Monitoring Methods on Evaluating the Water-related Green Infrastructure Performance

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Abstract. Green Infrastructure (GI) theoretically can provide multiple ecosystem services, but its performance is uncertain and dynamic which will vary under the different environmental conditions, time and others. In different scenarios, it will probably provide optimal ecosystem service while also probably provide extremely less ecosystem service. This paper mainly focuses on exploring how to use implementable but simple monitoring methods to evaluate the performance of water-related green infrastructure, and discussing that the performance monitor is an indispensable part of GI’s design and practice. The process of “design-practice-monitor-feedback-adjustment”, effectively enhances the local GI’s design, construction, maintenance as well as the policy development level, and helps to achieve good ecological, economic and social benefits in the subsequent process.

1. Introduction
Green Infrastructure (GI) is considered to be an innovative stormwater management approach that also offers numerous other environmental benefits, and it has been gradually accepted and used worldwide [1]. With the urbanization process, the underlying surface of urban become covered by the impervious pavement, causing urban to be affected by the problem of rainwater overflow and water pollution. In the past in the United States, urban runoff is considered as wastewater instead of a usable resource. From 1970’s, the US government promote “best management practice”. And then in 1990’s, it’s developed to the theory of “low impact development”. Now in the 21\textsuperscript{st} century, the strategy of “green infrastructure” enrich the sustainable stormwater management mode. In 2007, the US environmental protection agency formally introduced the concept of GI into urban stormwater management measures while the conventional gray infrastructure gradually shows its drawback in dealing with the urban stormwater problems. The GI simulates natural ecosystems that absorb, slow down and filter rainwater [2]. With the impetus of institutions such as ASLA, water-related green infrastructure which to treat runoff on site by using vegetation and soil has become an important measure of solving urban stormwater problems. GI provide multiple ecosystem services, and plays important roles in offering ecological, environmental and social benefits.

Ecosystem service, the benefits that humans gain from the ecosystem [3], identified four major categories: provisioning, regulating, cultural and supporting services [4]. Water quality improvement and water quantity control are belonging to its regulating services. The evaluation of ecosystem services performance has been widely used in the practices of urban green infrastructure in the United States, and has become an important driving force for improving the construction of green infrastructure. Through monitoring its performance, analyzing its effectiveness level, assess how much ecosystem service could the green infrastructure provide. Combining this procedure with urban
planning decisions making to promote improvement of GI’s performance level, is a subject that is currently being explored and practiced worldwide.

This paper will discuss the practical monitoring methods of how to evaluating the improvement of urban runoff after implementing typical water-related green infrastructure, such as rain garden, permeable pavement, bio-retention and others.

2. Water-related ecosystem service provided by GI

Previous studies have confirmed that water-related green infrastructure can help to improve the quality of urban water, improve the public health level, bring economic benefits, and promote the value of the community, which is the main content of building a healthy city [5]. The effectiveness of GI practices can be determined by evaluating hydrological functioning and pollutant removal capabilities [1]. Green infrastructure reduces the volume of stormwater and cleans stormwater before it flows into rivers, streams, and lakes: reduces volume of stormwater by infiltrating runoff into soils which contributes to reduce flooding risks and recharges underground water; improves water quality by cleaning stormwater before it flows into the drain system and ultimately into local water bodies. Thus, water-related green infrastructure provides two major ecosystem services: improving stormwater quality and controlling stormwater quantity.

2.1. Improving stormwater quality

Water-related green infrastructure improves stormwater quality in four ways: sediment removal, nitrogen removal, phosphorus removal, and pollution control.

- Sediment removal: Soils and plants in green infrastructure can filter sediments in stormwater runoff.
- Nitrogen and phosphorus removal: Plant roots and soils in green infrastructure can absorb nitrogen and phosphorus pollutants through chemical and biological reactions.
- Organic pollution control: Green infrastructure also improves stormwater quality by reducing pollutants like oil, asphalt, and rubber tires in stormwater.

Pollutants will contaminate rivers, killing organisms living in rivers, and harmful to public health. Plants and soils, however, green infrastructure can trap and decompose those pollutants. Stormwater is purified before discharged into streams, rivers, and lakes.

2.2. Controlling stormwater quantity

Water-related green infrastructure control stormwater quantity in two aspects: stormwater runoff management, and flooding control.

- Stormwater runoff management: Stormwater infiltrates into soils instead of flowing into the sewer system directly.
- Flooding control: Green infrastructure allows stormwater runoff infiltrating into the soils, minimizing runoff volumes, and reducing peak flow.

