Water-Energy Nexus 3 (2020) 186–197

Contents lists available at ScienceDirect

Water-Energy Nexus

journal homepage: www.keaipublishing.com/en/journals/water-energy-nexus/

Establishment and implementation of green infrastructure practice for healthy watershed management: Challenges and perspectives

Bo-Wei Liu [a], Ming-Huang Wang [b], Tse-Lun Chen [c], Po-Chih Tseng [c], Yongjun Sun [d], Andrew Chiang [e], Pen-Chi Chiang [c,*]

[a] *W Booth School of Engineering Practice and Technology, McMaster University, 1280 Main St W, Hamilton, ON L8S 4L8, Canada*
[b] *Department of Marine Environmental Engineering, National Kaohsiung University of Science and Technology (NKUST), Kaohsiung 81157, Taiwan*
[c] *Graduate Institute of Environmental Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei City 10617, Taiwan*
[d] *College of Urban Construction, Nanjing Tech University, Nanjing 211800, China*
[e] *Department of Computer Science, Emory University, Atlanta, GA 30322, USA*

A R T I C L E I N F O

Article history:
Received 15 November 2019
Revised 30 April 2020
Accepted 9 May 2020
Available online 23 June 2020

Keywords:
Healthy watershed
Green infrastructure
Bioretention
Sustainability
Watershed management

A B S T R A C T

The water management in various countries of the world provides a comprehensive understanding of the international movement on healthy watershed management. Watershed characteristics including River basin management in the UK, eco-health watershed management in Canada, sustainable water management in Korea, integrated watershed management in Japan, and healthy watershed management in the US have been examined in this review. Pioneering countries utilize green infrastructural applications to improve their resilience against climate change by adopting adaptive solutions and mitigating pollution sources. This paper includes an overview of the implementation of green infrastructure exemplified by bioretention in urban development and ecosystem maintenance. The good engineering practice for bioretention was established by applying data collected from other research. Biomantle and semi-direct injection of storm water are the two methods for sustaining bioretention functionalities for peak flow reduction and soil stability enhancement. Maximum pollutants reduction efficiencies by bioretention were reported in the past research, including 99% of phosphorus, 82% of nitrate, 92% of heavy metals, and 96% of suspended solid. Lastly, a conclusive benefit analysis of green infrastructure from environmental, economic, and social perspectives was conducted.

Contents

* Corresponding author.
E-mail address: pcchiang@ntu.edu.tw (P.-C. Chiang).

https://doi.org/10.1016/j.wen.2020.05.003
2588-9125/

1. Introduction

Anthropological activities, including domestic sewage, agriculture, and industrial effluents, play a significant role in water pollution (Goldar and Banerjee, 2004) and damage the natural watershed ecosystem and human health. One of the prerequisites for sustainable development is to maintain watershed and ecosystem at a healthy level. In order to achieve the goal, we need to ensure that the watershed is resistant to natural disturbance, self sustaining, and without effects on its surroundings, beneficial to communities with ecological value (Luo et al., 2003). The approaches and preservation need to be connected in laterally, vertically and longitudinally; and variability of natural particularity and temperature is obliged to be taken into account (Naiman et al., 1992). The advanced watershed management in 1990s provided a holistic perspective that the health of the society and watershed depends on each other. In other words, they are mutually beneficial to each other (Flotemersch et al., 2016a). And the term "Watershed Integrity" is now used to describe the systems which provide the service to our society with sustainable flow (Flotemersch et al., 2016a). Climate change has already reduced water availability and strained the ability of local water companies to supply water. It has brought us into a water-stressed stages where the excessive runoff in wet season cannot be beneficial during dry seasons (Arnell, 2004). In order to clarify and face climate change, regional and local scale approach is required for mitigation and adaptation strategies (Xu et al., 2009). The adaptive management describes one's ability to cope with climate change and the ability to adjust in different scales while maintaining the development of our socio-ecological system (Pahl-Wostl, 2007). In other words, the flexibility is to determine how well the management can deal with upcoming events, such as flooding.

Green infrastructure serves as the planning tool for existing pubic land, such as parks, forest preserves, greenways, alleyways and roadside right-of way zones. Lovell and Taylor (2013) brought up the idea that the flexibility of green infrastructure can furnish unused open areas in the cities (Lovell and Taylor, 2013). Besides the need for a policy, it also demands a transitional period of time for the connection between multiple social ecological systems which promote connectivity, accessibility, physical activity, and leaning (Lovell and Taylor, 2013). The hierarchy theory can be used to understand green urban infrastructure planning. The theory that promotes a multi-scale system should prioritize only one issue (O'Neill, 1985). Hierarchy systems can also explain landscapes. Heterogeneous spaces are considered to be a huge net where larger regions are essential to urban ecological process due to their higher monetary value and more complex structures (Ahern, 2007).

Applying green infrastructure to agriculture water control intends to regulate eutrophication caused by overusing fertilizers and pesticides. For example, an ecological study of eelgrass reported by Latimer and Rego (2010) suggests the nitrogen overload should significantly harm to eelgrass (Latimer and Rego, 2010). Therefore, green technologies and green infrastructure would be beneficial for on-site use at different locations. Advanced modeling, sharing data, and amended approaches are of essential ways to target varying and emerging issues. Software will increase productivity whilst implementing green infrastructures. A study conducted by Charalambous et al. (2012) introduced a user-friendly tool that uses water loss quantification and visualization to minimize inefficiencies (Charalambous et al., 2012). With proper planning, spatial planning plays an indispensable role in urban expansion (Madhu and Pauliuk, 2019). Planners and stakeholders intend to formulate policies based on the existing problems regarding watershed maintenance and water scarcity (Matthews et al., 2015). Planners currently face challenges in redesigning facilities to increase sustainability, so there is a need to understand how green infrastructure can be integrated as an innovative practice (Matthews et al., 2015).

The objectives of this review article are: (1) to review the development for healthy watershed management in various countries, (2) to examine and highlight current barriers with corresponding strategies, (3) to establish Key Performance Indicators for healthy watershed environment, (4) to conduct beneficial analysis from environmental, economic, and social aspects for green infrastructure, (5) and to assess and evaluate challenges and perspectives for both short-term and long-term sustainable development.

2. Development of health watershed

From a historical point of view, different countries have all made contributions to its watershed management development. This review has chosen the UK, Canada, Japan, Korea, and the US as examples to illustrate how water is managed. A worldwide roadmap regarding water management development is shown in Fig. 1.

2.1. River basin management-UK

In the UK and other developed countries, river quality, and groundwater contamination from the point and non-point source pollution have always been the primary concerns (McGonigle et al., 2012). Temperature and hydrology change and biogeochemical cycles, such as carbon cycle, were noted in upland catchments in England under climate change (Curtis et al., 2014). However, substantial progress to drinking water and rivers has been made ever since privatization. For example, over the past two decades, biology has contributed to water quality improvement in the UK to large reductions in acid deposition (Curtis et al., 2014). River basin management plan with the focus on Thames River has been

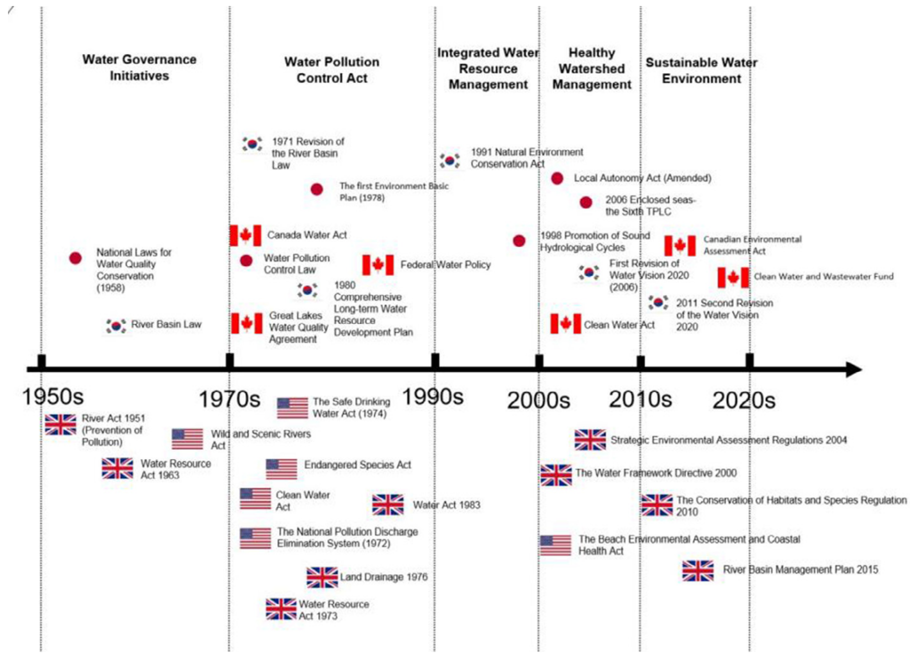

Fig. 1. Development of sustainable water management including USA, UK, Canada, Japan, and Korea from 1950 to 2020.

