Urban Forestry & Urban Greening 12 (2013) 401–407

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels

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ARTICLE INFO

Keywords:
Hydrologic benefits
Stormwater attenuation
Urban forestry
Vacant and underutilized land

ABSTRACT

This paper presents research that was undertaken to determine whether planting deciduous trees, using intensive tree planting schemes, on vacant and underutilized urban land provides significant hydrologic benefits. This work contributes to an ongoing discussion on how to use vacant and underutilized land productively, and may be important to land use decision-makers, whose policies support the use of green infrastructure for stormwater management. Tree growth parameters for four monoculture planting schemes were modeled (all trees had a 50.8 mm caliper at planting) and included (i) 450 *Ginkgo biloba*, (ii) 92 *Platanus* × *acerifolia*, (iii) 120 *Acer saccharinum*, and (iv) 434 *Liquidambar styraciflua*, on a 1.6-acre parcel. i-Tree Hydro (formerly UFORE-Hydro) was used to derive a simplified Microsoft Excel-based water balance model to quantify the canopy interception potential and evaporation, based on 7 years (2002–2008) of historical hourly rainfall and mean temperature data in Hamilton, Ontario, Canada. This study revealed that three of the species responded similarly, while one species (*L. styraciflua*) performed significantly better with respect to total canopy storage potential and evaporation, capturing and evaporating 2.9 m^3/tree over the 7 years analyzed, or 1280 m^3 for the total tree stand of 434 trees. The analyses presented herein demonstrate that the tree canopy layer was able to intercept and evaporate approximately 6.5%–11% of the total rainfall that falls onto the crown across the 7 years studied, for the *G. biloba*, *P.* × *acerifolia* and *A. saccharinum* tree stands and 17%–27% for the *L. styraciflua* tree stand. This study revealed that the rate at which a species grows, the leaf area index of the species as it matures, and the total number of trees to be planted need to be determined to truly understand the behavior and potential benefits of different planting schemes; had the mature leaf area been used as the sole indicator of the stormwater attenuating potential for each species, the *A. saccharinum* would have been the selected species. Also, had attenuation and evaporation per unit of tree been the only measurement reported, the *P.* × *acerifolia* stand would have been deemed the best performing tree, attenuating and evaporating 8.1 m^3/tree. While the actual values presented herein may be uncertain because of a lack of locally-derived tree growth models, the approach described warrants further investigation.

Introduction

Between 2000 and 2005, the Province of Ontario, Canada experienced 10 storms that exceeded intensities of 1 in 100-year storms, resulting in damages exceeding CAD$ 360 million (Conservation Ontario, 2009). A recent report calls on agencies to develop strategies to assist in flood management, as Ontario's flood management system does not currently have the capacity to cope with the resulting changes in flood patterns (Conservation Ontario, 2009). Mekis and Hogg (as cited in Milly, 2008), studied trends in precipitation for the Lake Huron and lower great lakes drainage basin and found that total rainfall amounts in Spring, Summer and Fall have increased by statistically significant amounts. Potential reasons for the increased incidence of flooding include increased rainfall intensities, increased urbanization (hardscaped surfaces), aging urban infrastructure, and deficient infrastructure capacities (i.e. existing infrastructure was not designed for current rainfall intensities). As a result, the ability of watersheds to mitigate stormwater runoff in many planning jurisdictions around the world has decreased. We present findings from recent research that aims to clarify whether planting trees on vacant and underutilized land, on a temporary basis, can provide enhanced hydrologic benefits. The research revealed that urban trees can contribute significantly

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http://dx.doi.org/10.1016/j.ufug.2013.03.003

in terms of intercepting, attenuating and evaporating rainfall. It is important to note that there are numerous benefits that are derived from urban forests beyond stormwater interception including, air pollutant removal, reductions in building cooling and heating loads, cooling summer air temperatures, removing carbon dioxide, and releasing oxygen into the atmosphere (McPherson et al., 1999). The study conducted by McPherson et al. (1999), which analyzed Modesto California's 90,000 urban trees, found that reductions in stormwater runoff of 292,000 m^3 resulted in a cost savings of USD$ 616,000 (or USD$ 7/tree or USD$ 2.11/m^3). Despite these numerous benefits, the discussion herein will be limited to a description of recent hydrologic modeling efforts and the corresponding results of four monoculture tree planting schemes that were modeled on a temporary basis: *Ginkgo biloba*, *Platanus x acerifolia*, *Acer saccharinum*, and *Liquidambar styraciflua*.

