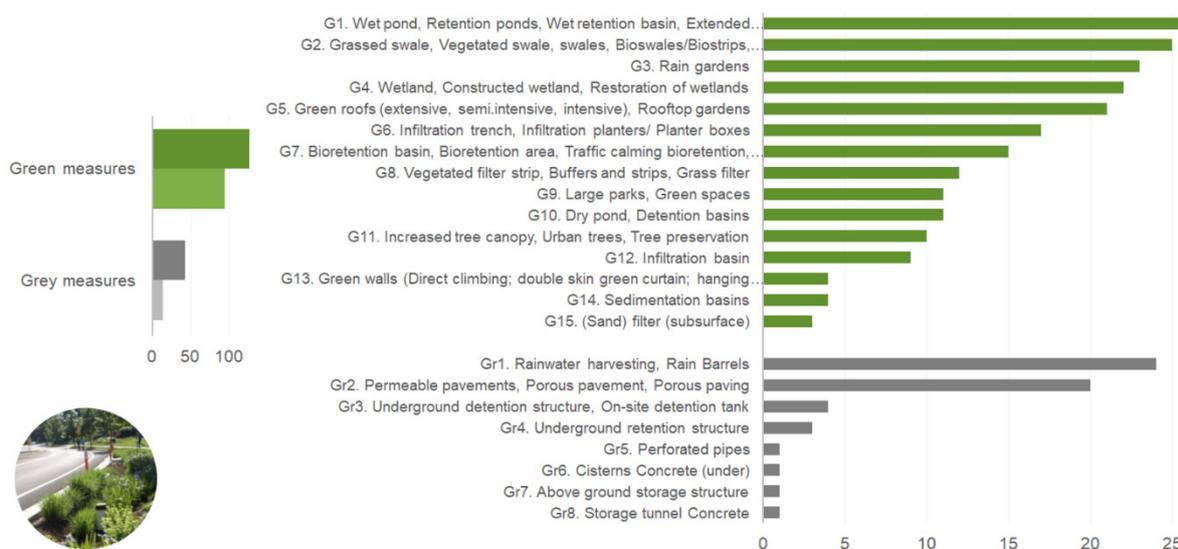
Numerous schemes exist for classifying outputs, i.e., the physical components of a SUWM. Table 3 presents seven different classification schemes identified within the sample, namely [43,59–64].

Particularly, the classification proposed by [59] assumes a gray–green stormwater infrastructure continuum, and considers both green and gray source control measures (SCMs), whereas the other classifications focus predominantly on green measures. Notably, the classification of [59] accounts for the type of construction material (concrete, earthen, plants), drainage area (city to parcel level), types of dominant hydrological processes involved (retention, detention, evapotranspiration, infiltration, and transpiration), dominant water quality processes (active treatment, settling, uptake, filtration, and straining), costs, and community benefits (flood protection, green space, parks, and aesthetic improvement). In Appendix B, Tables A6 and A7 present a detailed comparison of seven different classification schemes of gray and green measures identified in the reviewed articles.

**Table 3.** Types of green and gray outputs according to seven classification schemes reported in the reviewed literature. For a detailed comparison, see Table A6 in Appendix B.

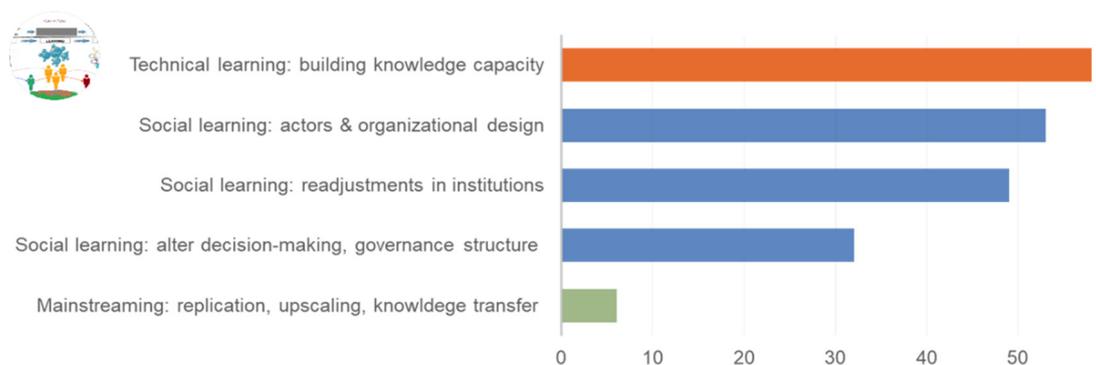
Type of Outputs (Green and Grey)	Reference
Cisterns; permeable pavements; rainwater harvesting; construction/restoration of wetlands; infiltration planters/planter boxes; green roofs (blue roofs); vegetated detention strips; bioswales/biostrip; bioretention area; traffic calming bioretention; increased tree canopy.	[43]
Wastewater Treatment Plant (WWTP); storage tunnel concrete; aboveground storage structure; underground detention structure; underground retention structure; underground gravel beds; concrete cisterns (under); perforated pipes; porous pavements; sand filter; sand filter (subsurface); wet pond; dry pond; constructed wetland; infiltration basin; infiltration trench; green roof; vegetated filter strip; grassed swale; bioretention basins.	[59]
Permeable pavements; retention ponds; sedimentation basins; wetlands; infiltration trenches; swales (vegetated); bioretention basins.	[60]
Water features; green roofs; vegetated swales; urban trees; large parks, green spaces.	[61]
On-site detention tank; permeable pavements; ponds; rainwater harvesting; wetlands; green roofs; biofiltration systems, buffers; swales; bioretention devices.	[62]
Cisterns, sidewalk storage; porous pavements; filters; rain barrels; detention basins; rooftop gardens; buffers and strips; vegetated swale/swales; bioretention cells; tree preservation.	[63]
Porous paving; wet retention basin; constructed wetland; infiltration basin; grass filter; grass swale; extended detention basin.	[64]

Figure 11 shows the aggregated and detailed frequency of the different types of outputs considered in the literature. Generally speaking, green measures outweigh (by almost thrice the amount) gray measures. Specifically, wet ponds, grassed swales, and raingardens are the three most frequently mentioned green measures. Rain barrels, porous pavements, and detention tanks are the gray measures most often cited. In the reviewed case studies, the outputs were either planned, implemented, and/or evaluated. They consisted of both hypothetical (e.g., planned or modeled) and actual outputs (e.g., already implemented, installed, or existing). Notably, we identified 63 terms used to refer to different types of outputs—tentatively grouped here into green and gray measures.



**Figure 11.** Type and frequency of outputs mentioned in the sample. In the aggregated graph (left), the darker color represents hypothetical output (planned or modeled), while the lighter color refers to actual outputs (already implemented, installed, or existing).

Figure 12 illustrates our results concerning outcomes within the sample. A key assumption here is that the outcomes of experimentation and transition are manifested in three primary aspects: Technical learning through developing and building a knowledge capacity, and the transition to a new ‘technology’; social learning and change; and mainstreaming—replication, upscaling, and knowledge transferability to other contexts [16,28,45,49,51,52,56,65,66]. Using our interpretation, the majority of the studies could be assumed to have achieved some level of technical (e.g., installing and running hydrological–hydrodynamic models) and social learning (e.g., action-research involving marginalized communities). Conversely, fewer articles could be associated with mainstreaming outcomes (Figure 12).



**Figure 12.** Number of articles that could be associated with outcomes in terms of technical and social learning and mainstreaming.

#### 4. Discussion

##### 4.1. Geography, Scale, Journals, and Authorship

The years of publication and the geography of the articles reveal a rising academic interest for SUWM, particularly in the USA and Australia (where most of the empirical cases are concentrated). This is unsurprising considering these countries’ sizes, the intense environmental and/or societal pressures in both contexts, e.g., [6,76,81], and the longstanding legislations and policy responses that have driven the planning and implementation of SUWM facilities at different scales [13,81].

In the European context, Sweden has placed the greatest focus on SUWM approaches. This could be explained by the emphasis that other studies place on the Swedish government's aspiration for the country to be a world leader for sustainable urban sociotechnical systems, such as environmentally adapted stormwater solutions, as a means of consolidating its position in the global market [82–84]. Other European regions might have been under-represented in the results. Germany is a prime example of a country with a long and advanced experience of SUWM practices in [85,86]. Over the past 40 years (with support from innovative policy approaches), SUWM-related technologies in Germany have evolved from experiments to common practices based on developed standards and norms that were also transferred to other contexts [85].

The results include a limited number of articles from Asia [21,87–90], only one from Africa [91], and none from South America. This could be partially explained by the fact that studies on sociotechnical transition do not consider a shift from mainstreamed underground drainage pipe systems relevant for the Global South, where the 'modern infrastructure ideal' is largely absent [32,92]. Others instead argue that the immediate challenges of the urban water sector in the Global South remain the lack of access to safe water, sanitation, and adequate drainage systems [3].

We also observed that most of the cases address the planning and implementation of sustainable urban water projects at either suburban/neighborhood (55) or urban (46) levels, but relatively less frequently at the regional, watershed, and river scales (12). One explanation for the lack of case studies addressing urban water challenges at the watershed/catchment scale may be due to our selection criteria, which limited our review to include case studies of urban water. Another explanation could be due to the lack of an integrated approach for urban water management because of organizational challenges regarding intra-municipalities and multi-scale collaborations—challenges often perceived as impediments to desirable transformation and outcomes [6,8,13,75,93,94]. As explained by others [95,96], these challenges from the mismatch of political/judicial and hydrologic boundaries, if resolved, have the potential to significantly transform the policies and practices of governmental authorities towards sustainable outcomes, according to [8].

#### 4.2. Terminology

Ref. [3], in line with others [11,13], describes SUWM as an overarching concept under which many terms are used to reflect a generalized goal to manage the urban water cycle so as to produce greater (and more plentiful) benefits than those delivered by traditional approaches. In the reviewed articles, we counted 63 different terms—although these articles do not necessarily use these terms consistently. Most of the articles would use one term, but mention 4–5 other terms with similar connotations to those used. The described terms are clustered into 14 groups. The most commonly used terms, as other studies have stressed [11], are 'Green Infrastructure' (GI)/42, 'Low-Impact Development' (LID)/35, 'Best Management Practice' (BMP)/23, 'Sustainable Urban Drainage System' (SUDS)/13, 'Water-Sensitive Urban Design' (WSUD)/18, and 'Integrated Urban Water Management' (IUWM)/13.

