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QUANTITATIVE ASSESSMENT OF GREEN ROOF BENEFITS FOR VANCOUVER

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Abstract

The three main environmental benefits (stormwater management, energy savings, and air quality improvement) were incorporated in a cost-benefit analysis for green roof deployment in the city of Vancouver. Stormwater management benefits calculated based on fee structures for pervious surfaces in twenty-six American cities totaled $1.2–1.7M/y, when adapted to the Vancouver greening plan. Infrastructure benefits such as receiving water quality improvements, reduction in major storm flows development cost charges (DCC), reduction in risks due to climate change, reduced storm water impact to aquatic habitat, and reduction of receiving stream erosion ranged from $3.4M to $4.1M/y. Energy savings based on electricity and natural gas use resulted in avoided nitrogen oxide (NO_X), sulfur oxide (SO_X), and carbon dioxide (CO_2) emissions, and in air conditioner downsizing opportunities, resulting in $2.7M to $3.1M savings annually. Air quality improvement benefits were based on NO_X and particulate matter with particles of 10 micrometers or less (PM_{10}) captured by green roof systems using experimental and modeled data. The results demonstrate that the net present value (NPV) is 28 to 48% less than that of conventional roofs over the lifetime of the green roof (40 years), and that green roofs become NPV-positive in as soon as six years, driven primarily by health benefits from air pollution mitigation and stormwater management benefits.

1. Introduction

Although green roofs have been built in Metro Vancouver for more than 35 years, their installation in this area remains an exception rather than the norm due to their higher cost compared to traditional roofs, and because their initial deployment focused primarily on the aesthetic qualities provided by intensive green roof designs (Metro Vancouver 2009).

Over the last few years, a number of reports have emerged that are providing increasingly rigorous analysis of the cost-benefit analysis of green roofs, as a function of climate, local incentives, and scale of deployment. The major economic benefits tend to be in the stormwater, energy, and health areas, particularly if infrastructure benefits at scale are considered (Clark et al. 2008; Niu et al. 2010). In the case of Vancouver, on account of its regional climate, the reliance on hydropower as its primary energy source, and local greening policies, the most significant benefits are likely related to stormwater management. Stormwater management requirements have increased and changed substantially over the past ten to fifteen years in the Vancouver region (Metro Vancouver 2009) and green roof proposal designs must meet the current stormwater criteria. These are outlined in the Department of Fisheries and Oceans' (DFO) *Urban Stormwater Guidelines* (Department of Fisheries and Oceans 2001) or in *Stormwater Planning: a Guide Book for British Columbia* (Stephens et al. 2005). Additionally, municipalities have local stormwater control bylaws, prescribed in their integrated stormwater management plans (ISMPs). A recent report, titled *Design Considerations for the Implementation of Green Roofs* (Metro Vancouver 2009), was developed to provide background information and data to assist regional municipalities and developers in understanding the benefits, issues, and costs associated with green roof installations, and to provide guidance on where research and the green roof business are headed in the near future. The report lays out the various benefits, and even provides economic background information, but stops short of integrating the benefits and costs in a net present value (NPV) scenario to help developers and municipalities assess whether the investment in green roofs outweighs the premium costs over time.

The goal of this paper is to evaluate the monetary value of green roof benefits (stormwater management, energy savings, and air quality improvement) under the climate, energy, and policy conditions that apply to Vancouver, Canada; and incorporates these benefits into a cost-benefit analysis tool NPV model to quantify the breakeven of green roof deployment at the urban scale for this region.

2. Methodology

The potential green roof area was based on Vancouver's greening plan, which indicates a total area estimated at 12.3M square meters (m^2) (11.2% of the total land use) (based on roof areas considered in the Metro Vancouver 2009 report): multi-family buildings represent 3.4% of the total land use or 3.7M m^2; institutional buildings cover 1.8% of the total land use or 2.0M m^2; commercial buildings are 3.6% at 4.0M m^2; and the area of industrial buildings is 2.4% or 2.6M m^2. The methodology of estimating economic stormwater, energy, and health benefits was adapted from Clark et al. (2008) and Niu et al. (2010), and incorporated the stormwater infrastructure benefits articulated in the Vancouver Greening Plan (see Table 1).