Vacant and underutilized urban land

Many cities around the globe, regardless of size or geographic location struggle with the presence of vacant and underutilized land in the urban environment; to date long-term solutions that contribute to the recovery of declining areas have not been implemented on a consistent basis, if at all (Pagano and Bowman, 2000). Bowman and Pagano (2004) state that while all cities contain vacant land, the type and supply of vacant land and the condition of said land can vary greatly. The authors further state that the phenomenon of vacant land has not been widely studied and that cities continue to search for ways to best transform vacant spaces (Bowman and Pagano, 2004). In an attempt to understand the complexity of the vacant land issue, Bowman and Pagano (2004) conducted a survey of planning directors in U.S. cities with populations of 50,000 or greater and found that on average approximately 15% of a city's land area can be classified as vacant or underutilized. This untapped resource presents enormous opportunities socially, environmentally and economically. One such opportunity would be to employ a reuse strategy such as a tree planting program.

Objective of research

While there is great potential to utilize vacant land in a variety of productive ways, the opportunity to do so may be limited by the short-term (0–5 years), medium-term (5–10 years), or longer-term (10+ years) availability of said land (Cleveland Land Lab, 2009). These time frames recognize that an ultimate, higher-order purpose for a vacant parcel may be established at some point in the future. The question then remains as to how to reuse these spaces on an interim basis in meaningful and productive ways. Therefore, the objective of this research is to determine whether significant hydrologic benefits can be achieved by developing relatively intense planting schemes for vacant and underutilized land, recognizing the temporal nature of this reuse strategy. The methodology used for studying the hydrologic benefits of the urban forest canopy with respect to capturing and attenuating stormwater is described in the following section.

Methodology

The research described herein required the identification and selection of an underutilized lot in the City of Hamilton, Ontario, Canada, the selection of four, common urban tree species for analysis, the selection of a tree growth model to predict various tree parameters (leaf area, tree height, crown diameter, crown height, and diameter at breast height), and the application of a Microsoft Excel®-based stormwater model, derived from the work described in Wang et al. (2008) for i-Tree Hydro (formerly UFORE-Hydro), to quantify the hydrologic benefits of the four planting schemes. Finally, a sensitivity analysis was conducted to explore the potential implications of global environmental change on the ability of each species to respond to an increased amount of total rainfall. All modeling and analyses were carried out using Microsoft Excel®. Rainfall data were provided by the Hamilton Conservation Authority (2009) for the Christie Dam Station, having a latitude of 43°16′37″ N and a longitude of 80°0′29″ W.

To aid in improving urban forest management, the i-Tree Hydro model was developed by the USDA Forest Service to provide a process-based planning tool with robust water quantity and quality predictions, given data limitations common to most urban areas (Wang et al., 2008; Yang et al., 2011). As described in Wang et al. (2008), i-Tree is an object-oriented, physical-based model that simulates interception, depression storage, evapotranspiration, infiltration and runoff processes, using land cover data, elevation data, meteorological data, as well as soil and runoff parameters as inputs. This model has been incorporated within a suite of free, technically supported, urban forest software tools called i-Tree (www.itreetools.org).

Tree planting scenarios

To simplify the modeling required for this analysis, four monoculture tree planting scenarios were selected: *G. biloba*, *P. × acerifolia*, *A. saccharinum*, and *L. styraciflua*. The four species were chosen from city street tree planting lists in the greater Toronto and Hamilton Area (Hamilton, 2009, Toronto, 2009). While the four species were generally favoured due to their tolerance to urban conditions, they have notable variations in leaf and branching structures, canopy size and shape, and growth rates (Gilman, 1997).

Water balance using historical data

A water balance was carried out using 7 years (2002–2008) of hourly rainfall and mean temperature data in Hamilton, Ontario, Canada, for a 1.6-acre underutilized parking lot, theoretically designed with a turf layer and planted with four monoculture deciduous tree layers. Four unique planting schemes and water balance models were developed for the four species. The water balance models analyze the effects of the tree canopies in attenuating and evaporating stormwater over a period from May 1 through November 19, as this period typically encompasses the budding/leafing, full leaf-on, leaf shedding, and full leaf-off processes for deciduous trees in the Province of Ontario (Elliot, personal communication, October 16, 2009). The amount of rainfall that falls through the canopy and becomes throughfall was also calculated.

Sensitivity analysis

Prodanovic and Simonovic (2007) predict that rainfall magnitude and intensity will increase significantly as a result of climate change, while Cheng et al. (2007) posit that climate change could have the following results with respect to rainfall:

(i) number of days with measurable rainfall could increase by 20%;
(ii) frequency of future heavy rainfall events could increase anywhere from 25–50% during this century, and
(iii) seasonal rainfall totals (Apr–Nov) could increase by about 20–35%.

This manuscript presents a case whereby the historical total hourly rainfall amounts were increased by increments of 5% to an upper limit of 35%, in an effort to demonstrate a potential scenario for increased seasonal rainfall totals. It should be noted that