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Estimating stormwater runoff for community gardens in New York City

Mara Gittleman[1] · Carson J. Q. Farmer[2] · Peleg Kremer[3] · Timon McPhearson[4]

Abstract Community gardens are critical ecological infra-structure in cities providing an important link between people and urban nature. The documented benefits of community gardens include food production, recreational opportunities, and a wide number of social benefits such as improving community stability, reducing crime, and physical and mental health benefits. While much of the literature cites community gardens as providing environmental benefits for cities, there is little empirical evidence of these benefits. Here we examine the stormwater runoff benefits of community gardens by comparing two methods to estimate absorption rates of stormwater runoff in urban community gardens of New York City. The first method uses general land cover classes as determined by a land cover dataset; the second methods adds a land cover specific to community gardens — raised beds, typically used for food production. We find that in addition to the stormwater mitigation performed by pervious surfaces within a garden site, community gardens in New York City may be retaining an additional 12 million gallons (~45 million liters) of stormwater annually due to the widespread use of raised beds with compost as a soil amendment.

✉ Mara Gittleman
mara.gittleman@kbcc.cuny.edu

Carson J. Q. Farmer
Carson.Farmer@Colorado.EDU

Peleg Kremer
peleg.kremer@villanova.edu

Timon McPhearson
timon.mcphearson@newschool.edu

[1] Kingsborough Community College, CUNY, Brooklyn, NY, USA

[2] Department of Geography, University of Colorado at Boulder, Boulder, CO, USA

[3] Department of Geography and the Environment, Villanova University, Villanova, PA, USA

[4] Urban Ecology Lab, Environmental Studies Program, The New School, New York, USA

Introduction

Cities and urbanized areas face significant environmental challenges due to built-up infrastructure, which affects climate, hydrology, air quality and many basic factors affecting health of social and ecological communities. Stormwater run-off in particular is a major challenge in urbanized areas. In a rural environment, rainwater percolates through the soil and replenishes the aquifer beneath it. Cities, however, are covered with impervious surfaces that prevent rainwater from entering the soil directly. As a result, much of the rainwater becomes runoff, causing flash flooding and overwhelming water treatment centers. In New York City (NYC), the sewer system relies on combined sewer overflows (CSOs), which release raw sewage and stormwater runoff into local waterways during most precipitation events. CSO events can occur after as little as one tenth of an inch of rain falls on the city (New York City 2007). Over the course of a year, approximately 30 billion gallons (114 billion liters) of wastewater (including raw sewage, are discharged into NYC waterways through CSOs (Strickland 2012). Climate change predictions for New York City in the near future suggest that these numbers are likely to rise as precipitation and storm intensity increase (NPCC 2015).

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Decreasing the amount of contaminated runoff that enters local waterways through CSOs is part of a federal mandate issued by the EPA under the Clean Water Act for NYC and many cities across the country (Salzman et al., 2001; Postel and Thompson 2005). Adding built infrastructure to address runoff is an economically costly endeavor that does not provide the benefits associated with comparable green infrastructure solutions (DEP 2010). To mitigate stormwater runoff and achieve compliance with the Clean Water Act, the NYC Department of Environmental Protection (DEP) released *NYC Green Infrastructure Plan: A Sustainable Strategy for Clean Waterways* (DEP 2010), a formal plan for increasing green infrastructure throughout the city. Green infrastructure leverages ecosystem functions such as soil infiltration and plant evapotranspiration to reduce or slow the stormwater entering the sewer system (Dunn 2010; DEP 2010). Green infrastructure also provides a cost-effective way to complement NYC's 'grey' infrastructure (such as holding tanks), while contributing additional benefits in the form of green space. Adding vegetation to a site and using pervious materials can decrease stormwater runoff, with the added benefits of decreasing local temperatures, improving air quality, sequestering carbon, and raising property values (DEP 2012). Some types of green infrastructure have been widely studied and empirically tested. For example, Berardi et al. (2014) review more than 100 papers published over the last decade about technical, social and environmental aspects of green roofs. Their review suggest that water management is one of the most important impacts of green roofs, particularly in their capacity to reduce stormwater runoff. They find a wide range of runoff mitigation capacity between 25 and 100 %.

Community gardens are another, less studied, type of green infrastructure that contributes to stormwater mitigation efforts. Community gardens are already considered green infrastructure in some federal and municipal publications. The US Environmental Protection Agency (EPA) lists community gardens as green infrastructure with additional ecosystem services such as space for recreation and connecting with nature (EPA 2014). Across the country, municipalities value community gardens and urban agriculture as important contributions to green infrastructure in their cities (WFRC 2012; SEMCOG 2014). However, some municipalities — including NYC — do not consider community gardens as part of their plans for open space and green infrastructure.

Community gardens are built and managed by local residents on vacant land, often as acts of resistance to urban decline and disinvestment (Saldivar-Tanaka and Krasny 2004). They have a number of documented benefits, particularly in the social realm: they have been shown to improve community stability, reduce crime, and provide a number of tangible health benefits (Smith and Kurtz 2003; Saldivar-Tanaka and Krasny 2004; Lawson 2005; Lin et al. 2015). While much of the literature also cites community gardens as providing environmental benefits for cities, studies that quantify these benefits are only beginning to emerge. For example, a growing body of literature is beginning to measures the ecosystem services of urban community gardens (Lin et al., 2015; Andersson et al. 2007; Dunn 2010; Yadav et al. 2012; Gittleman et al. 2012; Meyers et al. 2014).