3. Monitoring Methods

3.1. Methods to measure water quality improvement level

Multiple monitoring wells can be installed under green infrastructure (see Fig.1): one is in the infiltration layer, the other in the groundwater layer. With these two sampling wells water samples can be collected to measure nutrient/pollutant levels before, and after treatment by subsoil. Samples in the monitoring well can be analysed for its nitrogen, phosphorus, and other pollutants level (see Table 1). Water quality improvement can be analysed by comparing the water quality of stormwater flow into the traditional grey infrastructure and the water quality of stormwater that is cleaned and filtered by green infrastructure system collected in the monitoring well.
Figure 1. Installing monitoring devices into a water-related green infrastructure to collect samples

Table 1. Monitoring index to measure water quality improvement level

| Ecosystem Service                  | What to Measure                                      | How to Measure                                                                 |
|-----------------------------------|------------------------------------------------------|-------------------------------------------------------------------------------|
| sediment removal                  | 1. Water Turbidity                                    | 1. Collect inflow and outflow water samples and measure them in laboratory or directly in the installed devices |
|                                   | 2. Total Suspended Solids (TSS)                      |                                                                               |
| nitrogen and phosphorus removal   | 1. Nitrogen and Phosphorus Content                    | 2. The quantity of aquatic plants (like algae) and the types of plankton are good indicators of nitrogen and phosphorus rates |
| organic pollution control         | 1. Biochemical Oxygen Demand (BOD)                   |                                                                               |
|                                   | 2. PH                                                |                                                                               |
|                                   | 3. Water Temperature                                 |                                                                               |
|                                   | 4. Dissolved Oxygen                                  |                                                                               |
|                                   | 5. Bacteria                                           |                                                                               |

3.2. Methods to measure water quantity controlling level

V-notch and flow gauge are two basic tools to measure water quantity. A V-notch is integrated with a check dam/weir which contains scale to monitor the water quantity. In order to evaluate the performance of green infrastructure system, V-notch or flow gauge at the outflow can be implemented. The performance of green infrastructure can be evaluated by comparing the water quantity of stormwater that flows into the GI system and the water quantity of stormwater that isn’t processed by this system (measure methods see Table 2).
Table 2. Monitoring Methods to measure water quantity controlling level

| Ecosystem Service | What to Measure | How to Measure |
|-------------------|----------------|---------------|
| Stormwater runoff management | 1. Inflow and outflow rates | 1. Measuring flow velocity by installing flow monitoring meter |
|                    | 2. Inflow and outflow volume | 2. Installing V-notch weir or flow gauge to measure inflow and outflow volume |
|                    | 3. Time of stormwater concentration | |
| Flooding Control | 1. Flooding rate | 3. Monitoring river maximum water level and flow velocity |
|                   | 2. Maximum river water level | |
|                   | 3. Peak flow | |

4. Significance of monitoring the GI practices
Numerous research studies and practical applications concluded that GI approaches could effectively mitigate urban hydrology problems [1], [6], [7]. By properly monitoring the water quality and quantity to evaluate the performance of green infrastructure, the research process and implementing practice can be well connected, which will help to break the boundaries of design, construction and maintenance, continually applying the research findings to practice. Through the cycle process of “research-practice-monitoring-feedback-adjustment-practice improvement-research renewing”, the concept of “learning by doing” [8] in green infrastructure practice field will be achieved.

5. Discussion and Conclusion
Previous researches and practices have demonstrated that there is no doubt that green infrastructure can solve urban stormwater problems and obtain some water-related ecosystem services benefits. In the United States, green infrastructure is expected to reduce wastewater treatment costs by 661,000 dollars per year [9]. However, the performance of water-related ecosystem services provided by green infrastructure will vary with different environmental conditions, time, and their composition. Thus, the assessment of its performance cannot just rely on the results of previous studies. It is necessary to test the performance of different water-related green infrastructure in different regions, different times, and different scenarios.
The success of green infrastructure requires adequate investigation and monitoring of the site before and after the project implementation. meanwhile, its assessment methods should also be standardized. First, affected by different factors such as regional environment, climatic conditions and local tree species, the performance level of ecosystem services provided by the same green infrastructure is different. Therefore, through the evaluation of green infrastructure performance such as stormwater quality improving capability and stormwater quantity controlling capability on different sites, the construction of green infrastructure should be considered as an interrelated whole.
Secondly, green infrastructure is a dynamic system whose performance will changes as plants grow and mature. Keeping monitoring its performance at different periods is also important for assessing its overall performance.
Thirdly, unlike traditional grey infrastructure which typically provides only a few kinds of service, green infrastructure provides multiple types of ecosystem services. Through monitoring its performance, it can be seen how the green infrastructure cooperates with each other under different scenarios to have the best performance.
By exploring relevant monitoring methods and assessment methods, it is possible to effectively improve local green infrastructure practices and policy decision making, and achieve good ecological, economic and social benefits in the subsequent process.
6. References

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Acknowledgments
Authors wishing to acknowledge funding supports from 2019 Project of Enhancing School with Innovation of Guangdong Ocean University (570219083; 230419106); Guangdong Ocean University Undergraduate Innovation Program (CXXL2019057); and Guangdong Ocean University PhD. Scientific Research Program (R19045).