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Review

Post Construction Green Infrastructure Performance Monitoring Parameters and Their Functional Components

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Academic Editors: Yu-Pin Lin, Dirk S. Schmeller, Wei-Cheng Lo and Wan-Yu Lien
Received: 14 September 2016; Accepted: 19 December 2016; Published: 22 December 2016

Abstract: Drainage system infrastructures in most urbanized cities have reached or exceeded their design life cycle and are characterized by running with inadequate capacity. These highly degraded infrastructures are already overwhelmed and continued to impose a significant challenge to the quality of water and ecological systems. With predicted urban growth and climate change the situation is only going to get worse. As a result, municipalities are increasingly considering the concept of retrofitting existing stormwater drainage systems with green infrastructure practices as the first and an important step to reduce stormwater runoff volume and pollutant load inputs into combined sewer systems (CSO) and wastewater facilities. Green infrastructure practices include an open green space that can absorb stormwater runoff, ranging from small-scale naturally existing pocket of lands, right-of-way bioswales, and trees planted along the sidewalk as well as large-scale public parks. Despite the growing municipalities' interest to retrofit existing stormwater drainage systems with green infrastructure, few studies and relevant information are available on their performance and cost-effectiveness. Therefore, this paper aims to help professionals learn about and become familiar with green infrastructure, decrease implementation barriers, and provide guidance for monitoring green infrastructure using the combination of survey questionnaires, meta-narrative and systematic literature review techniques.

Keywords: green infrastructure; functional components; monitoring; parameters; performance; runoff; uncertainty

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1. Introduction

In the past, green space or green infrastructures such as parks, and open playgrounds were created or protected by land use planners, developers or rules and regulations of municipalities to preserve and protect the natural existing landscape and ecosystem functions. Green infrastructure defined as an open green space that can absorb stormwater runoff, includes small scale naturally existing pocket of lands, right-of-way bioswales, and trees planted alongside the sidewalk as well as large scale public parks. Recently, the use of green infrastructure practices to supplement urban stormwater management and retrofitting conventionally engineered drainage system has gained considerable interest in big cities such as New York City, Boston, Chicago, Seattle, Montgomery County, Baltimore, Washington D.C., Paris and London [1–7]. In contrast to conventional/gray drainage infrastructure, which usually has only one objective, green infrastructure practices can provide multifunctional benefits for different city agencies and stakeholders. For example green infrastructure can contribute to air pollution control, stormwater runoff volume and discharge rate reduction, water quality improvement, potential flood risk management, urban heat island effects relief, wildlife conservation, and recreational needs [8–11]. However, despite the growing municipalities' interest to retrofit existing stormwater drainage systems with green infrastructure, few studies and relevant information are available on their performance and cost-effectiveness [12–15].

2. Increasing Green Infrastructure Practices in Public Parks: Benefits and Tradeoffs

Most of the green infrastructure practices are consist of wide range of environmental features that function in different scales from minor practices such as infiltration trench to major functional unit ecosystems, such as forests, swamps, wetlands, and public parks [8,14,16–19]. Figure 1 below shows elements of green infrastructure. For example currently, big cities like New York, Chicago, Atlanta, Georgia, Birmingham, Alabama, Cambridge, Massachusetts, and Washington DC. in the USA, and London and Paris in Europe, are retrofitting public park spaces to handle more stormwater runoffs from adjacent streets and surrounding areas using green infrastructure practices. Using these park spaces could present a win-win opportunity for the cities to manage and reduce runoff volume that would have gone to CSO's and improving water quality in Municipal Separate Storm Sewer System (MS4) areas, while also meeting residents' recreation needs. However, modifying current park spaces to handle stormwater run-off or volume have advantages and disadvantages, on the upside; the land is available at no cost and on the downside, the park's existing features and uses may be altered to current users who then resist any design or management changes. Therefore, green infrastructure practices are not simple, one-size-fits for all solutions. It needs to be carefully designed, implemented and maintained in order to protect the public parks' resources and at the same time manage stormwater over the long term [18,20,21]. Even if, using cities public parks to manage stormwater is not only a revolutionary step and current time-honored tradition that creates an opportunity for civil engineers and planners to work together with ecologists, recreationists, hydrologists, public health experts and developers, it also requires new rules and regulations, advanced technologies and practices to monitor their performance with academic scientific research involved [8,22–24].