According to [11], the recent evolution of complex terminology has the potential to increase confusion and miscommunication. Nevertheless, it also promotes a shared local understanding and, as long as communication between disciplines and contexts remains uncompromised, can advance professionalism by being explicit and accurate in its application. Otherwise, according to [59], concepts under which operational measures and applications are not classified and accurately described pose analytical challenges in terms of the explicit and various inputs that decision-makers should consider for optimal water planning outcomes. Thus, for comparative analysis, the authors of [59] call for either a uniform and consistent classification scheme for SUWM technology or, rather than a specific term, suggest following the designs and practices of where an SUWM technology is implemented.

According to these premises and views, the 63 terms used within the sample could potentially add to the challenges faced by the facilitation of change. For instance, differing terms of communication and coordination between disciplines and global regions could complicate the development of appropriate knowledge and policy agendas. Perhaps it is precisely this confusion regarding the core aims and

operational implications (in terms of the required type of water infrastructure and the management of urban water cycles) that has driven studies to seek a resolution to this issue [11,32].

#### 4.3. Pressures and Purposes, and Values Integrated in Designed SUWM Facilities

From the perspective of sociotechnical transition, socioeconomic and environmental pressures—as well as their intensity, scope, and frequency—cause disruptions and destabilize existing regimes, thereby creating opportunities for technological innovation and social structural change [39–42]. On the role of pressures as a key factor in driving change, Furlong et al. (2016) presented clear evidence on how socio-environmental pressures have shaped the rise and fall of strategies supporting innovation and a transition towards SUWM within Melbourne’s water sector.

The analyzed articles show that the types of pressures that have driven change in the urban water landscape correspond to the same types of purposes and values integrated in the designed SUWM systems. Social and environmental pressures play relatively equal and important roles in driving change—an issue that resonates with most of the literature addressing the sustainability limits of existing urban water systems from a predominantly environmental and societal perspective [1,3,13,95,97]. Economic pressures play a less decisive role as a driving force for experimentation and innovation. Our results also lend weight to the notion that SUWM systems are primarily planned and designed for their social and environmental purposes/goals, rather than for economic values. Most of the mentioned economic values relate to energy savings, reduction of water users’ bills, and increasing values of real estate property. It should be stated that these are context-dependent, and knowledge on whether alternative systems save energy and increase property values is still uncertain and subject to system performances and public acceptance and engagement [27].

Ref. [3,13], among others [6,59,96,98,99], addresses the issue of the lack of economic valuation input as a major constraining factor to technological innovation regarding sustainable urban water approaches. According to these views (and as opposed to gray infrastructure), SUWM solutions promise to deliver long-term intangible socio-environmental benefits and spatially distributed externalities (non-market valued) [100], although these can result in a lack of economic frameworks for the accounting and cost/benefit sharing, which are necessary inputs in decision-making processes. Ref. [59] uses the term ‘co-benefits’ to define them as ancillary positive ecological, environmental, and societal outcomes that coincide with the installation of structural SUWM facilities, grouped into hydrologic-, climate-, habitat-, and community-related benefits. Other scholars have referred to these co-benefits as ‘added values’ [14]. Political ecologists [38,101] have advocated engagement with communities (considered knowledgeable subjects for valuing these co-benefits) as input into the decision-making processes for optimal sociotechnical infrastructure outcomes. However, the lack of a solid economic framework that incorporates costs (i.e., risks) and benefits has forced municipalities (in certain US regions, for example) to focus on compliance for management of water quality and quantity, and have thus prioritized gray water structural measures for minimizing project cost over green measures [59,101]. More generally, based on evidence relating to Australia, Ref. [6] argued that there is an inherent conflict between neo-liberal and environmental policy agendas that support sustainable urban water policy.

Economic rationality for alternative solutions, as opposed to water pipe systems, plays a particular role. Decentralized systems become economically feasible where the risk of droughts and/or flooding is relatively high and imposes unforeseen socioeconomic consequences and costs. Replacing aging infrastructure is constrained by budget limitations and where developing markets for exporting innovative decentralized SUWM systems are sought [6,62].

#### 4.4. Context and Instruments

In sociotechnical transition literature, a receptive context is one that is ‘aware’ of certain pressures and both ‘acknowledges’ and ‘articulates’ them [31,42]. According to this general understating, the included case studies describe receptive contexts to different extents that cannot be quantified from the review.

An adaptive context and capacity is defined in terms of political, legislative, and financial support and the ability to mobilize resources (human and financial) for the networking and coordination of responses to articulate particular pressures [42,47]. Other studies have stressed a particular human agency to materialize transition. Accordingly, pressures need to be taken up and translated by actor agency [29,44–46]. Considering these views, context adaptability varies both between countries and within them, e.g., in Onondaga County Metropolitan and the city of Philadelphia [102,103]. Based on only the reviewed articles, all of the adaptability elements on context and capacity (including human agency) are found in Philadelphia, which, according to [103], is the first city in the US to attempt an entirely green approach to meeting federal regulations, and was subsequently recognized as a leader in transitioning to SUWM. Table 2 presents some examples of noteworthy findings related to the adaptability of context and transition perspectives.

Similarly, our results show the variety of instruments used to promote the shift towards a sustainable urban water approach. These include decision support tools for modelling and building scenarios; visioning and planning tools, policy designs, and legislations; and financial incentives and mechanisms. They also reveal the significance of a participatory approach involving relevant interest groups as a tool for allowing a space for experimentation and the development of technical niches and policy and societal innovations. The significance of these particular types of tools is stressed as a factor facilitating desirable sociotechnical changes [28,44,52–55].

As shown in the reviewed literature—but also stressed in studies outside of the sample—the availability of technical knowledge and modeling tools is key [22,59,67]; however, these tools are neither fully utilized nor aid urban planning processes [35,67,93]. Prior studies have also highlighted the critical need for socioeconomic and environmental assessment tools by incorporating socio-economic factors alongside biophysical and planning factors [3,6,13,59,99]. Contemporary efforts are being made to cover these research spots and construct decision support tools and methods for a holistic analysis approach by incorporating urban planning policies and socio-economic factors alongside biophysical models for optimal and long-term outcomes [22,67,94].

#### 4.5. Actors

Our results emphasize the diversity of actors involved in new urban water projects. Experts and users are emerging actors and have (or are thought to have) important roles in the promotion and support of new water projects. However, it is unclear from the review whether experts are consultants or scientists. The analyzed articles do not focus on actors' values, vested interests, human agency, influence, or roles, despite these being deemed important factors in enabling/stabilizing or constraining the shift towards new sociotechnical systems and defining outcomes [3,15,28,29,51,52]. Still, our review highlights the extended range of actors involved, including relevant experts, as well as the communities and users required by new water infrastructure solutions—a finding that resonates with other studies that stress the variety of actors involved and the vital role of close interdisciplinary collaboration at various levels to achieve maximal benefits [1,15,48–50,98].

Findings concerning actors also illustrate that SUWM niches and projects are mainly developed by public organizational actors at different levels (national, municipal, and water agencies). Business actors have minimal and restricted roles in urban development projects, a finding supported by the fact that most of the socio-environmental co-benefits that SUWM solutions promise to deliver are non-market valued externalities.

The business sector's marginal role is also explained in the literature pertaining to sustainable entrepreneurship, which stresses the importance of public support and funding and cautions against the potential for substantial socio-technical changes towards sustainability initiated by industries [104]. According to this view, industries are not motivated to change business models and bear high financial risks for developing innovative infrastructure services in the absence of economic and supportive legal frameworks that accurately define costs, risks, and benefits. The leadership role of public authorities

and landscape and urban planning agencies in the transformation process towards SUWM has been emphasized by other studies [26,85,86].

Three aspects are worth remarking upon from these results. First, the mapping exercise of involved actors shows the key roles of four types of actors: Water engineers, urban planners, landscape architects, and environmental (and, to a lesser extent, social) scientists. This resonates with the ideals of SUWM that place water as visible features of a city, and has thus required the early integration of water infrastructure, as well as urban and land use planning, for the design and implementation of SUWM projects [1,5,67,94]. This shift in the roles of traditional actors is supported by other studies. Indeed, a shift from the current water infrastructure planning approach that often occurs in isolation from the broader planning of our urban environments and other social services has become a prerequisite for the optimal and effective system design, location, and management of space [49,55,94].

The second aspect relates to the visibility of academic experts in the landscape of developing niches and projects for sustainable urban water—a non-traditional role in planning conventional urban water systems. This role is likely significant for circumscribing the uncertainty and risks present in new water projects, and has been often discussed in the relevant literature [3,13].

Third, the results show a more significant role played by water engineers compared to urban and landscape planners. These roles and their significance are likely contextual. Other studies have shown planners to take a more leading role than water engineers [26,67], which is perhaps an issue related to the types of drivers and defined goals of urban water policy and projects.

#### 4.6. Processes

Most of the reviewed articles focus on either the first or second phase of planning cycles; i.e., identifying and recognizing a problem, defining goals and opportunities, and/or problem analyses at different levels. Less emphasis was placed on processes of planning and system design or the implementation of SUWM projects. Most noticeably, analyses of monitoring processes and system performance were less explored by the literature. This is perhaps due to the literature review's limitation of focusing only on planning, and not necessarily reflecting on the type and frequency of processes that occur in real-life contexts. A few articles have implied the existence of monitoring programs, although these have not been described or focused upon [8,22,74,105].

Generally, many studies have highlighted the lack, or sub-optimality, of monitoring processes of constructed water systems. One explanation is given by [59,103] in their report that maintaining and monitoring system performance is labor intensive and thus entails high operation costs. Others highlight different factors by addressing governance challenges to the maintenance and monitoring of new urban water projects [13,34,75,96,97,99,103]. These include fragmentation and shifted roles of responsibility, as well as the lack of an institutional capacity to accommodate new water projects in terms of organizational relations, appropriate legislations and mandates, adequate funding and financial mechanisms, operational guidance and standards, and the workforce skills necessary for the maintenance, operation, and long-term commitment to a multi-decadal planning cycle. According to sociotechnical transition premises, the lack (or limited number) of these types of processes could likely compromise learning outcomes, cause the up-take of experimentation results, and defer the urban sustainability agenda [16,38,52,57,58,106].

