Different Methods to Assess Green Infrastructure Costs and Benefits in Housing Development Projects

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Received: January 31, 2012 Accepted: February 20, 2012 Published: April 1, 2012
doi:10.5539/jsd.v5n4p2 URL: http://dx.doi.org/10.5539/jsd.v5n4p2

Abstract

Given the general lack of empirical data for evaluating green infrastructure (GI) in housing development projects, this study analyzed the costs and anticipated benefits of a GI housing project development in the City of Vaudreuil-Dorion, Quebec, Canada, including roads, drainage, water supply, and wastewater. The concept of managing storm water, wastewater, and water supply connected to a constructed lake within a closed loop has not been evaluated in detail previously. This study evaluated the economic costs and benefits of the investment in dollar terms using three methods of calculation: (1) the Center for Neighborhood Technology National Green Values^{TM} Calculator, (2) the Canada Mortgage and Housing Corporation's Life Cycle Costing Tool, and (3) cost-benefit analysis. The findings of this study indicate that a GI project can provide significant economic and environmental benefits to cities.

Keywords: Green infrastructure, Hedonic price, Benefit transfer method

1. Introduction

There is increasing public and government interest in establishing green technologies in project development, due to their demonstrable environmental benefits (United States Environmental Protection Agency, 2009). Despite their potential as a climate change adaptation and mitigation tool and their widespread use in Europe and the USA, there are very few examples of green development in eastern Canada. Further, even though there is increasing interest in sustainability in many locations and demonstrated capacity for urban design solutions, cities today are having difficulty investing in systems that are long term and ecologically sound (Suzuki et al., 2010). One of the major barriers to increasing the prevalence of extensive green projects is the lack of scientific data available to evaluate their applicability in local conditions. A second barrier is the absence of comparable costs for developing a project with a 'green approach'. However, it has been suggested that green infrastructure (GI) can accomplish many of the same goals as hard-engineered infrastructure at a lower cost (Hansen, 2010) and that an integrated GI approach to housing development can deliver economic and environmental benefits as well as significant cost savings for municipal infrastructure (Wise et al., 2010).

The terms "value system," "value," and "evaluation" have a range of meanings in different disciplines. "Value system" refers to norms and precepts that guide human judgment and action (Farber et al., 2002). The term "value" means the contribution of an action or object to user-specified goals, objectives, or conditions (Costanza, 2001). In the current context, "ecosystem evaluation" is the process of expressing a value for ecosystem goods or services to provide the opportunity for scientific observation and measurement (Farber et al., 2002). In the specific case of housing development, “value” means willingness to pay a sum to acquire a house. “Benefit” refers to tax revenue for the municipalities and improvement value to the environment.

Infrastructure investments have brought GI and low impact development (LID) practices into cities’ municipal infrastructure investment strategies. The difficulty lies in integrating the evaluation of multiple benefits, quantifying benefits that may not be easily monetized and bringing recognition of these values into infrastructure investment decisions by developers, communities, and agencies (Wise et al., 2010). When services are directly tradable in normal markets, the price is the exchange value. When there are no explicit markets for services, we must resort to a more indirect means of assessing economic values (Farber et al., 2002). In the context of municipal planning and infrastructure investment, the prudent application of limited financial resources may appear at first as a constraint to sustainable development. However, there is growing evidence that strategies and technologies that are supportive of sustainability are possible and relevant, and that they provide services at lower costs, and even at lower capital investment, than conventional approaches (Centre for Sustainable Community Development, 2004).

The City of Vaudreuil-Dorion, Quebec, Canada has decided to introduce green concepts in new housing development projects to attract new stakeholders. To determine how GI compares with conventional infrastructure (CI) in the suburban context, this study evaluated the construction cost of infrastructure such as roads, drainage, water supply, and sewerage facilities in a new housing development in Vaudreuil-Dorion. Housing is an extreme example of a differentiated product, in the sense that every house is different both in terms of its physical characteristics, and in terms of its location (Hill, 2011). A green environment may increase house value by 5 to 25 percent.

The hedonic price method (HPM) is used to value ecosystems or ecosystem services that directly affect market prices (King & Mazzotta, 2000). Hedonic price models have been used commonly to estimate house prices and property values (Limsombunchai et al., 2004). In France, Cavailhès (2007) established a hedonic price for scenery. The results of another study confirmed the positive amenity effect of proximate urban green spaces on house prices in Jinan City, China (Kong et al., 2006). In another study, green space amenity variables that were statistically significant at the 5 percent level included the size–distance index of forest scenery and accessibility to park and plaza green space types (Kong et al., 2006). In the Regional County Municipality (MRC) of Vaudreuil-Soulanges, where Vaudreuil-Dorion is located, the development of projects in different cities has demonstrated the attraction of buying a house in a green environment. Saint-Lazare, which has a naturally greener environment than Vaudreuil-Dorion, has a housing evaluation per inhabitant that is 27 percent higher than that of Vaudreuil-Dorion. These figures are supported by the following case study.

2. Literature Review

The economic dimension of value is only one of the many relevant factors that make humans value ecosystems (Villa et al., 2007). Traditional valuation techniques, such as cost-benefit analysis and contingent valuation, may not be adequate for valuing the ecological and social functions of urban green spaces, which is required to strengthen their role in the decision-making process within local communities (James et al., 2009).

In 2011, Hill published a paper for the Organisation for Economic Co-operation and Development on hedonic methods. House prices as a function of a vector of characteristics were deemed particularly useful for this purpose. In his report, Hill considered some of the developments in hedonic methodology as applied in a housing context that have occurred in the last three decades. Hill mainly presented and explored modeling methods to predict house prices. It is often difficult to see how hedonic methodology indexes relate to each other. For this reason, Hill attempted to impose some structure on the literature by developing a taxonomy of hedonic methods, and demonstrated how existing methods fit into this taxonomy.

There are many methods used to estimate dollar measures of economic values associated with ecosystems. King and Mazzotta developed an approach to evaluate ecosystems in general and, specifically, in the housing market. They outlined ten different methods to measure the cost of projects in their publication: Market Price Method; Productivity Method; Hedonic Pricing Method; Travel Cost Method; Damage Cost Avoided, Replacement Cost, and Substitute Cost Methods; Contingent Valuation Method; Contingent Choice Method; and Benefit Transfer Method (King & Mazzotta, 2000).

In the context of housing development, HPM and the benefit transfer method (BTM) are more relevant for identifying benefits because willingness to pay can be quantified; therefore, this study will refer to these methods. Traditional house price prediction is based on cost and sale price comparison that is lacking in accepted standards and a certification process (Limsombunchai et al., 2004).

There are few tools available for comparing construction costs in different types of housing development. In 2008, the Canada Mortgage and Housing Corporation (CMHC) created the Life Cycle Costing Tool (LCCT) for community infrastructure planning to allow users to estimate the major costs of community development and to compare alternative development scenarios. The tool is geared toward estimating planning level costs and revenues associated with the residential component of a development (Pollard, 2008). In 1996, the Asian Development Bank published *Economic evaluation of environmental impacts: a workbook* (Bando et al., 1996). The book provides a set of working tools to incorporate environmental costs and benefits within project analysis. Today, the workbook is considered current still because it emphasizes evaluation of environmental economic analysis. In 2009, the Center for Neighborhood Technology (CNT) produced the National Green Values™ Calculator (GVC) and published the detailed benefits of GI. The CNT reviewed current methods of evaluating the economic and social benefits of GI practices (Center for Neighborhood Technology, 2009b).

Another tool is the Environmental Valuation Reference Inventory™ (EVRI), which is a searchable storehouse of empirical studies on the economic value of environmental benefits and human health effects. The EVRI has been developed as a tool to help policy analysts use the benefits transfer approach, as an alternative to conducting new valuation research (Environment Canada, 2006). The EVRI can provide indicators for evaluating environmental benefits. Environment Canada developed the EVRI in collaboration with a number of international experts and organizations, particularly the Office of Water, United States Environmental Protection Agency.