Figure 1. Elements of green infrastructure.

3. Barriers to Implementing Green Infrastructure Practices

Generally, the primary barriers to implementing green infrastructure can be categorized as design standards and codes, rules and regulations, community awareness, politics, operation and maintenance and capacity. These barriers could present vital hindrance throughout the processes of planning any particular green infrastructure projects. The nature and effects of these barriers could be so deeply intertwined or serve as a condition to implicitly whether to continue in a project set up and implementation or not [15,25–30]. Figure 2 below outlines some of the common barriers to implementing green infrastructure practices. The possible solutions for overcoming or addressing these primary barriers are provided in Figure 3 also.

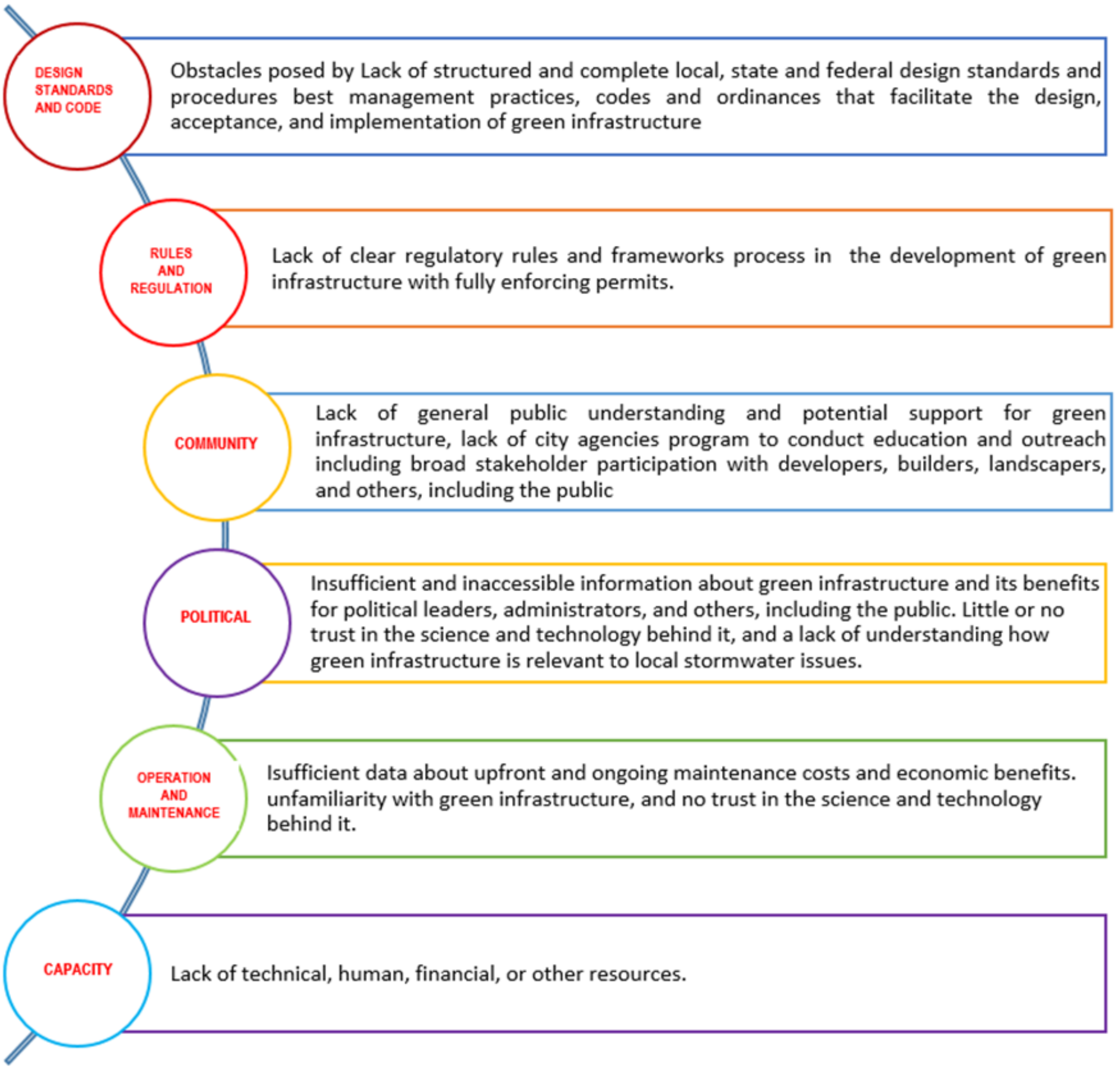

Figure 2. Common barriers for the implementation of green infrastructure initiatives.

4. Potential Solutions for Overcoming Barriers

The potential solutions for overcoming the barriers for implementing green infrastructure practices were identified with combination of fifty survey questionnaires, and one hundred ten survey recipients/ professionals included different city agencies, professional engineers, design practitioners and local leaderships (New York City Department of Environmental Protection, Department of Design and Construction, New York City Department of Parks and Recreation, New York City Department of Transportation, District of Columbia Water and Sewer Authority, City and County of San Francisco, San Francisco Public Utilities Commission, etc.) and meta-narrative and systematic literature review techniques. Meta-narrative reviews "look historically at how particular research traditions have unfolded over time and shaped the kind of questions being asked and the methods used to answer them" [31,32]. Fifty survey questionnaires were distributed among one hundred ten survey recipients/professionals and 101 responded. The questionnaire was designed to assess the potential solutions for overcoming the barriers for implementing green infrastructure practices. After exploring the knowledge, beliefs, attitudes and behavior of a group of geographically dispersed professionals and the range of approaches taken to overcome these barriers and evaluate the mechanisms, contexts and outcomes the summary of the recommended potential solutions are as follows: providing intensive training; improving ordinances; developing successful demonstration sites in all communities such as parks and ROW; cultivating local leadership; exploring uniform funding strategies; working at the watershed level through multi-municipal cooperation; and developing a social marketing strategy and public perception and acceptance of green infrastructure as illustrated in Figure 3.

