XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

MAXIMIZING THE HYDROLOGICAL IMPACT OF STREET TREES THROUGH SIDEWALK DESIGN

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CSBE101082 – Presented at the 10th American Ecological Engineering Society Annual Meeting (AEES) Symposium

ABSTRACT Urbanization increases the total area of impervious ground cover leading to post-development rain runoff quantities that can damage and flood the natural downstream catchment. The Low Impact Development aim is to ensure that a resulting runoff from a given area is equivalent to pre-development levels. Trees, both in a natural and urban environment, play a vital role in the surrounding hydrology through interception, transpiration, evaporation, and infiltration. This increase of rain runoff created by a greater percentage of impervious surfaces can be in-part accommodated and improved by sidewalk design engineered to support healthy urban trees. Engineered soils can be used to meet the required bearing capacity of traditional compacted sidewalk subgrade soils while increasing volume available for root growth and water retention. Different engineered soils will be tested for their compatibility with pervious pavement materials to determine the most effective draining system that still meets the required load carrying capacity demanded by municipal sidewalk regulations. In combination with the structural soils further changes to the traditional sidewalk design are proposed to create beneficial growing conditions and maximize tree health. An assessment of the initial investment and cost of maintenance for this street tree catchment design will be explored to determine if the relief afforded to the stormwater management of a developed area justifies the expense. This paper will focus on the tools and methods used to pursue the analysis of the hydrological effect of sidewalk design centered on urban trees, with a specific concentration on application in Montreal, Canada.

Keywords: Low Impact Development, urban forestry, stormwater management, hydrology

INTRODUCTION

"*The key to protecting urban watershed health is to maintain the water balance as close to the natural condition as is achievable and feasible by preserving and restoring soils, vegetation and trees. Accomplishing this requires major changes in the way we approach urban drainage and in the way we develop land.*"(Stephens et al. 2003).

Urbanization increases the total area of impervious ground cover, leading to rain runoff quantities far greater than those of pre-development. These increased volumes overload city stormwater systems and treatment facilities, causing damage and flooding to the natural downstream catchment. Low Impact Development (LID) practices are aimed at matching post-development rain runoff quantities to those of pre-development as closely as possible (Gregory al. 2006; Dietz 2007). LID goals attained through stormwater Best Management Practice (BMP) (Guo 2008) implementation is one approach to address the issues arising from an ever increasing impermeable city surface and alleviate the load on municipal sewer systems (Villarreal et al. 2004).

Bioretention of rain water is an effective component of many BMPs (Echols 2008) and can be used to reduce the total impervious surface area with green roofs and raingardens. Yet, there will still remain a discrepancy between pre-and post-development runoff levels (Dietz 2007) that can potentially negatively affect downstream environments (Davis 2009). This margin of difference starts to become significant when considering peak levels during rainstorms and snow melt. The advantage of green roof and raingarden technology is that no additional space is needed for implementation. The feasibility of bioswales and the use of engineered ponds to address post-development hydraulic overflow is limited by their space requirements and their tendency to alter natural flows to a catchment basins by regulating outflows rather than letting water recharge groundwater and simulate pre-development conditions (County 2004). Bioretention can still provide crucial remedial possibilities when incorporated into city street planning. The aim of this paper is to illustrate how, through effective sidewalk design, street trees can ameliorate the disparity between pre- and post-development hydrology.

Trees affect the surrounding hydrology through rain interception, evaporation, transpiration, infiltration, storage, and increase of ground water recharge (Nowak 2006; Agronomy 2008; Bartens et al. 2009). Although the canopy storage capacity of a tree will be exceeded during heavy storms, interception of rain by the canopy will nevertheless mitigate city pollution entering the watershed. A 12-15m maple or oak tree can soak up to approx. 190 L of rain in the canopy (Staedter 2007). The interception of this rainwater delays the onset of peak flows in minor rain events that are responsible for the majority of pollutant wash-off (Xiao et al. 2006; McPherson et al. 2007) . The increase in soil aeration, infiltration rate, and water retention capacity associated with the growth of roots can significantly reduce the effects of flooding (Xiao et al. 1998).