Several studies *do* include community gardens as green infrastructure (Freshwater Society 2013; Krasny et al. 2014; Andersson et al. 2014), and the few studies that estimate or quantify stormwater runoff for community gardens illustrate their value in maintaining a healthy urban ecosystem (Meyers et al. 2014). In a study for Openlands in Chicago, Illinois Meyers et al. (2014), installed stormwater runoff collection devices on a variety of garden types, including a rain garden and a community garden, to measure the quantity and quality of the runoff. They compared the runoff rate and volume from one community garden with the runoff rate and volume from the roof of a nearby building. They found that the community garden provided a runoff coefficient (inches of runoff per inch of rain) that was nearly four times lower than that of the roof (Meyers et al. 2014). Measuring the runoff rate during one storm, the peak runoff from the roof was 0.22 cubic feet per second (cfs) per acre, while the peak runoff from the community garden was 0.0019 cfs per acre. Pauleit and Duhme (2000) use literature-based coefficients to compute infiltration rates for multiple urban land covers including allotment gardens. Their findings suggest that storm water infiltration rates in allotment gardens is similar (about 30 % of annual precipitation) to that of parks and other urban green space. The Center for Neighborhood Technology (2007) developed the "Stormwater Management Calculator"- a planning tool that estimates runoff at the site, neighborhood and new development scales using assumptions about landcover and proxy infiltration values from the literature. The tool enables the comparison of performance of green infrastructure strategies such as home gardens, green roofs, swells and trees, but does not include community gardens.

Community gardens present a unique challenge in the estimation of stormwater retention. Common literature values rely on the identification of soil type and land cover. However, in community gardens, the majority of growing areas often comprise combinations of newly introduced soil treated with compost, or filled entirely with compost (Edmonson et al. 2014, Mitchell et al. 2014). The soil in many cities in the US suffers from heavy metal contamination and compaction due to the legacy of manufacturing, leaded paint and gasoline, and dumping. Growing in raised beds amended with compost, with paths covered in wood chips can help gardeners avoid contact with toxic soil and raise healthy crops (Shayler et al. 2009, Mitchell et al. 2014). Amending urban soils with compost can also increase stormwater infiltration rates (Harrison et al. 1997; EPA 1999; Pitt et al. 2002; Freshwater Society 2013). Harrison et al. (1997) found that

amending urban soil with compost at a 2:1 ratio of compost to soil doubled infiltration rates and the EPA (1999) suggests a potential increase in infiltration by a factor of 1.5–10.5. The Portland Stormwater Management Manual (2014) uses a static runoff rate (a curve number of 48) to represent all "contained planter boxes," which may be comparable to raised beds.

In this study we focus on community gardens specifically, as opposed to school gardens, urban farms, and other types of growing spaces, because of their distinct heterogeneity: community gardens offer a mix of land uses beyond just food production, including trees and shrubs, seating areas, open recreational spaces, small buildings, and compost. Community gardens are also treated differently than other forms of urban agriculture in municipal policy, warranting a separate investigation of the services they provide (Mees and Stone 2012). Quantifying the benefits generated by community gardens through the framework of ecosystem services, can help establish their importance as urban green infrastructure and support efforts to protect and preserve community gardens in cities. Lacking a more robust understanding of the ecosystem services benefits associated with community gardens, the case for community gardens is often framed around financial trade-offs with other types of urban land-use, such as housing (Lin et al. 2015).

In this study, we evaluate the stormwater management benefits of community gardens as green infrastructure comparing two methods for estimating the stormwater infiltration rates of community gardens across NYC. This study contributes to the body of knowledge about community gardens and urban agriculture as types of green infrastructure and their potential to perform important stormwater runoff mitigation services.

Study area

With over eight million residents, NYC is the largest city in the United States, and contains hundreds of community gardens managed by over 20,000 community gardeners (GreenThumb 2014). The modern community gardening movement began in the 1960s and 1970s during widespread urban disinvestment in cities across the Northeastern United States, particularly in communities of color (Saldivar-Tanaka and Krasny 2004). Federally funded urban renewal projects justified the demolition of entire city blocks (Mogilevich 2014). During this time and continuing through the present, community gardens were often built on vacant plots of land that had been abandoned by their owners as the city crumbled (Schmelzkopf 1995; Nemore 1998; Schukoske 2000; Smith and Kurtz 2003).

Today, there are over 500 publically accessible community gardens across the NYC that allow individuals and families to grow food and green space for themselves and for their community. Many community gardens are located in neighborhoods that overlap significantly with the NYC DEP's

Priority CSO Tributary Areas, marking them as priorities for green infrastructure, but they are often left out of programs such as the DEP Green Infrastructure Program (Fig. 1). There are also 400 school gardens and nearly 700 gardens on NYC Housing Authority (NYCHA) property, which also commonly feature food-producing raised beds, and dozens of urban farms growing commercially on rooftops and on the ground (Design Trust for Public Space 2012; GrowNYC 2014). These additional spaces, however, are beyond the scope of this study, which focuses specifically on community gardens. At least 132 community gardens in NYC use rainwater harvesting systems with a total holding capacity of over one million gallons, contributing to their stormwater retention capacity (GrowNYC 2015b). In NYC, 80 % of community gardens grow food (Gittleman et al. 2010). In most cases, though, food production does not cover the entire site, as it might with an urban farm. The proportion of a garden devoted to food production varies widely, with some producing no food at all, and the rest allotting from 0.25 - 74 % of the growing area for food production (Farming Concrete 2015).

Methods

Community garden data

The spatial dataset for community gardens in NYC comes from GrowNYC (2015a) as part of their Open Space Greening program. It contains records that fall outside the scope of this work, including school gardens and private gardens, and contains some out-of-date records of community gardens that have been demolished. Furthermore, some of the garden footprints were incorrectly located and/or drawn differently than the garden's actual location. In many cases, the footprint was drawn to incorporate nearby buildings. The first step of this analysis was to review the dataset and remove those that do not fall under this work's definition of community garden, and use aerial imagery to edit incorrect garden footprints. The total number of community gardens included in this study is 529.

