Documenting the Urban Water Cycle and Implications for Determining the Effectiveness of Transforming the Landscape with Green Stormwater Infrastructure

Documentation du cycle de l'eau en milieu urbain et conséquences pour la détermination de l'efficacité de la transformation du paysage avec une infrastructure verte de gestion des eaux pluviales

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RÉSUMÉ

En raison des interventions humaines ayant une incidence sur le transport et le drainage de l'eau, le cycle de l'eau en milieu urbain comprend un certain nombre de flux hydrologiques mal caractérisés, voire jamais. Par conséquent, il est très difficile de documenter l'efficacité de l'infrastructure des eaux pluviales écologiques dans la réduction du volume des eaux pluviales générées sur les sites réaménagés. L'absence d'observations sur le terrain des bassins versants et des réseaux d'égouts urbains entrave également l'exécution des routines de vérification et d'étalonnage du modèle pluie-débit. Cela conduit à l'utilisation de modèles non calibrés pour la quantification des techniques de gestion des bassins versants urbains. Pour mieux comprendre la gestion des bassins versants urbains, un consortium de partenaires académiques, à but non lucratif et gouvernementaux a entrepris une surveillance complète du cycle de l'eau dans un sous-bassin d'environ 5 hectares situé à Detroit, Michigan (États-Unis). Le site est en cours de réaménagement pour intégrer l'agriculture urbaine et l'infrastructure des eaux pluviales vertes afin de capturer les eaux pluviales qui entreraient autrement dans le système de collecte des eaux usées combinées. Les implications pour la planification, la modélisation et l'amélioration des pratiques de gestion des égouts sont décrites afin de démontrer comment cette étude est transférable à d'autres environnements urbains.

ABSTRACT

Due to human interventions that affect the conveyance and drainage of water, the urban water cycle includes a number of hydrological fluxes that are poorly, if ever, characterized. Therefore, documenting the effectiveness of green stormwater infrastructure in reducing the volume of stormwater generated at redeveloped sites is very challenging. The lack of field observations of urban watersheds and sewersheds also hampers the execution of rainfall-runoff model verification and calibration routines. This leads to the use of uncalibrated models for the quantification of urban watershed management techniques. To better understand urban watershed management, a consortium of academic, non-profit, and governmental partners have undertaken full water-cycle monitoring in an approximately 5 hectare subcatchment located in Detroit Michigan (USA). The site is undergoing redevelopment to incorporate urban agriculture and green stormwater infrastructure to capture stormwater that would otherwise enter into the combined sewer collection system. Implications for planning, modeling, and improved sewer-management practices are described to demonstrate how this study is transferable to other urban environments.

KEYWORDS

green stormwater infrastructure, modeling, monitoring, urban drainage systems, urban agriculture

1. INTRODUCTION

Stormwater management in urban landscapes has significant challenges, especially when the urban area is serviced with combined sewers where sanitary and stormwater is mixed in a single system. The initial step in addressing those challenges is to accurately conceptualize the local urban water cycle. Figure 1 is our graphical depiction of the urban water cycle with the effect of green stormwater infrastructure (GSI) included. GSI uses rainwater harvesting, vegetation, amended soils, and natural processes to manage stormwater and create healthier urban environments. As such, GSI is an increasingly common tool for retrofitting around traditional infrastructure to manage stormwater in urban environments. An estimating approach, based on a model of anticipated performance, is commonly used to determine "effectiveness" of GSI because of the difficulties associated with accurately modeling green infrastructure. As such, the "success" or cumulative effect of green infrastructure implementation is often estimated and not measured. Therefore, this research had two overarching goals – 1) to document the urban water cycle and 2) to determine the effect of GSI retrofits on combined sewers based on calibrated models.