From our review, we can claim that programs for evaluating systems exist, from which SUWM assets databases, technical manuals, design practices, and tools to support decision-makers have been developed [74,76,79,93,103,107].

Additionally, over 40 articles in our sample address the processes of evaluation and assessment of, for example, public acceptance, economic values, environmental impacts, design and implementation of water projects with respect to policy designs, and stormwater mitigation, etc. However, excluding a handful, e.g., [67], articles that address and analyze the evaluation processes of system performance by actors and planned and designed the systems in an integrated approach are largely missing from our literature review.

The sample does not cover in-depth processes of urban planning and water system design, implementation, operation and maintenance, governance processes for evaluating system performance for social and technical learning, and institutionalization stressed in sustainability transition. Ref. [99] put forward similar remarks and explained that, since SUWM approaches are relatively new and involve an increased level of complexity, there are wide knowledge gaps in their planning, design, implementation, operation, and management. However, we do not claim that our literature review is comprehensive or inclusively captures the developed knowledge of SUWM due to the aforementioned limitation. As such, there exists a need for examining empirical cases that focus on these processes so as to inform policy and practice.

#### 4.7. Outputs and Outcomes

According to [59]'s scheme that we followed in order to classify SUWM technologies in the literature, the green measures that are either planned, modeled, implemented, or existing are double those of gray measures. The implication here is that there is a shift towards experimenting, complementing, or replacing gray for green measures regarding SUWM. This corresponds to the proposed claims that the urban water sectors in Australian and US cities (where most of the empirical cases are concentrated) are in stages of transition [6,15,16,75,76,92,99,102,103].

In the United States, however, scholars do not refer to these shifts as transition, but instead use such terms as 'successful cities' [20], 'first city' [103], 'national leader city' [102], or 'leading city' [72,95] in transitioning to SUWM. Concerning technical functions, most gray and green structural measures are primarily designed for detention and retention or, to a lesser extent, as a secondary function.

Regarding the outcomes, the reviewed articles do not generally discuss/analyze or expressly cover processes of social and technical learning or the institutionalization of learning outcomes as core activities in long-term planning processes assumed by transition theorists. Nevertheless, we have assumed, as argued or implied by certain articles [74,79,93,94,103], that technical and organizational learning for developing knowledge capacity is manifested in the experimentation of using (aforementioned) diverse instruments and tools, and is gained through action processes in different phases of the planning cycle. According to this interpretation, we could associate the examined case studies with significant technical learning and knowledge capacity building (approximately 60 articles), social learning in terms of actors and organizational design (55 articles), social learning that has had the capacity to induce institutional re-adjustments (50), and alterations of governance structures and decision-making processes (30). However, fewer case studies discuss mainstreaming as outcomes (6). Despite the significant technical and organizational learning, such edification is not sufficiently adequate to enable a stabilized breakthrough in the urban water sector due to the few articles that, explicitly or implicitly, discuss or describe mainstreaming, i.e., replication, upscaling, and knowledge transferability to other contexts [20,102,103,105].

Only a handful of articles have shown that social and technical learning outcomes are taken up through the provision of strategies, policies, long-term plans, funding schemes, practices, and technical standards, tools, and guidelines for the implementation of urban development projects that have led to societal and organizational changes [85,95,107].

This is in line with [94], who argued that, despite more than 25 years of Australian development in this area, SUWM systems have not yet reached maturity due to sub-optimal outcomes of planning practices and disappointing system performances. According to them (page 154), the experiences indicated that 'reactive and incremental approaches to planning are ill-suited to guide a transition towards widespread adoption of Water Sensitive Urban Design (WSUD) approaches'.

Supported by the types of described outcomes, as well as the few cases of mainstreaming, learning outcomes could be said to be unsystematic—except for a few case studies [93,107]. To facilitate such change, there is a need for decadal experimentation [49], collective action and reflection among actors and organizations involved in experimentation, and the institutionalization of continuous learning and changes to its operations in order to achieve long-term desirable sustainability outcomes [103,108,109].

## 5. Conclusions

In this section, we review the worldwide empirical initiatives covered in this study, return to our research objective regarding the status of available knowledge on the transition towards alternative SUWM solutions to cope with rising urban water stresses and the impacts of climate change, and present our key findings.

The paper is distinctive compared to other literature reviews. To fulfill the objective of the study, we followed an innovative methodological framework that analyzed the main factors viewed as significant for materializing sociotechnical regime change, which are both multiple and interdependent. Thus, this approach has both strengths and weaknesses. Regarding its strengths, the paper outlines available knowledge and advances our understanding of the status and the pace of change in SUWM systems worldwide. It does so through an in-depth analysis of each of the factors outlined in the methodological framework. Nevertheless, analyzing specific causal relations between these factors, such as the relation between purposes and outputs/outcomes or the relationship between context, actors, and outcomes, is lacking. Such an analysis would have produced interesting and valuable results and conclusions; however, this was not possible because the reviewed articles rarely, if at all, thoroughly addressed these factors together.

One of the current study's key findings is the wide diversity in (a) the terminology used to describe the key principles of SUWM; (b) the typology of actors involved in planning processes; and (c) the technical and societal instruments used to mobilize human and financial resources, as well as their coordination so as to plan, spatially locate, and design new systems.

Compared to the substantially important roles played by social and environmental factors, another clear finding is that economic pressures are less significant in driving the change towards SUWM facilities, and economic values are often lacking as input to decision-making processes and in defining the purposes and goals for planning these systems. This also serves to explain the dominant role played by public actors at different levels in promoting new SUWM systems, and the decreased involvement of business actors as initiators, niche developers, and experimenters. When there is a lack of supportive legal and economic frameworks that accurately define costs, risks, and benefits, business actors tend to feel less motivation to bear high financial risks for developing innovative infrastructure services.

The difficulty in analyzing the capacity and adaptability of the contexts in which empirical cases are examined as being subjected to the authors' interpretation, rather than a straightforward criteria, should be noted. Despite this, we can still provide examples of cities where there have been (a) long-term political, legislative, and financial support and commitment; (b) a clear mandate and defined responsibilities; (c) a coordination between human resources and effort; and (d) the inclusion and engagement of interest groups, the mobilization and sustaining of financial resources, and the adoption of human agency as leaders for the transitioning to SUWM infrastructure. The study shows a few cities in the USA and Australia (and, to a lesser extent, certain European countries) in which their context is adaptable, and their leadership of the process of change has been successful in achieving sustainable approaches and SUWM facilities. However, as our literature review is dominated by scholarly work on Australia and the USA, we are well aware that our analysis may be biased in favor of these countries and cities.

The review has also shown the wide range of available societal and technical instruments to promote SUWM, as well as the importance of local context in terms of the institutional and knowledge capacity to design instruments for the development of technical policy and societal niches.

Two main conclusions follow from the study regarding the actors involved. First, a shift towards sustainable urban water projects is mainly driven by politicians and public bodies in response to a multitude of local environmental and social concerns, which, in turn, define their purposes and are manifested in the design of water projects. Second, the shift towards urban water sustainability necessitates a multi-disciplinary approach so as to integrate a diversity of existing and emergent actors in the landscape of urban water management, namely experts and users.

What emerges from our study is the lack of focus or in-depth analysis of processes regarding the monitoring and evaluation of SUWM systems performance, social and technical learning, and the institutionalization of outcomes. This could reflect real-life contexts due to the highlighted profound challenges of the analyzed articles, as well as being due to the scope of our study focusing mainly on planning. However, the study shows that a few cities have managed to shift to sustainable urban water systems, thereby implying that processes coming after the first and second planning phases are likely to be locked in by institutional hurdles. This could lead to a compromising of the desirable outcomes and a deferral of the urban sustainability agenda.

Despite the decadal experimentation in SUWM systems, we can generally conclude the existence of well-recognized challenges, such as governance issues, bridging technical and societal knowledge gaps for optimal planning outcomes and design, and a lack of economic frameworks for accounting and sharing costs, risks, and benefits among societal actors. The study also highlights two uncovered areas in empirical research: The lack of in-depth empirical research regarding both governance structures, and the processes beyond the experimentation and implementation phases of SUWM infrastructure facilities.

**Supplementary Materials:** The secondary data used in this paper consist of peer-reviewed articles retrieved in the Web of Science v.5.32. References of the reviewed articles, together with additional results, are available online at <http://www.mdpi.com/2071-1050/12/11/4481/s1>.

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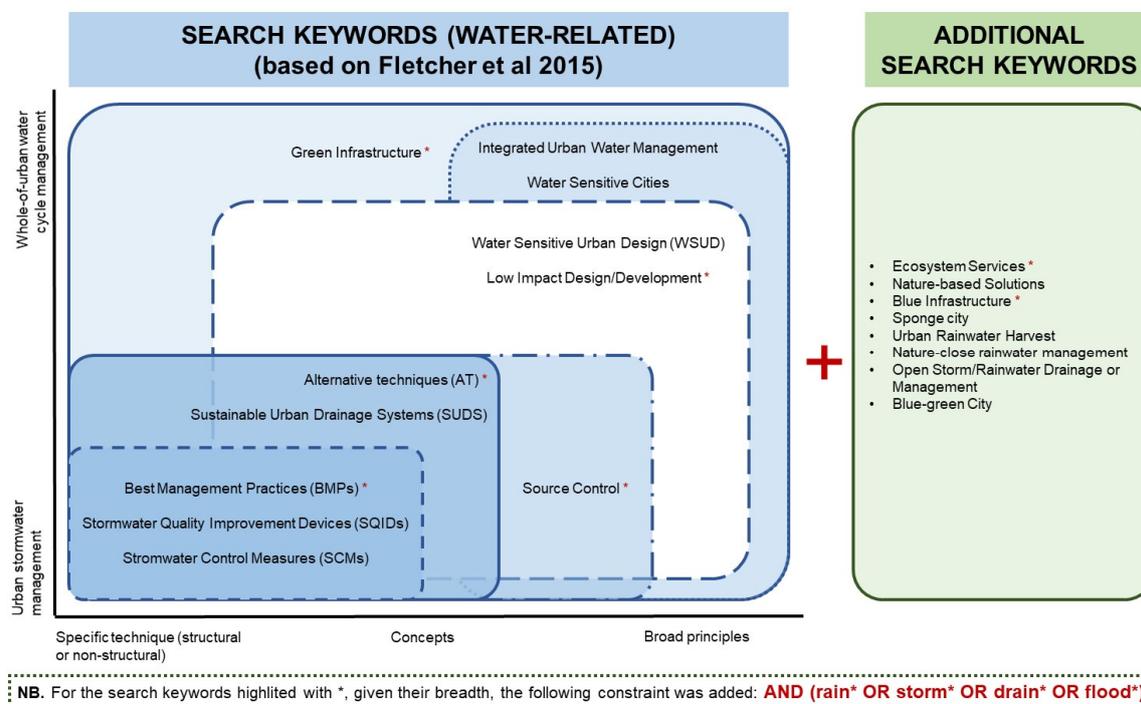
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## Appendix A Materials and Methods

### Appendix A.1 Sample Selection



**Figure A1.** Terminology and classification of SUWM proposed by Fletcher et al. used as a reference for the keyword search (left). Additional keywords included to broaden the search of the literature (right).