We used the NYC 2010 land cover dataset with resolution of 3 ft. (~1 m) (UVM Spatial Analysis Laboratory and NYC Urban Field Station 2012) to identify land cover within community gardens, using the GrowNYC (2015a) data for the borders. Manual inspection of the gardens, comparing the land cover classifications with aerial photography, showed that many of the gardens were incorrectly classified in the land cover data or had incorrectly drawn borders, inadvertently including more impervious surfaces. The presence of extra impervious surface means that this analysis may result in an inaccurate measure of the stormwater mitigation benefits of community gardens. To improve the accuracy of the analysis, all garden footprints with >25 % building coverage were

Fig. 1 Locations of community gardens (orange), DEP green infrastructure projects (teal), and 2011–2013 DEP green infrastructure grantees (magenta) in New York City (GrowNYC 2015a; DEP 2013b; DEP 2014; Claro et al. 2013) overlain on DEP Priority CSO Tributary Areas (DEP 2013a; Claro et al. 2013)
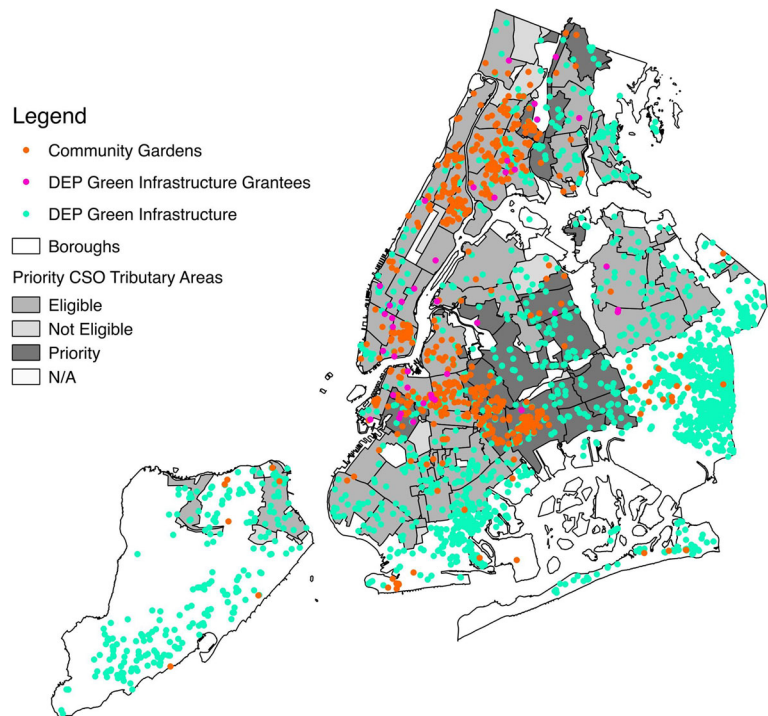
corrected by retracing the borders of each garden to fit the borders of the tax lots they occupied, and the garden and land cover areas were recalculated.

Calculating stormwater runoff volume

We calculate stormwater runoff for community gardens using two different methods: one method from the literature and one new method that takes into account empirical data specific to community gardens. Both methods in this study begin with the methodology and values included in the USDA Soil Conservation Service TR-55 report (1986), one of the most commonly used methodologies for estimating stormwater runoff. The TR-55 methodology identifies curve numbers (*CN*) that describe the proportion of runoff for a given rain event while taking into consideration land cover type, soil characteristics, and the fact that infiltration capacity of soils change over the course of a storm. Method 1 calculates stormwater runoff for each community garden following this method, while Method 2 introduces new land cover data that better represents urban agricultural activities.

TR-55 (USDA 1986) calculates inches of runoff for a given precipitation event using the following formula:

$$Q = \frac{(P-I_a)^2}{(P-I_a) + S} \qquad (1)$$

where Q is runoff in inches for a P-inch rain event, S is the potential maximum runoff after runoff begins (determined by CN), and I_a is the initial abstraction in inches. Initial

abstraction (I_a) is "all losses before runoff begins" and "includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration" (USDA 1986). It is related to S by: $I_a = 0.2S$. So (1) can be rewritten as:

$$Q = \frac{(P-0.2S)^2}{(P + 0.8S)} \qquad (2)$$

where S is derived from the CN by:

$$S = \frac{1000}{CN} - 10 \qquad (3)$$

CN values used in this analysis come from Table 2.2 in TR-55 (USDA 1986, p.2–5 - 2-7) and rely on hydrologic soil groups and land cover identification (Table 1). Hydrologic soil groups represent information about soil quality and drainage. Soils are classified into four hydrologic soil groups (A, B, C, and D) according to their minimum infiltration rate (USDA 1986). Soils in hydrologic soil group A have the lowest runoff potential, while soils in hydrologic soil group D have the highest potential. Hydrologic soil groups for NYC soils came from the Natural Resources Conservation Service, which releases soil data at the county level through the Soil Survey Geographic Database (SSURGO 2003).

In order to obtain useful CN values for community gardens, we utilized values used for gardens in the Center for Neighborhood Technology (CNT) Green Values Stormwater Calculator, which was developed in

Table 1 Curve numbers for open space, bare soil, and paved areas (USDA 1986)

Land Cover	Hydrologic Group			
	A	B	C	D
Open Space				
Poor condition (grass cover <50 %)	68	79	86	89
Fair Condition (grass cover 50 % to 75 %)	49	69	79	84
Good Condition (grass cover >75 %)	39	61	74	80
Bare soil	77	86	91	94
Paved	98	98	98	98

collaboration with the US Environmental Protection Agency (EPA) Office of Wetlands, Oceans, and Watersheds, Assessment and Watershed Protection Division, Non-Point Source Branch to help planners and green infrastructure designers across the United States predict the benefits of their projects (Center for Neighborhood Technology 2009). The tool synthesizes measurements for estimating runoff reduction, carbon sequestration, energy reduction, and financial savings associated with green infrastructure. The methodology uses runoff curve numbers adapted from comparable land uses in Table 2-2 of TR-55 for each soil type (Center for Neighborhood Technology 2007). For gardens and swales, the runoff curve numbers for each soil type are in Table 2:

Runoff volume was then calculated using Q values by:

$$R = \left(\frac{Q}{12}\right) * A_t. \qquad (4)$$

Where R is runoff volume in cubic feet, Q is the runoff rate in inches for a given P-inch rain event, and A_t is the total area in square feet of the community garden. Runoff volume can be converted to gallons by multiplying by 7.48.