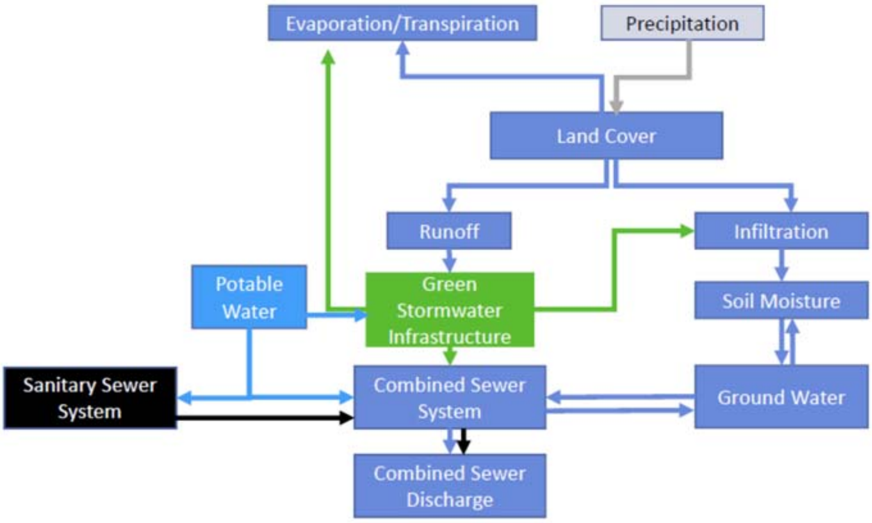

Figure 1: Schematic Depiction of Urban Water Cycle

2. RESULTS AND DISCUSSION

The neighborhood being modeled and monitored has been altered from the natural hydrologic condition since the late 1800's. Development of homes and roads, catch basins, and combined sewers changed the natural system by draining water directly to the Detroit River instead of infiltrating or flowing into small streams that originally traversed the landscape. The neighborhood reached its peaked density in the early 20th century before urban decay returned the landscape into an urban meadow by the early 21st century (Figure 2). The project site is referred to locally as Recovery Park. Recovery Park provides opportunities for people with barriers to employment in the food production, processing and distribution sector (https://www.recoveryparkfarms.com/).

The plan is for Recovery Park to transform the vacant landscape into a multi-block production scale urban agriculture farm including greenhouses, rainwater harvesting systems, and GSI. Redevelopment of 20 hectares began in 2016 with the installation of GSI and the initial greenhouses and will continue into the near future as further funding allows. The GSI includes curb-cuts along the roadway into conveyance swales and large scale bio-retention areas to promote retention, absorption and evapotranspiration. The GSI is conservatively designed to capture 85% of the 2-year 24-hour rain event (4.8 centimeters). The design was intentionally replicable for other areas in Detroit and in cities where vacant land can be repurposed.

Of the 20 hectares being redeveloped, three adjacent blocks (approximately 5 hectares) were instrumented with sensors to evaluate the effectiveness of the implemented GSI and to document the urban water cycle. The monitoring network (Figure 3) included an array of groundwater level sensors in both shallow and deep wells (red dots in Figure 3), seven in-pipe flow meters (blue dots in Figure 3), a weather station, shallow soil borings, and infiltration testing. A

