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Estimating stormwater infiltration and canopy interception for street tree pits in Manhattan, New York

Estimation de l'infiltration des eaux pluviales et de l'interception de la canopée pour les fosses d'arbres de rue à Manhattan, New York

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RÉSUMÉ

Les estimations de la quantité d'eaux pluviales capturées par les arbres urbains se sont concentrées sur les précipitations interceptées par les feuilles et les branches, tandis que la quantité de ruissellement des eaux pluviales qui s'écoule dans une fosse d'arbre depuis le trottoir environnant n'a pas été bien quantifiée. Cette étude a estimé la quantité d'eau pluviale qui s'infiltré dans une fosse d'arbre en calculant d'abord la zone de drainage des affluents qui s'écoule vers les fosses d'arbres de rue de différentes largeurs et pentes de trottoir. Avec Manhattan, New York, comme étude de cas, l'étude a utilisé le logiciel i-Tree pour constater que pour les arbres de rue à Manhattan, l'infiltration des eaux pluviales dépassait largement l'interception de la canopée, dans un rapport de 3 à 1 : l'infiltration des eaux pluviales était en moyenne de 6842 L/an, tandis que l'interception de la canopée était en moyenne de 2228 L/an. Les résultats contredisent des recherches antérieures qui affirmaient que l'interception de la canopée est le principal moyen par lequel les arbres de rue assurent le contrôle des eaux pluviales. L'étude fournit également une méthode pour calculer les aires de drainage des arbres de rue qui améliorerait les estimations de la quantité d'eaux pluviales captées par les arbres de rue, en mettant en évidence le rôle dominant joué par la largeur et les pentes des trottoirs. L'infiltration était en moyenne de 4 221 L/an pour une largeur de trottoir de 3 m et de 14 774 L/an pour une largeur de trottoir de 10 m. L'infiltration a également été en moyenne de 5 607 L/an pour une pente de rue de 0,5 % et de 18 383 L/an pour une pente de rue de 10 %.

ABSTRACT

Estimates of the amount of stormwater captured by urban trees have focused on the rainfall intercepted by leaves and branches, while the amount of stormwater runoff that flows into a tree pit from surrounding sidewalk has not been well quantified. This study estimated the amount of stormwater that infiltrates into a tree pit by first calculating the tributary drainage area that drains to street tree pits of varying sidewalk widths and slopes. With Manhattan, New York, as a case study the study used i-Tree software to find that for street trees in Manhattan, stormwater infiltration greatly exceeded canopy interception, by a ratio of 3 to 1: stormwater infiltration averaged 6842 L/yr, while canopy interception averaged 2228 L/yr. The results contradict prior research which asserted that canopy interception is the primary means by which street trees provide stormwater control. The study also provides a method to calculate street tree drainage areas that would improve estimates of the amount of stormwater captured by street trees, by highlighting the dominant role played by sidewalk widths and slopes. Infiltration averaged 4221 L/yr for a sidewalk width of 3 m and 14774 L/yr for a sidewalk width of 10 m. Infiltration also averaged 5607 L/yr for a street slope of 0.5 % and 18383 L/yr for a street slope of 10 %.

KEYWORDS

Canopy interception, infiltration; i-Tree, stormwater, street tree

1 INTRODUCTION

While street trees are increasingly viewed as an important component of a city stormwater management plan (McPherson et al., 2005), there is no standard estimate for the amount of stormwater captured by street trees and their canopy (Selbig et al., 2022). i-Tree is a free, publically-available software program developed by the United States Department of Agriculture Forest Service, and it is currently the leading program used by scientists and city-planners internationally to quantitatively estimate the benefits of urban trees (Hilde and Paterson, 2014; Kirnbauer et al., 2013; Nyelele et al., 2019; Soares et al., 2011; Tan et al., 2021). Its estimates are largely based on annual canopy interception from forest rather than urban trees using measured tree species and tree diameter data (Berland and Hopton, 2014; Soares et al., 2011).