Land cover data for NYC comes from the University of Vermont Spatial Analysis Laboratory and New York City Urban Field Station (2012) at 3-ft (~1 m) resolution, based on 2010 LiDAR data and 2008 4-band orthoimagery (MacFaden et al. 2012). Our first method follows the TR-55 methodology outlined above. The second method doubles the infiltration rate of the area covered by raised beds, which is a

Table 2 Runoff curve numbers for gardens and swales (Center for Neighborhood Technology 2007)

Hydrologic Group	A	B	C	D
Garden CN	35	51	63	70

conservative estimate consistent with Harrison et al. (1997) and the EPA (1999). This allows us to keep the underlying soil characteristics in the model, as opposed to choosing a method that applies *one* curve number value to represent *all* raised beds, regardless of the quality of the soil underneath the raised beds (e.g., Center for Neighborhood Technology 2007, Portland Stormwater Management Manual 2014).

Method 1

To identify land cover types for each community garden, the land cover dataset (MacFaden et al. 2012) was clipped to the NYC Community Gardens dataset (GrowNYC 2015a). Seven land cover classes were mapped in this dataset: (1) tree canopy, (2) grass/shrub, (3) bare earth, (4) water, (5) buildings, (6) roads, and (7) other paved surfaces. Area was calculated for each land cover type within each community garden. Based on the computed areas, the proportion of each type of land cover was calculated and adapted to fit the TR-55 classifications: "tree canopy" and "grass/shrub" were combined to form an "open space" classification, and "buildings," "roads," and "other paved surfaces" were combined as "paved," or impervious. "Bare earth" was kept as "bare."

Center for Neighborhood Technology (CNT) curve numbers for gardens and swales were assigned to "open space," and curve numbers for "bare" and "paved" land cover came from Table 1. Weighted CN values were calculated for each community garden as a whole based on the areas of each land cover and soil hydrologic group within the garden. To develop these weighted curve numbers, curve numbers assigned by land cover type and soil hydrologic group were multiplied by the areas of each land cover type within each garden and divided by the total garden area:

$$C_w = \frac{\left(C_o * A_o + C_b * A_b + C_p * A_p\right)}{A_t} \qquad (5)$$

where C_w is the weighted curve number (CN), C_o is the CN for open green space, A_o is the area of the garden classified as open green space, C_b is the CN for bare soil, A_b is the area of the garden classified as bare soil, C_p is the CN for paved surfaces, A_p is the area of the garden classified as paved, and A_t is the total area of the garden. These weighted CN values were then plugged into (2) to calculate Q values, or stormwater runoff, for each community garden, and then Q values were plugged into (4) to calculate runoff in gallons.

Method 2

To better represent community gardens, and thus potentially calculate a more accurate estimate of stormwater runoff, we introduce food production as a land cover type to the data in Method 1 and measure the change in estimated runoff.

Community gardeners in NYC typically use raised beds for food production to avoid heavy metal contamination (Gittleman et al., 2010; EPA 2011; Spliethoff et al. 2014), so we combine data about the size and quantity of food-producing raised beds from Farming Concrete and GreenThumb as a proxy for all food production in NYC community gardens.

Farming Concrete is an NYC-based project that has been helping community gardens, school gardens, and urban farms develop and use metrics to evaluate community garden activities since 2010. For example, food production is a critical metric for understanding the contribution of community gardens to social and ecological benefits in the city. Crop Count, the Farming Concrete method for assessing food production, provides an inventory of edible crops and area under production. This includes the number and dimensions of the food-producing raised beds, creating a dataset collected entirely by community gardeners; while the data may therefore be incomplete, it is the largest dataset of self-reported food production for NYC community gardeners and participants closely followed the Croup Count methodology to maintain accuracy. GreenThumb, the branch of the NYC Department of Parks and Recreation that works with community gardens, also conducts site visits with its registered gardens and surveys raised beds.

These two datasets were combined and analyzed with a model that uses a third-order polynomial transformation on the total area of a garden to predict the total area of the garden occupied by raised beds. The polynomial terms allow us to better fit the cases where we have extremely small or extremely large community gardens. The formula can be written as:

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + \varepsilon \qquad (6)$$

where a is the total area of the garden, and y is the total area of the garden occupied by raised beds, and the polynomial terms are orthogonal with respect to the constant polynomial of degree 0. Fitting the above equation using ordinary least squares (OLS) regression yields the following set of coefficients (Table 3), with an adjusted R^2 of 0.52. In other words, our regression model explains just over 50 % of the variation in the total area of gardens occupied by raised beds. All coefficients and the F-statistic of 42.21 on 3 and 113 degrees of freedom are significant at the 95 % confidence level (p-value <0.05). Two additional modes (a simple linear model ($R^2 = 0.45$) and a second order polynomial model ($R^2 = 0.50$)) are given in Fig. 2 for comparison. Note the improved fit of the polynomial models with larger values for both total raised beds area and total garden area. Using the above model, we are able to estimate raised bed coverage for community gardens for which raised bed data is missing.

Raised beds were added into the land cover calculations used in Method 1 to measure the effect on runoff by halving runoff rates (Q) for the area of each garden covered by raised beds. We adapt equation (4) to calculate runoff volume to include these new considerations:

$$R = \left(\frac{Q}{24}\right)\left(A_t * \left(\frac{A_{rb}}{A_t}\right)\right) + \left(\frac{Q}{12}\right)\left(A_t * \left(\frac{A_g}{A_t}\right)\right) \qquad (7)$$

where R is runoff volume in cubic feet, Q is the runoff rate in inches for a given P-inch rain event, A_{rb} is the area (square feet) covered by raised beds, A_g is the area covered by the rest of the garden, and A_t is the total area of the garden. We then convert the result to gallons by multiplying R by 7.48.