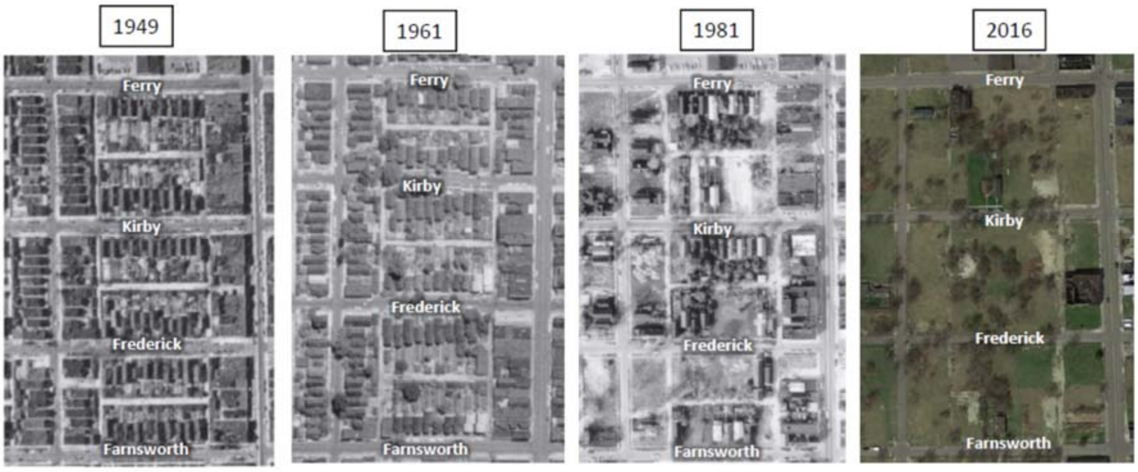

Figure 2: Recovery Park Neighborhood Landscape Transformation

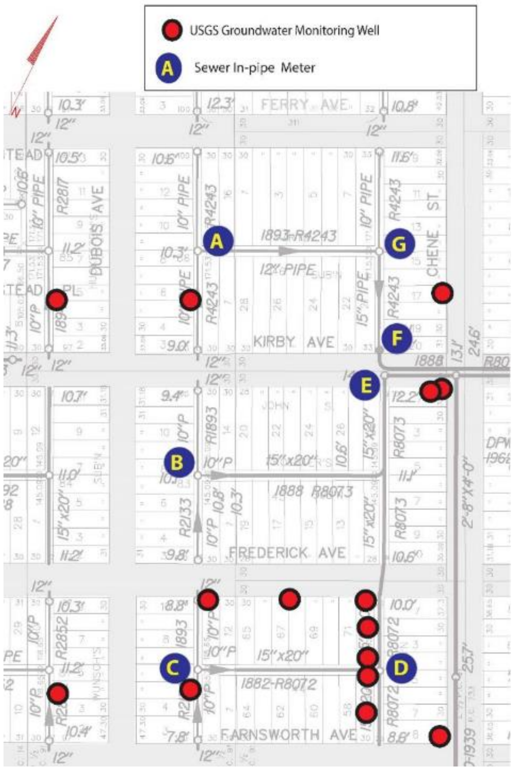

Figure 3: Monitoring Configuration

Hydrologic modeling was performed using three methodologies including U.S. Environmental Protection Agency (EPA) Stormwater Management Model (SWMM) version 5.1 (Rossman 2010; Rossman 2014), U.S. EPA Online Storm Water Calculator (https://www.epa.gov/water-research/national-stormwater-calculator), and a spreadsheet based Natural Resource Conservation Service (NRCS) Curve Number (CN) Method (NRCS 2004). The NRCS Curve Number (CN) which was developed for agricultural watersheds in the United States, but is commonly used for predicting stormwater runoff volumes in urban conditions. The CN Method is event-based and provides volume reduction for specific sized storm events. The other hydrologic models are capable of continuous simulation and are more accurate in determining the performance of GSI. All three model were calibrated based on 2015 monitoring data and are being used to predict flow from existing and redeveloped GSI conditions for this site and at other sites in Detroit.

Figure 4 provides the average annual runoff for the two continuous simulation models with the 2015 condition representing the calibrated condition. Based on the models, the 2015 runoff volume is approximately 30% of the historic (1960) maximum. Once GSI is implemented (2015 w/GI in Figure 4), the annual runoff will be further reduced to less than 10% of historic maximum. Over the next ten years, the addition of urban agriculture production facilities will increase the runoff, but not at a level that will exceed the 2015 condition.

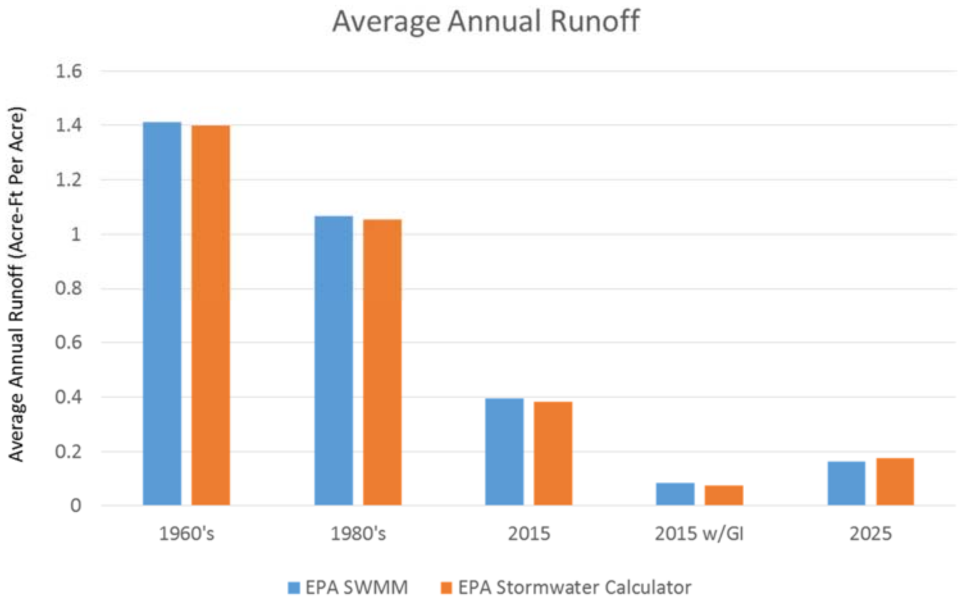

Figure 4: Calibrated Model Estimates of Annual Runoff

3. CONCLUSION

There are several key results that are transferrable to similar urban land transformation projects. The first is that the watershed (as might be determined from topographical survey) can vary dramatically from the sewershed (as determined by underground pipe connections) and that urban drainage areas can adjust significantly based on GSI design. The second is that soil storage and evapotranspiration is a significant component in the urban water cycle in areas where there is vacant land (urban meadows) or urban agriculture but these items are not always accurately included in modeling or performance estimates. Third, event based computer models are commonly used for design purposes but the actual hydrologic performance of GSI is not well captured by event based models. Continuous simulation models are necessary for modeling the urban water cycle and ultimately determining the influence of GSI in reducing combined sewer flow. Finally, be cautious of monitoring data quality when calibrating rainfall-runoff models for urban scenarios. While data quality is always a concern in hydrologic investigations, the difficulty in monitoring flow in exacerbated in aging urban pipe networks.

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