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Research article

Approach and case-study of green infrastructure screening analysis for urban stormwater control

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ABSTRACT

Urban stormwater control is an urgent concern in megacities where increased impervious surface has disrupted natural hydrology. Water managers are increasingly turning to more environmentally friendly ways of capturing stormwater, called Green Infrastructure (GI), to mitigate combined sewer overflow (CSO) that degrades local water quality. A rapid screening approach is described to evaluate how GI strategies can reduce the amount of stormwater runoff in a low-density residential watershed in New York City. Among multiple possible tools, the L-THIA LID online software package, using the SCS-CN method, was selected to estimate relative runoff reductions expected with different strategies in areas of different land uses in the watershed. Results are sensitive to the relative areas of different land uses, and show that bioretention and raingardens provide the maximum reduction (~12%) in this largely residential watershed. Although commercial, industrial and high-density residential areas in the watershed are minor, larger runoff reductions from disconnection strategies and porous pavement in parking lots are also possible. Total stormwater reductions from various combinations of these strategies can reach 35–55% for individual land uses, and between 23% and 42% for the entire watershed.

1. Introduction

One of the major challenges for the growing number of megacities (>10 million inhabitants, Li et al., 2015) is water, specifically management of urban stormwater (Larson et al., 2016). Managing urban stormwater is a critical topic because global population became majority urban in 2010 according to data from the United Nations and World Bank. In many older cities, existing wastewater infrastructure is surcharged in wet weather, resulting in combined sewer overflows (CSO), when untreated sanitary wastewater dominated by stormwater is diverted into nearby waterways. In the United States, many large municipalities are thereby out of compliance with the Clean Water Act, and are compelled by the US EPA to identify ways of reducing CSO to limit local environmental impact and improve water quality. Better control of stormwater is therefore a major concern of urban water managers.

Until recently, the default “gray infrastructure” approach to controlling stormwater and CSO was to construct ever larger-capacity pipe systems and subsurface storage facilities. Climate change and sea-level rise, especially in coastal cities, are likely to overwhelm this traditional approach to stormwater management, so urban water managers are exploring more sustainable approaches involving source control of stormwater. These more environmental approaches, collectively known as sustainable urban water management (SUWM) (Marlow et al., 2013), include techniques such as Low Impact Development (LID), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), or SUDS (Sustainable Urban Design Systems) in different parts of the world (Fletcher et al., 2014), all of which are generally referred to as Green Infrastructure/Low Impact Development (GI/LID) in this study.

This sustainable urban water management approach to controlling stormwater at the source is expected to be more cost-effective since it is amenable to adaptive management (AM) (Chaffin et al., 2016), in which short-term co-benefits (Demuzere et al., 2014) are realized. Co-benefits such as improved public health and other ecosystem services (Berland and Hopton, 2014) contribute to improved quality of life for urban dwellers as well as help mitigate climate change. Climate change and resulting changes in urban hydrology are also major drivers that favor flexibility, resilience and adaptability – hallmarks of AM - in municipal water management decisionmaking (Casal-Campos et al., 2015; Brown, 2014). Compared to traditional (gray) wastewater

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infrastructure construction in which upfront investment is followed by a lengthy time period for construction before reductions of environmental impact, AM allows a phased experimental implementation of “green” stormwater controls combined with monitoring, evaluation and adjustment (Chaffin et al., 2016; Allen and Garmestani, 2015). As part of its Long Term Control Plan (LTCP) process for requiring US metropolitan areas to meet the standards of the Clean Water Act, the US EPA has encouraged GI/LID as a primary strategy for controlling and reducing CSO (USEPA, 2014). A number of major US cities, such as Philadelphia (PWD, 2011), Baltimore (Baltimore DPW, 2015), Chicago (City of Chicago, 2014) and New York (NYCDEP, 2010) have made investments of differing magnitude in such GI/LID adaptive management approaches.

GI/LID, by its largely decentralized nature and multiple spatial scales, includes numerous techniques to control and exclude stormwater from urban water pipe infrastructure: specifically various types of bioretention (stormwater wetlands, street tree infiltration trenches, rain gardens, green roofs), infiltration enhancement (permeable pavement, infiltration swales), rainwater harvesting (rain barrels, cisterns), and public facility rebuilding (greenstreets, schools, parkland). These highly differentiated and customizable source-controls each have differing suitability and public acceptance (Hopton et al., 2015) on public and private property with different urban land uses. This makes it difficult to predict a-priori which ones will have the maximum ability to retain and manage urban stormwater. Efforts are underway in many municipalities (e.g. NYCDEP, 2014a) to pilot, evaluate and standardize designs for urban GI/LID in order to minimize these variables. However, for planning purposes, the level of technical detail in many GI/LID designs often hampers the ability to predict their effectiveness. In addition to institutional and organizational obstacles (Chaffin et al., 2016) to more rapid and widespread implementation of these techniques, a major problem for water managers has been to identify the best combination of these techniques to maximize stormwater runoff reduction in areas of differing land use in a given urban watershed. Such a screening step is desirable at the outset of an AM-driven process to implement GI/LID.