Figure 3. Potential solution to overcome barriers to implementing green infrastructure initiatives.

5. Developing Monitoring and Evaluation

Developing monitoring and evaluation plan are critical to track construction green infrastructure practice's performance and ease decision-making. Monitoring and evaluation plan describes what the green infrastructure did, how it work, and why the monitoring outcome results matter. It also laying out the components of the green infrastructure practices and the steps needed. The data gathered in an established systematic fashion through these monitoring activities over time about the performance, maintenance and operational issues such as failures in technical implementation, changing funding modalities, change in funding opportunities and different stakeholder interests, etc. can be used to analyze, interpret, and draw conclusions. This allows decision makers to make informed decisions about how to adapt and make the necessary adjustments to the design of future green infrastructure practices [33–39]. However, a baseline mapping or threshold should be established and defined by the initial state of the Watershed (CSO's, MS4), or flooded areas before performing monitoring and assess the impacts and benefits of post constructed green infrastructure projects. The monitoring and evaluation of project's performance program includes several components and models. While the fundamental goals of green infrastructure practices include runoff volume reduction and increase water quality, it also offers an array of added benefits that maximize the value of these investments across multiple sectors. Therefore, identifying and measuring these added benefits through monitoring also contribute to promote and improve the cost benefit analysis and public participation for green infrastructure programs. Therefore, developing post constructed green infrastructure monitoring program must consider a comprehensive plan across goals, benefits and co-benefits beyond stormwater management to create accurate performance standards [40–43]. Moreover, developing the process of monitoring the performance of post-constructed green infrastructure practices for each site conditions and objectives should be carefully planned and scaled [41,44]. Figure 4 below shows the common components of post constructed green infrastructure monitoring and evaluating programs.