Measuring the area that drains onto a site is generally the first step in quantifying stormwater capture for green infrastructure practices (NYC, 2021). For street trees however, the dimensions of sidewalk drainage areas and the volumes of stormwater runoff that drain from them into tree pits remain surprisingly unstudied (this is perhaps because traditional street trees often fall outside the innovative practices termed ‘green infrastructure’). For a street tree pit on a wide sidewalk, the sidewalk drainage area would be quite large, allowing the tree to capture and infiltrate substantial volumes of water. If the tree were also a small, young tree, it would have little leaf surface area to intercept water in its canopy, making canopy interception a smaller component of the water balance. This would contradict the hypothesis put forth by Berland et al. that canopy interception is the primary means by which urban trees capture stormwater runoff (Berland et al., 2017). To what extent then does stormwater infiltration into tree pits compare to canopy interception, as estimated by i-Tree? Better quantification may be the first step towards modifying street tree planting in ways that would increase future stormwater capture (McPherson et al., 2005). To respond to this need, this study compared stormwater infiltration and canopy interception for street trees.

2 METHODS

First, stormwater infiltration was estimated by calculating the amount of area that drains to street tree pits of varying sidewalk widths and slopes. Using Manhattan, New York, as a case study, sidewalk widths were measured to estimate sidewalk drainage areas. In this study, the total tributary drainage area (TDA) for each tree pit was calculated as the sum of three sub-areas: TDA 1, TDA 2, and TDA 3 (Figure 1).

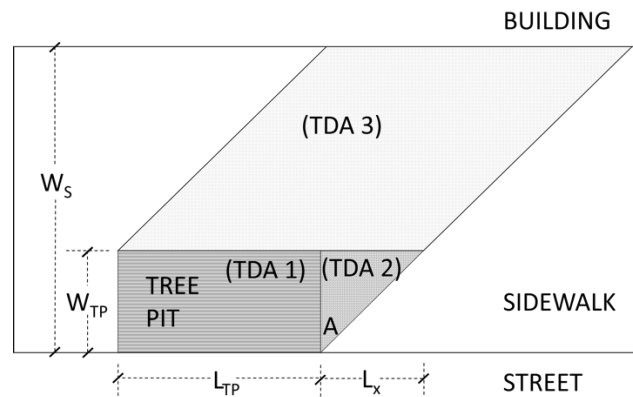


Figure 1. The tributary drainage area (TDA) for a street tree pit can be sub-divided into three separate drainage areas: TDA 1, TDA 2, and TDA 3. L_{TP} and W_{TP} are the length and width of the tree pit, W_S is the total width of the sidewalk, and L_x and A are a length and angle, respectively, whose dimensions depend on the slopes of the sidewalk and street, and are required to calculate the areas of TDA 2 and TDA 3.

For each of 4121 total storms found over 40 years (March 1977–March 2017) of historical weather data from LaGuardia International Airport, the curve number method was used to estimate stormwater runoff overflowing from all street trees in Manhattan (NRCS, 1986). Stormwater infiltration per tree was calculated as the difference between the volumes of stormwater entering and overflowing from the tree pits for all 4121 storms. The study then used the latest version of i-Tree, i-Tree Eco, to estimate canopy interception based on known tree diameters and tree species in Manhattan, New York, from a street tree census conducted in 2015 (City of New York, 2022).

3 RESULTS AND DISCUSSION

For stormwater capture overall, infiltration outperformed canopy interception by a ratio of 3 to 1. Based on actual sidewalk widths in Manhattan, the average per tree stormwater infiltration into tree pits as modeled by the curve number method assuming a highly compacted scenario (curve number 98) was 6842 L/yr. In contrast, the average per tree canopy interception as modeled by i-Tree for Manhattan's street trees was 2228 L/yr, based on tree species and DBH data. Infiltration exceeded canopy interception for most DBH and sidewalk width sizes in Manhattan (Figure 2). Infiltration exceeded interception for nearly all trees with a DBH less than 30 cm (that is, 76 % of NYC's street trees). For trees with a diameter between 30 and 60 cm (22 % of NYC street trees), infiltration exceeded interception for most tree pits with sidewalk widths greater than 3 m. The only tree diameter category where infiltration was consistently less than canopy interception was for the largest trees, with a DBH greater than 60 cm (2 % of NYC street trees).