put into application in modern river basin management in the UK. The plan contains two parts which aim to prevent water body deterioration and protect conserved land and water bodies, and improves water quality and provides actions and future regulation suggestions. Large infrastructures are applied along the river basin district. Other than river basin based management, the sustainable drainage system is another way to cost-effectively improve water quality and quantity besides surface water solution (Ashley et al., 2015). Upon sustainable drainage system in the UK, integrated systematic planning of "street" greening, along with the optimization of existing biofiltration technique, green roofs, downspout disconnection, and sub-catchment riparian corridors was suggested as the improved approach for urban development (Ellis, 2013).

2.2. Eco-health watershed management-Canada

Anthropological activities impact the watershed ecosystems ability to provide products and service which underlie human health. In Canadian water management history, a safe drinking water source is progressively becoming a primary concern because of waste discharge, excessive nutrients, and chemical use. Many waterborne diseases and outbreak incidents were originated from treatment industries. Although the intensity of the treatment is well taken care of, poor source water quality control can be the inherent threat associated with potential health risks. In Canada, the roles of federal and provincial governments differ from jurisdictions in the context of drink water protection. Under the clear division cooperation system, provincial governments are in charge of the authorization of use of water, water development, flow regulations, legislate water supply and pollution control where the federal government is responsible for keeping jurisdiction in terms of overall navigation, fisheries, national part inspection and aboriginal reservations (Davies and Mazumder, 2003). One of the noted methodologies is the framework of watersheds, ecosystem, social systems, and health well-being. The watershed governance, a three-dimension framework, unifies from four basic elements and integrates them into two emergent approaches: eco-health and watershed-based integrated water resources management. The former argues that the human health and well being are not only the consequences but reflection as well and the later states the point of watersheds being appropriate units (Parkes et al., 2010). Upon this theory, methodologies like environmental flow which is to maintain water quantity at an acceptable level in regard to sustainable development for aquatic biota is applied to Maritime provinces (Tharme, 2003). Multi-barrier approach which aims to reduce the vulnerability of drinking water contamination targeting on first nations safety (Patrick, 2011) are noted in Canada watershed management as well.

2.3. Sustainable water management-Korea

Sustainable water management is essential to the future for the world that programs to protect the ecosystem while propping growth and development. The transformation of Korea watershed management was from water quality management to watershed management system. Better participation and cooperation plus successful policies, which include Total Pollution Load Management System (TPLM), Buffer Zone System, Land Purchase System, Supports for the Source Water Management Areas (SWMA), and Water Use Charges and the Basin Management Funds, are complementary to each other while providing benefits for various zones. One major water issue among Asia countries is flooding and drought even due to climate change (Azam et al., 2017b). Government is essential to Korea adaptive watershed management as well as participation from stakeholders (Kang and Park, 2015). Data collection and utilization, therefore, is of one of the important factors required for design and measures for reducing damage from flooding, such as hydrological engineering center's hydrology modeling system (HEC-HMS). The application is useful for policy-makers and other regulations to mitigate the risks with suitable measures (Azam et al., 2017b). The decision supporting system (DSS) which has evolved to several subsystems including database, model base, knowledgebase, and general user interface (GUI). With incorporating with HEC-HMS, flow prediction and urban water demand forecasting can be better predicted (Zeng et al., 2012).

2.4. Integrated water management-Japan

Integrated management can be classified into many kinds. Integration of different agencies plays an irreplaceable role in establishing the intact administration in watershed management (Nakamura, 2008). Reasonably allocating resource to departments and institutes can dramatically save time, space and human resources to reach a product management level. Japan, as a pioneer, applied software and computer science in the watershed development and efficiently integrated the capability of society and government functions to prevent, inspect and evaluate watershed (Berndtsson and Jinno, 2008). Ministries in Japan play a critical role in water management. However, the need for a more comprehensive top-down approach is required. Although integrated management has contributed to water quality and quantity improvement, ministries policymakers need to perform more collaboratively. Besides, strengthening local government capacity is also a solution although its corresponding financial problem remains a challenge (Kataoka, 2011).

2.5. Healthy watershed management-US

The pursuing towards sustainable development is of the mainstream in the United States due to the growing exploitation in the regions where lack of water is the problem. The aggressive demand is also growing in terms of natural habitats, urban area, water, and other source-based features. Hence, the most significant challenge the US facing currently will be how to manage resources in a sustainable manner (Thorud et al., 2000). The role of technology and sophisticated tools suddenly becomes critical and indispensable. Properly utilization helps policymakers to have a clear view of whom or what aspects being left behind (Thorud et al., 2000). Social science is equally crucial to water managing at this moment. The planning and design outcomes are needed to be implemented by policymakers who generally have a wilder point of view.

One of the most sophisticated smart infrastructures is green infrastructure, the popular storm water management tool. This relatively new approach, which is encouraged by the U.S. Environmental Protection Agency (EPA), was introduced to reduce storm water runoff incorporating with other smart devices and technologies (Meng and Hsu, 2019). An example from (Tsegaye et al., 2019), proposed the methodology Gray to Green (G2G) approach by using Tampa and Milwaukee as examples to prove that green infrastructure could potentially become a more flexible, effective, and benefit-providing solution for treating and managing the urban water system. Water sustainability is defined as the available freshwater supply during climate change, extreme weather, drought and flood, and overpopulation (Mays, 2007). In the past, conserving water resources was executed with gray infrastructure practices. Yet, the exploitation of water and improvement in urbanization required more integrative and innovative systems (Al-Jayyousi, 2003), such as a green system.

2.6. Summary of roadmap for watershed management

In the early 1930s and 1940s, watershed management was regarded as "watershed management from the viewpoint of the forester" in 1938. In the 1940s, watershed management requiring economic studies were brought up (Kotok, 1938). The main focus on sustainable development was brought up in 1962 by Rachel Carson's *Silent Spring*, which brought up toxicology, ecology, and epidemiology together to exhibit a better understanding the attribute of environment management with the combination of social and economic (Hsu and Chao, 2020). The period between 1950s–1970s under the growing industrialization was known as water governance initiatives where most of the first version laws and water protection policies were carried out in different countries. For instance, England has published River Act 1951 to prevent progressive pollution. In 1968, the Intergovernmental Conference for Rational Use and Conservation of the Biosphere came up and showed the world the whole systematic idea of ecologically sustainable development. Then, environmental issues, especially for water problems, became one of the dramatic concerns from 1970 to 1985. Therefore, the second phase of watershed protection is about water pollution control. The urgent alarm brought peoples' attention. Many of the global conferences and legislation emerged during this time. For instance, the National Environmental Policy Act was passed in 1969 for addressing the environmental problem around the United States. International Institute for Environment and Development (IIED), conducted by the United Kingdom, followed up right after First Earth Day in 1971. It built up the concept of seeking the best of both worlds between economic development and environmental deterioration and resource consumption. Canada also started to take actions on preventing environment and resources with a competitive measure, namely Greenpeace. Also, the Great Lake Water Quality Agreement in Canada and the United States was out for protecting and restoring desirable lake area. After the 1990s, the world trend has entered into an urbanization period where climate change becomes a primary issue in the worldwide. Integrated Watershed Management was officially introduced. An example from Japan was the establishment of the First Environment Basin Plan, also refers to the integrated approach. Not only has individual movement among countries been awakened by the climate change meeting in 1985 regarding global warming in Austria, but it was reported by the World Meteorology Society, the United Nations Environment Programme (UNEP), and the International Council of Scientific Unions respectively. In 1996, ISO 14001 is officially accepted as the international standard operation for environmental management.