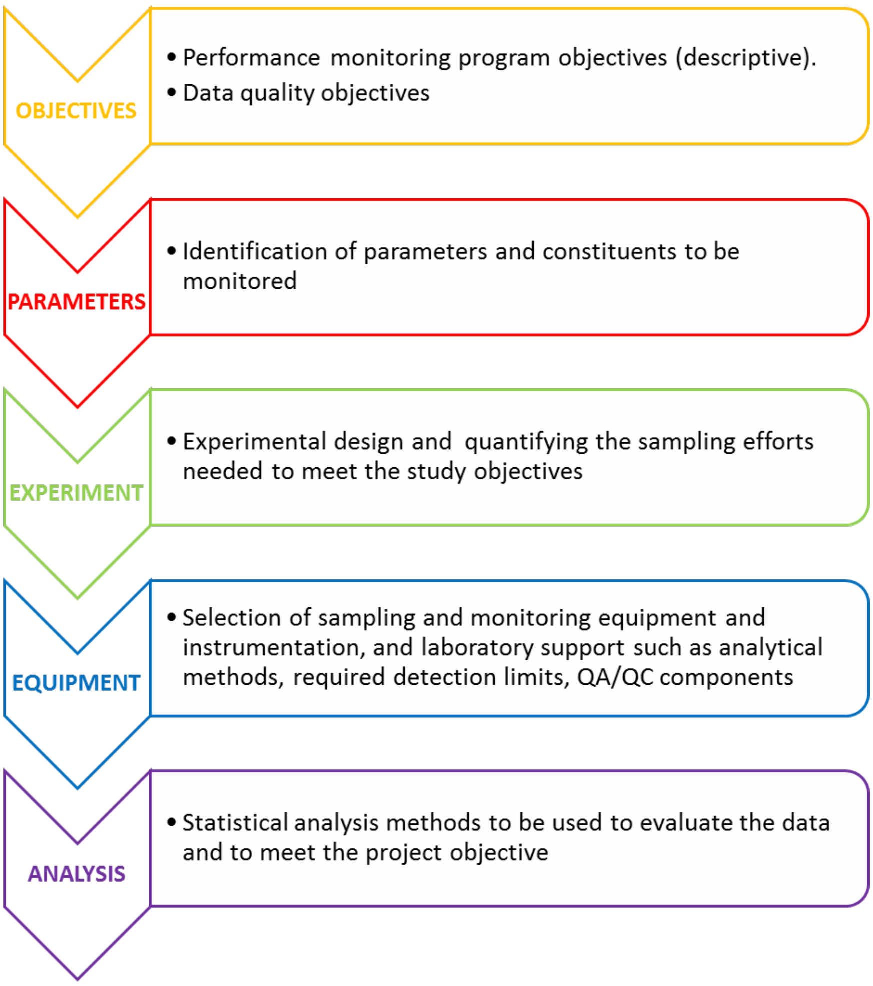

Figure 4. Components of green infrastructure monitoring program.

In general monitoring and evaluation of post-construction green infrastructure practices have three step processes. However, additional sub-questions shall be addressed in order to formulate a "well-organized" process see Figure 5 below [8,37,41,43,45]. These three step processes in conjunction with the components of green infrastructure monitoring program (Figure 4) can be elaborated in each step. These steps are fundamentals to create accurate successful and well organize green infrastructure practices monitoring and evaluating programs [36,37,41,46]. Below are the range of supplemental sub questions that should be addressed to create accurate performance standards. (I) The stormwater runoff parameters and constituents to be monitored, (II) The performance design requirements for the candidate green infrastructure practices that going to be monitored such as water quality, runoff volume and peak discharge reduction, and regulatory compliance (III) Data structure and collection plan, (IV) Types, duration and frequencies of data collection such as during which seasons, pre-construction vs. post-construction, influent vs. effluent (V) How we compare performance results to maintenance (VI) What types of monitoring equipment to be used, (VII) Who will Fund it and how much it Cost (VIII) Who will perform work, (IX) How will Data going to be collected/downloaded/and who maintained the equipment.