We use two P values in this study in order to generate a range of results. The NYC DEP 2012 *Green Infrastructure Monitoring* Report uses a 1.5″ (3.8 cm) rain event as an example storm. Past studies have used a 5″ (12.7 cm) rain event as a benchmark for a 5–10 year storm that would overwhelm NYC's water treatment system (McPhearson et al. 2013; Kremer et al. 2016). Viewed as a range, these benchmarks can tell us how community gardens absorb and release rain for both Method 1 (M1) and Method 2 (M2) (Table 3).

Results

The 529 community gardens included in this study are 83 % green space, 16 % paved, and 1 % bare. They cover 5,246,505 square feet of land, or about 120 acres (~49 ha). The results show a higher percentage of water absorbed during the 1.5″ (3.8 cm) rain event than during the 5″ (12.7 cm) rain event across methods. Weighted CN values for NYC community gardens using Method 1 ranged from 35 to 93 with a mean of 63.05. These CN values resulted in mean Q values of 0.09 for the 1.5″ (3.8 cm) storm and 1.60 for the 5″ (~12.7 cm) storm. In other words, for each storm level respectively, 0.09″ (~2.3 mm) and 1.60″ (~4.1 cm) of water would become runoff for each square inch of the garden. For Method 2, with food producing raised beds included, Q values were halved for the area covered by raised beds, following the conservative end of results found in the literature (Harrison et al. 1997; EPA 1999). We compare the results of using these altered Q values with two different storm events (1.5″/ 3.8 cm and 5″/12.7 cm)

Table 3 Model coefficients

	Estimate	Std. Error	t-value	p-value
Intercept	1227.76	83.15	14.766	0.000***
Garden Area	9431.82	899.38	10.487	0.000***
Garden Area^2	3148.46	899.38	3.501	0.000***
Garden Area^3	1884.08	899.38	2.095	0.038*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

Fig. 2 Scatterplot of raised beds areas and garden areas (square feet) with three fitted model lines
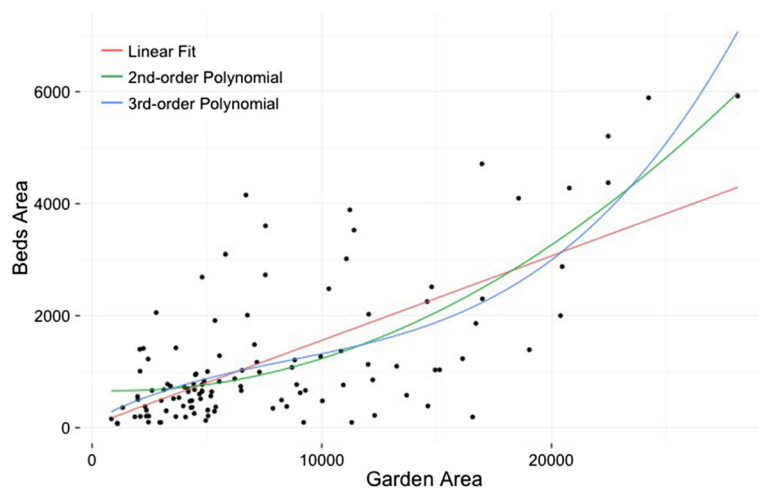
in the TR-55 (USDA 1986) method for estimating stormwater runoff in Table 4.

A 1.5″ (3.8 cm) rain event on the 5,246,505 sq. ft. (120 acres or ~49 ha) of community gardens located throughout NYC is equivalent to 4,905,482 gal of stormwater. Community gardens would retain 4,652,748 gal (~17 million liters), or 94.8 % of total rainfall. A 5″ (12.7 cm) rain event would drop 16,351,608 gal (~62 million liters) of water on community gardens, which would retain up to 12,175,459 gal (~46 million liters) of this total, or 74.5 %. For a 1.5″ (3.8 cm) rain event, including food-producing raised beds in the model increases infiltration by 22,669 gal (~85,812 l), or 0.5 %. For a 5″ (12.7 cm) rain event, raised beds increase infiltration by 387,986 gal (~1.5 million liters), or 3.2 %.

In Table 4, we can see that adding raised beds into the model impacts minimum stormwater retention values the most. This may be due to the varying amounts of green space within community gardens. For those with less green space, adding compost-amended raised beds into the model may impact runoff rates more than those that already have a lot of green space. For example, the garden that represents the minimum retention values, Rev. Linnette C. Willianson Memorial Park, is 87 % paved. The green space that is there consists of raised beds (Fig. 3).

Figure 4 shows the relationship between the amount of green space a garden maintains and stormwater retention. The data are separated into three distinct lines illustrating the three most common soil hydrologic groups in NYC: A (top), B (middle), and C (bottom).

In this scatterplot, the relationship between green space and stormwater retention is easily visible. The quality of the green space varies, however depending on what the gardeners plant; understanding how gardeners maintain the land is crucial to developing an accurate model.

Discussion

Community gardens are producing ecosystem services through stormwater management. An average of 52.5 in. (~1.33 m) of rainwater fell on New York City annually between 1990 and 2015 (NOAA 2016), amounting to over 170 million gallons (~644 million liters) of stormwater that fall on community gardens, 130–143 (492–541) million of which would be prevented from becoming runoff, estimated using Method 1 (without raised beds) and Method 2 (with raised beds) respectively.