**Table A1.** Results of the four-stage selection process to identify the final sample of articles. Stage 1: Keyword search in Web of Science v.5.32 (concluded on 3 May 2019) based on terminology reported in Fletcher et al. (2015) plus additional terms; Stage 2: Refinement using four inclusion criteria based on additional keywords; Stage 3: Abstract screening; Stage 4: Full text assessment.

STAGE 1: Keyword Search Based on Terminology from Fletcher et al. 2015	N. of Articles
(TS = ("stormwater control measur*") OR TS = ("stormwater quality improvement devic*") OR TS = ("best management practic*" AND (rain* OR storm* OR drain* OR flood*)) OR TS = ("sustainable urban drainage system*") OR TS = ("alternative techn*" AND (rain* OR storm* OR drain* OR flood*)) OR TS = ("source control" AND (rain* OR storm* OR drain* OR flood*)) OR TS = ("water sensitive urban") OR TS = ("low impact design" AND (rain* OR storm* OR drain* OR flood*)) OR TS = ("low impact devel*" AND (rain* OR storm* OR drain* OR flood*)) OR TS = ("integrated urban water management") OR TS = ("water sensitive cit*") OR TS = ("green infrastruct*" AND (rain* OR storm* OR drain* OR flood*)) OR TS = ("blu* infrastruct*" AND (rain* OR storm* OR drain* OR flood*)) OR TS = ("sponge cit*") OR TS = ("urban rain* harvest*") OR TS = ("nature-based solut*" OR "nature based solut*") OR TS = ("ecosystem servic*" AND (rain* OR storm* OR drain* OR flood*)) OR TS = ("nature close rain* management") OR TS = ("open stormwater drain*") OR ("open stormwater manag*") OR ("open rainwater drain*") OR ("open rainwater manag*")) OR TS = ("blue-green Cit*")) Timespan: All years. Databases: WOS, DIIDW, KJD, MEDLINE, RSCI, SCIELO. Search language = Auto	8855
Refined by: LANGUAGES: (ENGLISH)	8542
Refined by: DOCUMENT TYPES: (ARTICLE OR REVIEW)	7002

Table A1. Cont.

STAGE 2: Keyword-based inclusion criteria	N. of articles
<b>Criteria 1: Focus on policy, planning, and/or decision-making</b>	
plan *	3711
polic *	926
decision mak *	540
<b>(All of the above terms)</b>	<b>4170</b>
<b>Criteria 2: Case study application</b>	
case	1223
appl *	2537
implement *	1231
monitor *	1121
evaluat *	1744
assess *	2677
<b>(all of the above)</b>	<b>5490</b>
<b>Criteria 3: Involvement of individual and institutional actors</b>	
stakehold *	309
actor *	46
agent *	140
user *	138
citizen *	90
inhabit *	67
(non-government * organization * OR NGO * OR grassroots * OR association * OR movement * OR activis *)	685
(decision maker * OR policy maker * OR politician * OR mayor OR governor * OR minist * OR administr *)	455
communit *	1507
public AND (sector OR organization OR administration OR body OR enterprise)	216
private *	145
busines *	83
(investm OR investin *)	257
partner *	66
<b>(all of the above)</b>	<b>2976</b>
<b>Criteria 4: Level of participation</b>	
inform OR informin *	245
communic *	127
particip *	306
involv *	431
consult *	32
engage *	108
empow *	15
advoca *	52
<b>(all of the above)</b>	<b>1094</b>
<b>AND (Criteria 1 AND Criteria 2 AND Criteria 3 AND Criteria 4)</b>	<b>471</b>

Table A1. Cont.

<b>STAGE 3: Abstract screening</b>	<b>N. of articles</b>
Included articles	138
Excluded articles (lacking focus on SUWM systems, e.g., dealing with rural farming, strict biodiversity conservation, or forest management)	333
<b>STAGE 4: Full text Assessment</b>	<b>N. of articles</b>
Included articles	100
Review articles (main points summarized in the introduction)	14
Excluded articles (not relevant or not available)	24

The asterisk (\*) represents any group of characters, including no character.

## Appendix B Results

### Appendix B.1. Terminology

**Table A2.** Frequency of the terms used to refer to SUWM systems and their grouping into 14 clusters.

<b>Terminology Used</b>	<b>N. of Articles</b>
<b>Cluster 1: Blue/Green Infrastructure; Blue/Green Stormwater Infrastructure</b>	<b>51</b>
Green Infrastructure (GI)	42
Urban Green Infrastructure (UGI)	2
Blue–Green Infrastructure (BGI)	1
Green/Blue Infrastructure	2
Green Stormwater Infrastructure (GSI)	3
Green Storm Infrastructure (GSI)	1
<b>Cluster 2: Low-Impact Development (LID) (systems) Low-Impact Urban Design and Development (LIUDD)</b>	<b>38</b>
Low-Impact Development (LID) (systems)	35
Low-Impact Urban Design and Development (LIUDD)	2
Low-Impact Urban Development and Design (LIUDD)	1
<b>Cluster 3: Sustainable (urban) Drainage System (SUDS/SuDs)</b>	<b>25</b>
Sustainable urban drainage system (SUDS)	13
Sustainable Drainage Systems (SuDS)	7
Sustainable urban drainage systems/sustainable drainage systems (SUDS/SuDs)	3
Sustainable Urban Development Systems (SUDS)	2
<b>Cluster 4: Best Management Practice (BMP)</b>	<b>25</b>
Best Management Practice (BMP)	23
Green technology best management practices	1
Stormwater best management practices	1
<b>Cluster 5: Water-Sensitive Urban Design/Development (WSUD)</b>	<b>21</b>
Water-Sensitive Urban Design (WSUD)	18
Water-sensitive urban development (Australia)	1
Water-Sensitive Design	2
<b>Cluster 6: Integrated Urban Water Management (IUWM), Integrated Water Resource Management (IWRM)</b>	<b>19</b>
Integrated urban water management (IUWM)	13
Integrated Water Resource Management (IWRM)	3
Integrated water management (IWM)	2
Integrated Urban Drainage Management (IUDM)	1

Table A2. Cont.

Terminology Used	N. of Articles
<b>Cluster 7: Stormwater Control Measures (SCMs); Source Control</b>	<b>14</b>
Stormwater control measures (SCMs)	7
Stormwater source control (SC)	2
Gray SCMs	1
Green SCMs	1
Source control	1
Source control system	1
Storm control measures (SCM)	1
<b>Cluster 8: Nature-Based Solutions (NBS) (action)</b>	<b>9</b>
Nature-Based Solutions (NBS) (action)	8
Nature-based stormwater management strategies	1
<b>Cluster 9: Green spaces (GS); Open space; Blue–Green Measures; Blue–Green Design;</b>	<b>9</b>
Green spaces (GS)	3
Open space	2
Open space provision	1
Blue–green measures	1
Green and blue adaptation measures	1
Green building/green neighborhood design	1
<b>Cluster 10: Green/Sustainable (urban) Stormwater Management</b>	<b>8</b>
Green Stormwater management	1
Storm Water Management	1
Stormwater Management	1
Stormwater management practices (SWMPs)	1
Stormwater management system	1
Sustainable Stormwater management	1
Sustainable urban water management (SUWM)	1
Watershed-level Stormwater management	1
<b>Cluster 11: Water-Sensitive City; Blue–Green Cities</b>	<b>6</b>
Water-Sensitive City	5
Blue–Green Cities	1
<b>Cluster 12: Conservation Design for Subdivisions (CDS)</b>	<b>4</b>
Conservation subdivisions	2
Conservation Design for Subdivisions (CDS)	1
Conservation subdivision design (CSD)	1
<b>Cluster 13: Sponge City</b>	<b>3</b>
<b>Cluster 14 Rainwater Harvesting Systems (RWHS)</b>	<b>2</b>

## Appendix B.1 Pressures

**Table A3.** Examples of four types of pressures (environmental, social, climatic, and economic) in the reviewed articles.