Foster, Lowe, and Winkelman (2011) proposed an evaluation of all feature benefits. The value of GI actions is calculated by comparison to the cost of hard infrastructure alternatives, the value of avoided damages, or market preferences that enhance value (such as property value). GI benefits can be divided generally into five categories of environmental protection: (1) land-value, (2) quality of life, (3) public health, (4) hazard mitigation, and (5) regulatory compliance (Foster et al., 2011).

In 2005, Wachter used the New Kensington Greening Program to model the economic benefits of place-based investment strategies. The potential benefits of these investments can be identified by measuring the additional value that people place on living in neighborhoods where such investments have been made (Wachter, 2005). Wachter employed hedonic regression techniques in her study. The study found that vacant land improvements result in surrounding house value increases of as much as 30 percent, and new tree plantings increase surrounding house values by approximately 10 percent. In the New Kensington area, this translates to a $4 million gain in property value through tree planting, and a $12 million gain through lot improvements. The direct and indirect effects of greening on the city's property tax base are likely to contribute to the overall fiscal health of the city of Philadelphia (Wachter, 2005).

In the housing context, a distinction can be drawn between omitted variables that relate to the physical characteristics of a dwelling and those that relate to its location. Many characteristics may appear in hedonic regressions for housing, such as square footage, land area, bedrooms, garages, and swimming pools (Hill, 2011). In the current study, these parameters need not be considered, because the focus is on willingness to live in a green development. In 2005, Bourassa, Cantoni, and Hoesli used a sample of sales transactions from Auckland, New Zealand, to demonstrate that housing submarkets defined as small geographical areas have more practical utility than submarkets defined without regard to spatial contiguity. Moreover, submarkets matter in a way that underscores the value of the practical knowledge of appraisers (Bourassa et al., 2003). Not only do submarkets matter, but geography also makes a difference. The sale price is approximately 10 percent higher when there is a water view (Bourassa et al., 2005). The quality of the neighborhood is very important, and higher quality is associated with higher prices. A property with high quality neighboring properties would be valued, on average, 38 percent higher than the same property with poor quality neighbors (Bourassa et al., 2003).

Hill (2011) explored modeling methods to predict house prices. King and Mazzotta (2000) surveyed multiple methods to estimate dollar measures of economic values associated with ecosystems. Wachter (2005) modeled the economic benefits of place-based investment strategies. The tools commonly preferred in the literature to compare housing development are the LCCT and Green Values Calculator. In the context of housing development, the HPM and BTM are relevant for measuring benefits and increases in property value.

3. Methodology

The management of storm water, wastewater, and water supply connected to a constructed lake in a housing development is a relatively new concept that has not received much attention in the past. The Vaudreuil-Dorion 540 Development Project is in the preliminary phase of project preparation, and is conceptualized here with a new framework. The proposal is currently at the stage of investigation.

This study addresses hard costs and house values. The economic analysis was of a quantitative type, and the economic evaluation used was the rapid analytic method, including the BTM and HPM. The basic analytical framework considered a preliminary design of infrastructure components, comparing the CI and GI approach. Three methods of evaluation were used: the LCCT, the CNT calculator, and economic analysis. Hard costs were determined first, and then the HPM and BTM were used to determine the value of the housing properties.

The HPM is a "revealed preference" method of valuation, because it infers the value of environmental features from the prices of traded goods (Gundimeda, 2007). It is applicable in those cases where the price of a good is influenced directly by environmental factors (Alberini, 2004). The HPM of environmental valuation uses surrogate markets for placing a value on environmental quality, and the HPM relies on information provided by households when they make location decisions (Gundimeda, 2007).

The HPM is appropriate in the housing market because it expresses preferences and willingness to pay a price. The price of a property is determined by the characteristics of the house. The HPM is used to estimate the extent to which each factor affects the price. In the present case, building with GI should be beneficial to the housing project. The benefit may be demonstrated by an increase in hedonic price value. For this reason, this method of valuation is very effective in demonstrating the benefit of GI to customers who are looking for a better quality of life (Hill, 2011). According to the literature, GI design should increase house prices by 5 to 25 percent (Wachter, 2005; Bourassa et al., 2005), because householders are willing to pay more for a green environment. This study tests this estimation.

The BTM is an alternative method of obtaining non-market values. It is used to assign monetary values to non-market goods. This approach is applied often to evaluate the environmental impact of a project: "It involves 'transferring' values that have already been estimated for a similar good or service from another location to the current location. The approach is useful because surveys are costly in terms of time and money" (United Nations Economic and Social Commission for Asia and the Pacific, 2011). The use of the BTM as an alternative valuation method has some advantages. From a practical perspective, the BTM has the advantage of reducing both time and financial resources t needed to develop separate evaluations for each individual policy decision (Eshet et al., 2007). BTMs apply valuation results produced in prior research to a new context, and conserve time and resources by obviating the need to carry out an original study (Jenkins & Kramer, 2008; Plummer, 2009). For this reason, the BTM was selected also to evaluate costs in this proposed case. In this study, the BTM was used as a complementary method to demonstrate benefits and estimate costs. Unit costs from other completed projects were used in the comparison and valuation of the Vaudreuil-Dorion project site infrastructure costs. As an example of BTM in this specific study, the CNT calculator estimates costs only in US cities. Nevertheless, the conditions described in the US cities near the Canadian border can be considered similar to the Canadian context. To use the CNT calculator in Canada, a similar city must be selected in the USA, and then the results for that city can be transferred to the designated city in Canada. This is what was done in this study for Vaudreuil-Dorion.

A third method, the LCCT, was used to correlate results. Meta-analysis is a general term for any methodology that summarizes results from several studies. In the case of environmental benefit transfer, benefit estimates gathered from several studies serve as the dependent variable in regression analysis, and the characteristics of the individual studies serve as the independent variables (Dumas et al., 2005). The present study combines different methods to calculate prices and costs.

Economic evaluation is different from financial analysis, which is concerned with a project's return on investment or its profits and losses. Financial analysis of projects relates to the costs, revenues, and payments of a financial measure in market price. Conversely, economic evaluations are based on the project's costs and benefits to the economy as a whole, measured in economic values (Bando et al., 1996). The present study develops an economic analysis.

Beauchamp, Adamowski, and Beauséjour (2011) presented a paper to structure the development of a new green development project. The authors used a new framework to design the proposed project. The framework includes six steps: (1) inventory, (2) hydrological and hydraulic assessment, (3) integrated water resources management, (4) land planning, (5) consultation, and (6) master plan (Beauchamp et al., 2011). This methodology can be applied in a housing development project. In the next section, this approach will be applied to the Vaudreuil-Dorion housing project, and the described valuation methodology will be applied to calculate the costs and benefits of the project. It should be noted that the first author of this paper is a Senior Vice President at Exp, the engineering consulting firm that was involved in the preliminary study of the Vaudreuil-Dorion housing development project. The first author of this paper was involved in all aspects of the design of this proposal and, as such, all the calculations and design considerations and specifications presented in this paper are the outcome of the work conducted by the first author.

4. Case Study: Vaudreuil-Dorion 540 Development Project

The City of Vaudreuil-Dorion is a suburban neighborhood of Montréal in the Province of Quebec, Canada. Its population has grown from 5,000 in 1982 to 31,471 in 2011. The existing master plan was designed to service 35,000 residents. The City of Vaudreuil-Dorion is evaluating the feasibility of creating a new development covering a 600-hectare (ha) area in an underdeveloped sector. This project gives the city an opportunity to plan an eco-sustainable development close to the urban perimeter of the city and protect the city's greenbelt. As the city's existing infrastructure was not designed to handle the extra demand generated by new development, a new master plan must be developed to provide services such as roads, drainage, water supply, and wastewater collection to housing and institutional development in this area. Incorporating GI practices at the scale of the municipal neighborhood and site could protect the environment and avoid flood problems in the sector. Figure 1 shows the site to be developed. The existing residential area of the city is located between highways 40, 20, and 540, and the lake of Two Mountains. The potential new development is located southwest of highway 540 between the railroad and highway 20 (see Figure 1).