Adding raised beds into the model for estimating stormwater runoff in community gardens may therefore have

Table 4 Stormwater infiltration for a 1.5″ and a 5″ rain event

	% Green space	1.5″ Rain event		5″ Rain event	
		% of total precipitation retained		% of total precipitation retained	
		M1	M2	M1	M2
Min.	12.6	40.8	46.3	15.4	23.2
1st Quart.	72.0	92.0	92.6	59.5	62.6
Median	86.2	97.1	97.4	67.4	70.0
Mean	80.1	94.0	94.5	68.1	70.8
3rd Quart.	93.9	98.9	99.0	79.7	81.6
Max.	100.0	100.0	100.0	98.3	98.8

Fig. 3 Reverent Lineette C. WIlliamson Memorial Park. Photo credit: williamsonparks.org

a significant impact on future analyses, as community gardens may be retaining an additional 12 million gallons (~45 million liters) of stormwater annually due to the widespread use of raised beds with compost as a soil amendment. Since we only analyze community gardens and not other spaces where residents are creating and managing gardens, also often in raised beds, we suggest this estimate for stormwater absorption by gardens across the city is conservative and would expand significantly if other types of gardens (school gardens, backyard gardens, New York City Housing Authority gardens) were included in a similar analysis. Understanding gardeners' actual use of the land can help improve analysis of ecosystem services production in community gardens.

The results of this study are comparable to other findings in the literature, which indicate that community gardens can provide important benefits of stormwater runoff mitigation in comparison to other land uses, such as vacant and residential

lots, due to their soil amending practices and composting activities (Dunn 2010; Cogger 2005). It has been shown in other studies in NYC that vacant land can also have significant storm water runoff mitigation benefits (McPhearson et al. 2013) suggesting that a more comprehensive study examining the stormwater benefits of multiple types of green infrastructure (e.g. Kremer et al. 2016) would be of high value to the city in meeting targets for stormwater runoff mitigation. In community gardens, compost can increase the porosity and water retention capacity of compacted, compromised urban soils, and some municipalities are experimenting with greening vacant lots as a form of green infrastructure through the application of compost and managed vegetation (Washington State Department of Ecology 2001; Yang and Zhang 2011; Cogger 2005; Pennsylvania Horticultural Society 2015). Adding compost could be a low-cost amendment to non-garden sites as well for improving water retention capacity,

Fig. 4 Scatterplot showing percent green space and percent stormwater retention for M1, 5″ storm. The outlier is Victory Garden, which includes a body of water
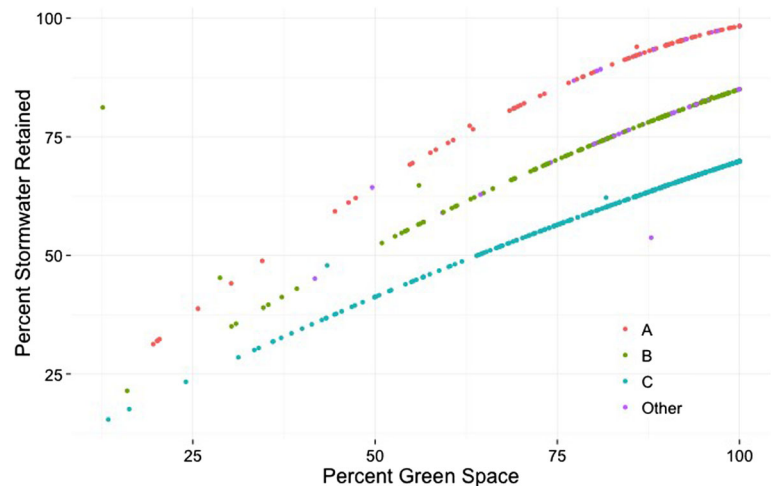
for example on vacant lands, in parks, backyards, and other public and private spaces that are currently under managed.

Conclusions

The Department of Environmental Protection frames its runoff reduction goals in reference to the amount of impervious surface in its combined sewer areas with a target of a 10 % reduction in runoff off of impervious surfaces by 2030, which amounts to an estimated 1.5 billion gallons (~5.7 billion liters) of water/year (DEP 2010). Community gardens attain approximately 11 % of that figure annually. As such, it may help to achieve their reduction targets by introducing policies that support the continuation of community gardens, especially in these priority areas, to prevent losing valuable green space.

Future research could contribute to empirical measurements of stormwater runoff in a variety of vacant lots, community gardens, and urban farms. Rather than estimating a curve number using data from 1986 that relies on an approximation of land cover type, we need primary data that looks at community gardens with and without food production, with and without structures like greenhouses and rainwater harvesting systems, etc. Better information about how these sites handle stormwater will improve analyses like these. Using a more accurate land cover dataset to better differentiate community gardens with and without significant amount of impervious surface may further improve the accuracy of this analysis.

Community gardens also provide many additional co-benefits in addition to stormwater runoff mitigation, which is important when considering how to achieve multi-functionality from green infrastructure and other nature-based solutions. However, co-benefits in terms of ecosystem services provided by community gardens in NYC and more broadly in the U.S. are not well studied, with additional quantitative studies on the various other ecosystem services produced by community gardens still needed. For example, community gardens compost organic waste, diverting it from the waste stream; produce tons of food annually, with a lower carbon footprint than conventionally grown food shipped from thousands of miles away; plant native flora, providing habitat for biodiversity; mitigate the effect of the urban heat island effect on local temperatures; and provide space for building community, recreation, and opportunities for environmental education. Understanding how these services can help achieve cities' sustainability plans will build an understanding of their role in the urban environment worldwide.

Community gardens are critical components of green infrastructure and we argue that these spaces should be prioritized for green infrastructure investment to improve existing gardens for stormwater runoff mitigation, but also as a type of green infrastructure that the city should focus on in order to generate strong stormwater and co-benefits for the city and local residents. It is clear that community gardens contribute to many of the sustainability goals outlined by the New York City government (New York City 2015). Quantitative analyses of the ecosystem services produced by community gardens can help justify policies for long-term land tenure, ensuring their place in the landscape of stormwater management (and in the fabric of communities) for years to come. Understanding how gardeners use the land and including soil management practices, such as amending with compost, can potentially improve methods for estimating stormwater retention rates.