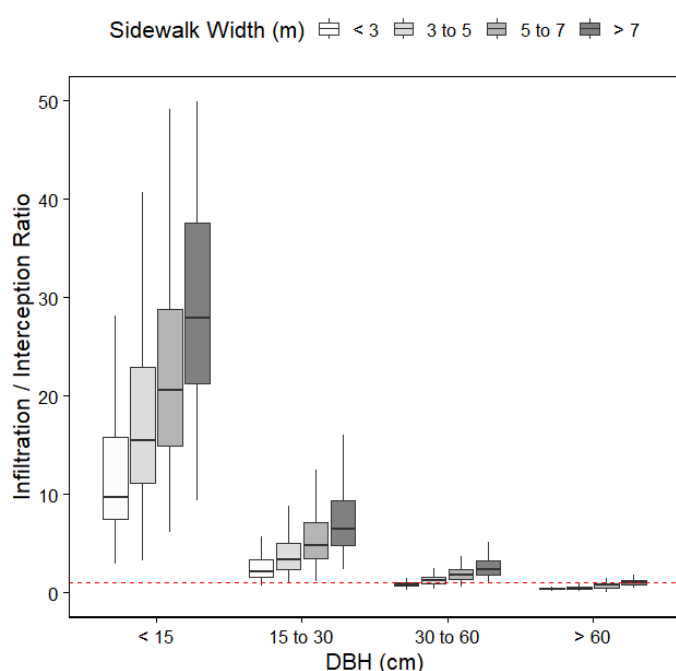


Figure 2. Ratio of stormwater infiltration into tree pits and canopy interception for various diameters at breast height (DBH) and sidewalk widths. Dotted line denotes a 1:1 ratio.

This study found that stormwater infiltration exceeded canopy interception for most street tree pits in Manhattan (Figure 2), by a ratio of 3 to 1. While the largest trees with a DBH greater than 60 cm admittedly had greater canopy interception than infiltration, these large trees only represent 2 % of the street trees of Manhattan. Even assuming that tree pits are highly compacted, conservative estimates of stormwater infiltration (narrow sidewalks, shallow street slopes) surpassed estimates of canopy interception. This finding contradicts Berland et al., who hypothesized that canopy interception is the primary means by which street trees provide stormwater control (Berland et al., 2017). This also contradicts Hirabayashi, whose models inform i-Tree Eco, who estimated total stormwater capture as a mere fraction of canopy interception (Hirabayashi, 2013).

4 CONCLUSIONS

This study provides a method to determine the TDA for a street tree pit, which allows the calculation of stormwater infiltration volumes. Its findings hold many important implications for city land managers, particularly that street tree planting should be modified so as to increase stormwater capture (McPherson et al., 2005). In neighborhoods where excess stormwater runoff poses the most severe water quality and/or flooding problems, tree planting should be prioritized for streets with significant slopes and wide sidewalks, because trees on these streets have large TDAs, and will therefore capture and infiltrate significant volumes of stormwater runoff. These trees could also be targeted for measures that increase their stormwater capture, such as the incorporation of a drainage layer, or an expanded pit size. Street tree planting should also be modified to improve tree health and survival. Given that

street trees typically experience high levels of drought stress (Szota et al., 2019), particularly drought-intolerant tree species should be planted on streets with large TDAs. This is because the tree species that are most vulnerable to drought stress would benefit the most from greater stormwater infiltration volumes. Conversely, drought-tolerant tree species should be specified for streets with narrow sidewalks and shallow slopes, because such hardy tree species may thrive despite limited stormwater flowing in from surrounding sidewalks.

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