The population of the regional county municipality (MRC) of Vaudreuil-Soulanges is projected to grow to 270,000 in the next 20 years, meaning that a new institutional pole will be needed to service the region. Vaudreuil-Dorion wishes to develop this institutional pole and welcome 10,000 new residents to live in the sector. The principles of sustainability, environmental protection, and ecological balance will be highly valued in the development of this project. Vaudreuil-Dorion proposed a "green development," which is a broader concept than GI. Green development involves green space management that conserves natural ecosystem functions and provides associated benefits to ecosystems, including humans. It involves hubs and links. There are green hubs, such as forests and lakes; functional hubs, such as housing; as well as commercial and institutional hubs. Roads and pedestrian alleys are urban links; these may or may not be green. Conservation corridors, greenways, and greenbelts provide links between green hubs. Green development needs GI, and green links are essential to preserve green hubs. This concept has been applied to the design of this project. Figure 2 shows the actual situation in combination with the proposed scheme, which respects existing links and hubs.

5. Project Framework

The following sections describe the proposed housing project with reference to the framework proposed by Beauchamp et al. (2011). The six components are summarized below.

5.1 Inventory

Following the site inspection and inventory, poles and hubs are shown in a schematic (see Figure 2). Figure 2 shows hubs and links. The main function of the future development is the institutional function, which is central to the development. Other functions are housing and commercial services. The hubs in the area include a river, two existing wetlands, a forest, and a creek. The topography shows two small canyons, one for the river crossing the development and the other where the creek is flowing. The site forms a large catchment area flowing into the river and there are three sub-catchments on the site. Available topography is not detailed, although it does show principal levels. Existing hubs and proposed functions are represented. Links between proposed functions and existing hubs were created. Existing wetlands and green space are to be preserved and linked, creating a greenbelt around the project. A new lake would be built to become the core node of the water management cycle.

5.2 Hydrology and Hydraulic Assessment

The study area is a sub-catchment basin of the Quinchien River. The entire catchment area of the Quinchien River covers 2,846 ha across three municipalities: Vaudreuil-Dorion, Saint-Lazare, and Les Cèdres. An extensive hydraulic study of the river was completed in 2007, identifying a risk of flooding in downtown Vaudreuil-Dorion. One of the solutions proposed was to create a retention basin. The retention basin could be incorporated into the present project. In this case study, the SWWM5 model was used to develop hydrographs of the sub-catchment areas. The WinTR-20 model of the US Department of Agriculture was used to calculate open ditch runoff, and the HEC-RAS model of the Hydrologic Engineering Center of the US Army Corps of Engineers was used to perform river hydraulic calculations under various conditions. In this study, the Type II synthetic rainfall pattern developed by US Soil Conservation Services was used to develop synthetic design storms based on data from the Sainte-Anne-de-Bellevue meteorological center from 1963 to 1990.

5.3 Integrated Management Practices

The sustainable management of water is one of the key challenges in the development. The planning and design of water management infrastructure should respect the Leadership in Energy and Environmental Design (LEED) criteria if the developer wants to qualify for the program and then integrate LID techniques into the approach. In this study, it is proposed that the project be taken a step further than the LID standards: the domestic water in the project will form a closed circuit, and none will be rejected from the project. The principle of the design of housing services will include water use reduction, consumption at source reduction, water-efficient landscaping, use of non-potable water, innovative wastewater technologies, and storm water management. Integrated water resource management (IWRM) is a strategy that integrates all facets of the water cycle, including points of consumption and discharge, water supply (potable and non-potable), sewage and storm water management. The conceptual IWRM model developed for this project is shown in Figure 3.

The conceptual IWRM model includes the following features. All infrastructure services for housing will be integrated in a new concept, where water consideration drives other elements of the design such as roads, bridges, and landscape. As a measure of water use reduction, the domestic water demand is separated into two groups: potable water and non-potable water (water required for fire protection, watering of plants, street cleaning, and toilet flushing is categorized as non-potable). Separating non-potable from potable water reduces the capital and operational costs of the wastewater treatment plant (WWTP).

Domestic wastewater will be separated into two streams: greywater and blackwater. Greywater is wastewater generated from domestic processes such as dish washing, laundry, and bathing. Wastewater from toilets is categorized as blackwater. The main difference between greywater and blackwater is the organic loading. Blackwater has a much higher organic loading than greywater. By keeping greywater separate from blackwater, greywater can be treated readily by natural ecological treatment systems. This leads to a reduction in the capital and operational costs of the WWTP.

Upon completion of the project, a reservoir (lake) will receive inflow from three sources: (1) runoff from the catchment basin, (2) direct rainfall, and (3) inflow from the wastewater reuse facilities. Runoff from the catchment basins and the inflow from the wastewater reuse facility need to be adequately treated. Here, attention is directed to protecting the water quality of the lake. Following the LID criteria, the proposed infrastructure aims to protect the reservoir from undesirable elements that could be introduced from the influents. Wetlands and bioswales are two types of biological infrastructure that can be used to filter and treat water inflows ecologically. Bioswales act as a channeling network for urban runoff drainage control, collecting runoff during rainfall. One of the components in the reservoir water-balance equation is the inflow coming from the catchment basin’s runoff. Before entering the reservoir, this important inflow must be adequately treated, which can be achieved by passing it through wetland.

For the management of storm water, LID techniques will be used to create a treatment system. Peak storm water flow from the catchment area will be attenuated by three types of infrastructure: (1) green roofs, (2) rain gardens, and (3) LID techniques, including bioswales and wetlands in the project site.

5.4 Land Planning

At this stage, an initial conceptual plan of land uses is proposed for evaluation and consultation. While maintaining more than 40 percent green space, the project could support a population equivalent to 34,000 people at maturity of the institutional pole. Of these, 16,000 would be inhabitants and 18,000 would be in the workforce.

The MRC of Vaudreuil-Soulanges studied the type of land use to preserve the natural habitat. The urban planning firm Sotar prepared a study to determine the location of a new hospital. Table 1 shows the maximum population that the sector can accommodate. However, environmental studies will reduce these figures upon completion of the land protection plan. For the purposes of the present study, the preliminary design has been calculated for a maximum of 13,600 inhabitants.

5.5 Consultation

The City of Vaudreuil-Dorion and the MRC initiated a series of consultations with stakeholders, including developers, the Union des Producteurs Agricoles (UPA) (Union of Farmers), and five governmental ministries (health, environment, municipal, tourism, and agriculture). From these consultations, a preliminary master plan is proposed (for study only).

5.6 Master Plan

Two proposals were prepared for consideration: one using a standard development approach and the other using a green development approach. Neither of the proposals has been accepted yet. Figures 6 and 7 present the two options in terms of land use and road distribution. For the conventional approach, streets are larger and longer, and housing is more spread out. For the green approach, density is increased and green space is maximized; streets are narrower and shorter and land use is reduced when using a green development approach.

The second approach differ from conventional scheme in that it has less roads and it is more dense. Using the green approach, housing buildings are grouped around green space, such as rain gardens (or bioretention areas), retention ponds, green alleys, and urban forestry.

6. Project Evaluation

This section summarizes the data and technical characteristics of the project. Table 2 shows the characteristics of the project, comparing the CI and GI designs. The description and evaluation by unit cost is then calculated and presented for each scheme. Currencies are in Canadian dollars (which were close to US dollars in value in 2011).

6.1 Infrastructure in the Conventional Development Scheme

The infrastructure in the conventional development scheme includes a road network, a water distribution network, a sewage collection network, and a storm water collection network. The existing municipal water treatment plant (WTP) supplies potable water. However, to cater for increased demand, the plant capacity needs to be increased. Therefore, a new WTP would be constructed for the new development. The capacity and cost of the infrastructure were evaluated, and are discussed below.

6.1.1 Road Network

The road network would consist of 54 kilometers (km) of paved roads, including a beltway that links all the subsectors, a principal road that passes through the central institutional and commercial zone, and local roads in the residential zone. The cost for the construction of paved roads is estimated to be $54,000,000. Paved roads occupy a total area of 505,500 square meters (m^2), representing eight percent of the total development area. This would cause a significant increase in peak surface runoff.