The annualized benefits were integrated in an NPV analysis to assess the cost of green roofs over their lifetime (40 years), as compared to conventional roof replacement. The federal interest (discount) rate was selected at 0.65% (2009), and an inflation rate of 0.31% in 2009 (Canadian Consumer Price Index 2010). The discount rate was selected to be consistent with other studies reporting on the NPV for green roof annual savings; these do not represent the lending rates for green roof infrastructure capital projects. For capital expenditure analysis (stormwater infrastructure savings, receiving water quality improvements, and reduction in risks due to climate change), an infrastructure facilities discount of 6% (10 year depreciation) was used as reported by the District of Columbia Water and Sewer Authority (Niu et al., 2010). Air conditioning equipment (AC) discount rates of 7% were used, assuming a 10 year depreciation (similar to rates reported for discounting AC by the Oregon Department of Energy 2004).

Table 1. Input parameters for the economic analysis of green roof benefits in Vancouver (Metro Vancouver 2009 unless otherwise cited)

Benefits	Detail Benefits	Data
Costs of Roof	Conventional Roof	\$86–\$129/m^2 (Lower Mainland). Increased by \$32/m^2 between 2001 and 2004 due to insurance costs (fires).
	Green Roof	Range: \$184/m^2 (100 mm) to \$238/m^2 (300 mm). Baseline green roof standard used \$205/m^2 (150 mm). Maintenance costs (first 2 years): \$13-21/m^2 Comparison: Silva Building in Vancouver, \$178/m^2.
Stormwater	Governmental Credits	Based on 26 US city stormwater fees (stormwater fees of \$0.28±0.22/m^2, and 35% or 50% credit).
	Receiving Water Quality Improvements	Using effective impervious area (US Energy Information Administration [EIA], 2010) relationship, removal of >50 μm particles results in \$0.5M savings due to green roof. Typical stormwater estimated benefits: 20 times higher.
	Reduction in Major Storm Flows	Reduction in development cost charges (DCC) of 15% for green roof deployment. Average DCC: \$95.48/m^2 (residential); \$118.30/m^2 (commercial). Green roof benefit: \$14.32/m^2 (residential); \$17.74/m^2 (commercial). Total savings: \$205M.
	Reduction in Risks Due to Climate Change	Reduction of impervious area by >50%) results in longer duration storms governing discharge, and less effect of climate change on the conveyance system. Example estimate from the 15th St catchment resulted in reduced infrastructure upgrade needs of \$0.2M.
	Reducing Stormwater Impact to Aquatic Habitat	Based on \$3000 stormwater mitigation cost per lot, for a typical roof area of 186 m^2, this translates to a cost of \$16.15/m^2, and a total savings at \$198M, assuming all land use building costs are equivalent.
	Reduction of Stream Erosion	Erosion valuation at \$5055 per hectare (ha) of green roof; translates into total \$6.2M savings.
	Stormwater Retention	Measured stormwater retention ability ranging from 26% to 29%. The operational fees for stormwater management are estimated at \$0.01/gallon.
Energy Savings	Electricity & Natural Gas Savings	Energyplus ('lodge'/'office/professional' defaults). Electricity: 7.13c/kWh (residential); 4.87c/kWh (commercial). Natural gas: 5.9c/kWh (residential) and 4.5c/kWh (commercial). Scaled 350m^2 (residential) and 2000 m^2 (commercial) roofs: urban savings \$2M.
	Avoided emissions (NO_X, SO_X, CO_2)[a]	Emission factors based on Idaho (mainly hydropower): 0.6lb/kWh (NO_X); 1.2lb/kWh (SO_X); 184lb/kWh (CO_2)
	Air Con. Size	See Niu et al. (2010).

Table 1. (continued)

Benefits	Detail Benefits	Data
Air quality	Health benefits (see also Niu et al. 2010)	Scenarios: 1. Experimental NO_x uptake of 0.27Kg/m^2; PM_{10} reduction of $2.8*10^{-3}$kg/m^2). 2. SEDUM model NO_x uptake calibrated for Vancouver (0.03kg/m^2); PM_{10} as in 1. Health benefit (US Environmental Protection Agency [EPA]): \$6380/ton (NO_X); \$6980/ton (PM_{10}). Total: \$2.6M/y to \$21.4M/y.

[a] NO_x = nitrogen oxide; SO_x = sulfur oxide; CO_2 = carbon dioxide.