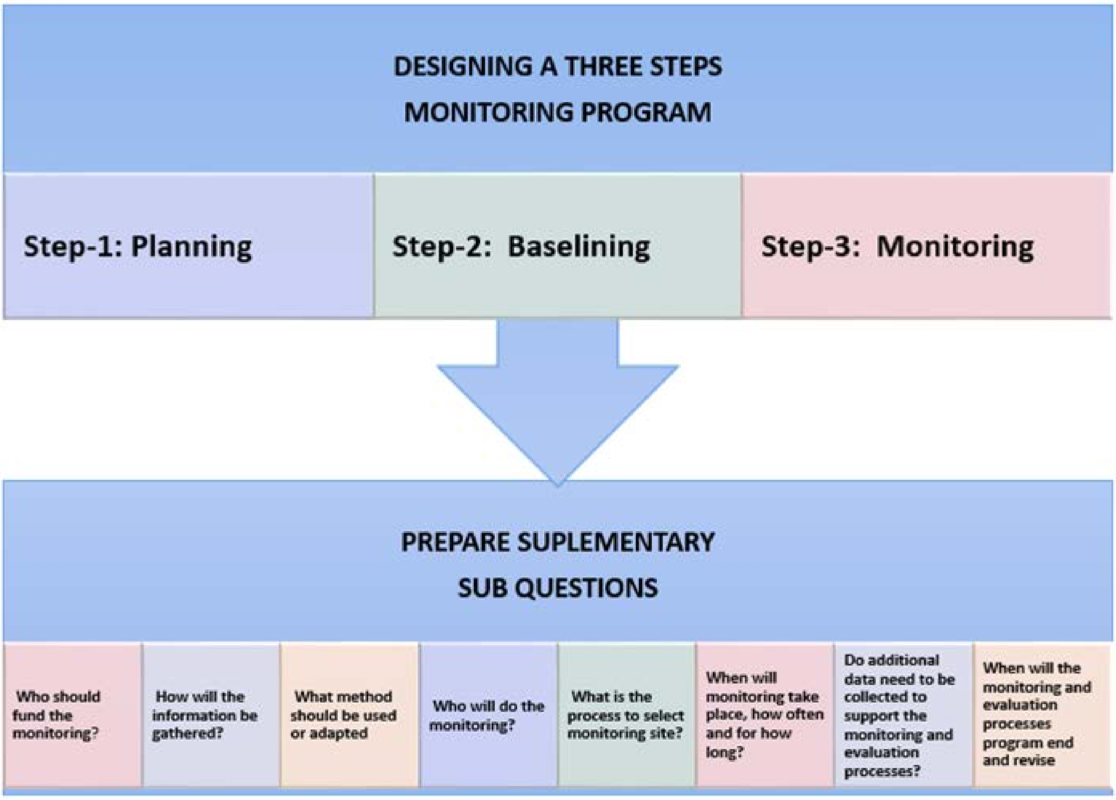

Figure 5. Three steps processes of monitoring post-construction green infrastructure and supplementary sub questions.

Designing a monitoring program also must consider many site characteristics and objectives. For monitoring purposes, it is necessary to initially select representative catchments with a different range of green infrastructure in terms of types and areas in the city. Each city agency shall establish a process that accounts for its socioeconomic and biophysical conditions [43,45,47]. Figure 6 show some of the fundamental site characteristics and objectives to design a monitoring program.