6.1.2 Water Distribution Network and Water Supply

Water main pipes are to be installed along all roads, forming a looped water distribution network. The total length of water pipes is 50 km, and pipe diameters range from 150 to 300 millimeters (mm). The water distribution network will not only provide water for domestic consumption but also provide it for fire protection, plant watering, street cleaning, and various other public uses. The total clean water demand of the development is estimated to be 13,000 cubic meters per day (m^3/d). The source of water supply is the existing municipal WTP. This water distribution network would be connected to the existing municipal network via 2 km of 400 mm water main pipes. A booster pumping station will be required to ensure adequate pressure in the water distribution network. The existing municipal WTP needs to be expanded to satisfy the additional demand from the development. The total hard costs of the water works, including the booster pumping station, the distribution network, and the transfer pipe, is estimated to be $10,828,000 and the cost for increasing the municipal WTP capacity is estimated at $5,000,000 - bringing the total cost for the proposed conventional water supply network to $15,828,000.

6.1.3 Sewer Networks

The wastewater collection network consists of 53 km of gravity sewer pipes, ranging from 200 to 350 mm in diameter. There are three main collectors: (1) the north collector, located along the north bank of Quinchien River, which collects wastewater from subsectors 1,100, 1,200, 1,300, 1,400, and 1,500; (2) the central collector, which is located along the principal road and collects wastewater from subsectors 2,100 and 2,200, as well as from the institutional and commercial zones; and (3) the south collector, which is located along the southern beltway and collects wastewater from subsectors 3,100, 3,200, 3,300, 3,400, 4,100, 4,200, 4,300, 4,400, and 4,500. The cost for installing these sewer networks is estimated to be $8,113,000. This estimate includes an allowance for five small lifting stations.

The storm water sewer network consists of several sub-networks, each having its proper outfall to either the Quinchien River or the creek. The network pipes have been designed to cope with one-in-five-year storms. An MRC regulation requires a runoff control of 25 li/sec/ha, necessitating a retention basin. Pipe diameters range from 350 to 2,700 mm. The total cost for installing the sewer pipes is estimated to be $30,500,000.

ISSN 1913-9063 E-ISSN 1913-9071

6.1.4 Wastewater Treatment Plant

The wastewater discharge from the new development is estimated to be 10,500 m^3/d. The city's existing WWTP, located some 4 km away from the development site, is not able to accept this additional load. It is proposed to construct a new WWTP with a 10,500 m^3/d capacity on the site of the new development. The plant will be located on Route Harwood, near the entrance to the development zone. The plant includes pretreatment, a microfilter membrane bioreactor, tertiary treatment, ultraviolet treatment, and sludge treatment. The cost for the construction of the new WWTP is estimated to be $16,150,000.

6.2 Infrastructure in the Green Development Scheme

In the green development scheme, the water supply is carried by two separate networks: one for potable water, the other for non-potable water. The source of the potable water supply is a new WTP. The source of the non-potable water supply is a pumping station drawing water from the lake. Domestic wastewater is separated into two streams at source: blackwater and greywater. Blackwater is sent to the new wastewater reuse plant for treatment and reuse. Greywater is treated at source with ecological systems, as mentioned in Section 5.3. Surface runoff is treated by bioswales and other LID techniques before being discharged into the environment. The entire water system forms a closed circuit, in that the WTP draws raw water from the lake to produce potable water, and the lake is, in turn, replenished by the effluent of the wastewater reuse plant. Part of the wastewater reuse plant effluent is directly reused for non-potable purposes. It is clear that more pipes will be needed for a green development.

6.2.1 Road Network

The road network in the green development scheme has been planned with a reduced paved road surface to conserve green space. The network would consist of 45 km of paved roads covering 365,000 m^2, which represents 5.8 percent of the total development area. The main structure of the network is similar to that of the conventional development scheme, with a beltway that links all the subsectors, a principal road that passes through the central institutional and commercial zone, and local roads in the residential zone. The cost for the construction of paved roads is estimated to be $35,000,000.

6.2.2 Water Distribution Networks and Water Supply

The installation of two separate water supply networks is proposed: one for potable water and another for non-potable water (see Figure 8). The water main pipes of the two networks would run in parallel, along all roads. The total pipe length of each network would be 41.8 km. The pipe diameters range from 150 to 200 mm for potable water, and from 150 to 250 millimeters for non-potable water. The total cost for constructing the two networks is estimated to be $12,300,000.

The potable water demand of the development is estimated to be 7,800 m^3/d, and the non-potable water demand is estimated at 5,200 m^3/d. The new WTP would be located near the constructed lake. The estimated cost for the construction of the plant is $7,223,000, bringing the total cost for the construction of the water supply networks using GI to $19,523,000.

6.2.3 Blackwater Collection and Treatment

By separating blackwater and greywater at source, the blackwater flow to be carried by the sewer network is reduced. Blackwater represents about 40 percent of total domestic wastewater. The total blackwater flow from the development is estimated to be 4,150 m^3/d. Following the preliminary examination of the topography of the site, the installation of three separate networks is proposed. (1) The northern network will service subsectors 1,100, 1,200, 1,300, 1,400, and 1,500 (from which the average blackwater flow is estimated to be 490 m^3/d). (2) The central network will collect wastewater from subsectors 2,100 and 2,200, as well as from the institutional and commercial zones, with an estimated average blackwater flow of 1,900 m^3/d. (3) The southern network will collect wastewater from subsectors 3,100, 3,200, 3,300, 3,400, 4,100, 4,200, 4,300, 4,400, and 4,500. The estimated average flow from these is estimated to be 1,760 m^3/d. The approximate length of sewer pipe required for all three networks is 53 km. The pipe diameters range from 200 to 350 mm. The cost for installing the sewer networks is estimated to be $6,858,000, including an allowance for five small lifting stations.

Three WWTPs could be constructed, one for each blackwater network. The plants would use Ecophyltre, a green wastewater treatment technology (see Figure 4). Table 3 provides a summary of the proposed plants and their costs. Alternatively, the construction of a centralized plant, with the same processes as a conventional plant, plus the addition of membranes and reverse osmosis, would be $17,539,000 and still permit the recycling of water as non-potable water.

6.2.4 Greywater Collection and Treatment

Greywater will be treated at source at the household level using an ecological system, consisting of a septic tank followed by a vertical-flow planted filter (VFPF). The treated effluent will then be discharged into the storm water network. For the purpose of the present study, the estimated cost is based on a typical system of 1.2 m^3/d capacity, which includes a septic tank of 1.8 m^3, a VFPF of 8 m^2, and 25 m of 100 mm diameter discharge pipe. To treat 6,226 m^3/d of greywater, 5,188 equivalent typical systems would be required. The total cost for constructing greywater collection and treatment systems is estimated to be $23,128,000.

6.2.5 Storm Water Management Works

In the green development scheme, the main infrastructure of storm water management is bioswales and wetlands. The green roofs and rain gardens, although an integrated part of the storm water management strategy, will be implemented at household level and are excluded from the infrastructure cost. These costs constitute developer costs. The storm water collection and conveyance network consists of 36.2 km of bioswales and two constructed wetlands of 20 ha and 12 ha, respectively. The total cost for constructing the bioswales and wetlands is estimated to be $13,060,000.

6.3 Cost Summary of Two Schemes of Housing Infrastructure

The previous section described all schemes and costs for the two approaches, CI and GI. Costing has been evaluated from the 2011 Exp International Services database for unit price. Table 4 provides a cost summary for each option, CI and GI. The first part of the Table shows public investment for housing and institutional pole infrastructure services; the second part indicates the investment required from developers or stakeholders.

Table 4 also illustrates the baseline of cost evaluation for all infrastructure required to serve the proposed housing development. The cost of public infrastructure is $21,078 per house unit for conventional design and $19,475 per house unit for green design. However, the developer will have to invest an additional $10,084 per house unit to reach the goals of GI. Using this method of evaluation, the investment is 29 percent higher for a green option. Nevertheless, public investment for GI is lower than for CI.

