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Modeling the cost-effectiveness of stormwater best management practices in an urban watershed in Las Vegas Valley

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ABSTRACT

The Las Vegas Valley is one of the fastest growing urban areas in the United States. Any future urbanization and climate change, especially if the climate becomes wetter and there are more intense and frequent storm events, will undoubtedly cause excessive urban stormwater runoff and exacerbate flooding in the Valley. Stormwater management is therefore one of the key challenges to the local government. The main goal of this study was to ascertain the utility of Best management Practices (BMPs) in mitigating stormwater runoff in the Duck Creek watershed in the Las Vegas Valley. The cost-effectiveness of different BMPs were also compared so as to determine the best BMP arrangement under the current and future climate and land use change conditions. By applying SUSTAIN (System for Urban Stormwater Treatment and Analysis INtegration) as a comprehensive GIS-based modeling and decision support system in the BMP analyses, modeling results show that although the installation of the existing three detention basins in the watershed can provide a 9% flow reduction, these three detention basins alone will not be adequate in the future with the impending changes in climate and land use. To alleviate the potential problems of water resources, SUSTAIN was further used to determine the number of additional BMPs required, the optimal types of BMPs (such as, detention and infiltration BMPs), and their locations in reducing storm runoff in the watershed under the future land-use and climate regimes. By comparing the performances of five potential BMP implementation scenarios, it was found that a mixed implementation of one additional detention BMP and one infiltration BMP to the existing detention BMPs in the downstream area of the watershed would be the most cost-effective stormwater runoff control solution in face of future urbanization and climate change. Depending on the locations of the new detention and infiltration BMPs, surface flow, even without BMP retrofit options, could be reduced by 27–31%. The cost for such installations would range from $1,141,000 to $1,319,000. This information may be useful to local planners and water resource managers in their efforts to develop alternative stormwater management plans in the arid Southwest.

1. Introduction

1.1. Background

Watershed stormwater management is facing increasing challenges in the new era due to anthropogenic and natural changes, such as urbanization and the impending climate change. Urbanization is the transformation from natural landscape to urban impervious land surface, and this type of land-use change can have significant impacts on both the quantity and quality of water resources in a watershed (Lambin & Geist, 2006; Xian, Crane, & Su, 2007). The increase of impervious surface can lead to an increase of excessive stormwater runoff and can cause severe urban flooding. Moreover, the non-point source (NPS) pollutants carried by urban runoff will deteriorate water quality in receiving water bodies, such as lakes, seas, or oceans (Tong, Sun, Ranatunga, He, & Yang, 2011).

Apart from urbanization, climate change is another important factor that affects watershed hydrology. According to the assessment by the Intergovernmental Panel on Climate Change (IPCC, 2008), our global temperature is increasing due to the increase in

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greenhouse gases, and the precipitation trend is changing as well. The changing temperature and shifting precipitation patterns can increase the chance of severe weather conditions, such as tornados, hurricanes, thunderstorms, and prolonged heavy precipitation (IPCC, 2008). In the arid American Southwest, climate change can cause more erratic and unpredictable rainfall events with short duration but extremely high intensity, which will increase the likelihood of flash floods, particularly in the urban areas (Melillo, Richmond, & Yohe, 2014).

Nestled within the Las Vegas Valley is the Las Vegas metropolitan area, one of the fastest growing urban areas in the United States. From 2000 to 2010, among all the metropolitan areas in the United States, Las Vegas was the third fastest-growing area; its population increased from 1,375,765 in 2000 to 1,951,269 in 2010, with a growth rate of 41.8% (U.S. Census Bureau, 2016). Currently, the population in the Las Vegas metropolitan area is still growing, and it is estimated to reach 3 million by 2050 (LVRDA, 2016). As population growth and urbanization continue in Las Vegas, the demand for clean water supply will increase. Besides, there will be more impervious surfaces, such as pavements, roads, parking lots, buildings, and rooftops (Acevedo, 1999; Auch, Taylor, & Acevedo, 2004). These impermeable land areas will increase the amount of stormwater runoff and aggravate urban flooding problems. Changes in future climate, in terms of temperature and precipitation patterns, can also affect water demand, urban hydrology, as well as the frequency and magnitude of floods in the Las Vegas Valley. According to the reports from the Regional Flood Control District of Clark County in Nevada (CCRFCD, 2014), between 1905 and 1975, there were about 200 flood events, many of which occurred in the Las Vegas Valley. But since 1980s, the flood events are more frequent, particularly in 1991, 1999, and 2012. Flash floods during the summer time have been causing numerous damages. In one of those storms that occurred on August 22, 2012, the peak flow of most major rivers in the Las Vegas Valley reached more than 5000 cubic feet per second (cfs), and near the downstream of Duck Creek where it joins Las Vegas Wash, the peak flow even reached as much as 10,300 cfs (CCRFCD, 2014).