The terminology "Green" appeared in public within a high frequency after 2005, green economy, green transportation, and green infrastructure were consistently accepted by people, organizations, and regulations. A significant change of focus in the 2000s in terms of water contamination prevention was from pollution control to drinking water and human health. The term "Healthy" was the keyword during the 2000s. Healthy watershed management with green infrastructure started to play a relatively important role. In September 2015, the United Nation (UN) General Assembly adopted a resolution identifying 17 Sustainable Development Goals (SDGs) with a combination of 169 associated targets to achieve by 2030, which were supported by every county involved in the United Nations. Sustainable watershed development became the name of the game. Water sustainability is defined as the available freshwater supply during climate change, extreme weather, drought and flood, and overpopulation (Mays, 2007). In the past, conserving water resources was executed with gray infrastructure practices. Although the focus has been switched from protection and prevention to response and recovery, the current issues still need to be solved separately and individually. Due to the inherent problems are various and independent, analysis and strategies are required according to their characteristics. The main issues are listed out as follows: water quality contamination, ecological condition deterioration, water quantity insufficiency, lack of integration of governance, insufficiency of adaptation measures to climate change

3. Barriers and strategies

Although we are stepping into a sustainable watershed management period, water issues cannot be avoided entirely. Some historical water problems remain as obstacles. The barriers are sorted into five categories and further discussed in the following sections. The strategies and key performance indicators will also be provided, respectively.

3.1. Barriers and issues

Water scarcity was never distributed evenly in the world. In the specific region around the world, such as arid areas, Central Asia, and North Africa, water is severely scarce and irrigation for agriculture will become a significant issue (Rijsberman, 2006). The shocking data collected by (Mekonnen and Hoekstra, 2016) proved that two-third of the population, which is approximately 4.0 billion people, has been suffering insufficient water for at least a month per year. Water quality contamination is the main reason behind it and has been the primary concern for centuries. Industry privatization, urbanization, and technology development contributed to this specific issue. Although it has been mitigated significantly, the proper strategies are required for future build out and growth. The progressive phase for the water issue is of the ecological condition deterioration. The precondition to solve the degradation problem is to have a clear understanding of how it was damaged in the first place. The very early sign is the reduction of wildlife. However, restoring ecosystem of habitats and natural resource requires incorporating with other studying factors which includes individual, population, community, ecosystem, and landscape conditions. The gap between conceptual strategy and practical implementation is mainly associated with the lack of action from stakeholders to apply theoretical principles (Kraff and Steinman, 2018). Enforcement to the locals and individuals is required. Although public participation is encouraged, some stakeholders stated their perplexity of the federal systems. Such phenomenon exhibits the status quo issue of water management integration (Kraff and Steinman, 2018). Recruiting proper participators is another challenge due to the scarcity of labor. The insufficiency of adaptive measurement to climate change exposes critical issues, such as water quality contamination and water quantity control. In addition, there is a lack of tools to analyze hydrometric condition in hazardous areas. A study done by (Mishra and Coulibaly, 2010) revealed that many basins do not have sufficient data flow to execute decision making. Insufficient gauges are not able to cover the entire watershed area. However, distributing inspection tools in large watersheds incur the increase of expenditures. Fundamental aspects of sustainability are education, collaboration, communication, and engagement. Individual activities or single organization are not capable of changing the entire problem. Therefore, cultivating shared values motivate people to protect the watershed. These shared values include the understanding of green chemistry, green infrastructure, and climate change (Taye et al., 2019).

3.2. Strategies and current approaches

To address the current critical watershed issues, five strategies are suggested in this review correspondingly.

1. Clarify the water environment

Enhance drinking water and catchment management with protective policies and Best Management Practice (BMPs). Utilize Low Development Impact (LID) concept benchmark to enforce institutes abided by the laws and regulations. Establish watershed management and comprehensive water management system, and incorporate water source protection into the assessment system (Ajaero et al., 2020).

2. Maintain the healthy ecological processes in habitats

Develop a holistic river basin health assessment guideline and formulate corresponding policies. Promote the implementation of green infrastructure, and create buffer system within and outside of the urban region. Build ecological corridors and habitats, and simulate the natural environment towards the eco-friendly approach.

3. Promote public awareness and participation

Appeal low carbon lifestyle and set up an incentive system to promote public acceptance.

Strengthen community and organization functions, and promote "green" concept in education. Establish renewable energy and water sustainability information platform to enhance the utilization rate of the government.

4. Implement comprehensive management of watersheds

Cooperate with the national development and conservation plan, and draw up a water supply system for water reconstruction and restoration. Integrate and utilize various resources such as water, soil, forest, agriculture, and optimize coordination of divisions. Review domestic and foreign water management experiment and actions, and adopt suitable approaches and methodologies where can be applied.

5. Consolidate disaster preparation precaution

Establish a water supply system operation management database and technology exchange platform, and strengthen related management program in terms of communication, coordination, and cooperation mechanisms. Develop water security and risk management assessment along with new technology development for the response of extreme situations. Develop contingency plans and strengthen the monitoring and early warning capability of sudden changes in water quality and quantity.

3.3. Key performance indicators

Upon the establishment of the strategies, a set of secondary and tertiary indicators which can be determined according to its primary indicators shown in Fig. 2.

3.3.1. Clean river water

Performance indicators are important in helping long planning and vision. Clean river water is an indicator of the clearness of the water itself. It also points out the importance of the water quality, sediment quality, biotic condition and public acceptance. The more specific indicators presented in Table 1 are broken down based on river water quality; for example, contain dissolved oxygen concentration and various nutrient levels. The analysis of sediment quality consists of its river bed stability and sediment transport degree. A buffer system protects watersheds functions against trapping sediments and improving water quality by eliminating nutrients. Watershed quality inspection plays an important role in public acceptance. The opinions from individuals which can be conducted and collected by questionnaires and surveys represent the public voice. Inspection data can be seen as the fundamental elements of models setup and data collection, as well as a decision making process for resource allocation. Drinking water quality and recreation water bodies develop the first fence before going into the deeper data analysis. The success of data analysis and control relies on post-assessment, design, planning, and accuracy. Non-structural flood risks management can be another approach to achieve water quantity control in terms of combining physical and theoretical practice (Dawson et al., 2011). The forthcoming development for flood control risk management practice needs to incorporate hydro-meteorological information with real-time weather forecasts (Azam et al., 2017a). Another recommendation given by (Lovell and Sullivan, 2006) suggested to amend

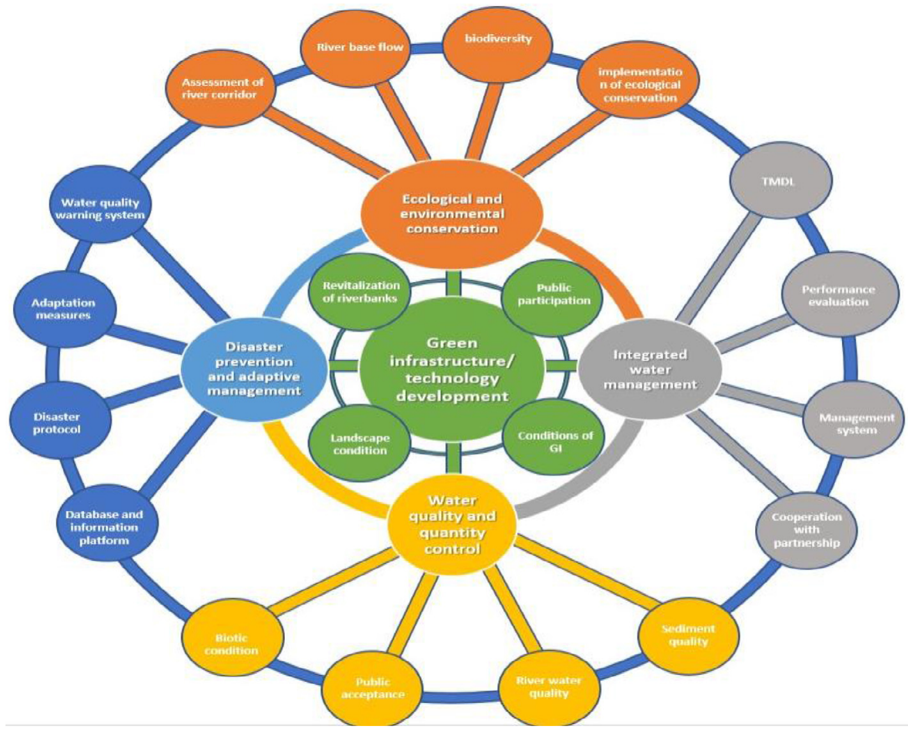

Fig. 2. Key performance indicators for healthy watershed management.