Environmental Pressures	Extracts from the Reviewed Articles
<b>Pollution of receiving surface water bodies</b>	<ul style="list-style-type: none"> <li>• Polluted surface; degraded water quality; impaired water bodies, degraded aquatic ecosystems; contaminated stormwater; Surface water impairment; water quality degradation, degradation of surface water quality; improve receiving water quality;</li> <li>• Combined Sewer Overflow (CSO) discharge into rivers or lakes, CSO to receiving waters, CSOs cause 850 billion gallons/yr of pollution; CSOs and polluted runoff; discharge of treated wastewater to receiving waters; runoff and CSO responsible for surface water quality and quantity.</li> <li>• Non-point pollutions source (NPS) pollution affecting water quality and local ecology; eutrophication processes from local diffuse and point pollution sources; pollutants from urban areas and discharges into receiving waters; NPS pollution from stormwater runoff; increased runoff volumes and pollutant loads; pollution of the receiving watercourse, eutrophication, deterioration of the water quality of receiving waters, pollution of surface-water resources; point pollution and NPS.</li> </ul>
<b>Degradation of ecosystems and loss of biodiversity</b>	<ul style="list-style-type: none"> <li>• Loss of native vegetation, loss of biodiversity and habitat connectivity, highly fragmented landscapes, loss of natural riverine wetlands, reduced integrity of floodplain ecosystem functions, disconnected from the river, severely altered by intense human uses; decline of aquatic ecosystems, destruction of biodiversity, water scarcity for freshwater ecosystems, detrimental to surrounding ecosystems.</li> <li>• Degradation of ecosystem services (ES) and loss of benefits; increased demand for environmental services, ecological disturbance regimes, environmental degradation, decreased green open spaces, increased water–soil–air pollution, loss of agrobiodiversity, washing away aquatic wildlife habitat, risks to aquatic ecosystems, degradation of downstream ecology, biodiversity deterioration, negative environmental impacts, impact of new development on surrounding environment.</li> </ul>
<b>Impact on ground water resources</b>	<ul style="list-style-type: none"> <li>• Reduced groundwater recharge; reduced water table or groundwater recharge; reduced available ground water for urban vegetation;</li> <li>• Pollution of groundwater resources; degradation of groundwater quality.</li> </ul>
<b>Alteration of rivers, streams, and natural waterways</b>	<ul style="list-style-type: none"> <li>• Degradation of urban rivers and streams; pollution of waterways from urban runoff, pollution of natural waterways; pollution of waterways, urban waterway degradation; environmental protection of waterways; overflow of stormwater sewers degrades stream health, impaired tributaries, polluted waterways, stream bank erosion; sedimentation and streambank erosion; altered flow regimes; reduced baseflow in the downstream rivers; reduced baseflow in channels; quantity and velocity stream water flows;</li> <li>• Stream functioning, ecosystem health; deterioration in the health of urban waterways; degrader of urban stream ecosystems (quantity and quality); effects of stormwater runoff on stream ecosystems; increase pollutant delivery, and impair stream ecology.</li> </ul>

Table A3. Cont.

Environmental Pressures	Extracts from the Reviewed Articles
<b>Altered hydrological response</b>	<ul style="list-style-type: none"> <li>Altered hydrological response; pressures to the hydrological cycle; disruption of hydrology; hydrological disruption and devegetation; disturbs the natural water cycle; disturbance of natural hydrological regimes; dramatic changes in the hydrologic regimes of whole watersheds; transforms local hydrologic behavior; urban water socio-ecological systems in a degraded and unsustainable regime.</li> <li>Changes in runoff behavior; increased frequency and magnitude of storm-flows and reduced infiltration to feed baseflows; greater discharges and runoff volumes, high runoff volumes and flow rates, higher peak flows, larger volumes, shorter times to peak and accelerated transport of pollutants; increased runoff rate and volume, increased surface runoff volumes and high flows, increases in volume and peak flow.</li> </ul>
<b>Over-exploitation of water resources</b>	<ul style="list-style-type: none"> <li>Over-exploitation of water resources; extraction of freshwater resources; inefficient use of water; limits on water resources; poor nutrient control, wasted energy, and insufficient institutional capacity.</li> </ul>
SOCIAL PRESSURES	EXTRACTS FROM THE REVIEWED ARTICLES
<b>Population and urban growth</b>	<ul style="list-style-type: none"> <li>Population growth; Changing populations; Mass migration towards cities; Demographic change (internal/international migration); Rapid population growth; Increased urban densities; Rural-to-urban population shifts.</li> </ul>
<b>Urbanization, urban development and sprawl and its impacts</b>	<ul style="list-style-type: none"> <li>Urbanization processes; Increasing/Heavy urbanization; Urban/Land development; Expanding urban landscape; Urban consolidation; Unplanned urban development; Urban sprawl; Revitalization projects; Industrialization; Densification.</li> <li>Paved/impervious/impermeable surfaces, hardscapes, changing land use and land cover (LULC) patterns; Highly fragmented landscapes, anthropogenic modifications (of wetlands); society shaping all of the components of the water cycle.</li> </ul>
<b>Growing demand for water services and water security</b>	<ul style="list-style-type: none"> <li>Growing housing/water demand; higher living standards/increased demand for water; demand for secure and reliable water supplies, focus on fit-for-purpose and non-traditional water sources; water supply shortage; scarce water resources; inter-sectoral competition, interregional and international conflicts; threats to a secure water supply and sanitation; demand for urban and peri-urban land for food growing.</li> </ul>
<b>Increasing health and safety concerns around water</b>	<ul style="list-style-type: none"> <li>CSO public concern over health impacts; health impacts (from inadequate sanitation and contaminated water supplies); health threats, unregulated dumping of household and industrial effluents;</li> <li>Safety of urban residents; public safety threat, and social inconvenience; safety and public health concerns; trade-off between ES access and risk of water-related hazards (floods);</li> <li>Health effects of urban heat island (UHI); impervious surfaces in cities 2 °C warmer; premature deaths to ambient air pollution 3.7 million.</li> </ul>

Table A3. Cont.

SOCIAL PRESSURES	EXTRACTS FROM THE REVIEWED ARTICLES
<b>Demand for resilient cities and communities and sustainable urban water management</b>	<ul style="list-style-type: none"> <li>• Increased political, social, and environmental pressures for planners;</li> <li>• Sustainability expectations (UN in Local Agenda 21);</li> <li>• Demand for sustainable development, risk management, and improvement of the living environment (e.g., secondary benefits, multi-functionality, ES, vulnerability, and resilience); intergenerational equity;</li> <li>• Demands to green the city, plans for sustainable and resilient cities;</li> <li>• Growing aspiration for aesthetic urban environments more cyclical systems,</li> <li>• Protecting sensitive environments, water conservation, and landscape amenity;</li> <li>• Call for integrated water resource management and urban water management;</li> <li>• Moving GI to intentional multi-functionality;</li> </ul>
<b>Public acceptance, awareness, and appreciation of GI benefits</b>	<ul style="list-style-type: none"> <li>• Public understanding of the value of water systems;</li> <li>• Residential scrutiny and preferences of visible BGI, landscape amenity;</li> <li>• Social amenity considerations and unsustainable water usage patterns;</li> <li>• Recreational use of urban floodplains, raising demand for nature conservation;</li> <li>• Engaging individuals and communities to address: Human activity, NPS pollution, N and P from fertilization of residential lawns, and basement flooding.</li> <li>• Cultural norms affecting personal landscaping practices. Human behavior (e.g., perception of lawns in communities is linked to social status and acceptance). Using education to mitigate impacts targeted towards a group versus an individual</li> </ul>
<b>Seeking environmental justice and inclusion</b>	<ul style="list-style-type: none"> <li>• Addressing relative park poverty, environmental injustice; ensuring access to services (especially for the urban poor, elderly, and children);</li> <li>• Admitting role of power and culture in the adaptive capacity of GI;</li> <li>• Risks of ecological gentrification, 'green' gentrification due to GI; ethno-cultural preferences, lack of "sense of belonging", lack of local socio-cultural context in urban environmental governance, management, and planning;</li> <li>• Exclusion of socially vulnerable communities (less voice);</li> <li>• Inclusive and participatory decision-making processes</li> </ul>

Table A3. Cont.

CLIMATIC PRESSURES		EXTRACTS FROM THE REVIEWED ARTICLES	
Climate Change and adaptation	<ul style="list-style-type: none"> <li>• Climate change; changing climate; uncertain climate futures; global climate change; anthropogenic climatic change; shifts in climate patterns;</li> <li>• Adapt to climate; adapting to changes in regional climate; climate change adaptation.</li> </ul>		
Shifts in precipitation patterns	<ul style="list-style-type: none"> <li>• A higher rainfall intensity; Increases in size and occurrence of extreme rainfall; increases in the frequency, intensity and magnitude of storm events; Rainfall intensification; Heavy rainfall events;</li> <li>• Increase in intensity and frequency of extreme weather events; severe meteorological conditions; severe weather patterns; erratic precipitation patterns; atmospheric precipitation.</li> </ul>		
Acute and Chronic hazards	<ul style="list-style-type: none"> <li>• Flooding and storm surge; Increase flooding risks; Catastrophic flooding events; Higher flood risk levels; Increases runoff and flooding potential; Amplified downstream flood peaks; Urban flooding; increased peak flows; Higher frequencies of flooding; Severe disasters.</li> <li>• Drought; changes in the range for infectious diseases vectors, temperature, water scarcity; extreme drought conditions.</li> </ul>		
ECONOMIC PRESSURES		EXTRACTS FROM THE REVIEWED ARTICLES	
Flooding damage to infrastructure and property	<ul style="list-style-type: none"> <li>• Damages due to flooding (exceeding 1 billion GBP) and CSOs, flood risk within development, high costs of flooding.</li> </ul>		
Burden on existing infrastructures	<ul style="list-style-type: none"> <li>• Burden to limited capacity of wastewater services, treatment plants in CS; New developments affecting existing drainage infrastructure; High cost of treating/storing runoff from CSS at the wastewater treatment plant; Leakage/wastage (50%) in urban water distribution systems.</li> </ul>		
Financing aging infrastructure	<ul style="list-style-type: none"> <li>• Financing the replacement of aging water infrastructure, budget shortfalls; High physical capital investments in centralized systems, demanding massive public investment. Financial and institutional constraints (e.g., in developing countries), municipal infrastructure lags urban growth; Reduced infrastructure financing to compliance with environmental regulations. Resource and capacity constraints (coarse environmental datasets, data scarcity).</li> </ul>		
Long-term economic crisis/decline	<ul style="list-style-type: none"> <li>• Post-industrial cities struggling to meet the diverse needs of vulnerable populations, handicapped by eroded tax and infrastructure user bases. Economic and political crises (e.g., in Indonesia, 1997–1998);</li> </ul>		