Although an established as economically advantageous and an integral part of sidewalk design (Nowak and McPherson 1993), street trees are not afforded the resources for maximizing their potential impact on municipal hydrology. Health of the tree must be considered to be at least as important as the structural demands of the city regulations. Modern street trees are subjected to a barrage of negative pressures: vandalism, exhaust, damage from construction and demolition, underground utilities and overhead wire conflicts, high temperatures not suitable for root growth that are further exacerbated by the insulting qualities of concrete and asphalt, toxic soils, false horizons and altered light patterns caused by tall buildings, nutrient and moisture stress, desiccating winds channelled by ‘urban canyons’, and confined rooting conditions (Bassuk and Whitlow 1985; Dexter 2004; Guo 2006; Roman 2006; Day and Dickinson 2008). It is not surprising that street trees, especially during establishment, have high mortality rates and a life expectancy of less than 10 years from the time of transplanting (Grabosky et al. 2001; Roman 2006). The majority of these stresses are unavoidable in a municipal environment; unsuitable soil conditions are not. Proper planning and proper sidewalk design can mitigate the impact of this stress and create conditions favourable for tree health.

Sidewalk damage is the second most common reason, after disease, that street trees are removed. Each year, cities spend millions of dollars on dealing with the sidewalk repairs (McPherson et al. 2007). Municipal sidewalk design does not allocate sufficient space in tree pits and further hinders root growth by compacting peripheral soils so that they are impenetrable to roots ($\geq$1.75 g/cm^3 in sandy soils, $\geq$ 1.5 g/cm^3 in fine textured soils) (Edwards and Gale 2004). The result is shunted roots and trees that do not have the required growth room to attain full size (Grabosky and Bassuk 1995). For maximum tree growth and potential hydrological impact a tree requires a rooting area that is approximately 2 times the diameter of the tree's ultimate canopy (Day and Dickinson 2008) . The shoot extensions in urban trees are typically just over ½ that of a similar tree in a nursery environment (Edwards and Gale 2004). If the ratio of roots to shoots is too low, water absorption can fall behind transpiration and the tree will suffer from water stress (Bartens et al. 2009). Water stress is considered to be one of the most significant pressures on urban trees, especially during the summer months (Cregg and Dix 2001; Quigley 2004). Municipalities are required to compact sidewalk subgrade to these bulk densities to meet sidewalk bearing capacity regulations. The resulting condensed soils have a lower porosity, aeration rate, and water holding capacity that limit moisture and nutrient availability (Chasse 1975; Roman 2006). Combined with reflected heat from buildings and pavement, the insulating qualities of sidewalk concrete, and the impervious nature of the surrounding surfaces, this low moisture soil creates an arid environment unsympathetic to root proliferation and tree growth (Edwards and Gale 2004). To be successful a large tree must be able to draw water and nutrients from areas other than the tree pit as often the tree pit does not retain enough to sustain healthy growth (Edwards and Gale 2004). A tree must also have sufficient rooting space to anchor a fully-grown tree (Jim 1998). To maximize the hydrological impacts of street trees and reduce the load on city storm sewers, street trees require more rooting volume and greater access to moisture than is currently provided in typical sidewalk design.

Inventive BMPs have been suggested and implemented, with varying success, to relieve street trees of the confining stresses of urban tree pit design and improve municipal hydrology. Suspended concrete pavers over non-compacted subgrade soil have been proposed to allow for better soil infiltration and root growth. The method has shown success in downtown Charlotte, NC, tree plots, for instance. This approach has received little attention, however, for use in areas where vehicle and pedestrian traffic exist, as this would require pre-fabricated pavers engineered to meet load bearing requirements (Smiley et al. 2006). The University of California at Davis has developed an engineered soil, called Davis Soil™, with superior porosity and pollutant capture than typical tree pit fill, to be used in tree wells in small plazas and parking lots (Staedter 2007). The soil promotes deep rooting of trees and prevents swelling during rainstorms, thus limiting the damage to surrounding infrastructure. Davis Soil has the added bonus of promoting groundwater recharge but must still be compacted to bulk densities typical of soils beneath sidewalks and roads (Xiao et al. 2006). In 2001, the City of Seattle completed its Street Edge Alternative (SEA) pilot project in a northern city suburb and has had near 100% rate of reduction of rain runoff through shrub and evergreen planting, swale retention, and diminished impervious surfaces. SEA success, however, is limited to suburban areas where street width can be decreased and total impervious surface area is much lower (Horner et al. 2002).