Table 1
Key performance indicators – clean river water.

Primary Indicator	Secondary Indicators	Tertiary Indicators	SDGs
Clean River Water	1.1 River water	DO, Heavy metal contents	Goal 6
		RPI	Goal 14
		Nutrients	Goal 15
	1.2 Sediment quality	Riverbed stability	Goal 6
		Annual sediment transport	Goal 14
		Heavy metals contents	Goal 15
	1.3 Biotic condition	IBI index or SEARS index	Goal 6
		B-IBI index	Goal 14
		Algae	Goal 15
	1.4 Public acceptance	Survey result about river water quality	Goal 3
		Survey result about recreation water area	Goal 14
		Use frequency of recreation facilities in water area	Goal 11

Table 2
Key performance indicators – ecological and environmental conservation.

Primary Indicator	Secondary Indicators	Tertiary Indicators	SDGs
Ecological and Environmental Conservation	2.1 River base flow	Days of river flowrate to meet the base flow	Goal 14
	2.2 Assessment of river corridor	Ecological conditions of river corridor and habitats	Goal 14
		Terrestrial habitat and aquatic connectivity	Goal 15
		Riparian connectivity	
	2.3 Biodiversity	Ecology	Goal 14
		Conservation	Goal 15
		Biological control	
	2.4 River integrity	Hydrological regulation	Goal 13
		Regulation of water chemistry	Goal 14
		Sediment regulation	Goal 15
		Hydrological connectivity	
		Temperature regulation	
		Habitat provision	

strategies for a better choice indication of stakeholders and society. In addition, biotic condition, such as bacteria and algae concentration level, needs to be restricted at a certain level. An index of biotic integrity (IBI) and a benthic index of biotic integrity (B-IBI) are used to measure, quantify and comparing biological condition in streams for watershed health assessment (Minns et al., 1994). It is also important to carefully select the candidate metrics and evaluate the competent habitats by comparing to the reference site. The accumulative scaling and equal weighting in each factor allow researchers to visualize how much each metric contributes to fair score (Weisberg et al., 1997). The reflection of the indicators to SDGs includes good health and well being, clean water and sanitation, life below water, life on land, and sustainable cities and communities.

3.3.2. Ecological and environmental approach

As the SDGs are the guidance of every aspect, ecological and environmental conservation has become one of the primary key performance indicators and four sub classes are used as secondary indicators. Details listed in Table 2 contains each indicator and the corresponding SDGs. To understand the recharge and base flow, two methods, "water balance" and "stream flow filter and recession", can be used in the estimation. The benefit for using the filter/recession technique is the simple requirement of daily stream flow. Many models provide the simulation of management and various climate scenarios which include changes in temperature, radiation humidity, precipitation and gaseous condition such as CO2 emissions (Arnold et al., 2000). Besides river base flow, the assessment of river corridor could be employed as the tool for stream channel design and rehabilitation. Habitats, aquatic connectivity, and riparian connectivity are the three tertiary indicators to evaluate the healthy level of a river corridor. The research from (Bennett et al., 2008) has suggested that a cost effective, more stable and better drainage system could be developed with the design flow of a meandering stream corridor with vegetation. The third sub indicator is considered as the biodiversity. Three indicators brought up by (Duelli and Obrist, 2003) in agricultural landscapes represent the three systems conservation, ecology, and biological control. Similarly, watershed indicators are not too different from those of agriculture. Conservation which means the number of the species in a defined area, ecology which represents natural level and resilience, and biological control which indicates the defence system from species invasion can be established as the healthy watershed indicators.

The integrity of environmental resources, green infrastructure implementation, and public awareness are the three major components of the United States watershed management. The equation referring to a conceptual design to describe the integrity of a watershed is introduced as the Index of Watershed Integrity (Flotemersch et al., 2016b):

$$WI = WI_{HYD} \times WI_{CHEM} \times WI_{SED} \times WI_{SCONSIN} \times WI_{TEMP} \times WI_{TH\ ABT}$$

In the equation, WI ranging from 0 to 1 represents the holistic integrity of the watershed and a larger the number means higher watershed integrity. Hydrological regulation, regulation of water chemistry, sediment regulation, hydrological connectivity, temperature regulation and habitat provision are the six key functions providing references for determining the index. Due to the difficulties in the determination of these components, the practicality can be changed by the impact of different stressors. The index can be helpful for water reclamation and restoration as in the entire management system (Thornbrugh et al., 2018).

3.3.3. Green infrastructure development

The most important key performance indicator, the green infrastructure development which covers 10 out of 17 SDGs is shown in Table 3 First of all, the distribution of Green Infrastructure (GI) includes green covering area, the utilization of green infrastructure, and distribution patterns. Knowing the infrastructure coverage rate is the first move to be aware of the city deficiency and availability. Sufficient green space carries the value beyond its environmental and economic benefit. It restores the livability and enhances healthy vibe within the city. However, the judgement can be made based on the pattern of how green is distributed. It is important to have knowledge of how and where the green infrastructures were dispensed. One way to examine the pattern of GI is by observing the edge of each district. Appling GI in a board cutter factory, for example, may provide the aesthetic value as well as other potential benefits. Landscape condition can be evaluated as the secondary indicator to correspondingly reflect SDG Goal3, Goal 14 and Goal 15. A habitat assessment score system where it is used to compare with River Habitat Survey can be employed to assess the worth of the area (Raven et al., 1998). Based on the type of basin outlet system, which means either detention BMP or infiltration BMP, surface flow could be reduced by 27–31% and the cost is $1,141,000–$1,319,000 (Sun et al., 2016). In addition to adopting newly generated technologies, management practices are a major part of green infrastructure (Fig. 3). Unlike the previous indicators, public participation acts the intangible but obligatory role which delivers the better city/community resilience, cleaner energy and more extensive partnership. Different forms of participation are acquired, such as the participation of forestation and planting, public adopting parks and green space, as well as community green-action (reforest). Lastly, riverbank revitalization including water accessibility and usability, area ecologically conserved in riverbanks, and level of river coast lines, plays a critical role for determining water cleanness and life qualities. In addition, climate change and human well-being are the indirect but long-term impact in this case.

Table 3
Key performance indicators – green infrastructure development.

Primary Indicator	Secondary Indicators	Tertiary Indicators	SDGs
Green Infrastructure Development	3.1 Distribution of GI	Utilization GI covering rate Distribution pattern	Goal 9 Goal 11 Goal 12 Goal 15
	3.2 Landscape condition	Habitat assessment score Economic value	Goal 3 Goal 14 Goal 15
	3.3 Public participation	Participation o afforestation and planting works Participation of adopting parks and green area Participation of community greenification and landscape development	Goal 7 Goal 11 Goal 17
	3.4 Revitalization of riverbanks	Water accessibility and usability Area percentage of ecologically conserved in riverbanks River coast lines	Goal 3 Goal 6 Goal 13 Goal 14

3.3.4. Integrated water management

Successful strategic management is the key towards an integrated development. A good management team is also to optimizing resource allocation to departments so that the institutes can dramatically save time, space, and human resources. By achieving so, project management is essential for proper arrangement to inaugurate the standardized systematic approach. Meanwhile, a sustainable steady economic growth under integrated management relies on financial support, such as annual budget from the government. It is the sign of endeavour from the top management. The detailed indicators along with their corresponding SDGs are summarized in Table 4.

