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Implications of bioretention basin spatial arrangements on stormwater recharge and groundwater mounding

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ABSTRACT

Stormwater bioretention basin recharge has the potential to raise the watertable and adversely impact subsurface infrastructure, undermining the benefits of naturalizing the urban water cycle. This research examined how groundwater mounding responded to three spatial arrangements of bioretention basins, from separated units to clustered units to single units, and changes in hydraulic conductivity, storm intensity, and antecedent recharge, for 28 sub-watersheds in an 8-ha Syracuse, New York, sewershed with 43% impervious cover. Bioretention basin volumetric capacities were designed for a 24-h duration 2-yr return interval rainfall event. MODFLOW simulations with hydraulic conductivity at 1 cm h^{-1} predicted an increase in median groundwater mounding from 0.28 m to 0.72 m when separation distances were reduced from equally distributed to single units. In sag points, however mounding exceeded 1 m. By setting hydraulic conductivity to 0.01 cm h^{-1}, a worst case scenario, median mounding was greater than 1 m for all spatial designs, in all locations. Groundwater mound overlap was identified for spatial arrangements where intersecting streets created superposition, and greater mounding was observed at corner-situated bioretention basins. After 30 years of recharge, the steady state watertable had risen by 1.1 m, and subsequent storm event mounding could interfere with subsurface infrastructure in approximately 20% of the watershed, localized in the floodplain. This study recommends an expanded investigation of long-term watertable adjustment, possibly followed by removal of some floodplain infrastructure or designs to enhance watertable tolerance.

1. Introduction

Impervious land cover typically prohibits or retards rainfall infiltration, and thereby alters site hydrology, typically degrading water quantity and quality (Horner et al., 1994; Schueler, 1994; Endreny, 2005), and adversely impacting both society and nature. As a response, low impact design (LID) has been promoted as a sustainable method for watershed development and restoration, where LID minimizes imperviousness and maximizes naturalized hydrologic cycling (PGC DER, 1999). One stormwater LID is the bioretention basin, also called a rain garden by landscape architects, which naturalizes stormwater recharge (Winogradoff and Coffman, 2001) and has other ecological attributes. Ecological attributes of the bioretention basin include nutrient cycling, air and water pollutant abatement (Davis et al., 1998; Nowak et al., 2002), carbon sequestration (Nowak and Crane, 2000), habitat augmentation and connectivity (FISRWG, 1998), street-side beautification (Westphal, 2003), reducing building heating and cooling costs (Heisler, 1986), and urban heat island mitigation through direct shading and indirect evaporative cooling (Akbari, 2002; Streiling and Matzarakis, 2003). In practice, a spatial array of

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street-side bioretention basins is needed to achieve LID, yet existing construction typically prohibits optimal bioretention placement. This paper examines the hydrological implications of compromising optimal bioretention basin placement in an urban residential area.

In this research, computer simulation is used to examine the impact of bioretention basins on groundwater mounding, in an attempt to balance recharge naturalization and infrastructure safety. General design guidelines suggest the bioretention basin is approximately 5–7% of the effective upslope drainage area contributing runoff (USEPA, 1999); however, the density of bioretention basins is controlled by available space, local rainfall depths, infiltration rates and extent of impervious cover in the watershed. In this design, the basins are constructed to process on-site infiltration depths that are greater than depths found in typical natural conditions. Excessive bioretention infiltration depths have the potential to lead to excessive groundwater recharge and mounding, and generate subsurface infrastructure risk. Recharge in climatic regions where rainfall depths exceed evaporative demand set up watertables vulnerable to mounding, and provide a conservative scenario for identifying groundwater mounding threats. This research is conducted in such a region. Further, changes in the spatial arrangement of the bioretention basins should affect mounding patterns, so this research adjusts basin patterns while maintaining a constant basin density. The sections that follow describe the study site, the different bioretention basin spatial arrangements, the rainfall-runoff simulation, and groundwater mounding impacts, and provide a discussion and conclusion.