3. Results

Assuming the areas considered in the greening plan of the City of Vancouver, the installation costs of green roofs were estimated to be 51% higher than those of conventional roofs for the same area (\$2851M vs. \$1884M). Since maintenance costs are only incurred during the first two years, they were not included in the lifetime cost analysis. However, when all benefits are considered (Table 1), the NPV of green roofs was found to be 28 to 48% less than that of a conventional roof over 40 years. This is similar to the economics of green roofs for Washington, DC (30 to 40%; Niu et al. 2010). At the city scale in Washington, DC, air pollution benefits were by far the largest contributor (using experimental NO_x uptake values), with stormwater and energy a distant second and third, respectively (data not shown).

The distribution of the major three benefits (stormwater, energy, and air pollution — health) under two scenarios is shown in Figure 1. A few observations can be made here: (i) there needs to be improved information on the NO_x uptake by green roofs under air quality and climate conditions in Vancouver, because of the wide range observed between experimental and modeled data; (ii) energy benefits are impacted by the price of carbon resulting from avoided emissions (see also Table 3), even when most of the primary energy source is not carbon-intensive (as is the case for hydropower); (iii) stormwater benefits are potentially very significant contributors to the green roof NPV, particularly when the multitude of benefits are considered as described in Table 1.

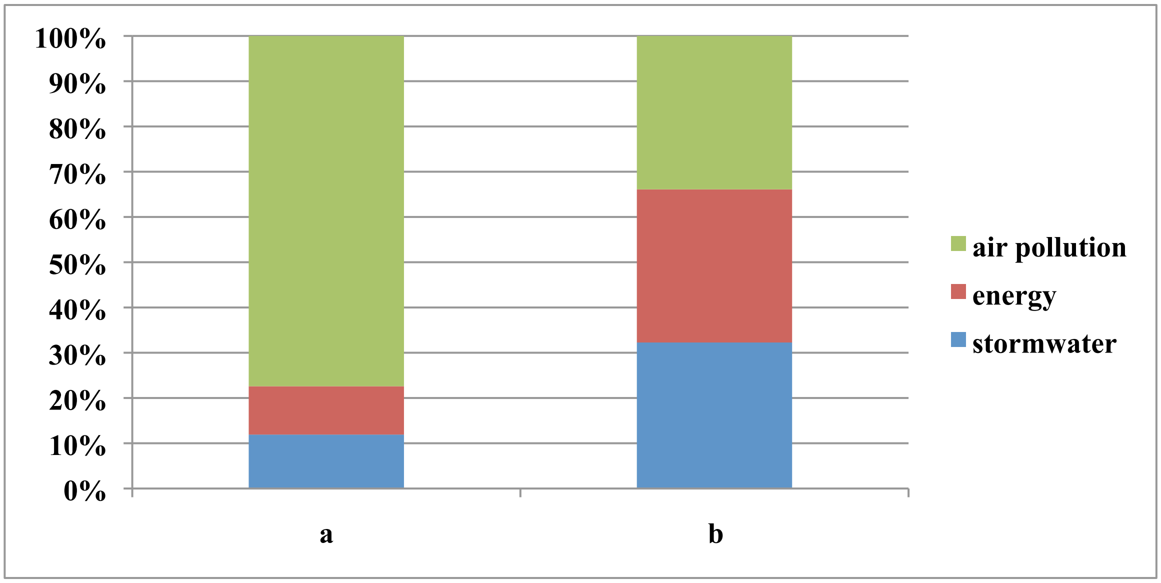

Figure 1. The distribution of total stormwater benefits, total energy savings, and air quality benefits of the total NPV savings from green roof systems over 40 years at the urban scale in the City of Vancouver (all annual savings and capital expenditure savings). Scenario (a) depicts 50% stormwater fee reduction benefits, high receiving water quality improvements benefits, high CO_2 *allowance estimates (European markets), and high air quality benefits (using experimentally measured uptake of* NO_x*). Scenario (b) shows 35% stormwater fee reduction benefits, low receiving water quality improvements benefits, low* CO_2 *estimate (using the voluntary carbon market prices), and modeled (SEDUM-based)* NO_x *air-quality benefits.*

The stormwater benefits play a much more significant role for City of Vancouver, because the primary objective of the green roofs project is to address stormwater management concerns derived from the wet weather in the Pacific region and because of the more stringent stormwater laws (Metro Vancouver 2009). Based on Table 2 (40 year NPV savings), it is apparent that fee-based benefits, reduction of storm flows and aquatic habitat impacts drive the benefits from stormwater. The annual savings estimated from DCC and aquatic habitat are based on pilot projects, whereas the total savings in these two categories are derived from an estimated infrastructure benefit of $205M and $198M, respectively, discounted (6%) over 40 years.