Integrated management of different agencies plays a major role in establishing cohesive administration in watershed management. In addition, the integration of technology and infrastructure sets up an advanced approach for reducing water consumption and improving food quality, particularly in the United States and China. Applying a combination of retention and solar energy in agriculture as an underground submersible solar photovoltaic pump promotes water efficiency by Meerow and Newell. This concept illustrates how sustainable development practices align with Best Management Practices (BMPs). The Integrated Watershed Committee should encourage public involvement and bring stakeholders together to represent common benefits for successful integrated management (Taye et al., 2019) .

The economy, social well-being, and the environment are closely bonded by water. The Watershed Governance Prism Heuristic can present its relationship in 4 clear perspectives which convey the essentiality of balancing ecosystem and social systems. When social systems develop at a steady pace, ecological systems thrive (Morrison et al., 2012). Specifically, a healthy watershed aids in promoting wellbeing by supplying high quality freshwater. In addition, partnership may setup within private enterprises, or link outside with non-profit organizations and even with government. The larger the network and more interactions between

Fig. 3. The gradient of green infrastructure practice towards water sustainability.

organizations is, the more chance is able to development city and community resilience. Local institutes are the driving force in adaptation management. There are three levels of institutes as in rural areas: public, private and civic. The public, also known as states scale, consists of local agencies and local governments. Private indicates service organizations and private businesses. Civic refers to membership organizations and cooperatives. The community-based and participatory approach for cross-level collaboration conducted by (Daley et al., 2015b) suggests that a comprehensive assessment of community values and behaviors should be considered. Community-based planning focuses on eliminating resource pollution boosts the recovery of the aquatic habitats. There are four principles for community-based watershed management: collaboration of the local stakeholder and investors, preservation of the integrity of the system, clarification of scientific information and social values, and adoption of adaptive management (Daley et al., 2015a). Moreover, the cooperation between educational institutes and policymakers for the improvement of training on management, infrastructure, and technology can contribute to better water quality. Another benefit to achieve water sustainability with education is the non-profit aspect. Although this partnership requires initial investment in capital, the rate of return produces profit.

Table 4
Key performance indicators – integrated watershed management.

Primary Indicator	Secondary Indicators	Tertiary Indicators	SDGs
Integrated Watershed Management	4.1 TMDL (Total Maximum Daily Load)	Pollution reduction from point source Pollution reduction from non-point source	Goal 6 Goal 11 Goal 13
	4.2 Management system	Project management Financial support – Annual budget	Goal 8 Goal 17
	4.3 Performance evaluation	Performance evaluation for river pollution prevention Performance evaluation for ecological conservation in watersheds Performance evaluation for disaster prevention in watersheds	Goal 3 Goal 6 Goal 7 Goal 14 Goal 15
	4.4 Cooperation with partnership	Cooperation with private enterprises Cooperation with non-profit organization Government	Goal 11 Goal 17

3.3.5. Disaster prevention and adaptive management

SDG 13, climate actions, is running through this section, which can be observed in Table 5. The author has suggested four sub indicators for adaption management in terms of disaster prevention and control. The management describes the ability to cope with climate change and to adjust in different scales while maintaining the development of our socio-ecological system (Pahl-Wostl, 2007). In other words, the flexibility is to determine how well the management can deal with upcoming events such as flooding. On the other hand, the indicators are used for practitioners instead of planners and policy makers. In this case, the loop can be formed where more positive feedbacks can be collected and implement back into practice. Therefore, an integration of green and gray infrastructure and contingency plans are required as adaptive measures. Upon measures, standardized protocol can be the solutions to address the sudden events and emerging conditions. In addition, the use of database and information technology as another secondary indicator includes detective measures and geographic information system. Used as tertiary indicators, the system is correspondingly reflecting the improvement of marine ecosystem, green infrastructures and water quality, which represent SDG 6, SDG 9, and SDG 14, respectively.

Table 5
Key performance indicators – disaster prevention and adaptive management.

Primary Indicator	Secondary Indicators	Tertiary Indicators	SDGs
Disaster Prevention and Adaptative Management	5.1 Adaptation measures 5.2 Pre-warning system for water quality monitoring	Green and gray infrastructure Contingency plans Abi8lity to adjust in different scale of water bodies	Goal 11 Goal 14 Goal 15 Goal 3 Goal 6 Goal 13 Goal 14
	5.3 Protocol for disaster or emerging conditions	SOP in disaster or emerging conditions	Goal 9 Goal 11 Goal 13
	5.4 Database and information platform	Detective measures GIS	Goal 6 Goal 9 Goal 14

4. Green infrastructure benefits

Conceptualized GI management is the key towards a successful watershed management. In this section, quantified benefits of GI will be discussed and the summery of environmental, economic and social benefits of green infrastructure practice are listed in Table 6.

4.1. Environmental

As the main functionality for green infrastructure, environmental protection and recovery are always considered as primary tasks. Groundwater recharge functionality is one type of design objectives for Low Impact Development. Many direct and indirect benefits are concluded from the past experience. Due to the exclusive design purpose of bioretention, not only for groundwater replenishment, it also recharges and reuses for base flow in hydrologic cycles (Davis et al., 2009). Bioretention assessment pointed out there is a 96.5% peak flow reduction for small and medium-size storm events, which is an outstanding result of its physiochemical property (Demuzere et al., 2014). According to the review from (Davis et al., 2009), the removal efficiency of total phosphorus, total nitrogen and total suspended solid from selected field laboratory were 52%–99%, 65%–99%, and 59%–99%, respectively. Other than water quality, green infrastructure may significantly elevate air quality in urban area by noise reduction, air pollutants removal and pollutants avoidance. Sonic environment improvement through leave-absorbing-energy is the main mechanism for noise elimination (Wang et al., 2014). From aesthetic point of view, a cost-benefit analysis conducted under a certain scenario in New York city presented an annualized medium value of $74,050,538 which is generated by green roof aesthetic/ recreation (Rosenzweig et al., 2006).

Biodiversity can be improved over time and space in a green area especially in larger regions and it gives people the wildness-experience in some green developed area in Europe (Mabelis and Maksymiuk, 2009). One proof is that diversified plant species are able to strengthen soil stability at high elevation (Pohl et al., 2009) and ecological redundancy. In this case, biodiversity could also improve ecosystem resilience due to the composition of functional group of organisms with its individual responses to the environment (Walker, 1995). Green corridors play a significant role to strengthen biodiversity in green area and it presents that the efficacy of corridors has a direct relation to urban ecological development (Vergnes et al., 2012). Corridor projects are important building blocks for green infrastructure in the United States (Benedict and McMahon, 2012).

For climate change regulation, vegetation intends to mitigate the urban heat island effect where the area has high surface temperature (Meerow and Newell, 2017). Green infrastructure helps to decrease air and ground temperature through offering shades and to promote evapotranspiration process throughout a long-term climate change (Demuzere et al., 2014). In addition, vegetations in green infrastructure are also able to reduce greenhouse gas (GHG) including carbon dioxide (Demuzere et al., 2014), nitrogen oxide, and ozone levels (Meerow and Newell, 2017).