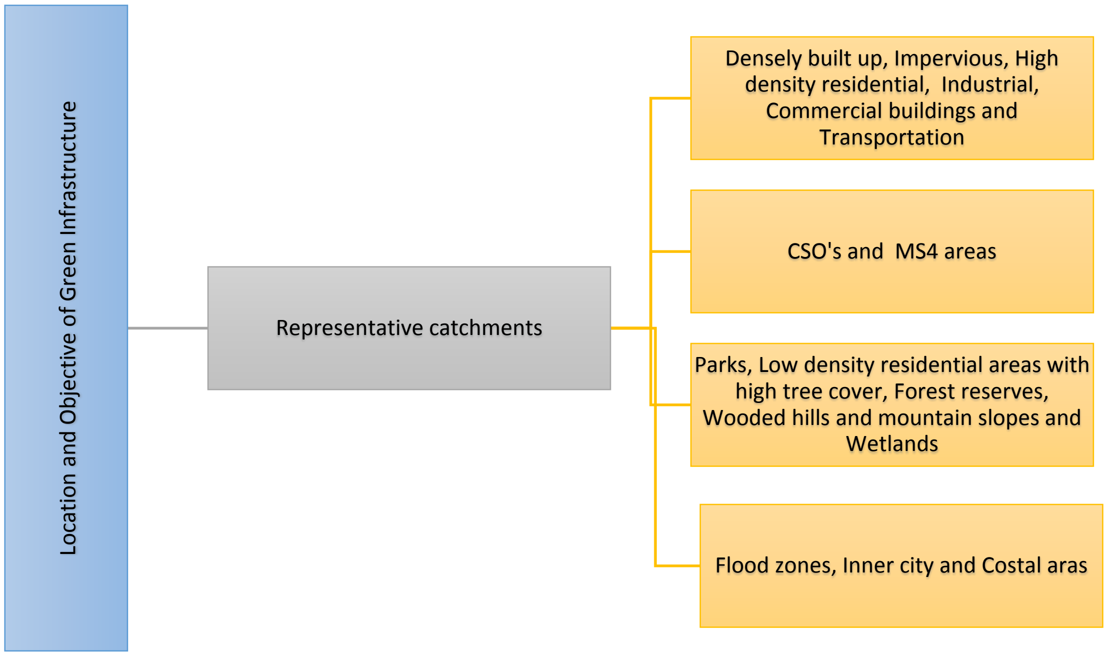

Figure 6. Site characteristics to design a monitoring program.

6. Quantitative and Qualitative Functional Components of Performance Monitoring Variables

To validate post construction green infrastructure practices are performing per designed objectives, such as minimizing the impact of stormwater runoff volume and discharge rate on the CSO or MS4 drainage areas, performance monitoring shall be performed. Therefore, municipalities need to have effective ways of performance monitoring and validating programs as part of the planning process [20,38,48,49]. Potential green infrastructure projects can be planned and designed in different ways, forms, settings, and technologies and materials depend on their functional goals and objectives. Therefore, the types of performance monitoring variables and their functional components have different identifiable qualitative and quantitative variables [31,41,44,50,51].

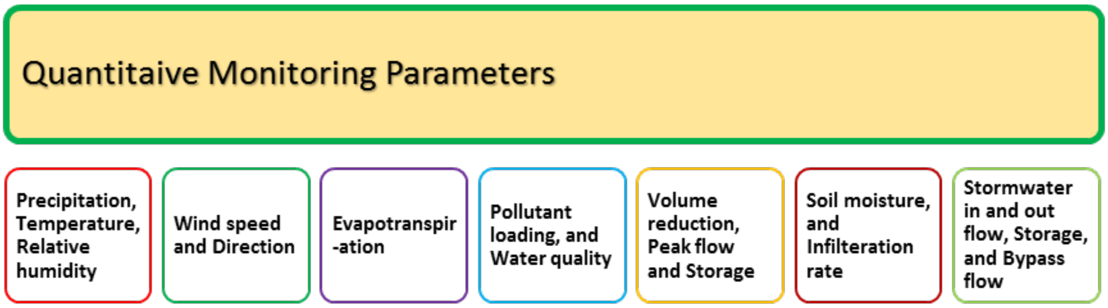

Figure 7. Quantitative monitoring variables.