When climate and land-use changes are coupled together, the hydrologic impacts can be substantial, affecting not only the amount of urban runoff but also water quality. An increased amount of urban runoff from the Las Vegas metropolitan area can carry more non-point source (NPS) pollutants, delivering them to the downstream receiving water bodies, such as Lake Mead (Fig. 1). Because Lake Mead is the primary drinking water supply for the entire metropolitan region and other southwestern states (USEPA, 2006; USGS, 2000), any water quality deterioration can have profound impacts on the area. Sustainable water resource management and urban development has therefore become one of the main challenges to the local government.

In order to protect the valuable water resources and to alleviate the potential flooding problems in the Las Vegas Valley in the face of future urbanization and climate change, it is important to derive improved methods to reduce urban stormwater runoff. The use of Best Management Practices (BMPs) can be an effective stormwater management strategy to resolve the challenges brought by the anticipated negative hydrologic impacts of urbanization and climate change (CCRFCD, 2014).

BMPs refer to water resource management strategies which use different types of infrastructures and techniques to minimize water quantity and quality problems, such as flooding and NPS water pollution (USEPA, 2015). In highly urbanized watersheds, the implementation of appropriate BMPs can control urban stormwater runoff caused by the increase of impervious land surfaces and reduce the risk of urban flooding (USGS, 2000). In a study of Kansas City, Missouri, Lee et al. (2012) found that appropriately designed structural BMPs can effectively reduce discharges from stormwater runoff by more than 50% in a small urban watershed. But the choice of BMPs is often dependent on the objectives of such installation and the cost-effectiveness of the scheme, and most importantly, the physical constraints and the spatial scale of the watershed. For example, among the most commonly used BMPs in urban watersheds, such as detention basin, infiltration basin, stormwater wetland, sand filter, bioretention basin, rain barrel, riparian buffer, and vegetated filter strip, detention and infiltration facilities are the most appropriate BMPs for an arid urban environment with a larger spatial scale (Caraco, 2000; Lai et al., 2007).

Although there are several studies on urbanization, water quality, and water management in the Las Vegas Valley (see for example, Morris, Devitt, Crites, Borden, & Allen, 1997; Reginato & Piechota, 2004; Stave, 2003), little work has been done on the cost-effectiveness of different stormwater BMPs in this arid urban area in attenuating urban runoff and reducing flash floods during intense summer rain storms. Research is therefore needed to identify the optimal number, locations, and types of BMPs needed to control stormwater runoff. In this study, the performances and cost-effectiveness of different BMP implementation scenarios (detention BMPs, infiltration BMPs, or both) in reducing stormwater runoff in the Duck Creek watershed under future land-use and climate regimes were explored using System for Urban Stormwater Treatment and Analysis Integration, SUSTAIN (Lai et al., 2007), as a GIS-based modeling and analytical tool. Although other BMPs could be used in an urban watershed environment, only detention and infiltration BMPs were modeled in this watershed due to the small size of the watershed, its semi-arid and hilly physical environmental conditions, and the requirements for BMP implementations, such as the availability of flat area, soil conditions, and terrain.

1.2. BMP analyses and SUSTAIN

In many BMP studies, the processes of watershed modeling and BMP modeling are separated, and each process relies on its own model for its analyses. For example, in the study of stormwater management in the Los Angeles International Airport, Akerman & Sterin (2008) used a watershed hydrologic model, the Hydrological Simulation Program-Fortran (HSPF), to simulate the hydrologic conditions in the area. The results from the HSPF simulation were subsequently fed into a BMP simulation model to analyze the effectiveness of BMPs in reducing stormwater runoff. Similar procedures were also employed in the BMP studies conducted by Sample et al. (2003) and Morari, Lugato, and Borin (2004). Since their approach uses separate models and the methods are not integrated under one platform, there is no interface for data inputs and model outputs. Tedious work of non-GIS to GIS data format conversion (such as from ASCII format to GIS shapefile) and model verification are often required. It therefore renders the research effort extremely cumbersome and complicated.

For other researchers, they use Soil and Water Assessment Tool (SWAT) to simulate the effects of BMPs. Although SWAT integrates watershed modeling with BMP modeling, its application is limited, as most of its BMPs are confined to agricultural use (Gitau, Gburek, & Bishop, 2008; Kieser & Associates, 2008; Strauch, Lima, Volk, Lorz, & Makeschin, 2013; Zhang & Zhang, 2011). Hence, there remains a lack of a comprehensive spatial modeling approach for urban BMPs that can integrate watershed and BMP modeling under a common framework.

SUSTAIN, on the other hand, is a comprehensive GIS-based decision support system for modeling and assessing the performances of BMPs in urban watersheds. The key components of SUSTAIN include a watershed module, a BMP simulation module, a BMP