4.2. Economic

Many economic benefits are the reflection of the social and environmental benefits. It has been acknowledged as the important natural capital where the tangible material benefits can be seen, rather than being social and environmental conceptual advantages (Matthews et al., 2015). Green infrastructure, such as the aforementioned green roof, offers development advantages to both public organizations and private institutions. Life Cycle Assessment (LCA) can be used for environmental impact analysis to provide decision makers with more holistic view of environmental risks, economic data, and quality of life impact. A cost-benefit LCA of green roofs compared to traditional roofs was conducted in (Carter and Keeler, 2008). The analysis indicated that the green roof had valuation advantage (Muerdter et al., 2018) by decreasing green roof production costs. With the implementation of green roof, property value can also be elevated. Investment opportunities increasingly appear with respect to incremental green space. The research also suggests that the implementation of an incentive framework could expedite the economic yields. Other studies estimate the value of green roofs to be 20–25% higher than conventional roofs, based on benefits from reduced electricity costs, increasing air-quality benefits by 40% (Foster et al., 2011). An integration approach of using gray and green infrastructure combination was investigated and it was found out that a partial replacement of gray infrastructure with green infrastructure can provide a saving around $35 million within its life cycle (Cohen et al., 2011).

Green investment can boost the number of cyclists to switch car to biking and lower the emission of carbon dioxide (CO2), nitrogen oxide (NOX) and PM10 as well. Expense can be saved by reduction of the emission with a unit price of € 30/kg for PM10 and € 6.5/kg for NOX, respectively (Vandermeulen et al., 2011). Green infrastructure can mitigate health problems due to slighter urban heat island effect from climate change perspective (Meerow and Newell, 2017). Green infrastructure or space can be a significant influential factor regarding to treating cardiovascular disease because of it functionality of fixing air conditions and heat reduction (Shen and Lung, 2016). Trees and other plants are also able to reduce radiant energy by providing shading and through evapotranspiration, which vaporize water to cool the air (Simpson, 2002). Study suggested that even a short visit to the natural environment can obviously have a positive influence on stress relief than artificial surroundings (Tyrväinen et al., 2014).

4.3. Social

Green infrastructure can benefit the social matrix in cities and communities. As green infrastructure encourages people to join in social activities, social interactions; thus satisfaction can be observed in high density urban areas when extreme events are encountered. It indicates that green infrastructure can improve physical (Demuzere et al., 2014) and mental health (Meerow and Newell, 2017), and the reduction of psychological stress as well.

Table 6
Environmental, Economic and Social Benefits of Green Infrastructure.

Aspects	Sub-aspect	Related benefits	Reference
Environmental	Water quality and quantity	• Water quality improvement • Peak runoff control • Groundwater replenishment	(Demuzere et al., 2014) (Davis et al., 2009)
	Air quality	• Pollutants removal • Noise reduction • Aesthetic attraction	(Meerow and Newell, 2017) (Wang et al., 2014)
	Soil quality	• Soil stabilization • Lift head rate • Suppress erosion	(Pohl et al., 2009)
	Ecological conservation	• Biodiversity • Ecological habitat and corridor • Ecosystem resilience	(Mabelis and Maksymiuk, 2009) (Vergnes et al., 2012) (Walker, 1995)
	Climate regulation	• Thermal comfort and reduced energy use • Heat island effect • Greenhouse gas reduction	(Demuzere et al., 2014) (Meerow and Newell, 2017)
Economic	Ecological value	• Environmental quality improvement • Environmental protection and radiation control • Landscape aesthetics • Increase property value • Improve economic growth and investment opportunities	(Benedict and McMahon, 2012)
	Cost reduction	• Reduce sewage treatment costs • Reduce facility maintenance costs • Reduce costs for air pollutants removal	(Foster et al., 2011)
	Health benefit	• Reduce psychological stress and related diseases • Reduce the disease caused by air pollution • Reduce heart and brain diseases such as heart disease	(Wang et al., 2014)
	Energy Saving	• Indirect energy saving • Direct energy saving • Energy production	(Wang et al., 2014)
Social	Public health	• Extend life expectancy • Improve physical health • Improve mental health	(Meerow and Newell, 2017) (Takano et al., 2002) (Demuzere et al., 2014)
	Community development	• Community cohesion • Reduce crime rate • Support urban community development	(Kuo and Sullivan, 2001) (Meerow and Newell, 2017) (Demuzere et al., 2014)
	Culture	• Public education • Participation • Positive emotion	
	Public participation	• Competencies • Livable space • Art creation, travel and social	(Mell, 2009)
	Livability	• Urban attraction • Living and working environment • Healthy and sustainable lifestyle	(Benedict and McMahon, 2012)

Living environment surrounded by walkable spaces has a positive relation with longer life expectancy for elders (Takano et al., 2002) since it creates healthier and more breathable air (Benedict and McMahon, 2012). It contributes to physical connectivity of habitats and urban landscape with a supportive ecosystem (Meerow and Newell, 2017). Another study proved that people who live in a "greener" area are less fearful to its surrounding and less violent incidents are reported (Kuo and Sullivan, 2001). Both of the contributions improve community and city development in a long-term run. It was suggested that practical experiment sometime is more useful than theoretical approach to help people understand the imbalance between urban development and ecosystem restoration. Using public access gardens as a mutually beneficial method can educate people heterogeneously about the relationship of environmental and society (Demuzere et al., 2014). With an educational purpose, more participation with positive attitudes can be expected. A checklist approach used in Sweden and currently being developed in UK including seven elements emphasises health, education and regeneration, which are used to evaluate high quality living standards in the context of urban renaissance (Mell, 2009). A higher livability area where green infrastructures are applied also intends to be more attractive to business investments, tourism and homeowners, which can bring more opportunities for the incoming real estates. Economically and environmentally, friendly smart growth is the type of development that helps to improve community and city livability with a better living condition.

5. Challenges and perspectives

Despite the benefits of green infrastructure to human beings, a few recurring issues are observed and followed by the impact of urbanization where population densification and closed-packed city structure. Unhealthy phenomenon will lead to several problems that have been emerged in the past including degradation of green space quality on private properties and territories, social inequalities when green measures are implemented and resulted in lower quality green space in urban areas in the context of exploitation (Haaland and van den Bosch, 2015). Currently a movement to solve the upcoming challenges without causing further damage to the existing environment and surroundings is to review past experience from the research and regulatory action. Also, strengthening public awareness is essential for long-term development. Other potential problems such as insufficient funding and inconsistent data among regions can be interpreted as the reflection of the lack of attention from the government. Modified and amended policies, regulations, and the law must be put into practice correspondingly.

Additionally, standardized criteria for green infrastructure are emergent under the current situation. It is necessary to conduct both top-down and bottom-up approaches to implement the criteria. In other words, local landscape-scale planning is more likely to become increasingly useful by establishing assessments which can provide a more useful approach and a detailed plan. In the United States, most states have established design guidelines for various types of green infrastructure because of geographic differences. However, uniform guidelines for each geographic characteristic should be clearly stated. More research and effort should put into Best Management Practices for adaptive strategies as well as address climate change within various scenarios. Cooperation among the individual homeowner, academia, business with the non-profit sector, along with government, must be well coordinated. Financially, stable financial sources and consistent incentive measures would support evaluation and assessment of performance and cost-benefit.

The bottom-up approach is fully reflected in the implementation as shown in Fig. 3. Compared to gray infrastructure, green infrastructure intends to develop a long-term outcome. Developed landscape and hard infrastructure require each decision-maker to have alternative and contingency plans. The combination of gray and green infrastructures would be the ideal solution which would be highly suitable for current circumstances. On the one hand, it can contribute to on-site runoff attenuation and combined sewerage reduction. On the other hand, with the optimized engineering design and regularly sanitation maintenance, stormwater would be able to become more purified in a cost-effective way. The systematic optimization then, leads us to a municipal scale where a sponge city, for example, is ready to build upon. Clean domestic water supply and an optimized water-energy nexus can be expected. As a result, closer landscape connectivity with improved city livability will come with the change of structures and strategies. To adapt to climate change, the actions will assist and guide us to a relatively sustainable developing environment where the ecosystem can be restored and sustained.