The use of gap graded skeletal soil materials that have been combined with hydrogel in an attempt to form a strong uniform soil matrix that meets structural needs while still sustaining plant growth shows promise as an effective solution (Grabosky et al. 2001). A joint study involving the University of California at Davis, Virginia Tech, and Cornell University is focused on the use of engineered structural soil as a potential replacement for sidewalk and asphalt subgrade materials (Davis 2009). The study was designed to specifically tackle problems faced by extensive impermeable surfaces and damaged soils by facilitating positive growth in street trees in order to take advantage of the subsequent hydrological benefits. The engineered soils involved have matrices specifically designed to achieve desired sidewalk subgrade bearing capacity while maintaining porosity and other soil characteristics that support nutrient and water retention, root penetration, and thus tree growth (Day and Dickinson 2008). Tree pit dimensions remain the same, but root growth is facilitated beneath the surrounding impervious surfaces. The surrounding area is designed to channel water flow into the engineered soil fill, which acts as a reservoir and recharge zone (Grabosky and Bassuk 2008; Davis 2009). Two different structural soils were used and compared: CU-Soil, developed by Cornell University in the 1990s, and Carolina Stalite, produced by Carolina Stalite Company in North Carolina (Bassuk et al. 2005; Day and Dickinson 2008). The results showed a significant improvement of subgrade root penetration over that typically seen in traditional packed soil. No soil nutrient deficiencies associated with structural soils have been recorded (Bassuk et al. 2005; Bartens et al. 2009; Davis 2009).

Proper tree pit fill that is high in nutrient concentration and organic content to facilitate tree establishment should still be used as the primary rooting medium. Engineered soils typically are composed approximately of 20% soil by volume and 2-5% organic content to ensure sufficient nutrient and water holding capacity, and are not designed to replace tree pit fill soil (Smiley et al. 2006; Day and Dickinson 2008).

Research Objective The goal of this study is to prepare a complete sidewalk tree pit redesign appropriate to streets in downtown Montreal, Canada. Engineered structural soils will be used to replace conventional sidewalk subgrade to create an environment favourable to street tree health. The hydrological impact of urban trees will be integral in the modeling and planning of a stormwater management system.

Proposed Methodology The study proposed involves a review of the work completed on pairing engineered structural soils with porous pavement and concrete. Percolation and infiltration tests will have to be performed on various combinations of available structural soils and porous pavement. Water retention capacities of the materials will need to be assessed and compared to the ideal growing conditions of typical street tree species in Montreal. The effect of Montreal’s colder climate on the soil moisture retention and permeability will need to be evaluated experimentally. The tests must be carried out at temperatures consistent with Montreal soils at time of high rainwater runoff flow rates e.g. summer rainstorms and spring snow melt.

Current sidewalk design adheres to strict regulations put in place to ensure that a sidewalk is resilient to all expected pressures and performs all tasks required of it, in harmony with the surrounding infrastructure. Any change to sidewalk specifications must be made to ensure that all requirements of the end product are still met. If not, the positive impacts of any proposed changes to sidewalk construction, designed to improve the living conditions of urban trees, must be weighed against any negative effects the changes will have on the sidewalk’s ability to meet a requirement. It must then be determined whether or not the difference is acceptable and the improvement justified. To this end a review of modern sidewalk design guidelines and specifications is essential to the proposed study.

The study will include a complete analysis of the economic feasibility of incorporating LID based sidewalk design into standard practice and whether or not the estimated return on investment justifies initial expense. A comprehensive investigation of the costs involved in the use of new materials, implementation of changes in sidewalk construction, and changes to sidewalk and urban tree maintenance will be established and compared to existing sidewalk expenses. This will require a review of current sidewalk expenditures taking into account costs of tree maintenance and tree associated damage that would theoretically be mitigated with increased rooting room.

In the most conservative predictions of climate change, Montreal is still expected to experience an increase in average annual rainfall (Zhang et al. 2000; Hanson et al. 2005). Strategies to mitigate the impact of an increased load on the city storm sewers and subsequent downstream catchments must be formulated and implemented in preparation. The research proposed in this paper will help to develop efficient and economically sustainable BMPs that address the increase of runoff associated with ever increasing impermeable surface area while, at the same time, providing a favourable environment for tree growth and success. The influx of city wash-off and any associated harmful chemicals to the receiving watershed will be reduced by increased soil retention and bioaccumulation by root uptake. This has the effect of reducing and isolating the area of impact of detrimental runoff. The positive impacts are not limited only to stormwater management and downstream catchment but also minimizing the heat island effect, air particulate capture, carbon sequestration, and an improved ecosystem are some benefits that accrue from healthy urban trees (Nowak and McPherson 1993; Maco et al. 2005).

Enhancing the stormwater management system of a city through the integrated use of the bioretention and the hydrological attributes of healthy street trees represents an important step in integrating sustainable ecosystems with society.

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