6.3.1 Center for Neighborhood Technology National Green Values™ Calculator

The second method used to compare cost between CI and GI was the National Green Values™ Calculator (GVC). The parameters of the project were entered into this software, which was developed by the CNT (Center for Neighborhood Technology, 2009a). The simulation calculates the cost of each alternative (conventional and green) for storm water LID design. However, the calculator does not include water supply or wastewater infrastructure cost. The GVC calculates the annual precipitation depth and cost price for an LID project in any site in the USA. Therefore, in this case study, the BTM was considered appropriate to determine the value for Vaudreuil-Dorion from another site in the USA. The city of Malone, located in northern New York State, 55 km south of Vaudreuil-Dorion, was chosen for this purpose, as its weather conditions are similar to those of Vaudreuil-Dorion, and the characteristics of the site are appropriate for the BTM. The RS Means Building Construction Cost Database and RS Means Site Work and Landscape Cost Database were used by the GVC for referencing unit costs.

Table 5 shows a total investment per house for public infrastructure in housing and local owners' investment of US$20,290.15 for CI, compared with US$26,649.03 for GI. This calculation indicates that each house unit would need 24 percent more investment for a green option.

6.3.2 Life Cycle Costing Tool

The LCCT was the third method used for calculation for comparing the CI with GI. The CMHC developed this tool to help users explore and compare the costs of different forms of development and community planning alternatives that could help contribute to more sustainable development (Pollard, 2008). The tool is capable of providing planning level cost and revenue estimates only. However, the tool does not calculate all green costs at lot level. Basic project data were introduced into the costing tool. Table 6 provides the results.

The tool includes costing variables to allow for the estimation of costs for the following major categories: hard infrastructure, municipal services, private user costs, and external costs. In this case study, items retained for comparison were roads, sewers, storm water facilities, and management services. The tool revealed that the cost of infrastructure for each housing unit is CAD$20,993 for CI and CAD$23,525 for GI. Using this method, the investment differential is 11 percent more for a green option.

7. Project Value and Benefits

This section will evaluate direct benefits to the City. The Greater Montréal Real Estate Board (GMREB) is a nonprofit organization that brings together most of the real estate brokers who work in the Greater Montréal area. The GMREB publishes statistics on housing prices. In December 2010, the median price of a single-family home in Greater Montréal was $262,000; this was an increase of nine percent compared with December 2009. The median price of condominiums also increased by nine percent to $218,000 over this period, while that of duplexes increased by 10 percent to reach $385,000 (Ménard, 2011).

As discussed in Section 2, studies show that buyers are willing to pay between 5 and 38 percent more to buy a house in a quality neighborhood. EQuilibrium™ is a national sustainable housing initiative created and led by the CMHC. It strives to balance the demands of housing needs with those of the natural environment (Pollard, 2008). In 2009, the CMHC carried out market research with Canadians who were expecting to buy a home in the next five years. According to the findings, 90 percent of respondents were interested in this green initiative, citing concern for the environment as the reason for their interest. The majority recognized the need for this type of housing, with about half willing to pay an additional $5,000 to $25,000 (and an additional 15 percent willing to pay more than $25,000) for an EQuilibrium home, with the expectation that the savings from reduced energy costs would offset the initial extra expense over a reasonable period (CMHC, 2010).

There have been numerous studies on land use and the green environment. Des Rosiers, Thériault, Kestens, and Villeneuve (2002) demonstrated that house prices in Quebec City increase by 0.2 percent for each percent of trees on the land and an attractive landscape increases the house value by 7.7 percent. Kestens, Thériault, and Des Rosiers (2006) demonstrated the positive value of greening within 40 meters of housing. In Michigan, Thorsnes (2002) demonstrated that houses near forests were valued between 19 and 35 percent more than similar houses in non-forested areas. Hobden, Laughton, and Morgan (2004) found that, in the suburbs of Vancouver, corridors to parks increased house values by 6.9 percent and green pedestrian walkways increased property value by 11 percent. In France, Cavailhès (2007) determined that green outlooks have the effect of increasing house prices by between one and five percent.

To quantify the hypothesis that property value increases in a green environment, six cities in the MRC of Vaudreuil-Soulanges were chosen, and municipal evaluations were compared. Using the Ministère des Affaires Municipales, des Régions et de l'Occupation du Territoire (MAMROT) 2011 database, Table 7 shows an evaluation of property in the housing sector for six cities: Ville de l'Ile-Perrot, Notre-Dame de L'Ile-Perrot (NDIP), Pincourt, Vaudreuil-Dorion, Hudson, and Saint-Lazare. Three of these cities were greener than Vaudreuil-Dorion: NDIP, Saint-Lazare, and Hudson. For these cities, housing evaluations per inhabitant were 15, 27, and 100 percent higher, respectively, than for Vaudreuil-Dorion.

As discussed in Section 2, a green approach increases the hedonic value of property. From the comparison presented in Table 7, it can be seen that 15 percent is a conservative value for the hedonic increase value in the proposed housing project due to willingness to pay for houses in a green neighborhood, as shown in Vaudreuil-Soulanges. This corresponds with the value showing a difference between the Vaudreuil-Dorion and NDIP housing evaluation; therefore, this study proposes a hedonic value of 15 percent more for a house in a green development. It is noted that it could be more (27 percent), as in Saint-Lazare, where the forest environment is predominant. The percentage of forest coverage can be determined by measuring the canopy of each city from an aerial view. There is a linear regression between property value and canopy size.

In Table 8, house values are calculated for the proposed project using conventional housing prices, with a hedonic increase in value of 15 percent. Column A shows the number of total units of each type in the proposed development; B, the unit price as per Greater Montréal statistics in 2010 from the GMREB; C, the total evaluation for a CI project; D, the hedonic value; and E, the total value of housing in a GI project. The total increase in value for the municipal housing project would be CAD$202,902,000 for a GI scheme. The results shown in Table 8 were used to determine the potential additional tax revenue for the city (shown in Table 9). In Table 9, 2011 tax rates were multiplied by the new building value and compared with tax revenue from houses being constructed in a conventional scheme. Tax revenue increases by $1,458,115.68 per year for a green development. The city would collect $245.35 of extra tax per house unit per year from a project built using GI.

8. Conclusion

Infrastructure costs for conventional design and green design were evaluated using three different methods for the proposed Vaudreuil-Dorion Project. The total infrastructure cost for CI averages CAD$125,000,000 for the proposed project. The total infrastructure cost for GI could vary from CAD$140,000,000 to CAD$200,000,000, including investment at lot level. The public component of the GI investment could vary from

CAD$100,000,000 to CAD$120,000,000. The minimum increase in value of the total property evaluation would be CAD$202,902,000 for a GI scheme in the Vaudreuil-Dorion project. The minimum extra taxes collected annually would be $1,458,115.68 per year. In a new development, the evaluation of the hard costs of infrastructure shows that the public costs of the CI and GI designs are very close, if investment at lot level is excluded. According to the three different methods of calculation, GI design is determined to cost 29, 24 or 11 percent more, respectively, including householders' extra landscape investment at lot level, depending on the nature of the investment. However, the hedonic value of a house built in a GI scheme will increase by 15 to 27 percent. Therefore, the increase in value and the increase in cost are balanced.

This study does not address the environmental costs and benefits of the project, which may require further research. Nevertheless, using the CNT calculator, the environmental benefits of the project were evaluated at US$276,858 per year. This includes reduced air pollutants, carbon dioxide sequestration, the compensatory value of trees, ground water replenishment, reduced energy use, and reduced treatment requirements. Another point of interest is the operating cost: the CNT calculator predicted an increase of US$216,979, excluding WTP or WWTP operating and maintenance costs. The third method, the Life Cycle Cost Tool, predicted an additional annual operating cost of CAD$278,367 for a green solution, compared with a conventional solution. These paradigms will require further research. Compared with conventional development practices, the implementation of sustainable devices for drainage, water supply, and sewerage reduces the need for infrastructure expansion and provides economic and environmental benefits.