CRediT authorship contribution statement

Bo-Wei Liu: Conceptualization, Data curation, Investigation, Resources, Writing - original draft. **Ming-Huang Wang:** Conceptualization, Methodology, Investigation. **Tse-Lun Chen:** Resources, Writing - review & editing. **Po-Chih Tseng:** Conceptualization, Methodology, Investigation. **Yongjun Sun:** Writing - review & editing, Project administration. **Andrew Chiang:** Writing - review & editing. **Pen-Chi Chiang:** Project administration, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

High appreciation goes to the Ministry of Science and Technology (MOST) of Taiwan under Grant Number MOST 107-2221-E-002-009-MY3, MOST 108-2911-I-002-525 and MOST 108-2911-I-002-562 for the financial support. Authors also wish to thank the Water Resources Agency of the Ministry of Economic Affairs (MOEA) of Taiwan for its financial support under grant number MOEAWRA1070458.

References

Ahern, J., 2007. Green Infrastructure for Cities: The Spatial Dimension. In, Citeseer.
Ajaero, Chukwuemeka, Meulen, Ian Vander, Simair, Monique C., Roux, Mignon le, Parrott, Joanne, Peru, Kerry M., McMartin, Dena W., Headley, John V., 2020. Developments in Molecular Level Characterization of Naphthenic Acid Fraction Compounds Degradation in a Constructed Wetland Treatment System. Environment 7 (89). https://doi.org/10.3390/environments7100089.
Al-Jayyousi, O.R., 2003. Greywater reuse: towards sustainable water management. Desalination 156 (1–3), 181–192.
Arnell, N.W., 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. Global Environ. Change 14 (1), 31–52.
Arnold, J.G., Muttiah, R.S., Srinivasan, R., Allen, P.M., 2000. Regional estimation of base flow and groundwater recharge in the Upper Mississippi river basin. J. Hydrol. 227 (1–4), 21–40.
Ashley, R., Walker, A., D'Arcy, B., Wilson, S., Illman, S., Shaffer, P., Woods-Ballard, P., Chatfield, C., 2015. UK sustainable Drainage Systems: Past, Present and Future. Thomas Telford, pp. 125–130.
Azam, M., Kim, H.S., Maeng, S.J., 2017a. Development of flood alert application in Mushim stream watershed Korea. Int. J. Disaster Risk Reduct. 21, 11–26.
Azam, M., San Kim, H., Maeng, S.J., 2017b. Development of flood alert application in Mushim stream watershed Korea. Int. J. Disaster Risk Reduct. 21, 11–26.
Benedict, M.A., McMahon, E.T., 2012. Green Infrastructure: Linking Landscapes and Communities. Island Press.
Bennett, S.J., Wu, W., Alonso, C.V., Wang, S.S., 2008. Modeling fluvial response to in-stream woody vegetation: implications for stream corridor restoration. Earth Surf. Process. Landforms J. Brit. Geomorphol. Res. Group 33 (6), 890–909.
Berndtsson, J.C., Jinno, K., 2008. Sustainability of urban water system: examples from Fukuoka, Japan. Water Pol. 10 (5), 501–513.
Carter, T., Keeler, A., 2008. Life-cycle cost–benefit analysis of extensive vegetated roof systems. J. Environ. Manage. 87 (3), 350–363.
Charalambous, K., Bruggeman, A., Lange, M.A., 2012. Assessing the urban water balance: the Urban Water Flow Model and its application in Cyprus. Water Sci. Technol. 66 (3), 635–643.
Cohen, J.P., Field, R., Tafuri, A.N., Ports, M.A., 2011. Cost comparison of conventional gray combined sewer overflow control infrastructure versus a green/gray combination. J. Irrig. Drain. Eng. 138 (6), 534–540.
Curtis, C.J., Battarbee, R.W., Monteith, D.T., Shilland, E.M., 2014. The future of upland water ecosystems of the UK in the 21st century: a synthesis. Ecol. Ind. 37, 412–430.
Daley, K., Castleden, H., Jamieson, R., Furgal, C., Ell, L., 2015. Water systems, sanitation, and public health risks in remote communities: Inuit resident perspectives from the Canadian Arctic. Soc. Sci. Med. 135, 124–132.
Davies, J.-M., Mazumder, A., 2003. Health and environmental policy issues in Canada: the role of watershed management in sustaining clean drinking water quality at surface sources. J. Environ. Manage. 68 (3), 273–286.
Davis, A.P., Hunt, W.F., Traver, R.G., Clar, M., 2009. Bioretention technology: overview of current practice and future needs. J. Environ. Eng. 135 (3), 109–117.
Dawson, R.J., Ball, T., Werritty, J., Werritty, A., Hall, J.W., Roche, N., 2011. Assessing the effectiveness of non-structural flood management measures in the Thames Estuary under conditions of socio-economic and environmental change. Global Environ. Change 21 (2), 628–646.
Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A., Mittal, N., Feliu, E., Faehnle, M., 2014. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manage. 146, 107–115.
Duelli, P., Obrist, M.K., 2003. Biodiversity indicators: the choice of values and measures. Agric. Ecosyst. Environ. 98 (1–3), 87–98.
Ellis, J.B., 2013. Sustainable surface water management and green infrastructure in UK urban catchment planning. J. Environ. Plann. Manage. 56 (1), 24–41.
Flotemersch, J., Leibowitz, S., Hill, R., Stoddard, J., Thoms, M., Tharme, R., 2016. A watershed integrity definition and assessment approach to support strategic management of watersheds. River Res. Appl. 32 (7), 1654–1671.
Foster, J., Lowe, A., Winkelman, S., 2011. The value of green infrastructure for urban climate adaptation. Center Clean Air Policy 750, 1–52.
Goldar, B., Banerjee, N., 2004. Impact of informal regulation of pollution on water quality in rivers in India. J. Environ. Manage. 73 (2), 117–130.
Haaland, C., van den Bosch, C.K., 2015. Challenges and strategies for urban green-space planning in cities undergoing densification: a review. Urban For. Urban Greening 14 (4), 760–771.
Hsu, Kuo-Wei, Chao, Jen-Chih, 2020. Economic Valuation of Green Infrastructure Investments in Urban Renewal: The Case of the Station District in Taichung, Taiwan. Environment 7 (56). https://doi.org/10.3390/environments7080056.
Kang, M.G., Park, S.W., 2015. An adaptive watershed management assessment based on watershed investigation data. Environ. Manage. 55 (5), 1006–1021.
Kataoka, Y., 2011. Water quality management in Japan: recent developments and challenges for integration. Environ. Pol. Governance 21 (5), 338–350.
Kotok, E.I., 1938. Watershed-management from the viewpoint of the forester. Advancing Earth and Space Science, 629–634. https://doi.org/10.1029/TR019i002p00629.
Kraff, D., Steinman, A.D., 2018. Integrated watershed management in Michigan: challenges and proposed solutions. J. Great Lakes Res. 44 (1), 197–207.