2. Methods

2.1. *Study site watershed and climate characteristics*

This analysis of bioretention basin impacts on groundwater mounding used simulation of an urban residential site in Syracuse, New York, USA, with a population density of 23 people per hectare. Syracuse is characterized by a continental humid climate, with the annual precipitation evenly distributed through all months. Eighty years of records from the local Hancock International Airport (NYS Climate, 2002) give an average annual precipitation depth of 1017 mm, of which 307 mm liquid equivalent is snow. The average January minimum air temperature is −10 °C and the average July maximum air temperature is 28 °C. Rainfall, which is of interest in our study, is primarily delivered by spring and autumnal mid-latitude cyclones and summer convective storms. Soils in the study are floodplain alluviums and glacial tills and urban fill (Craul and Klein, 1980).

The study site is 8-ha of sewer service area federally permitted as combined sewer overflow (CSO) 050, which is being separated into stormwater and sanitary sewers in 2008. The area has 4.2 km of curb or street edge, 27 stormwater drainage inlets, and 1.4 km of sewers that will be dedicated to stormwater conveyance (see Fig. 1). The stormwater will discharge into the adjacent Onondaga Creek, which is part of the larger Lake Ontario drainage basin. The drainage area CSO 050 is bounded at the west by a drumlin, and at the east by Onondaga Creek, which was incised through a series of drainage and flood control projects in the 1900s (Endreny, 2004), incrementally lowering the local watertable. Groundwater depths are reported at various municipal and private contractor boring sites nearby CSO 050, and range from 3.3 m to 4.2 m below the land surface at distances 5–25 m from Onondaga Creek (Onondaga County, 2001).

Sewer separation will result in less water sent to the wastewater treatment plant, and the increase in stormwater discharge into Onondaga Creek was examined by Black and Endreny (2006) using the Stormwater Management Model (SWMM) (Huber and Dickinson, 1992). Analyzing 50 historic precipitation events, SWMM predicted sewer separation will increase median discharge peak magnitude by 113%, duration by 2044%, and volume by 617%. In simulation of design storms,

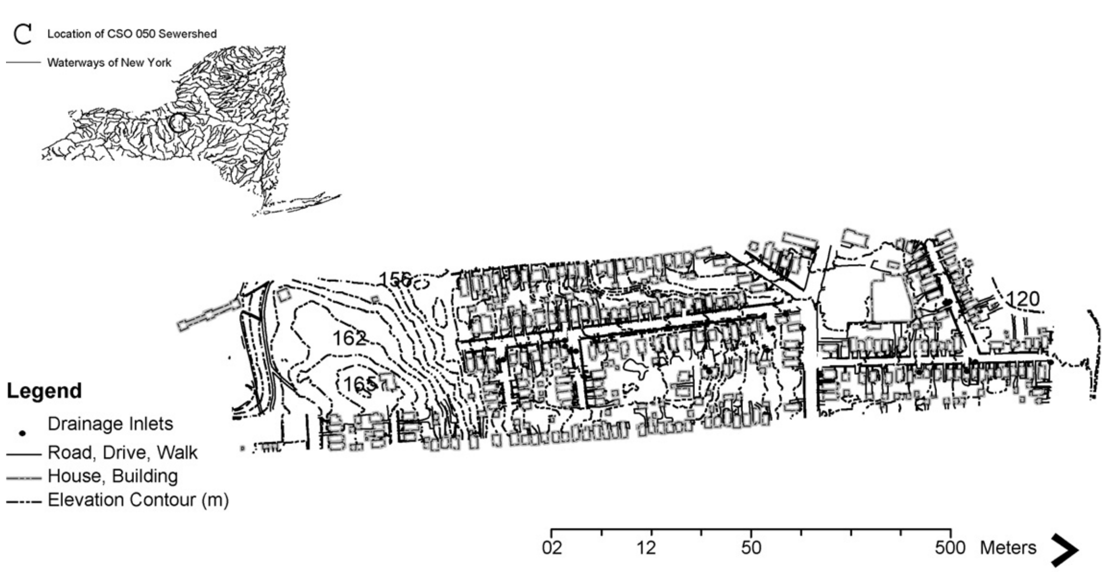

Fig. 1 – Plan view of the 8-ha residential study site with an inset showing its approximate location in New York. The study site map notes existing stormwater drainage inlets, roads, buildings, and elevation contours (m).