References

Andersson E, Barthel S, Ahrne K (2007) Measuring the social-ecological dynamics behind the generation of ecosystem services. Ecol Appl 17(5):1267–1278

Andersson E, Barthel S, Borgström S, Colding J, Elmqvist T, Folke C, Gren Å (2014) Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services. Ambio 43:445–453

Berardi U, GhaffarianHoseini AH, GhaffarianHoseini A (2014) State-of-the-art analysis of the environmental benefits of green roofs. Appl Energy 115:411–428

Center for Neighborhood Technology (2007) Green values stormwater calculator methodology. http://www.greenvaluescntorg/calculator/methodologyphp Accessed 31 January 2015

Center for Neighborhood Technology (2009) National Green Values Calculator Methodology. http://www.greenvaluescntorg/national/calculatorphp Accessed 31 January 2015

New York City (2015) OneNYC: the plan for a strong and just City. The City of New York Office of the Mayor, New York, NY

Claro A, Formato T, Huyhua S, Lock R, Martineau K, Moore A, Michaelides P, O'Neal E, Ruge S, Santner A, Trotman L (2013) Leveraging the multiple benefits of green infrastructure. Unpublished master's project, Columbia University, New York

Cogger C (2005) Potential compost benefits for restoration of soils disturbed by urban development. Compost Science & Utilization 13(4):243–251

Farming Concrete (2015) Crop Count data for New York City Community Gardens http://www.farmingconcrete.org/mill. Accessed 1 March 2015

Design Trust for Public Space (2012) Five borough farm: seeding the future of urban agriculture in New York City. Self-published

Dunn A (2010) Citing green infrastructure: legal and policy solutions to alleviate urban poverty and promote healthy communities. Boston College Environmental Affairs Law Review 3(1):41–66

Edmonson JL, Davies ZG, Gaston KJ, Leake RJ (2014) Urban cultivation in allotments maintains soil qualities adversely affected by conventional agriculture. J Appl Ecol 51:880–889

Environmental Protection Agency (EPA) (1999) Infiltration Through Disturbed Urban Soils and Compost Amended Soil Effects on Runoff Quality and Quantity. EPA Publication No. 600R-00016

Environmental Protection Agency (EPA) (2011) Evaluation of Urban Soils: Suitability for Green Infrastructure or Urban Agriculture. EPA Publication No. 905R1103

Environmental Protection Agency (EPA) (2014) Enhancing Sustainable Communities with Green Infrastructure. EPA 100-R-14-006

Freshwater Society (2013) Urban Agriculture as a Green Stormwater Management Strategy. Accessed 25 April 2015

Gittleman M, Librizzi L, Stone E (2010) Community garden survey. New York City Results 2009/2010 http://www.greenthumbnycorg/pdf/GrowNYC_community_garden_reportpdf Accessed 25 April 2015

Gittleman M, Jordan K, Brelsford E (2012) Using Citizen Science to Quantify Community Garden Crop Yields. Cities and the Environment 5(1):Article 4

GreenThumb NYC (2014) About GreenThumb. Brochure, NYC Department of Parks and Recreation http://www.greenthumbnycorg/pdf/greenthumb-brochure_3-10-14pdf Accessed 7 April 2015

GrowNYC (2014) GrowNYC 2014 Annual Report http://www.grownyc.org/about/annualreport_financials Accessed 7 April 2015

GrowNYC. 2015a. Community Gardens Database.

GrowNYC 2015b. Rainwater Harvesting Systems in Community Gardens Database.

Harrison RB, Grey MA, Henry CL, Xue D (1997) Field test of compost amendment to reduce nutrient runoff. University of Washington, City of Redmond, College of Forestry Resources

Krasny M, Russ A, Tidball K, Elmqvist T (2014) Civic ecology practices: participatory approaches to generating and measuring ecosystem services in cities. Ecosystem Services 7:177–186

Kremer P, Hamstead Z, McPhearson T (2016) The value of urban ecosystem services in New York City: a spatially explicit multicriteria analysis of landscape scale valuation scenarios. Environmental Science & Policy Available online 17 May 2016. doi:10.1016/j.envsci.2016.04.012 .

Lawson L (2005) City bountiful: a century of community gardening in America. University of California Press, Berkeley, CA

Lin B, Philpot S, Jha S (2015) The future of urban agriculture and biodiversity-ecosystem services: challenges and next steps. Basic and Applied Ecology 16:189–201

MacFaden S, O'Neil-Dunne JM, Royar AR, Lu JT, Rundle A (2012) High-resolution tree canopy mapping for new york city using lidar and object-based image analysis. J Appl Remote Sens 6(1):063567

McPhearson T, Kremer P, Hamstead Z (2013) Mapping urban ecosystem services in New York City: applying a social-ecological approach in urban vacant land. Ecosystem Services 5:11–23

Mees C, Stone E (2012) Zoned Out: The Potential of Urban Agriculture Planning to Turn Against its Roots. Cities and the Environment (CATE) 5(1): Article 7

Meyers S, Beyer Clow L, Daniel G, LoVerde K, Rodriguez-Ochoa E, Seaman T, Zaplatosch J (2014) Community Based Green Infrastructure Solutions: Changing how we manage stormwater. Openlands. http://www.openlands.org/filebin/pdf/Community-Based_Green_Infrastructure_Solutions_-_Openlands.pdf Accessed 15 March 2015

Mitchell R, Spliethoff H, Ribaudo L, Lopp D, Shayler H, Marquez-Bravo L, Lambert V, Ferenz G, Russell-Anelli J, Stone E, McBride M (2014) Lead (Pb) and other metals in New York City community garden soils: factors influencing contaminant distributions. Environ Pollut 187:162–169