The evaluation of green development projects is an economic concern for cities. This study analyzed the quantitative values and costs of a green development project in comparison with a conventional development project. In considering these two forms of development, city decision makers will have to answer two questions: (1) Are the benefits of the project greater than the cost to taxpayers? (2) Is city spending being managed in such a way as to maximize benefits? The value of each unit increases by $34,100 for a green development. The hard infrastructure cost was evaluated at $19,475 per unit and the extra cost of building green to be paid by the developer was evaluated at $10,084 (at lot level), resulting in a total of $29,557. Overall, the benefits exceed the costs. If the developer contributes to city infrastructure investment, the City will increase its revenue.

This study has demonstrated that the householders and the city will benefit by choosing a GI approach in the proposed project. The indicators also show that the environment may be protected by choosing this option.

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Table 1. Maximum land use distribution

Type	Density	Area	Population
	pers/ha	ha	
Commercial	261,1	32,91	7417
Institutional	138,5	84,99	11768
Residential		251,46	15959
Condos	140,8	51	7260
Townhouses	60,7	60	3640
Houses 1st buy	43,9	69	3016
Houses luxury	28,7	71	2044
Green space	41%	260,74	
Total		630,1	

Table 2. Infrastructure housing project description

Design criteria	Scheme	Conventional design	Green infrastructure
Water supply	Sourcing Treatment Pumping Storage Distribution Non-potable supply Potable supply Fire protection	Municipal Conventional 2 km 6000 m^3 From city network None One pipe Minimum 250 mm	Constructed lake Membranes 100 m 3000 m^3 From filtration plant One pipe One pipe Direct pipe from lake
Storm water	Surface reception flow Conveyance Retention/Detention Treatment Discharge	Storm drains Pipes 25 li/s/ha None River	Green roofs Bioswales Rain gardens Wetlands Lake
Wastewater	Conveyance Treatment Discharge Bio-solids management Site level treatment	Pumping and pipes Conventional plant River Mechanization None	Small pipes and swales Septic tanks and wetlands Constructed lake Mechanization Yes
Transportation	Roads Sidewalks Pathways Parking facilities	11 and 9 m Conventional None Conventional	9 and 7 m Integrated in design Integrated in design Infiltration material

Table 3. Wastewater treatment plant costs

Description	Northern network	Central network	Southern network	Total
Average flow	490 m^3/d	1900 m^3/d	1,760 m^3/d	4150 m^3/d
Surface area	185 × 60 m	360 × 120 m	335 m × 120 m	94 500 m^2
Discharge	To Quinchien River	To wetland	To wetland	n/a
Cost	$3 283 000	$12 783 600	$11 792 000	$27 858 600

Table 4. Cost of projects from detailed unit price calculation

Public infrastructure	Conventional development	Green development
Cost for public municipal infrastructure		
Roads network	$54 000 000.00	$35 000 000
Water distribution network		
- Potable water	$10 828 000.00	$5 851 000
- Non-potable water	n/a	$6 462 000
Water treatment plant	$5 000 000.00	$7 223 000
Sanitary (blackwater) sewer networks	$8 113 000.00	$6 858 000
Wastewater treatment plants	$16 151 000.00	$17 539 468
Greywater treatment system	n/a	$23 128 000
Storm water sewer networks	$30 500 000.00	$13 060 000
Subtotal	$124 592 000.00	$115 121 468
Extra developer costs for green option		
Green roof		$42 600 000
Filter box + rain garden		$17 000 000
Subtotal		$59 600 000
Total	$124 592 000.00	$174 721 468
Cost/unit without cost at lot level	$21 078	$19 475
Cost/unit with green cost at lot level	$21 078	$29 559

 ISSN 1913-9063 E-ISSN 1913-9071

Table 5. Center for Neighborhood Technology National Green Values^{TM} calculator results

Storm water LID costs, US$			
Infrastructure	Conventional	Green	Difference
Concrete sidewalk	$921 225.00	$921 225.00	–
Curbs and gutters	$3 055 320.00	$1 330 337.00	$1 724 983.00
Street	$24 541 747.00	$17 901 415.00	$6 640 332.00
Parking lot	$132 240.00	–	$132 240.00
Conventional storm water storage	$20 012 656.00	$ 2 636 073.00	$17 376 583.00
Permeable pavement, Porous asphalt	–	$(735 440.00)	$735 440.00
Turf	$11 331 881.00	$11 536 751.00	$(204 870.00)
Rain garden	–	$413 000.00	$(413 000.00)
Roadside bioswales	–	$5 999 940.00	$(5 999 940.00)
Bioswales in parking lot	–	$2 100 000.00	$(2 100 000.00)
Planter box	–	$792 000.00	$(792 000.00)
Additional soil	–	$19 980 000.00	$(19 980 000.00)
Subtotal	$59 995 069.00	$62 875 301.00	$(2 880 232.00)
Owners			
Standard roof	$59 940 000.00	$29 970 000.00	$29 970 000.00
Green roof	–	$62 937 000.00	$(62 937 000.00)
Cisterns	–	$1 740 000.00	$(1 740 000.00)
Subtotal	$59 940 000.00	$94 647 000.00	$(34 707 000.00)
Total	$119 935 069.00	$157 522 301.00	$(37 587 232.00)
5911 units	Conventional/unit	Green/unit	
Infrastructure	$10 149.73	$10 637.02	$(487.28)
Owners at lot level	$10 140.42	$16 012.01	$(5 871.60)
Total	$20 290.15	$26 649.03	$(6 358.88)

Table 6. Life cycle cost tool results

Life Cycle Costing Tool		Conventional development	Green development
		CAD$	CAD$
Hard infrastructure	Local roads	$63 435 397	$51 023 386.00
	Regional roads	$1 226 480	$566 927.00
	Water distribution and water treatment	$11 700 000	$9 300 000.00
	Sanitary sewers and wastewater treatment	$12 630 000	$10 150 000.00
	Storm sewers and water management	$35 100 000	$28 910 000.00
Green infrastructure	Items		$39 112 360.00
	Total	$124 091 878	$139 062 673.00
	Cost/unit	$20 993	$23 526

Table 7. Housing evaluation in six Vaudreuil-Soulanges cities

	A	B	C	D	E	F
	Municipality	Population	Total housing evaluation	Evaluation per habitant	Ratio	Forest canopy
				C/B	D/D4	%
1	L'Ile-Perrot	10 515	$749 239 482	$71 254 35	0,86	16
2	ND-de-l'Île-Perrot	10 564	$1 007 255 704	$95 347 95	1,15	29
3	Pincourt	13 679	$1 123 409 805	$82 126 60	0,99	17
4	Vaudreuil-Dorion	31 461	$2 599 697 064	$82 632 37	1,00	26
5	Hudson	4 954	$823 222 050	$166 173 20	2,01	39
6	Saint-Lazare	18 922	$1 987 503 965	$105 036 68	1,27	40

Table 8. Green building evaluations for Vaudreuil-Dorion 540 development

Building value		Buildings	Buildings	+	Buildings
	A	B	C	D	E
		2010	100% evaluation	15%	100% evaluation
Type	Unit	Unit Price	Total conventional	Hedonic value	Total green
Unifamilial	1874	$262 000.00	$490 988 000.00	$73 648 200.00	$564 636 200.00
Townhouse	1348	$192 500.00	$259 490 000.00	$38 923 500.00	$298 413 500.00
Condo	2689	$218 000.00	$586 202 000.00	$87 930 300.00	$674 132 300.00
Commercial	32	$500 000.00	$16 000 000.00	$2 400 000.00	$18 400 000.00
Institutional	6	$50 000 000.00	$300 000 000.00	0	$300 000 000.00
Total	5949		$1 652 680 000.00	$202 902 000.00	$1 855 582 000.00