Table 2. Stormwater management benefits from green roof deployment in Vancouver

Benefits	Total Savings (over 40 years)	Annual savings
Fee-based benefits	$48–68M	$1.2-1.7M/y
Receiving water quality improvements	$0.5–10M	$0.04–0.8 M/y
Reduction in major storm flows (DCC)	$20M	$1.3M/y
Reduction in risks due to climate change	$0.2M	$0.02M/y
Reducing stormwater impact to aquatic habitat	$19.3M	$1.3M/y
Reduction of receiving stream erosion	$6.2M	$0.5M/y

The energy benefits included reduced energy use, avoided emissions as determined under a predominantly hydropower energy supply scenario (similar to Idaho), and air conditioner size reduction benefits; energy savings contributed the major share of these benefits. The total energy savings from a 350-m^2-roof residential facility were 1.7 MWh, with 0.6 MWh from electricity savings and 1.1 MWh from natural gas savings, as compared to a conventional roof. The total energy savings from a 2000-m^2 commercial facility were 6.7 MWh with 4.1 MWh from electricity savings and 2.6 MWh from natural gas savings over a conventional roof. When these building pools are aggregated to the city scale, the electricity savings are 6300 MWh, and natural gas savings are estimated at 11,616 MWh for the residential facility pool. For the commercial building pool, electricity savings are 17,733 MWh and natural gas savings total 11,005 MWh. These savings translate into $2.4M/y. The energy savings have less impact on the NPV for the City of Vancouver, as compared to, for example, Washington, DC, due to the relatively lower energy prices. The data in Table 3 indicate that, of all avoided emissions, carbon drives this benefit category. However, the overall avoided energy benefits are very small compared to energy-efficiency savings, due to the use of hydropower as the predominant primary energy source.

Table 3. Economic value of avoided emissions due to reduced energy use[c]

Reduced Pollutants and Material	**Electricity Generation Reduction ($'000)**	**Natural Gas Generation Reduction ($'000)**	**Building Emission Reduction ($'000)**	**Total Reduced Emission Savings ($'000)**
CO_2 (CCX)[a]	8.5±4.3	6.7±3.4	27.3±13.7	42.5±21.4
CO_2 (ECX)[b]	75.8±15.1	59.7±11.9	242.1±48.1	377.6±75.1
NO_X	10.4	2.6	13.6	26.6
SO_2	10.6		13.7	23.3

[a] *CCX = Chicago Climate Exchange market.*
[b] *ECX = European Climate Exchange market.*
[c] *The emissions tallied in this table do not account for the carbon footprint of growing media production (e.g. kiln fired vs. natural sources; transportation and installation energy necessary).*

There were two scenarios included in the health benefits from air pollution mitigation. The 'high estimate,' based on greenhouse experiments, result in the removal of 3321 metric tons NO_x/y (mean value). Using the health cost of $6380/metric ton, this benefit translated into $21.2M/y. The modeled estimate is based on the SEDUM model, which is informed by NO_x concentrations in Vancouver air. In this case, NO_x removal was projected to be 369 metric tons/y, or almost one-tenth of the experimental values; the economic benefit would then be $2.4M/y. Based on our earlier work (Clark 2008; Clark et al. 2008; Niu et al. 2010), the model appears to underestimate (because it is process-based, and not all NO_x species are represented), and the experimental work overestimates (due to the use of elevated concentrations in the experiments) the actual uptake of NO_x by green roofs. The health benefits from PM_{10} removal were based on UFORE model results (Deutsch et al. 2005) and $6980/metric ton cost (EPA 1998), and translated into $0.2M/y. Hence, the total savings from air quality improvement benefits ranged from $2.6M/y to $21.4M/y at the urban scale.

Using these benefit scenarios, the earliest breakeven (the lower bound NPV) of green roofs in City of Vancouver was found to be six years, which is even earlier than that estimated for Washington, DC (seven years) (Niu et al. 2010). The latest breakeven is around 21 years, and is controlled by the replacement cost of the conventional roof. This outcome indicates that even in regions where the primary energy source is largely carbon-neutral (e.g., hydropower), the economic benefits of green roofs can exceed the cost of deployment (short term positive NPV), provided strong incentives are in place for green stormwater management practices.

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