## Appendix B.2 Actors

**Table A4.** Examples of four types of actors (institutions, experts, users, and businesses) in the reviewed articles.

A. Institutions	Examples from Reviewed Articles
<b>A1. City/municipal decision-makers</b>	<ul style="list-style-type: none"> <li>Decision-makers, City officials, Elected officials, End-user of decision support systems (DSS), Mayors, Policy makers, City leaders, Politicians, Public health officials, Municipal/City Council, City council members, Municipal authorities/Council.</li> </ul>
<b>A2. City/municipal water utilities</b>	<ul style="list-style-type: none"> <li>Water services authorities, Water Supply Department, Water utilities, Water works company, Water companies, Water agency, Water authorities, Water authority board</li> </ul>
<b>A3. City/municipal departments</b>	<ul style="list-style-type: none"> <li>City agencies, Dept. of Water Affairs; GI Task force; Dept. of planning, transportation, finance, procurement, economic development, public health, and education; Dept. of public works/transportation; Dept. of city planning, zoning, development control.</li> </ul>
<b>A4. Government/state/federal/provincial authorities</b>	<ul style="list-style-type: none"> <li>Central government actors, Government agencies/bodies/organizations, State government cabinets/departments, State law making institutions/powers, State regulatory reviewers, Federal authorities, law-making institutions/powers, regulatory reviewers, Provincial authorities, government actors, Regional agencies, Regional Sewer District, Department of Justice (Water quality issues)</li> </ul>
B. EXPERTS	Examples from reviewed articles
<b>B1. Water engineers</b>	<ul style="list-style-type: none"> <li>Engineers, urban water practitioners, water engineers, water professionals/managers, water resources managers, Stormwater Engineers/managers, Technical practitioners and engineers</li> </ul>
<b>B2. Planners</b>	<ul style="list-style-type: none"> <li>Planners, urban planners, and designers</li> </ul>
<b>B3. Landscape architects</b>	<ul style="list-style-type: none"> <li>Landscape architects, designers, Architects, horticulture</li> </ul>
<b>B4. Environmental scientists</b>	<ul style="list-style-type: none"> <li>Environmental managers/scientists, ecologists</li> </ul>
<b>B5. Social scientists</b>	<ul style="list-style-type: none"> <li>Social scientists, Economists</li> </ul>
<b>B6. Multidisciplinary teams</b>	<ul style="list-style-type: none"> <li>Interdisciplinary/Multidisciplinary team</li> </ul>
<b>B10. Academia</b>	<ul style="list-style-type: none"> <li>Research organizations, research universities, Researchers, lecturers, Scientific community, Academia, Academic institutions</li> </ul>

Table A4. Cont.

<b>C. USERS</b>		<b>Examples from reviewed articles</b>
<b>C1. Users, land owners, residents</b>	<ul style="list-style-type: none"> <li>Communities, Citizen (participation), Consumers (preferences, incentives), ES beneficiaries (location, population density, choice experiment), General public, Visitors, users, Individuals, Residents, Residential users/areas, Land/Property owners/managers.</li> </ul>	
<b>C2. Vulnerable groups</b>	<ul style="list-style-type: none"> <li>Marginalized communities (poor, non-white communities); vulnerable groups (elderly, young children, and recent immigrants).</li> </ul>	
<b>C3. NGOs, pressure groups, media</b>	<ul style="list-style-type: none"> <li>NGOs (environmental stewardship, community based), local citizens group (Partnership for x Creek), environmental groups, Public concerned citizen/stakeholder groups, Representatives from community groups/homeowners, Pressure Groups, Press, Local organizations (Botanical Garden, The Wildlife Society, Horticultural Society, Community partners.</li> </ul>	
<b>D. BUSINESSES</b>		<b>Examples from reviewed articles</b>
<b>D1. Developers, business</b>	<ul style="list-style-type: none"> <li>Developer/investors private (George Mitchell), Business interests, partners (Philadelphia Industrial Development Corporation), Commercial customers/users/areas; Agricultural interests; Industrial managers; Private industry, Private entities, Representatives from businesses</li> </ul>	

Appendix B.3 Instruments

**Table A5.** Examples of five types of instruments: Decision Support, Planning Instruments, Policy and Governance, Funding and Incentives, and Participatory Implementation.

Decision Support	Examples from Reviewed Articles
<p><b>Decision Support: Frameworks, Concepts, and Tools</b></p>	<ul style="list-style-type: none"> <li>• Gray–Green stormwater infrastructure continuum classification (overcoming inconsistency in naming);</li> <li>• (City blueprint) Framework for assessing sustainability of urban water management (based on water footprint; urban metabolism; ES);</li> <li>• Metrics for assessing the efficiency of SCMs, based on ‘rainfall domains’;</li> <li>• Sustainability Index for Integrated Urban Water Management (SIUWM)</li> <li>• Four-stage decision-support tool to customize GI siting, design, operation, and maintenance decisions;</li> <li>• A diagnostic planning intervention model as add-on to a strategic planning process (“stress-testing”);</li> <li>• “Framework for Adaptive Socio-Hydrology” (FrASH) for GI planning and implementation; archetypes of GI implementation approaches (Lone ranger; Situated GI; The collective; Specialized);</li> <li>• Flexible participatory planning framework;</li> <li>• Framework for evaluation of socio-hydro-ecological systems;</li> <li>• Framework to aid mainstreaming of urban green planning, design, and retrofit;</li> <li>• McHarg’s design process: The landscape suitability assessment framework (“layer-cake” model for mapping), flow chart of the ecological planning process;</li> <li>• Multi-level framework for participation in IUWM, based on a system perspective;</li> <li>• Place-based approach for analyzing GI;</li> <li>• Social Indicator Planning and Evaluation System, a system to measure progress towards environmental goals by looking at social outcomes;</li> <li>• Sustainable development framework for neighborhood development</li> <li>• Multi-Criteria Analysis (MCA); multicriteria decision analysis (MCDA); Four-step spatial multicriteria analysis (SMCA) approach;; MCA methodology for the evaluation and accreditation of SUDS structures; MCA: Web-based Adaptive Decision Support System, to help the end-user define stormwater management strategies; MCDA—“mDSS4” used to analyze the data; MCDA: SUDS Decision Support Key = flow diagram for identifying suitable sites based on nine criteria; MCDA; Framework; DSS; Green Infrastructure Spatial Planning (GISP) model, i.e., SMCA of six benefit criteria as collaborative decision-support tool;</li> <li>• Agent-based Modeling (ABM) to assess the sustainability of complex infrastructure decisions by simulating underlying physical and social factors;</li> <li>• Multi-objective optimization of alternative systems, tool to assist planning;</li> <li>• An optimization framework for complex environmental management problems;</li> <li>• Decision Support (DS) tool for assessing and optimizing an integrated urban water system at in-house, household, and development level, based on genetic algorithms;</li> <li>• Evolutionary optimization techniques (meta-heuristic search technique): Optimization Component (Water quantity and quality, and cost)</li> <li>• Land use analysis, satellite image analysis, and visits to the area; DS tool: Decision tree supported by maps;</li> <li>• Planning instrument: Planning support system (PSS) software; Planning support tools, e.g., spatial software (ArcGIS), spreadsheet-based tools;</li> </ul>

Table A5. Cont.

Decision Support	Examples from Reviewed Articles
Hydrologic–hydraulic and water quality modeling	<ul style="list-style-type: none"> <li>• SWMM modeling; Exploratory hydrological modeling; Exploratory modeling; Flooding simulation with different scenarios; GIS-based hydrological modeling; Hydrologic–hydraulic modeling (MUSIC-BreZO); Hydrologic and hydraulic modeling; Hydrologic modeling and runoff monitoring; Long-term hydrologic impact assessment LID (L-THIA LID) model; Modeling runoff generation; SWAT, a physically based semi-distributed watershed model; Simulation of the hydrologic performance of different SCMs; MUSIC (Model for Urban Stormwater Improvement Conceptualization); Nomographs for rain garden sizing (based on the hydrological model); Ranking of priority sites based on stormwater management potential; Digital flood map, identifying riparian and flood hazard zones;</li> <li>• Hydrologic and water quality modeling; Hydrologic/hydraulic/water quality modeling (BMP Simulation); Fuzzy-based model for modeling pollutant loads; Integrated hydro-environmental assessment of LID practices; Evaluating GI performance at improving stormwater quality: streamflow data collected, and water samples analysis in the Utah Water Research Laboratory; Field experiment: Measuring infiltration.</li> </ul>
Scenarios	<ul style="list-style-type: none"> <li>• Scenario; Scenario-based approaches; Scenarios of LID implementation; Criteria weighting scenario; Scenario interpreted in terms of flood assessment, and potential for enhanced recharge in an urbanized catchment; SCMs scenario; Hypothetical GI measures implemented; Planning scenarios in Santa Cruz; Scenario analysis; Scenario comparison; Scenario development; Scenario modelling; Scenario planning; Scenario simulation; Bayesian Belief Network (BBN) Scenario simulation for water reserve extension; Scenarios for future freshwater availability modelled with Variable Infiltration Capacity model and Water Availability Model; Scenarios of LID measures; Scenario at catchment, corridor, and site level;</li> </ul>
Ecosystem Services Valuation, Assessment, Quantification, Mapping, etc.	<ul style="list-style-type: none"> <li>• Ecosystem service (ES) valuation methods; Natural capital asset valuation; ES assessment; ES valuation;</li> <li>• ES assessment Modeling—trade-off analysis;</li> <li>• ES preferences based on consultation;</li> <li>• ES quantification and mapping;</li> <li>• Identification of ecosystem services (ES) related to SUDS;</li> <li>• Robust economic instruments capable of assigning a monetary value to stormwater;</li> <li>• Valuation of ES locally (site specific) and within the catchment;</li> </ul>
Cost–Benefit Analysis	<ul style="list-style-type: none"> <li>• Cost–Benefit Analysis;</li> <li>• Cost–benefit trade-off curve for selecting the suitable BMP settings;</li> <li>• Estimation of implementation cost and LID payback period;</li> </ul>
PLANNING INSTRUMENTS	Examples from reviewed articles
Visions and Strategies	<ul style="list-style-type: none"> <li>• Blue–Green City vision for New Castle; Vision for water sensitive Bendigo in 50 years; Vision for the waterfront (1999–2003); Visioning through workshops; Visions and transition scenarios; Visions of better water quality; Visions important for challenging the dominant perspectives and informing thinking and actions.</li> <li>• Melbourne’s 2012 Integrated Water Cycle Strategy; The Melbourne “Open Space Strategy” to increase community wellness and resilience by increasing the amount and quality of the city’s UGI; A catchment strategy of WSUD consisting of five sub-strategies; Concept plan for the development of the catchment; Participatory conceptual master plan development of low-impact urban/landscape design.</li> </ul>

Table A5. Cont.