Table 9. Proposed new development tax revenue for the city

Building value	Infrastructure	Infrastructure	Taxation	Conventional	Green
	Conventional building values	Green building values	$ per $100 evaluation	Revenue for the city	Revenue for the city
			2011	per year	per year
Unifamilial	$490 988 000.00	$564 636 200.00	0.67	$3 289 619.60	$3 783 062.54
Townhouse	$259 490 000.00	$298 413 500.00	0.73	$1 894 277.00	$2 178 418.55
Condo	$586 202 000.00	$674 132 300.00	0.73	$4 279 274.60	$4 921 165.79
Commercial	$16 000 000.00	$18 400 000.00	1.61	$257 600.00	$296 240.00
Institutional	$300 000 000.00	$300 000 000.00	1.61	$4 830 000.00	$4 830 000.00
Total	$1 652 680 000.00	$1 855 582 000.00		$14 550 771.20	$16 008 886.88

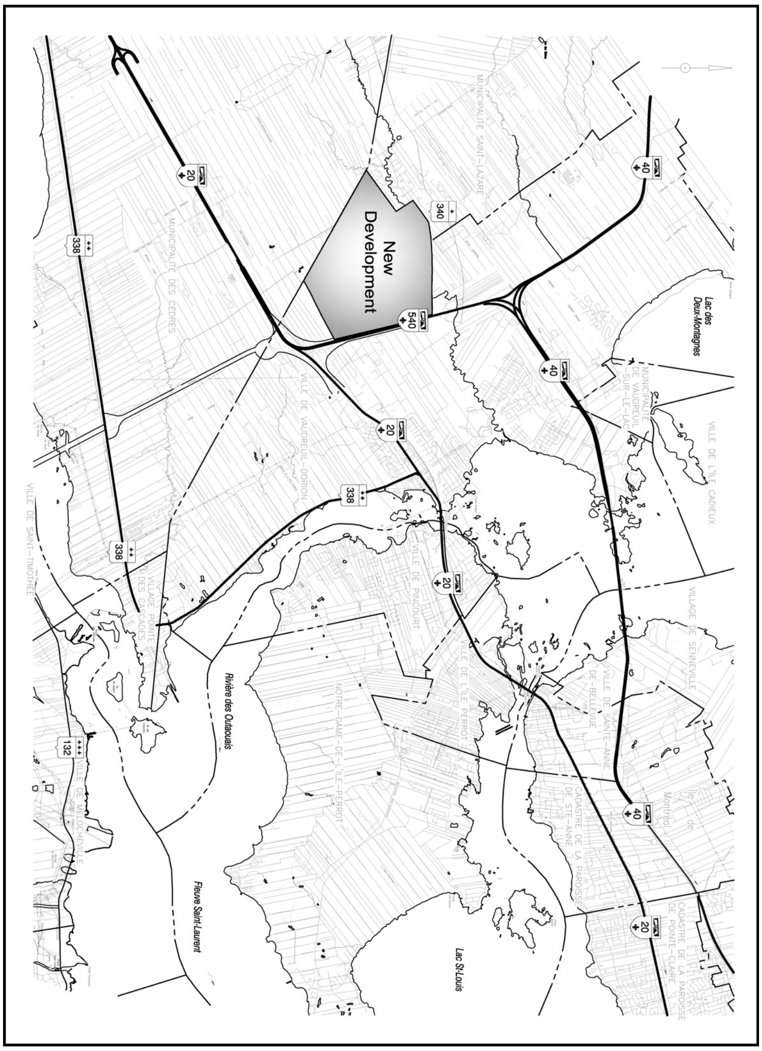


Figure 1. New development site

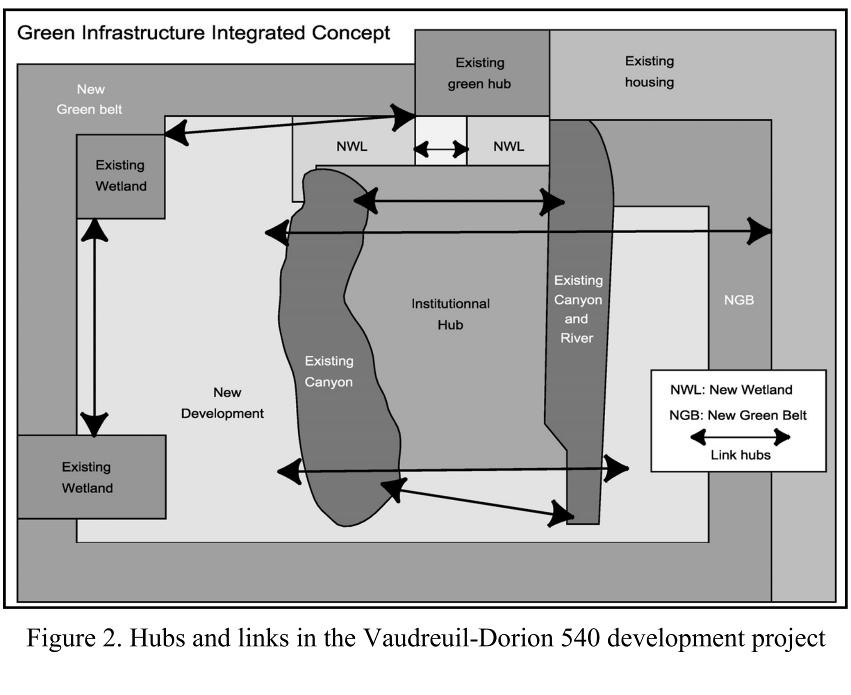


Figure 2. Hubs and links in the Vaudreuil-Dorion 540 development project

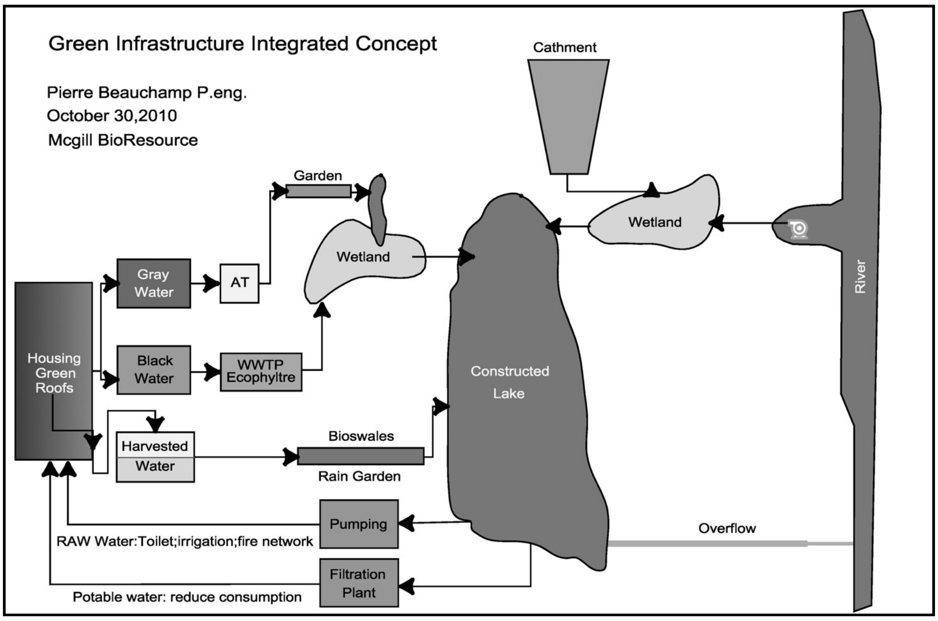
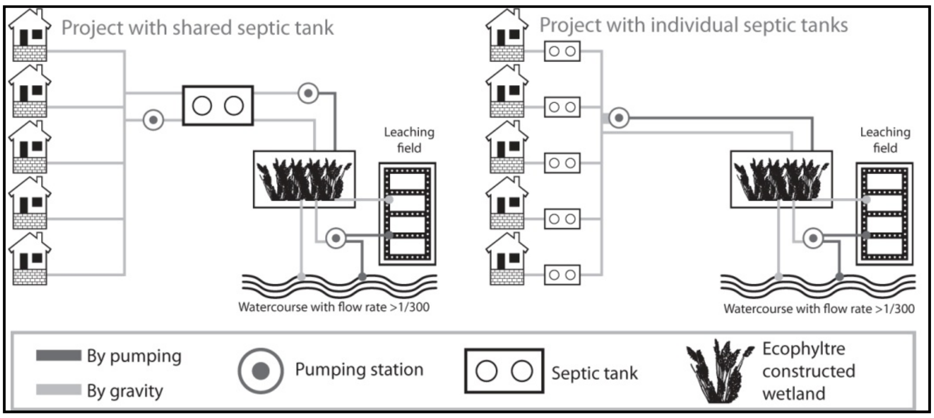
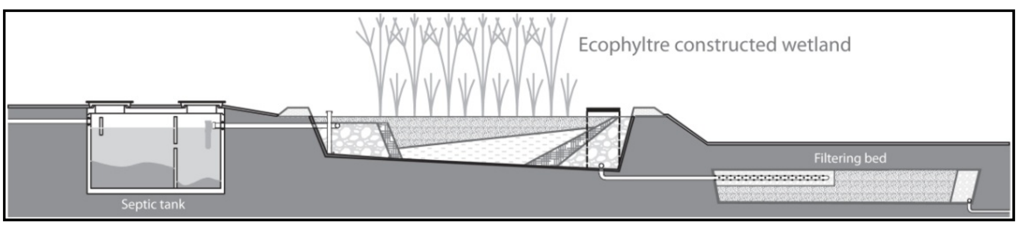