Variables are conditions that have an effect on the green infrastructure programs implementation, its functional performance as designed and maintain its functionality over time. Figure 7 above and Figure 8 below show the different qualitative and quantitative monitoring variables and activities. These monitoring activities and their functional parameters can be varied by locations, physical settings, and types of the practices, materials, land use, land cover, policy/partnerships implementation strategies and community acceptance [21,37,43,52–54].

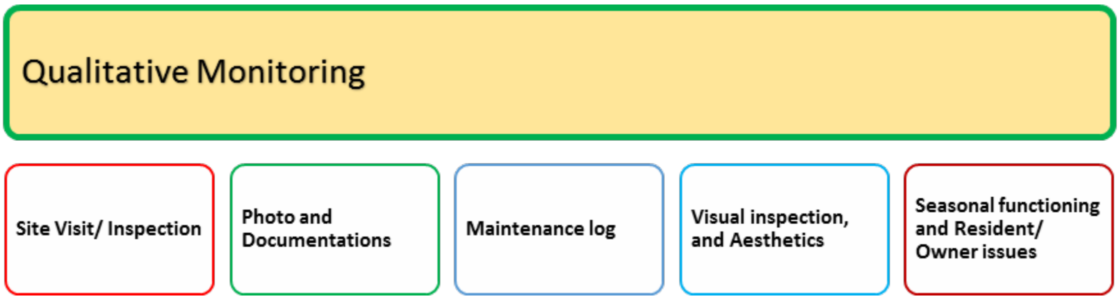

Figure 8. Qualitative monitoring activities.

For example, if the models set up to monitor the performance of post-constructed green infrastructure practice using quantitative variables such as rainfall and its functional components as hydrology and hydraulics in a particular watershed, model result should provide us information on flow quantities, qualities, and time of concentrations, what is the stormwater runoff flow pattern and how much are going to flow into green infrastructure practices? What will be the volume captured, and velocity of flow in the green infrastructure practices? How will the post-constructed green infrastructure manage and treat the stormwater runoff flows, the volume and concerned pollutants? Moreover, the hydrology and hydraulics (H&H) functional components of the rainfall can also be used to evaluate the performance of post constructed green infrastructure practices proposed as a stormwater runoff volume control measures to provide storage function for a defined storm size in the CSO drainage systems areas. An example of this might be a constructed wetland, retention basin, or right-of-way Bioswales. Since in many cases green infrastructures practices can perform beyond their design objectives of reduction of stormwater runoff volume or rate practices such as rain gardens can allow infiltration and evapotranspiration with different performance monitoring variables and functional components. Therefore, care must be given during identification of appropriate qualitative and quantitative variables to monitoring the performance of post constructed green infrastructure to produce reliable results.

7. Conclusions

Monitoring many aspects and functional performance of post-constructed green infrastructure practices are very complex and need to use an appropriate level of scientific rigor. Although some elements of post constructed green infrastructure practices with simple functions and objectives are easy to measure, it can be challenging to formulate generalized overall performance evaluation methodologies to evaluate using quantitative scientific procedures that encompass all the different green infrastructure practices objectives. Monitoring the performance of post-constructed green infrastructure practices requires a combination of qualitative or descriptive assessments with sound quantitative measures and statistical analysis. However, it is highly recommended to integrate post-normal or contextualized science concept as one of the parameters to evaluate the social robustness of the post-constructed green infrastructure projects in terms of its potential to appeal stakeholders and expand over different geographical areas and municipal laws and regulations.

Conflicts of Interest: The author declares no conflict of interest.

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