Many tools and approaches for evaluating GI/LID exist, ranging from the extremely complex, requiring considerable data and expertise, to the much simpler, easier-to-use techniques that employ widely available data. In this work, after a brief survey of available software tools, I present one approach of screening analysis for a large urban watershed in New York City. Using an online modeling application, I analyze potential stormwater runoff reductions from GI/LID, and discuss sensitivity to relative proportion of different watershed land use areas. It is expected that some types of GI/LID are more effective than others in capturing stormwater depending on the land use in the watershed. Given the highly differentiated and customizable GI/LID techniques for runoff source control, a generalized rapid screening process is useful to prioritize the best techniques for a cost-effective, experimental implementation according to the principles of AM. Hence, the objectives of this study are to demonstrate such an approach and identify the most effective combinations of different GI/LID techniques for the study watershed to address the problem of excess stormwater. This screening technique can be easily applied to large areas of urbanized watershed to determine the potential benefits, and assist water managers in making choices among options of GI/LID. In contrast to more time-consuming intensive studies, such rapid screening is increasingly necessary as major decisions involving investment of billions of dollars of public funding are pending in multiple watersheds around the urban area of New York City and other US urban areas.

2. Materials and methods

2.1. Choice of study site location

The New York City Department of Environmental Protection (NYCDEP) has divided the New York City metropolitan area into eleven watersheds draining to different waterways, for which proposals called Long Term Control Plans (LTCPs) are developed to meet standards of the Clean Water Act. Some of these LTCP proposals are complete and pending approval by the state regulatory authority acting for the USEPA, while others are in progress. Public and regulatory authority comments are solicited over a period up to a year or more for each, resulting in revisions and modifications, after which the LTCPs are expected to be approved, and together result in a Citywide plan in 2018 to invest billions of dollars to improve local coastal water quality.

These watershed LTCPs address regions of differing land-uses, some located in highly urbanized, commercial, even industrial areas, while others are dominated by high to low-density residential housing, but each covers areas of thousands of square hectares. For this study, one of these urban watersheds was selected for analysis, the Alley Creek watershed (Fig. 1), because it was one of the first areas for which a LTCP was completed (NYCDEP, 2014b), and the location of a previous study (Eaton et al., 2013). Although street-level analyses of stormwater have been conducted elsewhere by the NYCDEP, data are not available for this area, however the flashiness of USGS hydrograph records confirm that stormwater affects Alley Creek. The Creek is a small waterway draining a relatively undeveloped natural wetland area surrounded by the low-density, largely residential community of Douglaston (Fig. 1), and discharging into Little Neck Bay on the north shore of Long Island.

However, Alley Creek has experienced significant water quality problems due to stormwater and CSO discharge (NYCDEP, 2014b; Eaton et al., 2013). This major source of pathogens, floatable and oxygen-consuming wastes from CSO prevents the waterway from attaining a higher quality than secondary contact recreation and fishing, and threatens the higher water quality in Little Neck Bay into which it discharges. It is unclear whether the proposed LTCP will be sufficient to significantly improve creek water quality, because the main strategy of the NYCDEP is not to retain additional CSO, but to disinfect existing CSO discharges using chlorination (NYCDEP, 2014b). Control of stormwater is currently the focus of a separate ongoing MS4 permitting process.

2.2. Comparisons and selection of method

Several different classes of tool have been used to evaluate the feasibility of sustainable methods of stormwater control known as Green Infrastructure. Possible tools range from simple online web-based rating systems through decision support systems (DSS), up to highly sophisticated modeling applications, including stand-alone proprietary software packages. Data requirements and user skills to operate these tools are quite variable. Some are simple, online calculators or spreadsheet planning applications for specific sites that anyone can use, provided data can be obtained. Others are more complex, requiring some application of hydrologic principles, and many regional scale applications involve intensive use of digital (GIS) data (Table 1). Depending on the objectives for which they were designed, such tools address considerably different levels of detail, or require different levels of data complexity or technical skill to process input or interpret output data.

A comprehensive evaluation and intercomparison of all these different packages is beyond the scope of this paper, but three major considerations constrain the selection of the appropriate tool for this study: 1) scale and applicability, 2) purpose or intent of the