Figure 3. Integrated approach for the Vaudreuil-Dorion 540 development project



Plan and schematic view



Elevation view

Figure 4. Ecophyltre: the installation of small wetlands; HG Environnement, Blainville, PQ, CAN

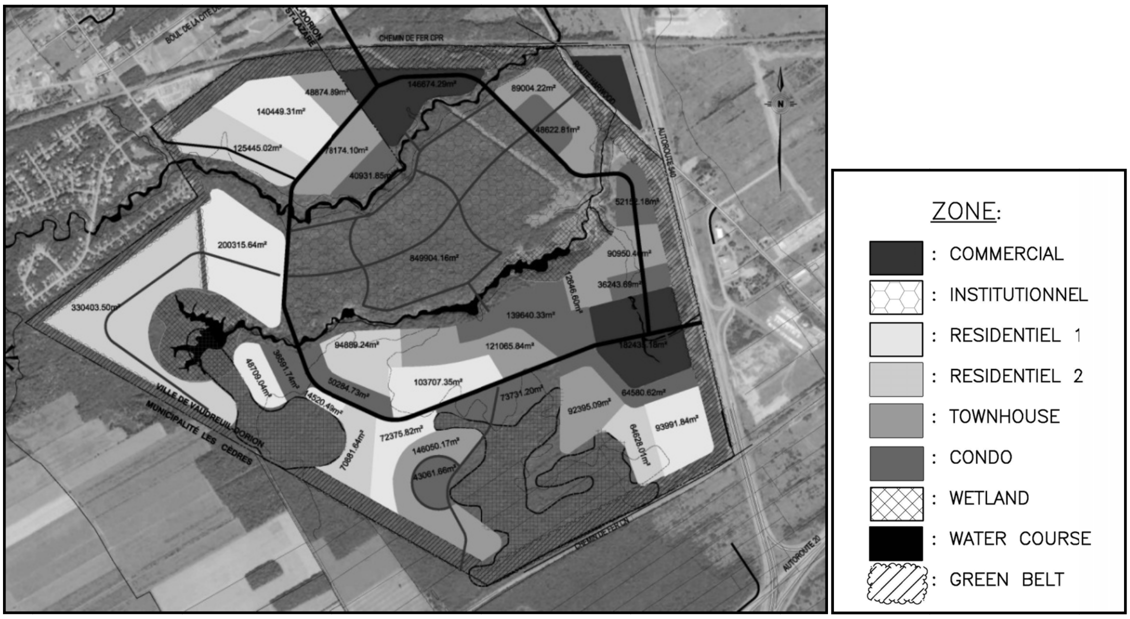


Figure 5. Optional land use proposal for consultation

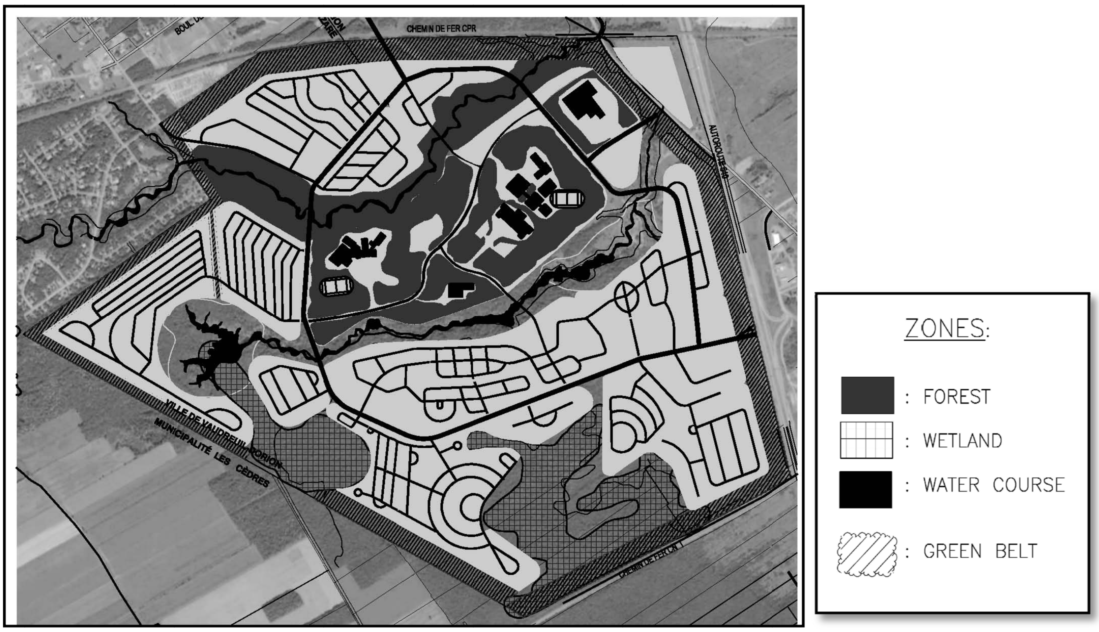


Figure 6. Road distribution for conventional design

Figure 7. Road distribution for green design

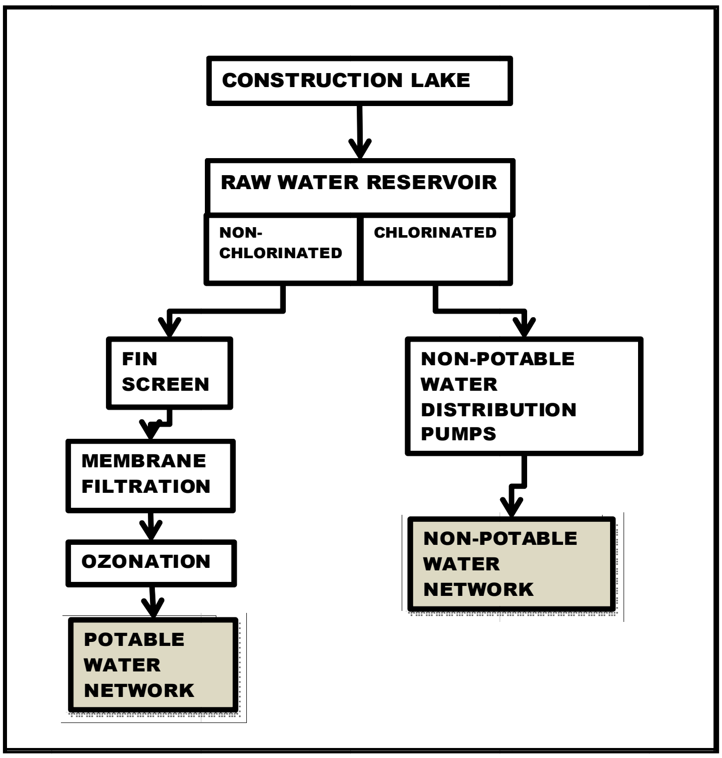


Figure 8. Water distribution networks