Kuo, F.E., Sullivan, W.C., 2001. Environment and crime in the inner city: does vegetation reduce crime? Environ. Behav. 33 (3), 343–367.
Latimer, J.S., Rego, S.A., 2010. Empirical relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. Estuar. Coast. Shelf Sci. 90 (4), 231–240.
Lovell, S.T., Sullivan, W.C., 2006. Environmental benefits of conservation buffers in the United States: evidence, promise, and open questions. Agric. Ecosyst. Environ. 112 (4), 249–260.
Lovell, S.T., Taylor, J.R., 2013. Supplying urban ecosystem services through multifunctional green infrastructure in the United States. Landscape Ecol. 28 (8), 1447–1463.
Luo, Y., Zhou, Z., Sun, Y., Deng, H., Zhang, P., Wu, G., 2003. Assessment methods of watershed ecosystem health. Acta Ecologica Sinica 23 (8), 1606–1614.
Mabelis, A.A., Maksymiuk, G., 2009. Public participation in green urban policy: two strategies compared. Int. J. Biodivers. Sci. Manage. 5 (2), 63–75.
Madhu, Kavya, Pauliuk, Stefan, 2019. Integrating Life Cycle Assessment into the Framework of Environmental Impact Assessment for Urban Systems: Framework and Case Study of Masdar City, Abu Dhabi. Environment 6 (105). https://doi.org/10.3390/environments6090105.
Matthews, T., Lo, A.Y., Byrne, J.A., 2015. Reconceptualizing green infrastructure for climate change adaptation: barriers to adoption and drivers for uptake by spatial planners. Landscape Urban Plann. 138, 155–163.
Mays, L.W., 2007. Water Resources Sustainability. McGraw-Hill, New York.
McGonigle, D., Harris, R., McCamphill, C., Kirk, S., Dils, R., Macdonald, J., Bailey, S., 2012. Towards a more strategic approach to research to support catchment-based policy approaches to mitigate agricultural water pollution: a UK case-study. Environ. Sci. Policy 24, 4–14.
Meerow, S., Newell, J.P., 2017. Spatial planning for multifunctional green infrastructure: growing resilience in Detroit. Landscape Urban Plann. 159, 62–75.
Mekonnen, M.M., Hoekstra, A.Y., 2016. Four billion people facing severe water scarcity. Sci. Adv. 2 (2), e1500323.
Mell, I.C., 2009. Can green Infrastructure Promote Urban Sustainability?. Thomas Telford Ltd., pp. 23–34.
Meng, T., Hsu, D., 2019. Stated preferences for smart green infrastructure in stormwater management. Landscape Urban Plann. 187, 1–10.
Minns, C.K., Cairns, V.W., Randall, R.G., Moore, J.E., 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' areas of concern. Can. J. Fish. Aquat. Sci. 51 (8), 1804–1822.
Mishra, A.K., Coulibaly, P., 2010. Hydrometric network evaluation for Canadian watersheds. J. Hydrol. 380 (3–4), 420–437.
Morrison, K.E., Parkes, M.W., Hallstrom, L.H., Neudoerffer, R.C., Bunch, M.J., Venema, H.D., 2012. Ecohealth and watersheds: watersheds as settings for health and well-being in Canada. Network for Ecosystem Sustainability and Health (Publication Series No. 3) and the International Institute for Sustainable Development, Winnipeg, MB. Accessed at http://www.iisd.org/pdf/2012/ecohealth_watersheds_canada.pdf
Muerdter, C.P., Wong, C.K., LeFevre, G.H., 2018. Emerging investigator series: the role of vegetation in bioretention for stormwater treatment in the built environment: pollutant removal, hydrologic function, and ancillary benefits. Environ. Sci. Water Res. Technol. 4 (5), 592–612.
Naiman, R.J., Beechie, T.J., Benda, L.E., Berg, D.R., Bisson, P.A., MacDonald, L.H., O'Connor, M.D., Olson, P.L., Steel, E.A., 1992. Fundamental Elements of Ecologically Healthy Watersheds in the Pacific Northwest Coastal Ecoregion. Springer, pp. 127–188.
Nakamura, K., 2008. River Restoration Efforts in Japan: Overview and Perspective. Public Works Research Institute, Japan. http://www.pwri.go.jp/eng/activity/pdf/reports/k.nakamura 80601
O'Neill, R.V., 1985. Hierarchy Theory and Global Change. Oak Ridge National Lab, TN (USA).
Pahl-Wostl, C., 2007. Transitions towards adaptive management of water facing climate and global change. Water Resour. Manage. 21 (1), 49–62.
Parkes, M.W., Morrison, K.E., Bunch, M.J., Hallström, L.K., Neudoerffer, R.C., Venema, H.D., Waltner-Toews, D., 2010. Towards integrated governance for water, health and social–ecological systems: the watershed governance prism. Global Environ. Change 20 (4), 693–704.
Patrick, R.J., 2011. Uneven access to safe drinking water for First Nations in Canada: connecting health and place through source water protection. Health Place 17 (1), 386–389.
Pohl, M., Alig, D., Körner, C., Rixen, C., 2009. Higher plant diversity enhances soil stability in disturbed alpine ecosystems. Plant Soil 324 (1–2), 91–102.
Raven, P., Holmes, N., Dawson, F., Everard, M., 1998. Quality assessment using river habitat survey data. Aquat. Conserv. Mar. Freshwater Ecosyst. 8 (4), 477–499.
Rijsberman, F.R., 2006. Water scarcity: fact or fiction?. Agric. Water Manag. 80 (1–3), 5–22.
Rosenzweig, C., Gaffin, S., Parshall, L., 2006. Green roofs in the New York metropolitan region: research report. Columbia University Center for Climate Systems Research and NASA Goddard Institute for Space Studies. New York, pp. 1–59.
Shen, Y.-S., Lung, S.-C.-C., 2016. Can green structure reduce the mortality of cardiovascular diseases?. Sci. Total Environ. 566, 1159–1167.
Simpson, J.R., 2002. Improved estimates of tree-shade effects on residential energy use. Energy Build. 34 (10), 1067–1076.
Sun, Yu, Tong, Susanna, Yang, Y. Jeffrey, et al., 2016. Modeling the cost-effectiveness of stormwater best management practices in an urban watershed in Las Vegas Valley. Applied Geography 76, 49–61. https://doi.org/10.1016/j.apgeog.2016.09.005.
Takano, T., Nakamura, K., Watanabe, M., 2002. Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces. J. Epidemiol. Community Health 56 (12), 913–918.
Taye, Mintesinot, Simane, Belay, Zaitchik, Benjamin F., Selassie, Yihenew G., Setegn, Shimelis, 2019. Rainfall Variability across the Agro-Climatic Zones of a Tropical Highland: The Case of the Jema Watershed, Northwestern Ethiopia. Environment 6 (118). https://doi.org/10.3390/environments6110118.
Tharme, R.E., 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Res. Appl. 19 (5–6), 397–441.
Thornbrugh, D.J., Leibowitz, S.G., Hill, R.A., Weber, M.H., Johnson, Z.C., Olsen, A.R., Flotemersch, J.E., Stoddard, J.L., Peck, D.V., 2018. Mapping watershed integrity for the conterminous United States. Ecol. Indic. 85, 1133–1148.
Thorud, D.B., Brown, G.W., Boyle, B.J., Ryan, C.M., 2000. Watershed management in the United States in the 21st Century. In: Ffolliott, Peter F., Baker Jr., Malchus B., Edminster, Carleton B., Dillon, Madelyn C., Mora, Karen L., tech. coords. Land Stewardship in the 21st Century: The Contributions of Watershed Management; 2000 March 13-16; Tucson, AZ. Proc. RMRS-P-13. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. pp. 57–64. 13.
Tsegaye, S., Singleton, T.L., Koeser, A.K., Lamb, D.S., Landry, S.M., Lu, S., Barber, J.B., Hilbert, D.R., Hamilton, K.O., Northrop, R.J., 2019. Transitioning from gray to green (G2G)—a green infrastructure planning tool for the urban forest. Urban For. Urban Greening 40, 323–334.
Tyrväinen, L., Ojala, A., Korpela, K., Lanki, T., Tsunetsugu, Y., Kagawa, T., 2014. The influence of urban green environments on stress relief measures: a field experiment. J. Environ. Psychol. 38, 1–9.
Vandermeulen, V., Verspecht, A., Vermeire, B., Van Huylenbroeck, G., Gellynck, X., 2011. The use of economic valuation to create public support for green infrastructure investments in urban areas. Landscape Urban Plann. 103 (2), 198–206.
Vergnes, A., Le Viol, I., Clergeau, P., 2012. Green corridors in urban landscapes affect the arthropod communities of domestic gardens. Biol. Conserv. 145 (1), 171–178.
Walker, B., 1995. Conserving biological diversity through ecosystem resilience. Conserv. Biol. 9 (4), 747–752.
Wang, Y., Bakker, F., De Groot, R., Wörtche, H., 2014. Effect of ecosystem services provided by urban green infrastructure on indoor environment: a literature review. Build. Environ. 77, 88–100.
Weisberg, S.B., Ranasinghe, J.A., Dauer, D.M., Schaffner, L.C., Diaz, R.J., Frithsen, J.B., 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. Estuaries 20 (1), 149.
Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y., Wilkes, A., 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. Conserv. Biol. 23 (3), 520–530.
Zeng, Y., Cai, Y., Jia, P., Jee, H., 2012. Development of a web-based decision support system for supporting integrated water resources management in Daegu city, South Korea. Expert Syst. Applications 39 (11), 10091–10102.