Mogilevich M (2014) What was, and is, Urban Renewal in New York City? Urban Reviewer http://wwwsmartsigncom/urbanreviewer/#map=12/407400/-739462&page=essayshtml Accessed 4 May 2015

Nemore C (1998) Rooted in Community: Community Gardens in New York City, A Report to the New York State Senate. New York Senate Minority Office. http://www.cityfarmer.org/NYcomgardens.html Accessed 18 March 2015

New York City (2007) PlaNYC: a greener, greater New York. The City of New York Office of the Mayor, New York, NY

New York City Panel on Climate Change (NPCC) (2015) Building the Knowledge Base for climate resiliency: New York City panel on climate change 2015 report. The City of New York. Office of the Mayor, New York, NY

NOAA. National Oceanic and Atmospheric Administration. Monthly & Annual Precipitation at Central Park. (2016) http://www.weather.gov/media/okx/Climate/CentralPark/monthlyannualprecip.pdf. Accessed 24 Jun 2016

NYC Department of Environmental Protection (DEP) (2010) NYC green infrastructure plan: a sustainable strategy for clean waterways. NYC Department of Environmental Protection. http://www.nycgov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml Accessed 20 October 2014

NYC DEP (2012) Guidelines for the design and construction of stormwater management systems. NYC Department of Environmental Protection. http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml Accessed 20 October 2014

NYC DEP (2013a) New York City Green Infrastructure Combined Sewer Area Reference Map. http://www.nyc.gov/html/dep/pdf/green_infrastructure/green_infrastructure_combined_sewer_reference_map.pdf Accessed 15 February 2015.

NYC DEP (2013b) Department of Environmental Protection Awards $4.7 Million in Grants to Community-Based Projects that will Improve the Health of Local Waterways http://www.nyc.gov/html/dep/html/press_releases/13-053pr.shtml#.Vm9bEnuZ7KA Accessed 14 December 2015

NYC DEP (2014) DEP green infrastructure Shapefile. NYC OpenData Available at https://www.datacityofnewyorkus/Environment/DEP-Green-Infrastructure/496p-fwvq Accessed 15 February 2015

Pauleit S, Duhme F (2000) Assessing the environmental performance of land cover types for urban planning. Journal of Landscape and Urban Planning 52(1):1–20

Pennsylvania Horticultural Society (2015) Philadelphia LandCare program. http://phsonlineorg/greening/landcare-program Accessed 3 May 2015

Pitt R, Chen SE, Clark S (2002) Compacted Urban Soils Effects on Infiltraion and Bioretention Stormwater Control Designs. Presented at the 9th International Conference on Urban Drainage. IAHR, IWA, EWRI, and ASCE. Portland, Oregon, September 8–13, 2002.

Portland Stormwater Management Manual. (2014) https://www.portlandoregon.gov/bes/article/474156 Accessed 9 February 2015

Postel S, Thompson B (2005) Watershed protection: Capturing the benefits of nature's water supply services. Nat Res Forum 29(2):98–108

Saldivar-Tanaka L, Krasny M (2004) Culturing community development, neighborhood open space, and civic agriculture: the case of Latino community gardens in NYC. Agric Hum Values 21:399–412

Salzman J, Thompson B, Daily G (2001) Protecting ecosystem services: science, economics, and law. Stanford Environmental Law Journal 20:309–332

Schmelzkopf K (1995) Urban Community gardens as contested space. Geogr Rev 85(3):364–381

Schukoske JE (2000) Community development through gardening: state and local policies transforming urban open space. Legislation and Public Policy 3:351–392

Shayler H, McBride M, Harrison E (2009) Soil contaminants and best practices for healthy gardens. Cornell Waste Management Institute, Ithaca, NY

Smith C, Kurtz H (2003) Community gardens and politics of scale in New York City. Geogr Rev 93(2):193–212

Soil Survey Geographic Database (SSURGO) (2003) Dataset for hydrologic soil groups for New York City. Natural Resources Conservation Service. Accessed 31 January 2015

Southeast Michigan Council of Governments (SEMCOG) (2014) Green infrastructure vision for Southeast Michigan. http://semcogorg/Plans-for-the-Region/Environment/Green-Infrastructure Accessed 21 April 2015

Spliethoff HM, Mitchell RG, Ribaudo LN, Taylor O, Shayler HA, Greene V, Oglesby D (2014) Lead in New York City community garden chicken eggs: influential factors and health implications. Environ Geochem Health 36(4):633–649

Strickland CH (2012) How New York City leads green infrastructure movement: blueprint to achieve greener stormwater systems. Clearwaters http://www.nyweaorg/clearwaters/12-2-summer/6pdf Accessed 24 April 2015

United States Department of Agriculture (USDA) (1986) Urban Hydrology for Small Watersheds. TR-55. Natural Resources Conservation Service: Conservation Engineering Division.

University of Vermont (UVM) Spatial Analysis Laboratory and New York City (NYC) Urban Field Station (2012) New York City Landcover 2010 (3 ft version) Dataset https://www.nycopendata.socrata.com/Environment/Landcover-Raster-Data-2010-/9auy-76zt Accessed 20 October 2014

Wasatch Front Regional Council (WFRC) (2012) The Wasatch Front Green Infrastructure Plan. http://wfrc.org/new_wfrc/Green_ Infrastructure/%28Re%29Connect%20The%20Wasatch%20 Front%20Green%20Infrastructure%20Plan.pdf Accessed 21 April 2015

Washington State Department of Ecology (2001) Stormwater manual for western Washington volume 5, Publication 99–15 https://www.fortresswagov/ecy/publications/publications/0510033pdf Accessed 4 April 2015

Yadav P, Duckworth K, Grewal P (2012) Habitat structure influences below ground biocontrol services: a comparison between urban gardens and vacant lots. Landsc Urban Plan 104(2):238–244

Yang JL, Zhang GL (2011) Water infiltration in urban soils and its effects on the quantity and quality of runoff. J Soils Sediments 11:751–761