PLANNING INSTRUMENTS	Examples from reviewed articles
<b>Plans: Comprehensive, Strategic, Integrated, etc.</b>	<ul style="list-style-type: none"> <li>• Comprehensive Plans;</li> <li>• Comprehensive planning/introduction of integral master plan;</li> <li>• Binding land-use plans;</li> <li>• Land use plan: Inventory and analysis of legal, social, economic, and political factors; Analysis of users' needs and desires;</li> <li>• City's master or vision plan;</li> <li>• Strategic spatial planning;</li> <li>• Strategy of GI measures to reduce flood risk;</li> <li>• A catchment-based structure plan incorporated into the District Plan;</li> <li>• Land regulations/planning rules;</li> <li>• Assessing impediments and constraints in the planning stage;</li> <li>• IUWM project planning;</li> <li>• Specific GI plan, less formalized plan, or no plans;</li> </ul>
<b>Detailed Design, Guidelines, Manuals</b>	<ul style="list-style-type: none"> <li>• Development Management Ordinances;</li> <li>• Architectural and site program for the project, restoration measures, and its physical expression (2003–2007); State Environmental Quality Review Act (SEQR), Environmental Impact Statement (EIS), and approved mitigation plan;</li> <li>• Detailed site development plans for implementation by subcontractors (standards and natural infrastructure to be provided);</li> <li>• Example of design for the Pollok area. SUDS Option Decision Support Tools = suitability of SUDS for implementation in study areas;</li> <li>• IUWM project design;</li> <li>• Assessing impediments and constraints in the stage of design and development;</li> <li>• State Environmental Quality Review Act (SEQR) process, Environmental Impact Statement (EIS), and approved mitigation plan</li> <li>• Design Manual developed based on experience of 250 Green Streets projects;</li> <li>• Compulsory rainwater management and ecological construction guidelines for all public construction projects;</li> <li>• GI good practice catalogue;</li> <li>• Operational guidelines and a plan of action to help adopting effective strategies to improve the hydrological budget, water availability, and water quality;</li> <li>• Manuals and guidelines, e.g., the "Urban Stormwater Management Manual for Malaysia"; "Guidelines for installing a rainwater collection and utilization system";</li> <li>• Formal or informal rules to regulate gardening practice;</li> <li>• Special planning provision to ensure new developments meet the LSC project's stormwater runoff objectives (collaboration with MW and council);</li> <li>• Stricter regulations and data-driven approaches (Chicago);</li> <li>• The new Swedish design standard SWWA (new stormwater systems to resist a 10 year design storm event without surface ponding);</li> <li>• The Manatee County Fertilizer Ordinance.</li> </ul>

Table A5. Cont.

POLICY and GOVERNANCE	Examples from reviewed articles
<b>Policies and Legislation</b>	<ul style="list-style-type: none"> <li>• Legislation and post-construction runoff controls to encourage the installation of GI in new developments. Local building codes updating to permit GI/LID implementation;</li> <li>• New policy to address and promote GI by binational agencies;</li> <li>• No regulatory sticks that mandate onsite stormwater control, for most private property in the US, at the national level (but trickle-down effects of the Federal Clean Water Act). Clean Water Act “Stormwater Rules for Construction and Post-Construction”; “Combined Sewer Overflows Enforcement”. “Save the Rain” Program exhibits the characteristics of a stick but lacks legally binding sticks within the program, as no local regulations are in place to require GI.</li> <li>• Policies to implement SCM in flood-prone areas;</li> <li>• Riparian buffer policies, e.g., Chesapeake Bay Critical Area Protection Act, the Non-Tidal Wetlands Protection Act of 1989, Water Supply Protection Act of 1989;</li> <li>• Policy guidelines on GI; New greenways statute allowing urban agriculture;</li> <li>• Policy innovation: area-based billing (2010), parcel-based stormwater fee for non-residential properties, and monthly fee based on parcel size for residential customers (2014);</li> <li>• Policy tools and strategies of US cities (Seattle, Portland, Chicago, Philadelphia);</li> <li>• Policy transfer in practice;</li> <li>• Stormwater policy stressing the importance of infiltration and retention zones;</li> <li>• Stormwater-oriented policies;</li> <li>• Water policy and regulations (EU and national). Separate stormwater fees (“use pays” principle) and discounts for implemented LID measures;</li> <li>• “Policies without publics”; Policy framework for statutory and non-statutory plans and guideline based on LIUDD principles and methods;</li> <li>• (Indirectly) water is “cheap” in Saudi Arabia because of government subsidies;</li> <li>• Institutionalizing routine collective choice (surface water quality and quantity in a 16 county region: Governing Board, Technical Coordinating Committee, Basin Advisory Group), and non-routine collective choice (Clean Water Initiative Task Force).</li> </ul>
<b>Governance and Management</b>	<ul style="list-style-type: none"> <li>• “Homeowner agreement”, not legally binding; e.g., maintenance and periodic monitoring scheme;</li> <li>• Assessing impediments and constraints in maintenance and operation of WSU developments;</li> <li>• Inventory of WSUD; Database of 167 SUDS structures: French National Urban Runoff Program; Database of information available on structural and non-structural BMPs at the pan-European scale (“DayWater” project);</li> <li>• Different management practices adopted in different countries;</li> <li>• Efficient monitoring; Monitoring scheme; Operational goals; Stormwater infrastructure assessment;</li> <li>• Integrated management approaches; Data-driven approaches;</li> <li>• Management system for the urban greenways; Setting-up a municipal committee to manage the greenways; A municipal charter of collaboration and permanent dialogue for climate resilience;</li> <li>• A two-tiered hybrid (hierarchical, market, and network governance approaches) model, consisting of a local hydrological district and a city-level agency;</li> <li>• “Waterscape” management plan for the Pirai River watershed to strengthen the provision of watershed ES to the city of Santa Cruz;</li> </ul>

Table A5. Cont.

FUNDING AND INCENTIVES	Examples from reviewed articles
<b>Funding Schemes and Incentives Programs</b>	<ul style="list-style-type: none"> <li>• Annual budget of the city council allocated to WSUD in capital works;</li> <li>• About 10 million USD/year earmarked for GI from stormwater fees;</li> <li>• Estimated cost 19.96 million AUD;</li> <li>• Assembling the different ownership parcels of the Long Dock site (1997);</li> <li>• Collaborative land purchase by the City and NGOs;</li> <li>• Land provided by the municipality, funding for gardening tools and materials;</li> <li>• EPA grant funding to assist in stormwater management study; EPA grant (Christina Basin Clean Water Partnership);</li> <li>• Funding for works from Melbourne Water, the Victorian Water Trust, Australian federal and Victorian state government;</li> <li>• Funding from Central Government;</li> <li>• Housing and Urban Development (HUD) funding: 60 million USD in Community Development Block Grant;</li> <li>• Retrofitting existing public buildings with GI by municipalities (e.g., Chicago and Minneapolis);</li> <li>• Financial incentives (an economic-incentive program); Government subsidies to decrease impervious cover in dense city-center;</li> <li>• Water Stormwater Offset Scheme to provide a market for Total Nitrogen (TN) removal;</li> <li>• Carrots: Direct Provision; Rebates and Cost Shares; stormwater credits;</li> <li>• Community engagement through market-based instrument to install SCMs;</li> <li>• Economic incentive by reverse-auction;</li> <li>• GI Banking and Credit Program (BCP);</li> <li>• Grant program and intercity competition;</li> <li>• Green–blue certification scheme for new urbanizations;</li> <li>• Landscaper Certification;</li> <li>• Procurement (or reverse) auction as coordinating mechanism for installing SCMs;</li> <li>• Stormwater Management Incentives Program: Grants/low-interest GI financing.</li> </ul>

Table A5. Cont.

PARTICIPATORY IMPLEMENTATION	Examples from reviewed articles
Stakeholders/Experts Participation and Engagement	<ul style="list-style-type: none"> <li>• Consultation of stakeholders: A survey of municipal officers, interviews with the officers and mayors</li> <li>• Consultation with water industry experts</li> <li>• Experience of local practitioners</li> <li>• Expert weighting</li> <li>• Consultation with water professionals, utilities, and other stakeholders.</li> <li>• National online survey with participants from private and public organizations and professional associations</li> <li>• National survey to collected experimental feedback on BMPs from users/professional</li> <li>• On-line survey to local professionals</li> <li>• Stakeholders' interactive discussions in strategic management;</li> <li>• Stakeholders' consultation to build a (shared) vision of sustainability in the urban water sector</li> <li>• Science-to-Policy Capacity-Building Workshop</li> <li>• Stakeholders' consultation; Involvement of stakeholders;</li> <li>• Community planning process for integrating climate change adaptation;</li> <li>• Community/Industry Workshops; Focus groups (marginalized groups);</li> <li>• Community-scale analysis; Information on stakeholders' demographics and watershed use, perceptions, familiarity, and preferences for BMP;</li> <li>• Door-to door survey to evaluate citizens' environmental knowledge, perception, and participation likelihood toward GI solutions</li> <li>• Evaluation of residents' perceptions and behaviors around GI;</li> <li>• Market information about consumer interest in CSD and LID features;</li> <li>• Qualitative attitudinal and behavioral assessments of SUDS structures;</li> <li>• Community Consultation Process</li> <li>• Prioritizing GI benefits based on stakeholders' preferences</li> <li>• Stakeholders' weights; Stakeholders' input</li> <li>• Widespread support from citizens, including a vote of confidence to secure Council funding for the next ten years.</li> <li>• Awareness building to engender change in the management of stormwater runoff from properties; Awareness-raising through media and social communication. Water resource conservation in school curriculum;</li> <li>• Citizen–municipality interactions;</li> <li>• Citizen Advisory Board: Participation mechanism at operation level (wastewater treatment facility);</li> <li>• Focus on children and schools</li> <li>• Demonstration rain garden</li> <li>• Mainstreaming providing real-life evidence for arid environments, and translation into Chinese;</li> <li>• Participatory Geographic Information Systems (PGIS) research to document flooding issues; Water quality testing and resident health surveys; Public survey questionnaire to assess the public perception. Public participatory geographic information system (PPGIS)</li> <li>• Professional expertise provided by the organization(s) or individuals initiating the garden(s);</li> <li>• Social IT media and digital mapping “Map Kibera”</li> <li>• Stormwater System Outreach. Methods to ensure stricter enforcement for residents</li> <li>• Public and private measures to achieve their implementation goals;</li> <li>• Community engagement through market-based instrument to install SCMs on 231 private properties</li> <li>• Stormwater credits for large properties that manage stormwater onsite;</li> <li>• Public engagement in GI management via carrots and sermons;</li> <li>• Nature-Based Approaches a better platform for citizen engagement.</li> </ul>

Table A5. Cont.

PARTICIPATORY IMPLEMENTATION	Examples from reviewed articles
<b>Research and Development, Action Research, Piloting, etc.</b>	<ul style="list-style-type: none"> <li>• A long-term social–ecological study (Before–After–Control–Reference–Impact (BACRI) design);</li> <li>• Action research; Action research inquiry; Applied research; Before–After, Control–Impact (BACI) experimental design;</li> <li>• Experimentation as a mechanism for learning; Urban experiments (an experimental framework for policy, implementation, and evaluation of GSI); Sponge City Pilot;</li> <li>• Learning and Action Alliances (LAAs);</li> <li>• Participatory research project: Partnership agreement/memorandum of understanding;</li> <li>• Evidence-based process to evaluate the effectiveness of WSUD in achieving objectives; Post-implementation assessment of developments with WSUD;</li> <li>• Demonstration rain gardens; Field experiment infiltration capacity, density, and strength; Pilot-scale rain garden and flow measurement.</li> </ul>

Appendix B.4 Outputs

Table A6. Comparison of seven classifications of outputs (green and gray) identified in the reviewed sample of articles. (Source: [43,59–64]).

[59]	[60]	[43]	[61]	[62]	[63]	[64]
WWTP	-	-	-	-	-	-
Storage tunnel Concrete	-	-	-	-	-	-
Above ground storage structure	-	-	-	-	-	-
Underground detention structure	-	-	-	On-site detention tank	-	-
Underground retention structure	-	-	-	-	-	-
Underground gravel beds	-	-	-	-	-	-
Concrete Cisterns (under)	-	Cisterns	-	-	Cisterns, Sidewalk storage	-
Perforated pipes	-	-	-	-	-	-
Porous pavement	Permeable pavements	Permeable pavements	-	Permeable pavements	Porous pavement	Porous paving

Table A6. Cont.

[59]	[60]	[43]	[61]	[62]	[63]	[64]
Sand filter	-	-	-	-	Filters	-
Sand filter (subsurface)	-	-	-	-	-	-
Wet pond	Retention ponds	-	Water features	Ponds	-	Wet retention basin
-	Sedimentation basins	-	-	-	-	-
-	-	Rainwater harvesting	-	Rainwater harvesting	Rain barrels	-
Dry pond	-	-	-	-	Detention basins	-
Constructed wetland	Wetlands	Constructed/Restored wetlands	-	Wetlands	-	Constructed wetland
Infiltration basin	-	-	-	-	-	Infiltration basin
Infiltration trench	Infiltration trenches	Infiltration planters/Planter boxes	-	-	-	-
Green roof	-	Green/Blue roofs	Green roofs	Green roofs	Rooftop gardens	-
Vegetated filter strip	-	Vegetated detention strips	-	Biofiltration systems, Buffers	Buffers and strips	Grass filter
Grassed swale	Swales (vegetated)	Bioswales/Biostrips	Vegetated swales	Swales	Vegetated swale, swales	Grass swale
Bioretention basin	Bioretention basins	Bioretention, Traffic calming bioretention	-	Bioretention devices	Bioretention cells	Extended detention basin
-	-	Increased tree canopy	Urban trees	-	Tree preservation	-
-	-	-	Large parks, Green spaces	-	-	-

**Table A7.** Classification of outputs (green and gray) based on [43,59–64].

Type of Output	Equivalent Names in the Reviewed Articles
<b>Underground detention structure, On-site detention tank</b>	Underground detention structure; On-site detention tank; Detention tanks.
<b>Underground retention structure</b>	Underground retention structure; Underground storage; Belowground storage tanks; Sidewalk storage
<b>(Sand) filter (subsurface)</b>	(Sand) filter (subsurface); Soil filter; Structural Sand-Based Soils
<b>Wet pond, Retention ponds, Wet retention basin, Extended detention basin</b>	Wet pond, Retention ponds, Wet retention basin, Extended detention basin; Ponds and Lakes, containing all constructed open water bodies; Community ponds; Flooding ponds; Lagoon (Pond), open dam; Lake for swimming; Offline ponds; Ponds; Lined ponds; Lake (with fountains); Water playground; Recreation pond, Wet pond. Lakes; Reservoirs flood ponds; Retention pond; Stormwater ponds; Swales/retention ponds; Water features; Water storage pond; Wet basins; Wet detention basins; Wet Retention basin; Wet retention ponds.
<b>Sedimentation basins</b>	Sediment detention basin; Sedimentation basin; Sedimentation basins; Sedimentation ponds; Settling ponds
<b>Dry pond, Detention basins</b>	Dry pond, Detention basins; Detention pond; Dry basins; Dry detention basins; Dry pond (turned into a shallow wetland due to clogging); Designated flood area; Dry wells; Extended detention basin; Extended dry detention basins;
<b>Wetland, Constructed wetland, Restoration of wetlands</b>	Constructed wetland systems; Designed wetlands and settling ponds; Dry pond turned into a shallow wetland; Flood plain (scenario options of hydraulic reconnection); Restoration of wetlands; Re-created ecosystems–wetland; Reservoir flood pool reallocation (restore flood plains); Stormwater wetlands; Wetland; Wetland sites; Wetland treatment of lake water; Wetland Enhancement, Wetlands with swales and seeps; Dynamic intertidal zone.
<b>Infiltration basin</b>	Infiltration basin; Infiltration basins (football pitch in dry weather); Infiltration only systems; Landscape Infiltration; Stormwater infiltration (via soakaways).
<b>Infiltration trench, Infiltration planters/Planter boxes</b>	Infiltration trench, Infiltration planters/Planter boxes; Box/Pit, including planter box rain gardens and tree pits; Engineered tree pits with/without trees; Groundwater recharge through infiltration ('Biopori' technology); Infiltration system; Infiltration trench; Natural infiltration (in roads); Soakaways; Tree Box Filter; Tree drains; Tree trenches, Downspout planter installations.
<b>Green roofs (extensive, semi-intensive, intensive), Rooftop gardens</b>	Green roofs (extensive, semi-intensive, intensive), Blue roofs; Cool roofs; Roof storage; Rooftop gardens; Vegetated Roof.
<b>Green walls (Direct climbing; double skin green curtain; hanging planted on ground)</b>	Façade greening; Green facades; Green walls (direct climbing; double skin green curtain; hanging planted on ground); Vegetated Wall.
<b>Vegetated filter strip, Buffers and strips, Grass filter; Biofiltration systems, Buffers</b>	Buffers; Buffers and strips; Buffer enhancements; Filters; Filter strip; Grass filter; Impervious surface (>5%) in the riparian buffers; Natural filtration of stormwater into the urban landscape; Retention soil filters; Rip rap naturalization, Streambank naturalization; Stormwater Management Soils; Stream with a forest buffer; Vegetated filter strip; Vegetated Filter Strips for controlling and infiltrating pollutants and slowing down rapid runoff; Soil filter

Table A7. Cont.

Type of Output	Equivalent Names in the Reviewed Articles
<b>Grassed swale, Vegetated swale, swales, Bioswales/Biostrips</b>	Bio-retention swales; Bio-swale; Established meadow; Grass/ed swale; Infiltration/Swale; Natural drainage bioswales; Open drainage; Swale, Shallow swale; Swales with French drains; Vegetated drainage ditches; Swales/retention ponds; Vegetated swale.
<b>Bioretention basin, Bioretention area, Traffic calming bioretention, Bioretention devices, Bioretention cells</b>	Bioretention; Bioretention basin; Bioretention area; Bioretention devices; Bioretention cells; Bioretention system sites; Bioretention systems; Traffic calming bioretention; Vegetated detention strips.
<b>Rain gardens (including all other types of rain gardens and bio-retention systems)</b>	Backyard rain gardens; Gardens; Greened courtyards; Natural landscaping (BMP); Rain garden; Downspout disconnection; Lawn depression;
<b>Permeable pavements, Porous pavement, Porous paving</b>	Permeable parking surfaces; Permeable pavement; Porous pavement; Porous paving; Permeable surface; Pervious pavement; Pervious pavers; Pervious Paving; Porous driveway/sidewalks; Porous pavements with reservoir structure
<b>Rainwater harvesting, Rain Barrels</b>	Cisterns; Projects incorporating harvesting and reuse; Rain barrel; Rain tanks; Rainwater harvesting; Rainwater harvesting facilities; Rainwater harvesting interventions; Rainwater harvesting tank; Rainwater projects; Rainwater tank; Rainwater utilization modules; Rooftop rainwater harvesting scheme, tanks; RWH; RWHS; Stormwater harvesting project; Stormwater harvesting through podium building design
<b>Increased tree canopy, Urban trees, Tree preservation</b>	Green corridors; Greenway; Increased tree canopy; Lining neighboring streets with trees; Peri-urban forests; Planted trees; Revegetation (indigenous plant and tree species); Transportation corridor GI; Traditional market gardens; Tree planting (reinforcing banks); Trees for Cities; Tree Cover (<75%); Tree preservation; Tree protection at street right-of-way and individual parcels; Trees; Urban trees.
<b>Large parks, Green spaces</b>	“Greened acres”; Forest; Green open spaces; Green spaces; Large parks; Large, permanent forest preserved; Open space; Park; Peri-urban forest; Parkland (landscaped), Pockets of nature; Urban greenspace (to alleviate flooding).

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